Terrestrial mammal responses to habitat structure and quality of remnant riparian forests in an Amazonian cattle-ranching landscape

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ABSTRACT

Extensive 1970–2010 deforestation in the Brazilian Amazon has generated a ~1.5 Mha fragmented region known as the 'arc of deforestation'. Farmers and cattle ranchers throughout Brazil are legally required to set-aside riparian forest strips within their landholdings, but recent legislative changes have relaxed the minimum mandatory conditions of these riparian forests. In this context, we assessed the functional role of riparian forest remnants as landscape connectors for medium to large-bodied terrestrial mammals in a vast fragmented landscape of southern Amazonia. We selected 38 riparian forest strips and five riparian sites within continuous forest, installed four to five camera-traps along each riparian zone (199 camera-trap stations), and sampled the terrestrial mammal assemblage for 60 days per station during the dry seasons of 2013 and 2014. We compared mammal use of riparian forests within both continuous and highly fragmented forests, and examined the effects of corridor width, corridor habitat structure, and landscape context on mammal species richness, composition, and functional diversity, all of which were higher in continuous forests than in riparian remnants. Functional diversity differences between corridor type was trait-independent and mediated by differences in species richness. Forest habitat degradation was associated with overall lower species richness, whereas forest specialists were more species-rich in increasingly wider corridors. Compositional shifts indicate that deforestation and forest degradation favours matrix-tolerant species with lower levels of forest habitat specificity. We show the potential landscape connectivity role for forest mammals of riparian corridors, whose width and forest degradation status are key predictors of community-wide responses. We provide evidence on the importance of these relict riparian strips to forest vertebrates, strengthening the scientific arguments that help justify the recently embattled legal requirements to maintain effective riparian corridors in Brazil.

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1. Introduction

Brazilian Amazonia retains ~28% of the world's remaining tropical forests (FAO, 2015), but has exhibited the fastest absolute tropical deforestation rates in human history (Peres et al., 2010). Deforestation over the last four decades has therefore created extensive fragmented forest landscapes with varying degrees of forest cover, largely within the so-called Amazonian 'arc of deforestation' (Fearnside, 2005). This region comprises ~1.5 million km² across 248 municipal counties of southern Amazonia that are currently dominated by cattle pastures and, to a lesser extent, cropland (IBGE-SIDRA, 2016). This resulted in both the fragmentation and degradation of large tracts of once continuous forest (Soares-Filho et al., 2006). Although governmental efforts in the past decade have successfully curbed much of this trend, a recent set-back in the Brazilian Forest Act, brought forward by the political pressure exerted by agribusiness lobbyists, has caused deforestation

rates to rise once again across the Brazilian Amazon (Fonseca et al., 2015). In particular, changes sanctioned by congress members have reduced the total and proportional amount of legally required forest set-asides within private landholdings. These changes are non-trivial, since over half of the land throughout Brazil lies within private properties (Sparovek et al., 2015), and there are few forest reserves in the public domain set-aside for biodiversity conservation throughout most of the 'arc of deforestation' region (Ferreira et al., 2012).

It is therefore highly relevant to understand how biodiversity, especially taxa of conservation concern, respond to forest-pasture conversion in one of Earth's most biodiverse regions. Medium and large-bodied terrestrial mammals can be used as ecological indicator taxa, since their response patterns to deforestation and forest degradation are highly idiosyncratic (Wiens et al., 1993), mainly because their ecology and patterns of habitat use are highly diverse. This includes small to large-bodied species of varying population densities, several trophic guilds from herbivores to carnivores, species using small to very large home ranges, and a diverse socioecological profile, ranging from solitary to large-group-living species (Eisenberg and Thorington Jr., 1973).

Ecological tolerance to anthropogenic land uses is also widely variable, since some species may freely venture into the modified open-habitat matrix, while others are strict forest specialists, strongly avoiding highly degraded areas (Parry et al., 2007). This ecological and behavioural diversity likely reflects both species responses to habitat loss, and ripple effects on ecosystem functions mediated by these species, ranging from seed dispersal to top-down control of prey populations (Ahumada et al., 2011; Pavoine and Bonsall, 2011).

Maintaining riparian corridors is one of the most widespread landscape management strategies, and by no means a new conservation tool (Beier and Noss, 1998). Brazilian law requires that a minimum riparian forest remnant should be set-aside as a 'Permanent Protection Area (APP)' within all ~5.5 million private landholdings throughout the country to protect both hydrological functions and biodiversity (Brazil, 2012). Such riparian strips are ubiquitous throughout the country, providing an obvious opportunity to maintain landscape-scale connectivity through a functioning network of ecological corridors. Relict riparian strips, even where they fail to connect two ecologically important forest patches, still play a key role in maintaining overall landscape connectivity by reducing patch isolation (Hawes et al., 2008). Moreover, riparian habitats, and consequently, riparian corridors are important biodiversity repositories (Hilty et al., 2006), and safeguard critical resources, since a large fraction of local faunas depend on access to water and riparian food sources (Naiman et al., 1993). However, the way in which different species use these connectors is far from straightforward, with many studies concluding that the importance of ecological corridors for biodiversity is highly idiosyncratic and should be considered on a case-by-case basis (Beier and Loe, 1992; Wiens et al., 1993).

Several environmental factors have been shown to affect the performance of forest corridors as a management strategy, including (1) the structural features of corridors (e.g. width, length and continuity) (Hilty et al., 2006; Hawes et al., 2008); (2) the internal quality of the vegetation, mediated by the intrusion of external disturbances such as logging activity, overgrazing by domesticated livestock (Harrison, 1992; Beier and Noss, 1998; Lees and Peres, 2008); (3) the surrounding landscape configuration (Saunders et al., 1991; Prist et al., 2012); (4) the harshness of the matrix to any given species (Umetsu et al., 2008); and (6) the quality of forest source patches connecting corridors (Lindenmayer, 1994). The extent of a forest corridor in relation to the perceived scale of an organism should also affect corridor use for dispersal, and ultimately discriminate those species that use corridors only as landscape connectors from those that use them as integral parts of their foraging home ranges (Ricketts, 2001).

Here, we assess the role of remnant riparian forests as landscape connectors for medium to large-bodied terrestrial mammals in a fragmented landscape of southern Brazilian Amazonia. In particular, we compare mammalian use of riparian forests embedded within large tracks of continuous forest with those remaining as relict habitat in highly fragmented landscape contexts. We expect that community richness and functional diversity to be higher in continuous riparian forests than in remnant corridors, as well as a shift in community composition between these forest corridor types. Secondly, we quantitatively assess corridor use by the mammal assemblage, and relate richness, functional diversity, and composition patterns to corridor structure and quality, and landscape context. We hypothesize that both species richness and functional diversity will be lower, and species composition will be simplified in narrower and more isolated corridors of lower habitat quality, particularly those connected to distant and smaller source patches. This study focused on observed patterns of corridor use, resulting in direct conclusions on how intrinsic features of corridors affect their use by forest wildlife, and indirect conclusions on the role of riparian corridors in maintaining landscape connectivity.

2. Materials and methods

2.1. Study area

This study was conducted across a 16,200-km2 landscape encompassing three municipal counties in the northern state of Mato Grosso, southern Brazilian Amazonia: Alta Floresta (09°53′S, 56°29′W), Paranaíta (09°40′S, 56°28′W), and Carlinda (09°58′S, 55°49′W). All three counties were subjected to high deforestation rates in the past four decades, and collectively represent one of the most fragmented regions of the Amazonian 'arc of deforestation'. Prior to the onset of deforestation in 1978, this entire region consisted of a similar baseline mosaic of forest formations, including mostly upland (*terra firme*) forests and to a lesser extent seasonally flooded forests. However, only ~53% of the study landscape currently retains its original forest cover. Although human settlement patterns vary among those three counties, their anthropogenic habitat matrix is similar, and consists primarily of extensively managed livestock pastures under low cattle stocking densities (Michalski et al., 2008).

2.2. Study design

We selected 43 sampling sites including 38 remnant riparian forest corridors of varying width, which were embedded into a cattle pasture matrix, and five relatively homogenous pseudo-control riparian areas embedded within relatively large tracts of continuous forest in the landscape (>5000 ha; Fig. 1). We defined a riparian corridor structurally, as a narrow forest remnant (relatively to its length) maintained along streams. All riparian sites were at least 1000 m in length and spaced apart by a minimum distance of 1500 m. At each sampling site, we installed four to five digital camera traps (Bushnell Trophy Cam and Reconyx HC500 HyperFire) along the riparian zone, which were spaced apart by 250–300 m. These two camera trap models were randomly distributed across corridors, in order to avoid model-dependent biases due to differential animal detection of cameras (Meek et al., 2014). Our observational sample size thus amounted to 199 camera-trapping stations, whereas our inferential sample size consisted of 43 independent s.

At least 45 camera traps were used to sample batches of 10 riparian sites simultaneously for a period of 30 consecutive days. All cameras were then translocated to a new set of between seven to ten additional sites each month, until all 43 sites had been sampled over a 5-month period. This sampling schedule was deliberately restricted to the dry season (May–October), and repeated over two consecutive years (2013 and 2014). The chronological sequence of sampling across all sites was systematically rotated between years, so that sites that had been sampled at either the onset or at the end of the dry season in the first year were sampled during the peak of the dry season in the second year. We chose to restrict sampling to the dry season due to logistical reasons, including lack of physical access during the wet season, when large portions of all riparian floodplains were inundated. All camera-trap stations were baited with sardine tins pierced with multiple holes and fixed 0.75 m above ground on trees or poles placed in front of the cameras. Because of technical problems with some cameras and exceptional cases of camera theft, sampling of some riparian corridors were restricted to only four stations, resulting in a variable exposure time between stations considering both years of study (range = 28–62 sampling days). This difference in sampling effort was, however, subsequently taken into account in the analyses. Consecutive camera-trapping records of the same species were defined as independent if they were separated in time by a minimum interval of 24 h, since this is the time-lag within which we observed temporal correlations of conspecific records (conspecifics being recorded more often by the same camera). As to the spatial independence between cameras, we conducted our analysis using a hierarchical approach in which a random factor was included to account for the autocorrelation among cameras within corridors (see below).