ARTICLE IN PRESS

Biological Conservation xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

African apes coexisting with logging: Comparing chimpanzee (*Pan troglodytes troglodytes*) and gorilla (*Gorilla gorilla gorilla*) resource needs and responses to forestry activities

David Morgan[a,b,*,1], Roger Mundry[c,1], Crickette Sanz[b,d], Crepin Eyana Ayina[b], Samantha Strindberg[e], Eric Lonsdorf[f], Hjalmar S. Kühl[g,h]

[a] *Lester E. Fisher Center for the Study and Conservation of Apes, Lincoln Park Zoo, United States*
[b] *Congo Program, Wildlife Conservation Society, Republic of Congo*
[c] *Max Planck Institute for Evolutionary Anthropology, Germany*
[d] *Department of Anthropology, Washington University in Saint Louis, United States*
[e] *Global Conservation Program, Wildlife Conservation Society, United States*
[f] *Institute on the Environment, University of Minnesota, United States*
[g] *Max Planck Institute for Evolutionary Anthropology, Department of Primatology, Germany*
[h] *German Centre for Integrative Biodiversity Research (iDiv), Halle-Jena-Leipzig, Germany*

A R T I C L E I N F O

Keywords:
Congo Basin
Forestry
Logging
Apes
Conservation

A B S T R A C T

The extraction of timber often conflicts with the well-being and conservation of wildlife. In particular, there is a need to better understand the impact of tree removal under selective logging regimes on local ecological communities. We conducted ape nest counts along line transects before, during, and after logging to assess the impact of timber harvesting and associated activities on sympatric chimpanzees and gorillas in a forestry concession in northern Republic of Congo. We used generalized linear models to relate ape nest counts to a set of predictor variables, representing the impact of logging and controlled for variation in environmental conditions including food availability, habitat and rainfall. Commercial forest inventory data were used to assess the baseline influence of food availability and forest structure on ape distribution. Higher numbers of chimpanzees were found in proximity to their preferred tree foods, whereas gorillas were associated with more heterogeneous habitats. Chimpanzee nest encounter rates decreased with increasing intensity of human impacts. Gorillas also avoided areas with active timber exploitation and roads, but were attracted to recently logged areas with abundant terrestrial herbaceous vegetation. Species-specific responses were consistent with theoretical predictions of niche partitioning and cumulative human influence. Based on these findings, we provide recommendations to improve existing guidelines and forest certification standards aimed at safeguarding ape populations.

1. Introduction

Among the anthropogenic influences on environmental services and biodiversity in the tropics, timber exploitation plays a prominent and complex role (Asner et al., 2010; Barlow et al., 2016; Brandt et al., 2016; Nasi et al., 2012). Rates of ecosystem conversion have increased and become more widespread (Gibbs et al., 2010; Hansen et al., 2013) with roughly 20% of the tropical forest worldwide having been subjected to selective logging at the turn of the century (Asner et al., 2009). Logging can provide important revenue streams and opportunities for infrastructure development in some of the most disenfranchised regions of the world (FAO, 2011), but these benefits have costs with regards to tropical forest health (Lewis et al., 2015) and conservation of biodiversity. The advent of sustainable forest management (SFM) provides counter measures to alleviate potential negative impacts on the environment (see review by Putz et al., 2008) characterizing selectively logged forest as "middle way" toward maintaining biodiversity (Putz et al., 2012).

Most of the timber estate in the Congo Basin has already experienced one or two cycles of exploitation (Perez et al., 2005). As a result, the floral composition and structure of these production forests are under transition. Forest conversion can have neutral, beneficial or

* Corresponding author at: Lester E. Fisher Center for the Study and Conservation of Apes, Lincoln Park Zoo, 2001 North Clark Street, Chicago, IL 60614, United States.
E-mail address: dmorgan@lpzoo.org (D. Morgan).
[1] Co-first authors.

https://doi.org/10.1016/j.biocon.2017.10.026
Received 27 February 2017; Received in revised form 27 June 2017; Accepted 23 October 2017

detrimental effects on wildlife depending on species-specific traits and coping mechanisms (Burivalova et al., 2014). Within converted landscapes, the distribution of wildlife is likely to be altered and understanding the risks to particular species is key to their conservation. Life history traits such as niche breadth and habitat specificity are a few factors linked to species sensitivity to anthropogenic impacts (Henle et al., 2004). The response of sympatric western gorilla and central chimpanzee to anthropogenic impacts are of interest given these species subtle differences in resource use and social systems.

Gorillas have classically been referred to as generalists belonging to the folivore guild (consuming mostly herbaceous ground vegetation) and chimpanzees as specialists grouped within the frugivore guild (consuming mostly fruit) (Bourliere, 1985). Based on these differences in their ecological profiles, scientists have suggested that chimpanzees are expected to be more negatively impacted by human impacts. Prior studies partially supported such assertions, with decreases in chimpanzee populations after a first cycle of selective logging (Arnhem et al., 2008; Clark et al., 2012; White and Tutin, 2001). In contrast, gorilla numbers remained similar or increased in some exploited forests (Haurez et al., 2014; Huijbregts et al., 2003).

Both species are wide ranging and capable of identifying refugia to avoid areas with active timber harvesting but they differ in social constraints to shifting their ranging patterns. Home ranges of gorilla groups may overlap completely without dispute. Tolerance may afford the opportunity for gorillas to spatially shift their ranges to avoid localities with high levels of human impact (Arnhem et al., 2008; Matthews and Matthews, 2004), as has been observed in Bornean orangutans living in proximity to logging (Ancrenaz et al., 2004; Davies, 1986; MacKinnon, 1971; Morrogh-Bernard et al., 2003; Russon et al., 2001). In contrast, chimpanzees are territorial and aggressively defend resources in their home range from incursions by neighboring groups, which limits their ability to shift spatially (Goodall, 1986; Mitani et al., 2010). In Gabon, an immediate and significant decline of chimpanzees occurred after the onset of timber exploitation, which was attributed to lethal conflicts between neighboring groups as they were displaced from their territories by logging (White, 1994; White and Tutin, 2001). There have been few studies of apes' responses to logging that integrate ecological and anthropogenic factors, habitat selection, and potential ecological trade-offs (Haurez et al., 2016; Imong et al., 2014; Sawyer and Brashares, 2013). Though similar approaches have proven informative outside of the Congo Basin in different anthropogenic contexts (Hardus et al., 2012; Henle et al., 2004; Hockings et al., 2009; Felton et al., 2003; Felton et al., 2010; Melbourne et al., 2004; Rode et al., 2006; Potts, 2011).

To assess the impact of selective logging on the ape guild, we conducted ape nest counts over a nine-year period along standardized line transects using a before, during and after (BDA) methodology. The potential influence of forest structure and food availability on ape distributions was estimated with commercial timber inventory (CTI) data from the study area. Based on their ecological and social profiles, we hypothesized that chimpanzees and gorillas would show different responses to logging activity. We predicted that chimpanzees would avoid areas of active exploitation through small-scale spatial shifts. Gorillas were also predicted to avoid zones of high human impact, but through larger spatial shifts resulting in convergence in secondary habitats comprised of their preferred food resources. We used Generalized Linear Models to relate chimpanzee and gorilla nest counts to a set of predictor variables, representing the impact of logging and controlled at the same time for variation in environmental conditions including food availability, habitat, and rainfall. Given the potential long-term risks that logging poses to their survival, conservation priorities at the concession level need to be based on the resource needs of these critically endangered gorillas and endangered chimpanzees (IUCN, 2016).

2. Methods

2.1. Study site

The study was conducted in the Kabo Forestry Management Unit, the first Forest Stewardship Council (FSC) certified concession in central Africa. The concession is adjacent to the Nouabalé-Ndoki National Park (NNNP) (2°05′–3°03′N; 16°51′–16°56′E) in northern Republic of Congo. The area had been logged 30 years ago, but timber extraction was selective and many of the largest tree stems were left intact. Our baseline ape density estimates were within the range of those found in neighboring pristine forests, and botanical inventories suggested that natural forest recovery was underway and preferred ape foods available (Morgan unpublished data). Altitude within these lowland forests ranged from 330 to 600 m. The climate can be described as transitional between the Congo-equatorial and sub-equatorial climatic zones.

2.2. Study design and data collection

We used the automated survey design component of the custom DISTANCE software to generate systematically spaced line transects with a random start in the study area (Thomas et al., 2010). Results from a line transect pilot study indicated that a survey design comprised of fourteen parallel line transects separated by 1.5 km would provide sufficient survey effort for the desired precision. This systematic design ensured that each location in the study area had the same probability of being sampled (Fig. 1).

Line transects were surveyed twelve times between 2004 and 2012, and conducted in adherence to best practice guidelines for surveys and monitoring of great ape populations (Kühl et al., 2008). The first passage was conducted in 2004, before the current timber harvesting began in 2006. Surveys were conducted twice a year while active logging took place in the study area between 2006 and 2009 (8 times). Post-logging surveys were conducted between 2010 and 2012 (3 times). Ape nests and human signs were recorded on each survey passage. See Morgan et al. (2006) for a detailed description of data collection protocols and methods.

2.3. Timber inventory data

An agreement between the local logging company, the Wildlife Conservation Society (WCS), and the Government of Congo was signed in 1999 to ensure environmental and social values were maintained within the production forests. As part of concession management planning in central Africa (Cerutti et al., 2008) and FSC certification, the local logging company, in collaboration with the Government of Congo, conducted a commercial timber inventory (CTI) prior to initiation of timber removal. Similar studies focused on flora traits using CTI datasets have proven reliable (Réjou-Méchain et al., 2011) at a variety of spatial scales and improved understanding of the ecological characteristics of production forests (ter Steege, 1998; Réjou-Méchain et al., 2008). The georeferenced CTI for this study zone was conducted in 2003 and included tree stems with minimum diameter of exploitation ranging between 60 and 100 cm at breast height (DBH) depending upon species (Congolaise Industrielle des Bois, 2006). The spatially explicit inventory of individual trees surveyed in the study zone included stems from 40 different species of marketable and non-marketable trees. Nearly 90% of the timber volume removed was comprised of *Triplochiton scleroxylon*, *Milicia excelsa*, *Entandrophragma cylindricum*, and *E. utile* (Congolaise Industrielle des Bois, 2006). Annual Allowable Cut (AAC) areas were spatially defined based on the volume of timber approved for removal occurring within the region to be exploited. Delimitation of AAC areas and road construction occurred in advance of timber exploitation. As part of the third party certification, the logging company was audited once a year with auditors making field visits to the concession and interacting directly with the forestry company's