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Global agricultural expansion and carnivore conservation biogeography

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ABSTRACT

Global conservation prioritization must address conflicting land uses. We tested for spatial congruence between agricultural expansion in the 21st century and priority areas for carnivore conservation worldwide. We evaluated how including agricultural expansion data in conservation planning reduces such congruence and estimated the consequences of such an approach for the performance of resulting priority area networks. We investigated the correlation between projections of agricultural expansion and the solutions of global spatial prioritizations for carnivore conservation through the implementation of different goals: (1) purely maximizing species representation and (2) representing species while avoiding sites under high pressure for agriculture expansion. We also evaluated the performance of conservation solutions based on species' representation and their spatial congruence with established global prioritization schemes. Priority areas for carnivore conservation were spatially correlated with future agricultural distribution and were more similar to global conservation schemes with high vulnerability. Incorporating future agricultural expansion in the site selection process substantially reduced spatial correlation with agriculture, resulting in a spatial solution more similar to global conservation schemes with low vulnerability. Accounting for agricultural expansion resulted in a lower representation of species, as the average proportion of the range represented reduced from 58% to 32%. We propose that priorities for carnivore conservation could be integrated into a strategy that concentrates different conservation actions towards areas where they are likely to be more effective regarding agricultural expansion.

1. Introduction

Threats to biodiversity are unevenly distributed around the globe – some areas are highly vulnerable, whereas others remain relatively safe (Sanderson et al., 2002). This has prompted two important research agendas in conservation biogeography: evaluating conservation conflicts (*sensu* Balmford et al., 2001) and developing systematic conservation planning (*sensu* Margules and Pressey, 2000).

Broad-scale studies focusing on conservation conflicts seek to know whether geographical patterns in human development coincide with areas harboring special biological features, such as high levels of biological diversity. Most studies have revealed that such conflicts are widespread (e.g., Balmford et al., 2001; Araújo, 2003; Luck, 2007a). Systematic conservation planning, in turn, has incorporated different biological and socioeconomic information to propose sets of priority areas for conservation investment. Such information encompasses human land use (e.g., Visconti et al., 2011; Faleiro et al., 2013); land costs (e.g., Ando et al., 1998; Loyola et al., 2009, see also Naidoo et al., 2006 for a review); opportunity costs (e.g., Carwardine et al., 2008; Wilson et al., 2011) and synthetic data such as human footprint (e.g., Loyola et al., 2008; Terribile et al., 2009).

Global strategies for biodiversity conservation have historically dealt with these conflicts under two opposing (but complementary) approaches: reactive and proactive (see Brooks et al., 2006, for a review and Dobrovolski et al., 2011, for an analysis of agricultural expansion over these priorities). The purpose of the former is to mitigate threats by prioritizing highly vulnerable areas (e.g., Biodiversity Hotspots; Myers et al., 2000), whereas the latter prioritizes less-impacted areas (e.g., Last of the Wild; Sanderson et al., 2002), thus aiming to minimize conservation conflicts.

Recent prioritization approaches have included socioeconomic information such as human population density or land cost (which can be considered surrogates for human threat) to define more

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cost-effective conservation priorities (Moilanen et al., 2009; Faleiro and Loyola, 2013). When such information is considered, conservation planning is implicitly sought to alleviate conservation conflicts and will likely find conservation solutions similar to those identified by proactive conservation approaches. Conversely, approaches that do not incorporate socioeconomic information will likely lead to conservation conflicts and, consequently, will be similar to reactive approaches.

One of the main threats to biodiversity is the destruction of natural habitats resulting from anthropogenic land conversion (Schipper et al., 2008; Foley et al., 2011; Hoffmann et al., 2011), mainly propelled by agricultural expansion (Tilman et al., 2001, 2011; Foley et al., 2011). Indeed, the increase in human population and human consumption of resources – including meat and agrofuels (Hill et al., 2006) – has caused a constant expansion of areas destined for agricultural production. The need to understand these patterns of land use change has yielded many models of agricultural extent, for both the past (Goldewijk et al., 2011) and the future (IMAGE Team, 2001). These models are used to anticipate the consequences of this expansion for biodiversity and to devise conservation strategies that could avoid conservation conflicts (Sala et al., 2000; Scharlemann et al., 2004; Dobrovolski et al., 2011).

Mammals have been routinely used as a target group for conservation applications, such as the definition of spatial conservation priorities, and are considered a flagship taxonomic group (e.g., Ceballos et al., 2005; Cardillo et al., 2006; Schipper et al., 2008; Rondinini et al., 2011). Among mammals, carnivores are of particular interest for conservation applications (e.g., Valenzuela-Galván et al., 2007; Loyola et al., 2008, 2009) because they occupy high trophic positions, thus implying low population densities and increased vulnerability to extinction in response to agriculture and other threats (Woodroffe and Ginsberg, 1998). Therefore, carnivores are “the flagship among flagships”. Consequently, there is much biological information available about this group, including low uncertainty about their geographical distribution, compared with other mammals (e.g., Bininda-Emonds et al., 1999; Purvis et al., 2000; Valenzuela-Galván et al., 2007; Cardillo et al., 2004; Loyola et al., 2008, 2009; Diniz-Filho et al., 2009). Furthermore, as predators, carnivores often play an important role in the top-down regulation of ecosystem dynamics (Terborgh et al., 2001; Williams et al., 2004).

Here, we tested the following hypotheses: (i) there is a conflict between the forecasted agricultural impacts for the 21st century and the best areas for investment in carnivore conservation. (ii) Potential conflicts can be alleviated when conservation planning considers agricultural expansion. (iii) Conservation solution obtained by unconstrained conservation planning overlaps with reactive global priorities, whereas that obtained when agriculture expansion is considered matches proactive global priorities. Additionally, we evaluated whether solutions obtained by both prioritization approaches (incorporating or not incorporating agricultural information) differ with respect to their performance in representing carnivore occurrences.

2. Methods

2.1. Data

We overlaid the extent of occurrence maps of 245 carnivores (Mammalia: Carnivora) obtained from the Global Mammal Assessment onto a grid with a spatial resolution of 0.5° × 0.5°. We considered a species to be present in a cell if any extent of its mapped distribution occurred in the focal grid cell. We generated a map of species richness by overlapping these presence/absence maps. We retrieved the conservation status of all species from the IUCN Red List of Threatened Species (IUCN, 2011) and converted them into numerical values of increasing extinction risk following Purvis et al. (2000): 0 (least concern), 1 (near threatened), 2 vulnerable, 3 (endangered), and 4 (critically endangered). We assigned 4 (critically endangered) to data-deficient species as a conservative strategy, following the precautionary principle advocated by Mace et al. (2008). To test for the effect of this decision, we also ran the analyses attributing 0 (least concern) to data-deficient species. We used the above information to obtain the minimum range size and maximum value of extinction risk across species co-occurring in each grid cell. The reference coordinate system of all spatial data was WGS-84.

We mapped agricultural land-use forecasts for the 21st century using the land cover map produced by the Integrated Model to Assess the Global Environment (IMAGE, version 2.2) (IMAGE Team, 2001). The resulting map summarized at a resolution of 0.5° the number of years that each grid cell is cultivated during the 21st century (agricultural impact, hereafter) as an average of all six scenarios of the Special Report on Emissions Scenarios (SRES; IPCC, 2000) used by IMAGE. Consequently, the higher the grid cell value, the higher the agricultural impact the area is forecasted to undergo until the end of the 21st century.

For a comparison with global prioritization strategies, we obtained maps of five global prioritization schemes (Brooks et al., 2006): Biodiversity Hotspots (Mittermeier et al., 2004) and Crisis Ecoregions (Hoekstra et al., 2005), which are both reactive approaches; and Frontier Forests (Bryant et al., 1997), Last of the Wild (Sanderson et al., 2002) and High-Biodiversity Wilderness Areas (Mittermeier et al., 2003), which are proactive approaches.

2.2. Spatial prioritization analyses

We used the Zonation framework and software (version 3.1; Moilanen et al., 2012a) to derive global priorities for carnivore conservation. Zonation provides maximum utility conservation solutions in accordance with the core principles of systematic conservation planning: comprehensiveness, adequacy, representativeness, and efficiency. The main output of Zonation is a spatial ranking of conservation priorities (Moilanen et al., 2009). Zonation has been used to solve different conservation problems in different environmental contexts for various focal taxonomic groups and at several spatial extents, and it has the advantage of allowing the integration of various costs (e.g., monetary) in the prioritization process (Kremen et al., 2008; Eklund et al., 2011; Moilanen et al., 2011; Moilanen et al., 2012a; Faleiro and Loyola, 2013).

We performed the prioritization analyses using two major Zonation analysis variants, the additive benefit function (ABF) and core-area Zonation (CAZ) (Moilanen et al., 2012a). ABF favors grid cells with higher species richness, combined with a species-area approach to minimize extinction rates (Moilanen et al., 2012a). CAZ considers each species separately, securing high-quality locations for all species, even when they occur in otherwise species-poor regions. CAZ prioritizes sites gathering a higher proportion of species' geographical distribution, thus favoring the rarest species in the final solution. We ran both ABF and CAZ because they represent conceptually different views of conservation value (Moilanen et al., 2012b) which can yield different results. However, we believe that CAZ is the best option because representing the rarest species is more directly related to the complementarity strategy, which is considered a better metric to orient conservation efforts in comparison to species richness (Araújo and Rahbek, 2007).

We obtained two different conservation solutions using both ABF and CAZ removal rules (see Moilanen et al., 2012b). The first solution aimed only to maximize the representation of carnivore biodiversity (*biosolution*, hereafter). The second solution (*agrosolution*, hereafter)