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Evaluating the effectiveness of local- and regional-scale wildlife corridors using quantitative metrics of functional connectivity

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ABSTRACT

While corridors in conservation have a long history of use, evaluations of proposed or existing corridors in conservation landscapes are important to avoid the same fate as poorly-functioning “paper parks”. We used resistance surface modeling and circuit theory to evaluate a number of corridors developed at regional and at local scales that aim to improve connectivity for large wildlife in the central part of the Kavango-Zambezi transfrontier conservation area. We used hourly GPS data from 16 collared African elephants (*Loxodonta africana*), and associated environmental data at used versus available movement paths, to develop a hierarchical Bayesian path selection function model. We used the resulting resistance surface across the study area as an input into circuit theory modeling to assess how well connectivity levels were captured by both types of corridors relative to several alternative scenarios. We found that the majority of regional-scale corridors performed relatively well at capturing elevated levels of connectivity relative to non-corridor comparisons, with 7 of 9 corridors rated as good or better in terms of how they captured electrical current levels (a proxy for connectivity). In contrast, only 14 of 33 smaller-scale, local corridors captured significantly higher levels of connectivity than adjacent non-corridor areas. Our results have practical implications for the design and implementation of wildlife connectivity conservation efforts in the world's largest transfrontier conservation landscape. Modern connectivity science approaches can help evaluate which proposed corridors are likely to function as intended, and which may need further refinement.

1. Introduction

For large-bodied, wide-ranging wildlife species to persist in the Anthropocene, conservation landscapes that contain core protected areas within a matrix of human-dominated land uses must somehow be linked or connected with one another (Bolger et al., 2008; Caro et al., 2009). Movement corridors represented a key advance in the design of conservation landscapes. While there were early debates over the effectiveness of corridors as a conservation tool (Beier and Noss, 1998; Haddad et al., 2000), a recent meta-analysis covering 20 years of experimental corridor research found that corridors increased the movements of species between habitat patches by 50% as compared to non-connected patches (Gilbert-Norton et al., 2010). Though their effectiveness in conservation landscapes is less clear-cut (Caro et al., 2009; Jain et al., 2014), corridors remain popular and widespread tools used in conservation planning, land use zoning, and sustainable development plans around the world (African Wildlife Foundation, 2017; Brodie et al., 2016; Jain et al., 2014; Jones et al., 2012; National Fish and Wildlife Federation, 2017).

In recent years there has been an increasing emphasis on broadening the evaluation of connectivity from a focus on corridors to the entirety of landscapes and regions in which conservation occurs. The development of tools such as least-cost path mapping (Sawyer et al., 2011), circuit theory (McRae et al., 2008), and a variety of GIS-friendly connectivity toolkits (e.g., CorridorDesign, 2017) have allowed conservation scientists and planners to quantify connectivity across entire conservation landscapes with ever-increasing degrees of sophistication. The results of such exercises have been useful for investigating a wide variety of academic questions related to connectivity across different landscapes and species (Cushman and Lewis, 2010; Elliot et al., 2014; Walpole et al., 2012; Zeller et al., 2014), as well as for informing conservation plans using the latest methods in connectivity science

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(Cushman et al., 2016; Poor et al., 2012).

Evaluations of existing or proposed corridors in real-world conservation landscapes can provide useful feedback to policy makers and conservation planners on their effectiveness (Bond et al., 2017; Brodie et al., 2016; Caro et al., 2009). Corridor evaluations can also be used to redesign landscape connectivity in instances where existing corridors are not functioning. Recent work from southeast Asia warns that in the same way that many protected areas are protected in name only, expert-defined "paper" corridors that do not improve ecological connectivity are rife in the region (Jain et al., 2014). Evaluating proposed or actual corridors using modern connectivity science approaches can help inform conservation policy on existing or upcoming corridors and provide land managers and other interested stakeholders with confidence that corridors will work as intended (Cushman et al., 2013). Such evaluations can be especially important for regional-scale, transfrontier corridors that are designed for wide-ranging flagship species such as jaguars *Panthera onca* (Rabinowitz and Zeller, 2010), grizzly bears *Ursus arctos* (Proctor et al., 2015), and African elephants *Loxodonta africana* (Roever et al., 2013), where it may be difficult to gather empirical evidence of use at corridors identified across such large scales. In these instances, modeling of connectivity levels in corridors may provide the next best evaluation alternative to independently-collected empirical data (Koen et al., 2014; McClure et al., 2016).

Here, we use GPS movement data from African elephants to assess connectivity captured by wildlife corridors in the central part of the Kavango-Zambezi (KAZA) transfrontier conservation landscape in southern Africa. We first estimated landscape resistance to elephant movements, using a Bayesian hierarchical path selection function based on environmental and anthropogenic landscape variables. We then applied circuit theory (McRae et al., 2008) to the resistance layer to evaluate the effectiveness of corridors at capturing connectivity at two scales: (1) regional-scale corridors that have been identified in the KAZA master integrated development plan (KAZA TFCA Secretariat, 2014); and (2) small-scale corridors identified and mapped by local communities on their traditional lands (B. Jones, unpublished data). We translate our evaluation results into practical scoring and recommendations for managers to consider.

2. Materials and methods

2.1. Study site

Our work covers the central part of KAZA, the world's largest transfrontier conservation landscape ($> 500,000\ \text{km}^2$) that includes a complex of protected areas, communal lands, and other land use types across parts of Angola, Botswana, Namibia, Zambia, and Zimbabwe. Fundamental to KAZA's vision are functioning, connected socio-ecological systems spanning 5 countries that allow for the movements and migrations of large wildlife species, upon which most tourism in the area is premised. While the movement ecology of a variety of species has been studied in KAZA (e.g., Cozzi et al., 2013; Loarie et al., 2009b; Naidoo et al., 2016; Naidoo et al., 2012), only a few studies have explicitly examined wildlife connectivity (Cushman et al., 2016; Elliot et al., 2014). An explicit assessment of wildlife connectivity is critical in this region since the multitude of fences, roads, and anthropogenic landscape uses in the region have the potential to significantly disrupt wildlife space use and migratory movements (Chase and Griffin, 2009; Naidoo et al., 2014). Connectivity research is also important from a policy standpoint because various types of corridors are currently being suggested for the central KAZA landscape with little formal development or evaluation using modern connectivity conservation approaches, including regional Wildlife Dispersal Area (WDA) pathways and over 50 local-scale "micro-corridors" that have been identified by local communities as key wildlife movement areas (Fig. 1). See Appendix A in Supplementary material for additional details on the study site and our methodologies.

2.2. Movement data

We evaluated functional connectivity at our study site using data from 16 elephants (15 females, one male) collared in the Namibian part of central KAZA (Fig. A1). Ten of the elephants were collared in October 2010, with most of these collars functioning without issue from deployment until they were removed in August 2012, except for the male elephant's collar which stopped functioning in May 2011. The remaining 6 elephants were collared in March 2016, and we used data collected through mid-September 2016 from each of these. For both sets of animals, GPS locations were recorded hourly for each collar. Overall, our data set encompasses over 73,000 observations across 6 separate wet and dry season periods. While our sample of 16 collared individuals is modest, the collars (with the exception of the single male) were embedded in breeding herds of between 8 and 60 individuals, and therefore at a minimum our movement trajectories are representative of those of several hundred elephants.

2.3. Path selection functions

We used path selection functions (PSF) to develop models of how resistant our study landscape was to elephant movement. Path selection functions divide movement trajectories of animals into segments, and then characterize the environmental conditions at these 'used' segments compared to a set of non-used segments that would have been 'available' for the elephant to use. Key decisions to be made when constructing a PSF involve the time period an individual path segment should cover, the maximum distance away from the path that non-used paths are located within, and how many non-used paths should be employed. To determine path temporal length, we used data from collared elephants in the hot dry season of 2011 (August – November) to determine that individual elephants had an average drinking interval at permanent water bodies of between 1.1 and 3.7 days (median 1–3; max 3–16, mode 2). Others have also noted that on average elephants drink every 2 days (de Knegt et al., 2011). We thus used 2 days as the most representative drinking interval for elephants, and therefore as the minimum path unit that is representative of regularized elephant behavior during the most resource-restrictive period of the year. In addition, net displacement for 90% of the 2-day pathways from our collared elephants was < 20 km. We therefore used 20 km as the maximum distance away from the middle of the 2-day trajectory in question at which randomly-rotated control paths could occur. We also used 20 random paths per used path (following Northrup et al., 2013) to generate the randomly selected non-used paths (Fig. A2). See Appendix A for a review of these issues in wildlife path selection function studies.

2.4. Environmental variables

We developed a hierarchical path selection function using data from all 16 of our collared elephants. We selected two categories of variables to include as predictor variables in our PSF. Boundary variables, which we expected would exert a negative or blocking effect on elephant movement path, included rivers, paved roads, fences, infrastructure development, and anthropogenic land uses such as agriculture and urban areas. These variables were coded as dummy variables, i.e., 1 – the boundary was crossed during a two-day path, or 0 – the boundary was not crossed. We also quantified 4 variables representing vegetation and other critical resources needed by elephants along used and available paths. These included the average Enhanced Vegetation Index (EVI) from the MODIS satellite, the average percentage of tree cover, and the presence of 2 key land use/land cover classes: woodland and floodplains. Finally, we included an interaction with season and all vegetation variables, to reflect the hypothesis that elephants' preferences for vegetation type and amount may be different across dry versus wet seasons. See Appendix A for further details.