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Land-use heterogeneity by small-scale agriculture promotes amphibian diversity in montane agroforestry systems of northeast Colombia

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ABSTRACT

Habitat fragmentation, the transformation of interconnected large habitats into several small patches, is generally considered to have a negative influence on biodiversity. Management policies should therefore favour strategies that minimize fragmentation. We studied amphibian diversity and compositional patterns in a complex montane agroforestry matrix of north-eastern Colombia to assess whether small-scale agroforestry is a viable way of reconciling crop production, farming, and biodiversity conservation. A total of five different land-use systems, including natural cloud forest, were compared. We used standardized visual and acoustic transect sampling routines in combination with field-based habitat assessments to establish amphibian assemblage data sets and corresponding habitat templets. Data sets were analysed using classical species richness and diversity statistics in combination with multivariate procedures to address compositional aspects. PER(mutational) MANOVA models were applied to identify environmental and land-use type-specific drivers of shifts in assemblage composition. Results show that agricultural management has a strong influence on amphibian species richness and diversity. With the exception of high intensity cattle pasture, diversity was generally highest in agriculturally used sites particularly in shaded plantations. Species composition differed markedly between different land-use types, indicating that there was not a single best land-use type that supported all species. This highlights the need for a landscape approach to biodiversity conservation in fragmented forests and consequently requires refocusing on conservation in management units as well as in the matrix. In human modified montane forest landscapes small-scale agriculture that generates landscape heterogeneity should therefore be promoted to effectively safeguard biodiversity.

1. Introduction

Over the past decades, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history (MEA, 2005). As the worlds population grows, the demands for food, fresh water, timber, fibre, and fuel will continue to grow and thus particularly the need for agricultural land will increase (Foley et al., 2005, De Fries et al., 2010). In light of an unprecedented anthropogenically triggered loss of biodiversity, balancing these growing agricultural demands and the undisputable need to conserve global biodiversity represents a major challenge for the future (Phalan et al., 2011).

Agricultural systems can differ strongly in structure, degree of natural habitat consumption, and the amount of biodiversity retained after land-transformation (Altieri, 1999). Very uniform agroecosystems, e.g. pastures or monocultures, have been shown to exhibit very low levels of biodiversity at various trophic levels (Altieri and Nicholls, 2004; Rudel et al., 2005). More complex agroecosystems, on the other hand, can have the potential to meet human needs for food and fuels, restore soils, and even contribute to biodiversity conservation, if managed in a sustainable way (Isbell et al., 2017).

A prominent example for diversified and more complex agriculture, particularly in the tropics, is a land-use system commonly known as agro-silviculture or agroforestry (Nair, 1993; Schroth, 2004). The role

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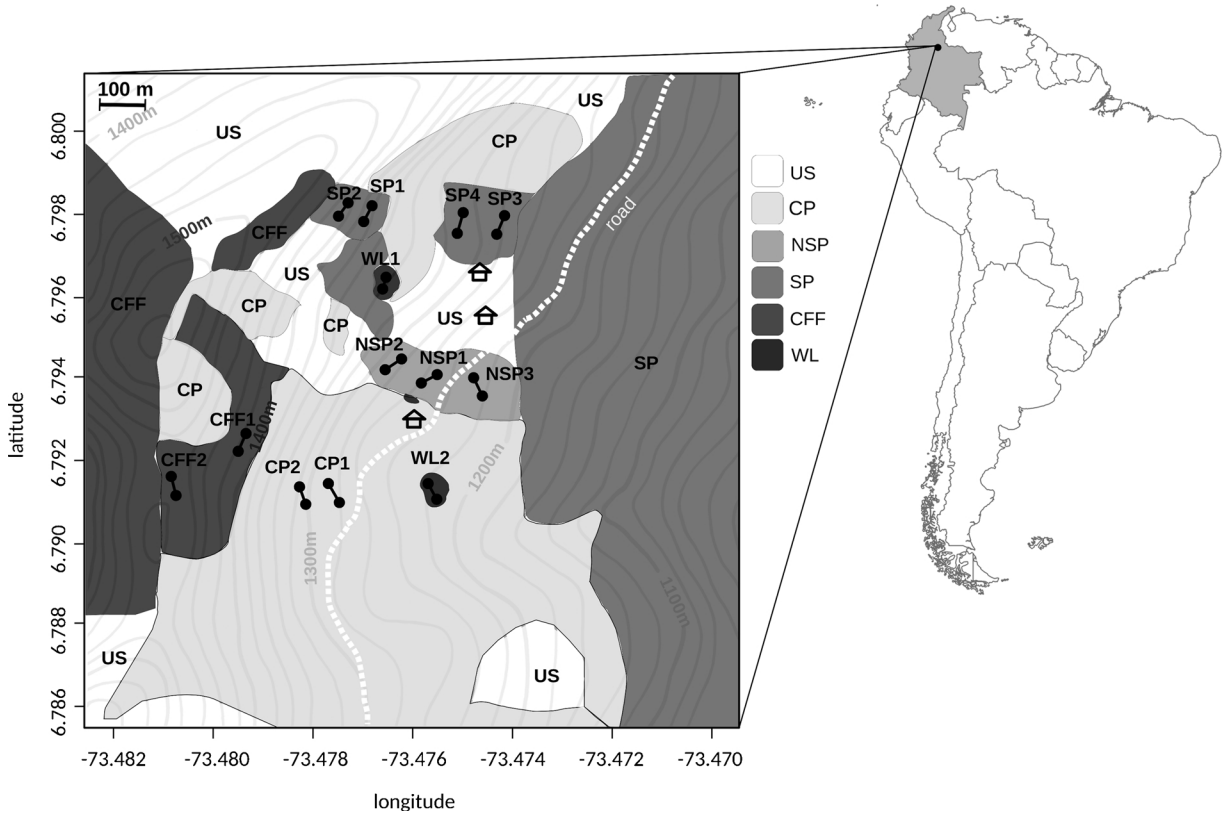

Fig. 1. Topographic terrain model of study site (map data © 2016 Google) depicting core study site with land-use units and surrounding matrix. Straight lines indicate transect location and dots respective starting and end points. CP = cattle pasture, NSP = non-shaded plantation, SP = shaded plantation, CFF = cloud forest fragment, WL = wetland, US = unspecified.

of agroforestry in protecting the environment and providing a number of ecosystem services is widely promoted as a key benefit of integrating trees into farming systems (Newaj et al., 2016). Coffee and cocoa agroforestry systems have previously been shown to exhibit higher structural diversity and thus to provide habitat for a significant number of animal and plant species (Perfecto et al., 1996, 2014; Cramer and Willig, 2005). Particular species can either directly profit from agroforestry systems, which they use as alternative habitats (Bhagwat et al., 2008; Guzmán et al., 2016), or cultivated areas can serve as buffer zones in the peripheral areas of nature reserves (Schroth, 2004) and as corridors between habitat fragments (Estrada et al., 2006). The additional timber production in agroforestry also reduces the dependency of farmers on natural forests (Rice and Greenberg, 2000; Schroth, 2004; Bhagwat et al., 2008), particularly in already densely populated areas with comparatively easy access to natural resources, such as the South American Andes (Etter and van Wyngaarden, 2000; Weiss et al., 2018). As a consequence, agroforestry began to attract the attention of the international development and scientific community, primarily as a means for increasing and sustaining agricultural production in marginal lands and remote areas of the tropics that were not benefited by the Green Revolution (Tewari and Sah, 2016). Here, coffee and cocoa are probably among the economically most important cash crops that have been cultivated widely throughout the tropics. Due to the biology of these crop plants, agro-silvicultural systems in mid to high elevations provide ideal conditions for their cultivation. Montane cloud forests ideally match these conditions, and this is why many cocoa- and coffee-based agroforestry systems are found in this biome (Manson et al., 2008; Méndez-Castro and Rao, 2014).

Tropical montane forest ranks among the most endangered habitats on earth (Aldrich et al., 1997). Its unique ecology and geographic location make it particularly susceptible to deforestation and climate change (Bubb et al., 2004). Only 0.26% of the earth's surface can be considered suitable to support montane cloud forest, accounting for only about 2.5% of tropical forests in general (Bubb et al., 2004). This unique ecosystem is rich in biodiversity, and it harbours a high number of endemic species (Hamilton, 1995; Foster, 2001; Bubb et al., 2004; Manson et al., 2008). Currently, the biggest threat to this biome is clearing for intensified agricultural use. The agricultural use of previously forested areas leads to habitat loss, erosion, reduction of water availability (Hamilton, 1995), and loss of biodiversity (Donald, 2004; Harvey et al., 2008). Promoting supposedly more sustainable forms of agriculture, such as agroforestry, has therefore been hailed as one of the most promising ways to safeguard these exceptional ecosystems in the long-run, while at the same time utilizing important forest resources (Beer, 1987; Rice and Greenberg, 2000).

To assess whether agroforestry approaches in tropical coffee, cocoa, and cattle productions systems are indeed a viable way of reconciling the need for economic crop production and biodiversity conservation, we analysed anuran amphibian communities, a suitable, sensitive organismal model system for analysing the impacts of environmental change on community structure, composition, and diversity at both taxonomic and functional levels (Ernst et al., 2006; Ernst and Rödel, 2008; Hölting et al., 2016). Due to their peculiar biology and particular diversity of reproductive strategies (Wells, 2007), amphibians are affected by small changes in their microhabitats, e.g. changes in microclimate or habitat structure, and should therefore be particularly prone to the effects of land-use. We tested the following main hypotheses:

(1) Different land-use systems differ in terms of species richness (species number), species diversity (alpha diversity), and species composition (beta diversity) with natural cloud forest habitats generally being the most diverse systems (2) Differences can be linked to structural habitat differences, separating true forest habitats from open land systems, with cloud forest and cattle pasture representing the respective extremes along the forest cover gradient.