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thesis abstract

Integrating agricultural expansion into conservation biogeography: conflicts and priorities

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Abstract. Increasing food production without compromising biodiversity is one of the great challenges for humanity. The aims of my thesis were to define spatial priorities for biodiversity conservation and to evaluate conservation conflicts considering agricultural expansion in the 21st century. I also tested the effect of globalizing conservation efforts on both food production and biodiversity conservation. I found spatial conflicts between biodiversity conservation and agricultural expansion. However, incorporating agricultural expansion data into the spatial prioritization process can significantly alleviate conservation conflicts, by reducing spatial correlation between the areas under high impact of agriculture and the priority areas for conservation. Moreover, developing conservation blueprints at the global scale, instead of the usual approach based on national boundaries, can benefit both food production and biodiversity. Based on these findings I conclude that the incorporation of agricultural expansion as a key component for defining global conservation strategies should be added to the list of solutions for our cultivated planet.

Keywords. agriculture, biodiversity hotspots, conservation conflicts, global biodiversity conservation priorities, mammals' conservation, protected areas, spatial conservation prioritization.

Introduction

Both biodiversity and the human activities that threaten it are unevenly distributed around the globe. Thus, evaluating whether they are spatially congruent (i.e., whether there are conservation conflicts *sensu* Balmford et al. 2001) and choosing the best areas for conservation actions given the distribution of these conflicts (i.e., developing spatial prioritization analysis *sensu* Moilanen et al. 2009) are central problems in conservation biogeography (Ladle and Whittaker 2011).

The magnitude of the current biodiversity crisis, coupled with the limited resources available for protecting biodiversity, implies that prioritization is unavoidable. Spatial prioritization seeks to identify the areas that are likely to yield the best benefits for biodiversity given a particular conservation investment. It may be applied at a variety of scales, including global (Ceballos et al. 2005), regional (Moilanen et al. 2013), national (Kremen et al. 2008) and sub-national (Faleiro et al. 2012) levels. Spatial conservation prioritization analyses can be based solely on the distribution of the biological features to be protected (e.g., species; Ceballos et al. 2005). Alternatively, prioritization analyses can include socioeconomic variables that represent threats to biodiversity or opportunities for conservation, such as human population density, land cost and land use (e.g., Faleiro et al. 2013).

Agriculture is the human activity that represents the main threat to the environment (Foley et al. 2011). It constitutes the largest land use on the planet, using 38% of Earth's ice-free land surface and 70% of global human freshwater uptake. Food production accounts for 19% of Earth's net primary productivity and 30-35% of global greenhouse gases, with direct impacts on biodiversity (reviewed in Foley et al. 2011). The burden on the environment may be higher in the future as the human population is expected to increase to more than 10 billion by 2050 (Bloom, 2011). Moreover, a billion people are currently chronically malnourished as a result of lack of access to food (Foley et al. 2011). Given the value of biodiversity for human well-being (Millennium Ecosystem Assessment, 2005), understanding the potential impacts of future agricultural expansion on biodiversity is a key issue for humanity.

The general aim of my PhD thesis was to evaluate the potential impact of agricultural expansion on biodiversity conservation during the 21st century. Specifically, I evaluated four interrelated issues: conservation conflict between agricultural expansion and the global biodiversity conservation priorities (chapter I) and the Brazilian system of protected areas (chapter II); the effect of incorporating agricultural expansion data into spatial prioritization models for the conservation of world carnivores (chapter III); and the benefits of a globalized conservation strategy for food production and for biodiversity conservation (chapter IV; Figure 1).

Methods

The impact of future socioeconomic development pathways, including land-use trends, on biodiversity can be accessed by means of quantitative scenarios (Pereira et al. 2010). For all analyses presented here, I obtained future scenarios of agricultural expansion from land cover maps produced by the Integrated Model to Assess the Global Environment (IMAGE, version 2.2; IMAGE Team 2001). IMAGE forecasts, at a resolution of 0.5° × 0.5°, the number of years that each area will be cultivated during the 21st century for six socioeconomic scenarios (IMAGE Team, 2001). For chapter IV, I also included an estimation of potential agricultural productivity in each grid cell, based on climate, relief, soil constraints and irrigation impact (Fischer et al. 2008).

For the first chapter, I overlaid the spatial polygons of the Global Biodiversity Conservation

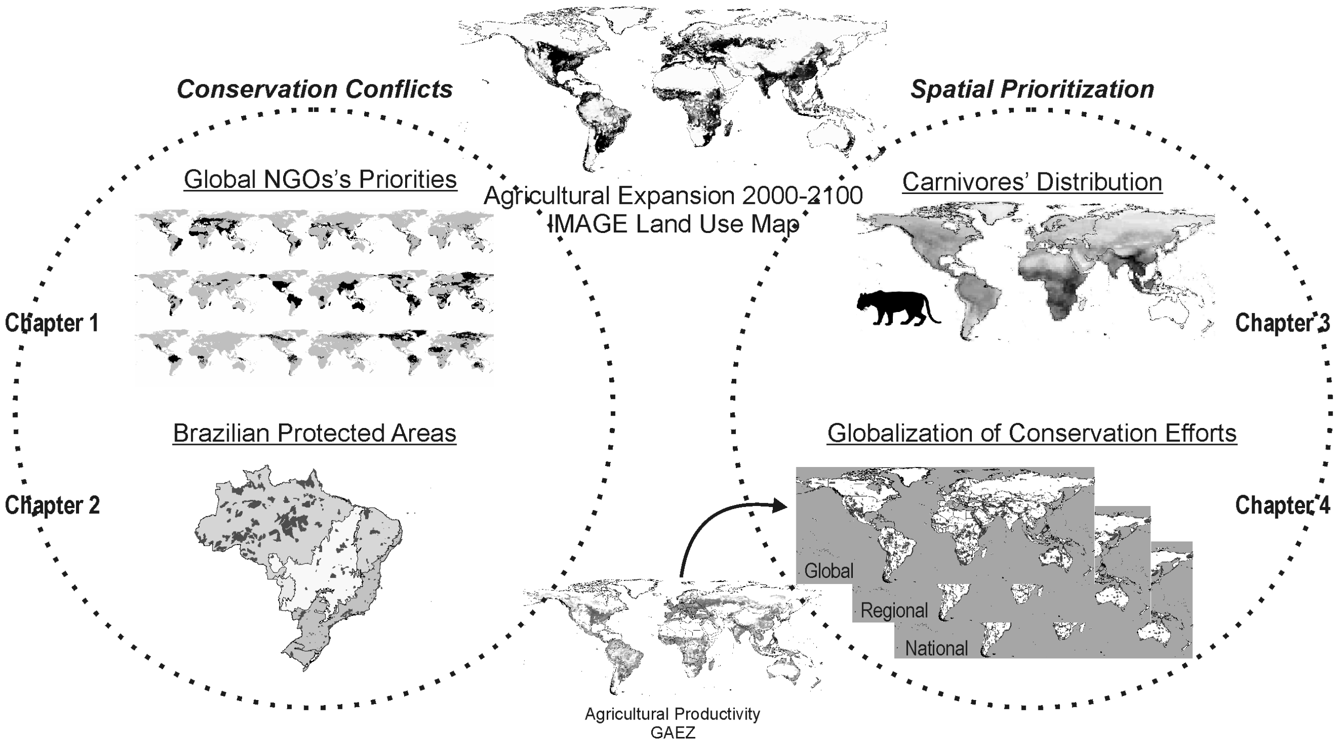

Figure 1. Schematic representation of the thesis' chapters. I tested the conservation conflict between agricultural expansion in the 21st century, according to the land use map from the Integrated Model to Access the Global Environment (IMAGE Team 2001) and both global biodiversity conservation priorities (reviewed in Brooks et al. 2006) (chapter I; Dobrovolski et al. 2011a) and the Brazilian Protected Areas (chapter II; Dobrovolski et al. 2011b). I developed global spatial conservation prioritization, considering the projected agricultural expansion, for carnivores (chapter III; Dobrovolski et al. 2013). I also did this for terrestrial mammals, adding agricultural productivity using Global Agro-Ecological Zones (GAEZ; Fischer et al. 2008) and evaluating the effect of globalizing conservation efforts (chapter IV; Dobrovolski et al. 2014).

Priorities (Brooks et al. 2006) onto a grid with a spatial resolution of 0.5° × 0.5°. I tested whether areas defined by their higher vulnerability (i.e., reactive schemes such as the Biodiversity Hotspots; Mittermeier et al. 2004) were more affected by agriculture in the year 2000. The opposite was expected for areas with low vulnerability (i.e., proactive schemes like High Biodiversity Wilderness Areas; Mittermeier et al. 2003). I also tested whether these priority areas would be more affected by agricultural expansion during the 21st century than expected by chance (Dobrovolski et al 2011a).

To address the aims of chapter II, I overlaid the IMAGE's land-use model with Brazilian protected areas to calculate the conflict between these two land uses. I obtained Brazilian protected areas' polygons from the World Database of Protected Area (WDPA 2009). I also included 10 km buffers around each protected-area polygon to represent the legal buffer zone usually used in Brazil, which is an area where human activity is restricted. I then tested whether these areas were more affected in the present and in the future than expected by chance. Additionally, I tested whether there was difference between the integral protection protected areas (IPPA: IUCN categories I to IV) and sustainable use protected areas (SUPA: the other IUCN categories) (*cf*. Redford and Sanderson, 2000). In both chapters I and II, I evaluated the probability of such conflicts to be found by chance using spatial randomization tests developed in R (R Development Core Team, 2012), considering 1000 iterations (Dobrovolski et al 2011b).

To meet the objectives of chapters III and IV, I performed global spatial conservation prioritization using Zonation (version 3.1[1]; Moilanen et al. 2011). Zonation's algorithm provides a nested hierarchical ranking of the sites, maximizing the representation of species' distributions. To define the ranking of importance of sites for conservation, Zonation analyses can also incorporate costs such as potential agricultural production. For all prioritization analyses, I defined the target proportion of areas to be protected as 17%, following the Convention on Biological Diversity (CBD 2010), which proposed this percentage as the goal to be met by 2020. I obtained information about mammal species' distributions from the International Union for Conservation of Nature's Red List of Endangered Species. I overlaid the spatial polygons onto a grid with a spatial resolution of 0.5° × 0.5°. For chapter III, I focused on 245 terrestrial carnivore species. In chapter IV, I used 5216 terrestrial mammals. These taxonomic groups have been the focus of many conservation programs (Trimble and van Aarde 2010) and they are often considered to represent a potential surrogate for other taxonomic groups (e.g., Lamoreux et al. 2006, Qian et al. 2008). To test whether there is a spatial conflict between the global carnivore conservation solutions obtained in chapter III and the agricultural expansion, I performed spatial correlation analyses using the Spatial Analysis in Macroecology (SAM) software (Rangel et al. 2010).

The objectives of chapter IV were achieved by defining global conservation priorities considering three levels of political integration: (a) individual countries, (b) regions (based on current economic blocks—e.g., the European Union, the North American Free Trade Agreement, the Union of South American Nations), and (c) globalized (disregarding political boundaries). I also evaluated the effect of considering, or not, agricultural costs for spatial conservation prioritization. The different conservation solutions were evaluated in terms of the relative amount of food production lost by setting aside sites for conservation and the representation of the geographic distribution of species within those sites. I also evaluated whether the most underdeveloped countries would be subject to higher losses in food production under the global strategy. For this, I correlated the percentage of food production and area lost to sparing land for biodiversity conservation with three development indicators: the Human Development Index (HDI), the per-capita gross domestic product (GDP), and the percentage of GDP added by agriculture (Dobrovolski et al. 2013).

1 Conservation Biology Informatics Group, Helsinki, Finland; http://cbig.it.helsinki.fi/software/zonation, last accessed 31 March 2014
2 http://www.iucnredlist.org/initiatives/mammals, last accessed 31 March 2014

Results

I found that reactive global biodiversity priorities had about 49% of their area impacted by agriculture in the year 2000 ($p < 0.001$). Conversely, proactive schemes had a low intersection with the agricultural distribution (5.2%; $p < 0.001$). By the end of the 21st century, there will be an overall increase in world agricultural area from 26.5% of the analyzed area in 2000 to 34.6% in 2100, according to IMAGE, and the difference between the proactive and reactive schemes is predicted to hold true. However, High Biodiversity Wilderness Areas, a proactive scheme, is predicted to suffer agricultural impact similar to the reactive schemes, with 73.5% of its area affected, if the worst-case scenarios are realized (Dobrovolski et al. 2011a).

In Brazil, a megadiverse country in which agribusiness is the pillar of economy, agricultural expansion is a major conservation concern (Lapola et al. 2013). According to IMAGE, agricultural land use represented 22% of Brazilian land coverage in 2000 and is predicted to increase up to 40% by 2100, according to a business-as-usual scenario. Moreover, the percentage of protected areas affected is predicted to increase from 11% to 30%, with no difference between IPPAs and SUPAs (Dobrovolski et al. 2011b).

I found spatial conflicts between the best areas for terrestrial carnivore conservation and agricultural expansion in the 21st century (Pearson's $r = 0.472$; $p < 0.001$). These conflicts were alleviated when I incorporated agricultural expansion information into the spatial prioritization process ($r = -0.593$; $p < 0.001$). Nevertheless, accounting for agricultural expansion resulted in a lower representation of species' geographical ranges: the average proportion of represented ranges was reduced from 58% to 32%. This reduction affected mainly those species with small geographic distributions. In addition, the best solution for global carnivore conservation changed from a spatial distribution closer to that of the reactive global conservation priority schemes to one more like proactive ones.

Looking at the impact of globalization for conservation and food production, I found that combining the use of agricultural expansion data and integrating countries in a globalized conservation blueprint to meet the 17% target for terrestrial protected areas, resulted in a 78% reduction in the costs of food production (Dobrovolski et al. 2014). Furthermore, this globalized conservation approach represented an increase of 30% in the representation of the species in the protected-areas network. The regional-scale conservation solution resulted in similar losses in food production, compared to the globalized solution, and an increase of 17.5% in terms of representation of mammals' geographical ranges (Dobrovolski et al. 2014).

Discussion

Conservation actions in the different areas of the world should be planned according to the expected agricultural expansion in the 21st century. Some areas can hold mega-reserves (protected areas with more than 1 million ha; Peres, 2005), while other areas should focus on the development of wildlife-friendly agricultural practices. Within Brazil, my findings suggest that the risk of agricultural expansion should be included in the management of protected areas and associated buffer zones.

Globally, conservation actions for carnivores should consider agricultural expansion because this may significantly influence the distribution of areas where conservation actions could be more effective in the future (Dobrovolski et al. 2013). The regional scale may represent an intermediate step towards the global integration. Economic agreements may evolve to common conservation policies, since this has already been done in the European Union by means of the Natura 2000 network (Araújo et al. 2011).

By comparing differences in the distribution of protected areas among countries in the different scenarios, I found that the poorest countries will not be negatively affected by participating in this globalized conservation blueprint. However, the particular cases in which poor countries would be impaired in their development process should be a focus of compensatory policies in order to guarantee the participation of these countries within the global approach. Moreover, such compensatory policies may help to overcome socio-economic problems such as poverty and inequality, which are known to be detrimental to the success of conservation actions (Mikkelson et al. 2007).

Feeding an increasing human population, with rising per-capita consumption, while managing the environmental impacts of agriculture, is one of the greatest challenges for global policy. In my thesis, I demonstrated that agricultural expansion will continue to represent an important threat to biodiversity throughout the 21st century. Reducing food waste, increasing agricultural resource efficiency, closing yield gaps, and fostering organic agriculture are tools available for solving this challenge (Foley et al. 2011, Tilman et al. 2011, Seufert et al. 2012). I propose that considering future agricultural expansion data and promoting globalized conservation solutions for defining spatial priorities should be included in this toolbox for sustainability. Only by the careful analysis of future scenarios of agricultural expansion and other human activities will it be possible to predict their impacts on biodiversity and, most importantly, act effectively to reduce the worst impacts of human land use on the environment.

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