Dynamics of biodiversity change after deforestation

Dinámica de cambios de diversidad después de deforestación

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Abstract
The many changes that forests have suffered over the last century have led to biodiversity loss around the planet. In order to understand these processes and try to predict future biological diversity loss, spatial comparisons have commonly been used. This research uses spatial and temporal data aiming to understand better the dynamics of these changes caused by deforestation. A meta-Analysis was conducted compiling information from 13 studies using before-after-control-impact design (BACI) to examine abundance response to deforestation. The results show clearly that biodiversity tends to decline in the five years after forest loss, though losses are not significant within the first two years. It was also found that the effects of deforestation on species abundance varied significantly among taxonomic groups, physical level species occupy in the ecosystem, type of disturbance, type of perturbation, and constancy in the surveys. The outcome of this research agrees with results of studies with spatial comparisons, though it is not yet possible to conclude which is best to predict biodiversity changes. However, these findings deepen our understanding of the complexity of biodiversity change and deforestation and emphasize importance of generating more studies that include temporal data.
Keywords: Biodiversity, BACI, Changes, Deforestation.

Resumen
Los cambios que han sufrido los bosques en el último siglo han conducido a pérdida de diversidad en el planeta. Para entender estos procesos y tratar de predecir pérdidas de diversidad biológica generalmente se utilizan comparaciones espaciales. Esta investigación usa datos temporales y espaciales para entender mejor la dinámica de estos cambios causados por deforestación. Se realizó un meta-análisis con información de 13 estudios con diseño Antes-Después-Control-Impacto para examinar la respuesta de la abundancia de los organismos ante la deforestación. Los resultados muestran claramente que la biodiversidad tiende a declinar en los cinco años después de la pérdida de un bosque, aunque esta no es significativa hasta los primeros dos años. También se encontró que los efectos de la deforestación sobre la abundancia de las especies variaron significantemente entre los grupos taxonómicos, a nivel físico, tipo de perturbación, tipo de alteración, y constancia en los muestreos. Los resultados de esta investigación tienen similitudes con los resultados de estudios con comparaciones espaciales, por tal razón, no se puede determinar cual enfoque es el mejor para entender y predecir cambios en biodiversidad. Estos hallazgos ayudan a comprender la complejidad e importancia de generar más estudios usando información temporal.
Palabras claves: Biodiversidad, BACI, Cambios, Deforestación.

Introduction

The pressure from anthropogenic actions, including deforestation, is threatening the planet's biodiversity (Aronson et al., 2014; Fahrig, 2003; Sala et al., 2000). In the last century, forests have suffered extraordinary rates of degradation and destruction caused by human activities (Morris, 2010; Krauss et al., 2010). We can use these human threats along with other ecological divers as good predictors of declining species diversity (Mace et al., 2010; Morris, 2010). It is, therefore, essential to know and understand them, to create new policies and reduce the possible damage (Chomitz & Gray, 1995; Dornelas et al., 2012). In general,

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reducing the damage is important because directly or indirectly we depend on the services provided by ecosystems (e.g., food, fuel and medicines) to survive (Mace et al., 2010).

The effects of negative anthropogenic actions on biodiversity can differ depending on the taxa, geographic region and trophic level (Gibson et al., 2011; Krauss et al., 2010). In ecosystems, while some species decline in abundance, some others that are more resistant to changes increase in abundance. For example, species at high trophic levels decrease because they are more vulnerable as those have small population sizes (Mace et al., 2010; Newbold et al., 2013). Regarding geographical region, the flux in biodiversity as a response to land use changes differs between continents, mainly caused by the intensity of the pressures generated on every continent (Phillips et al., 2017). As an example, Ernst et al. (2006) showed that amphibian species richness in West Africa was not affected by logging, whereas in South America it was.

Similarly, taxa differs in their vulnerability to extinction (Owens & Bennett, 2000 and Basset, 2001). For example, generalists and migratory birds show no reduction in abundance and in some cases are even benefited by habitat modification, probably caused by the availability of a particular resource, preference to open areas, or migratory behaviour (e.g. Newbold et al., 2014; Garrison et al., 2005; Navedo & Masero, 2008; Dickson et al., 2009; Kotliar et al., 2007). In contrast to this, specialists, larger long-lived and non-migratory birds typically show decreases as a result of human disturbances (e.g. Newbold et al., 2013; Lindenmayer et al., 2009; Bicknell et al., 2015; Hache at al., 2013; Barlow & Peres, 2004). Mammals are considered one of the most vulnerable groups to habitat loss (Bright, 1993) and, as in birds, few specialists are unlikely to exist in non-primary habitats (Newbold et al., 2014).

A similar pattern occurs in other animal groups. Among arthropods, species in Coleoptera are more sensitive on average than those in Hymenoptera or Lepidoptera, according to a global meta-analysis of tropical forests (Gibson et al., 2011). Open areas may benefit reptiles and amphibians, explaining why they are more abundant in urban areas or secondary forests than in primary forest in another pan-tropical analysis (Newbold et al., 2014). In order to understand such patterns, we need to evaluate not only spatial but also temporal dynamics (Songer et al., 2009). At present, quantifying how natural and anthropogenic disturbance cause biodiversity to change through time is challenging (Mace et al., 2010; Loh et al., 2005). However, it seems necessary because time series potentially provide a better perspective of temporal trends.

Time series data are essential to understand how these changes are happening, what their causes are and their future consequences too (Dornelas et al., 2012). So knowing the history of the place of study may be necessary to detect patterns of change in the ecosystem that will be indispensable to produce good predictions (Ernst et al., 2006; Krauss et al., 2010).

While analysing the time information and detecting the changes that occur, we must be aware of the real causes of the variations in biodiversity and do not assume that they are all results of human affectation. Some apparent changes can arise from errors in the research methodology and not by anthropogenic or natural actions (Underwood, 1992). Once such mistakes have been recognized and minimized, we need to identify correlation patterns between the changes in biodiversity and the possible predictors, to predict future changes in biological diversity (Dornelas et al., 2012).

Temporal information has some characteristics that bring both undoubted advantages and disadvantages. One of the primary benefits is that time moves in one direction and thanks to this feature, based on the principle of causality, we can make stronger inferences about the future. Furthermore, time is one-dimensional, meaning that data in a time series is related to the past (what caused it) and the future (what it will produce) in just one dimension, making it easier to investigate in contrast to space, which is three-dimensional (Dornelas et al., 2012). It is also important to note that past events will not happen in the future exactly as they already did, but we can use them to understand how life on Earth has reacted to drastic change events for the purpose of mitigating and avoiding loss of biodiversity.

Moving to the disadvantages, there are fewer time series than spatial comparisons for several taxa and ecosystems in the world (Loh et al., 2005), to overcome this; researchers must be opportunistic and decide which existing information is going to be adequate. For this purpose, we can use various sources of information such as chronological sequences or historical records (Dornelas et al., 2012). Also, it is well known that the number of organisms varies from time to time by natural causes. A potential human impact in the ecosystem is not always the cause of the changes (Underwood, 1992). For this reason, some authors (e.g., Underwood, 1991 and Stewart-Oaten et al., 1986) suggested that a study design with multiple samples (control and impact sites) as well as temporal sampling is necessary before and after a potential impact occurs (BACI design).

The PREDICTS Project (Projecting Responses of Ecological Diversity in Changing Terrestrial Systems, http://www.predicts.org.uk/) and other studies (Ewers et al., 2015, Gibson et al., 2011) have focused on spatial rather than temporal comparisons to understand local and global biodiversity change. They had inferred a continued decrease in global biodiversity whilst analysis of time series (Dornelas et al., 2014, Vellend et al., 2013) infers an unclear change. It is important to clarify which approach explains better the changes in ecosystems and if the time series data available is representative enough to infer significant changes.

As part of The PREDICTS Project, this research focuses on temporal rather than spatial comparisons, with a particular interest in deforestation using BACI design. With this approach, and taking into account what previous authors have said, the current changes in biodiversity are expected to get a better understanding of it. Also, comparing the outcomes with the results from spatial comparisons could help understand the differences between this two approaches.

For all the reasons above, a meta-analysis aiming to capture all the information published with BACI design was performed. Since the 1990s, different fields, including ecology, have been using Meta-analyses (Boreinstein 2009). In general, these analyses are used to synthesize research findings, quantifying the relevant results from multiple studies which are addressing the same question (Arnqvist and Wooster, 1995). These results can be aggregated and compared showing an indubitable use in research. Also, one of the most significant advantages of meta-analyses is the possibility of performing them with few studies (Viechtbauer 2010), acting as a powerful tool for researchers in less studied areas.

Overall, human activities are affecting species in different ways throughout the world which end up producing global biodiversity declines. In order to understand this process better, provide more accurate predictions and generate policies to try to reduce future biodiversity loss, the focus of this research is to analyse and understand temporal changes as well as the drivers that lead to decreases in biodiversity such as taxonomic, trophic and ecosystem strata levels, type of human perturbation, spatial and temporal constancy of sampling, continent and climate. This meta-analysis is performed to address the questions: How is biodiversity changing over time after deforestation? And which are the main factors that drive biodiversity changes caused by deforestation?

Materials and methods

All analyses were conducted using R 3.2.2 (R Core Team, 2015).

Literature search and data compilation.

A literature search of studies of biodiversity change caused by deforestation was conducted through searches using Web of Knowledge with a combination of words in English and Spanish with the intention of capturing studies from non-English speaking countries. The following Keywords were used: [Land use*] AND [baci OR Before-After-Control-Impact] AND [forest] AND [fire OR logging OR deforestation OR anthropogenic] AND [biodiversity] AND [Antes-Despues-Control-Impacto OR ADCI] AND [bosques] AND [diversidad] AND [perdida]. The reference lists of relevant articles was also searched. Studies were only included in this analysis if they had at least one site without anthropogenic impact (control) and one site where with a land-use change (impact). Studies also had to report at least one year before, and one after any impact occurred. These studies also had to report at least one ecological measure such as Abundance or Species Richness, sample size and include the Standard Deviation (SD), Coefficient intervals (CI) or Standard Error (SE).

Categorical Moderators

Different categorical moderators were selected to test if they had any significant effect on the abundance variation. Species were classified into two taxonomic levels. First, a higher level: vertebrates, invertebrates, and plants. Second, a lower taxonomic level splitting vertebrates in birds, mammals, amphibian and reptiles. Because of the small amount of available data in the collected papers, for this second classification, invertebrates (arthropods: insects and arachnids) and plants were not sub classified.

Using the information of the species in each paper, and with the interest of testing other possible moderators, the trophic level they occupied in the food chain was classified. Organisms were classified as Producers, Herbivores, Small Carnivores and Carnivores.

Also, with the information reported by each author, the strata levels in which each species was living was considered, classifying them in Soil, if their habitat was below ground level, Ground, if they live in small vegetation forest, Herb if their habitat was between approximately 30 cm and 2.5 meters over the ground, and finally, Canopy, if they lived over the herb level (e.g. trees, branches, etc.) (Table 1).

The type of human perturbation was recorded as one of the following: Urbanization, fire, complete logging, a mix of fire and logging, or a selective harvesting. Furthermore, if these habitat alterations happened just one time, it was considered a pulse disturbance, and if it continually happened (e.g. annually harvesting) it would be classified as a press. This classification was considered because of the expected species response. When a pulse disturbance occurs in an ecosystem, a sudden change is likely followed by a recovery once the disturbance ceased; while with a pulse disturbance a permanently change is expected. (Glasby & Underwood, 1996)

Spatial and temporal constancy of the surveys was also taken into account to test if differences in the sampling method may produce diverse responses. For this reason, three categories were considered for spatial constancy: Constant, if the same area (size and geographical location) was sampled each year. Nearly, if one site or a few sites (depending on the length of

Table 1. Classification of strata levels used.

Strata level	Height
Soil	Below 0 m
Ground	0 to 30 cm
Herb	30 cm to 2.5 m
Canopy	Over 2.5 m

the study) were not sampled and not constant in the same area, if they wouldn´t have done the survey at the same plots each year. Similar to this, regarding on temporal constancy, four categories were classified: Calendar, when they sampled in the same calendar time each year (e.g. months or days); Season, if they sampled in the same season, being this category more flexible than the previous one; Nearly, if it were almost the same time each year but could not be classified as seasonal as they occurred in a different season, and finally, the last temporal category was not consistency in time.

The continent and climate information from each paper were also considered as moderators.

Data Treatment and Analysis:

The information was taken directly from the tables or complementary information of each study, information was not requested to the authors. If they only present the data in figures, the program *DataThief III. 2006* was used to extract it.

For each annual study, the mean abundance in control and impact sites were tabulated. The sample size (n) and Standard Deviation (SD) was also tabulated. If SD was not given directly in the study, it was calculated from the SE or CI.

The year information was recorded on a numeric scale, with zero being the year (or mean of years) before impact, and continuing an ascending scale for the next years. If the studies only recorded one mean instead of yearly data, the average point for the time series was calculated and recorded as the year because of the need for the analysis of having just one value each year.

The funnel scatterplot method was used to visualise publication bias and Egger's regression test to statistically assess the funnel plot asymmetry.

Variations in time:

To identify if there is any change (increase or decrease) in abundance between control and impact sites across time, meta-analysis was conducted. In the analysis, groups with high variance and smaller sample size received a lower weighting in the model, equal to where is the variance of the group effect size.

Pair-wise comparisons was made between abundance in control and impact sites. For this reason, studies without a control site were not considered for this research. The ratio of the two means was used as the effect size because of the sampling methods in the studies and a log transformation to maintain symmetry around zero (log response ratio). Response ratios are often used in ecology where the outcomes are binary data (e.g. events versus no events) measured on a physical scale. For each comparison the true effects were calculated, estimating them via weighted least squares being weights equal to $w_i = 1/ (vi + \hat{\tau}^2)$, where vi detonates the sampling variance and $\hat{\tau}^2$ the estimate of residual heterogeneity among the true effects (τ^2) (Viechtbauer, 2010). A negative effect size shows how the abundance decreases with time.

While analysing, cells with zero count can be problematic, and omitting studies where zero individuals were reported in any survey can introduce bias into the analysis, especially if these were the species with the most extreme responses. For this reason, the zero values in the data set were replaced by a small constant number (0.1) (as suggested by Martinson & Raupp, 2013 and Viechtbauer, 2010).

Because of the expected variation in the effect sizes between different studies, data was analysed using random-effects models instead of fixed-effects models. Random-effects models do not assume that true effect size is equal in each study (Borenstein et al., 2009). Also for ecological data, random-effect assumptions are more appropriated (Gurevitch and Hedges, 1999). Random effect model was fitted using Restricted Maximum-likelihood estimation (REML) (Raudenbush, 2009). The meta-analysis was conducted in the metaphor 1.9-8 R package (Viechtbauer, 2010). Distributional assumption of the data for each model was checked using probability plots (normal q-q plots).

A model simplification using backward stepwise selection was used. Each moderator was tested individually to see which one has significance effect on the abundance. After that, a full model was built including all these explanatory variables, and a set of models each missing one of the moderators. The model simplification was conducted and tested using Analysis of Variance (ANOVA) and Akaike's Information Criterion (AIC). For ANOVA, the full model with the next model that had just one less moderator was tested, if the p value was >0.05, one more variable was dropped and continue testing until p value was <0.05, meaning no more variables could be dropped. For AIC, all the models were tested together, the one with the lower value was the minimum adequate model (MAM).

Results

Egger's regression test did not reveal any evidence of obvious asymmetry in comparison of the control versus impact size (p= 0.456).

Time series showed a negative effect on the log-response ratio with an overall effect of -0.123 (95% confident intervals -0.199 to -0.047) that was significantly different from zero (p= <0.01) (Figure 1).

It was found that the effects of deforestation on the abundance of species varied by taxonomic group, physical level and type of disturbance. Taxa had different responses, the effect size is significantly positive among amphibians (estimate= 0.597; CI= 0.169 to 1.026; p=<0.01). Among the other taxa, only birds and arthropods showed a significantly different (more negative) effect size (estimate of difference= -0.7687; CI=-1.224 to -0.314; p=<0.001 and -0.633; CI= -1.129 to -0.137; p=<0.05) respectively. (Figure 2a).

Within physical levels, Canopy showed a negative effect size (Figure 2b; estimate= -0.210; CI= -0.367 to -0.053; p=<0.01). Among the other levels, ground level showed a significantly different (more positive) effect size (estimate of difference= 0.397; CI= 0.142 to 0.652; p=<0.01).

Urbanization was the only type of disturbance that had a significantly positive effect on abundance (estimate= 0.598; CI= 0.175 to 1.021; p=<0.01). Among the other types of disturbance, selective harvesting and complete logging showed significantly (more negative) effects sizes (estimate of difference= -0.823; CI= -1.272 to -0.373; p=<0.001 and -0.642; CI= -1.145 to -0.139; p=<0.05) respectively (Figure 2c).

The effect size among pulse studies is significantly more negative than among press studies (Figure 2d; estimate effect size=-0.397; CI= -0.766 to -0.029; p=<0.05). In spatial constancy, constant spatial surveys had a negative significant effect size (Figure 3a; estimate= -0.139; CI=-0.269 to -0.008; p=<0.05). Nearly constant space showed a significantly different (more positive) effect size (estimate of difference= 0.4741; CI=0.176 to 0.773; p=<0.01).

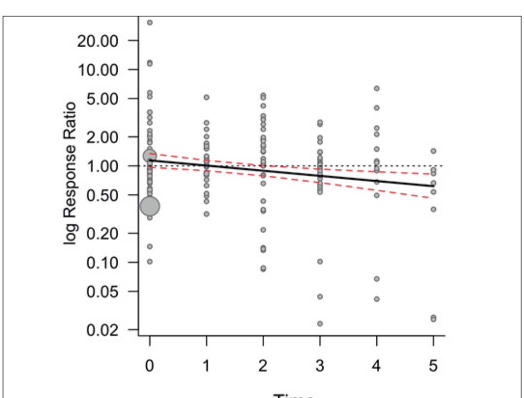

Figure1. Random-effects model – regression of log response ratio on time (years). Red dashed lines represent the ± 95% confident intervals

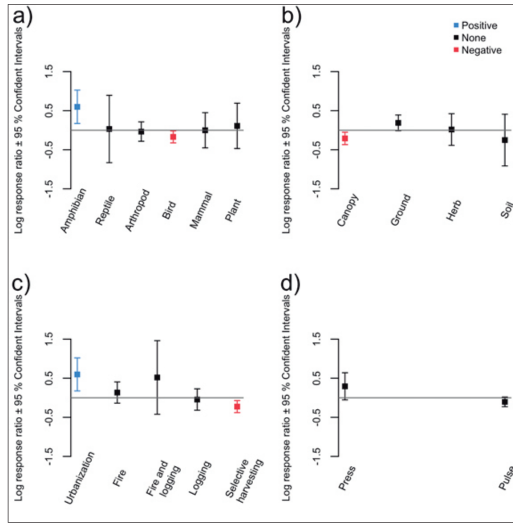

Figure 2. Response of species abundance (Log response ratio ± 95% confident intervals) to deforestation by a) taxa, b) strata in the ecosystem, c) Type of Disturbance and d) type of Perturbation. Log response ratios significantly greater than zero indicate higher abundance in impact sites compared to control sites (positive), whereas log response ratios significantly less than zero indicate the opposite (negative), and log response ratios not different from zero indicate no significant differences in abundance between sites (none).

The effect size among seasonal surveys is significantly different (more negative) than annual surveys (Figure 3b; estimate of difference= -0.461 CI= -0.731 to -0.192; p<0.001). Additionally, the other moderators did not show any significant difference, climate (p=0.271) continent (p=0.479), higher taxonomic group (p=0.814) and the trophic level (p=0.927).

Of the nine candidate models, the null model ranked last using AIC. The MAM included time series, type of disturbance, type of perturbation and spatial consistency in surveys.

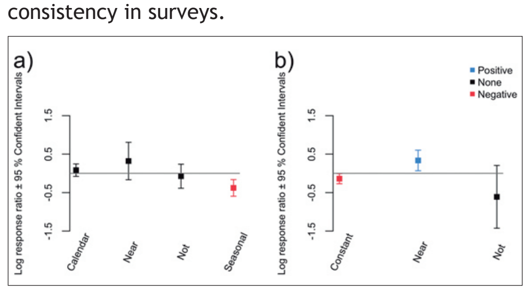

Figure 3. Response of species abundance (Log response ratio ± 95% confident intervals) to deforestation by designs with a) different Spatial Constancy, b) different Temporal Constancy. Log response ratios significantly greater than zero indicate higher abundance in impact sites compared to control sites (positive), whereas log response ratios significantly less than zero indicate the opposite (negative), and log response ratios not different from zero indicate no significant differences in abundance between sites (none).

Discussion

The results of the meta-analysis show clearly that biodiversity tends to decline in the five years after forest loss, though losses are not significant within the first two years. These results are relevant for an ongoing debate within conservation ecology, about whether biodiversity is showing a temporal trend. Analyses of assemblage time series (Dornelas et al., 2014; Vellend et al., 2013) suggest no overall trend, but the data used in those syntheses may have under-represented habitat loss (Cardinale 2014). It was shown that time series that include habitat loss do tend to show a reduction in diversity over time. The results are therefore consistent with suggestions that global species abundance is decreasing over time, despite the efforts of protecting species and ecosystems (Dirzo et al., 2014).

Time was a significant predictor of biodiversity changes in forests. However, the results corroborate the taxon-specific responses to deforestation reported by spatial comparison studies (e.g. Newbold et al., 2014). It was found that amphibians were the only taxonomic group with a positive effect over time. Similarly, Newbold et al. (2014) also suggest the increase of amphibians in human populated areas rather than secondary or primary forests.

As expected with forest clearance, birds were the most affected taxon probably caused by habitat requirements. Canopy openness can not only affect birds at the canopy level but also birds in the understory, primarily due to loss of resources (Basset, 2001). Burivalova et al. (2015) showed that birds' responses were not always immediate and can be long-lasting; this could be seen in the results where an effect was only observed after three years. There was no sign of recovery within the timescale of the studies in the dataset. Burivalova (2015) showed how most negatively affected species recovered 40 years after logging cessation, revealing the need of having very long time series to capture the temporal changes effectively.

According to Burivalova et al. (2015), the most significant predictors of shifts in bird abundance were the time since the most recent logging event, the feeding group and their interaction. Time since first anthropogenic impact was a significant predictor in the models as well, but trophic level was dropped during model simplification, perhaps because It was coded more coarsely (four levels rather than seven).

As explained by Tobias (2015), many species belong to multiple feeding groups, and they may change between groups over space and time. To address this possibility, future analysis should include more refined biological data such as moderators with more specific categories, as well as more specific data obtained in the field.

In general, deforestation is a direct driver of biological diversity loss, showing a negative effect on the abundance of many different taxa. More specifically, the type of disturbance was also an important explanatory factor in the MAM. Among the various causes of deforestation, urbanization was the only type that showed a positive effect. As seen in Table B1, there is only one paper about urbanization in the data set, which relates to changes in amphibian abundance; consequently, the data does not allow to distinguish between amphibians responding unusually or urbanization being unusual.

Although clear-cutting could be expected to be the most destructive process for many species, the results showed a significant negative effect only for selective harvesting. The possible reason to this might be related to taxon heterogeneity. Different species can respond differently to the same pressures (Winfree et al., 2015), so studying them at the higher taxonomic levels that were used might not allow detecting changes. Some species are more tolerant to changes (e.g.: generalist or migratory). If the taxa studied have species that resist these changes or can be benefited in clearcut areas, the overall abundance might not show significant responds to this type of disturbance. According to this, it would be sensible to include species as random effects in the models, however, it was not able to consider species as random effects due to the lack of multiple studies for the same species.

The type of perturbation was also a good explanatory factor of the changes in abundance over time. Press and pulse were significantly different from each other but contrary to what expected, pulse was more negative than press. A possible explanation to this could be the intensity of the human impact. If the press perturbations are of low impact while the pulse perturbations are of high impact, the type of results of this thesis could be explained. For this reason, future research should include a category of levels of affectation.

Underwood (1992) suggested that a study's design is crucial in determining whether or not the study can capture the real changes caused by human impacts. The results reveal the importance of: first, taking in account the best study design before starting the research; and second, considering them while modelling and predicting future changes in ecosystems. Overall, the different spatial consistency in surveys was a significant moderator in the MAM. Studies with spatial constancy showed the strongest effect (negative), while the random surveys had no effect. Suggesting the importance of having constancy in the surveys to capture better the effects.

Moving on to the interactions between sites and time, Underwood (1992) also argued that natural populations fluctuate from time to time and from different places. The model of interaction between sites showed significant differences through time and also between control and impact sites proving that having control sites to contrast could lead researchers to more accurate conclusions about the changes in biodiversity, as also suggested by Steen et al. (2015).

The biggest difficulty when trying to explain the response of different taxa to deforestation trough time is the research bias. Birds are one of the most studied taxa worldwide (Beissinger, 2000) as was observed in studies with BACI design. The majority of the studies were restricted to this taxon. Additionally, despite the efforts in the literature search, there is also a strong geographic bias lacking studies in tropical regions, maybe because of the complexity, time and costs they demand (Singh et al., 2003).

Another difficulty while using BACI designs is the small sample size within the studies. If we prove differences between sites it does not confirm that these are caused essentially by human impact, because naturally there are different patterns of temporal variation in populations between sites, for this reason, it is necessary to have several controls to contrast with (Underwood 1991). In this case, if the abundance at the impact site is different from the average of control sites, we can assume that the changes were caused by human impacts. Because BACI studies do not typically use multiple samples, the conclusions of these studies could be less precise.

The PREDICTS project has studied changes in biodiversity with spatial rather than temporal comparisons (Newbold et al., 2014). The results of both approaches are similar in the context of revealing different responses among taxonomic groups and in the response of species' abundance to land-use type. Despite the similarities in the results, analysing temporal data showed some advantages as well as disadvantages in comparison to spatial studies.

One of the disadvantages of time series is the complexity of planning researches across time, as was reported in many of the studies analysed. Overall, studies with spatial comparison are easier to conduct than temporal studies. In addition, when studying temporal data, it was common to observe that, in the same study, different researchers conducted the surveys across years. When this occurred, researchers tried to emulated the same methodology as used before showing difficulties in repeating the same plots every year since the first survey (spatial constancy). In contrast to this, surveys in space-for-time studies are easier to carry on as there is no need to repeat them over time.

Among the benefits, temporal data can provide information on how the biodiversity was before any human impact happened, and even give a trend before the changes occurred, helping to understand better the fluctuations in the ecosystem before and after any anthropic activity. On the other hand, working with space-for-time substitutions, researchers often infer or estimate this information. All these possible methodology errors could lead to several involuntary mistakes while using any of the two comparisons.
Generally, Space-for-time substitutions are widely used to predict changes in ecosystems across the world. Some studies, like the empirical test conducted by Blois et al. (2013) have demonstrated that, in some cases, space for time substitutions performed poorly compared to temporal data results. The main reason could be that ecosystems suffer different changes at different temporal rates triggered by diverse causes (natural or anthropic). However, spatial comparisons cannot capture these temporal linkages between the various stages in the ecosystems (Walker et al., 2010). For this reason, models using space for time substitution would not produce accurate predictions compared to models with temporal data.

Conclusions

1. The results of the meta-analysis show clearly that biodiversity tends to decline in the five years after forest loss, though losses are not significant within the first two years.

2. Time was a significant predictor of biodiversity changes in forests.

3. Despite the outcome of this research, it is not possible yet to decide which approach is better to understand and predict biodiversity changes. However, these findings help to understand the complexity and importance of generating more studies using temporal data.

Recommendations

As it was explained before, the small amount of data will always be a limitation when trying to understand multiple levels of interaction. Besides, the complexity of these interactions in ecosystems makes it even more challenging. It was considered sensible in this research not to try adding too many possible explanatory variables in the modelling process. Nevertheless, if more data is available, some other moderators could be important to consider in future researches.

Working with a control or various control sites to contrast them with the altered site could be useful, however, if these controls are too close to the impact sites, they could be influenced by the human disturbance and will not be acting as controls but as influenced area. For this reason, the distances between controls and impact sites should also be taken into account. Subsequent data examination showed that distances used by researchers cited in these study were 5.6 km in average.

Similarly, species local abundance is probably influenced by numerous biotic and abiotic factors (Price et al., 2012). For example, temperature, rainfall, relative humidity and duration of sunshine affects the abundance of moths (Intachat et al., 2001; Choi, 2008). Related to above, further studies should consider these parameters as explanatory variables.

Finally, Drapeau (2016) in a bird assemblages research evidenced that regions with few natural disturbances have species more sensible to reduction, suggesting that natural disturbances within the ecosystem history (e.g.: hurricanes, tsunamis, wildfires) could be important predictors. For this reason, studying them as possible explanatory factors could help making better predictions to create new policies that might reduce potential future damages.

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