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RESEARCH ARTICLE

Evaluating higher taxa as surrogates of harvestmen biodiversity (Arachnida: Opiliones) along a latitudinal gradient in the Atlantic Forest

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Abstract

Habitat loss and fragmentation have highlighted the importance of monitoring remaining habitats. For megadiverse groups such as arthropods, of which many species are still being discovered, the use of higher taxonomic levels as substitutes for diversity may be a useful tool. The aim of this study was to evaluate the use of substitute taxonomic resolutions to assess the richness and composition of Laniatores harvestmen (Arachnida: Opiliones). The five resolutions selected were as follows: genus, family, subfamily, indicator taxa and intermediate resolution (combination of genus and species identification levels). In addition, we evaluated whether the diversity substitutes provide good estimates of latitudinal gradients. Nineteen Atlantic Forest sites located along a latitudinal gradient in northeastern Brazil were sampled. We recorded a total of 88 harvestmen species/morpho-species, distributed in 7 families, 15 subfamilies and 36 genera. Genus and intermediate resolution were excellent substitutes for harvestmen species richness. The efficiency differed according to the substitute resolution used. Four resolutions were adequate to replace the harvestmen composition: genus, intermediate resolution, indicator taxa, and subfamily. The number of harvestmen species recorded was significantly different between Seasonal Semideciduous Forest and Costal Atlantic Rainforest. The same relationship was also observed the same relationship was observed when we consider genus and intermediate resolution. Our results suggest the use of genus as a substitute for richness and composition of harvestmen for reducing monitoring costs and providing evaluation in a shorter time and a more practical way.

KEYWORDS
biodiversity assessment, biodiversity surrogates, indicator taxa, intermediate resolution, species richness

[Correction added on 25 November after the first publication: The affiliation of Dr. Jacques Hubert Charles Delabie was wrongly attributed to Dr. Ricardo Pinto-da-Rocha. This has now been rectified]

INTRODUCTION

The accelerated decline in biodiversity due to human actions (Laurance et al., 2012), especially habitat loss (Fahrig, 2003; Hanski, 2005; Pimm et al., 2014) and fragmentation of native environments (Hanski, 2005), has led to the necessity of monitoring and conserving the remaining habitats. Fragmentation effects on several taxa have been described earlier, for example on birds (Blandón et al., 2016; Stratford & Stouffer, 2015), mammals (Crooks et al., 2017; Rodríguez-San Pedro & Simonetti, 2015), butterflies (Melo et al., 2019), beetles (Filgueiras et al., 2011; Larsen et al., 2008), ants (Santos et al., 2018; Solar et al., 2016) and harvestmen (Bragagnolo et al., 2007).

Among the biomes that are affected by habitat loss and fragmentation, the Atlantic Forest of Brazil stands out (Haddad et al., 2015; Ribeiro et al., 2009). This biome is one of the 25 global hotspots due to its higher species richness (Myers et al., 2000) and elevated endemism rates for various groups (Bataus & Fonte, 2015; Pimenta & Silvano, 2002; Pinto-da-Rocha et al., 2005). In Brazil, the Atlantic Forest has a large extent with a wide environmental gradient (Ribeiro et al., 2009) and several vegetation types (Fiaschi & Pirani, 2009; Oliveira-filho & Fontes, 2000). Currently, vegetation coverage comprises about 28% of its original area (Rezende et al., 2018), with fragments, several of which are smaller than 1000 ha (Haddad et al., 2015), in a matrix altered by anthropic activities (Vieira et al., 2008) and affected by an intense edge effect (Haddad et al., 2015).

In order to conserve the remnant habitats, research on species distribution patterns is fundamental (Amaral et al., 2017; Margules & Pressey, 2000). The distribution of birds (Carvalho et al., 2017; Xu et al., 2017), mammals and amphibians (Butchart et al., 2012; Safi et al., 2013) is often analysed in studies aimed at delimiting priority areas for conservation. However, for several taxonomic groups, particularly for specific invertebrates, both the knowledge of species distribution patterns and the mechanisms that shape such patterns remain little known (Gaston & Blackburn, 1995; Xu et al., 2018). However, analysing species distribution patterns may have obstacles such as the high cost of biodiversity-exhaustive inventories (Whittaker et al., 2005), high species richness, behavioural varieties and habitat preferences, which necessitate the application of a variety of sampling methods for several groups (Larrieu et al., 2018). In this context, the use of biodiversity surrogates becomes a useful tool for monitoring biodiversity (Araújo et al., 2004; Barton et al., 2015; Ward et al., 1999). Biodiversity surrogate measures can be defined as 'measures that are more easily determined and have a strong correlation with the measure of biodiversity you want to investigate', according to Gaston & Blackburn (2015). In addition to being an alternative to reduce the costs required for more complete inventories (Cardoso et al., 2004) and the time taken to complete them (Landeiro et al., 2012), this approach becomes important for megadiverse groups such as arthropods (Hodkinson & Jackson, 2005), which, besides to the difficulty of their identification, many species are still being discovered(Grelle, 2002).

The use of taxonomic levels alternative to 'species' as a unit of diversity measurement has been a common approach to represent the patterns of this diversity (Andersen, 1995; Cardoso et al., 2004; Grelle, 2002; Groc et al., 2010; Gutiérrez et al., 2017; Rosser & Eggleton, 2012; Souza et al., 2016, 2018; Vieira et al., 2012). Studies on mammals have indicated that the genus level was the best surrogate for species richness when compared to family and order richness (Grelle, 2002). The same result was found for spiders: the genus was the most adequate taxonomic level to predict species richness as well as to evaluate the classification of areas according to their conservation levels (Cardoso et al., 2004). The use of genus as a surrogate for ant species assessments in the Amazon Forest has been shown to be useful (Gutiérrez et al., 2017), independent of the sampling technique used, besides saving the costs of an inventory by 40% (Souza et al., 2016). In addition to the use of genus as a substitute for diversity, the use of intermediate resolution has also been shown to be efficient (Groc et al., 2010). This approach, proposed for ants, combines two levels of identification: genus and species, according to the available taxonomical information (Groc et al., 2010).

The inclusion of arthropods in monitoring programs becomes important given the sensitivity of the taxon to environmental disturbances (Kremen et al., 1993). Among them, harvestmen (Arachnida: Opiliones) have inspired the interest of ecologists given their sensitivity and response to changes in the environment (Bragagnolo et al., 2007; Merino-Sáinz & Anadón, 2018; Nogueira, Bragagnolo, DaSilva, Carvalho, et al., 2019; Nogueira, Bragagnolo, DaSilva, Martins, et al., 2019; Tourinho et al., 2020). The richness and diversity of these organisms are influenced by physical factors such as temperature and humidity (Curtis & Machado, 2007; Resende et al., 2012a), and biotic factors such as leaf litter characteristics (Adams, 1984) and the availability of microhabitats (Burns et al., 2007; Proud et al., 2012; Todd, 1949). For example, Proud et al. (2012) in a wet forest found the highest richness of harvestmen in specific microhabitats such as trees and fallen logs. Herbaceous cover also demonstrated positive effects on harvestmen species (Mihál & Černecká, 2017), considering that these microhabitats create shadows, which prevent organisms from being exposed to direct solar radiation. The harvestmen exhibit certain characteristics, such as their low dispersion capacity (Mestre & Pinto-da-Rocha, 2004; Pinto-da-Rocha et al., 2005) and preference for humid microhabitats (Gnaspini, 1996; Goodnight & Goodnight, 1976; Machado et al., 2000) due to their high susceptibility to desiccation (Pinto-da-Rocha et al., 2007), may contribute to aggravating the effects of natural habitat fragmentation on these organisms. These characteristics decrease their ability to transpose the matrix altered by anthropic activities (Bragagnolo et al., 2007) and to recolonize areas that have been affected by environmental disturbances. Habitat fragmentation in the Atlantic Forest has negative effects on the abundance, richness, and composition of harvestmen: habitat quantity and habitat quality (mature vs. secondary forest) affect the distribution of these organisms (Bragagnolo et al., 2007), which suggests that harvestmen can be used to monitor the effects of environmental changes in tropical forests.

Species-level identification is difficult for numerous taxa, especially in many arthropod groups (Uehara-Prado et al., 2009), including harvestmen. This taxon has a high potential for conservation studies due to its sensitivity to environmental changes (Bragagnolo et al., 2007; Uehara-Prado et al., 2009), we suggest the need to evaluate biodiversity surrogates for this group. This approach has been successfully applied in several arthropods such Araneae, Coleoptera, Formicidae, Hemiptera and Lepidoptera (Cardoso et al., 2004; Gaspar et al., 2010; Koch et al., 2021; Uehara-Prado et al., 2009). From this perspective, the aim of this study was to evaluate the use of diversity surrogates for harvestmen among five levels of taxonomic resolution: genus, family, subfamily, indicator taxa and intermediate resolution. Additionally, we evaluated whether the 'best' biodiversity surrogates respond to a latitudinal gradient in a similar way to that of species level. As evidenced for other arthropod groups, genus is expected to be the best substitute for harvestmen richness and composition and to respond to a latitudinal gradient similar to the response of species.

MATERIAL AND METHODS

Study area

To evaluate diversity surrogates, we studied the distribution of Laniatores harvestmen in 19 remnants of Atlantic Forest located in five states of northeastern Brazil. These remnants are distributed along a latitudinal gradient (Figure 1, Table 1) with a minimum and maximum latitude of 6°58'12” S and 17°07'11.6” S, respectively, along 1,300 km in extent. These remnants are classified as Coastal Atlantic Rainforest (13 localities) and Seasonal Semideciduous Forest (6 localities). The average altitude of the sampled localities varies between 8 and 700 m above sea level and the rainfall ranges between 1,032 and 2,114 mm/year (Fick & Hijmans, 2017). Among the sampled gradient, the largest number of protected Atlantic Forest areas are concentrated in Bahia (Nogueira, Bragagnolo, DaSilva, Martins, et al., 2019) and the most humid forest areas are found in the southern portion of this state.

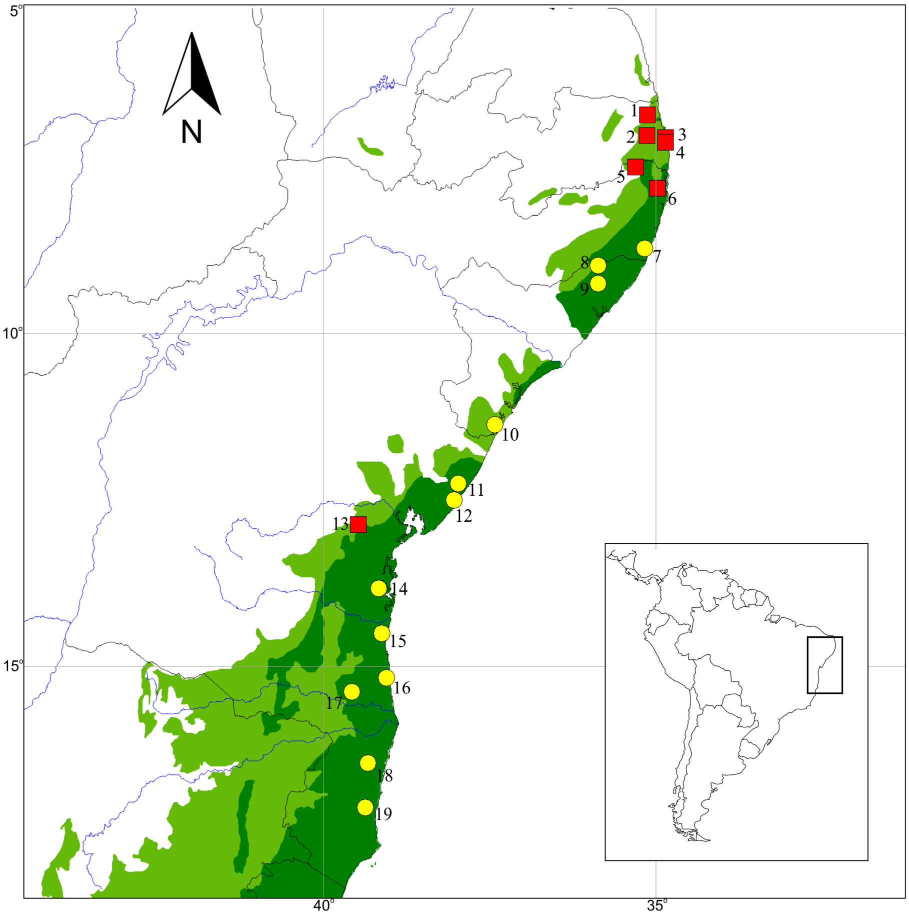

FIGURE 1 Locations of the 19 Atlantic Rainforest remnants sampled in the following states: Paraíba, Pernambuco, Alagoas, Sergipe, and Bahia (Brazil).1 = REBIO Guaribas, 2 = RPPN Fazenda Pacatuba, 3 = JB Benjamim Maranhão, 4 = FLONA de Cabedelo, 5 = Engenho Água Azul, 6 = Usina São José, 7 = REBIO de Saltinho, 8 = ESEC Murici, 9 = Usina Serra Grande, 10 = RPPN Mata do Crasto, 11 = RPPN Faz. Lontra/Saudade, 12 = Fazenda Camurujipe, 13 = Reserva Jequitibá, 14 = Reserva Ecológica da Michelin, 15 = PE Serra do Conduru, 16 = REBIO de Una, 17 = RPPN Serra Bonita, 18 = PARNA do Pau-Brasil, 19 = PARNA do Descobrimento. Dark green = Coastal Atlantic Rainforest (yellow circles are its considered localities), light green = Seasonal Semideciduous Forest (red squares are its considered localities).

TABLE 1 Information on the Atlantic Forest areas sampled in the present study in the states of Paraíba (PB), Pernambuco (PE), Alagoas (AL), Bahia (BA) and Sergipe (SE), Brazil. Geographic coordinates in degrees and minutes. SSF = Seasonal Semideciduous Forest; CAF = Coastal Atlantic Rainforest.

Locality	Geographic Coordinates	Area (km^2)	Vegetation type
Flona de Cabedelo (PB)	7°03' S; 34°51' W	113,72	SSF
REBIO Guaribas (PB)	6°43' S; 35°7' W	4.051,62	SSF
JB Benjamin Maranhão (PB)	7° 8' S; 34°51' W	343,79	SSF
RPPN Fazenda Pacatuba (PB)	7°2' S; 35°8 W	266,53	SSF
Engenho Água Azul (PE)	7°30' S; 35°18' W	600	CAF
REBIO Saltinho (PE)	8°43' S; 35°10' W	564,58	CAF
Usina São José (PE)	7°49' S; 34°59' W	28.000	CAF
Usina Serra Grande (AL)	8°59' S; 35°52' W	26.000	CAF
ESEC Murici (AL)	9°15' S; 35°52' W	6.131,53	CAF
RPPN Mata do Crasto (SE)	11°22' S; 37°25' "W	1000	CAF
Fazenda Lontra/Saudade (BA)	12°15' S; 37°58' W	1.377,33	CAF
Fazenda Camurujipe (BA)	12°30' S; 38°2' W	1.329	CAF
Reserva Jequitibá (BA)	12°52' S; 39°28' W	150	SSF
Reserva Ecológica da Michelin (BA)	13°49' S; 39°10' W	3.096	CAF
Parque Estadual Serra do Conduru (BA)	14°30' S; 39°7' W	9.275	CAF
REBIO de Una (BA)	15°10' S; 39°3' W	18.715,06	CAF
RPPN Serra Bonita (BA)	15°23' S; 39°34' W	2.500	CAF
PARNA do Pau-Brasil (BA)	16°27' S; 39°20' W	18.935,55	CAF
PARNA do Descobrimento (BA)	17°7' S; 39°22' W	22.693,97	CAF

Harvestmen sampling

For the harvestmen sampling, 36 plots of 300 m^2 (30×10 m), located at least 50 m apart from each other, were delimited in each locality. One hour of nocturnal collection (between 19:00 and 23:00 h) was undertaken by a collector in each plot, totalling a sampling effort of 36 h per locality and 684 h for the whole experiment. This protocol has been commonly used in arachnid inventories in the Atlantic Forest (Bragagnolo et al., 2007; Bragagnolo & Pinto-da-Rocha, 2003; Nogueira, Bragagnolo, DaSilva, Martins, et al., 2019; Resende et al., 2012b). In addition, nocturnal collection has proven to be the most effective method for harvestmen diversity studies (Tourinho et al., 2014). Since the harvestmen are extremely dependent on humidity (Curtis & Machado, 2007), the collections were undertaken during the rainy seasons (between the years July/2011 and march/2018) to maximize specimen capture in all localities. The harvestmen were captured from vegetation, rocks, leaf litter, tabular roots, fallen logs and ravines.

In order to capture harvestmen species of smaller body size that are difficult to detect through nocturnal hand collection, nine samples of leaf litter of 1 m^2 were collected from each locality. These samples were sieved and transferred to a Winkler extractor (see Bestelmeyer et al., 2000), where they remained for 48 h. The material was preserved in 70% ethanol and deposited in the arachnology collections of the Museum of the University of São Paulo (USP) and the Federal University of Paraíba (UFPB), where the individuals were identified by specialists.

Biodiversity surrogates

We evaluated five levels of potential surrogates for the taxonomic diversity of harvestmen. We reduced the taxonomic resolution by grouping species into (1) family, (2) subfamily and (3) genus. In addition, a genus subset was selected to be used as the indicator taxa (4), based on the assumption that more widely distributed genera with greater species richness can be good predictors of all the species in the community (Andersen, 1995). To be used as indicator taxa, genera that fit the following criteria were chosen: (i) genera that have been recorded in at least 4 of the 19 sampling sites and (ii) genera that contained species/morphospecies (hereafter referred to as species) that could be easily identified based on morphological characters.

The genera that satisfied these criteria were *Cynorta* Koch 1839, *Flirtea* Perty 1833*, Lacronia* Strand 1942, *Mitogoniella* Mello-Leitão 1936, *Paecilaema* Koch 1839, *Pickeliana* Mello-Leitão 1932, *Propachylus* Roewer 1913 and *Pseudopucrolia* Roewer 1912. In addition, the following selected genera were recently reviewed: *Flirtea* (Kury & Carvalho, 2016), *Pseudopucrolia* (Mendes, 2011), *Mitogoniella* (DaSilva & Gnaspini, 2010), and *Propachylus* (Carvalho et al., 2018). The last resolution, the intermediate resolution (5) mentioned earlier, is an adaptation of the mixed-level resolution proposed by Groc et al. (2010) for ants. This approach combines two levels of identification: genera and species, chosen according to the taxonomic complexity and the availability of recent reviews for each one. The mixed-level approach matrices in this study are composed of eight selected genera as indicator taxa identified at the species level and other harvestmen taxonomically identified only up to the genus level.

Data analysis

All analyses described below were performed with the localities of the Atlantic Forest studied as the unit of analysis. We used the reference values proposed by Leal et al. (2010) for predictions of species richness by diversity surrogates. Thus, based on r or r^2 values obtained a substitute was considered 'reasonable' if it predicts ≥60% and <70% of the founded variation with species-level data, 'good' if it predicts ≥70% and <80%, and 'excellent' if it can predict ≥80 %.

To test the different substitute resolutions, we compared the number of harvestmen species in relation to the number of different substitute taxonomic units (number of families, subfamilies, genus, indicator taxa and intermediate resolution) by locality using linear regression analyses, evaluating whether the richness of the substitute units is a good predictor of species richness through the obtained r^2 values.

The relationship between the original composition of the harvestmen and substitute resolutions was evaluated using the Mantel test to observe the correlation between the dissimilarity matrices of each locality calculated with the species resolution versus the other evaluated resolutions (Mantel, 1967). The Jaccard index (Rohlf, 1989) has been widely used to assess the compositional similarity of the assemblages (Manthey & Fridley, 2009), based on the presence-absence of different substitute taxonomic units. We used the Mantel test to assess whether the different substitute resolutions would change the structure in the similarity matrices. The Mantel test calculates the similarity between two given distance matrices, here using the Pearson correlation method. The statistical significance of the Mantel tests was estimated based on 5,000 permutations. Subsequently, the differences in how much each substitute matrix predicted the species matrix (represented by Pearson's correlation coefficients) were

TABLE 2 List of harvestmen species collected in 19 Atlantic Forest landscapes according to the type of environment (SSF = Seasonal Semideciduous Forest; CAF = Coastal Atlantic Rainforest) and classification according to the different taxonomic surrogate resolutions evaluated.

Family	Subfamily	Genus	Specie/Morphospecies	Indicator taxa	Environment	
					SSF	CAF
Cosmetidae			Cosmetidae sp.1			1
	Cosmetinae	*Cosmetus*	*Cosmetus* sp.1			2
		Cynorta	*Cynorta ceara* Roewer, 1927	X	3	3
			Cynorta seminata Roewer, 1917	X		1
			Cynorta sp.1	X		1
		Flirtea	*Flirtea picta* (Perty, 1833)	X	1	6
		Paecilaema	*Paecilaema albosigilatum* (Mello-Leitão, 1941)	X		1
			Paecilaema sp.1	X		1
			Paecilaema sp.2	X		2
			Paecilaema sp.3	X		1
			Paecilaema sp.4	X		3
			Paecilaema sp.5	X		1
			Paecilaema sp.6	X		2
Cryptogeobiidae			Cryptogeobiidae sp. 1			1
			Cryptogeobiidae sp. 2			1
Escadabiidae			Escadabiidae sp.1			1
			Escadabiidae sp.2			1
			Escadabiidae sp.3			1
		Escadabius	*Escadabius schubarti* Roewer, 1949		1	2
			Escadabius sp.			1
		Jim	*Jim benignus* H. Soares, 1979			1
Gonyleptidae	Mitobatinae	*Encheiridium*	*Encheiridium* sp.			1
	Pachylinae	*Discocyrtus*	*Discocyrtus* sp.1			2
	Caelopyginae	*Metarthrodes*	*Metarthrodes bimaculatus* Roewer, 1913			1
	Goniosomatinae	*Mitogoniella*	*Mitogoniella modesta* (Perty, 1833)	X	1	3
			Mitogoniella unicornis DaSilva & Gnaspini, 2009	X		1
	Gonyleptinae	*Acanthogonyleptes*	*Acanthogonyleptes* sp.1		1	1
			Gonyleptinae sp.1			2
			Gonyleptinae sp.2			1
		Metagonyleptes	*Metagonyleptes calcar* Roewer, 1913			3
	Heteropachylinae		Heteropachylinae sp.1			1
			Heteropachylinae sp.2			1
			Heteropachylinae sp.3		1	
			Heteropachylinae sp.4			1
		Heteropachylus	*Heteropachylus peracchii* Soares & Soares, 1974			4
			Heteropachylus crassicalcanei (H.Soares, 1977)		1	1
			Heteropachylus ramphonotus Mendes, 2011			2
			Heteropachylus sp.1			1

(Continues)

TABLE 2 (Continued)

					Environment	
Family	**Subfamily**	**Genus**	**Specie/Morphospecies**	**Indicator taxa**	**SSF**	**CAF**
			Heteropachylus sp.2			1
			Heteropachylus sp.3			2
			Heteropachylus sp.4			1
			Heteropachylus sp.5			1
			Heteropachylus sp.6			1
		Magnispina	*Magnispina* sp.1			1
			Magnispina sp.2			1
			Magnispina sp.3		1	
		Pseudopucrolia	*Pseudopucrolia incerta* (Mello-Leitão, 1928)	X		1
			Pseudopucrolia discrepans (Roewer, 1943)	X	4	4
			Pseudopucrolia mutica (Perty, 1833)	X	1	5
			Pseudopucrolia sp.1	X		2
			Pseudopucrolia sp.2	X	1	3
			Pseudopucrolia sp.3	X		1
	Mitobatinae		Mitobatinae sp.1			1
	Pachylinae	*Ceratoleptes*	*Ceratoleptes proboscis* Soares & Soares, 1979			1
		Eugyndes	*Eugyndes* sp.1			1
		Eusarcus	*Eusarcus acrophtalmus* Hara & Pinto-da-Rocha, 2010			1
			Eusarcus incus Soares & Soares, 1946			2
			Eusarcus sergipanus Hara & Pinto-da-Rocha, 2010			1
			Eusarcus sp.1			1
			Eusarcus sp.2			1
		Lacronia	*Lacronia* sp.	X	1	4
			Pachylinae sp.1			3
			Pachylinae sp.2			1
			Pachylinae sp.3			1
			Pachylinae sp.4			1
			Pachylinae sp.5			1
		Parapucrolia	*Parapucrolia ocellata* Roewer, 1917			2
		Propachylus	*Propachylus singularis* Roewer, 1913			4
	Tricommatinae		Tricommatinae sp.1			2
			Tricommatinae sp.2			2
			Tricommatinae sp.3			1
Kimulidae		*Tegipiolus*	*Tegipiolus pachypus* Roewer, 1949		1	
			Tegipiolus sp.1			2

TABLE 2 (Continued)

Family	Subfamily	Genus	Specie/Morphospecies	Indicator taxa	Environment	
					SSF	CAF
Stygnidae		*Gaibulus*	*Gaibulus schubarti* Roewer, 1943			1
			Gaibulus sp.		1	3
	Stygninae	*Paraphareus*	*Paraphareus* sp1		1	
		Pickeliana	*Pickeliana albimaculata* Hara & Pinto-da-Rocha, 2008	X		1
			Pickeliana capito (Soares & Soares, 1974)	X		8
			Pickeliana pickeli Mello-Leitão, 1932	X	6	5
			Pickeliana sp.1	X		2
			Pickeliana sp.2	X		2
			Pickeliana sp.3	X		2
			Pickeliana sp.4	X	1	
		Protimesius	*Protimesius bahiensis* Villareal-Manzanilla & Pinto-da-Rocha, 2009			1
			Protimesius junina Villareal-Manzanilla & Pinto-da-Rocha, 2006			1
			Protimesius mendopictus (H.Soares, 1978)			1
Zalmoxidae		*Pirassunungoleptes*	*Pirassunungoleptes sp.*			2
			Zalmoxidae sp.1		1	

tested by analysis of variance (ANOVA), followed by the Tukey multiple range test. Among the 19 localities studied, four were excluded from the analyses described above, as they had fewer than four harvestmen species: 'RPPN Fazenda Pacatuba', 'REBIO Guaribas', 'JB Benjamim Maranhão' and 'FLONA de Cabedelo'.

We evaluated whether the three best surrogate resolutions for taxonomic diversity of Opiliones are also good predictors of ecological patterns by assessing the relationship between the number of harvestmen species found in the Seasonal Semideciduous Forest (SSF) and the Coastal Atlantic Rainforest (CAF) with Student's t test. We also evaluated the relationship between the number of harvestmen species recorded by locality and the latitude of the studied landscape as well as for the two best substitute resolutions using linear regression analysis. All analyses were performed using the software R version 3.6.1 (R Development Core Team, 2019). All assumptions of the tests performed were tested and followed. We used the packages 'ggplot2' (Wickham, 2016) and 'vegan' (Oksanen et al., 2014).

RESULTS

A total of 88 harvestmen species/morpho-species, distributed in 7 families, 15 subfamilies, and 36 genera were recorded. The number of taxonomic units identified in the indicator taxa and the intermediate resolution was 28 and 52, respectively (Table 2). All the different substitute resolutions were able to predict the variation in species richness, with r^2 ranging from 0.318 to 0.939 (Figure 2). The intermediate resolution and genus were classified as excellent substitutes for the harvestmen richness ($r^2 = 0.939$; $p < 0.001$;

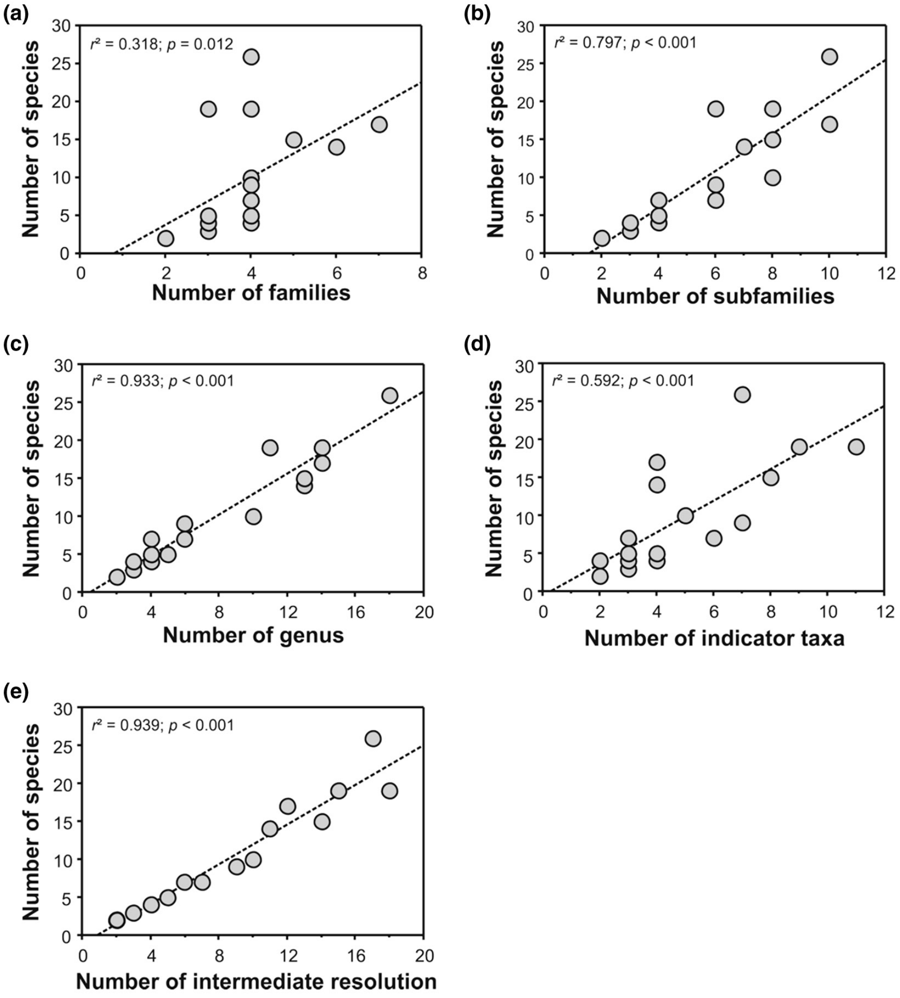

FIGURE 2 Relationships between the total species richness and the five levels richness of assessed substitute resolutions (family, subfamily, genus, indicator taxa and intermediate resolution) for the 19 sampled areas of the Atlantic Forest.

Figure 2e, r^2 = 0.933; $p < 0.001$; Figure 2c, respectively). Subfamily resolution was considered a good substitute (r^2 = 0.797; $p < 0.001$; Figure 2b). On the contrary, indicator taxa resolution was a reasonable substitute (r^2 = 0.592; $p < 0.001$; Figure 2d), while resolution at the family level did not reach the reasonable minimum value, being classified as an inadequate substitute for the harvestmen richness (r^2 = 0.318; $p < 0.019$; Figure 2a).

Regarding species composition, Mantel's correlation coefficients differed according to the substitute resolution used ($F_{4,70}$ = 8.729; $p < 0.001$; Figure 3). No differences were found between family and subfamily resolutions; however, these were different from other substitute resolutions. There were no significant differences between the genus, indicator taxa and intermediate resolutions (Tukey, $p < 0.001$; Figure 3). The highest correlations between the resolutions evaluated with the original data (Table 3) were observed for the intermediate resolution (mean = 0.995; standard deviation = 0.10), followed by genus (0.935 ± 0.122), indicator taxa (0.904 ± 0.141) and subfamily (0.808 ± 0.162), all classified as excellent substitutes for the harvestmen composition. Family-level resolution was classified only as a reasonable substitute (0.746 ± 0.157) (Figure 3).

The number of harvestmen species recorded was significantly different between Seasonal Semideciduous Forest (SSF) and Coastal Atlantic Rainforest (CAF) (T = –2.849; df = 17; p = 0.011). On average, the species number recorded from CAF was about three times the number recorded from SSF (Figure 4). The same relationship found for the number of species between CAF and SSF was also observed for the intermediate resolutions ($T = -2.936$; $df = 17$; $p = 0.009$) and genus ($T = -2.409$; $df = 17$; $p = 0.027$; Figure 4).

The number of harvestmen species showed a significantly positive linear relationship with latitude ($r^2 = 0.717$; $p < 0.001$; Figure 5a). This same relationship was also observed when using genus ($r^2 = 0.787$; $p < 0.001$; Figure 5b) and intermediate resolution ($r^2 = 0.691$; $p < 0.001$; Figure 5c).

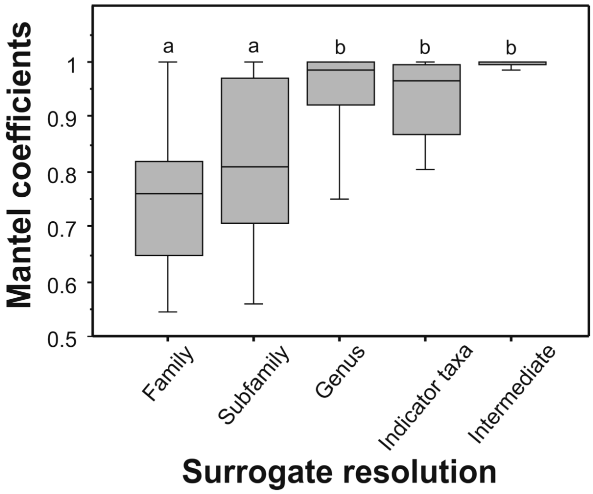

FIGURE 3 Variation in the Mantel correlation coefficients according to the five different levels of substitutes evaluated in 15 of the 19 sampled areas. The values represent the mean and standard deviation. The different letter represents the significant differences in surrogates' resolutions.

TABLE 3 Values for each of the 15 sites of Mantel correlation coefficients for comparisons between matrices of species and the different taxonomic surrogate resolutions evaluated.

Locality	Code	Family	Subfamily	Genus	Indicator taxa	Intermediate Resolution
RE da Michelin (BA)	Site1	0.801***	0.801***	0.98***	0.802***	0.991***
Reserva Jequitibá (BA)	Site 2	0.677***	0.888***	1.00***	0.857***	1.00***
PARNA do Pau Brasil (BA)	Site 3	0.637***	0.69***	0.998***	0.878***	0.998***
PARNA do Descobrimento (BA)	Site 4	0.758***	0.758***	0.984***	0.861***	0.984***
RPPN Mata do Crasto (SE)	Site 5	0.826***	1.00***	1.00***	1.00***	1.00***
Faz. Camurujipe (BA)	Site 6	0.777***	0.809***	1.00***	0.877***	1.00***
PE Serra do Conduru (BA)	Site 7	0.454**	0.561**	0.962***	0.937***	1.00***
REBIO de Una (BA)	Site 8	0.547**	0.553**	0.753***	0.966***	0.965***
RPPN Faz. Lontra/Saudade (BA)	Site 9	0.771***	0.993***	0.993***	0.992***	1.00***
RPPN Serra Bonita (BA)	Site 10	0.756***	0.849***	0.983***	0.988***	0.988***
Usina Serra Grande (AL)	Site 11	0.548**	0.565**	0.565**	0.994***	1.00***
ESEC Murici (AL)	Site 12	0.736***	0.75***	0.908***	1.00***	1.00***
REBIO de Saltinho (PE)	Site 13	0.908***	0.908***	0.908***	0.971***	1.00***
Engenho Água Azul (PE)	Site 14	1.00***	1.00***	1.00***	0.995***	1.00***
Usina São José (PE)	Site15	0.999***	1.00***	1.00***	0.454**	1.00***
Mantel's coefficients Mean ± SD		0.746 ±0.152	0.808 ±0.157	0.935 ±0.118	0.904 ±0.136	0.995 ±0.009

*=<0.05; **=<0.005; ***=<0.0005.

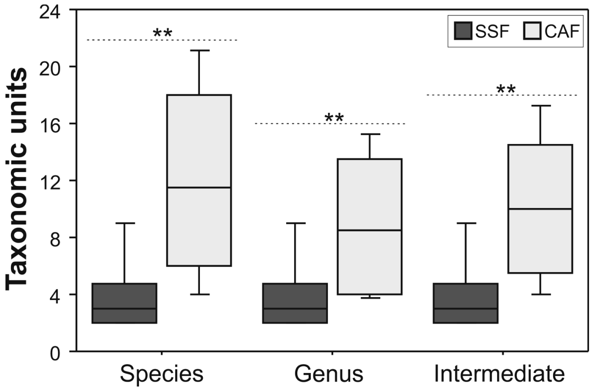

FIGURE 4 Number of taxonomic units in three levels of resolution evaluated (species, genus and intermediate resolution) between areas of Seasonal Semideciduous Forest (SSF) and Coastal Atlantic Rainforest (CAF). The values represent the mean and standard deviation for the 19 sampled areas.

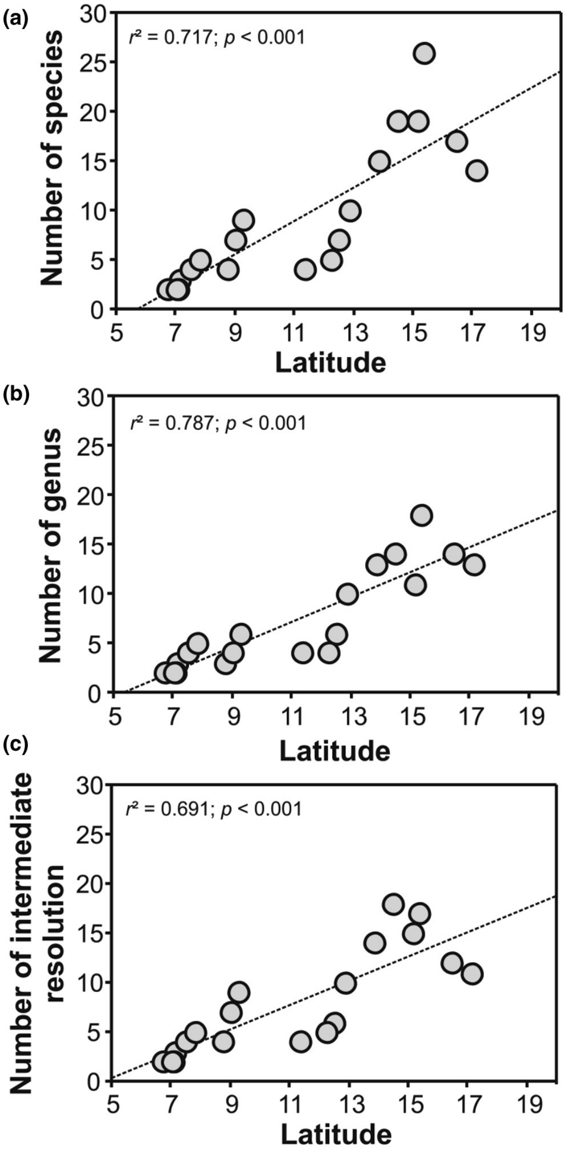

FIGURE 5 Relationship between the richness of the levels of taxonomic resolutions evaluated: species (a), genus (b) and intermediate resolution (c) with the latitude geographic variable considering the 19 Atlantic Forest localities sampled.

DISCUSSION

Our results pointed out that genus and intermediate resolution may be considered as suitable substitutes to harvestman species richness. The response of genus as a suitable substitute for predicting species richness has been documented in other invertebrate studies (Andersen, 1995; Cardoso et al., 2004; Rosser & Eggleton, 2012; Souza et al., 2016). For spiders, for example, genus richness is considered a good surrogate of species richness and evaluation and ranking of areas according to their conservation importance (Cardoso et al., 2004), In another study carried out with ants, also found genus as cost-effective surrogate, predicting 81% of site variation in species richness. (Souza et al., 2016) The strong relationship observed between genus and number of harvestmen species may be associated with the low number of species per genus recorded in each sampled locality, as also observed by Grelle (2002). The same pattern found in the present study has already been verified in other invertebrate studies (Groc et al., 2010; Koch et al., 2021; Souza et al., 2016).

The decline in species richness ratios with higher taxonomic levels is basically a global standard (Gaston & Williams, 1993). Family level performed poorly as a substitute taxonomic resolution of harvestmen richness. For spiders, closely related to harvestmen, as they are arachnids, family had a significant relationship with species richness, but was not considered a reliable substitute, while subfamily was an unsatisfactory substitute resolution (Cardoso et al., 2004). In contrast, family was positively correlated with species richness for other groups such as primates (Grelle, 2002), birds (Gaston & Blackburn, 1995), and molluscs (Terlizzi et al., 2009). Overall, we observed that higher-level taxa (family, subfamily) are poor predictors of invertebrate species richness (Andersen, 1995; Cardoso et al., 2004; Souza et al., 2016; Vieira et al., 2012).

Regarding species composition, the use of higher taxonomic levels may also not detect changes in the composition of invertebrate species (Groc et al., 2010). In this study, four resolutions were considered as good or excellent substitutes for harvestmen species richness: intermediate resolution, genus, indicator taxa, and subfamily. However, we do not recommend the use of subfamilies as a suitable substitute, as we observed localities with similar numbers of subfamilies but with very different species richness and composition. For example, the ‘Usina Serra Grande’ locality had four subfamilies and eight harvestmen species, while in the ‘PARNA do Descobrimento’ we recorded five subfamilies and fifteen species. These localities had three subfamilies in common, but did not share any species.

There are several advantages to using the genus as a substitute for harvestmen richness and composition. Given the high harvestmen diversity, with many species yet to be described, ecological studies often rely on morphospecies to perform the required analyses (Bragagnolo et al., 2007; Bragagnolo & Pinto-da-Rocha, 2003; Nogueira, Bragagnolo, DaSilva, Martins, et al., 2019; Pinto-da-Rocha et al., 2005). However, these morphospecies are not standardized among different researchers, making comparisons between species-level studies impossible, and allowing assessments only at the genus level. In addition, we highlight the importance of using genus as an operational taxonomic unit rather than species for evaluations that need to be performed in a short time. In such evaluations, one cannot expect all the taxonomic problems of the group to be resolved.

On the contrary, the use of genus as a substitute taxonomic level for the composition of harvestmen species may present challenges to its application (Cardoso et al., 2004; Groc et al., 2010; Vieira et al., 2012). First, we observed frequent changes in invertebrate systematics (Cardoso et al., 2004), and, for harvestmen, many taxonomic revisions are currently being published (*e.g*. Benavides et al., 2019; Carvalho et al., 2018; Coronato-Ribeiro & Pinto-da-Rocha, 2017; Kury & García, 2016). Second, genus identification for many individuals is still difficult (Cardoso et al., 2004), especially for non-specialists in the group. Several harvestmen diversity studies, mainly the ones prior to most recent reviews, present individuals that are not identified at the genus level, for example, in the subfamilies Gonyleptinae, Pachylinae and Tricommatinae (Andrade et al., 2009; Bragagnolo & Pinto-da-Rocha, 2003; Bragagnolo et al., 2007; Pinto-da-Rocha et al., 2005; Resende et al., 2012a, 2012b). The same was observed in the present study: subfamilies such as Pachylinae, Heteropachylinae, Tricommatinae and Escadabiidae presented individuals whose identification at the genus level was not possible. Third, the use of genus as a surrogate resolution may camouflage more subtle changes in assemblages that are only detected at the species level (Groc et al., 2010). Therefore, we suggest caution with genus-level assessments when the sampling effort is low.

Intermediate resolution was also able to predict the composition of the harvestmen, as observed for ants (Koch et al., 2021). The use of this taxonomic resolution allows us to: (1) reduce the effort of taxonomic identification of more complex and diverse genera in the Neotropical Region or with morphological characteristics difficult to differentiate between species, and (2) retain more information about the assemblies studied than other taxonomic resolutions (Groc et al., 2010). For ants, given the greater variety of species within the same genus, the use of intermediate resolution as a substitute diversity did not significantly reduce monitoring costs compared to species-level assessments (Souza et al., 2016). This is because there is a need for experts to identify certain individuals at the species level and a longer time to make these identifications.

Due to the low richness in SSF localities, we suggest that for more reliable compositional substitute assessments, a larger number of localities with such vegetation should be included. In the present study, most localities were excluded from the composition substitute analysis because of the low number of recorded species. Comparisons between arboreal and anthropic environments (Cardoso et al., 2004) as well as arboreal and shrubs (Vieira et al., 2012) indicated that the response of the selected taxonomic resolution was not the best diversity substitute. We also expect no difference in the response of substitute taxonomic resolutions to the harvestmen composition when comparing areas of Seasonal Semideciduous Forest and Coastal Atlantic Rainforest.

Variations in harvestmen species richness as a function of latitude were also observed for genus richness and intermediate resolution. This result reinforces the idea that these two resolutions are suitable substitutes for assessing the harvestmen species richness. Ideal substitutes should have the same or similar response to certain predictor variables as compared to species-level assessment (Souza et al., 2016). Species richness in Coastal Atlantic Rainforest localities was significantly higher than in Seasonal Semideciduous Forest areas (Nogueira, Bragagnolo, DaSilva, Martins, et al., 2019). Compositional differences and asymmetry in the distribution of harvestmen richness in the sampled gradient appear to be mainly caused by historical factors such as forest refuges and rivers as barriers to dispersal, but climate-influenced too (DaSilva et al., 2015; Nogueira, Bragagnolo, DaSilva, Carvalho, et al., 2019; Nogueira, Bragagnolo, DaSilva, Martins, et al., 2019). We observed that for areas of Seasonal Semideciduous Forest, the values of the taxonomic units for the intermediate resolutions, species and genus remained similar, indicating that these evaluated substitutes are related to the pattern found for species.

Assessments of diversity surrogates at larger spatial scales are constant (Cardoso et al., 2004; Gaston & Williams, 1993; Souza et al., 2016; Williams & Gaston, 1994). For spiders, the spatial scale used influenced the predictive power of diversity surrogates (Cardoso et al., 2004). For ants from the Amazon Rainforest, the predictive power of the evaluated substitutes was not weakened by the 1,800 km long latitudinal gradient. Our results are in agreement with those observed for ants (Souza et al., 2016). The latitudinal gradient evaluated here covers an extent of approximately 1,300 km, and the taxonomic resolutions considered in this study as effective substitutes (genus and intermediate resolution) had a high predictive power.

CONCLUSION

Different views on how to select priority areas for conservation have been commonly debated (Margules & Pressey, 2000). In general, biodiversity monitoring and conservation programs rely on alpha diversity to select such areas (Cardoso et al., 2004). However, based on the principle of complementarity, there is currently a concern with conservation of habitats not only based on richness, but also with those that allow the protection of a greater number of species considering the regional pool of species (Faith et al., 2004; Reyers et al., 2000). Harvestmen have been shown to be an interesting group for assessing environmental change (Bragagnolo et al., 2007), and we reinforce the importance of including this group in biodiversity monitoring programs. In studies with medium/high sampling effort, where rapid evaluation at lower cost is required for decision-making, we suggest using genus-level data as appropriate surrogates for harvestmen species richness and composition. Based on the data evaluated here, we observed that by using genus richness, we are conserving information of over 75% of the species/morphospecies recorded, since it was not possible to identify several individuals at the genus level. It is noteworthy that if the objective of a study is to identify and monitor harvestmen diversity with emphasis on biomonitoring environmental changes, intermediate resolution may constitute an appropriate surrogate.

AUTHOR CONTRIBUTIONS

Alessandra Rodrigues Santos de Andrade: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (supporting); investigation (equal); methodology (equal); writing – original draft (equal); writing – review and editing (equal). **Elmo Borges de Azevedo Koch:** Conceptualization (equal); formal analysis (equal); writing – original draft (equal); writing – review and editing (equal). **André do Amaral Nogueira:** Data curation (equal); funding acquisition (supporting); writing – review and editing (equal). **Ricardo Pinto-Da-Rocha:** Data curation (equal); funding acquisition (supporting); writing – review and editing (equal). **Cibele Bragagnolo:** Data curation (equal); writing – review and editing (equal). **Everton Lorenzo:** Data curation (equal); funding acquisition (supporting). **Márcio Bernardino DaSilva:** Data curation (equal); funding acquisition (supporting); writing – original draft (supporting); writing – review and editing (equal). **Jacques Hubert Charles Delabie:** Conceptualization (equal); writing – original draft (supporting); writing – review and editing (equal).

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CONFLICT OF INTEREST

The authors declare they have no conflict of interest.

DATA AVAILABILITY STATEMENT

Part of the data that support the findings of this study will be available at doi:10.6084/m9.figshare.20486370. A large proportion of the data are available from Supplementary material by Nogueira, Bragagnolo, DaSilva, Martins, et al., 2019 (http://dx-doi.ez427.periodicos.capes.gov.br/10.1139/cjz-2018-0032). Restrictions apply to the availability of these data, which were used under license for this study.

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REFERENCES

Adams, J. (1984) The habitat and feeding ecology of woodland harvestmen (Opiliones) in England. *Oikos*, 42, 361–370. Available from: https://doi.org/10.2307/3544406

Amaral, A.G., Munhoz, C.B., Walter, B.M., Aguirre-Gutiérrez, J. & Raes, N. (2017) Richness pattern and phytogeography of the Cerrado herb–shrub flora and implications for conservation. *Journal of Vegetation Science*, 28(4), 848–858. Available from: https://doi.org/10.1111/jvs.12541

Andersen, A.N. (1995) Measuring more of biodiversity: Genus richness as a surrogate for species in Australian ant faunas. *Biological Conservation*, 73, 39–43. Available from: https://doi.org/10.1016/0006-3207(95)90059-4

Andrade, A.R.S.A., Peres, M.C.L., Benati, K.R. & Dias, M.A. (2009) Ocorrência de *Gaibulus schubarti* Roewer, 1943 (Opiliones: Stygnidae) em ambientes de clareira natural de Floresta Atlântica. *Sitientibus*, 9(4), 204–207.

Araújo, M.B., Densham, P.J. & Williams, P.H. (2004) Representing species in reserves from patterns of assemblage diversity. *Journal of Biogeography*, 31(7), 1037–1050. Available from: https://doi.org/10.1111/j.1365-2699.2004.01051.x

Barton, P.S., Pierson, J.C., Westgate, M.J., Lane, P.W. & Lindenmayer, D.B. (2015) Learning from clinical medicine to improve the use of surrogates in ecology. *Oikos*, 124(4), 391–398. Available from: https://doi.org/10.1111/oik.02007

Bataus, Y. & Fonte, L.F.M. (2015) National conservation status assessment of Brazilian amphibian species. *FrogLog*, 115, 22–23.

Benavides, L.R., Hormiga, G. & Giribet, G. (2019) Phylogeny, evolution and systematic revision of the mite harvestman family Neogoveidae (Opiliones Cyphophthalmi). *Invertebrate Systematics*, 33(1), 101–180. Available from: https://doi.org/10.1071/IS18018

Bestelmeyer, B.T., Agosti, D., Alonso, L.E., Silvestre, R., Brandão, C.R.F., Brown, J.R.W.L. et al. (2000) Field techniques for the study of ground-dwelling ants. In: Agosti, D., Majer, J.D., Alonso, L.E. & Schultz, T. (Eds.) *Measuring and monitoring biological diversity: standard methods for ground living ants*. Washington, DC: Smithsonian Institution Press, pp. 122–144.

Blandón, A.C., Perelman, S.B., Ramírez, M., López, A., Javier, O. & Robbins, C.S. (2016) Temporal bird community dynamics are strongly affected by landscape fragmentation in a Central American tropical forest region. *Biodiversity and Conservation*, 25(2), 311–330. Available from: https://doi.org/10.1007/s10531-016-1049-2

Bragagnolo, C., Nogueira, A.A., Pinto-da-Rocha, R. & Pardini, R. (2007) Harvestmen in an Atlantic forest fragmented landscape: evaluating assemblage response to habitat quality and quantity. *Biological Conservation*, 139(3-4), 389–400. Available from: https://doi.org/10.1016/j.biocon.2007.07.008

Bragagnolo, C. & Pinto-da-Rocha, R. (2003) Diversidade de opiliões do Parque Nacional da Serra dos Órgãos, Rio de Janeiro, Brasil (Arachnida: Opiliones). *Biota Neotropica*, 3(1), 1–20. Available from: https://doi.org/10.1590/S1676-06032003000100009

Burns, J.A., Hunter, R.K. & Townsend, J.R. (2007) Tree use by haverstmen (Opiliones: Arachnida) in the Rainforests of Trinidad. *Caribbean Journal of Science*, 43(1), 38–142.

Butchart, S.H., Scharlemann, J.P., Evans, M.I., Quader, S., Aricò, S., Arinaitwe, J. et al. (2012) Protecting important sites for biodiversity contributes to meeting global conservation targets. *PloS One*, 7(3), e32529. Available from: https://doi.org/10.1371/journal.pone.0032529

Cardoso, P., Silva, I., Oliveira, N.G. & Serrano, A.R. (2004) Higher taxa surrogates of spider (Araneae) diversity and their efficiency in conservation. *Biological Conservation*, 117(4), 453–459. Available from: https://doi.org/10.1016/j.biocon.2003.08.013

Carvalho, R.N., Kury, A.B. & Santos, M.S. (2018) Conspecificity of semaphoronts – the synonymy of *Metadiscocyrtus* with *Propachylus* (Opiliones: Laniatores: Gonyleptidae). *The Journal of Arachnology*, 46(3), 488–498. Available from: https://doi.org/10.1636/JoA-S-17-082.1

Coronato-Ribeiro, A. & Pinto-Da-Rocha, R. (2017) Taxonomic revision and cladistic analysis of the genus *Metalibitia* Roewer, 1912 (Opiliones, Cosmetidae, Cosmetinae). *Zootaxa*, 4291(2), 201–242. Available from: https://doi.org/10.11646/zootaxa.4291.2.1

Crooks, K.R., Burdett, C.L., Theobald, D.M., King, S.R., Di Marco, M., Rondinini, C. et al. (2017) Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. *PNAS*, 114(29), 7635–7640. Available from: https://doi.org/10.1073/pnas.1705769114

Curtis, D.J. & Machado, G. (2007) Ecology. In: Pinto-da-Rocha, R., Machado, G. & Giribet, G. (Eds.) *Harvestmen: the biology of opiliones*. Massachussets, USA: Harvard University Press, pp. 208–308.

DaSilva, M.B. & Gnaspini, P. (2010) A systematic revision of Goniosomatinae (Arachnida: Opiliones: Gonyleptidae), with a cladistic analysis and biogeographical notes. *Invertebrate Systematics*, 23(6), 530–624. Available from: https://doi.org/10.1071/IS09022

DaSilva, M.B., Pinto-da-Rocha, R. & DeSouza, A.M. (2015) A protocol for the delimitation of areas of endemism and the historical regionalization of the Brazilian Atlantic Rain Forest using harvestmen distribution data. *Cladistics*, 31, 692–705. Available from: https://doi.org/10.1111/cla.12121

de Carvalho, D.L., Sousa-Neves, T., Cerqueira, P.V., Gonsioroski, G., Silva, S.M., Silva, D.P. et al. (2017) Delimiting priority areas for the conservation of endemic and threatened Neotropical birds using a niche-based gap analysis. *PloS One*, 12(2), e0171838. Available from: https://doi.org/10.1371/journal.pone.0171838

Fahrig, L. (2003) Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, 34, 87–515. Available from: https://doi.org/10.1146/annurev.ecolsys.34.011802.132419

Faith, D.P., Reid, C.A.M. & Hunter, J. (2004) Integrating phylogenetic diversity, complementarity, and endemism for conservation assessment. *Conservation Biology*, 18(1), 255–261. Available from: https://doi.org/10.1111/j.1523-1739.2004.00330.x

Fiaschi, P. & Pirani, J.R. (2009) Review of plant biogeographic studies in Brazil. *Journal of Systematics and Evolution*, 47(5), 477–496. Available from: https://doi.org/10.1111/j.1759-6831.2009.00046.x

Fick, S.E. & Hijmans, R.J. (2017) Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37, 4302–4315.

Filgueiras, B.K.C., Iannuzzi, L. & Leal, I.R. (2011) Habitat fragmentation alters the structure of dung beetle communities in the Atlantic Forest. *Biological Conservation*, 144(1), 362–369. Available from: https://doi.org/10.1016/j.biocon.2010.09.013

Gaspar, C., Gaston, K.J. & Borges, P.A. (2010) Arthropods as surrogates of diversity at different spatial scales. *Biological Conservation*, 143(5), 1287–1294. Available from: https://doi.org/10.1016/j.biocon.2010.03.007

Gaston, K.J. & Blackburn, T.M. (1995) Mapping biodiversity using surrogates for species richness: macro-scales and New World birds. *Proceedings of The Royal Society B-Biological Sciences*, 262(1365), 335–341. Available from: https://doi.org/10.1098/rspb.1995.0214

Gaston, K.J. & Williams, P.H. (1993) Mapping the world's species-the higher taxon approach. *Biodiversity Letters*, 1(1), 2–8. Available from: https://doi.org/10.2307/2999642

Gnaspini, P. (1996) Population ecology of *Goniosoma spelaeum*, a cavernicolous harvestman from south-eastern Brazil (Arachnida: Opiliones: Gonyleptidae). *Journal of*

Zoology, 239, 417–435. Available from: https://doi.org/10.1111/j.1469-7998.1996.tb05933.x

Goodnight, C.J. & Goodnight, M.L. (1976) Observations on the systematics, development, and habits of *Erginulus clavotibialis* (Opiliones: Cosmetidae). *Transactions of the American Microscopical Society*, 95, 654–664. Available from: https://doi.org/10.2307/3225390

Grelle, C.E.V. (2002) Is higher-taxon analysis an useful surrogate of species richness in studies of Neotropical mammal diversity? *Biological Conservation*, 108(1), 101–106. Available from: https://doi.org/10.1016/S0006-3207(02)00094-0

Groc, S., Delabie, J.H.C., Longino, J.T., Orivel, J., Majer, J.D., Vasconcelos, H.L. et al. (2010) A new method based on taxonomic sufficiency to simplify studies on Neotropical ant assemblages. *Biological Conservation*, 143, 2832–2839. Available from: https://doi.org/10.1016/j.biocon.2010.07.034

Gutiérrez, J.A.M., Rousseau, G.X., Andrade-Silva, J. & Delabie, J.H.C. (2017) Taxones superiores de hormigas como sustitutos de la riqueza de especies, en una cronosecuencia de bosques secundarios, bosque primario y sistemas agroforestales en la Amazonía Oriental, Brasil. *Revista de Biología Tropical*, 65(1), 279–291. Available from: https://doi.org/10.15517/rbt.v65i1.23526

Haddad, N.M., Brudvig, L.A., Clobert, J., Davies, K.F., Gonzalez, A., Holt, R.D. et al. (2015) Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances*, 1(2), e1500052. Available from: https://doi.org/10.1126/sciadv.1500052

Hanski, I. (2005) *The shrinking world: ecological consequences of habitat loss*. Oldendorf/Luhe, Germany: International Ecology Institute.

Hodkinson, I.D. & Jackson, J.K. (2005) Terrestrial and aquatic invertebrates as bioindicators for environmental monitoring, with particular reference to mountain ecosystems. *Environmental Management*, 35(5), 649–666. Available from: https://doi.org/10.1007/s00267-004-0211-x

Koch, E.B.A., Nascimento, I.C., Majer, J.D. & Delabie, J.H.C. (2021) Seeking surrogates for taxonomic and functional evaluations of leaf-litter ant faunas. *Ecological Indicator*, 122, 107305. Available from: https://doi.org/10.1016/j.ecolind.2020.107305

Kremen, C., Colwell, R.K., Erwin, T.L. & Murphy, D.D. (1993) Terrestrial arthropod assemblages: their use in conservation planning. *Conservation Biology*, 7, 796–808. Available from: https://doi.org/10.1046/j.1523-1739.1993.740796.x

Kury, A.B. & Carvalho, R.N. (2016) Revalidation of the Brazilian genus *Discocyrtanus*, with description of two new species (Opiliones: Gonyleptidae: Pachylinae). *Zootaxa*, 4111(2), 126–144. Available from: https://doi.org/10.11646/zootaxa.4111.2.2

Kury, A.B. & García, A.F. (2016) On the identity of *Flirtea* (Arachnida, Opiliones, Cosmetidae). *Zootaxa*, 4093(2), 231–247. Available from: https://doi.org/10.11646/zootaxa.4093.2.5

Landeiro, V.L., Bini, L.M., Costa, F.R.C., Franklin, E., Nogueira, A., Souza, J.L.P. et al. (2012) How far can we go in simplifying biomonitoring assessments? An integrated analysis of taxonomic surrogacy, taxonomic sufficiency and numerical resolution in a megadiverse region. *Ecological Indicators*, 23, 366–373. Available from: https://doi.org/10.1016/j.ecolind.2012.04.023

Larrieu, L., Gosselin, F., Archaux, F., Chevalier, R., Corriol, G., Dauffy-Richard, E. et al. (2018) Cost-efficiency of cross-taxon surrogates in temperate forests. *Ecological Indicators*, 87, 56–65. Available from: https://doi.org/10.1016/j.ecolind.2017.12.044

Larsen, T.H., Lopera, A. & Forsyth, A. (2008) Understand trait-dependent community disassembly: dung beetles, density functions, and forest fragmentation. *Conservation Biology*, 22(5), 1288–1298. Available from: https://doi.org/10.1111/j.1523-1739.2008.00969.x

Laurance, W.F., Useche, D.C., Rendeiro, J., Kalka, M., Bradshaw, C.J.A., Sloan, S.P. et al. (2012) Averting biodiversity collapse in tropical forest protected areas. *Nature*, 489, 290–294. Available from: https://doi.org/10.1038/nature11318

Leal, I.R., Bieber, A.G.D., Tabarelli, M. & Andersen, A.N. (2010) Biodiversity surrogacy: indicator taxa as predictors of total species richness in Brazilian Atlantic forest and Caatinga. *Biodiversity and Conservation*, 19, 3347–3360. Available from: https://doi.org/10.1007/s10531-010-9896-8

Machado, G., Raimundo, R.L.G. & Oliveira, P.S. (2000) Daily activity schedule, gregariousness, and defensive behaviour in the Neotropical harvestman *Goniosoma longipes* (Opiliones: Gonyleptidae). *Journal of Natural History*, 34, 587–596. Available from: https://doi.org/10.1080/002229300299453

Mantel, N. (1967) The detection of disease clustering and a generalized regression approach. *Cancer Research*, 27, 209–220.

Manthey, M. & Fridley, J.D. (2009) Beta diversity metrics and the estimation of niche width via species co-occurrence data: reply to Zeleny. *Journal of Ecology*, 97, 18–22. Available from: https://doi.org/10.1111/j.1365-2745.2008.01450.x

Margules, C.R. & Pressey, R.L. (2000) Systematic conservation planning. *Nature*, 405(6783), 243–253. Available from: https://doi.org/10.1038/35012251

Melo, D.H.A., Filgueiras, B.K., Iserhard, C.A., Iannuzzi, L., Freitas, A.V. & Leal, I.R. (2019) Effect of habitat loss and fragmentation on fruit-feeding butterflies in the Brazilian

Atlantic Forest. *Canadian Journal of Zoology*, 97(7), 588–596. Available from: https://doi.org/10.1139/cjz-2018-0202

Mendes, A.C. (2011) Phylogeny and taxonomic revision of Heteropachylinae (Opiliones: Laniatores: Gonyleptidae). *Zoological Journal of the Linnean Society*, 163(2), 437–483. Available from: https://doi.org/10.1111/j.1096-3642.2011.00706.x

Merino-Sáinz, I. & Anadón, A. (2018) Land use influences harvestman diversity in northern Spain: a case study involving secondary grasslands and forest plantations (Arachnida: Opiliones). *Journal of Insect Conservation*, 22(3), 363–376. Available from: https://doi.org/10.1007/s10841-018-0066-8

Mestre, L.A.M. & Pinto-Da-Rocha, R. (2004) Population dynamics of an isolated of the harvestman *Ilhaia cuspitata* (Opiliones, Gonyleptidae), in Araucaria Forest (Curitiba, Paraná, Brazil). *The Journal of Arachnology*, 321, 208–220. Available from: https://doi.org/10.1636/M02-61

Mihál, I. & Černecká, Ľ. (2017) Structure of harvestmen (Arachnida, Opiliones) communities in different, anthropically disturbed beech ecosystems (Western Carpathians, Slovakia). *Vestn Zool*, 51, 259–270. Available from: https://doi.org/10.1515/vzoo-2017-0032

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, 403, 845–853. Available from: https://doi.org/10.1038/35002501

Nogueira, A.A., Bragagnolo, C., DaSilva, M.B., Carvalho, L.S., Benedetti, A.R. & Pinto-da-Rocha, R. (2019) Spatial variation in phylogenetic diversity of communities of Atlantic Forest harvestmen (Opiliones, Arachnida). *Insect Conservation and Diversity*, 12(5), 414–426. Available from: https://doi.org/10.1111/icad.12356

Nogueira, A.A., Bragagnolo, C., DaSilva, M.B., Martins, T.K., Lorenzo, E.P., Perbiche-Neves, G. et al. (2019) Historical signatures in the alpha and beta diversity patterns of Atlantic Forest harvestman communities (Opiliones - Arachnida). *Canadian Journal of Zoology*, 97(7), 631–643. Available from: https://doi.org/10.1139/cjz-2018-0032

Oksanen, J., Blanchet, F.G., Friendly, M.I., Kindt, R., Legendre, P., McGlinn, D. et al. (2014) Vegan: community ecology package. *R package version* 2, 5–2. Available from: https://CRAN.Rproject.org/package=vegan

Oliveira-Filho, A.T. & Fontes, M.A.L. (2000) Patterns of floristic differentiation among Atlantic forests in southeastern Brazil and the influence of climate. *Biotropica*, 32, 793–810. Available from: https://doi.org/10.1111/j.1744-7429.2000.tb00619.x

Pimenta, B.V.S. & Silvano, D.L. (2002) *Pesquisa Biológica – Anfíbios, Relatório técnico preliminar, Subprojeto: Abordagens Ecológicas e Instrumentos Econômicos para o estabelecimento do corredor do Descobrimento*. Bahia, Brasil: MMA/PROBIO, IESB, Ilhéus.

Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N. et al. (2014) The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, 344, 987–997. Available from: https://doi.org/10.1126/science.1246752

Pinto-Da-Rocha, R., DaSilva, M.B. & Bragagnolo, C. (2005) Faunistic similarity and historic biogeography of the harvestmen of southern and southeastern Atlantic Rain Forest of Brazil. *The Journal of Arachnology*, 33, 290–299. Available from: https://doi.org/10.1636/04-114.1

Pinto-da-Rocha, R., Machado, G. & Giribet, G. (2007) *Harvestemen: the biology of opiliones*. Harvard, US: Harvard University Press.

Proud, D.N., Felgenhauer, B.E., Townsend, V.R., Osula, D.O., Gilmore, W.O., Napier, Z.L. et al. (2012) Diversity and habitat use of Neotropical harvestmen (Arachnida: Opiliones) in a Costa Rican rainforest. *ISRN Zoology*, 2012, 1–16. Available from: https://doi.org/10.5402/2012/549765

R Development Core Team. (2019) *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Resende, L.P.A., Pinto-Da-Rocha, R. & Bragagnolo, C. (2012a) Diversity of harvestmen (Arachnida, Opiliones) in Parque da Onça Parda, southeastern Brazil. *Iheringia. Série Zoologia*, 102(1), 99–105. Available from: https://doi.org/10.1590/S0073-47212012000100014

Resende, L.P.A., Pinto-Da-Rocha, R. & Bragagnolo, C. (2012b) The harvestmen fauna (Arachnida: opiliones) of the Parque Estadual Carlos Botelho, and the Floresta Panema, São Paulo, Brazil. *Biota Neotropica*, 12(4), 146–155. Available from: https://doi.org/10.1590/S1676-06032012000400016

Reyers, B., Jaarsveld, A.V. & Krüger, M. (2000) Complementarity as a biodiversity indicator strategy. *Proceedings of The Royal Society B-Biological Sciences*, 267(1442), 505–513. Available from: https://doi.org/10.1098/rspb.2000.1029

Rezende, C.L., Scarano, F.R., Assad, E.D., Joly, C.A., Metzger, J.P., Strassburg, B.B.N. et al. (2018) From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. *Perspectives in ecology and conservation*, 16(4), 208–214.

Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J. & Hirota, M.M. (2009) The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed?

Implications for conservation. *Biological Conservation*, 142, 1141–1153. Available from: https://doi.org/10.1016/j.biocon.2009.02.021

Rodríguez-San Pedro, A. & Simonetti, J.A. (2015) The relative influence of forest loss and fragmentation on insectivorous bats: does the type of matrix matter? *Landscape Ecology*, 30(8), 1561–1572. Available from: https://doi.org/10.1007/s10980-015-0213-5

Rohlf, F.J. (1989) *Numerical taxonomy and multivariate analysis system*. Setauket, USA: Exeter Publishing.

Rosser, N. & Eggleton, P. (2012) Can higher taxa be used as a surrogate for species-level data in biodiversity surveys of litter/soil insects? *Journal of Insect Conservation*, 16(1), 87–92. Available from: https://doi.org/10.1007/s10841-011-9395-6

Safi, K., Armour-Marshall, K., Baillie, J.E. & Isaac, N.J. (2013) Global patterns of evolutionary distinct and globally endangered amphibians and mammals. *PloS One*, 8(5), e63582. Available from: https://doi.org/10.1371/journal.pone.0063582

Santos, L.A., Bischoff, A. & Fernandes, O.A. (2018) The effect of forest fragments on abundance, diversity and species composition of predatory ants in sugarcane fields. *Basic and Applied Ecology*, 33, 58–65. Available from: https://doi.org/10.1016/j.baae.2018.08.009

Solar, R.R.C., Barlow, J., Andersen, A.N., Schoereder, J.H., Berenguer, E., Ferreira, J.N. et al. (2016) Biodiversity consequences of land-use change and forest disturbance in the Amazon: A multi-scale assessment using ant communities. *Biological Conservation*, 197, 98–107. Available from: https://doi.org/10.1016/j.biocon.2016.03.005

Souza, J.L.P., Baccaro, F.B., Landeiro, V.L., Franklin, E., Magnusson, W.E., Pequeno, P.A.C.L. et al. (2016) Taxonomic sufficiency and indicator taxa reduce sampling costs and increase monitoring effectiveness for ants. *Diversity and Distributions*, 22(1), 111–122. Available from: https://doi.org/10.1111/ddi.12371

Souza, J.L.P., Baccaro, F.B., Pequeno, P.A.C.L., Franklin, E. & Magnusson, W.E. (2018) Effectiveness of genera as a higher-taxon substitute for species in ant biodiversity analyses is not affected by sampling technique. *Biodiversity and Conservation*, 27(13), 3425–3445. Available from: https://doi.org/10.1007/s10531-018-1607-x

Stratford, J.A. & Stouffer, P.C. (2015) Forest fragmentation alters microhabitat availability for Neotropical terrestrial insectivorous birds. *Biological Conservation*, 188, 109–115. Available from: https://doi.org/10.1016/j.biocon.2015.01.017

Terlizzi, A., Anderson, M.J., Bevilacqua, S., Fraschetti, S., Włodarska-Kowalczuk, M. & Ellingsen, K.E. (2009) Beta diversity and taxonomic sufficiency: do higher-level taxa reflect heterogeneity in species composition? *Diversity and Distributions*, 15(3), 450–458. Available from: https://doi.org/10.1111/j.1472-4642.2008.00551.x

Todd, V. (1949) The habits and ecology of the British harvestmen (Arachnida, Opiliones), with special reference to those of Oxford District. *Journal of Animal Ecology*, 18, 209–229. Available from: https://doi.org/10.2307/1600

Tourinho, A.L., Benchimol, M., Porto, W., Peres, C.A. & Storck'tonon, D. (2020) Marked compositional changes in harvestmen assemblages in Amazonian forest islands induced by a mega dam. *Insect Conservation and Diversity*, 13, 432–444.

Tourinho, A.L., Souza, L., Baccaro, F.B. & Dias, S.C. (2014) Complementarity among sampling methods for harvestman assemblages. *Pedobiologia*, 57(1), 37–45. Available from: https://doi.org/10.1016/j.pedobi.2013.09.007

Uehara-Prado, M., Fernandes, J.O., Bello, A.M., Machado, G., Santos, A.J., Vaz-de-Mello, F.Z. et al. (2009) Selecting terrestrial arthropods as indicators of small-scale disturbance: A first approach in the Brazilian Atlantic Forest. *Biological Conservation*, 142(6), 1220–1228. Available from: https://doi.org/10.1016/j.biocon.2009.01.008

Vieira, L.C., Oliveira, N.G., Brewster, C.C. & Gayubo, S.F. (2012) Using higher taxa as surrogates of species-level data in three Portuguese protected areas: a case study on Spheciformes (Hymenoptera). *Biodiversity and Conservation*, 21, 3467–3486. Available from: https://doi.org/10.1007/s10531-012-0374-3

Vieira, S.A., Alves, L.F., Aidar, M., Araújo, L., Baker, T., Batista, J.L.F. et al. (2008) Estimation of biomass and carbon stocks: the case of the Atlantic Forest. *Biota Neotropica*, 8(2), 21–29. Available from: https://doi.org/10.1590/S1676-06032008000200001

Ward, T.J., Vanderklift, M.A., Nicholls, A.O. & Kenchington, R.A. (1999) Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity. *Ecological Applications*, 9(2), 691–698. Available from: https://doi.org/10.1890/1051-0761(1999)009[0691:SMRUHA]2.0.CO;2

Whittaker, R.J., Araujo, M.B., Jepson, P., Ladle, R.J., Watson, J.E.M. & Willis, K.J. (2005) Conservation biogeography: assessment and prospect. *Diversity and Distributions*, 11(1), 3–23. Available from: https://doi.org/10.1111/j.1366-9516.2005.00143.x

Wickham, H. (2016) *ggplot2: Elegant graphics for data analysis*. New York. ISBN 978-3-319-24277-4: Springer-Verlag. Available from: https://ggplot2.tidyverse.org

Williams, P.H. & Gaston, K.H.J. (1994) Measuring more of diversity: can higher-taxon richness predict wholesale species richness? *Biological Conservation*, 67, 211–217. Available from: https://doi.org/10.1016/0006-3207(94)90612-2

Xu, G., Zhang, S., Zhang, Y. & Ma, K. (2018) Environmental correlates underlying elevational richness, abundance, and biomass patterns of multi-feeding guilds in litter invertebrates across the treeline. *Science of The Total Environment*, 633, 529–538. Available from: https://doi.org/10.1016/j.scitotenv.2018.03.212

Xu, Y., Lin, S., He, J., Xin, Y., Zhang, L., Jiang, H. et al. (2017) Tropical birds are declining in the Hainan Island of China. *Biological Conservation*, 210, 9–18. Available from: https://doi.org/10.1016/j.biocon.2016.05.029

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