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Selecting terrestrial arthropods as indicators of small-scale disturbance: A first approach in the Brazilian Atlantic Forest

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ABSTRACT

The growing pressure placed by human development on natural resources creates a need for quick and precise answers about the state of conservation of different areas. Thus, identifying and making use of ecological indicators becomes an essential task in the conservation of tropical systems. Here we assess the effects of small-scale disturbance on terrestrial arthropods and select groups that could be used as ecological indicators in the Brazilian Atlantic Forest. Arthropods were sampled within a continuous forest in the Serra do Mar State Park, southeastern Brazil, both in disturbed and undisturbed areas of the reserve. The abundance of exotic species was higher in the disturbed site, and this pattern seems to be an adequate indicator of anthropogenic disturbance. Species richness of Araneae, Carabidae, Scarabaeidae, Staphylinidae, and epigaeic Coleoptera (pooled) was higher in the undisturbed site, while that of fruit-feeding butterflies was higher in the disturbed site. Species richness was not significantly correlated between any pair of taxa. In contrast, species composition was significantly correlated among most groups, and clearly discriminates the disturbed from the undisturbed site. Moreover, fruit-feeding butterflies and epigaeic Coleoptera composition discriminated disturbed and undisturbed sites even when species were grouped into higher taxonomic levels, which may be a way of overcoming the difficulty of identifying arthropod species from poorly studied, species-rich ecosystems. Potential applications for these indicators include the choice and evaluation of sites for the establishment of natural reserves, elaboration of management plans, and the assessment of ecological impacts due to human activities, either for the purposes of licensing or legal compensation.

1. Introduction

Practical approaches concerning the assessment of the ecological integrity of natural systems require the selection of organisms or groups of organisms that work as ‘shortcuts’, i.e., surrogates of the other elements of the system and of the ecological processes in which they are involved (Kremen et al., 1993; McGeoch, 1998; Feinsinger, 2001; Niemi and McDonald, 2004). These organisms may act as indices of environmental conditions or biological phenomena that are difficult, inconvenient or expensive to be directly measured (Landres et al., 1988), comprising an attempt to synthesize information and recognize key aspects that at length should guide reliable conservation decisions (Niemeijer, 2002; Niemi and McDonald, 2004).

Biological indication may take place in several ways, such as changes in species richness and abundance, shifts in biological attributes (such as body size or symmetry) or, in a more general way, by some change in species composition from an undisturbed state (New, 1995; Hodkinson and Jackson, 2005). Besides the universal need for developing ways to assess status and trends in environmental state (Niemi and McDonald, 2004), selecting organisms as indicators of anthropogenic disturbance to help conservation decisions is still a challenge in most biodiverse countries, where taxonomic and natural history knowledge is greatly deficient (Kim and Byrne, 2006). This task is especially urgent in the

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megadiverse countries, since their natural systems are being continually destroyed by human activities (e.g., Bawa et al., 2004; Hong and Lee, 2006; Miles et al., 2006).

The Brazilian Atlantic Forest is considered a 'hotspot' (sensu Myers et al., 2000) due to its high species diversity associated with high rates of endemism and elevated level of disturbance, attaining highest conservation priority (MMA, 2000; Myers et al., 2000). Having once covered 1.5 million km^2 of the Brazilian territory, the Atlantic Forest is now reduced to ca. 12% of its original condition, with its remnants occurring mostly in small fragments (Ribeiro et al., 2009). Besides habitat loss, Atlantic Forest suffers from wood harvesting, plant collecting, hunting, invasion by exotic species, among other anthropogenic pressures (see Tabarelli et al., 2005). Due to its shattered state, the development and testing of indicators to assess and monitor the state of Atlantic Forest remnants should be a priority (Tabarelli et al., 2005).

Terrestrial arthropods share a number of qualities that make them highly adequate as biological indicators. These include their sensitivity to habitat change, rapid responses to disturbance, and easy and cost-effective sampling (e.g., Brown, 1996; McGeoch, 1998; Basset et al., 2004, 2008; Hodkinson and Jackson, 2005; Lawes et al., 2005; Lewinsohn et al., 2005; Pearce and Venier, 2006; Bouyer et al., 2007; Gardner et al., 2008). However, their usefulness has been systematically neglected in conservation planning in Brazil, which focuses their attention on more "charismatic", but sometimes less informative groups (Landres et al., 1988; Lewinsohn et al., 2005). Even when arthropods were used in the assessment of anthropogenic disturbances in Brazil (see Lewinsohn et al., 2005), multi-taxonomic approaches have rarely been applied for this purpose (for exceptions see Barlow et al., 2007; Fonseca et al., 2009; Pardini et al., 2009), making it difficult to extrapolate the results from one taxon to another.

The main goal of this study was to select a set of arthropod taxa as small-scale ecological indicators (sensu McGeoch, 1998) of disturbance in the Brazilian Atlantic Forest. The specific objective was to answer the following questions: (a) How does forest disturbance affect arthropod groups in their abundance, species richness, and diversity? (b) Does disturbance change species composition of different arthropod groups? (c) Does a higher taxon approach affect the discriminatory ability of the arthropod groups? (d) Can some arthropod groups be established as efficient surrogates for others? Based on the responses of each group, we then propose which arthropod groups should be employed and/or deserve to be further investigated as indicators of small-scale rainforest disturbance.

2. Methods

2.1. Study area

The study was carried out in the Santa Virgínia nucleus of Serra do Mar State Park (23°17′–23°24′S, 45°03′–45°11′W), located on the Paraitinga-Paraibuna plateau, in the eastern region of the state of São Paulo, southeastern Brazil (Fig. 1a). The region is located on mountainous relief, with altitudes ranging from 870 to 1100 m (Ururahy et al., 1987). The regional climate is humid, without a dry season, with mean annual rainfall of 2180 mm, and no monthly rainfall below 65 mm (DNMet, 1992). The region was originally covered with Atlantic Forest vegetation, classified as montane rainforest (Ururahy et al., 1987).

The Santa Virgínia nucleus has an area of ca. 18 000 ha (J.P. Villani, pers. comm.) and is located inside a well-preserved vegetation continuum of 1,109,546 ha along the Serra do Mar (Ribeiro et al., 2009), a large mountain range near the Atlantic Ocean in southeastern Brazil (Fig. 1b). The Brazilian Ministry of the Environment considers the region where Serra do Mar State Park is located as an "area of extreme biological importance", of highest priority toward conservation of the Atlantic Forest (MMA, 2000).

In the 1960s, part of the forest that currently belongs to the Santa Virgínia nucleus suffered slash-and-burn management, and was subsequently replaced by pasture. Nowadays, this part of the reserve is a forest mosaic composed of old-growth forest, abandoned pastures occupied by woody vegetation, abandoned *Eucalyptus* plantations, and secondary forest at different regeneration stages (see Tabarelli and Mantovani, 1999 and references therein). Another section of the reserve (~8 km distant from the former) was severely logged for hardwood before the establishment of the Serra do Mar State Park in 1977 (J.P. Villani, pers. comm.), and now is a fairly well-preserved old-growth forest, with some nearby remnants of primary forest. Hereafter, these sites with different disturbance degrees will be referred to as "disturbed" and "undisturbed", respectively. It is worth emphasizing that both sites are embedded within a continuous, well-preserved forest context in the Serra do Mar region (see Ribeiro et al., 2009).

By comparing sites within a vegetation continuum, we seek to minimize noise due to fragmentation effects. We also hypothesize that if responses by arthropods are found in such apparently low-contrast sites, meaningful responses should also be achieved under higher-contrast conditions.

2.2. Sampling design and procedures

Twelve replicated sampling stations were set in the Santa Virgínia nucleus, six in the disturbed site and six in the undisturbed site, so that disturbance degree was homogeneous within sites (Fig. 1c). Replicates were set within structurally similar vegetation in both sites, but within spots with different history of disturbance. A pitfall trap sampling unit plus a bait trap sampling unit (each composed of five traps) set in the same location comprised a sampling station. Sampling stations were at least 100 m apart from each other (median: disturbed = 136.6 m; undisturbed = 141.1 m).

The bait traps were cylinders of netting, with an internal funnel, baited with a mixture of mashed banana and sugar cane juice, fermented for at least 48 h. Bait traps were disposed along pre-existing trails in the understory of each site, suspended at a height of 1.5–2.0 m above the ground with a distance of at least 23 m between adjacent traps. The average distance between traps did not differ among sampling stations (ANOVA $F = 0.213$, $P = 0.996$). The traps were checked every 48 h, and the baits replaced at each visit (see Uehara-Prado et al., 2007 for details on the sampling scheme).

The pitfall traps consisted in 500 ml clear plastic cups, 85 mm wide at the opening and 120 mm in depth, flush with ground level, with a polystyrene cover suspended above the cup by wooden sticks. Each trap contained ca. 50 ml of a mixture of 69.9% water, 30.0% propylene glycol, 0.1% formaldehyde, and a few drops of detergent. Pitfall traps were placed in lines parallel to the bait traps lines, inside the forest understory, at 2 m intervals, and at least 20 m from the trails.

Pitfall and bait traps were kept simultaneously in the field for 6 and 8 days/month, respectively. Sampling was done monthly from November 2004 to May 2005, including the most favorable season for the capture of arthropods in southeastern Brazil (butterflies: Brown, 1972; Scarabaeidae: Hernández and Vaz-de-Mello, in press; Opiliones: Almeida-Neto et al., 2006). Sampling effort was 60,840 trap-hours for pitfall traps; the effective effort for butterflies was 33,600 trap-hours (considering 10 h of sampling/day).

Most fruit-feeding butterfly species captured in the bait traps could be identified in the field and were released after marking. The few specimens that could not be recognized even with a field guide (Uehara-Prado et al., 2004) were collected for later identification. The remaining arthropods collected in bait and pitfall traps

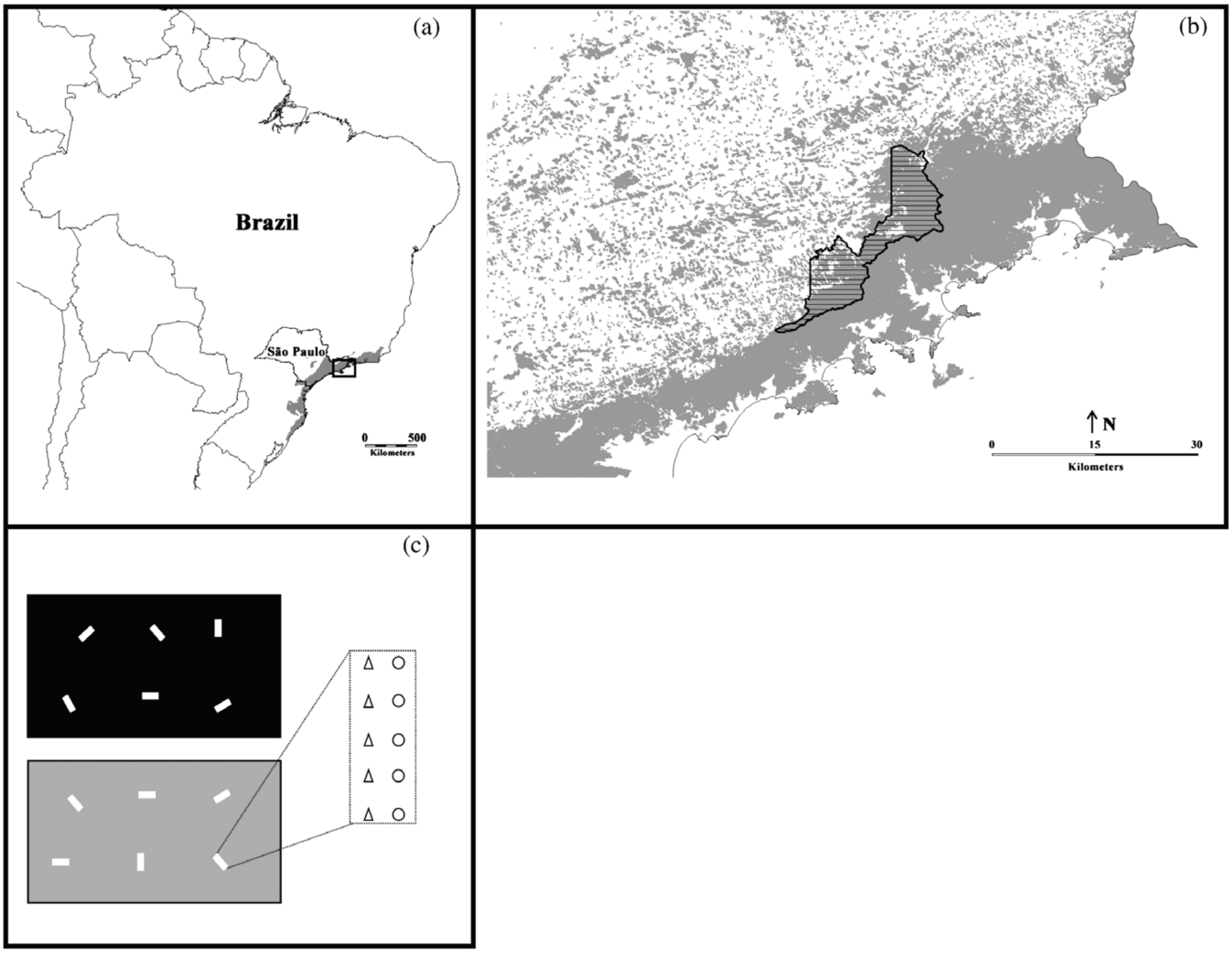

Fig. 1. Study location in Brazil. (a) Serra do Mar coastal forest ecoregion (grey); (b) the Santa Virgínia nucleus of Serra do Mar State Park (hashed), surrounded by ombrophilous montane forests (grey); and (c) Sampling scheme showing sampling stations (white bars) composed by five portable bait traps (triangles) and five pitfall traps (circles) in disturbed (grey rectangle) and undisturbed (black rectangle) sites.

were stored in 70% ethanol. In order to maximize the consistency of sorting, all pitfall samples were sorted by the first author or by laboratory assistants under his supervision. The first author also conducted the pitfall and bait trap sampling in the field.

2.3. Focal group selection

Except for the fruit-feeding butterflies, included in this study due to previous experience (Uehara-Prado et al., 2007), taxonomic groups were selected based on two simple criteria: (1) ease of sorting and ‘adequate’ abundance in the samples, i.e. neither too abundant (unfeasible to handle with) nor too scarce (low sample size) and (2) possibility of reliable identification, which demanded taxonomists to correctly identify the taxa, or at least to separate specimens into unidentified taxonomic species. The scarcity of structured regional terrestrial arthropod samplings in the Atlantic Forest of the state of São Paulo prevents the application of more sophisticated criteria (e.g., Bouyer et al., 2007). Additionally, some groups selected in this study (see below) have already been suggested as potential ecological indicators or have at least been shown to be sensitive to human-caused disturbance (e.g., Rainio and Niemelä, 2003; Pearce and Venier, 2006; Barlow et al., 2007; Bragagnolo et al., 2007; Nichols et al., 2007). The taxa not selected at this stage were sorted into several levels of detail, from family (e.g., Formicidae) to “other” (several arthropod orders pooled), and stored for future studies.

Nine taxa in the sample met the criteria adopted for their inclusion in at least part of the analyses: landhoppers (Amphipoda, Talitridae), woodlice (Isopoda, Oniscidea), ground-dwelling spiders (Araneae), harvestmen (Opiliones), ground beetles (Carabidae), rove beetles (Staphylinidae), scarab beetles (Scarabaeidae), false-blister beetles (Oedemeridae), and all epigaeic beetles pooled (Coleoptera). False-blister beetles captured in bait traps were initially considered by-catches, but their abundance justified their inclusion in the analysis.

Taxonomic accuracy varied among arthropod groups (Table S1). All individuals could be identified to species level in Amphipoda (a single exotic species, *Talitroides topitotum*), Oedemeridae (two species in the genus *Matusinhosa*), and fruit-feeding butterflies (52 species). Due to a high proportion of undescribed species and/or a lack of taxonomic knowledge on the different groups (i.e., a ‘taxonomic bottleneck’, see Kim and Byrne, 2006), the remaining taxa were separated either into unnamed taxonomic species or, whenever possible, into species. The proportion of taxonomic entities identified to species level (i.e., Latin binomials) in these groups ranged from 1.3% for rove beetles to 66.7% for harvestmen (median = 15.6%) (Table S1). Other families of epigaeic Coleoptera were sorted to species or unnamed species, but due to their low

Table 1

Mean abundance, species richness, similarity and diversity of arthropods in disturbed (*D*) and undisturbed (*U*) sites use in the Santa Virgínia nucleus, Serra do Mar State Park, São Paulo, Brazil. See methods for details on the disturbance history of each site.

Common name	Taxon	Mean abundance (±sd)[a]		Species richness[b]				Fisher's α[c]	
		D	*U*	*D*	*U*	Total	Sørensen's *S*	*D*	*U*
Landhoppers	Amphipoda, Talitridae	585.0 (650.9)**	13.8 (20.8)	1	1	1	–	–	–
Woodlice	Isopoda, Oniscidea	22.7 (29.8)	12.2 (9.2)^{ns}	3	4	4	–	–	–
Ground spiders	Araneae	28.3 (7.9)	50.8 (7.7)**	27	56*	63	0.48	9.04	20.13**
Harvestmen	Opiliones	16.2 (10.8)*	5.3 (4.4)	6	8	9	–	–	–
Fruit-feeding butterflies	Lepidoptera, Nymphalidae	87.8 (47.4)**	30.3 (10.7)	48*	22	52	0.51	12.84**	5.55
False-blister beetles	Coleoptera, Oedemeridae	7.8 (6.8)	27.7 (18.8)*	2	2	2	–	–	–
Ground beetles	Coleoptera, Carabidae	42.0 (36.4)	21.7 (10.2)^{ns}	14	14*	20	0.57	3.20	3.98^{ns}
Rove beetles	Coleoptera, Staphylinidae	14.3 (8.2)	28.5 (5.8)*	31	68*	78	0.42	17.39	41.77**
Scarab beetles	Coleoptera, Scarabaeidae	7.67 (6.3)	11.7 (8.8)^{ns}	6	18*	19	0.42	1.84	7.84**
Epigaeic beetles	Coleoptera[d]	83.8 (42.7)	104.2 (32.4)^{ns}	91	152*	190	0.44	32.47	63.94**

[a] Differences in abundance evaluated by *t*-test on $\log_{10}(x + 1)$ transformed abundance data.

[b] Differences in species richness evaluated by visual comparison of rarefaction curves and their 95% confidence intervals.

[c] Differences in Fisher's α evaluated by the bootstrapping procedure on each site's pooled data.

[d] Twenty seven families. See Table S1.

* $P < 0.05$.

** $P < 0.01$.

^{ns} $P > 0.05$.

occurrence in the samples, they were included only when data for epigaeic Coleoptera were pooled. Juvenile specimens of spiders were discarded from analyses. Although harvestmen females of the genus *Mischonyx* (=*Ilhaia*) could not be identified to species, the level of analysis used in this group (abundance of the order) allowed their inclusion in the dataset (see results).

2.4. Statistical analyses

The null hypothesis of no difference in abundance within arthropod groups between disturbed and undisturbed sites was assessed by the *t*-test on $\log_{10}(x + 1)$ transformed abundance data. Fisher's logarithmic series parameter (α) was compared between sites by the bootstrapping procedure (see Magurran, 2004) using the PAST software (Hammer et al., 2001). Overall similarity between sites was calculated by the Sørensen index. Species richness of arthropod groups with 12 or more species (see Table 1) was compared between sites by individual-based rarefaction analysis. The statistical significance (at $P < 0.05$) of differences in species richness was evaluated by comparing 95% confidence limits in the point of the rarefaction curves with same abundance (see Magurran, 2004). Rarefaction analyses were performed using the Analytic Rarefaction 1.3 software (available from http://www.uga.edu/strata/software/anRareReadme.html).

To evaluate if disturbance affected the species composition of the selected groups, we performed a non-metric multidimensional scaling (NMDS) on the resemblance matrix of Bray–Curtis distances for arthropod groups with $S \geqslant 12$ (see Table 1), with 1000 random restarts. This ordination method has been frequently used in ecological studies (e.g., Minchin, 1987; Clarke and Ainsworth, 1993; Brehm and Fiedler, 2004), and presents several advantages, such as minimizing the arch effect, releasing linearity constraints, and not requiring multivariate normality of data (Minchin, 1987). Moreover, as in other indirect gradient analyses, NMDS depicts the environment in the organism's point of view, or in Clarke and Ainsworth's (1993) words, allow the biota to "tell their own story". To test the null hypothesis of equal species composition between disturbed and undisturbed forest sites, we applied an analysis of similarities (ANOSIM – Clarke, 1993) on the matrix of Bray–Curtis similarities, with 999 permutations. Before running these multivariate techniques, a dispersion weighting was applied to the original dataset in order to downweight species of highly variable abundance, clumped into replicates (Clarke et al., 2006). These analyses were done using the PRIMER software (Clarke and Gorley, 2006).

To evaluate if grouping species into higher taxonomical categories would result in loss of multivariate information, we performed a NMDS on the matrix of families or subfamilies of the same dataset. We first performed a visual inspection of both ordinations and then compared their stress values. An increase in stress value in higher taxonomic category was interpreted as loss of multivariate information (Caruso and Migliorini, 2006; Clarke and Gorley, 2006).

We tested species richness surrogacy by two approaches (following Sauberer et al., 2004): (1) pairwise correlations of species richness among taxa; and (2) correlation of species richness of one taxon with the pooled richness of the remaining taxa. Correlations were done with Pearson's coefficient on $\log_{10}(x + 1)$ transformed data. A procedure to control for false discovery rate (FDR) was applied, due to the large number of correlations tested (Benjamini and Hochberg, 1995). To test surrogacy on species composition, RELATE tests (PRIMER software – Clarke and Gorley, 2006) with Spearman's correlation coefficient were used to correlate Bray–Curtis similarity matrices based on species composition. This function calculates the Spearman rank correlations between two similarity matrices and calculates the significance of this correlation by a permutation test. When comparisons were done between hierarchically related taxa (e.g., family vs. order), the lower taxon was removed from the higher taxon dataset.

3. Results

3.1. Abundance, species richness, and diversity

The proportion of individuals in both sites varied widely from group to group (Fig. 2). The most abundant taxon in the sample was Amphipoda, with 3593 individuals, 97.7% of which were found in the disturbed site (Fig. 2). Harvestmen were more abundant in the disturbed site as well (75.4%, Fig. 2), mainly due to individuals of the genus *Mischonyx* (see Table S1). In contrast, 77.9% of the false-blister beetles were sampled in the undisturbed site (Fig. 2). Although woodlice abundance did not differ significantly between the sites (Table 1), 80 of the 82 individuals of the exotic species *Styloniscus spinosus* were found in the disturbed site (Table S1).

The most speciose group within the selected taxa was the epigaeic Coleoptera, followed by Staphylinidae, Araneae, fruit-feeding butterflies, Carabidae, and Scarabaeidae (Table 1). Araneae and Staphylinidae showed a decrease in both species richness and abundance in disturbed sites, while the converse occurred for

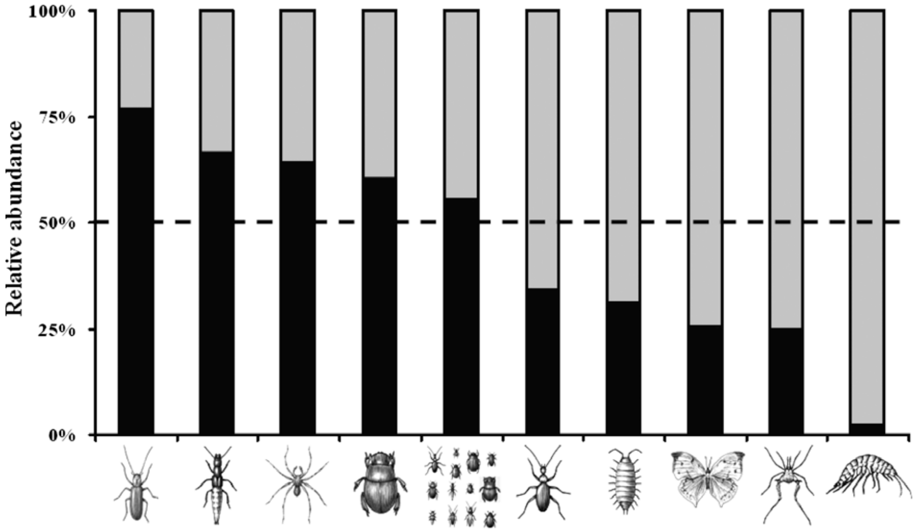

Fig. 2. Proportion of total arthropod individuals collected in disturbed (grey bars) and undisturbed (black bars) sites. From left to right: Oedemeridae, Staphylinidae, Araneae, Scarabaeidae, epigaeic Coleoptera pooled, Carabidae, Isopoda, fruit-feeding butterflies (Nymphalidae), Opiliones, and Amphipoda. See Table 1 for common names and abundance of each group.

fruit-feeding butterflies (Table 1; Fig. 2). The species richness of Carabidae, Scarabaeidae, and epigaeic Coleoptera pooled was higher in the undisturbed site, while their abundance did not differ between disturbed and undisturbed sites (Table 1; Fig. 2). Differences in species richness of the remaining taxa between disturbed and undisturbed sites were not analyzed due to their low species richness. Fisher's α comparisons between sites followed the same pattern of species richness, with the only exception of Carabidae, whose diversity did not differ between sites (Table 1). Sørensen's similarity between disturbed and undisturbed sites ranged from 0.42 in Scarabaeidae and Staphylinidae to 0.57 in Carabidae (Table 1).

3.2. Species composition

Non-metric multidimensional scaling results for Araneae, fruit-feeding butterflies, Carabidae, Staphylinidae, and epigaeic Coleoptera clearly showed different species composition between disturbed and undisturbed sites (Fig. 3). These results were confirmed by ANOSIM (Table 2). Scarabaeidae was the only group that showed no difference between sites (Fig. 3). When species data were aggregated into subfamilies (fruit-feeding butterflies, Carabidae, Scarabaeidae, and Staphylinidae) or families (Araneae and all epigaeic Coleoptera pooled), only fruit-feeding butterflies and epigaeic Coleoptera maintained the same pattern of aggregation in NMDS (Table 2), also confirmed by ANOSIM results (fruit-feeding butterflies: $R = 0.613$, $P = 0.002$; epigaeic Coleoptera: $R = 0.480$, $P = 0.002$).

3.3. Surrogacy

No significant results were observed in pairwise correlations of species richness (Table 3), and only fruit-feeding butterfly species richness showed a significant negative correlation with the pooled species richness of the remaining taxa. This group also showed a negative correlation with all other taxa in both approaches (Table 3), indicating that their species richness declined as the richness of the remaining taxa increased.

Comparison of species composition among arthropod groups revealed that five out of six analyzed groups had significant correlations, excluding Scarabaeidae (Table 3). Among the groups with significant correlations, fruit-feeding butterflies, Carabidae, and epigaeic Coleoptera correlated significantly with all the remaining groups, while Araneae and Staphylinidae correlated significantly with the remaining groups, but not with each other (Table 3).

4. Discussion

4.1. Abundance

Considering only the differences in abundance between study sites (Table 1), the fact that exotic species of Amphipoda and Isopoda were more abundant at the site where anthropogenic intervention was more intense in the past seems particularly promising. A similar result was obtained in the same area in a study with earthworms, which also presented more individuals of exotic species at the disturbed site (91.4%, $n = 58$, Fernandes et al., in press). Invasion by exotic species aided by different human activities has long been reported (Elton, 1958), and disturbed habitats are more likely to be invaded – indeed, many exotic species seem to be restricted to habitats created by human disturbance (Fox and Fox, 1986).

Our results are similar to that of previous works, which found that the abundance of a native South African terrestrial amphipod (*Talitriator africana*) was significantly higher in ecotones or disturbed habitats (Kotze and Lawes, 2008). In fact, Lawes et al. (2005) considered this amphipod an appropriate single-species ecological indicator for poor forest condition in South Africa. Although the outcomes of biological invasions remain widely unknown for Brazilian epigaeic arthropods, it seems appealing to use presence and abundance of exotic species within Atlantic Forest remnants as an indication of anthropogenic disturbance.

When looking exclusively at the abundance of different arthropod groups in our samples, some widespread, abundant species have the potential to be good indicators of anthropogenic disturbance in the Atlantic Forest. For example, harvestmen in the genus *Mischonyx*, the ground beetle *Galeritula carbonaria*, and the fruit-feeding butterfly *Morpho epistrophus* were at least three times more abundant in disturbed than in undisturbed sites (Table S1). In comparison to other species within their groups, the above species are larger, easily identifiable, and better known as concerns

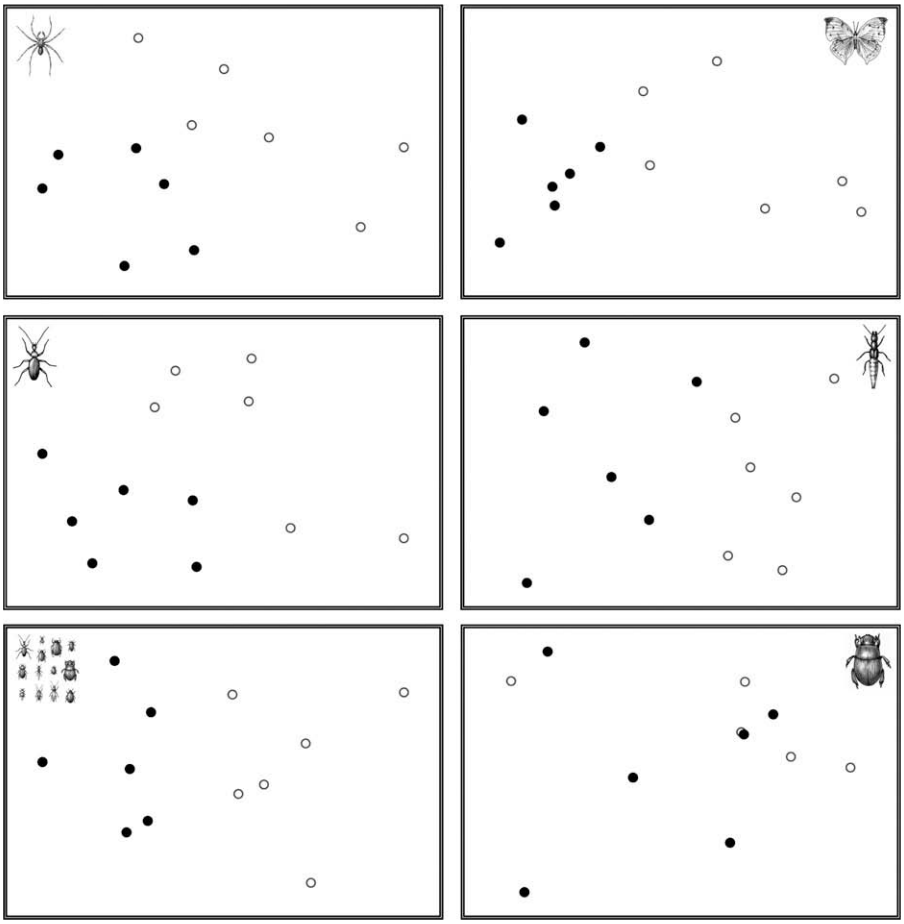

Fig. 3. NMDS ordination of disturbed (open circles) and undisturbed (solid circles) sites, based on different arthropod groups. See stress values in Table 2. Drawings inside the graphs indicate the arthropod groups according to Fig. 2.

Table 2
NMDS and ANOSIM results for arthropod groups sampled in disturbed and undisturbed sites in the Santa Virgínia nucleus, Serra do Mar State Park, São Paulo, Brazil.

	ANOSIM R	NMDS stress		Ordination quality at higher taxon level[b]
		Species	Higher taxonomic level[a]	
Araneae	0.526^{*}	0.13	0.14	Worse
Fruit-feeding butterflies	0.606^{*}	0.05	0.05	Same
Carabidae	0.581^{*}	0.10	0.10	Worse
Scarabaeidae	-0.043^{ns}	0.03	0.05	Worse
Staphylinidae	0.563^{*}	0.17	0.12	Worse
Epigaeic Coleoptera	0.641^{*}	0.12	0.13	Same

[a] Araneae and epigaeic Coleoptera grouped into families; Fruit-feeding butterflies, Carabidae, Scarabaeidae, and Staphylinidae grouped into subfamilies.

[b] Visual inspection of ordination diagrams.

* $P < 0.01$.

Table 3
Correlations among groups in species richness (above diagonal) and species composition (below diagonal). Correlations of each Coleoptera family with epigaeic Coleoptera pooled exclude that family from epigaeic Coleoptera. Alpha values adjusted for false discovery rate (Benjamini and Hochberg, 1995).

	Fruit-feeding butterflies	Araneae	Carabidae	Scarabaeidae	Staphylinidae	Epigaeic Coleoptera	Remaining taxa pooled
Fruit-feeding butterflies		−0.631	−0.290	−0.369	−0.477	−0.726	−0.754[a]
Araneae	0.641^{**}		0.156	0.046	0.687	0.599	0.329
Carabidae	0.577^{*}	0.573^{**}		0.306	−0.006	0.246	0.120
Scarabaeidae	−0.235	−0.037	−0.035		0.242	0.409	0.163
Staphylinidae	0.303^{*}	0.153	0.264^{*}	−0.047		0.4133	0.529
Epigaeic Coleoptera	0.406^{**}	0.372^{**}	0.344^{*}	0.089	0.375^{**}		−0.247

[a] Corrected $\alpha = 0.008$.

* $P < 0.05$.

** $P < 0.01$.

their natural history. Thus, they could be appropriate focal species for further studies with anthropogenic disturbance effects on arthropods. The great majority (77.9%) of individuals in the genus *Matusinhosa* (Oedemeridae) was sampled at the undisturbed site and should be considered for future studies as well. However, in contrast with the above examples, basic aspects of the biology of Brazilian Oedemeridae are still unknown.

We are aware that indicator-related interpretations that can be made from the results of particular taxon might be limited and that a set of species provides a more effective representation of ecological change (Lawton et al., 1998; McGeoch, 1998; Lawes et al., 2005). The applicability of these single taxa as disturbance indicators will depend critically on the generality of the results found in this study. Therefore, our results should be validated by additional studies in other areas of the Atlantic Forest domain.

4.2. Species diversity, composition, and surrogacy

The decrease in species richness with disturbance observed for five epigaeic arthropod taxa finds consistent correspondence in the literature only for tropical Scarabaeidae (Nichols et al., 2007). This result was found despite the use of unbaited traps in this study, a less efficient method for dung beetles. Patterns of response of the other groups (Araneae, Carabidae, Staphylinidae, epigaeic Coleoptera pooled) to disturbance are either unknown or poorly studied in tropical forests (e.g., Rainio and Niemelä, 2003; Pearson, 2006). Fruit-feeding butterflies was the only arthropod group whose species richness was higher in the disturbed site, the opposite result found for other studies at a similar scale (Hill and Hamer, 2004). Anthropogenic disturbance may affect species richness and diversity in several ways, and responses may vary within studies among taxonomic or functional groups or among studies within the same group (Kimberling et al., 2001; Kotze and Samways, 2001; Perfecto et al., 2003; Rainio and Niemelä, 2003; Hill and Hamer, 2004; Schulze et al., 2004; Barlow et al., 2007; Basset et al., 2008; Fonseca et al., 2009; Pardini et al., 2009). This variation may be attributed to several factors, such as the sensitivity of species richness to sampling effort, the spatial and temporal scale of the study, and disturbance intensity, frequency and type (e.g. Brown, 1996; Kimberling et al., 2001; Hill and Hamer, 2004; Barlow et al., 2007; Basset et al., 2008).

As reported in several previous studies, no surrogacy was found in correlations of species richness (e.g., Lawton et al., 1998; Perfecto et al., 2003; Schulze et al., 2004; Barlow et al., 2007). The lack of congruency in species richness correlations has been attributed to the high variability in ecological requirements inherent to the sampling of a number of different taxa (Lawton et al., 1998), among other causes (Weaver, 1995; Schulze et al., 2004; Oertli et al., 2005; Barlow et al., 2007). In this study, perhaps the sampling method was not as specific as would be desirable for some arthropod groups in order to catch such variability (e.g., Isopoda, Opiliones, and Scarabaeidae), which may have contributed to the lack of congruency found for species richness correlations. However, as the methods and sampling effort were the same in disturbed and undisturbed sites, we expect that comparability would be maintained. Additionally, our sampling protocol was designed in such a way that it could be conducted by one or two people in the field, minimizing operational costs and increasing the chance of replication in future studies (see Paoletti, 1999; Gardner et al., 2008). Adding several specific methods would certainly reduce the cost-effectiveness of our sampling. We expect that responses to anthropogenic disturbances found with non-specific sampling methods are applicable per se, and should be improved in later studies with specific methods.

The characterization of general diversity patterns of response to disturbance at the continental scale may be a very difficult task, due to functional and structural differences among biomes, and idiosyncrasies (e.g., history of disturbance) of different regional communities. However, general patterns may emerge from studies focused on specific biomes within regions (Kim and Byrne, 2006), validating the use of ecological indicators within specific geographical limits (in our case, the Serra do Mar biogeographical sub-region – see Ribeiro et al., 2009). Therefore, future studies about diversity patterns of potential ecological indicators in the Atlantic Forest should focus on increase the geographical sampling coverage of this biome, in search of well-defined patterns of response to disturbance.

As found in studies with more comprehensive taxonomic coverage (Barlow et al., 2007; Basset et al., 2008), responses to anthropogenic disturbance based on species composition were more informative than those based on species richness or diversity. In the present study, significant correlations among the species compositions of most selected arthropod groups also indicate that they represent each other and can effectively be used as surrogates of anthropogenic disturbance. This could be promising for the future application of ecological indicators in the Atlantic Forest, as one could sort just one of the selected groups, reducing sampling and sorting-related time and costs in situations with financial constraints.

However, the problem of identifying arthropods to species level persists. Fortunately, among the selected groups, fruit-feeding butterflies and epigaeic Coleoptera maintained the quality of discrimination between disturbed and undisturbed sites, even when species were grouped into higher taxonomic categories. Discovering disturbance-related response patterns at higher taxonomic levels may be important in a practical sense, since it is a manner of overcoming the difficulty of identifying arthropod species, particularly from poorly studied, species rich systems. Sometimes, the time lag from sampling to identifying a taxon may be decisive for its inclusion in assessment and monitoring studies with financial and time constraints (Pawar, 2003; Gardner et al., 2008). Though it may not be simple to sort Neotropical Coleoptera into families without previous taxonomic training, it is obviously much easier than sorting them into species. Sorting fruit-feeding butterflies into subfamilies, in turn, is an easy task and, despite potential drawbacks of working at this taxonomic scale (see Basset et al., 2008), it would prevent species level misidentifications, which are frequent in this group, notably among the small brown Satyrinae (A.V.L. Freitas, pers. obs.).

4.3. Practical constraints and advantages

The lack of taxonomists available to sort specimens into species hindered the selection and inclusion in our analyses of several taxa in the sample. Even in the majority of the selected taxa, most specimens had unnamed taxonomic species due to a lack of taxonomic studies on the sampled groups. Therefore, there is an urgent need for support for taxonomy and natural history research in the Atlantic Forest as well as other tropical ecosystems (e.g., Kim and Byrne, 2006; Gardner et al., 2008). Despite the clear advantage of using species composition showed by our results, the other approaches used in this study aiming for ecological indication (abundance and species richness) have their merits and drawbacks (see Basset et al., 2008). Choosing among them in practical situations may ultimately depend upon the availability of financial support and taxonomic expertise in the selected group(s).

Some benefits must be emphasized in this apparently discouraging scenario for the implementation of multi-taxonomic bioindication studies. Multiple taxa sampling in this ecosystem almost invariably adds new data on several aspects of the biology of both well and poorly studied arthropods, and possibly reveals undescribed species (e.g., Basset et al., 2004), as found in this study for Araneae, Coleoptera, Isopoda, and Opiliones. A wide taxonomic range also provides an opportunity to overcome "taxonomic chauvinism" (Pawar, 2003), as several groups not included in more specific sampling protocols may be seen in more detail and motivate further studies. Moreover, multi-taxonomic surveys can be undertaken with very little additional cost in the field, when compared to single taxon sampling (Gardner et al., 2008). Finally, as shown by our results, higher taxonomic level identification (a straightforward approach when sampling several taxa) may be enough for some groups to discriminate different disturbance levels.

5. Conclusion

In this study, we sampled, sorted, and selected arthropods that showed potential as local ecological indicators of forest disturbance in a reserve included in a large continuum of Atlantic Forest, a condition not often found in this highly fragmented ecosystem (e.g., MMA, 2000; Tabarelli et al., 2005; Ribeiro et al., 2009). Finding responses in this apparently low-contrast situation may be a good hint about the sensitivity of the selected indicators. Additional local-scale studies with different anthropogenic disturbances should enhance the generalization power of our results.

Basset et al. (2008) advocate the use of metrics based on species identity in biological assessment (as opposed to richness alone), as they "reflect a high sensitivity of arthropod assemblage to disturbance". Our results indicate that this statement could be valid in the studied site, since the species composition of most groups differentiated the disturbed from the undisturbed site. Moreover, surrogacy in species composition showed that different arthropod groups represent each other in the response to disturbance, while this was not observed for species richness. We recommend therefore that future studies on ecological indication in Atlantic Forest (and other ecosystems) do not limit their analyses to richness-related patterns. The composition of fruit-feeding butterflies and epigaeic Coleoptera pooled were the best indicators in this study, discriminating the disturbed and the undisturbed site even in higher taxonomic categories, and acting as surrogates of the remaining arthropod groups.

Some of the potential applications of terrestrial arthropods as ecological indicators in Brazil (and elsewhere) are the evaluation of sites for the establishment of reserves, the implementation of management plans in already established reserves, and the evaluation of ecological impacts due to human activities, either for licensing or legal compensation purposes. The absence of robust, tested ecological indicators for terrestrial ecosystems makes it unfeasible to conduct a quick, objective, and precise evaluation about the conservation status of target sites (see McGeoch, 1998; Niemi and McDonald, 2004). The overwhelming pressure imposed by human activities on natural systems puts at risk not only species and their interactions, but also limits conservation and management options, reducing the number of ways in which human populations can interact with natural remnants (Brown, 1996; Kim and Byrne, 2006). Identifying the effects that such disturbances have on the biota of a locality or region is only the first step in a long journey toward the conservation of the vanishing Atlantic Forest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2009.01.008.

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