Biological Conservation 169 (2014) 334–343

Contents lists available at ScienceDirect

Biological Conservation

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

Mining matrix effects on West African rainforest birds

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ARTICLE INFO

Article history:
Received 28 April 2013
Received in revised form 10 October 2013
Accepted 19 November 2013

Keywords:
Edge effects
Forest specialists
Functional groups
Matrix type
Remnants
Species richness
Surface mining
South-west Ghana

ABSTRACT

Globally, relatively low-contrast matrices are being converted to high-contrast through increases in land uses such as surface mining. Such conversion affects biodiversity not only at the impact site, but also potentially in adjacent remnant habitat, particularly for habitat types such as tropical rainforest. We investigated how the species richness of different functional groups of tropical rainforest birds varied in remnant rainforest patches embedded in two matrix types (mining vs. agricultural) at two distances to forest edge in fragmented Upper Guinean rainforest landscapes of southwest Ghana. We hypothesized that rainforest adjacent to high-contrast surface mining would support a relatively lower richness of forest-dependent birds than that adjacent to a lower-contrast agricultural matrix. Data from six point counts at each of 32 study sites were used to estimate species richness within ten avian functional groups based on (a) habitat preference (forest specialists, generalists, forest visitors, open country species); and (b) food preference (carnivores, frugivores, omnivores, nectarivores, insectivores and granivores). Species richness of each group was modelled as a function of adjacent matrix type, distance to patch edge and site-level vegetation characteristics using generalized linear mixed-effects models. Forest specialists and frugivores were most strongly negatively affected by adjacent mining, irrespective of distance to forest edge. Forest visitors were more common in forests adjacent to agriculture than mining, and they preferred edges to interior habitats. Forest specialist and frugivore richness also correlated positively with the density of large trees. This effect of a high-contrast matrix on forest birds suggests that even with no additional forest loss, increased surface mining in the Upper Guinea region is likely to result in population declines in forest-dependent birds. Preserving biodiversity in forest landscapes will require management of matrix quality. The widespread trend of increasing patch-matrix contrast from land use change in the matrix is likely to result in negative consequences for biodiversity in fragmented tropical forest landscapes.

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1. Introduction

The important role of the matrix surrounding remnant native habitat in affecting species persistence in landscapes is recognised worldwide (Bengtsson et al., 2003; Brady et al., 2009, 2011; Dunford and Freemark, 2005; Kupfer et al., 2006; Litvaitis and Villafuerte, 1996). An increasing trend in matrix land use is the replacement of relatively low-contrast land use systems, such as traditional farming, with high-contrast land uses, such as surface mining (Bridge, 2004; Palmer et al., 2010; Ripley et al., 1996). Surface mining creates one of the most hostile matrices for terrestrial wildlife (Kennedy et al., 2010). Thus, the increase in conversion of land to mining potentially has serious implications for conservation not only through conversion of natural systems, but also through the increased patch-matrix contrast when lower-contrast anthropogenic land cover types such as farmlands are converted.

Globally, over 19.5 million hectares of land area are converted annually due to industrialization including mining (United Nations Environment Programme, 2008). In particular, many developing countries are experiencing "mining booms" that have damaged many natural landscapes (Aryee et al., 2003; Hilson, 2002). For example, in the Choco region of Colombia, an estimated 1000 ha of native forest are lost annually due to increasing mining activity (Almeida et al., 2005). In Zimbabwe, small-scale gold exploration has led to the loss of over 100,000 ha of native ecosystems (Maponga and Ngorima, 2003) while in the Brazilian Amazon, widespread extraction of precious minerals has created 'moon-surface' terrains without any vegetation cover (Almeida et al., 2005). In many West African countries, gold extraction on both large and small scales has resulted in considerable vegetation loss and mass trenching (Hilson, 2002). This is of particular concern due to the fact that developing countries generally have weaker

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0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.11.030

environmental regulations (FAO, 2010; Strassburg et al., 2009) and also harbour the greatest biodiversity (Mittermeier et al., 1998).

Even the conversion of ecosystems outside of natural ecosystems to mining may affect biodiversity. The matrix surrounding remnant patches plays a key role in the structure and sustainable functioning of landscapes (Forman, 1995; Hanski and Ovaskainen, 2003; Lindenmayer et al., 2002; Ricketts, 2001). The matrix can influence the ability of species to disperse within landscapes (Kennedy and Marra, 2010) and the persistence of species in native habitat patches (Dallimer et al., 2012; Prevedello and Vieira, 2010), and its composition may determine the extent of edge effects on species such as nest predation and interspecific competition (Driscoll and Donovan, 2004). Gascon et al. (1999) found that populations of species that avoid inhospitable matrices tend to decline or disappear in nearby remnants. Empirical studies in the Colombian Andes have shown that matrices of different types surrounding tropical forest remnants had significantly different influences on the abundance of 65% of tropical forest bird species studied in those remnants (Renjifo, 2001). The common conclusion from these studies is that structural contrast between remnant patches and the surrounding matrix type is a key determinant of matrix effects on faunal species populations and communities in adjacent remnant habitat (Kennedy et al., 2010).

Much farmland is being converted to surface mining (Aryee et al., 2003).This conversion of farmlands to mining adjacent to remnant rainforest represents a significant increase in patch-matrix contrast. Mining is an extremely destructive land use, which has its impacts extending beyond the area directly affected by the industrial process (Álvarez-Valero et al., 2008; Bell, 2001; Heemskerk, 2001; Negley and Eshleman, 2006; Peterson and Heemskerk, 2001). Matrix effects associated with mining (noise, air, water pollutions, infrastructure) can penetrate into adjacent forest remnants influencing the population dynamics and community structure of biodiversity (Wickham et al., 2007). Understanding how these higher-contrast land uses affect fauna is essential for the conservation of native biotas in fragmented landscapes (Robinson et al., 1992).

In West Africa, rapid deforestation resulting in loss of much biodiversity is due to subsistence slash and burn agriculture and selective logging (Holbech, 2005, 2009); industrial and small-scale mining (Amankwah and Anim-Sackey, 2003; Aryee et al., 2003; Hilson, 2002); and rapid population expansion and urbanisation (Beier et al., 2002; Rudel et al., 2009). The mining industry is currently the major driver of most West African countries' socio-economic development (Hilson, 2002). These activities result in a heterogeneous matrix that surrounds remnant tropical rainforest. As in many developing countries, the mining industry in Ghana has expanded over the past 30 years in response to changes in economic policies (Amankwah and Anim-Sackey, 2003). The rapid expansion of the mining industry exacerbated by poor livelihoods in Ghana's tropical forest areas has led to the increase in small-scale mining in and near forest patches. An estimated 58,000 km^2 of both forest area, farmlands and human settlements been licensed for mining (Norris et al., 2010). Both agriculture and mining have fragmented a formerly unbroken forest into distinct patches within a non-forest matrix (Hawthorne and Abu Juam, 1995). Increasingly, forests once adjacent to a 'softer' matrix of low-contrast farmland now abut the highly inhospitable matrix of surface mining.

The aims of this study were to: (1) investigate how two contrasting land use systems (mining vs. agriculture) affect patterns of bird species richness of different functional groups in tropical rainforest remnants, at the edge and closer to the interior of the remnants; and (2) identify what landscape and site-level factors influence the differences in species assemblages within native remnants with these different matrices. We used generalized linear mixed-effects models in a model averaging framework to rank the relative influence of local and landscape variables (matrix type, distance to patch edge, density of large and fruiting trees, and forest extent) on bird species richness within several functional groups. We hypothesized that rainforest sites adjacent to high-contrast surface mining would support a relatively lower richness of forest-dependent birds than similar sites adjacent to a lower-contrast agricultural matrix; and that the species richness of habitat and food specialists avian species (especially frugivores and insectivores) would be most negatively impacted by matrix change.

2. Material and methods

2.1. Study area

The study was conducted in the fragmented upper Guinea forest, west Ghana. Ghana abuts the Gulf of Guinea in West Africa (3°5′W–1°10′E; 4°35′N–11°N), and covers an area of 238,500 km^2. Ghana extends over four main biogeographic zones: the Guinea-Congolian in the south-west, the Sudan in the north, the Guinea-Congolian/Sudanian transition zone in the centre and the south-east, and the Volta in the east (Hawthorne and Abu Juam, 1995). The forest areas are confined to the Guinea-Congolan zone, and are highly fragmented as a result of clear-fell logging for high-value timber products and rapid human population growth. These areas are also ideal climates for raising cash crops and food crops, and are exposed to recurring annual fires (Hawthorne and Abu Juam, 1995). This has led to the fragmentation of a formerly intact forest into distinct patches within a non-forest matrix. The area is also rich in minerals such as gold, bauxite, and iron ore, and their extraction is a serious threat to the region's forests (Hawthorne and Abu Juam, 1995). Gold mining is particularly damaging when located adjacent to forest reserves' with many large-scale surface gold mining operations recently being established (Amankwah and Anim-Sackey, 2003; Aryee et al., 2003; Hilson, 2002). The forest fragments of south-west Ghana are surrounded by a land use matrix dominated by forest cropland, which consists of small farms and fallow land. Relictual native forest trees are scattered within these croplands. The dominant crops found include cocoa (*Theobroma cacao*), plantain (*Musa paradisiaca*), cocoyam (*Xanthosoma sagittifolium*), corn (*Zea mays*), tomatoes (*Solanum lycopersicum*), garden eggs (*Solanum melongena*), cassava (*Manihot esculenta*), oil palm (*Elaeis guineensis*), and non-native teak (*Tectona grandis*) (Hawthorne and Abu Juam, 1995). Cocoa farms usually retain the over-storey of native emergent tree species and therefore have over-storey features similar to the natural forest type (Hawthorne and Abu Juam, 1995).

2.2. Conceptual model

Conceptual models of species environment-relationships are useful steps for building predictive species distribution models (Guisan et al., 2006; McAlpine et al., 2008). We present a conceptual model of the direct and indirect effects of matrix change on the probability of occurrence of avian species in native forest remnants within fragmented tropical rainforest landscapes (Fig. 2). The conversion of low-contrast agricultural land use matrices into higher-contrast matrices can directly lead to habitat loss, increase edge effects, fragmentation, altered disturbance regimes, pollution, modified microclimates, increase invasion and human pressure (Brotons et al., 2003; Kupfer et al., 2006). Loss of native vegetation through clearing and extraction of timber resources near and within existing forest remnants can result in loss or reduction in habitat resources for bird species within remnants (Jules and Shahani,

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