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Patch size matters for amphibians in tropical fragmented landscapes

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ABSTRACT

Several factors may affect the persistence of amphibian species in tropical fragmented landscapes, including the size of remaining patches. While fragment size is considered the main factor acting on species diversity for most taxa, it is less clear how it affects amphibian diversity. A possible reason is that the scale at which previous studies were conducted was too small (only few forest fragments and/or a small range of fragment sizes considered) and/or the sampling method was not the most optimal one. We investigate whether amphibian diversity is affected by patch size in the largest study (in terms of number of fragments and range of fragment sizes) ever conducted in tropical forests. We predicted that larger forest remnants hold higher amphibian diversity compared to smaller patches, and that continuously forest sites were more diverse than forest fragments. We used the visual encounter survey method to collect data from 24 sites (21 forest fragments between 1.9 and 619 ha and three sites within a large continuous forest remnant) located in the Brazilian Atlantic Forest, a highly threatened biodiversity hotspot. We recorded a total of 2839 individuals from 50 species. In line with our predictions, larger fragments had more species, more integer communities and a larger diversity of reproductive modes than smaller ones. In addition, we found higher values for all diversity measures in continuous forest sites compared to fragments. These results indicate that continuous forests are irreplaceable for amphibian conservation, but also show that large forest fragments outside these areas are important for sustaining amphibian diversity. Our study provides robust empirical evidence for the importance of fragment size for amphibian persistence in tropical fragmented landscapes and highlights the need for an adequate sampling design and method that enable the detection of a higher number of species.

1. Introduction

The species–area relationship (SAR), which depicts how communities lose species with reductions in area, is one of the most studied patterns in ecology (Coleman et al., 1982; Franzén et al., 2012; Sutherland et al., 2013; Matthews et al., 2014). As most of the natural environment worldwide has been reduced to small and scattered patches of native cover, understanding how patch size affects species richness is important to ensure species' persistence in fragmented landscapes, especially in tropical areas where the diversity and endemism rates are extremely high (Gardner et al., 2009; He and Hubbell, 2011; Gibson et al., 2013; Brown, 2014). Although the SAR is well known, it is not clear why larger patches have higher species richness, and several alternative hypotheses have been proposed to explain this pattern (Fattorini, 2007; Báldi, 2008). For example, the most popular explanation is the equilibrium theory of island biogeography. This theory assumes that species richness in a given patch results from a dynamic equilibrium between immigration and extinction rates, which is highly affected by patch size (MacArthur and Wilson, 1967). According to the passive sampling hypothesis, larger patches have higher species richness due to probabilistic reasons, as more individuals can reach the patches through dispersal (Coleman et al., 1982). Finally, the habitat heterogeneity hypothesis predicts that larger areas will have higher species richness due to greater habitat heterogeneity (Williamson et al., 2001; Tews et al., 2004).

Several studies on a broad range of organisms including mammals, birds, lizards and plants have found support for positive SAR in tropical landscapes (e.g., Flores-Palacios and García-Franco, 2006; Vieira et al., 2009; Banks-Leite et al., 2012; Almeida-Gomes and Rocha, 2014a). However, it still remains unclear if patch size also matters for amphibian diversity in fragmented tropical landscapes. While some studies have found a positive effect of patch area on frog diversity, including species richness (e.g., Vallan, 2000; Bell and Donnelly, 2006; Lima et al., 2015), species abundance (Marsh and Pearman, 1997) and genetic diversity (Dixo et al., 2009), other studies have found negative or null

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relationships (e.g., Hillers et al., 2008; Lion et al., 2014, see Table 1). Possibly, the reason is that existing studies considered a small number of sampling units, examined the effect of a limited range in patch sizes, or did not use the most optimal sampling method, as this can limit the robustness of results on the importance of patch size for amphibian diversity (Gardner et al., 2007).

The Brazilian Atlantic Forest (BAF), one of the most important and threatened biomes worldwide, is currently reduced to around 12–16% of its original area. Most forest remnants are less than 50 ha and scattered in highly fragmented landscapes (Ribeiro et al., 2009). Yet, this hotspot of imperiled biodiversity (Myers et al., 2000) still contains high biological diversity and endemism rates for several taxa such as mammals (Costa et al., 2000; de la Sancha et al., 2014), birds (Banks-Leite et al., 2010; Uezo and Metzger, 2011; Martensen et al., 2012), frogs (Fusinatto et al., 2013; Toledo et al., 2014), insects (Ribeiro et al., 2010; Leal et al., 2012) and trees (Saiter et al., 2011; Magnago et al., 2014). For example, more than 500 amphibian species are found in the BAF, and most of them (approximately 88%) are endemic to this biome (Becker et al., 2007; Haddad et al., 2013; Almeida-Gomes et al., 2014b). In such a highly fragmented and threatened biome, understanding the role of patch size can be crucial to design appropriate conservation actions to ensure species persistence. To date, six studies investigated the effect of patch size on frog species diversity in the BAF, but observed effects of patch size were highly variable (Dixo et al., 2009; Metzger et al., 2009; Almeida-Gomes and Rocha, 2014b, 2015; Bittencourt-Silva and Silva, 2014; Lion et al., 2014; Table 1).

Our aim was to investigate how fragment size affects frog diversity in a tropical fragmented landscape. Most studies that have investigated the effects of habitat fragmentation on amphibians were performed in patches that varied in size (e.g., Alcala et al., 2004; Bell and Donnelly, 2006; Bickford et al., 2010), which is why we use a similar patch-scale approach in this study as well. To the best of our knowledge, our study contains the largest range of patch sizes (1.9 to 619 ha) and number of patches (N = 21) ever in tropical fragmented forest. We used the visual encounter survey method (VES), which is considered the most optimal method for amphibian sampling (Doan, 2003). We computed several metrics of amphibian biodiversity (e.g., species richness, community composition, and diversity of frog reproductive modes). We expected that larger forest remnants harbor more diverse communities and that biodiversity would be higher in continuous forest sites than in forest fragments.

Table 1
Summary of studies (in chronological order) that evaluated the effect of patch size on amphibian diversity in tropical disturbed landscapes. We used the keywords (fragment size* or amphibia*) and (fragment size* or anura*) and (fragment size* or frog*) and (patch size* or amphibia*) and (patch size* or anura*) and (patch size* or frog*) in the 'ISI Web of Science' database to find these studies. '+', '−' and '0' refer to positive, negative and null relationships between patch size and a measure of species biodiversity (between parentheses).

Study	Country	Habitat type	Number of patches (range)	Sampling method or data source	Effect of patch size
Zimmerman and Bierregaard (1986)	Brazil	Primary forest reserves	7 (1 to 500 ha)	Active search	+ (species richness)[1]
Marsh and Pearman (1997)	Ecuador	Forest fragments	5 (0.25 to 200 ha)	Visual encounter survey	+ (species abundance)
Vallan (2000)	Madagascar	Forest fragments	7 (0.16 to 1250 ha)	Visual encounter survey	+ (species richness) + (species diversity) − (relative individual densities)
Alcala et al. (2004)	Filipinas	Forest fragments	9 (5 to 122 ha)	Cruising and plots	+ (species richness)[2]
Pineda and Halffter (2004)	Mexico	Forest fragments, shaded coffee, pasture	10 (11 to 122 ha)	Time-constrained technique	+ (proportion of terrestrial species) − (proportion of arboreal species) − (percentage of species with aquatic eggs and larvae)
Bell and Donnelly (2006)	Costa Rica	Forest fragments	9 (1 to 7 ha)	Plots and visual encounter survey	+ (species richness)[3]
Hillers et al. (2008)	Liberia	Forest fragments	10 (1 to 48 ha)	Plots	0 (species richness)
Watling and Donnelly (2008)	Bolivia	Forest fragments	24 (0.6 to 8.5 ha)	Pitfall traps	+ (species richness of generalists)
Dixo et al. (2009)[a]	Brazil	Forest fragments	15 (1 to 50 ha)	Pitfall traps	+ (genetic diversity of one toad species)
Metzger et al. (2009)[a]	Brazil	Forest fragments	20 (2 to 276 ha)	Pitfall traps	+ (species richness)[4]
Bickford et al. (2010)	Singapore	Forest fragments	12 (11 to 935 ha)	Visual encounter survey	+ (species richness)[5]
Cabrera-Guzmán and Reynoso (2012)	Mexico	Forest fragments	6 (1.4 to 17.4 ha)	Visual encounter survey	+ (species abundance) + (species richness)
Almeida-Gomes and Rocha (2014a)[a]	Brazil	Forest fragments	12 (4.1 to 262.4 ha)	Visual encounter survey	0 (species richness)[6]
Bittencourt-Silva and Silva (2014)[a]	Brazil	Land-Bridge Islands	8 (30 to 34,830 ha)	Literature and online databases	+ (species richness)
Lion et al., 2014[a]	Brazil	Forest fragments	23 (1.7 to 30 ha)	Pitfall traps	0 (species richness)
Almeida-Gomes and Rocha (2015)[a]	Brazil	Forest fragments	12 (4.1 to 262.4 ha)	Visual encounter survey	+ (diversity of frog reproductive modes)
Lima et al. (2015)	Brazil	Land-Bridge Islands	10 (3 to 2140 ha)	Pitfall traps and visual encounter survey	+ (species richness)
Present study[a]	Brazil	Forest fragments	21 (1.9 to 619 ha)	Visual encounter survey	+ (species richness) + (community integrity) + (diversity of reproductive modes) + (proportion of forest specialist species)

[1] Positive correlation with species richness, but the diversity of breeding habitats seems to be the main factor acting on amphibian species distribution.
[2] Individuals of frogs, lizards and snakes together.
[3] Positive correlation with species richness, but primarily an effect of the largest two sites.
[4] Frog species richness was weakly related to past and present fragment area.
[5] Larger fragments had higher species richness, but breeding habitat heterogeneity best explained frog species diversity and abundance in forest fragments.
[6] Small effect on species composition.
[a] Studies conducted in Brazilian Atlantic Forest.