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Authors: Victor Hugo Fonseca Oliveira, Jos Barlow, Toby Gardner, Julio Louzada

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Do we select the best metrics for assessing land use effects on biodiversity?

Running title: Discrepancies between variables importance and use.

Victor Hugo Fonseca Oliveira* [1,2], Jos Barlow [2,3], Toby Gardner [3] and Julio Louzada [1,2].

[1] Programa de Pós Graduação em Ecologia Aplicada, Universidade Federal da Lavras. Lavras, Minas Gerais, Brasil. CEP: 37200-000.

[2] Lancaster Environment Centre, Lancaster University. Lancaster, LA1 4YQ, United Kingdom.

[3] MCT/Museu Paraense Emílio Goeldi. Campus de Pesquisa, Av.Perimetral, nº 1901, Terra Firme. Belém, Pará, Brasil. CEP: 66017-970.

[4] Stockholm Environment Institute. Linnégatan 87D, Box 24218, Stockholm, 104 51, Sweden.

* Corresponding author: toru.oliveira@gmail.com, +55 35 3829 1923

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Abstract

Biased and subjective choices in the variable selection processes used in ecological studies commonly lead researchers to reach misleading conclusions regarding patterns of biodiversity response to disturbances. Nevertheless, little attention has been given to these processes in the majority of studies published to date. Here, we assess the extent to which variables commonly employed in ecological studies correspond to those deemed to be most important by researchers of the same studies. Specifically, we examined both biodiversity (response) and environmental (explanatory) metrics from a comprehensive literature review and compared their use with their relative importance, according to a survey with the studies' authors. We used the literature concerning land use change effects on dung beetles as our study case. Our results highlight marked disparities between researchers opinion and their choice of variables in published papers. We suggest that these disparities are due to the high costs of sampling and processing some variables, as well as to logistical constraints and researchers own bias. If current practices and these discrepancies persist then our understanding of the biodiversity consequences of land-use change will remain compromised, while further undermining our confidence in the results of ecological studies.

Keywords: Agricultural expansion; Conversion; Dung beetles; Inference; Research scope; Variables selection

Introduction

Over the last few hundred years humans have significantly altered the surface and functioning of the biosphere, heralding what is now widely recognised as the start of the Anthropocene (Ellis 2011). Agricultural systems such as croplands and pastures already encompass more than one third of the Earth´s land surface (Asner, Elmore, Olander, Martin & Harris 2004; Ramankutty & Foley 1999) and continue to expand to meet burgeoning human needs. This unprecedented modification of natural landscapes includes habitat loss and fragmentation, land-use intensification, and habitat degradation. The ecological impacts of these changes include biodiversity loss and species extinctions, turnover in species composition, and a loss of the critical ecosystem services provided by biodiversity (Millennium Ecosystem Assessment 2005; Sukhdev, Wittmer & Miller 2014). These events are particularly important in the tropics, which hold both the highest levels of biodiversity and the highest rates of land-use change (Hansen et al. 2013).

Despite recent advances in our understanding of environmental change and biodiversity responses to human disturbance, there are widespread uncertainties about the quality and reliability of information produced by ecological studies, which can be strongly influenced by (among other things) variable selection processes, inadequate sampling methods and biases in data analysis and interpretation (Guisan & Zimmermann 2000; Mac Nally 2004, 2005; Vaughan & Ormerod 2003). In particular, studies may fail to find significant effects if they focus on inappropriate response metrics (Barlow et al. 2007; Su, Debinski, Jakubauskas & Kindscher 2004), while interpretation of results can be confounded if researchers fail to capture the components of environmental variability that have the strongest influence on the biodiversity of interest. In both cases, such studies could easily reach misleading conclusions about the distribution and dynamics of biodiversity in human-modified landscapes, which in turn may have important consequences for policies and management recommendations aiming to safeguard the availability of ecosystem services and biodiversity.

Here we are interested in investigating researcher's choices of environmental explanatory and biodiversity response variables using dung beetle research papers and researchers as our study system. Dung beetles have been increasingly used to assess and monitor environmental changes in tropical forest ecosystems (Bicknell et al. 2014, Favila & Halffter 1997; Gardner et al. 2008; Halffter & Favila 1993; Nichols, Gardner, Peres & Spector 2009) and have been considered good ecological disturbance indicators (Barlow et al. 2010; Nichols & Gardner 2011). Their sensitivity to alterations in habitat structure, (micro) climate and natural environmental gradients is well documented in the literature through studies conducted worldwide (Jay-Robert & Marquez-Ferrando 2013; Menendez, Gonzalez & Somarriba 2006; Nichols et al. 2007) and across habitats under several different management regimes (Beiroz et al. 2014; Harvey, Gonzalez & Somarriba 2006; Korasaki et al. 2013; Neita & Escobar 2012; Spector & Ayzama 2003; Vieira, Louzada & Spector 2008). Dung beetles also play important ecological roles (Nichols et al. 2008), present different morphological and behavioural traits (Foley et al. 2005) and a relatively stable taxonomy (Philips, Pretorius & Scholtz 2004). We restric our analysis to the forested regions of the tropics, because (1) they have suffered some of the most severe land-use changes in recent decades (Hansen et al. 2013), (2) they are the richest reservoirs of the world's terrestrial biodiversity and hold the highest diversity of dung beetles (Nichols & Gardner 2011), and (3) they are where the majority of dung beetle studies have been conducted (Nichols & Gardner 2011).

We examined the choices researchers make by assessing the degree of correspondence between theory and practice in studies of the effects of land-use change on dung beetle communities in the tropics. To do so, we compiled information from a literature review and a structured survey of the authors of 48 different studies. This allowed us to compare the response and explanatory variables considered by researchers as most appropriate for understanding dung beetles' responses to land-use change with those variables actually selected and used by the same researchers in their published work. Variable selection processes were assessed separately for forested habitats and open agricultural lands because these systems are structurally divergent, host significantly different dung beetle communities and therefore should be driven by different environmental predictor variables. We also assessed justifications given for selecting certain variables and study design choices by researchers. We used this information to address the following questions: (1) To what extent are the response and explanatory variables deemed most appropriate by researchers actually being selected in published studies? (2) To what extent is the variable selection and study design processes clearly justified, and, if so, what kind of justification is presented in published work? We use our results to discuss some of the systemic problems in drawing ecological inferences from biodiversity and land-use change studies.

Material and Methods

We compiled information through a two-stage process. First, we undertook a literature review to identify the variables commonly selected in published studies, and to assess studies' justification level. Second, we surveyed the authors of the reviewed studies to identify the relative importance of variables according to researchers' opinions. Because dung beetle communities exhibit marked differences between forested habitats (e.g. primary and secondary forests, Eucalyptus sp.

plantations and shaded coffee) and open agricultural lands (e.g. soya plantations and pasturelands) and are unlikely to present similar responses to a single factor (Nichols et al. 2007), the information was analysed separately for both land-use types.

Literature search and papers' selection criteria

We searched ISI Web of Knowledge and Science Direct (accessed on 15 November 2013) using the following keywords: ((‘Tropical Forest' OR ‘Rainforest' OR ‘Deciduous Forest' OR ‘Dry Forest') AND (‘Dung Beetles' OR ‘Scarab*')). The search returned a total of 815 studies. From this total, we retained the papers addressing variations in dung beetle communities attributes (e.g. richness, abundance, composition and biomass) between two or more land-uses. Therefore, we excluded those focused on single species, on a single land-use (e.g. forest fragments of different sizes) or not focused on dung beetle communities' responses to land-use change (e.g. Nummelin 1998). We also excluded studies not conducted on tropical forests.

In order to avoid pseudo replication and maintain independence between studies, where two or more papers were based on the same dataset, we considered only the study published in the journal with the highest impact factor. We assume these studies represented the main findings of the work, and higher impact journals should also help ensure careful peer review and greater scientific influence. Finally, we disregarded papers on functional ecology (i.e. studies focused on seed dispersal and burial, flight activity, feeding behaviour) because the response variables usually are generally attributed to the functional groups (e.g. richness and abundance of traits of group x, y and z) rather to the entire community. Following all the criteria above, we selected 48 papers for analysis (Table S1).

Variables identification and grouping

Each paper was carefully revised for the identification and categorization of the response and explanatory variables presented. For each habitat type, variables were grouped into different categories to reflect their main use. For example, 'total species richness' and 'average species richness' were grouped into the category 'Species richness', while 'basal area of large trees' and 'canopy cover' were grouped into 'Forest structure'. Explanatory variables were grouped in a way that there were different categories according to their use for providing indirect measurements of resources availability (e.g. mammal abundance and biomass) or for describing environmental conditions at local (e.g. forest structure and local disturbance history), landscape (e.g. amount of forest in the surrounding landscape) or temporal (e.g. temporal pattern of forest loss in the surrounding landscape) scales. In total, we evaluated seven different categories of explanatory variables for open agricultural lands and eleven categories for forested habitats, due to a higher diversity of variables selected in these habitats. For response variables, we used seven categories for both habitat types. The full list of categories is presented in the Table 1.

Study design choices

We reviewed the papers to identify information about study design choices that can affect the reliability of ecological data collected. The evaluated choices were related to information about study area, sampling effort and sampling methods (Appendix A, Supplementary material).

Assessment of studies' justification level

We reviewed the 48 published papers to identify any justifications for variable and study design choices, providing a conservative measure of the description of the reasons underpinning these choices. Justifications were quantified based on presence-absence, and were considered as present when authors provided at least a justification for at least one of the variables or study design choices, irrespective of how detailed it was. Therefore, there was no distinction between studies that justified all the response and explanatory variables choices and studies where only one or few of the response and explanatory variables choices were justified. Justifications were categorised as follows: (1) available literature – when authors provided references to support their choices, (2) methodological constraints – when authors use the lack of logistical/financial resources, inadequacy of methods or impossibility of performing a specific choice as justification, and (3) researcher experience – when authors justify their choices based on previous research experience.

Survey of dung beetle researchers

The authors of the 48 focal studies were emailed a short survey containing a list of response and explanatory variables. Presented variables were selected based on their use in studies of the effects of land-use change on dung beetles and/or for being expected by experts to exert influence on dung beetle communities in modified habitats. Respondents were asked to rank the variables according to their relative importance. Variables were ranked separately for forested and open agricultural lands, and the ranks ranged from one (least important) to seven or 11 (most important), depending on the number of variables considered in each land use (seven in open lands, 11 in forests). For our purposes, we calculated the mean of rank values attributed to each variable by respondents. Two specific questions were asked: (1) “In your opinion, what are the response variables that are likely to most adequately capture the effects of land-use change on dung beetle communities?” And (2) “In your opinion, what are the explanatory variables that most adequately describe variability in habitat quality (due to land-use change) for dung beetles?” Respondents were allowed to add and rank additional variables that may have been missed from the list. In order to avoid possible bias, variables were randomised in the lists and presented in a different order for each respondent. The full survey is available in the Appendix B (Supplementary material).

Results

Variable selection in publication

The 48 studies selected for review encompassed 21 different countries, with the highest number in Brazil and Mexico (11 and 10 studies, respectively) (Fig. 1). In total, we reviewed 48 studies that presented data sampled on forested habitats. The highest ranked response variables selected in these studies were: ‘Species richness’ (included in 94% of papers), ‘Community composition and/or community structure’ (70%), ‘Evenness and/or dominance’ (32%), ‘Biomass’ (30%) and ‘Diversity’ (30%), ‘Species-level abundance’ (10%) and ‘Body size’ (9%) (Fig. 2). The explanatory variables selected in studies in forested habitats were: ‘Forest structure’ (19%), ‘Landscape connectivity’ (9%) and ‘Patch size’ (9%), ‘Topography’ (6%), ‘Leaf litter’ (4%) and ‘Understory structure’ (4%), ‘Local disturbance history’ (2%) and ‘Mammal abundance and biomass' (2%) and 'Mammal diversity' (2%). No paper presented variables related to either 'Landscape history' or 'Soil', that featured in the author survey of variable importance for being expected to exert influence on dung beetle communities in modified habitats.

In total, we reviewed 29 studies that presented data sampled on open agricultural lands. The response variables selected in studies were: 'Species richness' (97%), 'Community composition and/or community structure' (72%), 'Biomass' (31%) and 'Diversity' (31%) and 'Evenness and/or dominance' (31%), 'Species-level abundance' (21%) and 'Body size' (3%). The explanatory variables selected in studies in open agricultural lands were: 'Land cover class' (100%) and 'Vegetation structure' (3%). No paper presented variables related to any of 'History of use', 'Intensity of use', 'Landscape connectivity', 'Topography' or 'Soil' (Fig. 2).

One fifth of the studies reviewed did not present any justification at all for either the variables or study design choices used. Only 28 percent of studies presented some justification for at least one of the response variables, and only 10 percent in the case of explanatory variables. A total of 72 percent of studies presented some justification for at least one of the study design choices. When presented, justifications were mainly based on available literature (64%), followed by researcher experience (22%) and methodological constraints (10%).

Variable importance assessed by author

More than half (25/48) of the authors we approached responded to our survey. The highest ranked response variables in terms of their importance for studies in both habitat types were 'Community composition and/or community structure', followed by 'Species richness'. 'Evenness and/or dominance' received the lowest rank (Fig. 2). The highest ranked explanatory variables for studies in forested habitats were 'Mammal abundance and biomass', 'Forest structure', 'Local disturbance history', 'Patch size' and 'Landscape connectivity'; for studies in open agricultural lands, highest ranked variables were: 'Land cover class', 'Intensity of use' and 'Vegetation structure'. According to respondents, 'Leaf litter' and 'Topography' are the least important explanatory variables (Fig. 2).

Discussion

To our knowledge, this is the first study to compare response and explanatory variables importance according to experts' opinions with the use of these same variables in studies about land-use consequences for biodiversity in the tropics. We used data from the tropical forest dung beetles literature as our test case and found that researchers overwhelmingly do not select the explanatory variables that they themselves deem to be most important for answering the questions they are trying to address, although they do commonly select what are perceived to be the most important response variables. We also show that published studies commonly lack any justification regarding the variable selections and study design choices made by the authors. These findings undermine our ability to explain the patterns of biological communities responses to land use change that are reported in many dung beetles studies, and, assuming that there is no a priori reason why dung beetle studies should be systematically different to the treatment of other taxa, on biodiversity studies of land use change in general. The shortcomings we have identified reveal some important concerns about the adequacy of the design, implementation and publication of ecological studies about the consequences of land-use change to biodiversity.

Why are researchers failing to include in their studies the most important explanatory variables?

We identified three main reasons for this. First, obtaining information about some variables and/or processing these data in the appropriate way may be too expensive and/or too time consuming for projects' budgets and schedules. Despite the fact that dung beetles surveys are usually quick and cheap to conduct, measuring some of the explanatory variables deemed to be important can require either a relatively high investment of resources (e.g. acquiring remote sensing data to asses patch size, local disturbance history, landscape connectivity and intensity of use) or long periods of time for data processing, for example due to the difficulties in assessing specialists necessary to the study (e.g. plant species identification, Gardner et al. 2008). As such, unless researchers have access to sufficient resources and time, they end up having to choose between using inadequate measures (e.g. using gross measurements or categories, poor quality image or less field expeditions) or disregarding important variables.

Second, the use of land cover classes as the primary explanatory variable of interest offers an appealing "quick fix" to a study of land-use change effects. Making simple comparisons of species diversity between major land-use types allows comparison with the vast majority of published works, and allows researchers to use categorical variables as proxies for the whole suite of changes that may be too numerous to measure. Furthermore, it is much easier to find significant statistical differences between categories of land-use that are markedly different, than to understand what is happening within any given land-use in response to changes in more fine-scale predictor variables. In keeping with this, the majority of the studies we examined did not explicitly attempt to understand the processes that may be linked to finer-scale patterns of environmental heterogeneity, but were largely concerned with understanding broad patterns.

Finally, potential mismatches between the spatial scale of a given study and the spatial scales that describe much of the heterogeneity in explanatory variables may limit the variables that are selected. In particular, it could be challenging to link small-scale variation in the occupancy and abundance of dung beetles to the distribution and activity patterns of mammal communities that play out at much larger spatial scales (Nichols et al. 2009).

As a result of the combined effect of these three reasons, researchers opted to use only land cover classes to explain observed variability in biodiversity patterns in 80 percent of the studies reviewed. This dependence on land cover classes as the main explanatory factor means that we are lacking important information about variables that are very likely to exert a strong influence on dung beetles communities – a limitation that is also common to other taxa (e.g. amphibians and reptiles, Gardner, Barlow & Peres 2007).

Neglecting such variables could lead researchers to risk drawing misleading or spurious conclusions about species environment relationships, even when using meaningful response variables. For instance, changes in dung beetles diversity as a consequence of changes in mammal populations (e.g. due to overhunting) – and hence the availability and composition of dung resources – may have been erroneously attributed to a direct effect of habitat fragmentation (Nichols et al. 2009). Declines in mammal populations could also help explain the low levels of dung beetle species diversity in relatively un-fragmented areas of forest. Moreover, it could help explain observations of similar dung beetles communities between different land-uses (e.g. Estrada & Coates-Estrada 2002). In spite of the potential confounding influence of changes to mammal populations in disturbed and non-disturbed habitats on dung beetle communities, we found only two papers where authors attempted to sample differences in the diversity of both groups of organisms (i.e. Barlow et al. 2010; Estrada & Coates-Estrada 2002) – both of which were suggestive of a strong link between mammals and dung beetles.

The worrying implications of the inconsistencies we have observed between the stated importance of different variables and their occurrence in the literature are further exacerbated by the general lack of any form of justification for study design choices and variable selections in published papers. Almost all researchers failed to provide a biological or methodological explanation for their selection of response and explanatory variables, and provided justification for only a few of their study design choices. This lack of explicit justification prevents readers from understanding whether the choices made by researchers were based on biological and/or statistical understanding, projects constraints or simply based on arbitrary decisions (Jackson & Fahrig 2015).

Conclusion

While exposing some of the problems and difficulties of performing reliable assessments of land-use effects on biodiversity we reinforce the importance of careful study design and variable selection, and the need for constructive spaces to exchange ideas on methods and approaches between researchers. We believe that the number and reliability of inferences from studies on land-use change could be improved if researchers follow a few basic recommendations for good practice. Perhaps most obviously, researchers should assess what they consider to be the most important variables based on their personal experience, theory and familiarity with other work on the subject (see Fig. 2). Wherever possible, researchers should also use and test the relative importance of these variables in their own research, or provide a careful explanation of why certain variables were included and others were excluded. Shared protocols would be useful to standardise research, and make it easier for newcomers to sample key variables of interest.

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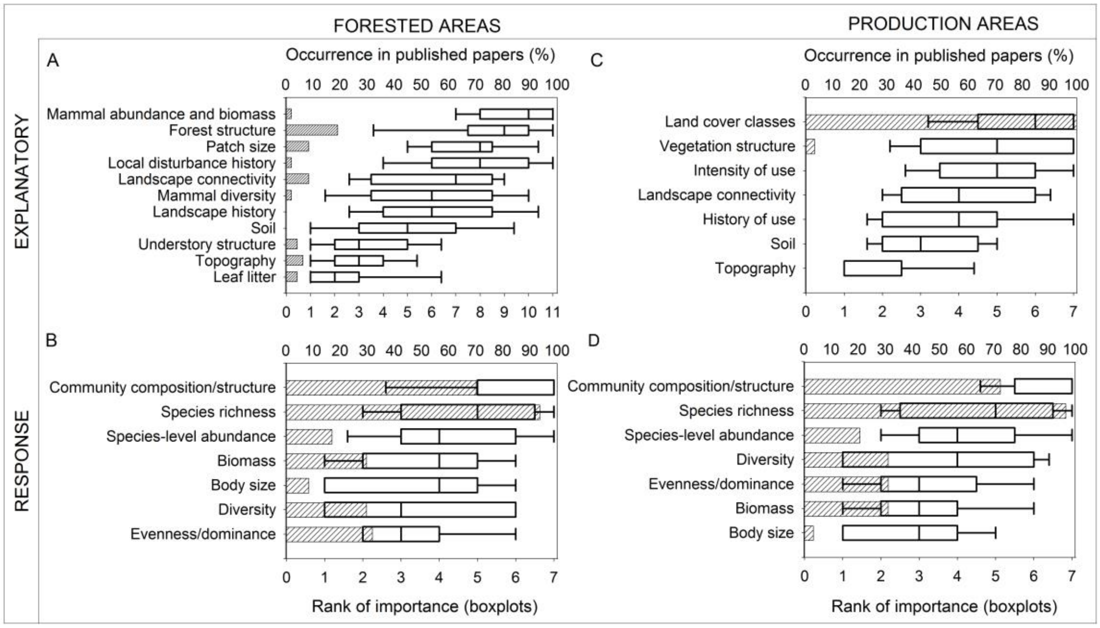
FIGURE LEGENDS

Figure 1. Studies occurrence by country. From light grey (no study) to dark grey (11 studies), colours correspond to the amount of studies about the effects of land-use change on dung beetles communities in tropical forests that were reviewed in this study.

Figure 2. The relative importance of response and explanatory variables according to both dung beetle researchers opinions and the occurrence of the same variables in the literature published by the same authors regarding the effects of land-use change on dung beetle in tropical forests. The rank of importance attributed to the explanatory (A, B) and response (C, D) variables relating patterns of dung beetles diversity to environmental change (boxplots), and the percentage of studies that actually selected each of the recommended variables for use (bar-plots) are represented for both forested habitats (A, C) and open agricultural lands (B, D).

411 **Fig. 1.**

Fig. 1.



FORESTED AREAS
PRODUCTION AREAS
EXPLANATORY
RESPONSE
A
B
C
D
Occurrence in published papers (%)
0 10 20 30 40 50 60 70 80 90 100
Mammal abundance and biomass
Forest structure
Patch size
Local disturbance history
Landscape connectivity
Mammal diversity
Landscape history
Soil
Understory structure
Topography
Leaf litter
0 1 2 3 4 5 6 7 8 9 10 11
Land cover classes
Vegetation structure
Intensity of use
Landscape connectivity
History of use
Soil
Topography
0 1 2 3 4 5 6 7
Community composition/structure
Species richness
Species-level abundance
Biomass
Body size
Diversity
Evenness/dominance
Rank of importance (boxplots)

Fig. 2.

TABLES

Table 1. Summary of the response and explanatory variables categories used for assessing variables selection in studies about the effects of land-use change on dung beetle communities in tropical forests.

Variable category	Habitat type	Example
Response variables		
Body size	Forested habitats and open agricultural lands	Average body length
Biomass	Forested habitats and open agricultural lands	Total biomass; Average biomass
Community composition/structure	Forested habitats and open agricultural lands	Community similarity based on Jaccard, Bray Curtis or other indices
Diversity	Forested habitats and open agricultural lands	Shannon and or Simpson's indices
Evenness and or dominance	Forested habitats and open agricultural lands	Pielou's evenness
Species-level abundance	Forested habitats and open agricultural lands	
Species richness	Forested habitats and open agricultural lands	Total number of species; Average number of species
Explanatory variables		

Soil	Forested habitats and open agricultural lands	Nutrient status, structure and humidity
Topography	Forested habitats and open agricultural lands	Altitude and slope
Forest structure	Forested habitats	Basal area of large trees; Canopy cover
Landscape connectivity	Forested habitats	Amount of forest in the surrounding landscape; Distance to the nearest source population
Landscape history	Forested habitats	Temporal pattern of forest loss in surrounding landscape
Local disturbance history	Forested habitats	Logging and fire history
Leaf litter	Forested habitats	Leaf litter depth
Mammal abundance/biomass	Forested habitats	
Mammal diversity	Forested habitats	
Patch size	Forested habitats	Patch area; Distance to the edge
Understory structure	Forested habitats	Density of small stems
History of use	Open agricultural lands	Time since deforestation or clear cut; Previous uses
Intensity of use	Open agricultural lands	If mechanised agriculture of received chemical inputs

Land cover class	Open agricultural lands	Agriculture; Pasture
Landscape connectivity and proximity to natural features	Open agricultural lands	Distance to the nearest source population
Vegetation structure	Open agricultural lands	Density of shrubs or weeds