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Incorporating movement behavior into conservation prioritization in fragmented landscapes: An example of western hoolock gibbons in Garo Hills, India

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ABSTRACT

Connectivity is increasingly of conservation concern due to ongoing habitat fragmentation, land-use dynamics and climate change. Connectivity patterns result from interactions between dispersers and the environment. However, connectivity assessments often ignore responses of dispersers to matrix types or characterize matrix resistance using habitat-use, rather than movement, data. We compare conservation rankings for connectivity of forest fragments in Garo Hills, India, where matrix resistance was quantified based on (a) distance among fragments, (b) habitat use, and (c) movement constraints for the arboreal western hoolock gibbon *Hoolock hoolock*. We first quantified matrix resistance based on gibbon movement, in terms of gap-crossing behavior, as a function of canopy gap and tree height, which was estimated using focal scans on seven gibbon groups. Second, we estimated matrix resistance based on gibbon habitat use of major land-use types in the study landscape. We then compared rankings of forest fragments using patch connectivity indices from network analyses using these quantified matrix resistances and Euclidean distance among sites. We found that matrix resistances based on movement data suggested greater resistance of plantations than did habitat-use data. Conservation rankings based on movement data were uncorrelated with those based on Euclidean distance. Rankings derived from movement data were correlated with those obtained from location data; however, there were several discrepancies between rankings, which were explained by landscape heterogeneity in the neighborhood of fragments. Incorporating movement behavior into connectivity assessments can improve our understanding of dispersal and provide a mechanistic basis for conservation prioritization in heterogeneous landscapes.

1. Introduction

Habitat fragmentation, land-use dynamics and climate change constitute ongoing and pervasive threats to species persistence worldwide (Wilcove et al., 1998; Fahrig, 2003; Doerr et al., 2011). Addressing these threats requires that conservation should no longer be restricted to intact regions of largely undisturbed habitat, but rather should be focused on heterogeneous landscapes comprised of habitat fragments interspersed in an anthropogenic matrix (Sanderson et al., 2002; Lindenmayer et al., 2008). Connectivity, or linkages between habitat patches (e.g., forest fragments), can enhance species persistence in such heterogeneous and dynamic landscapes through multiple mechanisms (Lindenmayer et al., 2008; Doerr et al., 2011), including colonization of unoccupied habitat (Hanski, 1998), population rescue (Brown and Kodric-Brown, 1977) and avoidance of inbreeding (Bengtsson, 1978). Conservation in heterogeneous landscapes therefore frequently encompasses processes leading to connectivity in addition to within-fragment processes (Sanderson et al., 2002; Zetterberg et al., 2010).

Functional connectivity requires the movement of individuals between habitat fragments (Clobert et al., 2012); here we focus on functional connectivity, where connectivity is measured based on both dispersal characteristics of species and landscape structure, rather than structural connectivity, or connectivity based

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solely on physical features of landscapes (Calabrese and Fagan, 2004). Species movement behavior can modify connectivity patterns in a multitude of ways (Belisle, 2005; Baguette and van Dyck, 2007). For instance, the ability of dispersers to perceive and appropriately respond to habitat cues can influence immigration into habitat fragments (Fletcher, 2006). Similarly, species may be constrained from dispersing through anthropogenically-modified landscapes by virtue of their movement mode (Ball and Goldingay, 2008). Thus, an understanding of species dispersal abilities is crucial for connectivity assessments and prioritizations and can lead to increased accuracy of predictions of potential connectivity, as well as more robust prioritizations, particularly in novel landscapes (McIntire et al., 2007; Hudgens et al., 2012).

Nonetheless, recent reviews indicate that data used in connectivity assessments typically do not encompass animal movement behavior (Sawyer et al., 2011; Zeller et al., 2012). Instead, connectivity assessments primarily use one of two approaches. First, connectivity assessments have had a long tradition in prioritization based on Euclidean distances among habitat fragments, which implicitly assumes a homogeneous matrix (Diamond, 1975; Calabrese and Fagan, 2004; Braaker et al., 2013). Land-cover types, however, often differ in the resistance they offer to species movement (Ricketts, 2001; Stevens et al., 2006); in turn, dispersers may differentiate land-cover types while traversing heterogeneous landscapes (Stevens et al., 2006; Revilla and Wiegand, 2008). Second, data on species location, or habitat-use, are increasingly used to inform our understanding of how matrix heterogeneity influences connectivity (Zeller et al., 2012). While data on species presence in different locations describe habitat associations, it may not always capture dispersal limitations for species (Stevens et al., 2006; Revilla and Wiegand, 2008; Eycott et al., 2012). This issue is particularly evident when we consider that dispersal among fragments largely occurs outside species habitat (Stevens et al., 2006; Revilla and Wiegand, 2008).

Simulation studies indicate that the description of relative resistance offered by different land-cover types can significantly influence our perception of potential connectivity in heterogeneous landscapes (Rayfield et al., 2010). Assumptions of a uniform matrix or describing matrix heterogeneity through insights obtained from species location may lead to misleading predictions of potential connectivity in heterogeneous landscapes (McIntire et al., 2007; Fletcher et al., 2011). Systematically incorporating species movement behavior into connectivity prioritization may provide useful guidance for ongoing and future conservation efforts (Belisle, 2005; Baguette and van Dyck, 2007; Baguette et al., 2013). Further, an assessment of the ramifications of these frequently made assumptions in terms of conservation prioritization can provide insights on the contextual utility of location data in connectivity prioritization and clarify the need for quantifying species movement limitations.

We compared conservation rankings of potential conservation areas in a fragmented landscape, where matrix resistance was quantified based on (a) an assumption of a homogenous landscape (simply distance among fragments), (b) location data, and (c) movement constraints for the western hoolock gibbon *Hoolock hoolock*, a highly endangered, arboreal species whose movement is largely restricted to forest canopies. To do so, we first tested whether gibbon location and movement, in terms of gap-crossing behavior, varied among matrix land-cover types in the landscape. We then used this information and data on species location within home-ranges from groups sampled from across the landscape, coupled with network modeling (e.g., McRae and Beier, 2007), to rank conservation areas for potential connectivity. In this comparison, we demonstrate how small-scale observations of individual movement can be integrated into available and commonly used techniques of connectivity assessments and prioritization. Finally, we discuss the tradeoffs of using data on species location for inferring movement limitations in fragmented and heterogeneous landscapes.

2. Materials and methods

2.1. Study region and species

The western hoolock gibbon inhabits village forest fragments in a human-dominated landscape of Garo Hills, Meghalaya, India (Alfred and Sati, 1990; Gupta and Sharma, 2005; Kakati et al., 2009; Kaul et al., 2010). Existing long-term community conservation initiatives in the region aim to collaborate with community members to demarcate village forest fragments that form habitat for the species as community reserves, but these initiatives currently lack information to prioritize fragments for conservation (Kaul et al., 2010). Conservation prioritization in this landscape is important as traditional practices of mixed plantations and protecting village forests are being replaced by monoculture plantations (Roy and Tomar, 2000; Kaul et al., 2010). Further, gibbons are arboreal and their movement mode is largely restricted to brachiation (i.e., swinging between branches using forelimbs) and jumping among closed canopies (Kakati et al., 2009; Mittermeier et al., 2009). This movement mode suggests that the relatively open canopy of modified land-cover types will constrain their movement, and hence, that connectivity will be an important limitation for their persistence in fragmented landscapes (Kakati et al., 2009; Mittermeier et al., 2009; Sharma et al., 2014).

For between-fragment connectivity assessments, we used remote sensing to classify land-cover types in the region. We used satellite imagery from the Linear Imaging Self Scanner IV camera of the Indian Remote Sensing satellite P6. The images used were obtained from Wildlife Trust of India, taken on the 9th of March 2009 and the 8th of February 2010, at a resolution of 5.8 m. In collaboration with Wildlife Trust of India, supervised classification was conducted in combination with visual interpretation of images and ground-truth data. We categorized land-cover types measured in this study as (a) open (no trees present within a 15 m radius, a distance sufficiently larger than records of gibbon movement), including river, or fallow *jhum* patches, (b) monoculture plantations ('plantations' hereafter), including areca nut *Areca catechu*, orange *Citrus* spp., banana *Musa* spp. and tea *Camellia sinensis* plantations, and (c) closed canopy regions, as coffee *Coffea* spp., bamboo, forests and mixed plantations. We used Idrisi Selva (Eastman, 2012), Google Earth (Google, California, USA), ArcGIS Version 9 (Environmental Systems Resource Institute, California, USA) and Quantum GIS Lisboa (Quantum GIS Development Team, 2011) for classification and geo-analyses.

2.2. Assessing movement constraints

We conducted 5-min focal scans on 20 individuals from 7 gibbon groups inhabiting village forest fragments between January and May 2011 (Altmann, 1974). As these groups were in forest fragments adjoining human settlements, they were habituated to human presence. Study groups were between 2 and 5 members in size, comprised of one adult male, one adult female and any young. We sampled the adults and immature individuals (subadults and juveniles) in each group (Table A.1). Gibbons show sexual dimorphism such that adult males have black pelage while adult females have light brown pelage; however, sexing immature individuals is difficult in the field (e.g., Kakati et al., 2009). We thus classified these individuals into three age–sex categories: adult males, adult females and immature individuals. The internal state or motivation for each of these categories may differ (e.g., Singh