SIBi

SISTEMA INTEGRADO DE BIBLIOTECAS
UNIVERSIDADE DE SÃO PAULO

Universidade de São Paulo

Biblioteca Digital da Produção Intelectual - BDPI

Outros departamentos - IB/Outros

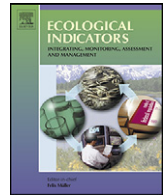Artigos e Materiais de Revistas Científicas - IB/Outros

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

How far can we go in simplifying biomonitoring assessments? An integrated analysis of taxonomic surrogacy, taxonomic sufficiency and numerical resolution in a megadiverse region

Victor Lemes Landeiro [a,*], Luis Mauricio Bini [b], Flávia R.C. Costa [a], Elizabeth Franklin [c], Anselmo Nogueira [d], Jorge L.P. de Souza [c], Jamile Moraes [c], William Ernest Magnusson [a]

[a] Programa de Pós Graduação em Ecologia, Instituto Nacional de Pesquisas da Amazônia, Av. André Araújo, 2936, Manaus, AM 69011-970, Brazil
[b] Departamento de Ecologia, Universidade Federal de Goiás, Goiânia, GO 74001-970, Brazil
[c] Departamento de Entomologia, Instituto Nacional de Pesquisas da Amazônia, Av. André Araújo, 2936, Manaus, AM 69011-970, Brazil
[d] Universidade de São Paulo, Instituto de Biociências, Departamento de Botânica, Rua do Matão, 277, São Paulo, SP 05508-900, Brazil

ARTICLE INFO

ABSTRACT

The need for biodiversity conservation is increasing at a rate much faster than the acquisition of knowledge of biodiversity, such as descriptions of new species and mapping species distributions. As global changes are winning the race against the acquisition of knowledge, many researchers resort to the use of surrogate groups to aid in conservation decisions. Reductions in taxonomic and numerical resolution are also desirable, because they could allow more rapid the acquisition of knowledge while requiring less effort, if little important information is lost. In this study, we evaluated the congruence among 22 taxonomic groups sampled in a tropical forest in the Amazon basin. Our aim was to evaluate if any of these groups could be used as surrogates for the others in monitoring programs. We also evaluated if the taxonomic or numerical resolution of possible surrogates could be reduced without greatly reducing the overall congruence. Congruence among plant groups was high, whereas the congruence among most animal groups was very low, except for anurans in which congruence values were only slightly lower than for plants. Liana (Bignoniaceae) was the group with highest congruence, even using genera presence–absence data. The congruence among groups was related to environmental factors, specifically the clay and phosphorous contents of soil. Several groups showed strong spatial clumping, but this was unrelated to the congruence among groups. The high degree of congruence of lianas with the other groups suggests that it may be a reasonable surrogate group, mainly for the other plant groups analyzed, if soil data are not available. Although lianas are difficult to count and identify, the number of studies on the ecology of lianas is increasing. Most of these studies have concluded that lianas are increasing in abundance in tropical forests. In addition to the high congruence, lianas are worth monitoring in their own right because they are sensitive to global warming and the increasing frequency and severity of droughts in tropical regions. Our findings suggest that the use of data on surrogate groups with relatively low taxonomic and numerical resolutions can be a reliable shortcut for biodiversity assessments, especially in megadiverse areas with high rates of habitat conversion, where the lack of biodiversity knowledge is pervasive.

1. Introduction

Comprehensive and reliable biodiversity data that allow the use of systematic conservation-planning procedures (Margules and Pressey, 2000) are available for only a few areas worldwide. Conversely, most of the species-rich areas are plagued by the absence of biological information (e.g., Hopkins, 2007; Schulman et al., 2007). Brown and Lomolino (1998) and Lomolino (2004) coined the terms "Linnean shortfall" and "Wallacean shortfall", respectively, to summarize this problem. The first term refers to the lack of information about species identities, whereas the second is related to the lack of data on the spatial distribution of species (see also Whittaker et al., 2005).

The world is experiencing severe human-induced impacts (e.g., Hansen et al., 2000; Vörösmarty et al., 2010), so we may not

* Corresponding author. Tel.: +55 62 35211732.
E-mail addresses: vllandeiro@gmail.com (V.L. Landeiro), lmbini@gmail.com (L.M. Bini), flaviacosta001@gmail.com (F.R.C. Costa), beth@inpa.gov.br (E. Franklin), anselmoeco@yahoo.com.br (A. Nogueira), souza.jorge@gmail.com (J.L.P. de Souza), jamile.mor@gmail.com (J. Moraes), bill@inpa.gov.br (W.E. Magnusson).

have time to solve the Linnean and Wallacean shortfalls before the impacts on biodiversity become irreversible or unmanageable. In addition, carrying out inventories of all biodiversity of megadiverse regions of the planet, apart from being expensive and time-consuming, may be a quixotic task (Magurran and Queiroz, 2010). The huge diversity found in the Amazon would require an inordinately large number of taxonomists for a basic inventory of this diversity (Hopkins, 2007), and many tropical areas are still practically inaccessible, especially in the Amazon region (Schulman et al., 2007).

Because of the Linnean and Wallacean shortfalls, most proposed systematic conservation plans are based on surrogate taxa, which are selected by the availability of data (Rodrigues and Brooks, 2007). However, decisions taken for a particular surrogate group may not be optimum for the conservation of all (unknown) biodiversity in a given area (Franco et al., 2009), and the effectiveness of these decisions is also scale-dependent. Because of the uncertainty about the efficiency of the surrogacy approach, the number of studies testing for community congruence (cross-taxon congruence or community concordance) is increasing steadily (e.g., Paszkowski and Tonn, 2000; Su et al., 2004; Macía et al., 2007). Two communities are said to be concordant when beta-diversity or community structures exhibited by these communities are correlated (e.g., Lopes et al., 2011). A similar response to major environmental gradients is the most common mechanism underlying community congruence (Heino et al., 2003). A good surrogate group should be easy to sample and identify, and have a distribution pattern congruent with those of other taxonomic groups. Independently of other requirements (availability of experts; costs of sampling, identification and enumeration), although rarely tested, congruence is a necessary condition for the reliable use of surrogate groups. Besides the analysis of community congruence, a different set of studies has focused on how well biodiversity patterns, obtained with species-level data, can be reproduced by data on higher taxa, in order to improve the cost-effectiveness of monitoring programs and community analyses in general (e.g., Attayde and Hansson, 2001; Bertrand et al., 2006).

The effects of taxonomic resolution on biodiversity patterns can be tested by combining species into coarser taxonomic classes and by evaluating the similarity between ordination patterns depicted by both species-level and lower-resolution data (Melo, 2005; Anderson et al., 2005). If the patterns are similar, then data for higher taxa can be used to replace species-level data (e.g., Terlizzi et al., 2003) that is more expensive and time consuming to obtain. The effects of numerical resolution (e.g., transforming abundance data into presence–absence data) on biodiversity patterns can be analyzed similarly (Melo, 2005; Carneiro et al., 2010). The reliability of higher taxa data for conservation planning is also scale-dependent, and in general, the effectiveness of surrogates increases with the increase of the spatial extent of the area under study (La Ferla et al., 2002; ter Steege et al., 2006).

Studies in the Amazon region have found cross-taxon correlations between similarity matrices derived from plant groups (Vormisto et al., 2000; Ruokolainen et al., 2007; Macía et al., 2007), but studies evaluating the congruence between floristic and faunistic data are largely lacking (see Paavola et al., 2006; Qian and Ricklefs, 2008 for studies in other regions). Variation in faunistic similarity might be better predicted by floristic similarity than by environmental similarity matrices (Oliver et al., 1998). The reason for this is that data on plant species composition integrate a number of important environmental factors, and because of the direct relationships between animal and plants (Schaffers et al., 2008).

Here we used a comprehensive dataset on the composition of different communities in a 100 km² Amazonian reserve to evaluate the congruence in the distribution patterns of 22 taxonomic groups. For those groups with the highest power in predicting the distribution of other groups, we also evaluated the degree to which biomonitoring assessments undertaken at this spatial scale can be further simplified by reducing the taxonomic and/or numerical resolution. Some previous studies have evaluated the use of surrogate groups (e.g., Banks-Leite et al., 2011; Rooney and Bayley, 2012), and the effect of taxonomic (e.g., Greffard et al., 2011; Rimet and Bouchez, 2012) and numerical resolution (e.g., Melo, 2005; Carneiro et al., 2010). However, to the best of our knowledge, no previous study has examined simultaneously the adequacy of surrogate groups, and taxonomic and numerical resolution.

Many investigations (e.g., Andersen et al., 2002) have used indicators for assessments of ecological integrity, but most of these studies focused on biological groups assumed to have strong relationships with particular environmental variables. In this study, we tested whether the distributional patterns of several taxonomic groups that are frequently used in biodiversity monitoring are congruent among themselves. That is, we searched for a biological group that best represented the patterns observed for other groups. After identifying this group, we evaluated whether the taxonomic and numerical resolutions of the best group (i.e., the one with the highest average congruence) could be reduced without loss of surrogacy capacity.

2. Materials and methods

2.1. Study area

This study was undertaken using data on 22 taxonomic groups collected at the Ducke Reserve of the National Institute for Research in the Amazon (INPA), located 26 km northwest of the city of Manaus, state of Amazonas (Fig. 1). The area corresponds to site 1 of the Brazilian Long-Term Ecological Research Program (Brazilian LTER), and is part of the Biodiversity Research Program (PPBio) of the Brazilian Ministry of Science and Technology (MCT). The reserve covers 10,000 ha (10 km × 10 km) of preserved *terra-firme* tropical rain forest, with a closed canopy 30–37 m high and emergents growing to 40–45 m (Costa et al., 2005). A central plateau splits the reserve into two drainage systems (Espírito-Santo et al., 2009) with altitude ranging from 40 to 110 m asl. The mean annual temperature is 26 °C and the mean annual rainfall is 2362 mm. Soils in the reserve vary in a continuum from clayey soils at higher altitudes to sandier soil at lower altitudes (i.e., stream valleys).

2.2. Sampling design and datasets

A research team working in the Brazilian Biodiversity Research Program gathered all datasets used in this study (PPBio; see Magnusson et al., 2005 and http://ppbio.inpa.gov.br/Eng). The basic sampling design used in this program is based on the RAPELD protocol (a combination of the acronyms RAP, for Rapid Assessment, and PELD, short for Long Term Ecological Research Program in Portuguese) with a system of trails and permanent plots in which a diverse range of taxa can be sampled (see Magnusson et al., 2005; Costa and Magnusson, 2010 for a detailed description of the sampling design). The RAPELD grid in the Ducke Reserve is a square 8 km on a side, containing 64 km² of trails connecting 72 plots with a distance of 1 km between them (Fig. 1). Each sample plot is 250 m long, and its width varies according to the taxa or life stage being sampled. The centerline of each plot follows an elevation contour line, thus minimizing altitudinal variation within plots. A detailed description of the sampling protocols used to collect the data on composition and abundance of the different taxonomic groups can be found in the metadata available together with individual datasets in the PPBio website (http://ppbio.inpa.gov.br/Eng).
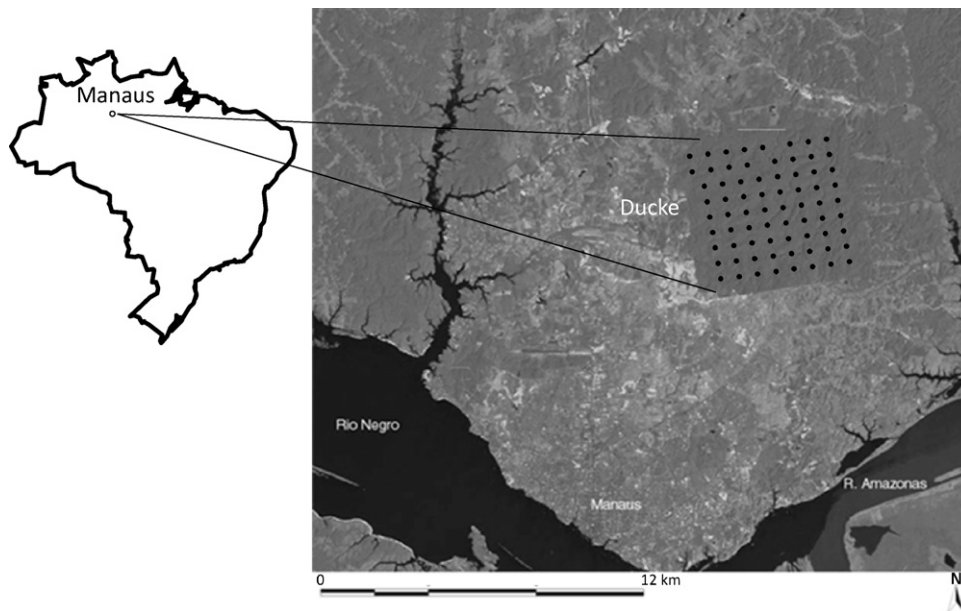
Fig. 1. Location of Ducke Reserve in the Brazilian Amazon. Points indicate the locations of each 250 m-transect sample plots on a 1 km equidistant sampling grid.

Of the 22 datasets used, 15 were of plant groups: (1) Burseraceae; (2) Chrysobalanaceae; (3) Euphorbiaceae; (4) Fabaceae; (5) Lauraceae; (6) Lecythidaceae; (7) Moraceae; (8) Myristicaceae; (9) Sapotaceae; (10) Palms; (11) Angiosperm Herbs; (12) Ferns; (13) shrubs of Piperaceae in the genus *Piper*; (14) Rubiaceae in the genus *Psychotria*; and (15) lianas (Bignoniaceae). Seven datasets were of animal groups: (16) diurnal anurans; (17) nocturnal anurans; (18) lizards; (19) bees; (20) ants; (21) soil-and-litter meso-invertebrates; and (22) mites of the suborder Oribatida.

All organisms were identified to species or morphospecies, except for soil and litter meso-invertebrates, which were identified to class, order or family. Samples were taken in the same plots; but some groups were not sampled in all plots (30–72 plots were sampled for each group). Environmental variables are also available from the PPBio data repository (http://ppbio.inpa.gov.br). In this study, we used five environmental variables (clay, silt and phosphorus (P) contents of the soil; terrain slope; and number of trees in the plot) that PPBio researchers had previously found to be the most important in explaining patterns in community structure of the different groups analyzed in this study (e.g., Costa et al., 2005; Kinupp and Magnusson, 2005; Baccaro et al., 2012).

2.3. Analysis of congruence

We first analyzed the congruence among all datasets using species abundance data. Abundance data were transformed into $\log(x+1)$ prior to analyses, to reduce the influence of outliers. To reduce the dimensionality of each dataset, we conducted a principal coordinate analysis (Legendre and Legendre, 1998) using the Bray–Curtis distance between sampling plots. The level of community congruence (between any two ordination solutions; i.e., between the eigenvectors extracted from the Bray–Curtis distance matrices) was quantified and tested for statistical significance by the Procrustean superimposition method and a Monte Carlo procedure (with 5000 permutations), respectively. The m^2 values (the goodness-of-fit statistic that measures the level of congruence between two ordination configurations) were transformed to Procrustes correlation (r) by calculating the square root of their complements ($r = \sqrt{1 - m^2}$) (Oksanen et al., 2011).

Mantel tests are also commonly used in studies of community congruence (see Table 2 of Heino, 2010). For this reason, we also evaluated the levels of community congruence by estimating the standardized Mantel correlation (r_M) between pairs of Bray–Curtis distance matrices. The significance level of each Mantel statistic was determined by comparing the observed value of r_M with those obtained after 5000 Monte Carlo simulations. Results from this test were similar to those obtained with Procrustes and are presented in Appendix A1. We present the results from the Procrustean approach in the body of the paper, because this approach has been shown to have higher power and lower type I error rates than the Mantel test (Peres-Neto and Jackson, 2001).

We submitted the matrix of congruence (pair-wise congruence) to a second-stage Non-Metric Multidimensional Scaling (NMDS) analysis to construct a plot to further examine the congruence between datasets. We calculated the average congruence that each group had with the others, and the group with the highest mean was considered the best surrogate.

2.4. Putative causes of congruence

We used a partial Redundancy Analysis (pRDA, Peres-Neto et al., 2006) to evaluate spatial and environmental patterns in each dataset (species abundance, using the Hellinger transformation). For this analysis, we used the five variables presented above as environmental predictors, while the spatial variables were the eigenvectors extracted, using an eigenfunction analysis (principal coordinates of neighbor matrices – PCNM), from a matrix of geographic distances between plots (Borcard and Legendre, 2002). We used a forward selection procedure (Blanchet et al., 2008) to retain spatial and environmental variables to be used in the pRDA. The results of variation partitioning were based on adjusted fractions of variation (Peres-Neto et al., 2006). Detailed descriptions of variation partitioning based on RDA can be found in Peres-Neto and Legendre (2010) and references therein.

Multivariate partitioning techniques have been extensively used to infer the relative roles of spatial and niche processes in structuring biological communities (Cottenie, 2005). However, these approaches were recently challenged by Gilbert and Bennett (2010), who indicated that different versions of these techniques produced biased estimates of the relative importance of spatial and

environmental patterns; and by Smith and Lundholm (2010), who showed that identical levels of dispersal and environmental control can produce very different variance components. We believe that these recent criticisms of multivariate partitioning techniques have stimulated an important debate (Landeiro and Magnusson, 2011), which is far from being settled. Thus, we used these techniques here cautiously and only as a way to detect either environmental or spatial patterns, instead of trying to measure their relative importance in community structuring. We predicted that biological groups that are more responsive to environmental and/or spatial gradients would have higher congruence between themselves than between groups with low environmental and/or spatial patterns.

We also regressed the mean level of congruence of each group with the environmental fraction [ab] and with the spatial fraction [bc] of the variance partitioning analysis. This regression enabled us to determine whether congruence levels were related to the magnitude of the explanation provided by environmental and spatial variables, respectively.

2.5. Impacts of reducing taxonomic and numerical resolution

After identifying the taxonomic group with the highest average congruence with the others, we evaluated the impact of decreasing the numerical and taxonomic resolution of the best group dataset on the levels of congruence. To accomplish this, we pooled species to genera (except for the meso-invertebrates, *Psychotria* and *Piper* datasets) and/or converted abundance to presence–absence data. We used the Sørensen distance for presence–absence data in the association matrix for the PCoA that was used in the Procrustes and Mantel analyses. The same procedures were used to measure the levels of congruence between the group with the highest average congruence (after reducing the taxonomic and numerical resolution) and all other groups.

2.6. Computational tools

All analyses were run in the R environment for statistical computing (R Development Core Team, 2011). Procrustes, Mantel tests, redundancy analysis, and variation partitioning analysis were all run using the functions *protest*, *mantel*, *rda* and *varpart* available in the vegan package (Oksanen et al., 2011).

3. Results

3.1. Analysis of congruence

The highest level of congruence found was between palms and lianas ($r = 0.87$; $P < 0.005$), and the lowest was between Burseraceae and mesofauna ($r = 0.04$; $P = 0.99$). In general, congruence was higher among plant groups (mean $r = 0.51 \pm 0.16$ SD) than among animal groups (mean $r = 0.24 \pm 0.12$ SD), and lianas was the group with the highest mean level of congruence (mean $r = 0.60 \pm 0.23$ SD, Fig. 2, see also Table A1 in Appendix A1). The second-stage NMDS represented well the patterns of congruence among the groups (Fig. 3), where groups with the highest congruence levels (mainly plants) tended to cluster together in the center of the ordination plot. Two plant groups (Euphorbiaceae and Lauraceae), which were poorly correlated with the other plant groups, were dispersed around the central group, as were the animal groups.

The ordination patterns observed for lianas (species-abundance data) were virtually unchanged after the conversion of abundance to presence–absence data (Procrustes, $r = 0.975$, $P < 0.001$), after pooling species into genera (Procrustes, $r = 0.857$, $P < 0.001$) or when genera-abundance data were converted to genera presence–absence data (Procrustes, $r = 0.777$, $P = 0.001$).
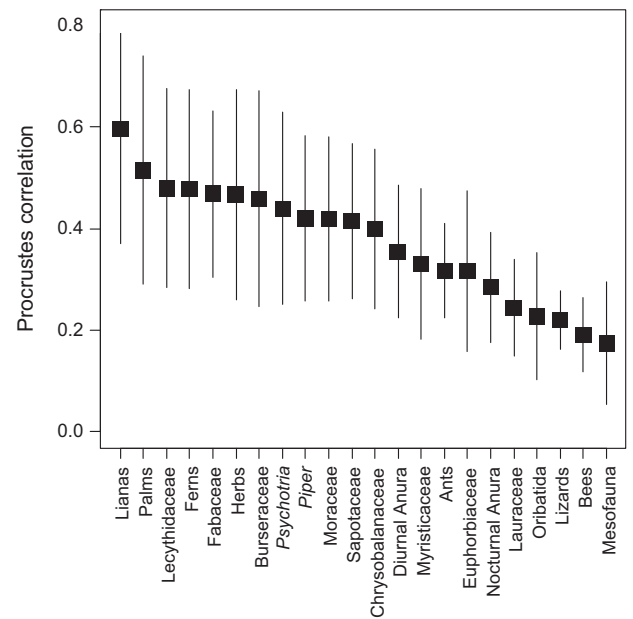

Fig. 2. Procrustean rotation results for species abundance data (5000 permutations). Congruence among 22 community datasets was evaluated with the correlations in Procrustean rotations. This figure was constructed using the average and standard deviation values presented in Table A1 in Appendix A1.
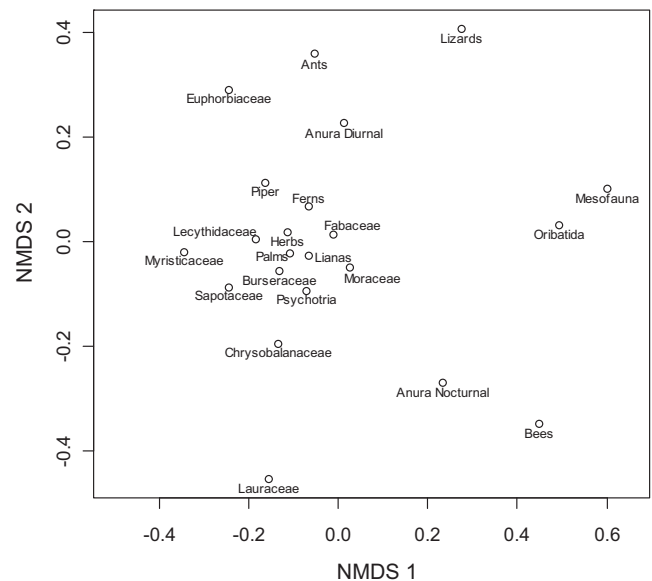

Fig. 3. Second-stage NMDS plot based on the congruence matrix (containing the Procrustean correlations among 22 community datasets – see Table 1). Stress = 0.204. The correlation of the distances in the final NMDS solution with the original matrix of congruence is 0.86.

3.2. Putative causes of congruence

Most datasets of plants and anurans showed close relationships with environmental and/or spatial predictors, while invertebrates and lizards were not significantly correlated with spatial or environmental predictors (Table 1). Lianas showed no spatial pattern, but had the second-largest environmental pattern ([a] = 0.253), being mainly associated with clay and P contents. The average level of congruence, obtained for each group, was closely related to the environmental fraction [ab] ($r^2 = 0.56$, $P < 0.001$, Fig. 4a), but the average level of congruence was not significantly related to the spatial fraction [bc] ($r^2 = 0.07$, $P = 0.24$, Fig. 4b).

Table 1
Variance partitioning analysis. Spatial filters (PCNMs) and environmental variables are shown in the order they were retained in the forward selection procedure. [a]: environmental fraction; [b]: shared fraction; [c]: spatial fraction; [a + b + c]: total variance explained.

	Environment	PCNMs	[a]	[b]	[c]
Lianas	clay, P	–	0.289	–	–
Palms	P, clay, slope, trees	30, 1, 2, 38, 8, 42, 31	0.262	0.152	0.025
Herbs	clay, slope, P, trees	34, 33, 29, 11, 2, 4, 1, 7, 6, 31, 40, 26, 8, 36, 35	0.109	0.143	0.114
Ferns	P, slope, clay, trees	11, 32, 33, 29, 34, 1, 25, 30, 10	0.185	0.165	0.105
Lecythidaceae	clay, P	1, 24, 2, 37, 3, 6, 13	0.148	0.042	0.068
Fabaceae	clay, P, slope	1, 2, 3, 44	0.094	0.002	0.028
Burseraceae	P, clay, slope, trees, silt	2, 28, 37, 48, 3, 8, 38, 1, 14, 26, 13, 30	0.11	0.068	0.081
Psychotria	P, clay, slope, trees	32, 2, 1, 3, 9, 37, 6, 5	0.142	0.079	0.176
Sapotaceae	clay, P, trees	3, 2, 1, 8, 45, 5, 6	0.054	0.034	0.045
Moraceae	clay, trees, P	2, 30, 47, 37, 1	0.104	0.041	0.036
Piper	clay, slope, P	1, 40, 4, 2, 6, 44	0.143	0.046	0.089
Chrysobalanaceae	P, clay	24, 2, 10, 48	0.048	0.005	0.031
Diurnal Anura	clay, slope, trees	1	0.218	0.005	0.053
Myristicaceae	clay, P, trees	–	0.112	–	–
Euphorbiaceae	P, slope	31, 37, 2, 42	0.056	0.015	0.039
Ants	–	2	–	–	0.043
Noturnal Anura	P, silt, trees, clay	2, 3, 37, 1, 4, 7, 10, 30, 46, 12, 48	0.098	0.111	0.214
Lauraceae	P, silt	35, 4	0.02	0.001	0.013
Oribatida	clay	1, 6, 34, 7, 2, 30, 25, 18, 49	0.008	0.01	0.078
Lizards	trees, clay	7	0.048	−0.003	0.018
Bees	silt	5, 7, 4	0.012	0.013	0.087
Mesofauna	–	16, 15, 35, 6, 3, 27, 7, 2, 1, 19, 8, 20, 12	–	–	0.219

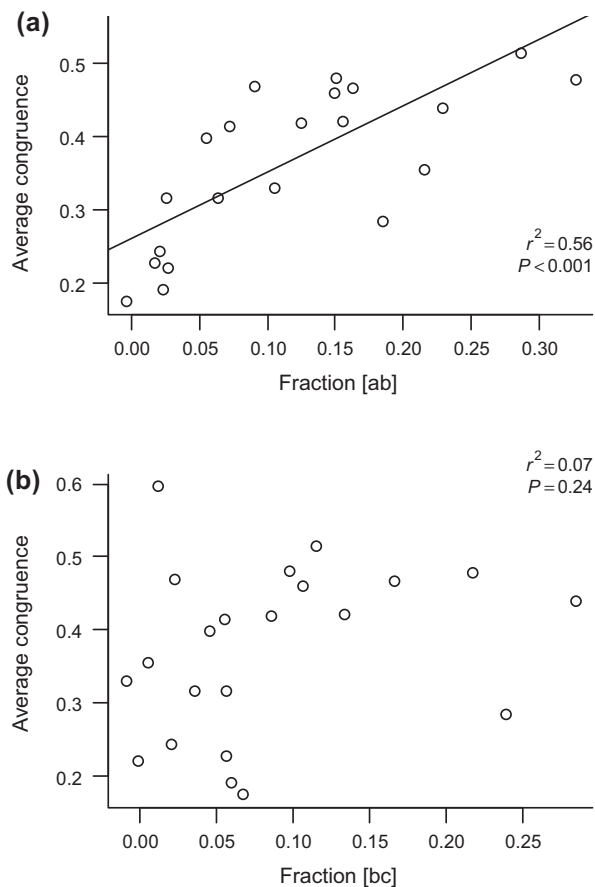–, no variable was retained in the forward selection procedure.

Fig. 4. Relationship between the average levels of congruence (Procrustes's *r*) calculated for each group and the fractions ([ab] and [bc]) derived from the partial RDA analyses. [ab] and [bc] represent the adjusted r^2 resulting from RDAs between the biological matrices and the environmental predictor matrix, and between the biological matrices and the spatial predictor matrix, respectively.

3.3. Impacts of reducing taxonomic and numerical resolution

Although not statistically significant (paired *t*-test = 1.09; $df = 20$; $P = 0.29$, mean of the differences = 0.005), the levels of congruence between lianas (the surrogate group with highest overall congruence) and other groups (especially herbs, palms, Chrysobalanaceae, Myristicaceae, diurnal/nocturnal anurans, oribatid mites and bees) were even higher after the liana-abundance data were transformed to presence–absence data. However, the levels of congruence between lianas and the other groups were statistically lower after the liana species-abundance data were grouped into genera-abundance data (paired *t*-test = 3.39; $P = 0.002$, mean of the differences = 0.048) or after both the taxonomic and numerical resolutions of the liana dataset were reduced (i.e., using the genera presence–absence data; paired *t*-test = 4.141; $P < 0.001$, mean of the differences = 0.080). However, even using genera presence–absence data for lianas (i.e., the coarsest numerical and taxonomic resolutions), the average level of congruence ($r = 0.516$, Table 2) was similar to the average congruence found for palms (mean $r = 0.515$), the group with the second-highest level of congruence (see Table A1 in Appendix A1). Thus, the ability of lianas to reproduce ordination patterns generated by other groups was largely maintained after the reduction of numerical resolution (abundance to occurrence), reduction of the taxonomic resolution (species to genera), or both (Table 2).

Similar results were obtained using Mantel tests to evaluate the patterns of congruence (see Appendix A1).

4. Discussion

The distribution patterns of most of the 15 plant groups analyzed showed high inter-group congruence (i.e., with all other groups), while invertebrates and lizards had low congruence with other groups. Anurans showed high congruence with plants, but the values were slightly lower than those among plants. Based only on congruence, lianas (Bignoniaceae) would be the best candidate for a surrogate group to represent these patterns. Although the overall congruence of lianas with the other groups was significantly lower after the decrease in its taxonomic and numerical resolution, congruence values remained high; even the coarsest resolution of lianas (genera presence–absence) had congruence values as high as

Table 2
Congruence between lianas (at different taxonomic and numerical resolutions) and other groups (species abundance, except for mesofauna). Congruence was evaluated using Procrustean rotations (5000 permutations).

Groups	Species		Genera	
	Abundance	Occurrence	Abundance	Occurrence
Palms	0.87	0.88	0.83	0.77
Lecythidaceae	0.78	0.77	0.70	0.64
Ferns	0.83	0.82	0.63	0.59
Fabaceae	0.76	0.73	0.68	0.62
Herbs	0.83	0.85	0.73	0.72
Burseraceae	0.81	0.80	0.73	0.68
Psychotria	0.78	0.76	0.68	0.62
Piper	0.68	0.67	0.69	0.65
Moraceae	0.74	0.70	0.72	0.65
Sapotaceae	0.67	0.66	0.56	0.50
Chrysobalanaceae	0.68	0.69	0.68	0.65
Diurnal Anura	0.59	0.61	0.59	0.58
Myristicaceae	0.55	0.56	0.47	0.40
Ants	0.34[a]	0.32[a]	0.40	0.45
Euphorbiaceae	0.69	0.67	0.63	0.57
Nocturnal Anura	0.60	0.62	0.55	0.50
Lauraceae	0.40	0.40	0.34	0.33
Oribatida	0.35	0.36	0.31[a]	0.29[a]
Lizards	0.24[a]	0.19[a]	0.16[a]	0.12[a]
Bees	0.15[a]	0.20[a]	0.15[a]	0.19[a]
Mesofauna	0.18[a]	0.17[a]	0.30[a]	0.32[a]
Mean	0.60	0.59	0.55	0.52
SD	0.23	0.23	0.23	0.23

[a] Non-significant values ($P > 0.05$).

the finest resolution of palms (species abundance data), the group with the second highest overall congruence.

4.1. Congruence among groups

The congruence in distribution patterns might be highly dependent on the geographic location (Cabeza et al., 2008) and spatial extent of an analysis (McKnight et al., 2007). McKnight et al. (2007), for instance, found that the congruence in beta diversity patterns among amphibians, birds and mammals was generally stronger in the Neotropical than in the Nearctic realm. Also, Rooney and Bayley (2012) indicated that the level of community concordance in constructed wetlands was lower than the level estimated for reference wetlands. Thus, extrapolation of our results to regions beyond the Amazon should be done with caution. Ideally, a similar study should be done, if there are available data, to evaluate the adequacy of the surrogates discussed here for other regions.

Based on Mantel tests, Ruokolainen et al. (2007), working in Amazonian forests, considered ferns (Pteridophytes) to be the best surrogate group for other plants. Our results based on Procrustean rotations (and Mantel tests, see Appendix A1) identified ferns as the fourth-best group, with a high average congruence value (which was slightly lower only than those for lianas, palms and Lecythidaceae). Because ferns are easy to sample, we agree with Ruokolainen et al. (2007) that this is a good option for rapid evaluations.

4.2. Putative causes of congruence

Differences in distributional patterns between communities may be due to dissimilar responses to environmental gradients, to different dispersal abilities, or both (Linares-Palomino and Kessler, 2009). Conversely, similar responses to environmental gradients may be the main causes of community congruence (e.g., Paszkowski and Tonn, 2000). The high congruence among plant groups observed here might be explained by their similar relationships with environmental variables, as the partial RDA indicated

that the variance in community structure accounted for by the environmental variables was significantly related to the average level of congruence of each group. Also, increasing the gradient length (either by increasing the spatial extent or by sampling across a disturbance gradient) would likely increase the average level of congruence among biological groups (Paavola et al., 2006).

The main causes for the high congruence among plants might be associated with similar responses to soil characteristics. Variation in densities of most plants was associated with clay and P contents. Lianas showed the closest relationship with soil variation (28.9% of the variance was explained by clay and P soil contents). In general, soil factors have been found to be better predictors of floristic patterns in the Amazon region than are spatial factors (e.g., Tuomisto et al., 2003; Costa et al., 2005). Lianas generally have high dispersal ability (Macía et al., 2007), which might account for the lack of spatial pattern observed. In general, our results also highlight the importance of the phylogenetic niche conservatism concept, which has been demonstrated in plants (e.g., Prinzing et al., 2001).

4.3. Lianas as a potential surrogate group

Lianas have many interesting ecological characteristics that may make them useful as a surrogate for other biological groups or as an indicator of environmental changes. Indeed, an entire volume of Forest Ecology and Management (vol. 190, 2004) was dedicated to the role of lianas in tropical-forest functioning, management and conservation (e.g., Wright et al., 2004; see also Schnitzer and Bongers, 2002). In this vein, Schnitzer and Carson (2010) have shown that lianas, in addition to contributing to diversity and community structure, profoundly alter tree growth and reduce the fecundity of some species, consequently changing the function and physiognomy of tropical forests. The importance of lianas is also realized if one considers that they comprise, respectively, about 25% and up to 44% of the woody-stem density and species richness in the Amazon forests (Schnitzer and Bongers, 2002).

In general, lianas are more abundant on rich soils (Putz and Chai, 1987) and are strongly dependent on vegetation structure (Nogueira et al., 2011) at local scales. These relationships may explain the finding that lianas are the best surrogate group, in that most plant groups are also related to vegetation structure. Indeed, many plant groups among those with high congruence were related to the number of trees and soil properties in the plots (Table 1).

At large spatial scales, lianas are associated with rainfall seasonality, and are more abundant and species-rich in regions with pronounced dry seasons (Schnitzer, 2005). Gap formation (Schnitzer and Bongers, 2002) and forest fragmentation (Laurance et al., 2001) may also increase the abundance and diversity of lianas. Therefore, proliferation of lianas profoundly affects forest structure and functioning (Laurance et al., 2001), with considerable implications for the carbon cycle and for the biodiversity of tropical forests (Phillips et al., 2002). Because the severity and frequency of drought events affecting the Amazon region are expected to increase (Lewis et al., 2011), the use of lianas as a surrogate group for other plants in the Amazon might be valuable not only due to their surrogacy capability, but also because they are an indicator group for environmental changes.

While lianas may be useful surrogates for biological variation, or as indicators of environmental changes, their high dispersal capability and close association with environmental factors may make them less suitable as surrogates for animal groups that show less local variation associated with soil characteristics (e.g., ants and mesofauna). Finally, monitoring programs, such as the PPBio (http://ppbio.inpa.gov.br), are only starting to accumulate integrated data on many taxa and environmental variables at wider scales, so selection of surrogates for wider scales should be made with caution.

4.4. Effects of numerical and taxonomic resolution

The reduction of the taxonomic resolution of lianas caused a significant decrease in the congruence of lianas with the other groups. However, the mean of the differences was low. In addition, even using low-resolution data, the group composed by lianas was the best surrogate (i.e., it had the highest mean congruence). Therefore, the taxonomic and numerical resolution of lianas can be reduced without great loss of information, at least at the spatial scale of this study. These results are in line with previous studies showing that the use of data with low numerical and taxonomic resolutions may be reliable for plant groups (e.g., Prinzing et al., 2003; Torre-Cuadros et al., 2007) and some animal groups (e.g., Attayde and Hansson, 2001). Conversely, there is a tradeoff between the taxonomic resolution used and the clarity of the pattern (e.g., the magnitude of the effect, Melo, 2005), which should be taken into account before determining the level of resolution of the data.

5. Conclusions

Our study provides information on the use of surrogate groups at local scales in the Amazon. Plant groups were highly congruent at the scale studied, while animal groups had low congruence with other animal datasets and with plant datasets. Lianas proved to be the best surrogate group, and may have many useful properties other than those related to their use as a surrogate group. Because lianas grow rapidly in new gaps and during dry periods, they might be used as an indicator group for monitoring global climate changes, such as increased drought periods. In addition to the use of lianas as a surrogate group to simplify monitoring assessments, the use of presence–absence data and genus-level identifications also could reduce the costs and labor of monitoring studies.

Acknowledgements

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2012.04.023.

References

Andersen, A.N., Hoffmann, B.D., Müller, W.J., Griffiths, A.D., 2002. Using ants as bioindicators in land management: simplifying assessment of ant community responses. J. Appl. Ecol. 39, 8–17.

Anderson, M.J., Connell, S.D., Gillanders, B.M., Diebel, C.E., Blom, W.M., Saunders, J.E., Landers, T.J., 2005. Relationships between taxonomic resolution and spatial scales of multivariate variation. J. Anim. Ecol. 74, 636–646.

Attayde, J.L., Hansson, L.A., 2001. Press perturbation experiments and the indeterminacy of ecological interactions: effects of taxonomic resolution and experimental duration. Oikos 92, 235–244.

Baccaro, F.B., de Souza, J.L.P., Franklin, E., Landeiro, V.L., Magnusson, W.E., 2012. Limited effects of dominant ants on assemblage species richness in three Amazon forests. Ecol. Entomol. 37, 1–12.

Banks-Leite, C., Ewers, R.M., Kapos, V., Matensen, A.C., Metzger, J.P., 2011. Comparing species and measures of landscape structure as indicators of conservation importance. J. Appl. Ecol. 48, 706–714.

Bertrand, Y., Pleijel, F., Rouse, G.W., 2006. Taxonomic surrogacy in biodiversity assessments, and the meaning of Linnaean ranks. Syst. Biodivers. 4, 149–159.

Blanchet, F.G., Legendre, P., Borcard, D., 2008. Forward selection of explanatory variables. Ecology 89, 2623–2632.

Borcard, D., Legendre, P., 2002. All-scale spatial analysis of ecological data by means of principal coordinates of neighbour matrices. Ecol. Model. 153, 51–68.

Brown, J.H., Lomolino, M.V., 1998. Biogeography, 2nd ed. Sinauer, Sunderland, MA.

Cabeza, M., Arponen, A., Van Teeffelen, A., 2008. Top predators: hot or not? A call for systematic assessment of biodiversity surrogates. J. Appl. Ecol. 45, 976–980.

Carneiro, F.M., Bini, L.M., Rodrigues, L.C., 2010. Influence of taxonomic and numerical resolution on the analysis of temporal changes in phytoplankton communities. Ecol. Indic. 10, 249–255.

Costa, F.R.C., Magnusson, W.E., 2010. The need for large-scale, integrated studies of biodiversity – the experience of the program for biodiversity research in Brazilian Amazonia. Nat. Conserv. 8, 3–12.

Costa, F.R.C., Magnusson, W.E., Luizão, R.C., 2005. Mesoscale distribution patterns of amazonian understorey herbs in relation to topography, soil and watersheds. J. Ecol. 93, 863–878.

Cottenie, K., 2005. Integrating environmental and spatial processes in ecological community dynamics. Ecol. Lett. 8, 1175–1182.

Espírito-Santo, H.M.V., Magnusson, W.E., Zuanon, J., Mendonça, F.P., Landeiro, V.L., 2009. Seasonal variation in the composition of fish assemblages in small Amazonian forest streams: evidence for predictable changes. Freshw. Biol. 54, 536–548.

Franco, A.M.A., Anderson, B.J., Roy, D.B., Gillings, S., Fox, R., Moilanen, A., Thomas, C.D., 2009. Surrogacy and persistence in reserve selection: landscape prioritization for multiple taxa in Britain. J. Appl. Ecol. 46, 82–91.

Gilbert, B., Bennett, J.R., 2010. Partitioning variation in ecological communities: do the numbers add up? J. Appl. Ecol. 47, 1071–1082.

Greffard, M.H., Saulnier-Talbot, E., Gregory-Eaves, I., 2011. A comparative analysis of fine versus coarse taxonomic resolution in benthic chironomid community analyses. Ecol. Indic. 11, 1541–1551.

Hansen, J.H., Sato, R., Lacis, A., Oinas, V., 2000. Global warming in the twenty-first century: an alternative scenario. Proc. Natl. Acad. Sci. U.S.A. 97, 9875–9880.

Heino, J., 2010. Are indicator groups and cross-taxon congruence useful for predicting biodiversity in aquatic ecosystems? Ecol. Indic. 10, 112–117.

Heino, J., Muotka, T., Paavola, R., 2003. Determinants of macroinvertebrate diversity in headwater streams: regional and local influences. J. Anim. Ecol. 72, 425–434.

Hopkins, M.J.G., 2007. Modelling the known and unknown plant biodiversity of the Amazon basin. J. Biogeogr. 34, 1400–1411.

Kinupp, V.F., Magnusson, W.E., 2005. Spatial patterns in the understorey shrub genus Psychotria in central Amazonia: effects of distance and topography. J. Trop. Ecol. 21, 363–374.

La Ferla, B., Taplin, J., Ockwell, D., Lovett, J.C., 2002. Continental scale patterns of biodiversity: can higher taxa accurately predict African plant distributions? Bot. J. Linn. Soc. 138, 225–235.

Landeiro, V.L., Magnusson, W.E., 2011. The geometry of spatial analyses: implications for conservation biologists. Nat. Conserv. 9, 7–20.

Laurance, W.F., Perez-Salicrup, D., Delamonica, P., Fearnside, P.M., D'Angelo, S., Jerozolinski, A., Pohl, L., Lovejoy, T.E., 2001. Rain forest fragmentation and the structure of Amazonian liana communities. Ecology 82, 105–116.

Legendre, P., Legendre, L., 1998. Numerical Ecology, 2nd ed. Elsevier, Amsterdam.

Lewis, S.L., Braun, W.J., Phillips, O.L., van der Heijden, G.M.F., Nepstad, D., 2011. The 2010 Amazon drought. Science 331, 554.

Linares-Palomino, R., Kessler, M., 2009. The role of dispersal ability, climate and spatial separation in shaping biogeographical patterns of phylogenetically distant plant groups in seasonally dry Andean forests of Bolivia. J. Biogeogr. 36, 280–290.

Lomolino, M.V., 2004. Conservation biogeography. In: Lomolino, M.V., Heaney, L.R. (Eds.), Frontiers of Biogeography. Sinauer Associates, Sunderland, pp. 293–296.

Lopes, P.M., Caliman, A., Carneiro, L.S., Bini, L.M., Esteves, F.A., Farjalla, V., Bozelli, R.L., 2011. Concordance among assemblages of upland Amazonian lakes and the structuring role of spatial and environmental factors. Ecol. Indic. 11, 1171–1176.

Macía, M.J., Ruokolainen, K., Tuomisto, H., Quisbert, J., Cala, V., 2007. Congruence between floristic patterns of trees and lianas in a southwest Amazonian rain forest. Ecography 30, 561–577.

Magnusson, W.E., Lima, A.P., Luizão, R., Luizão, F.J., Costa, F.R.C., Castilho, C.V., Kinupp, V.F., 2005. RAPELD: a modification of the Gentry method for biodiversity surveys in long-term ecological research sites. Biota Neotrop. 5, 1–6.

Magurran, A.E., Queiroz, H., 2010. Evaluating tropical biodiversity: do we need a more refined approach? Biotropica 42, 537–539.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.

McKnight, M.W., White, P.S., McDonald, R.I., Lamourex, J.F., Sechrest, W., Ridgely, R.S., Stuart, S.N., 2007. Putting beta-diversity on the map: broad-scale congruence and coincidence in extremes. PLoS Biol. 5, 2424–2432.

Melo, A.S., 2005. Effects of taxonomic and numerical resolution on the ability to detect ecological patterns at a local scale using stream macroinvertebrates. Arch. Hydrobiol. 164, 309–323.

Nogueira, A., Costa, F.R.C., Castilho, C.V., 2011. Liana abundance patterns: the role of ecological filters during development. Biotropica 43, 442–449.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Wagner, H., 2011. vegan: Community Ecology Package., http://CRAN.R-project.org/package=vegan.

Oliver, I., Beattie, A.J., York, A., 1998. Spatial fidelity of plant, vertebrate, and invertebrate assemblages in multiple-use forest in eastern Australia. Conserv. Biol. 12, 822–835.

Paavola, R., Muotka, T., Virtanen, R., Heino, J., Jackson, D., Mäki-Petäys, A., 2006. Spatial scale affects community concordance among fishes, benthic macroinvertebrates, and bryophytes in streams. Ecol. Appl. 16, 368–379.

Paszkowski, C.A., Tonn, W.M., 2000. Community concordance between the fish and aquatic birds of lakes in northern Alberta Canada: the relative importance of environmental and biotic factors. Freshw. Biol. 43, 421–437.

Peres-Neto, P.R., Jackson, D.A., 2001. How well do multivariate data sets match? The advantages of a Procrustean superimposition approach over the Mantel test. Oecologia 129, 169–178.

Peres-Neto, P.R., Legendre, P., 2010. Estimating and controlling for spatial structure in the study of ecological communities. Glob. Ecol. Biogeogr. 19, 174–184.

Peres-Neto, P.R., Legendre, P., Dray, S., Borcard, D., 2006. Variation partitioning of species data matrices: estimation and comparison of fractions. Ecology 87, 2614–2625.

Phillips, O.L., Martinez, R.V., Arroyo, L., Baker, T.R., Killeen, T., Lewis, S.L., Malhi, Y., Mendoza, A.M., Neill, D., Vargas, P.N., Alexiades, M., Ceron, C., Di Fiore, A., Erwin, T., Jardim, A., Palacios, W., Saldias, M., Vinceti, B., 2002. Increasing dominance of large lianas in Amazonian forests. Nature 418, 770–774.

Prinzing, A., Durka, W., Klotz, S., Brandl, R., 2001. The niche of higher plants: evidence for the phylogenetic conservatism. Proc. R. Soc. Lond. B: Biol. Sci. 268, 2383–2389.

Prinzing, A., Klotz, S., Stadler, J., Brandl, R., 2003. Woody plants in Kenya: expanding the higher-taxon approach. Biol. Conserv. 110, 307–314.

Putz, F.E., Chai, P., 1987. Ecological studies of lianas in Lambir national Park, Sarawak, Malaysia. J. Ecol. 75, 523–531.

Qian, H., Ricklefs, R.E., 2008. Global concordance in diversity patterns of vascular plants and terrestrial vertebrates. Ecol. Lett. 11, 547–553.

R Development Core Team, 2011. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org.

Rimet, F., Bouchez, A., 2012. Biomonitoring river diatoms: implications of taxonomic resolution. Ecol. Indic. 15, 92–99.

Rodrigues, A.S.L., Brooks, T.M., 2007. Shortcuts for biodiversity conservation planning: the effectiveness of surrogates. Annu. Rev. Ecol. Evol. Syst. 38, 713–737.

Rooney, R.C., Bayley, S.E., 2012. Community congruence of plants, invertebrates and birds in natural and constructed shallow open-water wetlands: do we need to monitor multiple assemblages? Ecol. Indic. 20, 42–50.

Ruokolainen, K., Tuomisto, H., Macía, M.J., Higgins, M.A., Yli-Halla, M., 2007. Are floristic and edaphic patterns in Amazonian rain forests congruent for trees, pteridophytes and Melastomataceae? J. Trop. Ecol. 23, 13–25.

Schaffers, A.P., Raemakers, I.P., Sykora, K.V., Ter Braak, C.J.F., 2008. Arthropod assemblages are best predicted by plant species composition. Ecology 89, 782–794.

Schnitzer, S.A., 2005. A mechanistic explanation for global patterns of liana abundance and distribution. Am. Nat. 166, 262–276.

Schnitzer, S.A., Bongers, F., 2002. The ecology of lianas and their role in forests. Trends Ecol. Evol. 17, 223–230.

Schnitzer, S.A., Carson, W.P., 2010. Lianas suppress tree regeneration and diversity in treefall gaps. Ecol. Lett. 13, 849–857.

Schulman, L., Toivonen, T., Ruokolainen, K., 2007. Analysing botanical collecting effort in Amazonia and correcting for it in species range estimation. J. Biogeogr. 34, 1388–1399.

Smith, T.W., Lundholm, T., 2010. Variation partitioning as a tool to distinguish between niche and neutral processes. Ecography 33, 648–655.

Su, J.C., Debinski, D.M., Jakubauskas, M.E., Kindscher, K., 2004. Beyond species richness: community similarity as a measure of cross-taxon congruence for coarse-filter conservation. Conserv. Biol. 18, 167–173.

ter Steege, H., Pitman, N.C.A., Phillips, O.L., Chave, J., Sabatier, D., Duque, A., Molino, J.F., Prevost, M.F., Spichiger, R., Castellanos, H., von Hildebrand, P., Vasquez, R., 2006. Continental-scale patterns of canopy tree composition and function across Amazonia. Nature 443, 444–447.

Terlizzi, A., Bevilacqua, S., Fraschetti, S., Boero, F., 2003. Taxonomic sufficiency and the increasing insufficiency of taxonomic expertise. Mar. Pollut. Bull. 46, 556–561.

Torre-Cuadros, M.D.L.Á., Herrando-Pérez, S., Young, K.R., 2007. Diversity and structural patterns for tropical montane and premontane forests of central Peru, with an assessment of the use of higher-taxon surrogacy. Biodivers. Conserv. 16, 2965–2988.

Tuomisto, H., Ruokolainen, K., Yli-Halla, M., 2003. Dispersal, environment, and floristic variation of western Amazonian forests. Science 299, 241–244.

Vormisto, J., Phillips, O.L., Ruokolainen, K., Tuomisto, H., Vásquez, R., 2000. A comparison of fine-scale distribution patterns of four plant groups in an Amazonian rainforest. Ecography 23, 349–359.

Vörösmarty, C., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature 467, 555–561.

Whittaker, R.J., Araujo, M.B., Paul, J., Ladle, R.J., Watson, J.E.M., Willis, K.J., 2005. Conservation biogeography: assessment and prospect. Divers. Distrib. 11, 3–23.

Wright, S.J., Calderon, O., Hernandez, A., Paton, S., 2004. Are lianas increasing in importance in tropical forests? A 17-year record from Panama. Ecology 85, 484–489.