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Effects of habitat suitability and minimum patch size thresholds on the assessment of landscape connectivity for jaguars in the Sierra Gorda, Mexico

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ABSTRACT

Maintaining habitat and its connectivity is a major conservation goal, especially for large carnivores. Assessments of habitat connectivity are typically based on the output of habitat suitability models to first map potential habitat, and then identify where corridors exist. This requires separating habitat from non- habitat, thus one must choose specific thresholds for both habitat suitability and the minimum patch size that can be occupied. The selection of these thresholds is often arbitrary, and the effects of threshold choice on assessments of connectivity are largely unknown. We sought to quantify how habitat-suitability and patch-size thresholds influence connectivity assessments for jaguars (*Panthera onca*) in the Sierra Gorda Biosphere Reserve in central Mexico. We modeled potential habitat for jaguars using the species distribution modeling algorithm Maxent, and assessed potential habitat connectivity with the landscape connectivity software Conefor Sensinode. We repeated these analyses for 45 combinations of habitat suitability based thresholds and minimum patch sizes. Our results indicated that the thresholds influenced connectivity assessments greatly, and different combinations of the two thresholds yielded vastly different map configurations of suitable habitat for jaguars. We developed an approach to identify the pair of thresholds that best matched the jaguar occurrence points based on the connectivity scores. Among the combinations that we tested, a threshold of 0.3 for habitat suitability and 2 km^2 for minimum patch size produced the best fit (area under the curve = 0.9). Surprisingly, we found low suitable habitat for jaguars in most of the core areas of the reserve according to our best potential habitat model, but highly suitable areas in the buffer zones and just outside of the reserve. We conclude that the best and most connected potential areas for jaguar habitat are in the central eastern part of the Sierra Gorda. More broadly, landscape connectivity analyses appears to be highly sensitive to the thresholds used to identify suitable habitat, and we recommend conducting sensitivity analyses as introduced here to identify the optimal combination of thresholds.

1. Introduction

Wildlife habitat and species' ranges are diminishing rapidly due to landscape modification (Lindenmayer and Fischer, 2013; Newbold et al., 2015), and human activities such as agriculture, livestock, mining, and the expansion of urban areas (Wood et al., 2013). In addition to the loss of habitat, changes in habitat configuration can diminish the connectivity among areas occupied by different populations of a given species (Tischendorf and Fahrig, 2000). This could reduce the ability of species to survive extreme events such as fires, diseases, and predation (Clark et al., 2011), thereby increasing the risk of extinction (Reed, 2004). Changes in landscape connectivity are particularly detrimental to apex predators that require large areas of suitable habitat, and securing habitat corridors for these species is critical for their long-term conservation (Soisalo and Cavalcanti, 2006). Thus, it is important to both preserve the remaining habitat available for species and to maintain or enhance habitat connectivity (Peterson, 2011; Sanderson et al., 2002a, 2002b).

Mapping species distributions is the first step when developing conservation management strategies that account for population and habitat patterns at local and landscape scales (Cavalcanti and Gese, 2009; Turner et al., 2001). Often, obtaining the actual species distribution is not possible because of time constraints or incomplete data. This is why presence-only models are often used to estimate potential habitat based on species occurrences (presence-only data) and predictor variables that are biologically meaningful for the species (Bradley et al., 2012). The resulting models can then be used to identify additional areas with similar environmental conditions that could potentially serve as habitat for the species of interest. Once these potential habitat areas are identified, they can be analyzed in terms of their spatial configuration and connectivity.

Connectivity can be measured in many different ways, either focusing only on patches of suitable habitat, or on the entire landscape (Calabrese and Fagan, 2004). However, connectivity assessments based on graph theory, which quantify the arrangement of habitat

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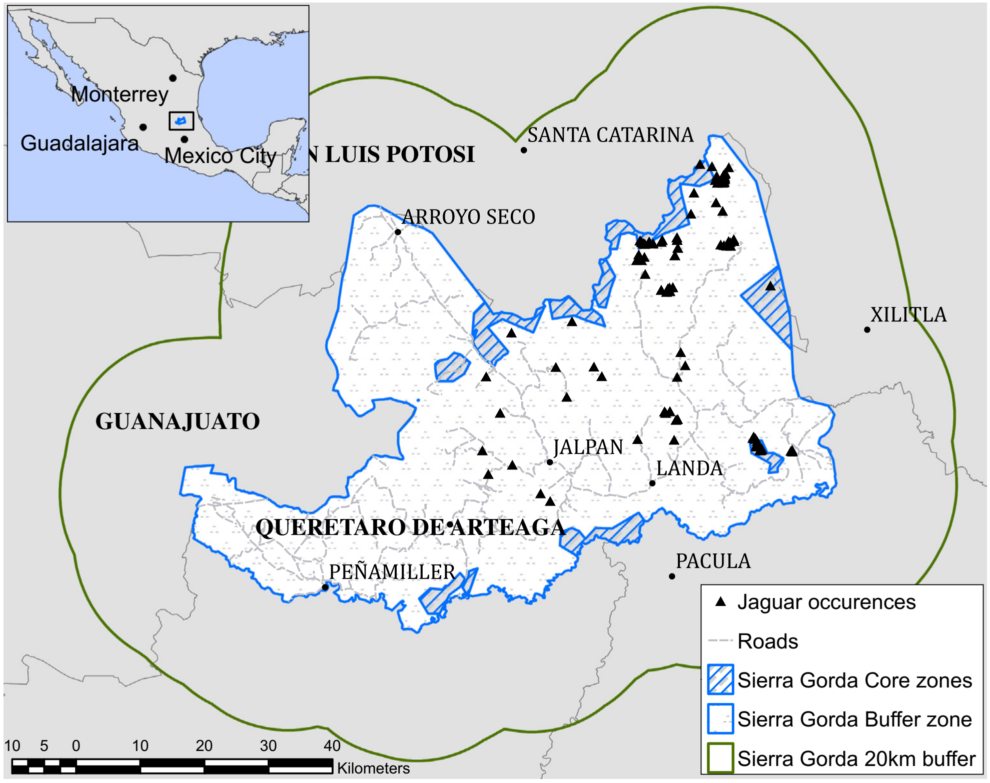

Fig. 1. Sierra Gorda Biosphere Reserve in Central Mexico. The core zones are located at the margins of the reserve.

patches, have become popular for conservation purposes (Correa Ayram et al., 2015). In the graph theory framework (Bunn et al., 2000), a potential habitat network is organized in patches of potential habitat (nodes) that are connected via edges (Urban and Keitt, 2001). However, there are several challenges associated with the assessment of habitat connectivity in this framework. First, because the output of potential distribution models is a continuum of suitability values, it is necessary to choose a threshold to differentiate habitat from non-habitat and hence delimitate potential habitat nodes. Different techniques have been proposed to define suitable habitat areas, such as using an arbitrary threshold (Manel et al., 1999) or to determine the threshold that minimizes the error rate for positive and negative observations in a potential habitat model (Jiménez-Valverde and Lobo, 2007; Liu et al., 2013). A second challenge is that any threshold of habitat suitability will result in patches that are highly variable in size, but many species can only occur in patches of a certain minimum patch size (Schutltz and Crone, 2005). Ultimately, the selection of both the suitable habitat and the minimum patch size thresholds may greatly affect the configuration of potential habitat patches (Saura and Martinez-Mlian, 2001; Turner, 1989; Wu, 2004) and therefore affect subsequent habitat connectivity analysis.

Analyses of habitat connectivity are inherently place- and species-specific, but case studies are valuable, especially in areas with high biodiversity and when the results can be translated to other ecosystems. One such area is Mexico, which has a high diversity of mammals, including several species of felines (CONABIO, 2008). Felines are considered a keystone species because they can control herbivore populations (Miller et al., 2001; Terborgh et al., 2001). Furthermore, felines are an important target for conservation plans, and their presence can indicate healthy ecosystems (Sanchez et al., 2002; Terborgh et al., 2001). However, populations of many felines, including jaguar (*Panthera onca*), have decreased in Mexico, and their habitats have become increasingly fragmented (Polisar et al., 2003). Prior studies have analyzed the potential habitat distribution of jaguars throughout Mexico (Cevallos et al., 2007; Rodríguez-Soto et al., 2011). There are also some local studies of jaguar habitat in southern (Figel et al., 2009), central (Monroy-Vilchis et al., 2008), and northern Mexico (Navarro-Serment et al., 2005), and jaguar habitat connectivity at local level in the northeast of Puebla state (Petracca et al., 2014). However, there is still uncertainty about landscape-scale jaguar habitat patterns, i.e., the scales where most conservation decisions are made. In terms of management, understanding habitat connectivity is important for the prioritization of conservation efforts, and to promote the effective allocation of conservation resources (Moilanen et al., 2009). Furthermore, studies on habitat connectivity are limited, despite their importance for the long-term conservation of wide-ranging species such as jaguar (Soisalo and Cavalcanti, 2006).

Here our goals were to a) assess potential habitat for jaguars and its connectivity in the Sierra Gorda reserve in Central Mexico, b) examine in detail the effects of different thresholds of habitat suitability and minimum patch size on the resulting connectivity, and c) develop a method to identify the optimal combination of these thresholds. Our hypothesis is that larger habitat patches, obtained with lower thresholds both for habitat suitability and minimum patch size, will promote better landscape connectivity for jaguars (Saura and Pascual-Hortal, 2007). It has been shown that larger patches of habitat promote landscape connectivity for large carnivores (Maehr and Deason, 2002; Theobald et al., 2011). Specifically, we predict that habitat suitability will have a stronger influence on connectivity than patch size. By integrating potential habitat and connectivity assessments, we hope to better understand habitat use by jaguars, and to assess habitat connectivity for other species and in other areas more accurately.

2. Methods

2.1. Study area

We conducted our study in the Sierra Gorda Biosphere Reserve (Sierra Gorda) in central Mexico, and all areas within 20 km of its border (11,548 km^2, Fig. 1). The Sierra Gorda is situated in the Sierra Madre