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Agricultural Expansion Can Menace Brazilian Protected Areas During the 21st Century

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Abstract

The main current threat to biodiversity is habitat destruction, which is motivated mostly by agricultural expansion. This threat is especially important in Brazil, a megadiverse country devoted to agribusiness. Here, we addressed the following hypotheses: i) protected areas are less covered by agriculture than areas not protected to date; ii) this pattern will hold throughout this century; iii) these effects differ between categories of protected areas. We overlaid an agricultural expansion model for the 21st century (IMAGE) and the Brazilian protected areas to calculate the conflict between these two land uses. Agricultural extent represents 22% of Brazilian area in current time but should increase up to 40% by 2100. Although the absolute values are relatively smaller, the increase of agricultural extent will be much higher in protected areas (12 to 30%). Consequently, strategic actions are needed to reduce the damages of this agricultural expansion to biodiversity.

Key words: Biodiversity Conservation, Brazilian Amazon, Conservation Conflict, Global Change, Land Use and Land Cover Change, Megadiverse Countries.

Introduction

Currently and in the foreseeable future, the main threat to biodiversity is the loss and degradation of natural habitats (Sala *et al.* 2000; Green *et al.* 2005). Such loss has been motivated by different human land uses, especially by agriculture (Foley *et al.* 2011). Studying the impacts of agricultural expansion is particularly relevant in the face of the global increase in human population and the consequent projected agricultural expansion, aimed at increasing food production (Green *et al.* 2005). Brazil is a megadiverse country and a key agricultural producer which indeed have promoted agricultural expansion as mean for development (Rodrigues *et al.* 2009); hence agricultural expansion must be considered a key component of strategic plans for both food production and for biodiversity conservation.

In a changing world it is important to make use of models that forecast the consequences of future possible scenarios, including those for land-use/land-cover change (see Sala *et al.* 2000). Such models may predict the extension of agricultural areas and other land uses in the future and help to envisage future conservation-development conflicts when these activities reach areas of high conservation value (Scharlemann *et al.* 2004; Dobrovolski *et al.* 2011). In Brazil this is likely to be the case, for example, in the Atlantic Forest and the Cerrado (Myers *et al.* 2000), along with some Amazon regions with high levels of endemism that were already impacted by agriculture (Da Silva *et al.* 2005).

The establishment of protected areas remains as the cornerstone of conservation actions (Bruner *et al.* 2001; Joppa *et al.* 2008, but see Curran *et al.* 2004). They may be designed to fulfill different conservation objectives of either strict conservation or sustainable use (Dudley 2008). The strict conservation or integral protection protected areas (IPPAs) is exclusively devoted to biodiversity protection, research and regulated visitation related to tourism or environmental education. Geographically, protected areas have been located on areas too remote or unproductive to be economically valuable (Margules & Pressey 2000) and this should be particularly true for IPPAs. The sustainable use protected areas (SUPAs) allow the use of natural resources, and their effectiveness against threats to biodiversity is a permanent source of debate (*e.g.*, Redford & Sanderson 2000; Schwartzman *et al.* 2000). The SUPAs are more permissive to human activities inside them, including subsistence farming. As these areas are related to some economic activities,

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SUPAs are supposed to be close to populated areas and roads or waterways that are routes of access to consumer markets. Consequently, SUPAs are supposed to be more susceptible to threats to biodiversity. However, a previous analysis has found that both kinds of protected areas are effective in terms of protecting biodiversity (evaluated by land cover change; Joppa *et al.* 2008).

As the two different types of protected areas are supposed to be located in areas with different susceptibilities to agricultural use, we tested four hypotheses related to the spatial congruence between protected areas and agricultural expansion: i) Brazilian protected areas are less covered by current agriculture presence than areas not protected; ii) this difference will hold in the future; iii) the increase in the proportion of Brazilian protected areas covered by agriculture will be lower than in the areas not protected; iv) the impact of agriculture is higher in protected areas of sustainable-use relative to areas of integral protection.

Methods

Data

We defined agricultural land according to the map generated by the Integrated Model to Access the Global Environment (IMAGE, version 2.2) (Image Team 2001). This is a geographically explicit model that considers cropping and livestock systems, based on demand for food and energy crops. It accounts for factors such as productivity, distance from agricultural land and water bodies to infer the presence of agriculture in each 0.5° x 0.5° latitude-longitude grid cell (Image Team 2001). Current and future agricultural extents were taken from the A1B scenario, which seems the scenario that better reflects current trends of the world society (*i.e.*, socially oriented to market and globally integrated). Also, the area affected by agriculture in the future according to the A1B scenario has an intermediate value amongst other scenarios, which made our analysis a conservative one (Figure 1).

We used these land cover maps to evaluate the present state and future trends of agricultural cover in Brazil. We represented the present state by the map for the year 2000. For the future, we combined the maps from 2010 to 2100. The grid cells covered by agriculture anytime during this period were considered as covered by agriculture. We did this combination for future because there will be a spatial variation in the agriculture cover during the time and some areas may be abandoned and used for restoration, however these areas do not have the same value for conservation than original ones (Barlow *et al.* 2007). For more details about the IMAGE model and our approach, see Dobrovolski *et al.* (2011).

We obtained the polygons of protected areas from the World Database of Protected Area (WDPA 2009). We selected the protected areas based in Brazil and that are classified as the IUCN categories I-IV (integral protection, IPPA) and V-VI (sustainable use, SUPA). We excluded protected areas not included in any of these categories like "Indigenous Areas". The final set of protected areas was composed of 448 IPPAs and 396 SUPAs, with the total amount of 488,320 and 2,835,078 km^2 protected, respectively (Figure 2). We created 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 (Alexandre *et al.* 2010). We transformed the vector polygons of the protected areas and their buffer zones into a raster image with 0.5° × 0.5° degree resolution, the same resolution as the IMAGE map. To be classified as a protected area, any given cell must have more the 50% of its area covered by the protected area polygon. If an area was covered by an integral protection and a sustainable use protected area simultaneously, we defined this area as an integral protection one.

Analysis

We overlaid the maps of agricultural extent in the present (2000) and future (2100) on the map of the protected areas. We calculated: i) the number of grid cells protected by IPPAs or SUPAs covered by agriculture in the present and in the future; ii) the increase of the impact of agriculture in both sets of protected areas as the ratio between the number of protected grid cells covered by agriculture in the future and in the present.

To test if these values were significantly greater than those that might be obtained by chance, we performed a Monte Carlo analysis. We shuffled the positions of the protected

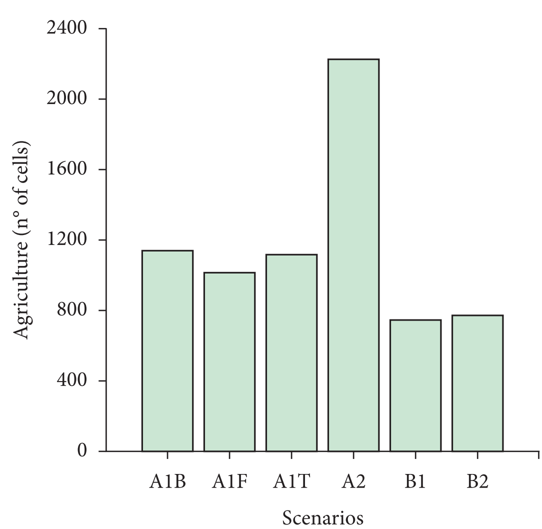

Figure 1. Area covered by agriculture in Brazil during the 21st century, represented by the number of cells, according to the six different scenarios of IMAGE (version 2.2).

area cells (both kinds together) 1000 times and calculated the metrics explained in the paragraph above for each. Then, we evaluated the number of times that we obtained impact metrics higher than the observed ones (*i.e.*, this gives the P-value). The analyses were done in R (R Development Core Team 2009).

Results

According to the A1B scenario of the IMAGE model, in the present period (the year 2000), 21.9% of Brazil is covered by agriculture. This effect differs among regions and varies from 2.5% in the Amazon to 46% in the Pampa biome (Table 1). In respect to protected areas, 11.9% of the IPPAs are covered by agriculture. For SUPAs this percentage is 9.7%. The Brazilian protected areas are less covered by agriculture than would be expected by chance ($P < 0.001$ for both IP and SU). Also, the two kinds of protected areas do not differ in relation to agriculture impact ($P = 0.13$) (Figure 3a).

In the future, the area covered by agriculture in Brazil will increase up to 40% of the country's area, an expansion of 82% over present-day agriculture. In the Amazon and in the Pampa, the proportion of area covered by agriculture will reach 18.7% and 80.4%, respectively (Table 1). Protected areas will continue to be less covered than other areas ($P < 0.001$ for IPPAs and $P = 0.003$ for SUPAs), and the impact of agriculture in IPPAs (27.1%) and SUPAs (33.4%) will be similar ($P = 0.072$) (Figure 3b). However, the increase in agricultural impact in protected areas is substantial relative to non-protected areas, the IPPAs will be 4.3 times ($P = 0.004$) and SUPAs will be 3.8 times ($P < 0.001$) more impacted by agriculture in the future than in the present. Again, the two kinds of protected areas do not differ in terms of encroachment from agriculture expansion ($P \approx 1.000$).

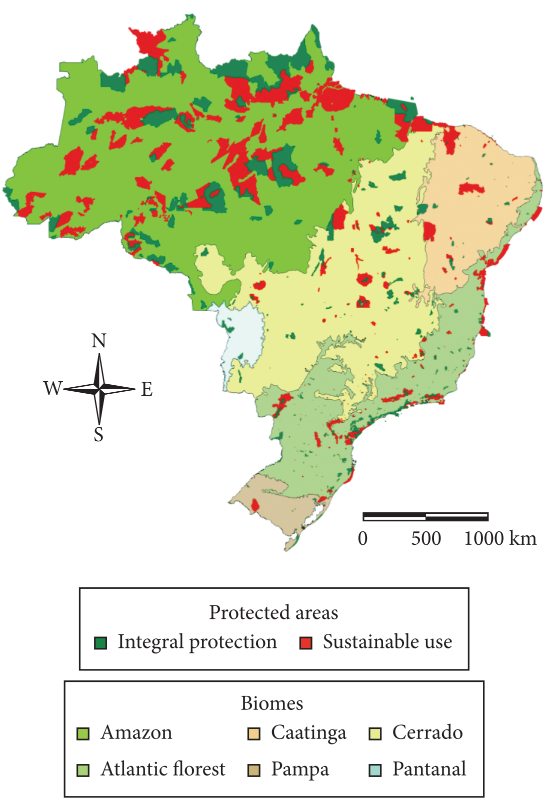

Figure 2. Map of the Brazilian protected areas, including the integral protection (IUCN I-IV) and sustainable use (IUCN V-VI) categories. The Brazilian biomes are also represented.

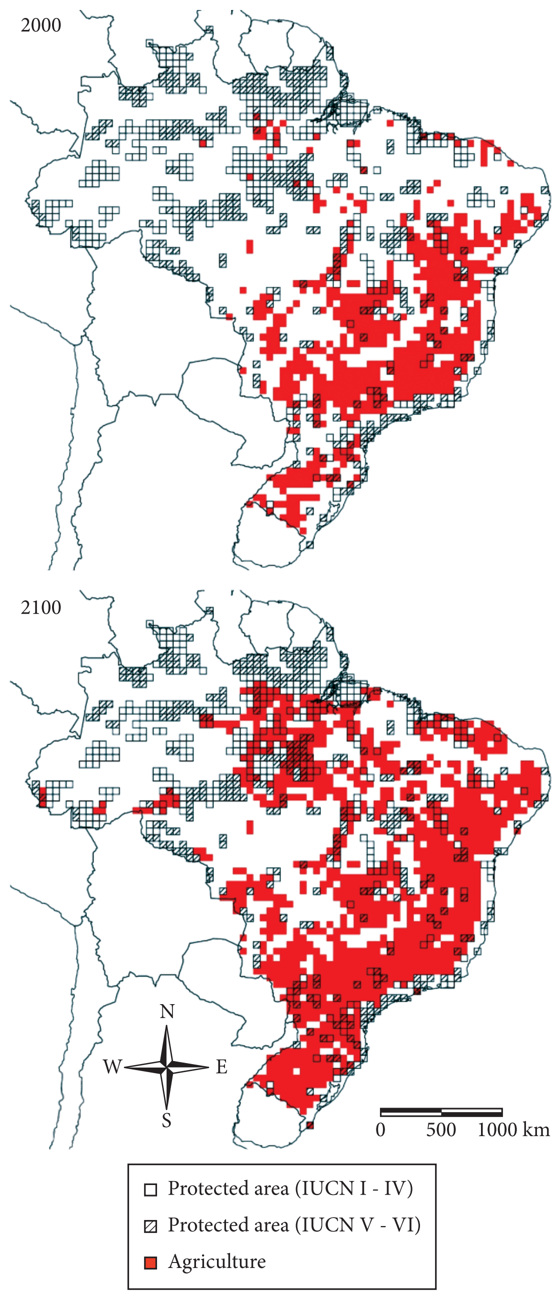

Figure 3. Map of the area covered by agriculture in Brazil, in 2000 and in 2100, according to IMAGE scenario A1B. The protected areas are shown in squares.

Table 1. Protected and agricultural area information for each Brazilian biome as we considered in this study (See Figure 3 and methods section): i) total area; ii) percentage or Brazilian territory; iii) protected areas and buffer zones (PA); iv) and its proportion represented by sustainable use (SUPA); v) and integral protection (IPPA) categories; vi) proportion of each biome covered by agriculture according to IMAGE in 2000; vii) and during the 21st century.

Biome	Area	(%)	Protected (%)	SUPA (%)	IPPA (%)	Agric. 2000 (%)	Agric. 2100 (%)
Amazon	4229823.4	49.5	33.8	57.2	42.8	2.5	18.7
Caatinga	835844.1	9.8	12.4	67.8	32.2	38.5	68.1
Cerrado	2025023.0	23.7	15.4	44.3	55.7	38.2	50.4
Pampa	162907.7	1.9	8.1	40.3	59.7	46.0	80.4
Pantanal	149805.6	1.8	5.9	0.0	100.0	29.4	47.2
Atlantic For.	1133358.5	13.3	22.1	38.8	61.2	44.5	68.7
Total (Brazil)	8536762.3	100.0	24.8	53.3	46.7	21.4	40.0

Discussion

Habitat destruction motivated by agriculture is globally the most important threat to biodiversity (Sala *et al.* 2000; Foley *et al.* 2011; Green *et al.* 2005). Here, we showed that this threat is supposed to increase drastically in Brazil during the 21st century, according to IMAGE forecasts of agricultural expansion. Agricultural expansion could even reach protected areas and their buffer zones. Indeed, and contrary to our expectations, the results suggest that the current threat imposed by land use changes generated by agriculture is not higher in sustainable use protected areas compared to integral protection ones. Moreover, as the forecast of agricultural cover suggests, the pressure on protected areas should increase in the next century equally for both types of protected areas. Consequently, it will be necessary for sustainable use protected areas to continue to play an important role in the conservation of biodiversity, especially in terms of maintenance of land cover (Joppa *et al.* 2008).

Further, our results reflect a division we have in the Brazilian territory. The Amazon biome represents about half the country's area and it is a focus of an international conservation attention. In the same way, it is found in an undeveloped socioeconomic condition, relative to other Brazilian regions. These characteristics have contributed to the Amazon contained about two thirds of the Brazilian protected areas (Table 1), following the well-known pattern of a preferential creation of protected areas in remote regions (Margules & Pressey 2000). Finally, the Amazon is currently virtually unaffected by agriculture. On the contrary, the rest of Brazil (mainly Atlantic Forest and Cerrado) are poorly protected and intensively impacted by agriculture. Consequently, most of the area available for agricultural expansion is located in the Amazon and our forecast indicates that this region will have the higher amount of land use change. Also, protected areas will become disproportionately impacted by agriculture because most of them fall in the Amazon. In short, agricultural expansion is homogenizing Brazil's territory, making the entire country more vulnerable to biodiversity loss.

Furthermore, some caveats about our study should be discussed. First, the reliability of the model of agricultural extent predicted by IMAGE should be compared to other estimates. For instance, in 2000 the area covered by agriculture in Brazil according to IMAGE model is 1.83 million km^2, while the Brazilian official agricultural census estimated 2.19 million km^2 for both 1995/6 and 2006 periods (IBGE 2009). Consequently, the extension of agriculture presented here is a conservative one. For the future, the projections are dependent on the assumptions used by the model and the future scenarios of human development. Our option by the scenario A1B, which presents intermediate values of agricultural expansion (Figure 1), was also an attempt to be cautious, avoiding extreme forecasts (see methods). Moreover, the trend of agriculture expansion is suggested not only from land cover models such as IMAGE and others (*e.g.* Soares-Filho *et al.* 2006), but also from the deforestation rates. In the Brazilian Amazon these rates have been equal to 18141 (±5075 S.D.) km^2/year between 1977 and 2010 (INPE 2011) and, in the Cerrado, equal to 14273 (±2366 S.D.) km^2/year between 1988 and 2010 (MMA 2010) – although it has been observed a significant reduction in the deforestation rates in the last few years.

Another critical point is that IMAGE is supposed to integrate the protected area data for the year 1998 (Image Team 2001). However, we found agriculture land cover in protected areas and their buffer zones in the present and in the future, both for protected areas created before or after 1998, the year of the database used by IMAGE. Further, we used the present network of protected areas in Brazil, and hopefully this network will change until the end of the century. The addition of new protected areas can change some results of our analysis, but it is conservative in respect to biodiversity conservation and, more important, it is unlikely to change our general conclusions. In fact, we understand that the coincidence between agricultural and protected areas that we found in our analysis does not mean that agricultural activity occurs precisely in the predicted proportions inside protected areas – actually, this is not permitted in for IPPAs. IMAGE is a global model that evaluates general trends. Consequently the aim of our analysis is not to say exactly where there is or will be agriculture inside protected areas, but instead measures the trends of influence of this activity and potential conservation conflicts. The areas evaluated as being covered by agriculture are likely to be under pressure of this activity and may be converted if there is not sufficient surveillance. Also, it has been shown that although the protected areas are able to protect the natural features inside it, human activities may increase in their neighborhood (Ewers & Rodrigues 2008, but see Andam *et al.* 2008). Consequently, even if the agricultural expansion shown here will not affect protected areas, it can threaten their buffer zones putting at risk species' populations in these areas by habitat destruction and other threats such as fire and hunting that can act synergistically (Brook *et al.* 2008). Despite the fact that agriculture can maintain part of biodiversity, particularly when agroecological practices are incorporated (Perfecto & Vandermeer 2010), many species are sensible to even supposedly biodiversity friendly agricultural practices (Phalan *et al.* 2011).

The habitat conversion to agriculture that is predicted to increase by 82% in this century will increase the pressure on protected areas. The risk of such an extent of the territory being converted into agriculture should raise concerns regarding how to make agricultural areas more wildlife-friendly, where to place different land uses (agricultural and protected areas) and which regulation tools might make this succeed. Currently, there is a wide discussion about changes to the Brazilian Forest Code (*e.g.*, Da Silva *et al.* 2011; Metzger 2010) in order to remove constraints on agricultural production. The expansion of agriculture has been suggested as a pathway for development despite the fact that such a process may not be sustainable (Rodrigues *et al.* 2009), while biodiversity protection can indeed contribute to alleviate poverty (Andam *et al.* 2010). We suggest that in face of the great expansion of agriculture threatening Brazilian protected areas and their buffer zones, the role of Brazilian Government should be to enforce the current legislation and supervise its observance. It is time to embrace portfolios of biodiversity protection (Ehrlich & Pringle 2008) and not to be compliant with environmental destruction.

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