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Identifying critical limits in oil palm cover for the conservation of terrestrial mammals in Colombia

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ABSTRACT

As oil palm plantations continue to expand in Neotropical regions, identifying critical transitions in land use, at which animal communities can be drastically altered, is crucial for conservation planning. Here, we investigated potential unexpected change points (thresholds) in the response of terrestrial mammal's richness and community composition to increasing oil palm cover in the Llanos region of Colombia. We deployed camera traps to detect species across 56 sites (landscapes of ~220 ha each) and used segmented regression and Threshold Indicator Taxa Analysis (TITAN) for the identification of these thresholds. We found a negative linear relationship between the proportion of oil palm and species richness, but no evidence of a threshold. In contrast, we found strong signs of a community threshold when oil palm cover in the study area reached 45–75%, at which mammalian species composition (taxon-specific changes of abundance and occurrence frequency) drastically changed. When species were assessed individually, a significant threshold relationship to oil palm cover was found to occur in 10 of the 15 examined species, with four (squirrel, agouti, spiny rat, common opossum) having a negative drastic change at approximately 45% oil palm cover. Five species showed no evidence for any critical threshold (giant and lesser anteater, jaguarondi, white-tailed deer and raccoon). We used the community threshold identified above as a baseline to evaluate the conservation status of the four oil palm production zones in Colombia. We found that approximately 41% of the total area covered by oil palm in Colombia has crossed the identified threshold of 45–75%, suggesting urgent need for forest restoration to increase its extent if a collapse of their resident mammal communities is to be avoided. These findings provide guidance for the design of sustainable landscapes within production areas in Colombia to promote the conservation of terrestrial mammals.

1. Introduction

Human activities have drastically altered the structure of landscapes around the world, modifying biological communities, destroying habitats and causing species extinction (e.g. Ceballos et al., 2017; Newbold et al., 2015). In this sense, the conversion of native grasslands, forests, wetlands, and other forms of natural land cover to cultivated lands has become the major driver of biodiversity loss (e.g. Gibbs et al., 2010; Laurance et al., 2014). Oil palm, in particular, is currently one of the major threatening processes for biodiversity retention in Southeast Asia (e.g. Danielsen et al., 2009). In this region, > 55% of oil palm expansion has occurred at the expense of native forest (Koh and Wilcove, 2008) and resulted in substantial biodiversity loss, including between 80 and 90% of species richness in birds and mammals (e.g. Maddox et al., 2007; Peh et al., 2006).

Oil palm production is rapidly expanding in Latin America (Furumo and Aide, 2017), where Colombia is the largest oil palm producer with approximately 500,000 ha currently under cultivation (Fedepalma, 2014). Oil palm production in Colombia is located in four zones (East, Pacific, Central and North region; Fedepalma, 2011), and the impact of this production varies across the zones (see Pardo et al., 2015). Contrary to Southeast Asia, most (~80%) of the oil palm expansion in Colombia, since the beginning of the 21st century, has taken place in previously transformed lands especially in areas historically used for cattle grazing (Furumo and Aide, 2017; Pardo et al., 2015). However, little is known about the likely impacts that the substantial increase in

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oil palm cover will have on Colombian biodiversity (Pardo et al., 2015). Few recent studies have suggested that oil palm plantations sustain significant lower levels of biodiversity than natural ecosystems (e.g. Gilroy et al., 2015; Pardo and Payán, 2015; Prescott et al., 2016). Nevertheless, no assessment has yet been conducted to provide guidance on the proportions of land that should be allocated to cultivation and set aside for conservation if the impacts on local fauna are to be minimized.

Ecological communities and their functioning are substantially affected by the degree of human alteration. Elements such as the amount of natural cover or the configuration of a human created matrix (often-agricultural land) between remnant habitat, among others, can play a crucial role in the long-term viability of species in agricultural landscapes (Gardner et al., 2009; Perfecto and Vandermeer, 2008). Of particular importance, species responses to land use change are not always linear. For example, some species are known to show particular change-points, also known as thresholds, that describe critical points in environmental conditions (e.g. habitat amount or habitat proportion within a landscape) that once surpassed can trigger a drastic decline in their populations (or richness) (Andrén, 1994; Suding and Hobbs, 2009). Identifying threshold responses of mammalian species across a gradient of oil palm cultivation is key to assisting management actions in these transformed landscapes, both in terms of conserving remaining biodiversity, and importantly for informing future plantation design and conservation planning. This “threshold analysis” is a relative recent, yet reliable, approach by which to anticipate critical changes in biodiversity response to land use cover change across human dominated landscapes (HDL) (e.g. Fahrig, 2001; Muylaert et al., 2016; Roque et al., 2018).

In this study, we aimed to identify whether there was a threshold in mammalian species richness and composition responses to oil palm cover increase in the Llanos region of Colombia. We used this approach in an attempt to anticipate the maximum percentage of oil palm that could be planted to minimize potential decline in mammal communities. Given the negative effect of oil palm on native fauna, and the likely non-linear response of different taxonomic groups to gradients of different land uses (e.g. Boesing et al., 2018; Roque et al., 2018), We predicted an abrupt decline (threshold) in species richness and composition in response to increasing oil palm cover within a landscape.

2. Material and methods

2.1. Study area

The study area is located in the Colombian Llanos Orientales region (hereafter Llanos), and included rural areas surrounding the towns of Restrepo, Cumaral, Cabuyaro, Acacias, Castilla la Nueva and San Carlos de Guaroa. All towns are situated in the department of Meta and are located between 194 and 394 m.a.s.l. (Fig. 1). This area has a long history of landscape modification by human activity and is currently dominated by oil palm plantations (here after referred as oil palm) and pastures (Pers. Obs. see also Romero-Ruiz et al., 2012). Other minor agricultural activities include rice and corn production. Oil palm production covers approximately 180,000 ha (Fedepalma, 2014), but it is predicted that the expanding oil palm cultivation in the region will occur at a faster rate than that of previous decades (Romero-Ruiz et al., 2012). The remnant natural ecosystem in the study area is secondary riparian forest (gallery forest) which varies in size and age, and some experience seasonal inundation.

2.2. Survey design

We sampled 56 sites (33 inside oil palm and 23 in riparian forest) located across an area of approximately 2000 km^2 (Fig. 1). Sites were selected strategically to examine a gradient of proportional area devoted to oil palm versus riparian forest cover (hereafter referred as forest). All sites within each land cover were at least 2 km apart to maintain sample independence. This site placement exceeded the minimum criteria recommended for inter-site distance when examining inventories of terrestrial mammals in the Neotropics (e.g. Silveira et al., 2003; Team Network, 2008; Tobler et al., 2008). Furthermore, previous research in the area (i.e. Ferrer et al., 2009; Pardo and Payán, 2015) suggests that this inter-site distance corresponds to the average diameter of home ranges for most mammal species expected to occur in the study area. Surveys were conducted during the dry season between September 2014 and January 2016 and all sampled plantations had been established for a minimum of 10 years (i.e. planted no later than 2006) to account for any confounding effect of plantation age.

We used seven Reconyx HC500 HyperfireTM digital cameras at each site (sampling unit) to detect medium to large sized mammals (i.e. $>$ 0.5 kg) without baiting. Cameras were placed along a 1.5 km transect with the first camera randomly located and the remaining cameras set along a transect at 250 m intervals. This protocol was used to increase survey success per site, as confirmed after a pilot study we conducted in the study area (data not published) (Pardo et al. unpublished data) and is more effective than the traditional mammal research practice of using one camera per site (Burton et al., 2015). Where possible, cameras inside forests were placed along animal paths or facing small gaps in the vegetation to maximize capture success. Cameras were positioned in a zigzag arrangement within oil palm to increase coverage due to the regular pattern of tree planting. All cameras were fixed to trees or wooden poles with a steel cable and were configured to the following criteria: high sensibility sensor, one second interval between consecutive pictures (3 per trigger), no delay or quiet period between triggers, a minimum distance from the potential path of the animal of 1.0 m and at 25–30 cm height depending on the terrain. Cameras were active for 30 to 40 days.

2.3. Landscape variable selection

We quantified the different land cover/use at each site using ArcGIS (V10.2.1; Environmental Systems Research Institute, Inc. Redlands, CA). This quantification was done by creating a buffer with a 500 m radius around each camera within each transect (i.e. site) and merging the individual buffers into one single area or landscapes of ~220 ha (Fig. 1). We then calculated the percentage of the different land cover/use types (forest, oil palm and others) within these landscapes. To avoid potential effects of spatial autocorrelation in our predictor variables, we assessed for autocorrelation using Moran's I in SAM software V4.0 (Rangel et al., 2010). In all instances Moran's I was not significant ($p > 0.05$).

To determine land cover type we used official spatial data describing the extent and locations of plantations in Colombia supplied by the National Federation of Oil Palm Growers (FEDEPALMA), and land cover maps acquired from the National Institute for Environmental, Hydrological and Meteorological Studies–IDEAM (IDEAM et al., 2007). We updated the information from IDEAM (1:500,000) prior to the analysis using: i) Google Earth imagery and ii) Claslite classification–30 m resolution (Asner et al., 2009) to identify and validate forested areas, as this provided more up-to-date and accurate data for this land cover, and iii) aerial photographs taken during a flight over the study area (August 2014).

2.4. Threshold and statistical analysis

The majority of studies using threshold analyses (i.e. identification of drastic change-points in the response of fauna; see introduction) focus on identifying the minimum amount of forested habitats in gradients of native vegetation loss, below which the population of species would likely go extinct (Andrén, 1994; Banks-Leite et al., 2014; Fahrig, 2001; Muylaert et al., 2016). Here, we focused on identifying the threshold for maximum percentage of oil palm plantation in a