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Impacts of selective logging management on butterflies in the Amazon

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ABSTRACT

Selective logging for timber production affects vast areas across the tropics, yet we lack detailed understanding of the impacts of logging intensity on biodiversity. These impacts can be studied at two levels: the impacts of logging intensity on overall diversity and community composition; and how logging intensity affects individual species' abundance-logging yield relationships. The latter underpins whether land-sharing logging (i.e. low intensity throughout) or land-sparing logging (i.e. high intensity with retention of some primary forest) is the optimal strategy. We examine both levels to determine the impacts of local-scale logging intensity on butterflies in Rondônia, Brazil, the global epicenter of butterfly alpha-diversity. Overall butterfly abundance was highest at intermediate logging intensity, whereas species richness increased after logging but was not affected by logging intensity, and that species composition increasingly changed from the primary community composition at higher logging intensities. Using individual species' abundance-yield curves, we then simulated species responses to a suite of logging strategies, ranging from total sharing to total sparing. Logging simulations predicted that more butterfly species would benefit from low-intensity land-sharing logging, having higher abundances than under land-sharing scenarios. However, some butterfly clades benefited disproportionally from the retention of primary forest within land-sparing logging concessions. Butterflies overall may benefit from intermediate logging strategies that promote a combination of low and high intensity logged areas, with some protected primary forest.

1. Introduction

Selective logging for timber production is a major driver of tropical forest degradation. With the exception of the Amazon and Papua New Guinea, selectively logged forest is now more widespread than old-growth primary forest (Edwards et al., 2014a), with 400 million hectares of rainforests now designated for timber production, an area more than twice the size of Mexico (Blaser et al., 2011). A key question is how to reconcile the burgeoning logging industry, in Amazonia and elsewhere, with biodiversity protection at a minimal opportunity cost.

Selective logging is a relatively low impact land-use change compared to, for example, conversion to agricultural or pasture land, as it retains species richness across many taxa (Edwards et al., 2014a). Research into the impacts of selective logging in the Amazon has revolved around improving harvesting practices with Reduced Impact Logging (RIL) schemes, which do not directly target logging intensities but focus instead on reducing collateral damage (Putz et al., 2008; Bicknell et al., 2015). Nonetheless, changes in species abundance and composition do occur with higher logging intensities (Bicknell et al., 2014) indicating the need for rigorous field studies that specifically incorporate logging intensity to identify management strategies that will minimise biodiversity losses from selective logging (França et al., 2017).

The impacts of logging intensity can be detected at two levels: (1) on overall diversity and community composition; and (2) on individual species' abundance-yield relationships. The latter underpins whether land-sharing logging, in which a whole concession is logged at a low intensity, or land sparing that protects one or several blocks of unlogged primary forest while logging the rest of the concession at higher intensity is the optimal strategy. To our knowledge, only one field study has examined the impacts of using measures of logging intensity that ranged from local (averaged across 10 ha) to large-scale (averaged across 90 ha), and found that only measures of local logging intensity explain overall changes in dung beetle community post-logging (França et al., 2017). However, this study lacked an analysis of individual

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species' responses. Thus, understanding how fine-scale local logging intensity measures affect community composition metrics and individual species remains a timely frontier.

In turn, no study explicitly considers individual species' responses to logging intensity, yet such understanding is critical for assessing land-sparing versus land-sharing logging (Edwards et al., 2014a). The only empirical study to date in Borneo, Southeast Asia, found that land sparing was best for birds, ants and dung beetles (Edwards et al., 2014b), with approximately twice the number of species that were winners (i.e. had higher abundances) from sparing than from sharing, resulting in higher projected species richness under sparing than sharing. However, but this study did not construct detailed species' abundance-yield relationships because it used a single 'averaged' logging intensity value for all high intensity plots and one for all low intensity plots. Applying an average intensity overlooks the important fine-scale local impacts of logging on forest structure, which determine species responses to logging intensity at small geographical scales, at which individuals interact with their environment and could thus lead to spurious inferences on the relative merits of land-sharing and land-sparing logging for biodiversity conservation.

Here, we address these issues by explicitly comparing butterfly community and individual species' responses to logging intensity, and then apply this understanding to simulations of land-sharing and land-sparing logging to estimate how many species would increase in abundance, i.e. winner species, under either strategy. We do so in Rondônia, south-western Brazilian Amazon, a region thought to host the highest butterfly local diversity on Earth (Emmel and Austin, 1990). Despite being flagship species for conservation in temperate zones, butterfly responses to the growing threat of selective logging remain largely unknown in the tropics (Lewis, 2001; Bonebrake et al., 2010), yet Brazil represents the third biggest producer of tropical wood worldwide (ITTO, 2016). We sampled butterflies along a gradient of known logging intensities in a concession practicing RIL techniques, and examined butterfly communities post-logging. We then used methods comparable to those in previous studies on land sharing versus sparing in an agricultural context (Phalan et al., 2011; Hulme et al., 2013; Gilroy et al., 2014) to model individual species responses to a range of hypothetical logging regimes that ultimately yield the same amount of timber. Finally, we examine whether logging regime preference is phylogenetically conserved among the studied butterfly clades.

2. Materials and methods

2.1. Study area

The study was based in the 46,184-hectare logging concession inside the Jamari National Forest, Rondônia, Brazil. The southern concession is managed by AMATA Brasil SA, which has been Forest Stewardship Council (FSC) certified since 2010. As part of their RIL strategy, all timber trees > 40 cm in trunk diameter within the designated logging units are digitally mapped and measured prior to logging. In addition, several silvicultural techniques such as road planning, prefelling vine cutting, and directional felling by highly trained operators are implemented. Records of the commercial yield of harvested trees are carefully kept by the company, enabling us to obtain logging intensity data within small patches of forest.

We sampled butterflies in the dry seasons of 2015 and 2016 in 20 primary forest sites and 40 sites that were selectively logged between 2011 and 2012 and spanned a range of known logging intensities. Butterfly abundance and species richness peaks in the dry season, and a study has shown that community structure does not vary significantly throughout the year in Amazonian rainforests (Barlow et al., 2007). Sites were ≥250 m away from logging roads or streams/rivers and at least ≥100 m apart from each other (Fig. 1) which has been shown to be sufficient to ensure butterfly community independence in previous studies (Hamer et al., 2003; Ribeiro and Freitas, 2012), and confirmed in our analyses of mark-recapture data among sites (SOM, Note S2). We tested spatial autocorrelation and species composition dissimilarity across sites, and found low levels of spatial autocorrelation across all sites (Note S1, Fig. S1), as a result of the majority of primary sites being in the East of the concession, but no spatial autocorrelation within habitat types (Fig. S2). Sites were not visited prior to their selection, hence there was no local-scale bias towards certain habitat structures, other than known logging intensity records, and were all at a similar elevation (mean 152.6 ± 9.2 m above sea level). Logging intensity per site was estimated for a 75-m radius (≈1.77 ha) from its centre, because trees felled ~25 m outside of the 50-m butterfly sampling radius would impact the community directly via damage incurred from falling lumber into the site and/or via edge effects from canopy gaps and skid trails. Mean logging intensity was 23.3 m^3/site of extracted timber volume across all study sites (range: 0–65.3 m^3/site), equivalent to an average of 4 felled trees per site (2.3 trees/ha) (SOM, Table S1).

2.2. Butterfly sampling

Each pre-selected site consisted of three baited traps, placed 15–25 m apart from one another. Traps were suspended from the nearest tree branch available 1 m above the ground, and vines and dense undergrowth within a 2-m radius were cleared to standardise trap accessibility for butterflies. We sampled fruit-feeding butterflies (Nymphalidae) using Van SomerenRydon cylindrical traps (Hughes et al., 1998), which were baited with a standardised mixture of mashed bananas and sugarcane juice that had been left in the sun fermenting in closed containers for 12 h. The butterflies captured in each site are assumed to represent the community in a 50-m radius forest surrounding it, based on the very low turnover rate observed between sites in this study (SOM, Note S2) and recent literature showing that Neotropical Nymphalidae butterflies are mostly influenced by their immediate surroundings (Ribeiro et al., 2012).

Traps were operated for 12 full days in cycles of eight sites at a time, with a total of 1260 individual trap-days. We visited the traps every 48 h between 06:00 h and 03:00 h to replace the bait with freshly fermented banana bait, and record all butterflies captured. We photographed, marked and released every individual found within traps on the spot, which resulted in a digital photographic collection of over 14,000 high-quality macro images. Marks were made by carefully removing scales from different areas of the wing each visiting day to facilitate tracing back recaptured individuals through the photographic collection. Species determinations were made by experienced lepidopterists, G.M.K and D.B., using recent literature and online reference collections (Warren et al., 2013). Species were divided into canopy/open habitat and understorey dwellers according to published literature (SOM, Table S2).

Butterflies have a strong vertical stratification in tropical forests (Ribeiro et al., 2016), and studies have shown that sampling canopy species is only needed when creating species inventories but not for assessing the impacts of anthropogenic disturbance (Dumbrell and Hill, 2005; Ribeiro and Freitas, 2012). We exclusively sampled understorey communities where bait-trapping has been shown to be more effective for most tribes than in the canopy strata (Whitworth et al., 2018), and because traps in logged sites with few tall canopies left can be hard to place (Dumbrell and Hill, 2005). Nevertheless, to test any potential differences in their responses, we present separate analyses for the understorey and canopy/open-habitat species in the SOM (Note S3, Figs. S4, S5).

2.3. Statistical analyses

2.3.1. Butterfly assemblage responses to logging intensity

We use generalized additive models (GAMs) to assess overall changes in species abundance and richness with increasing logging