Globalizing Conservation Efforts to Save Species and Enhance Food Production

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If the growing needs of humans are to be met, food production must increase; however, increasing food production will further compromise biodiversity. Can this seemingly irreconcilable conflict be mitigated? The solutions proposed so far include reducing food waste and closing yield gaps. Here, we investigate an alternative approach to reducing the impact of agricultural expansion on biodiversity without compromising food production by combining two strategies: taking agricultural production into consideration to solve the biodiversity crisis and promoting the definition of protected areas on the basis of a globalized blueprint. We found that combining these strategies could result in a 78% reduction in the agricultural opportunity costs incurred in the implementation of protected areas. Furthermore, a 30% increase in biodiversity protection could be achieved. We show that the movement toward global governance of natural resources would lead to reduced conflict between the needs of food production and biodiversity conservation.

Keywords: agriculture production, biodiversity conservation, conservation conflict, food security, spatial conservation prioritization

Earth is home to over 7 billion people, and this number is expected to increase to 10.6 billion by 2050 (UNPD 2011). Approximately 842 million people are chronically malnourished or lack access to food (FAO 2013). Improving the well-being of people in a world with an increasing population will inevitably lead to increased pressure on natural resources. Agriculture already accounts for 24% of Earth's primary net productivity and 30%–35% of global greenhouse gas emissions; moreover, agriculture uses 70% of the freshwater and 38% of the ice-free surface on Earth, representing its largest land use, which has a direct impact on biodiversity (for a review, see Foley et al. 2011, Balmford et al. 2012). Feeding an increasing human population with a rising per capita consumption while sustainably managing the environmental externalities of agriculture is one of the greatest challenges of human society. Ecologically and sustainably intensifying agricultural production (Cassman 1999, Tscharntke et al. 2012, Garnett et al. 2013), reducing food waste, shifting diets, increasing agricultural resource efficiency, closing yield gaps (Foley et al. 2011), and fostering organic agriculture (Seufert et al. 2012) might contribute to the solution. However, if the current rates of converting natural habitats into crop landscapes for food production remain unchanged, greater threats to biodiversity are inevitable. The critical question is whether food production needs can be met without further compromising biodiversity.

Spatial conservation priorities are mostly determined at the national level, but priorities constrained by political boundaries can lead to poor returns on the investment in comparison with unconstrained conservation solutions (e.g., Rodrigues and Gaston 2002, Araújo et al. 2007, Vazquez et al. 2008, Kark et al. 2009, Moilanen et al. 2013). Examples of conservation priorities that are defined across the political boundaries of individual countries include the Natura 2000 Networking Programme, designed by the European Union to complement individual countries' protected areas (Araújo et al. 2011), and the Mesoamerican Biological Corridor, which is designed to create a common network of protected areas in eight countries (Holland 2012). However, these initiatives are the exception rather than the norm. Conservation strategies tend to be implemented mostly at the subnational and national levels, and they are rarely informed by prioritization blueprints that are intended to effectively allocate limited financial resources for the conservation of globally relevant biodiversity (Zimmerer et al. 2004). Here, we argue that the lack of globalized planning may lead to an ineffective distribution of efforts dedicated to both expanding food production and protecting biodiversity.

It has been argued that conservation actions such as the creation of protected areas may negatively affect the development of the surrounding communities and the countries in which they are implemented (Adams et al. 2004, McShane...
et al. 2011, but see Andam et al. 2010). Therefore, if a globalized conservation blueprint implies greater conservation coverage in countries that are poor, underdeveloped, or economically dependent on agriculture, it would be more difficult to persuade such countries to agree to this globalized conservation strategy. In addition, the effects of losing food production would be intensified for these countries, because they tend to have fewer economic alternatives. Consequently, forecasting the economic winners and losers of globalized conservation strategies would help clarify the difficulty of implementing a politically integrated conservation blueprint in different parts of the world and would help in the designing of compensation policies that would encourage countries to agree to larger conservation areas in their territories without compromising their development.

In this study, we compared blueprints for global conservation and food production obtained by aggregating national or regional priorities to a global extent and comparing them with blueprints obtained by optimizing global conservation and food production. Our response variables were the relative amount of food production lost (agricultural opportunity cost) and the representation of the geographic distribution of species in each blueprint. We also examined whether the poorest countries, the least developed countries, or those countries with economies more dependent on agricultural production are exposed to higher losses in food production as a consequence of a high percentage of their land area being assigned to conservation under the global strategy.

We overlaid the geographic ranges of 5216 terrestrial mammal species obtained from the International Union for Conservation of Nature’s Red List of Endangered Species (www.iucnredlist.org/initiatives/mammals) onto a grid with a spatial resolution of 0.5 degrees (°) × 0.5°. We considered a species to be present in a cell if any of its mapped distribution occurred in the focal grid cell.

We chose mammals because they are the focus of many conservation programs (Trimble and Aarde 2010). Among mammals, there are many species that are charismatic, conservation “flagships,” or potential “umbrellas” for the conservation of other species (Redford et al. 2011). In addition, approximately one-quarter of all mammal species are threatened with extinction, and this situation is far from improving (Hoffmann et al. 2011). Finally, this group is often considered to represent a potential surrogate for other taxonomic groups (e.g., Lamoreux et al. 2006, Qian et al. 2008).

We created maps of potential agricultural production in the twenty-first century by synthesizing two maps: the extent of agriculture and potential productivity (supplemental figure S1). The areas forecast to be in use for agricultural production in the twenty-first century were defined according to the land-cover map produced by the Integrated Model to Assess the Global Environment (IMAGE, version 2.2, Netherlands Environmental Assessment Agency, Bilthoven), which incorporates six socioeconomic scenarios (from Nakićenović et al’s 2000 Special Report on Emissions Scenarios [SRES] report).

The SRES scenarios represent different socioeconomic storylines, or development pathways, that human societies can follow. These scenarios represent combinations of changes in technology, policy, economy, lifestyle, and political integration and are used as inputs to model different processes, such as climate change and land use. All SRES scenarios are deemed equally probable. IMAGE uses these scenarios to construct land-use maps. We combined the 60 IMAGE maps, at a resolution of 0.5° × 0.5°, from 2010 to 2100 (one map for every 10 years across six scenarios) to produce an average map for agricultural expansion in the twenty-first century (see Dobrovolski et al. 2013).

Information on the productivity of agricultural lands was obtained from Fischer and colleagues (2008). We assumed maximum productivity (100%) for all grid cells unless the environmental constraints related to climate, relief, or soil were defined by Fischer and colleagues (2008). Moreover, we added information on the impact of irrigation, which represents a potential gain in productivity (see Naïdoo and Iwamura 2007 for a similar approach). Therefore, we defined the total global production (P) as

\[ P = \sum p_i a_i t_i + w(p_i a_i t_i), \]

where \( p_i \) is the productivity of cell \( i \) of the area determined by environmental constraints, \( a \) is the area of the grid cell, \( t \) is the average time that the grid cell is cultivated over the twenty-first century and across all six SRES scenarios, and \( w \) is the proportion of the productivity that can be added by irrigation. All of the results shown here are presented as a proportion of the total agricultural production for the twenty-first century.

We defined the global spatial priorities for mammal conservation using Zonation (version 3.0.5, Conservation Biology Informatics Group, Helsinki, Finland; http://cbig.it.helsinki.fi/software/zonation; Moilanen et al. 2011). Zonation’s original core-area algorithm provides a maximum utility conservation solution and generates a nested hierarchical ranking of the study area, which maximizes the highest occurrence level (here, the presence or absence of data for mammal species) divided by the cost of the cell (here, the potential agricultural production) and accounting for complementarity in species’ ranges (see Moilanen et al. 2011). Zonation’s original core-area removal rule considers sites that contain higher proportions of species’ geographical distribution to be more valuable, thus favoring the rarest species in the final solution. Zonation is also able to incorporate mask files, which can be used to guarantee that specific areas of interest (e.g., a country or a region) are prioritized.

To evaluate the effect of incorporating agricultural costs in setting conservation priorities, we developed two different conservation solutions. We developed the first solution without considering any cost layer (the costs of all sites were set to be equal), focusing on obtaining the maximum possible coverage of mammal biodiversity. We found the second solution by constraining the prioritization process with agricultural
potential production. Therefore, given the same biodiversity importance of two sites (e.g., presence of the same species), the site with the lowest cost (i.e., potential agricultural productivity) has the highest value for conservation.

We evaluated the effect of political integration by performing, within each of the two approaches above, conservation prioritization analyses at the national, regional, and global scales. For the global approach, we generated a global conservation solution as if there were no political boundaries. We created a regional approach by integrating the conservation solutions that were found separately for each group of countries, which were integrated according to current economic blocks (e.g., the European Union, the North American Free Trade Agreement, the Union of South American Nations) using mask files in Zonation. This political scenario is based on the assumption that the economic integration represented by these blocks can lead to common conservation strategies across member states. The national approach is the result of the integration of the best conservation solutions obtained individually for each country using mask files in Zonation. The latter political scenario represents the business-as-usual conservation strategy.

Given the ongoing debate of how much is enough in terms of area requirements for conservation (e.g., Soulé and Sanjayan 1998), we developed different spatial conservation targets, from 5% to 50% and with 5% intervals in between. However, following the Convention on Biological Diversity (CBD 2010), which proposed that 17% of the terrestrial areas should be protected until 2020, we focused our analyses on the cutoff of 17%.

To compare the different conservation solutions, we evaluated conservation benefits by calculating the mean proportion of the geographical range of the species that would be protected if each conservation solution were implemented and the agricultural opportunity cost as the percentage of the global productivity in the twenty-first century that would be lost for each conservation solution. Furthermore, we investigated whether the differences in the proportion of the species’ geographical range protected would preferentially affect those species with the smallest ranges. We performed an analysis of variance using the proportion of geographical range protected for the species within the lowest quartile of the range-size frequency distribution (the 25% of species with the smallest range) as the response variable and the conservation strategy (national, regional, or global) as the independent variable.

To investigate the relationship between agricultural losses and the development of countries participating in a globalized conservation blueprint, we correlated the percentage of food production and area loss (productive or not) due to sparing land for biodiversity conservation with three development indicators: the Human Development Index (http://hdr.undp.org/en/data), the per capita gross domestic product (GDP), and the percentage of GDP added by agriculture (the latter two obtained from the World Bank; http://data.worldbank.org/indicator).

When conservation areas for mammals were selected at a national scale without considering the potential agricultural production, 17% of the most suitable areas would overlap with those that were predicted to produce 18.9% of the world’s food throughout the twenty-first century. Selecting at a regional scale, 24.1% of global food production would be lost for conservation purposes. Selecting at the global scale, 27.6% of agricultural lands would be off limits to food production (figure 1a). However, if the selection of priority sites were constrained by food production, they would overlap with only 4% of global food production when selecting at a national scale, with 4.2% at a regional scale, and with 4.2% at a global scale (figure 1a). We found that, when searching for 17% of the terrestrial area that maximized the conservation of mammals in the globalized conservation blueprint, explicitly avoiding conservation in productive arable lands could lead to a 78% reduction in the loss of agricultural production (figure 1a).

When conservation priorities are identified without consideration of agricultural production, the conservation benefits are the highest for the global-scale strategy (64.2% of species’ geographic ranges protected versus 51.5% and 35.6% with regional and national solutions, respectively; figure 1b). However, as was indicated above, the conflict between food production and conservation is higher when priorities are established globally rather than regionally or nationally. However, when agricultural production is taken into account while planning for biodiversity, the effectiveness of the global conservation network of areas for mammal species can improve by 29.8% (43.1% of species’ ranges protected by the global solution compared with 39% in the regional and 33.2% in the national solutions; figure 1b). Furthermore, when agriculture was considered in conservation planning, the quartile of the species with the smallest ranges was represented to a greater extent in the global or regional solutions than in the national one (F(3912,2) = 27.87, p < .001).

The spatial location of priority areas for mammal conservation varied across strategies. The coverage of protected areas increased at low latitudes in the global solution when agricultural costs were excluded (figure 2, supplemental figure S2 and table S1). As was expected, the areas with the high productivity, such as the Western United States and the South American grasslands, became off limits to conservation solutions when information about food production was included (figure 3, supplemental figures S3 and S4). Furthermore, we detected edge artifacts when the priorities were defined nationally; that is, many priority sites were located along country borders (e.g., the southern borders of Canada and the Russian Federation; Moilanen et al. 2013).

When we compared the effects of the different conservation strategies on the agricultural production of individual
countries, we found that most countries were unaffected when agricultural production was included in the conservation-planning process (132 out of 174 countries). The difference in food production, when comparing the global and national conservation strategies, showed no correlation with the HDI (Pearson’s $r(27) = .27, p = .16$) and per capita GDP ($r(26) = .30, p = .12$), but it was negatively correlated with the percentage of GDP derived from agriculture ($r(23) = -.54, p = .005$) when agricultural production was considered (supplemental figure S5). When we compared the global and the national conservation strategies, the following countries lost more than 5% of their agriculture production: Comoros, the Comoros Islands, Solomon Islands, Samoa, Armenia, São Tomé and Príncipe, Costa Rica, Papua New Guinea, Ecuador, Panama, Madagascar, Taiwan, Rwanda, and Sri Lanka; this list includes countries with a low HDI, a low per capita GDP, and a high dependence on agriculture. The Comoros Islands, Papua New Guinea, and Rwanda are countries of special concern, because they have more than 30% of their GDP associated with agriculture and are considered least-developed countries (supplemental table S2). In terms of the change in available area, the number of countries with no change was much lower (23 out of 174). We found weak positive correlations between the area lost to agriculture in a country and the HDI (Pearson’s $r(150) = .22, p = .006$) and between the area and the

Figure 1. (a) The proportion of the global agricultural production during the twenty-first century that would be affected by biodiversity conservation. (b) The mean proportion of the geographical range of mammal species that will be protected by the selected priority areas. The target represents the proportion of world land area that may be set aside for conservation purposes. Abbreviations: Agro, the approach in which agriculture was included; Bio, the approach in which agriculture was ignored; Glo, the global-scale analysis; Nat, the national-scale analysis; Reg, the regional-scale analysis.

Figure 2. Best unconstrained conservation solution for mammals, considering a target of 17% global protected area coverage. The upper map represents the globally integrated solution, and the middle and bottom maps represent conservation strategies that were designed to maximize biodiversity at regional and national levels, respectively.
per capita GDP ($r(139) = .19$, $p = .03$). There was no correlation between a country’s area lost to conservation and the percentage of GDP arising from agriculture ($r(134) = –.15$, $p = .08$; figure S5, supplemental table S3).

Our results reinforce previous findings of the importance of considering the distribution of agricultural areas while setting conservation priority schemes (Naidoo and Iwamura 2007, Araújo et al. 2008, Carwardine et al. 2008, Dobrovolski et al. 2011, 2013). Moreover, our proposal extends to the global scale the benefits of political integration that were found in previous studies performed in North America (Vazquez et al. 2008), southern Africa (Rodrigues and Gaston 2002), the Iberian Peninsula (Araújo et al. 2007), the Mediterranean Basin (Kark et al. 2009), and the Western Hemisphere (Moilanen et al. 2013). We previously reported an analysis of the consequences of incorporating agricultural expansion in setting conservation priorities (Dobrovolski et al. 2013).

Figure 3. The best conservation solution for mammals, taking into account agricultural cost and considering a target of 17% global protected area coverage. The upper map represents the globally integrated solution, and the middle and bottom maps represent conservation strategies that were designed to maximize biodiversity at regional and national levels, respectively.

Here, we extend our previous analyses by both incorporating data about land productivity and extending our analysis to the entire group of mammals. Finally, we show that incorporating forecasts of agricultural food production in a globalized conservation blueprint could lead to important reductions in the cost of a global network of protected areas.

Although setting priorities at the regional scale is bound to produce intermediate levels of benefits for both conservation and food production, regional action at the scale of existing economic blocks may emerge as a realistic option. Global governance issues have proven to be difficult to resolve because of development disparities among regions and other causes (Murphy 2000, Sand 2001, Zimmerer et al. 2004). This suggests that converting economic integration into policies directed toward the conservation of biodiversity could represent a first step toward a global integration with significant improvements for their efficiency. Such regional conservation actions can expand the list of the few current exceptions, which include the Natura 2000 Network, implemented across the European Union, and the Mesoamerica Biological Corridor.

The weak or nonexistent correlation between either the change in food production or the available area for countries’ economic growth and the level of development of countries suggests that poor countries choosing to engage in global cooperation will generally not be more affected than richer ones. This is in accordance with results for established protected areas (Upton et al. 2007). However, particular cases in which poor countries could be negatively affected by a significant loss of food production deserve special attention within the existing international agreements. The positive correlation between agricultural production and economic dependence on agricultural activity (the percentage of GDP from agriculture) supports this statement. Consequently, the adoption of a globalized conservation solution must be tightly linked to the transfer of funds and compensatory payments for poorer countries to guarantee a fair scenario for all countries (James et al. 1999). This flow of international assistance from richer to poorer countries can help...
the latter integrate this global conservation task and can also contribute to overcoming the social problems that impair their conservation actions, such as poverty and inequality (Mikkelson et al. 2007) and a lack of governance (Eklund et al. 2011).

Humans will face two great coupled challenges for food production in the future: meeting future food demand while mitigating its impacts on the global environment, including biodiversity. Globalizing conservation action (Zimmerer et al. 2004) while explicitly searching for solutions that optimize the conservation benefit and food production is one promising approach to meeting these challenges. For such an approach to become viable, international agreements should be reached at the level of biodiversity-related conventions, such as the CBD, the Convention on the Conservation of Migratory Species of Wild Animals, the Convention on International Trade in Endangered Species of Wild Fauna and Flora, the International Treaty on Plant Genetic Resources for Food and Agriculture, the Ramsar Convention on Wetlands, and the World Heritage Convention. These efforts must be informed by the need to expand agricultural production coupled with reducing food waste, promoting the ecological intensification of agriculture, including planning agricultural landscapes and other related efforts (Cassman 1999, Tscharntke et al. 2012, Garnett et al. 2013).

Here, we show that biodiversity and food production can be reconciled if agriculture opportunity costs are considered in a globalized conservation solution. This implies that there is a need to act globally, in addition to thinking globally and acting locally (Brundtland 1987). The leading mechanisms available for addressing global biodiversity conservation goals, targets, and priorities are biodiversity-related conventions—in particular, the CBD. Therefore, food production considerations must be discussed at the level of these international agreements along with their respective financial mechanisms, such as the Global Environment Facility. Analogous negotiations involving the role of climate-smart agriculture in reducing greenhouse gas emissions are currently under way under the United Nations Framework Convention on Climate Change. Both biodiversity conservation and food production would benefit from a paradigm shift in the way conservation planning and policy have been conducted so far in terms of international negotiation.

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Supplemental material


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