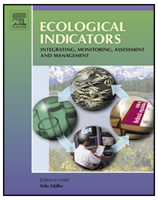
Ecological Indicators 83 (2017) 538–549

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Remote sensing improves prediction of tropical montane species diversity but performance differs among taxa

Christine I.B. Wallis[a,b,*], Gunnar Brehm[c], David A. Donoso[d,1], Konrad Fiedler[e], Jürgen Homeier[f], Detlev Paulsch[g], Dirk Süßenbach[h], Yvonne Tiede[a], Roland Brandl[i], Nina Farwig[a], Jörg Bendix[b]

[a] Conservation Ecology, Faculty of Biology, Philipps-Universität Marburg, Karl-von-Frisch-Straße 8, 35043 Marburg, Germany
[b] Laboratory for Climatology and Remote Sensing, Faculty of Geography, Philipps-Universität Marburg, Deutschhausstraße 12, 35032 Marburg, Germany
[c] Institut für Spezielle Zoologie und Evolutionsbiologie mit Phyletischem Museum, Friedrich-Schiller-Universität Jena, Erbertstraße 1, 07743 Jena, Germany
[d] Museo de Colecciones Biológicas (MUTPL), Universidad Técnica Particular de Loja, San Cayetano Alto s/n, Loja, Ecuador
[e] Department of Botany and Biodiversity Research, University of Vienna, Rennweg 14, 1030 Wien, Austria
[f] Plant Ecology, Albrecht von Haller Institute for Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany
[g] Gesellschaft für angewandte Ökologie und Umweltplanung mbH, Impexstraße 5, 69190 Walldorf, Germany
[h] Federal Environment Agency, Wörlitzer Platz 1, 06844 Dessau-Roßlau, Germany
[i] Animal Ecology, Department of Ecology, Faculty of Biology, Philipps-Universität Marburg, Karl-von-Frisch-Straße 8, 35043 Marburg, Germany

ARTICLE INFO

Article history:
Received 9 June 2016
Received in revised form 18 January 2017
Accepted 21 January 2017
Available online 27 March 2017

Keywords:
Ants
Birds
Gray-level co-occurrence matrix
Image textures
Moths
Orthophotos
Partial least-squares regression
Species turnover
Trees
Tropical mountain rainforest

ABSTRACT

Texture information from passive remote sensing images provides surrogates for habitat structure, which is relevant for modeling biodiversity across space and time and for developing effective ecological indicators. However, the applicability of this information might differ among taxa and diversity measures. We compared the ability of indicators developed from texture analysis of remotely sensed images to predict species richness and species turnover of six taxa (trees, pyraloid moths, geometrid moths, arctiinae moths, ants, and birds) in a megadiverse Andean mountain rainforest ecosystem. Partial least-squares regression models were fitted using 12 predictors that characterize the habitat and included three topographical metrics derived from a high-resolution digital elevation model and nine texture metrics derived from very high-resolution multi-spectral orthophotos. We calculated image textures derived from mean, correlation, and entropy statistics within a relatively broad moving window (102 m × 102 m) of the near infra-red band and two vegetation indices. The model performances of species richness were taxon dependent, with the lowest predictive power for arctiinae moths (4%) and the highest for ants (78%). Topographical metrics sufficiently modeled species richness of pyraloid moths and ants, while models for species richness of trees, geometrid moths, and birds benefited from texture metrics. When more complexity was added to the model such as additional texture statistics calculated from a smaller moving window (18 m × 18 m), the predictive power for trees and birds increased significantly from 12% to 22% and 13% to 27%, respectively. Gradients of species turnover, assessed by non-metric two-dimensional scaling (NMDS) of Bray-Curtis dissimilarities, allowed the construction of models with far higher predictability than species richness across all taxonomic groups, with predictability for the first response variable of species turnover ranging from 64% (birds) to 98% (trees) of the explained change in species composition, and predictability for the second response variable of species turnover ranging from 33% (trees) to 74% (pyraloid moths). The two NMDS axes effectively separated compositional change along the elevational gradient, explained by a combination of elevation and texture metrics, from more subtle, local changes in habitat structure surrogated by varying combinations of texture metrics. The application of indicators arising from texture analysis of remote sensing images differed among taxa and diversity

---

* Corresponding author.
E-mail addresses: christine.wallis@staff.uni-marburg.de (C.I.B. Wallis), gunnar.brehm@uni-jena.de (G. Brehm), david.donosov@gmail.com (D.A. Donoso), konrad.fiedler@univie.ac.at (K. Fiedler), jhomeie@gwdg.de (J. Homeier), d.paulsch@gefaoe.de (D. Paulsch), dirk.suessenbach@web.de (D. Süßenbach), yvonne.tiede@biologie.uni-marburg.de (Y. Tiede), brandlr@biologie.uni-marburg.de (R. Brandl), nina.farwig@biologie.uni-marburg.de (N. Farwig), bendix@geo.uni-marburg.de (J. Bendix).

[1] Present address: Instituto de Ciencias Biológicas y Museo de Historia Natural, Escuela Politécnica Nacional, Av. Ladrón de Guevara E11-253, Apartado: 17-01-2759, Quito, Ecuador.

http://dx.doi.org/10.1016/j.ecolind.2017.01.022

measures. However, these habitat indicators improved predictions of species diversity measures of most taxa, and therefore, we highly recommend their use in biodiversity research.

1. Introduction

Information derived from remote sensing (RS) provides cost-effective proxies for primary productivity and habitat structure (Rocchini et al., 2016, 2015; Wang et al., 2010). Species occurrence of individual species and species diversity are often correlated to these proxies (Cintra and Naka, 2012; Couteron et al., 2005; Estes et al., 2010; Goetz et al., 2007; Mairota et al., 2015; Rocchini et al., 2010; Tews et al., 2004). Therefore, RS provides useful information for models of ecological variables across large extents with a high spatial resolution. Such spatially-explicit models are of considerable importance in conservation planning if recurrent RS information is available as they provide maps and offer effective indicator systems for area-wide monitoring. However, the success of these models varies considerably among taxa and modeled variables of biodiversity. A deeper understanding of this variation in predictability of diversity measures would be helpful for planning and establishing monitoring systems for documenting environmental change, especially in biota where biodiversity inventories are difficult to achieve.

Particularly the use of RS texture metrics has strengthened statistical models of biodiversity (Culbert et al., 2012; Estes et al., 2010; Wallis et al., 2016b; Wood et al., 2013). In textural approaches, a new value is assigned to each pixel and characterizes the distribution of spectral values in a particular neighborhood, which is defined by a moving or fixed window (Haralick, 1979). Depending on the considered textural feature, which ranges from simple metrics (e.g., mean, variance) to complex metrics (e.g., contrast, correlation), such variables characterize different spatial aspects of habitat structure (e.g., habitat heterogeneity). For example, image textures based on very high-resolution optical imagery successfully predict and map the structure of forests (Wood et al., 2012) and distributional patterns of bird diversity (St-Louis et al., 2014). Models of a montane forest in southwestern Colorado that include texture metrics from RS are more strongly correlated with biomass than models using topographical or spectral metrics (Kelsey and Neff, 2014). Similar results have been obtained for mature biomass in a moist tropical forest (Lu and Batistella, 2005). Therefore, textural information from RS images might address the relationship between environment and biodiversity more effectively than raw spectral bands or common vegetation indices.

Tropical mountain rainforests, particularly Andean rainforests, are among the most diverse and threatened biodiversity hotspots of the world (e.g., Brehm et al., 2016; Tapia-Armijos et al., 2015). Studies of similarly diverse systems have investigated elevation and topography as predictors of biodiversity, and have successfully modeled the occurrence of certain tree species and species richness of moths and ants (e.g., Kübler et al., 2016; Malsch et al., 2008; Nakamura et al., 2015). However, the results are highly taxon dependent, and some taxa are difficult to predict from simple environmental variables (Fiedler et al., 2008; Tiede et al., 2016a). Thus, models of tropical diversity would benefit from the inclusion of structural habitat information.

A great challenge in tropical diverse systems is the assembly of meaningful biodiversity data. The extraordinary high species richness and the low availability of taxonomic and ecological information for most of the species forces ecological studies in tropical rainforest ecosystems to target well-known taxa, e.g., woody plants (Homeier et al., 2010), or taxa such as ants or birds that occupy different trophic levels within the food webs (Gerlach et al., 2013; Kati et al., 2004; Schuldt et al., 2014; Şekercioğlu et al., 2016; Tiede et al., 2017; Donoso and Ramón, 2009).

Most RS-based diversity research has focused on measures of alpha-diversity and has ignored community structure. Changes in species composition along environmental gradients are measured by a variety of metrics of species turnover, ranging from dissimilarity measures to scores along ordination axes (Socolar et al., 2016; Whittaker, 1972; Brehm and Fiedler, 2004). Various studies have shown that the composition of species usually provides detailed information on habitat characteristics (Banks-Leite and Cintra, 2008; Cintra and Naka, 2012; Farwig et al., 2014; Müller et al., 2009; Thiollay, 1994). RS-based habitat indicators might improve predictions of species turnover as spectral distances are, for example, strongly correlated to patterns of floristic species composition among sites in Ecuadorian Amazonia (Tuomisto et al., 2003). Unfortunately, the computation of spectral distances and species similarities among sites and the mapping of distance-based species turnover is time consuming because the number of spectral distances increases with the square of the number of sampled sites (Rocchini et al., 2016). A number of studies, therefore, have assessed species turnover using ordination techniques (Farwig et al., 2014; Feilhauer and Schmidtlein, 2009; Gu et al., 2015; Muenchow et al., 2013; Wallis et al., 2016b). For instance, Feilhauer and Schmidtlein (2009) performed a detrended correspondence analysis to identify different gradients in the composition of vegetation. Scores of sites along the ordination axes that represent these environmental gradients were regressed against topographical and spectral metrics calculated for the sites. Ordination techniques, therefore, might be the superior choice to assess species turnover when RS information are used to produce continuous maps of environmental gradients, e.g., the compositional change of bird species along habitat structure (Wallis et al., 2016b).

Here, we investigated models that consider species richness and ordinations of compositional change using non-metric multidimensional scaling (NMDS) as a measure of species turnover of trees, moths (Pyraloidea, Geometridae, Arctiinae), ants, and birds in a tropical mountain rainforest ecosystem. We fitted partial least-squares regressions for all taxa and diversity measures separately by assessing topographical metrics derived from a digital elevation model and image texture metrics derived from an airborne multi-spectral sensor. Our aim was to compare the predictability of species richness and species turnover across the six taxa. We identified differences among the selected taxonomic groups and examined which combination of habitat indicators served well for each taxonomic group as well as for the selected diversity measure. Our findings provide guidelines for the development of a RS-based indicator system for monitoring biodiversity in response to environmental changes in complex tropical forests.

2. Methods

2.1. Study area

The study area is located in southeastern Ecuador, an area known for its high climatic and environmental heterogeneity and high levels of species richness with numerous endemic taxa (Bendix