Global agricultural expansion and carnivore conservation biogeography

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A B S T R A C T
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.

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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...
cost-effective conservation priorities (Moilanen et al., 2009; Faleiro and Loyola, 2013). When such information is considered, conservation planning is implicitly suited 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 (Salas 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 flags. 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. Nevertheless, that obtained when agriculture expansion is considered 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)
was obtained by constraining the prioritization process with a cost layer that represented the agricultural land use forecasts for the 21st century (i.e., we considered the cost of a cell to be equivalent to the number of years the cell was forecasted to be cultivated along the 21st century), aiming to find a cost-effective solution in terms of prounes of the priority areas to be converted to agriculture during this century. Following the Strategic Plan 2011–2020 of the Convention on Biological Diversity (CBD, 2012), we used a cutoff of 17% to define the spatial extent of our conservation plans.

2.3. Analysis of agricultural conservation conflict

We evaluated the potential ongoing conflicts between agricultural demand and biodiversity conservation using spatial correlation analyses between the projected agriculture impact and global conservation value of each grid cell. We ran analyses for three measures of importance for carnivore conservation: (i) species richness and the ranking of grid cells according to (ii) the biosolution and (iii) the agrosolution. Due to computational limitations, we were not able to use all grid cells in the spatial correlation analyses. Therefore, we sampled 5000 grid cells randomly and analyzed them. Because of spatial autocorrelation in the data, correcting to achieve geographically effective degrees of freedom (see below) is necessary (resampling or reducing resolution is not expected to affect correlations).

2.4. Comparing solutions

To characterize the performance of conservation solutions (biosolution versus agrosolution) in terms of carnivore conservation, we used the following measures: (i) the number of species occurrences covered (a proxy for the number of populations protected – sensu Ceballos et al., 2005); (ii) the spatial correlation between the rankings of cells provided by the focal solution and the minimum range size among the species present in each grid cell; and (iii) the maximum extinction risk among the species present in each grid cell. Because geographical data are often spatially autocorrelated, we used Clifford et al.’s (1989) method to find the correct degrees of freedom for the statistical tests in all correlation analyses. These analyses were performed using SAM software (Spatial Analysis in Macroecology, v. 4.0; Rangel et al., 2010; freely available at www.eceevol.ufg.br/sam). Additionally, for each conservation solution we investigated (using species as statistical units) the relationship between the proportion of species' range under protection along with (i) the overall size of their geographical range and (ii) their extinction risk.

We evaluated the overall cost of each conservation solution in terms of prounes to agricultural conversion by summing the values of agricultural impact across the top 17% grid cells included in each conservation solution.

We tested for the significance of spatial congruence between the biosolution and the agrosolution and existing global biodiversity conservation priority schemes using randomization tests. We first quantified the observed spatial overlaps by counting the number of grid cells (containing at least one carnivore occurrence) that were included both in our conservation solutions and in the focal global prioritization schemes (i.e., observed value). We estimated the significance of these spatial overlaps by randomizing over the global grid (1000 times) the positions of the cells included in our conservation solutions and by calculating the proportion of spatial overlap between them and the global prioritization schemes as above. The proportion of randomized values equal or superior to the observed value was considered as the \( P \)-value of the randomization test. The null hypothesis that the observed overlap was not different from the values that could be found by chance was tested at the level \( \alpha \) of 5%.

3. Results

The total number of carnivore occurrences was 696,710, distributed over 62,498 grid cells. The highest carnivore species richness – up to 35 species per cell – was concentrated in southeastern Asia, the southern side of the Tibetan Plateau, the Indochinese Peninsula and Malaysia; tropical Africa, especially in the savannas; and the Colombian Andes (Fig. 1A). These areas also concentrated species with the smallest ranges, as shown by the map of minimum range and overlap with well-known biodiversity centers of endemism, such as Central America, Chile, California, Madagascar, Central Brazil, the Iberian Peninsula and Japan (Fig. 1B). These areas also harbored the most-threatened species (Fig. 1C).

The IMAGE projections for agricultural expansion during the 21st century forecasted more intense agricultural land use (through time and scenarios) in areas currently covered by agriculture, such as the Uruguayan savanna ecoregion in South America, the Corn Belt in United States, Southern and Eastern Africa, Europe and Southeastern Asia. Moreover, the agricultural extent can spread into areas not currently affected by agriculture, as is the case for most of Amazon, the western parts of Africa and North America, and even in some parts of Europe and Asia (Fig. 2).

The conservation solutions obtained either by CAZ or ABF were quite similar. The ranking of the grid cells were strongly correlated between CAZ and ABF (Pearson’s \( r = 0.81 \) for the biosolution, and Pearson’s \( r = 0.92 \) for the agrosolution). Therefore, we choose to present only CAZ results, as the different variations of Zonation’s removal rule we tested did not affect our conclusions.

According to the biosolution, the 11,326 best grid cells (17%) for carnivore protection were distributed in Africa (3449; 30%), Asia (2808; 25%), South America (2529; 22%), North America and Central America (1969; 17%), and Europe (572; 5%) (Fig. 3A). The ranking of grid cells according to this solution was correlated positively with species richness (Pearson’s \( r = 0.604; \ P < 0.001 \), negatively with minimum range size (\( r = -0.234; \ P = 0.045 \), Table 1) and positively with maximum extinction risk (\( r = 0.622; \ P < 0.001; \) Table 1 – see Table S1 for the influence of DD species), meaning that species with small ranges and higher extinction risk were preferentially represented. This solution encompassed 170,930 (24.5%) carnivore occurrences. The average proportion of species’ range represented was 58.1% (±33.4% sd), ranging from 100% for all species with a range size smaller than 418 grid cells (i.e., 75 species representing 30% of the rarest species) to 3% for Alopex lagopus, the arctic fox (range = 12,815 cells, extinction risk category = least concern), which had 380 presences represented. Twenty-two species were represented in less than 10% of their range; the minimum number of presences represented among this group of species is 299, and the species’ smallest range was 3210 grid cells. Using species as statistical units, we found that the proportion of species’ range represented using the biosolution was negatively correlated with their geographical range size (Pearson’s \( r = -0.595; \ P < 0.001 \) and was positively correlated with their extinction risk (Pearson’s \( r = 0.392; \ P < 0.001 \) for DD = 0 and \( r = 0.254; \ P < 0.001 \) for DD = 4).

The solution that incorporated information about agricultural expansion (agrosolution) matched 4992 grid cells (44%) of the biosolution. The best 11,327 cells for the protection of carnivores in the agrosolution were distributed in Africa (2884; 25%), Asia (3340; 30%), North America and Central America (2105; 19%), South America (1861; 16%), and Europe (1136; 10%) (Fig. 3B).

The ranking of grid cells in the agrosolution was positively correlated with species richness (\( r = 0.325; \ P = 0.003; \) Table 1) and the spatial distribution of maximum extinction risk (\( r = 0.435; \ P < 0.001; \) Table 1 – see Table S1 for the influence of DD species) but was not correlated with the distribution of minimum range.
size of species assemblage ($r = 0.085; P = 0.448$; Table 1). The number of presences represented according to this solution was 144,418 (20.7%). The average proportion of species’ range represented was 32.4% (±20.7), ranging from 100% for species with a range size up to seven cells to 3% for *Melogale maschata*, the small-toothed ferret-badger (range = 1218 cells, extinction risk category = least concern), which had 71 presences represented. Eleven species were represented in less than 10% of their range; the minimum number of presences represented in this group is 62 for *Prionilurus rubiginosus*, the rusty-spotted cat (extinction risk category = least concern), which had 71 presences represented. Eleven species were represented in less than 10% of their range; the minimum number of presences represented in this group is 62 for *Prionilurus rubiginosus*, the rusty-spotted cat (extinction risk category = least concern), which had 71 presences represented. Eleven species were represented in less than 10% of their range; the minimum number of presences represented in this group is 62 for *Prionilurus rubiginosus*, the rusty-spotted cat (extinction risk category = least concern), which had 71 presences represented. The proportion of species’ range represented in the *agrosolution* was negatively correlated with their geographical range size (Pearson’s $r = -0.333; P < 0.001$) and positively correlated with their extinction risk (Pearson’s $r = 0.255; P < 0.001$ for DD = 0; $r = 0.328; P < 0.001$ for DD = 4).

Agriculture expansion and carnivore species richness were positively correlated ($r = 0.427; P < 0.001$; Table 1). This positive correlation also holds for the ranking of grid cells according to the *biosolution* ($r = 0.339; P < 0.001$; Table 1). The *biosolution* presented an agricultural cost of 370,193 grid cells x year (25% of the world area cultivated per year in the 21st century). The agrosolution was negatively correlated with agricultural expansion ($r = -0.593; P < 0.001$; Table 1), and the total agricultural value of 17% of the network was very low compared with the *biosolution* (11,513 grid cells x year; 0.008% of the total).

Fig. 1. Geographical patterns of global carnivore species richness (A), minimum geographic range (in number of grid cells) (B), and the maximum extinction risk level according to IUCN (C) of species co-occurring in each grid cell resolved at a 0.5° x 0.5° grain size. Extinction risk level values: 0 (least concern), 1 (near threatened), 2 (vulnerable), 3 (endangered), and 4 (critically endangered). We attributed value 4 (critically endangered) to data-deficient species.
The biosolution substantially overlapped the Biodiversity Hotspots (43.5%, \( P < 0.001 \); Table 2) and Crisis Ecoregions (20.8%, \( P < 0.001 \); Table 2), both of which are reactive conservation schemes, but it also overlapped the High Biodiversity Wilderness Areas (HBWA) (35.2%; \( P < 0.001 \); Table 2). In contrast, the agrosolution had a lower overlap with reactive approaches and a higher overlap with proactive approaches (Table 2).

4. Discussion

4.1. Conservation conflict

According to our results, there is a clear conservation conflict between agricultural expansion in the 21st century and carnivore conservation. This conflict holds for the two metrics of conservation value used, i.e., species richness and the importance of grid cells as defined by the systematic conservation planning approach, our biosolution (which promotes, among other goals, complementarity in species representation). Spatial conservation prioritization based on core area Zonation is still rarely used within the context of continental or global prioritization (but see Moilanen et al., 2012b for New World and Eklund et al., 2011 for a global analysis). Our results support the idea that this approach is successful in retaining the species diversity of carnivores with a high number of presences, especially for the rarest and most-threatened species, as shown by the correlation between the grid cell ranking according to the biosolution and by the rarity or extinction risk. Indeed, this was in accordance with our objective when we focused in the zonation core-area, which was designed to protect the rarest species as an inbuilt feature (Moilanen et al., 2012a). Also, the correlation of maximum extinction risk and the conservation ranking of grid cells was generally robust to our decision to consider data-deficient species with the highest (critically endangered) or lowest (least concern) conservation status (see Supplementary material – Table S1). The use of Zonation differentiates our study from previous ones focusing on conservation conflicts, which have mostly quantified biodiversity using species richness (but see Faleiro and Loyola, 2013). Systematic conservation planning approaches are grounded in complementarity, which is more successful than other measures at representing biodiversity (Williams et al., 1996; Araújo and Rahbek, 2007).

Our findings of conservation conflict expand, for carnivores and future agricultural expansion at the global scale, the results of previous studies that investigated the ongoing spatial congruence between human enterprise (generally measured by human population density) and areas of high value for conservation identified using species richness (reviewed in Luck, 2007b and Araújo and Rahbek, 2007) (for other studies on future conflicts, see McKee et al., 2004; Scharlemann et al., 2004; Araújo et al., 2008; Dobrovolski et al., 2011).

4.2. Alleviating conflicts

The inclusion of agricultural expansion as a cost in the prioritization process, following the tendency of incorporating human-driven threats through socioeconomic data, allowed circumventing the conservation conflict between agricultural expansion and carnivore conservation. Such “conflict avoidance” (see also Luck et al., 2004; Carwardine et al., 2008; Wilson et al., 2011) exemplifies the benefit of incorporating socioeconomic data in systematic conservation planning, including future scenarios for threats to biodiversity (e.g., Sala et al., 2000; Pereira et al., 2010). However, the reduced number of carnivore presences represented under the agrosolution (144,418 versus 170,930 for the biosolution) suggests that the benefits of this conflict alleviation come at a biological cost. This reduced performance is also shown by the lower correlation of the agrosolution with species richness, minimum range size, and maximum extinction risk (Table 1). Furthermore, although we did not focus on countries as spatial units, Mexico, the Democratic Republic of Congo and Tanzania, three countries considered as priorities in a global analysis of future threats to mammals (Visconti et al., 2011), lost their importance for conservation because fewer grid cells were considered as conservation priorities when moving from the biosolution to the agrosolution (Fig. 2). Conservation solutions based on socioeconomic data should, therefore, be evaluated critically. After including costs in the prioritization process, it remains necessary to again check the biodiversity value of the conservation solution, not just evaluate the solution based on the socioeconomic benefits achieved, as is most often done (e.g., Carwardine et al., 2008; Wilson et al., 2011).

4.3. Overlap with other global conservation priority schemes

By testing the spatial overlap between the biosolution and agrosolution and the global conservation priorities used by non-governmental organizations, we highlighted similarities between the agriculturally efficient solution and the unconstrained carnivore conservation strategies and proactive and reactive global conservation priorities, respectively. Supporting our initial hypothesis, the biosolution matched the reactive schemes – the prioritization of
highly vulnerable areas (Table 2) – emphasizing that many irre-placeable areas are also among the most threatened (e.g., Myers et al., 2000). Additionally, the biosolution had a high overlap with High Biodiversity Wilderness Areas, a proactive approach that was designed not only to target low vulnerability but also high irreplaceability (Mittermeier et al., 2003). In contrast, the agrosolu-tion mostly reproduced the spatial pattern of global priorities focusing on low vulnerability, i.e., proactive schemes (Table 2). Indeed, both proactive schemes and systematic conservation planning approaches seek to avoid conservation conflicts by taking into account socioeconomic information. Conversely, unconstrained prioritization approaches that seek only to maximize biodiversity representation are likely to generate conservation conflicts due to the spatial congruence between biodiversity and human impact (see Luck, 2007a). It is important to highlight here that the proactive approaches were defined based on the present spatial distribution of threats. Here, we used information about agricultural expansion in the future, and some proactive approaches may be affected by this threat until the end of the century (see Dobrovolski et al., 2011).

Despite criticisms (e.g., Mace et al., 2000), these global prioritization schemes continue to be used to solve the problem of maximizing returns on investments in real-world conservation applications (Brooks et al., 2006; Halpern et al., 2006). Here, we Fig. 3. Priority map for conservation of world carnivores according to Zonation analysis. Map A represents an ideal unconstrained solution (biosolution). Map B is a solution that incorporates the agriculture impact in the 21st century according to IMAGE 2.2 (Fig. 1) (agrosolution). The top 5% of cells are represented in brown, 10% in red, and 17% in orange. C shows the combined solution, where the 17% best cells selected according solution 2 are in red, those selected according to solution 1 are in blue, and those selected by both solutions are in purple. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
highlighted varying degrees of spatial overlap between the two conservation solutions we found and the global conservation priority schemes. Consequently, the areas we found as priorities for carnivore conservation can partially benefit from current global conservation initiatives promoted by non-governmental organizations. These results also illustrate that different conservation strategies or methods for prioritization can converge to similar spatial solutions (e.g., biosolution and Biodiversity Hotspots). Consequently, the use of the most recent automatic algorithms for the selection of priority areas should not prevent conservation planners and practitioners from engaging in dynamic processes involving stakeholders to define biodiversity targets and costs. This process should pursue the best trade-offs between biodiversity conservation (e.g., taking into account rare or threatened species, populations or other components of diversity, such as functional and phylogenetic diversity) and feasibility (e.g., conflict avoidance by accounting for the socio-economic context, including agricultural needs, the cost of land and human population density).

### 4.4. Final considerations – a unified strategy for carnivore conservation?

Here, we typified two conservation options. The first is to focus on the best biological solution to face the forecasted agricultural expansion trend, which will be more difficult and more expensive. An alternative would be, for a given budget, to rely on conservation solutions by taking into account expanding threats, such as agriculture, de facto reducing costs but at the price of lower performance. Particularly in the case highlighted here, the reduction in conservation efficiency in the agrosolution compared with the biosolution should be acknowledged when taking conservation action. Do the benefits in reducing conservation conflicts compensate for the biodiversity lost when implementing lower performance conservation solutions? This is a question that prioritization methods cannot answer but that should be considered by conservation scientists and practitioners.

Hence, the best strategy could be the development of integrative approaches taking advantage of both solutions, in which different conservation actions could be used where they are likely to be more successful. In doing so, one could overcome fruitless dichotomies such as that of hotspots versus coldspots (Kareiva and Marvier, 2003) and contribute to a more comprehensive and effective conservation approach (Rondinini et al., 2011). For example, in priority areas where no conflict with agriculture is predicted (agrosolution), there is room for megareserves (Peres, 2005). Areas highlighted by the biosolution that will be under agriculture pressure in the future should be the focus of more-refined actions, including the detailed analysis of anthropic landscapes. This analysis embraces, for example, the identification of patches of natural vegetation and their spatial configuration or the investigation of the viability and genetic structure of remaining populations. With this approach, conservation initiatives adequate to these circumstances can be devised, including conservation agriculture practices (Baudron et al., 2009) and the use of private lands for conservation (Main et al., 1999). One could argue that these combined solutions would require more than 17% of the world to be effective. However, this target is related to protected area coverage only (CBD, 2012). Currently, conservationists do not manage only protected areas. Actions in private and indigenous peoples’ lands and other areas under environmental legal constraints have proven extremely useful for biodiversity conservation (Joppa et al., 2008). Moreover, such combined solutions would embrace the full diversity of conservation practitioners (Langholz and Krug, 2004) and would help re-orient them in terms of the location of their job and the way they are doing it.

Some limitations may affect this analysis, particularly the translation to effective action on the ground, which needs fine-scale data and collaboration with local practitioners (Fonseca et al., 2000; Rondinini et al., 2011). Additionally, the generality to other taxa of the parameters and prioritization patterns estimated here should be evaluated. However, previous results on convergent patterns of diversity and endemism among vertebrates suggest that the areas highlighted here as important for carnivores can also be important for other taxonomic groups (Lamoreux et al., 2006; Rodrigues and Brooks, 2007; Loyola et al., 2007; Qian and Ricklefs, 2008; Trinidad-Filho and Loyola, 2011; but see Grenyer et al., 2006). Also, here we did not take in account political boundaries that can affect conservation solutions (e.g., Moilanen et al., 2012b). Moreover, our study is a broad-scale definition of
conservation priorities that should be complemented by finer-scale analysis for the allocation of resources for conservation. Finally, there are obviously other threats to biodiversity such as hunting, mining, expansion of urban areas or expansion of forestry, which should be also considered in conservation planning. Here we focused on agriculture due to its current high impact and due to the fact that this impact is expected to increase in the 21st century, as we stated above.

Finally, the use of information about future threats to biodiversity such as agricultural expansion may help overcome the inability of conservation efforts to look forward in time at the global scale (Visconti et al., 2011). The expansion of agriculture and other threats can be particularly harmful to biodiversity when they interact synergistically with species’ intrinsic extinction risk, driving them to extinction (Cardillo et al., 2004, 2006). In this case, even the best prioritization solutions may not allow effective conservation for carnivores or other sensitive taxonomic groups. Consequently, conservation policies should also focus on the causes of the increasing threats to biodiversity (Visconti et al., 2011) and should aim to help prevent agricultural expansion and consider more sustainable practices (Foley et al., 2011; Balmford et al., 2012). In pursuing these goals, we can contribute to reconciling food production and biodiversity conservation, one of the great challenges facing humanity today.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.biocon.2013.06.004.

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