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Defining spatial conservation priorities in the face of land-use and climate change

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ABSTRACT

Creating and managing protected areas is critical to ensure the persistence of species but dynamic threats like land-use change and climate change may reduce the effectiveness of protected areas planned under a static approach. Here we defined spatial priorities for the conservation of non-flying mammals inhabiting the Cerrado Biodiversity Hotspot, Brazil, that overcome the likely impacts of land-use and climate change to this imperiled fauna. We used cutting-edge methods of species distribution models combining thousands of model projections to generate a comprehensive ensemble of forecasts that shows the likely impacts of climate change in mammal distribution. We also generate a future land-use model that indicates how the region would be impacted by habitat loss in the future. We then used our models to propose priority sites for mammal conservation minimizing species climate-forced dispersal distance as well as the mean uncertainty associated to species distribution models and climate models. At the same time, our proposal maximizes complementary species representation across the existing network of protected areas. Including land-use changes and model uncertainties in the planning process changed significantly the spatial distribution of priority sites in the region. While the inclusion of land-use models altered the spatial location of priority sites at the regional scale, the effects of climate change tended to operate at the local scale. Our solutions already include possible dispersal corridors linking current and future priority sites for mammal conservation, as well as a formal risk analysis based on planning uncertainties. We hope to provide decision makers with conservation portfolios that could be negotiated at the decision level.

1. Introduction

Human population growth has triggered many threats to biodiversity like global changes, overexploitation, pollution, and introduction of invasive species (Brook et al., 2008; Schipper et al., 2008; Hoffmann et al., 2010; Maclean and Wilson, 2011; Mantyka-Pringle et al., 2011). Among these threats, land-use change and climate change are considered the worst (Sala et al., 2000; Thomas et al., 2004; Pereira et al., 2010) and they have a clear synergistic effect (Brook et al., 2008; Asner et al., 2010; Mantyka-Pringle et al., 2011). Further, assessments of future global changes predict that biodiversity will continue to decline (Sala et al., 2000; Pereira et al., 2010).

Climate change causes selective micro-evolutionary pressures in species, favoring individuals capable of dispersing either locally or regionally to track suitable habitats (Holt, 1990; Parmesan and Yohe, 2003; Parmesan, 2006; Dawson et al., 2011). Given the proper timeframe, the dispersal process can result in range shifts that have been of great importance for species dealing with past and current climatic changes; thus, it is likely that dispersal should have great importance in the future (Graham and Grimm, 1990; Lyons, 2003; Parmesan and Yohe, 2003). However, human-driven landscape modifications may block dispersal from current to the future suitable habitats increasing species extinction risk by their synergistic effect with changing climates (Brook et al., 2008; Asner et al., 2010; Hof et al., 2011; Mantyka-Pringle et al., 2011).

The main issue here is that climate change, as well as other dynamic threats, poses a new challenge to the static way conservation planning is usually done (Hannah, 2010). Conservation biology has proposed creative solutions to deal with these threats, most focusing on the establishment of protected areas (Williams et al., 2005; Lawler, 2009; Mawdsley et al., 2009; Hannah, 2010; Dawson et al., 2011; Mawdsley, 2011; Loyola et al., 2012). Creating and managing protected areas is critical to ensure the persistence of species but these dynamic threats may reduce the effectiveness of protected areas planned under a static approach (Araújo et al., 2004; Hannah, 2010; Dobrovolski et al., 2011a,b). It seems necessary to incorporate species' range shifts in spatial conservation plans to ensure their effectiveness in the future (Araújo et al.,

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2004; Hannah et al., 2007; Hannah, 2010). Some recent studies did have included the effects of the future climate change aiming to deliver more effective conservation plans, but they usually ignore land-use changes (e.g. Hannah et al., 2007; Carroll et al., 2010) and considered subjective values or unrealistic species' dispersal capacity (e.g. Carroll et al., 2010).

Species distribution models (SDMs) have been used to predict the present and future species' distributions although different methods for modeling species distribution and different climate models (e.g. coupled Atmosphere–Ocean General Circulation Models, AOGCMs) may produce very distinct results increasing uncertainties in the projections and their applicability to conservation (Araújo and New, 2007; Diniz-Filho et al., 2009; Loyola et al., 2012). The inclusion and reduction of uncertainties in conservation planning is therefore important to increase the quality of spatial solutions (Regan et al., 2009; Wilson, 2010).

Here we developed spatial conservation plans that accommodate species' range shifts induced by climate change and landscape change predicted by a land-use model. Further, we measured and reduced uncertainties associated with SMDs, and modeled the dispersal capacity of each species aiming at minimizing the distance between their current and future distributions along priority sites for conservation.

2. Methods

2.1. The case study

We used mammals and the Brazilian Cerrado (a woodland savanna) as our case study for several reasons. First, the Cerrado has an enormous vegetation complexity that includes grassland, savanna and forest, harboring a highly threatened biodiversity (Myers et al., 2000; Klink and Machado, 2005; Ribeiro and Walter, 2008). Second, high rates of land conversion have already transformed more than half of its two million km^2 in anthropogenic land use (Klink and Machado, 2005). Although this region has been included in previous conservation schemes (see Brooks et al., 2006 for a review), currently only 2.2% of its area is under strictly protection (IUCN I–IV categories, see Klink and Machado, 2005). Third, it has been demonstrated that the effect of climate change and land-use change could be strong in the Cerrado given that climate change results in large species' range shifts and high rates of habitat conversion impedes species from tracking suitable habitats (Klink and Machado, 2005; Diniz-filho et al., 2009; Loyola et al., 2012). Fourth, mammals are under many threats from local to global scale, which results in a faster extinction rate than those recorded by background extinction (Schipper et al., 2008; Barnosky et al., 2011). It is also a well-known group both in terms of their natural history and evolution, making the access to biological traits easier than in other groups. Finally, planning for the conservation in the Neotropics in the face of climate and land-use changes are among the most cutting-edge and important topics in the science of spatial conservation prioritization (Moilanen et al., 2009a).

2.2. Land use model

We modeled land use changes with variables from different sources. We compared the Cerrado land use between 2002 and 2008 (http://siscom.ibama.gov.br/monitorabiomas/index.htm) to generate a matrix of transition probability between native areas to anthropogenic areas. We modeled the land use with the module Land Change Modeler – LCM, available in Idrisi Taiga Version (Eastman, 2009), using the following explanatory variables: digital elevation model and annual accumulated precipitation (www.worldclim.org), proximity to roads, proximity to recent deforested areas and proximity to cities (http://mapas.mma.gov.br/i3geo/datadownload.htm). LCM is a machine learning procedure that uses Markov Chains to project future land-use conditions. In order to evaluate model precision, we inverted the maps from 2002 and 2008 and the expected land-use was projected back into 1990. Then we generated a total of 458 control points to cover the entire Cerrado by doing a visual inspection of MrSID images from 1990 (https://zulu.ssc.nasa.gov/mrsid/). Finally, we predicted the land use in 2050 with a spatial resolution close to 500 $\times$ 500 m.

2.3. Species distribution models

We updated previous lists of non-flying mammals occurring in the Cerrado (Marinho-Filho and Juarez, 2002; Marinho-Filho et al., 2007) and obtained 154 species range maps (see Table A1) from the International Union for Conservation of Nature (IUCN version 2011; http://www.iucnredlist.org/technical-documents/spatial-data#mammals). We mapped the extent of occurrence maps of each species to the resolution of 0.1° $\times$ 0.1° of latitude/longitude (about 11,200 m in the Equator line) that covered the full extent of the Cerrado. From these maps, we derived species presences and absences considering that all cells inside the limits of a range map are presences and those outside the range map are absences (see Diniz-Filho et al., 2009).

We obtained the following current climatic variables from the WorldClim database (www.worldclim.org/current): annual mean temperature, mean diurnal range in temperature, temperature seasonality, annual precipitation, precipitation seasonality and precipitation of coldest quarter. These variables were generated by an interpolated climate data from 1950 to 2000 periods (Hijmans et al., 2005). We used the same climate variables projected into the future (year 2050) by three Atmosphere–Ocean General Circulation Models (AOGCMs: CCCMA_CGCM2, CSIRO-MK2.0 and UKMO_HADCM3) of the B2a emission scenario. These variables were generated by application of delta downscaling method on the original data from Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (available by International Centre for Tropical Agriculture in http://ccafs-climate.org). This method assumes changes in climates only over large distances and the relationships between variables are maintained from current towards the future (see http://ccafs-climate.org/ for more details). We rescaled both current and future climate variables to our grid resolution.

We used presence and absence data derived from species range maps and the climatic variables to model species distributions (see Fig. 1). The use of these data is still incipient in the SDM literature (but see Lawler et al., 2009; Diniz-Filho et al., 2009; Loyola et al., in press for recent examples). However, in regions with poor knowledge about species distribution and under high threat such as the Cerrado such approach may be a first assessment to identify general priorities that can be revised after data improvement (Lemes et al., 2011). This hierarchical approach is one of the proposals of conservation biogeography (Whittaker et al., 2005).

To generate SDMs, we used nine modeling methods, which differ both conceptually and statistically (Franklin, 2009). We grouped them into three separate sets (distance, statistical and machine-learning methods), and applied the ensemble forecasting approach within each set (see Fig. 1 and text below). We chose to keep these three different sets of SDMs separated to highlight the differences model prediction the performance of the methods as well as the consequences of their differences in our final prioritization scenarios. Distance methods (henceforth, DIST) were BIOCLIM (Busby, 1991), Euclidian and Gower distances (Carpenter et al., 1993). Statistical methods (STAT) were Generalized Linear Models (GLM; Guisan et al., 2002), Generalized Additive Models