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Topography and soil type are critical to understanding how bird and herpetofaunal communities persist in forest fragments of tropical China

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ABSTRACT

Habitat fragmentation in heterogeneous landscapes is a non-random process, with farmers selecting lands with flat topography and fertile soils. To understand the persistence of biodiversity in forest fragments in such landscapes, it is necessary to distinguish between factors associated with fragmentation (e.g., area and distance to edge) and characteristics of where fragments are located (e.g., topography and soil conditions). Location factors have been previously demonstrated to be important in explaining the persistence of trees in fragments in the environmentally diverse region of Xishuangbanna, China (Liu and Slik, Biological Conservation, 2014). However, it is unknown how location factors influence more mobile, short-lived organisms. We sampled 42 of the previous study's plots for birds and herpetofauna across two years. A multi-model inference approach indicated that topography was the most important predictor of amphibian diversity, with valleys having more than three times the species in other locations. Topography interacted with fragment size for bird species, and particularly forest interior (FI) species: diversity in valley plots climbed strongly with fragment area, but the relationship between area and diversity was less strong in other locations. Soil type (limestone or not) most strongly influenced the score of plots on the first axis of a NMDS ordination of FI birds. These results suggest that managers should consider the location of fragments in the landscape in prioritizing forest fragments for protection. For Xishuangbanna, all valley fragments are important to protect amphibians; amalgamating them into large fragments > 1000 ha will make them most useful for bird conservation.

1. Introduction

Tropical forests host at least two-thirds of the earth's terrestrial biodiversity and provide significant human benefits at local, regional and global scales through the provision of economic goods and ecosystem services (Gardner et al., 2009); therefore, the threat posed by anthropogenic disturbance to tropical forests is a global one. Among many problems, deforestation, driven by agricultural expansion, logging and urbanization, is considered as the primary threat to biodiversity, and habitat loss is also accompanied by fragmentation and degradation (Fahrig, 2003; Haddad et al., 2015). Much research has focused on fragmentation, and specifically how fragment area, shape and isolation affect plant and animal survival (Ewers and Didham, 2006; Fahrig, 2003; Matthews et al., 2014) and how fragmentation affects ecological and evolutionary processes, as reviewed by Haddad et al. (2015). The major conclusion from this research is that large fragments and corridors between fragments should be priorities for conservation. At the same time, protection of even very small fragments can retain some elements of biodiversity (Arroyo-Rodríguez et al., 2009; Chang et al., 2013).

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In conserving fragments in heterogeneous landscapes, however, there are other considerations beyond the size, shape and isolation of the fragments (Liu and Slik, 2014). In a topographically complex area, there is a need to understand how the location of the fragments (hereafter referred to as 'location factors') – their topography (e.g., valley vs. ridge) and soil (e.g., limestone vs. other kind of bedrock) – might influence the biodiversity they can retain. This is because agriculture is a biased process with farmers selecting flat topography, fertile soils, and sunny aspects (Liu and Slik, 2014), and agricultural expansion will consequently produce greater threats to biodiversity in these preferred areas (Warren-Thomas et al., 2015). Recently Liu and Slik (2014) showed that location factors were more important than 'fragmentation factors' (area, distance to edge) in predicting persistence of trees in forest fragments in tropical regions of southwest China. But trees are long-lived species with stationary adults, and fragmentation was recent (mostly within 40 years; Li et al., 2008). Hence, many of the individuals sampled may have simply persisted from an earlier time before fragmentation. A remaining question is whether location factors also influence short-lived mobile organisms, such as birds or herpetofauna, the latter of which is known to be understudied in fragmentation research (Deikumah et al., 2014).

The importance of location factors may vary among animal taxa, depending on the organisms' degree of mobility, and the strength and breadth of their habitat preferences. For example, amphibians are reliant on certain microhabitats and their associated abiotic conditions, often related to the availability of water (Baldwin et al., 2006; Beebee, 1996). Moreover, amphibians in particular may have difficulty moving through matrix land-types outside of forests (Behm et al., 2013). These characteristics suggest that amphibians may be particularly influenced by location factors. Reptiles may share many of the same problems of amphibians, but not be as extreme in their preferences, as they are more resistant to desiccation (Bell and Donnelly, 2006); reptiles have also been shown to be dependent on structural complexity and vegetation type at the site level (Bruton et al., 2016). Birds are much more mobile and have been a major taxa of focus in the study of fragmentation (Bregman et al., 2014; Vargas et al., 2011). Nevertheless, birds may have strong habitat preferences at some life stages, such as nesting (Walsberg, 1985), and some groups of species, such as understory insectivores, have particularly rigid habitat requirements (Powell et al., 2015). In general, assessment of habitat requirements of species, and subsequent prioritization of land for protection, requires inspection of multiple taxa, especially when these are of high conservation concern, such as amphibians (Beebee and Griffiths, 2005), and forest specialist birds (Bregman et al., 2014).

Southeast Asia is especially threatened by anthropogenic change and has been recognized as a priority region for conservation (Wilcove et al., 2013). Conversion of forest to agricultural crops, such as oil palm (*Elaeis guineensis*), rubber (*Hevea brasiliensis*) and tea (*Camellia sinensis*), is a key driver that leads to biodiversity loss in the region (Warren-Thomas et al., 2015; Wilcove et al., 2013). For example, in Xishuangbanna Prefecture, in Yunnan Province, China, 50% of forest cover has been converted primarily to rubber monocultures between 1976 and 2003 (Li et al., 2008; Xu et al., 2014). Xishuangbanna is located on the northern border of Southeast Asia, and is considered part of the Indo-Burma biodiversity hotspot, designated as one of the 25 biodiversity hotspots in the world (Myers et al., 2000). Unfortunately, forest conversion to agricultural land in Xishuangbanna is still continuing (Xu et al., 2014). Xishuangbanna is also a highly heterogeneous environment, with an undulating terrain (517–2415 m asl; Yi et al., 2014), and patchily distributed limestone soils (Clements et al., 2006; Tang et al., 2011), and hence a suitable area to look for the effects of location factors (Liu and Slik, 2014).

Here we compared the influence of fragmentation and location factors for multiple animal taxa in Xishuangbanna. We hypothesized that (a) that herpetofaunal species would be the taxa most influenced by location factors, due to their strong microhabitat preferences. We also hypothesized that (b) birds would be influenced by a mix of fragmentation and location factors, as topography and soil type influence structural and floristic differences of forest stands in different fragments (Bohlman et al., 2008), that then shape bird communities (MacArthur and MacArthur, 1961; Reidy et al., 2014). We further hypothesized (c) that fragmentation factors would be especially important for specific groups of birds, particularly those known to be very sensitive ('forest interior species') or tolerant ('open area species') of human disturbance, and thus influenced by fragmentation factors such as area and distance to the edge (Matthews et al., 2014).

2. Methods

2.1. Study area

The study was conducted within a 15 km radius circle centered on Xishuangbanna Tropical Botanical Garden (XTBG, 21° 55′N, 101° 15′E), a research institute of the Chinese Academy of Sciences, located in the Menglun township of Xishuangbanna Dai Autonomous Prefecture, Yunnan Province, China (Fig. 1). Xishuangbanna is bordered by Laos from the south and Myanmar from the southwest and lies within tropical Southeast Asia, with some characteristics of the subtropics (Cao et al., 2006). The climate is mainly governed by two seasons: dry, from November to April, and wet, from May to October. The annual temperature varies from 15.1 °C to 21.7 °C; annual precipitation varies from 1193 mm to 2491 mm (Cao et al., 2006). There are a few large nature reserves, and the rest of the landscape is a mosaic of forest patches, varying in their sizes and shapes, scattered among rubber monocultures. Rubber represents the majority of the matrix, with developed areas and banana plantations being minor components near the town of Menglun. Rubber itself contains a low percentage (37%) of extant bird species in the region, with only generalists being abundant in it (Sreekar et al., 2016). In this landscape, Liu and Slik (2014) established a priori 50 vegetation sampling plots that captured a wide range of environmental conditions (topographical positions, soil types) and fragment sizes (see Fig. 1, Table S1). As there were multiple plots in the larger fragments, fragment identity was included as a random variable in the analysis (see below).

2.2. Animal surveys

We placed a bird point count station in 42 vegetation plots from Liu and Slik's (2014) study that are found within 18 forest patches ('fragments', size ranging 1.71 ha to 13,837.27 ha), and at elevations ranging from 541 to 1477 m asl. Of the original 50 plots, two plots were deforested before the sampling for this project. In addition, we removed from the analysis two plots that had < 0.79 ha of forested area (the area of a circle of 50 m radius, the size of the point count for birds), and four plots that were too small linearly to place a 200 m long transect (for herpetofauna) inside them.

A variable radius (with all birds seen or heard designated to 10 m radius intervals within 50 m) point count method was applied to survey birds (Bibby et al., 2000). All the plots were visited five times (dry season: March–May 2014, November–December 2014 and March–May 2015; wet season: July–August 2014 and August–September 2015) by the same observer (SKD). Point counts of 15 min in length were conducted between 0700 h to 1030 h, when most of the birds are highly active, and all birds visually or aurally detected were recorded. The order of plot visitation routines was varied to ensure that each plot was sampled both early (close to 0700 h) and late (close to 1030 h) to avoid time-of-day effects. Rain, high wind and thick fog were avoided during the data collection. Camouflage clothes were worn and SKD spent 2 min motionless prior to the point count in order to minimize bias related to his disturbance.

We established one 200×5 m transect at each of the same 42 plots to sample herpetofauna. The transects were placed on the access paths of the vegetation plots so that the minimum distance between the starting point of transect and the forest edge was 25 m for the small (< 100 ha) forest fragments ($n = 12$) and > 100– m for the other fragments, and the center of the transect was at the center of the bird point count station.

We conducted visual and auditory encounter surveys, which are the most effective sampling methods for herpetofauna (Doan, 2003). Two observers (SKD and one local assistant) walked down the midline of the transect for 1 h, gently disturbing the forest ground and shrub layer with a stick and searching visually for amphibians, lizards, geckos and