

## Agricultural expansion and the fate of global conservation priorities

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**Abstract** Non-governmental organizations have proposed nine different global prioritization schemes, some of them focusing on areas with low vulnerability (a proactive reasoning) and some others targeting areas with high vulnerability (a reactive reasoning). The main threat to the remaining natural habitats of these areas is the expansion of agriculture. We evaluated the spatial congruence between agricultural land cover and global conservation priority areas in the present and in the future using a spatial model of land use cover change from 2000 to 2100. We showed that by the year 2000, the extent of agriculture was larger in reactive priority areas than in the rest of the world, while it was smaller in areas highlighted as important under proactive approaches. During the twenty-first century, we found a general increase in agriculture area and the difference between the approaches of conservation schemes is expected to hold true, although we found that high-biodiversity wilderness areas (HBWA), a proactive scheme, may be specially affected in certain scenarios of future change. These results suggest an increase in conservation conflicts over this century. In face of agricultural expansion, both kinds of prioritization approaches are important, but different strategies of protection are necessary (e.g., reactive approaches need the urgent protection of remnant habitats, while proactive ones have space to create megareserves). Further, conservation organizations must include agriculture expansion data and their uncertainty in conservation planning in order to be more successful in biological conservation.

**Keywords** Agriculture · Conservation conflict · Global biodiversity conservation priorities · Land use and land cover change · Biodiversity hotspots · High-biodiversity wilderness areas · Endemic bird areas · Crisis ecoregions · Megadiversity countries · Last of the wild

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## Introduction

Conflicts between biodiversity conservation and human development may threaten the livelihood of species worldwide. The world is faced by an astonishing increase in the number of species considered to be threatened (IUCN 2009) in response to growth of human population (United Nations Population Division 2008) and per capita consumption (Myers and Kent 2003) that generates an increasing pressure on natural resources. The biodiversity we are losing is important for ecological processes, human economy, and human leisure (Millennium Ecosystem Assessment 2005). Here, we assessed if agricultural expansion up to 2100 will threaten biodiversity inhabiting priority areas for conservation worldwide scaling up conservation conflicts in the future.

Throughout the world, there are places with special biological features (i.e., high diversity or high levels of endemism) that arouse the attention of conservation scientists, practitioners and planners. When these places are also subject to human development activities, a conservation conflict emerges. Such congruencies have been measured in different ways, including the correlation between the human population and species richness (Balmford et al. 2001; Araújo 2003; see Luck 2007 for a recent review), the comparison of human population inside and outside Biodiversity Hotspots (Cincotta et al. 2000), the correlation between avian endemism and deforestation (Balmford and Long 1994), the correlation between biodiversity and agricultural productivity (Huston 1993) and the extent of agriculture within the Endemic Bird Areas (Scharlemann et al. 2004). However, we are still in need of a proper evaluation of the different global conservation priority schemes versus agriculture expansion, both in the present and in the context of future changes. Such assessment may inform the conservation practitioners and scientists about foreseeable risks to biodiversity and conservation opportunities as well.

There is growing evidence that habitat loss is the main threat to biodiversity (Vitousek et al. 1997; Sala et al. 2000; Green et al. 2005). Humans destroy natural habitats through changes in land cover and land use mostly in order to expand agriculture areas that feed human populations and livestock (Tilman et al. 2001; Foley et al. 2005; Green et al. 2005). With the increase of human populations and their consumption per capita, it is expected that the area devoted to agriculture is going to increase worldwide (Tilman et al. 2001). Beyond habitat destruction, agriculture is related to other impacts, such as biological invasion, eutrophication, chemical contamination, and greenhouse gases emissions (Tilman et al. 2001). To understand the dynamics of land cover and land use change and its associated impacts on biodiversity and ecosystem services, a land change science has emerged (Sala et al. 2000; Turner et al. 2007). One of the tools used by this interdisciplinary field is the development of spatially explicit models, such as the Integrated Model to Assess the Global Environment (IMAGE), capable of forecasting land use change based on the joint modeling of human activities and environmental processes. To anticipate the consequences of different socioeconomic pathways that human societies can follow, different scenarios of land use change have been proposed (IPCC 2000; UNEP 2002; Millennium Ecosystem Assessment 2005; Pereira et al. 2010).

Since the foundation of the systematic conservation planning framework—epitomized by Myers' (1983) seminal paper—the conservation community has been looking for a “silver bullet” and seeking a way to get the “biggest bang for the buck”. However, even considering the existence of objective methods for analyzing data and establishing priorities, it is important to note that conservation strategies in a changing world can be done using different and alternative principles (Fonseca et al. 2000; Redford et al. 2003). Thus, important non-governmental organizations have proposed nine schemes during the

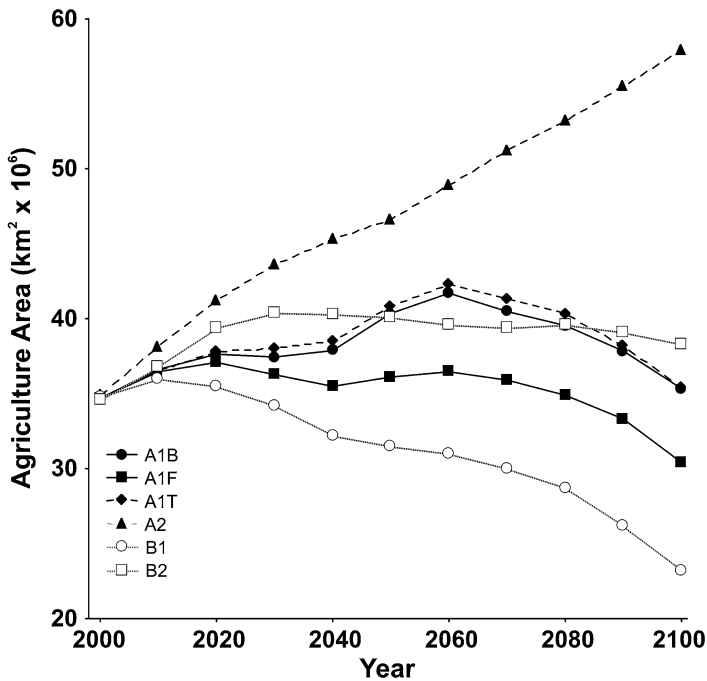
last two decades, which can be interpreted as nine major institutional templates for global conservation priorities (e.g., Stattersfield et al. 1998; Myers et al. 2000; Sanderson et al. 2002). These templates were revised and classified according to the conservation planning theoretical principles of irreplaceability and vulnerability (Brooks et al. 2006). Six of them incorporate irreplaceability by means of endemism of plants (WWF and IUCN 1994–1997; Mittermeier et al. 1997; Olson and Dinerstein 1998; Myers et al. 2000; Mittermeier et al. 2003) or terrestrial vertebrates (Stattersfield et al. 1998). Five templates take into account vulnerability that has been measured as a proportion of habitat loss (Myers et al. 2000; Mittermeier et al. 2003; Hoekstra et al. 2005), forest cover (Bryant et al. 1997), protected area coverage (Hoekstra et al. 2005) or human population growth and density (Sanderson et al. 2002; Mittermeier et al. 2003). As later suggested by Brooks et al. (2006), these prioritization schemes can be classified as reactive (i.e., those highlighting areas with high vulnerability, e.g., Biodiversity Hotspots), proactive (i.e., those that prioritize areas with low vulnerability, e.g., Last of the Wild) and approaches that do not incorporate vulnerability as a criterion (neutral approaches, e.g., Endemic Bird Areas).

Here, we asked if areas highlighted as priority under reactive or neutral approaches are likely to be more affected by agriculture than non-priority areas. We also investigate if areas included in proactive schemes, in contrast, are less affected than the rest of the world; i.e. the presence of agriculture reproduces the pattern of vulnerability that would be predicted by the conservation templates' design. Moreover, we evaluated whether agriculture expansion throughout the twenty-first century is more likely to occur inside global conservation priority areas than outside them, suggesting an increase in conservation conflict. We also assessed whether there will be a convergence in the proportion of the areas affected in each conservation template regardless of approach (reactive, neutral or proactive). Finally, we tested if the uncertainty regarding land use model scenarios was higher in these priority conservation areas.

## Materials and methods

### Land use data

We used the Integrated Model to Assess the Global Environment (IMAGE, version 2.2) (IMAGE Team 2001) to map agricultural land. This model is an “integrated assessment model” that is used to describe the environmental consequences of human activities. The objective of IMAGE is to explore the long-term dynamics of global environmental change, taking many feedback mechanisms within the society–biosphere–climate system into account (IMAGE Team 2001). It is also a spatially explicit model that analyzes the trends found in global land cover/land use and in the variables that influence its change. Global land use was mapped by IMAGE 2.2 on a  $0.5^\circ \times 0.5^\circ$  latitude–longitude grid. IMAGE 2.2 does not model land use in the Antarctic and in some oceanic islands; hence, we excluded these areas from our analyses. We defined agricultural land as cropland, fallow land, and grassland (excluding extensive grassland) (IMAGE 2.2 class one). To map the extent of agricultural land, IMAGE considers variables such as previous land cover, potential vegetation cover, crop productivity, management factors, human population density, and demand for food, biofuel and timber products (IMAGE Team 2001). The model's temporal span starts in 1970 and goes up to 2100, with maps for every 10 years, providing alternative pathways of future land use change based on six scenarios (A1B, A1F, A1T, A2, B1,



**Fig. 1** Change in global extent of agriculture from 2000 to 2100 according to the Integrated Model to Assess the Global Environment version 2.2 under six SRES scenarios (A1B, A1F, A1T, A2, B1, B2)

B2) developed by IPCC in the Special Report on Emissions Scenarios (SRES) (IPCC 2000; IMAGE Team 2001) (Fig. 1).

Briefly, the IPCC (SRES) scenarios are based on two axes: the degree of globalization versus regionalization and the level of orientation on material versus social and ecological values (IMAGE Team 2001). The A1 scenario family assumes a continuing globalization, very rapid economic growth, low population growth, and rapid introduction of new and more efficient technologies. This process results in convergence among regions due to increased cultural and social interactions and to a substantial reduction in regional differences in per capita income. The A1 scenario is divided into three possibilities, in accordance with their technological emphasis: fossil intensive (A1F), non-fossil energy sources (A1T), and balanced across all sources (A1B) (IPCC 2000).

In the A2 scenario, globalization slows down, generating a very heterogeneous world as nations and governments focus on cultural identity and traditional values and leading to slower economic growth, technological change, and fertility reduction. The other scenario used herein (B1), also starts from the same low population growth rate as A1, but it assumes important changes in economic structures toward a service and information economy, which represents a human focus on the environmental and social or immaterial aspects of life, and the introduction of clean and resource-efficient technologies. In this scenario, the emphasis is placed on global solutions to economic, social, and environmental sustainability, including improved equity (IPCC 2000). In scenario B2, people are organized to find solutions to economic, social, and environmental sustainability issues in the same way as in B1, except that they are focused on local and regional solutions. Thus, there is significant heterogeneity between regions. All these scenarios do not include explicit

climate policy interventions (IPCC 2000). Further details about each scenario are described by IPCC (2000) (see Millenium Ecosystem Assessment 2005 for a comparison with other proposed scenarios).

### Intersection of global biodiversity conservation priorities and land use maps

We used the nine major templates for Global Biodiversity Conservation Priorities (GBCP) (see Brooks et al. 2006). We also evaluated the conservation schemes resulted from overlaying reactive (Crisis Ecoregions, CE; and Biodiversity Hotspots, BH) and proactive conservation approaches (high-biodiversity wilderness areas, HBWA; Frontier Forests, FF; and Last of the Wild, LW) as proposed by Brooks et al. (2006). Conservation schemes that do not consider vulnerability, i.e., neutral approaches, are Endemic Bird Areas (EBA), Megadiversity Countries (MC), Centers of Plant Diversity (CPD), and Global 200 Ecoregions (G200) (Brooks et al. 2006). Template polygons were converted to a raster image with  $0.5^\circ \times 0.5^\circ$  resolution, which is compatible with those from IMAGE 2.2 land use maps. The cells whose area was covered in a proportion higher than 50% by the template polygon were considered part of the template. The reference coordination system of all spatial data was WGS 84.

Maps of agricultural extent and GBCP were overlaid using the Idrisi Kilimanjaro GIS software (Eastman 2003). We calculated the proportion of global agriculture cover as the area affected by this land cover type divided by the total terrestrial area mapped by the IMAGE. The same was repeated for each conservation template. The agriculture area in 2000 was defined by the overlay of the maps of this land cover type in the world in the six scenarios, given that we found a great congruence among them (84.4%).

For predictions about the future, we performed two analyzes. Firstly, we choose a particular future scenario to help to envisage a specific future scenario for world agriculture. In this simpler analysis, we summed the 10 images of the scenario A1B and assigned value one to any cell converted to agriculture anytime during the twenty first century. This approach was based on two assumptions: (i) the A1B is a plausible scenario, since the world nowadays can be classified as economically driven (A), we are under a process of international integration through globalization (1), and the non-fossil fuels have been gaining importance, so we seem to be going to a world of balanced use of fossil and non-fossil fuels (B). Also, A1B has an intermediate level of agriculture impact (Fig. 1); (ii) the areas once affected by agriculture will be permanently altered, since the secondary habitats do not have the same value for biological conservation than original ones (Barlow et al. 2007). In the second approach, that preserves all the complexity of the model, in terms of time and scenarios, the expansion of agriculture during the twenty-first century was defined by the overlay of the 60 maps available for the years between 2010 and 2100 for all six scenarios. This procedure resulted in an agriculture-proneness-score (APS) for each cell, which varied between zero (no agriculture at any date of any scenario) and 60 (presence of permanent agriculture in all scenarios). This second approach, which maintains all uncertainties, is important because it can help to understand key uncertainties in the future, can be used to incorporate alternative perspectives in conservation planning and probably can provide more resilience to decisions in response to changes (Peterson et al. 2003).

To evaluate if the proportion of agricultural land in 2,000 was randomly distributed between each conservation template and the rest of the world, we designed a randomization test. Initially, we defined the cells prone to agriculture conversion as any cell that was affected by agriculture any time in any SRES scenario during the twenty first century

(APS equal or higher than one). Then, we took the cells considered above as a constraint and, inside them, we randomized the position of the cells that were known to have agriculture in 2000. Finally, we calculated the number of cells with agriculture in this null model for each conservation template. The whole process was repeated 1,000 times.

Since we have different alternative hypothesis for reactive plus neutral in comparison to proactive templates, we used different one-tailed randomization tests in each case. For reactive and neutral templates, the proportion of randomized values equal or higher than the observed number of cells with agriculture ( $P$  value) was used to test if the observed value could be explained by chance alone ( $\alpha > 0.05$ ). For proactive templates, we did the same, but took into account the values equal to, or lower than, the observed number of cells. For the twenty-first century map, we followed the same general randomization procedure for the analysis of the A1B scenario, but multiplied the number of cells by their respective APS for the analysis that combined all scenarios. We estimated the  $p$ -value for significant tests by the proportion of APS calculated from random assignments of cells for each conservation template that was equal to or higher than the observed values. In all cases, the number of cells was corrected by cell area. All randomization procedures were done using R (R Development Core Team 2008).

### Scenario uncertainty evaluation

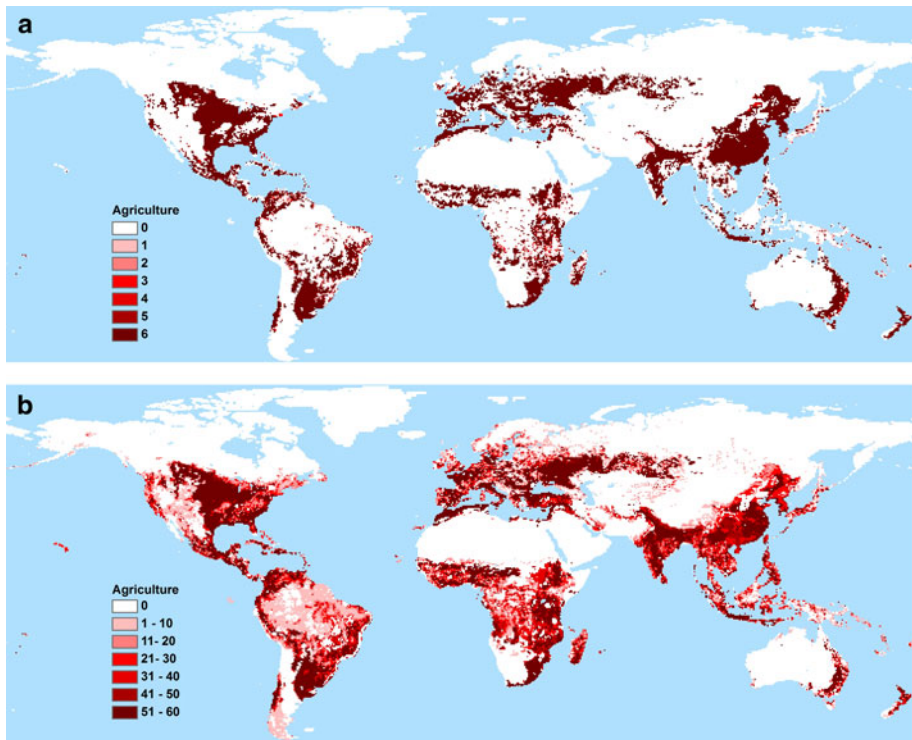
In our analysis, we had two main sources of uncertainty, particularly for the future, i.e., time and scenario. Scenario could be considered hierarchically more important than time in those analysis because, for conservation purposes, it is more important to know if an area will be or not affected by agriculture than when or for how many years. Thus, we performed an analysis of the uncertainty related to the difference among scenarios to clarify the source of uncertainty.

To perform this analysis, we summed all maps of the ten dates of each six scenarios. With this procedure, we managed to depict the areas that will be affected by agriculture anytime in the twenty-first century in each scenario. This procedure annulled the importance of time as a source of variation. The remaining differences among maps are derived only from the distinctions in the scenarios. To quantify this uncertainty score (US), we first added the six scenarios' maps of agriculture distribution. For areas that were affected by agricultural expansion in every scenario, uncertainty is zero. The same holds true for those areas not affected in any scenario. On the other hand, a cell affected by only one scenario has an US of five. Cells affected by two scenarios have US of four, and so on. We evaluated the probability of the sum of uncertainty score found in each conservation template through a randomization test as we have done for the presence of agriculture (see above). This procedure was done for the uncertainty of the areas of agriculture in 2000 and in the twenty-first century. The estimated the  $P$  value was the number of times that the sum of the uncertainty scores obtained through randomization was equal or lower than the observed value.

## Results

### Current land use

In 2000, 26.5% of the world's land surface was converted to agricultural land (Fig. 2a; Table 1). The only reactive template significantly more affected by agriculture than the rest



**Fig. 2** Map composed by the sum of the maps of the global extent of agriculture in 2000, simulated by the Integrated Model to Assess the Global Environment version 2.2 with six SRES scenarios (a). In b, there is the sum of the 60 maps of the global extent of agriculture for six future scenarios of 10 time periods from 2010 to 2100

of the world was CE (52.3%;  $P = 0.001$ ) (Table 1). All proactive schemes were less affected than the outside areas. For instance, LW had only 3.0% of its area affected and was 11 times less affected than the rest of the world ( $P = 0.001$ ) (Table 1).

The comparison of reactive and proactive approaches showed that the former (48.6%;  $P = 0.001$ ) are much more affected by agriculture than the latter (5.2%;  $P = 0.001$ ). For the approaches that did not consider vulnerability, we found different results. For example, EBA were 83% more affected than the rest of the world ( $P = 0.001$ ) (Table 1). Other neutral templates (MC, CPD, and G200) had proportions of agricultural land similar to those found in areas outside of them.

#### Agricultural expansion in the twenty first century

Agriculture in the world will reach 34.3% of the analyzed land surface during the twenty-first century according to the scenario A1B, which means an increase of 29.6% in relation to the agriculture extent in 2000. Reactive approaches whether combined (60.1%;  $P < 0.001$ ) or separately (CE = 63.9%;  $P < 0.001$  and BH = 56.7;  $P < 0.001$ ) besides EBA (53.8%;  $P < 0.001$ ) were particularly affected.

Our analyses of the 6 models and 10 dates combined (APS) reveal that there will be an increase of 80% of the world area affected by agriculture during the twenty-first century,



**Table 1** Agriculture intersection with global conservation priority schemes

Priority	In/Out	(All models) 2000 (%)	<i>P</i> -value	(A1B) 2100 (%)	<i>P</i> -value	(All models) 2100 (%)	2100 (S)	<i>P</i> -value
BH (R)	In	42.5	NS	56.7	<0.001	75.7	36	<0.001
	Out	22.6		29.0		41.0	32	
CE (R)	In	52.3	<0.001	63.9	<0.001	76.8	41	<0.001
	Out	15.5		21.7		35.2	27	
CPD (P)	In	29.5	NS	39.8	NS	60.9	29	NS
	Out	26.2		33.8		46.4	34	
EBA (N)	In	44.9	<0.001	53.8	<0.001	73.7	35	<0.001
	Out	24.5		32.2		44.9	33	
G200 (N)	In	26.8	NS	35.2	NS	52.9	31	NS
	Out	26.3		33.8		44.5	36	
MC (N)	In	35.3	NS	44.5	NS	64.0	32	NS
	Out	21.8		28.9		38.9	35	
HBWA (P)	In	11.3	<0.001*	25.9	NS	73.5	14	NS
	Out	27.9		35.1		45.3	36	
FF (P)	In	4.5	<0.001*	10.5	NS	34.2	12	NS
	Out	28.7		36.8		49.1	35	
LW (P)	In	3.0	<0.001*	5.7	NS	17.9	12	NS
	Out	34.1		43.7		57.4	36	
Reactive	In	48.6	<0.001	60.1	<0.001	74.7	39	<0.001
	Out	12.1		17.5		30.1	24	
Proactive	In	5.2	<0.001*	10.3	NS	26.1	15	NS
	Out	35.9		44.9		57.2	37	
World	In	26.5		34.3		47.7	34	

Percentage (%) of the area of each global biodiversity conservation priority scheme that was covered by agriculture in 2000, and its coverage prediction in 2100–2100 according to the Integrated Model to Assess the Global Environment version 2.2. Value of the agriculture-proneness-score (APS) mean of the cells of each conservation scheme resulted from the sum of the 60 maps (possible values = 0–60). Value of probability (*P* value) that the priority template area was more affected than the portion of the world that was convertible to agriculture (see text) (\* For proactive schemes in 2000, we tested the probability that the scheme was less affected)

Global conservation priority schemes and their respective authors are as follows: *BH* biodiversity hotspots, Myers et al. (2000), updated in Mittermeier et al. (2004); *CE* crisis ecoregions, Hoekstra et al. (2005); *CPD* centers of plant diversity, WWF AND IUCN (1994–1997); *EBA* endemic bird areas, Stattersfield et al. (1998); *G200* global 200 ecoregions, Olson and Dinerstein (1998), updated in Olson and Dinerstein (2002); *MC* megadiversity countries, Mittermeier et al. (1997); *HBWA* high-biodiversity wilderness areas, Mittermeier et al. (2003); *FF* frontier forests, Bryant et al. (1997); *LW* last of the wild, Sanderson et al. (2002). *R* reactive schemes; *P* proactive schemes; *N* neutral schemes

*In* inside the global biological conservation priority template area; *Out* outside of it. *NS* not significant;  $\alpha = 0.05$

reaching 47.7% of global land cells (Fig. 2b; Table 1). In our analyses these cells were affected, on average, by 34 out of the 60 possible combinations of scenarios each year (SD = 22.1).

Reactive templates, when analyzed separately or coupled, had about 75% of their area affected by agriculture; a higher proportion when compared to the global average. For



example, BH was found to be 75.7% covered by agriculture during the twenty-first century ( $P < 0.001$ ) (Table 1). The APS of their cells were also higher. In contrast, proactive templates, when taken together, had a smaller proportion and scores of affected area. However, when examined separately, HBWA had 73% of its area affected by agriculture, although it had a lower score, which means that it was reached by agriculture only in a few scenarios and for a short period of time ( $P$  value not significant); this proportion is similar to that of reactive templates.

With regard to neutral templates, only Endemic Bird Areas were significantly more affected by agriculture than expected by chance (73.7%;  $P < 0.001$ ).

### Scenario uncertainties

Uncertainty about the expansion of agriculture according to different scenarios also depends on the conservation approach. For 2000, although there was only 15.6% uncertainty, this uncertainty was not equally distributed among the conservation schemes. Only in CE (9.1%;  $P < 0.001$ ), MC (12.5%;  $P < 0.001$ ) and in the reactive approaches summed (12.4%;  $P < 0.001$ ) (Table 2; Fig. 3a) the agriculture presence was significantly less uncertain than for the rest of the world. The other templates had more uncertainty than the rest of the world. The proactive areas had more uncertainties when taken separately (HBWA = 424% higher; FF = 270% higher; LW = 261% higher; Table 2) or together (Proactive = 330% higher; Table 2).

In the future, the analysis of uncertainty becomes more important, as 50.6% of the area expected to be covered by agriculture in the future has some degree of uncertainty (Table 2; Fig. 3b). We found an opposite trend of agriculture uncertainty in relation to agriculture amount. The bigger agriculture extent is inside each conservation template, the smaller the uncertainty is. Therefore, in BH (51.4%;  $P < 0.001$ ), CE (36.3%;  $P < 0.001$ ), EBA (47.5%;  $P < 0.001$ ) and reactive approaches (12.4;  $P < 0.001$ ), our uncertainty was smaller than for the rest of the world. For proactive approaches, taken together or separately, the uncertainty was bigger inside them than for the rest of the world (e.g. the agriculture uncertainty in the sum of proactive approaches area was 96% higher than in the rest of the world).

## Discussion

Several authors have portrayed a spatial conflict between biodiversity conservation and human development (reviewed in Luck 2007). We analyzed the conflict between global conservation priorities and agriculture in current time and in the future. We found that the magnitude of the conflict depends on how the conservation priority was defined.

Reactive approaches, defined by high vulnerability, were strongly affected. This result was in concordance with the design of the Biodiversity Hotspots (BH), for example, which were defined by areas that had more than 70% of their natural vegetation cover destroyed (Myers et al. 2000), and the Crisis Ecoregions (CE), which were composed by ecoregions that had less than 50% of their natural areas preserved (Hoekstra et al. 2005). Our study shows that 42 and 52% of these areas, respectively, were already converted to agricultural land in 2000. However, by 2100, these areas may have about 60%, if we analyze only the A1B scenario and almost three-quarters of their total area impacted by agriculture, when combining all possible future scenarios.

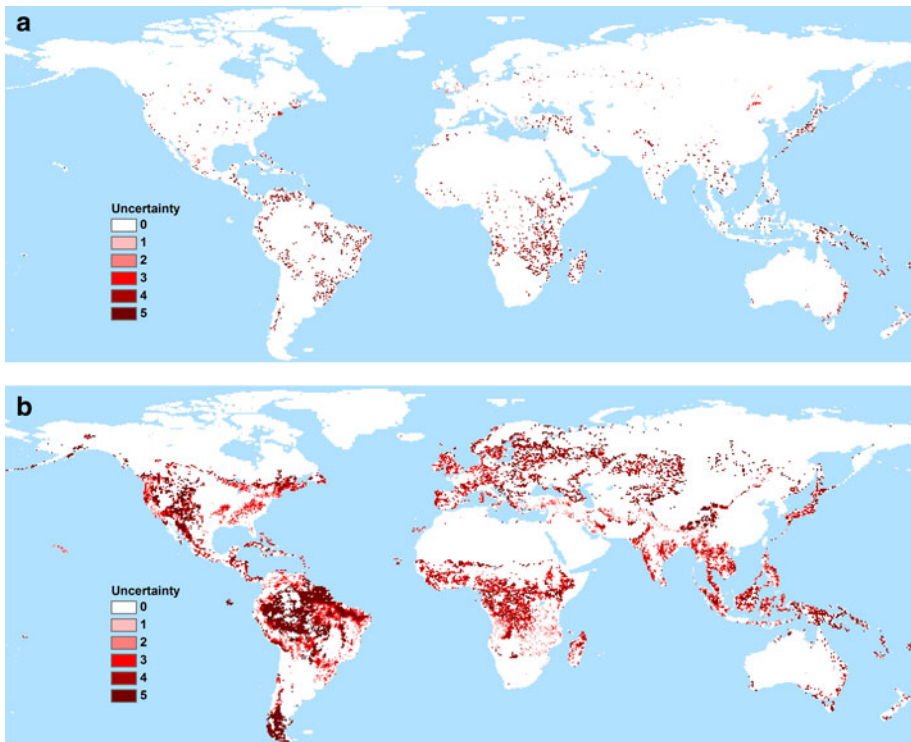
**Table 2** Uncertainty of global conservation priority schemes

Priority scheme	In/Out	2000 (%)	2000 (US)	<i>P</i> -value	2100 (%)	2100 (US)	<i>P</i> -value
BH (R)	In	21.7	0.43	NS	51.4	1.53	<0.001
	Out	12.7	0.25		50.3	1.77	
CE (R)	In	9.1	0.21	<0.001	36.3	1.11	<0.001
	Out	24.7	0.40		63.9	2.24	
CPD (N)	In	19.4	0.33	NS	59.0	2.12	NS
	Out	15.0	0.30		49.5	1.64	
EBA (N)	In	18.1	0.38	NS	47.5	1.56	<0.001
	Out	15.0	0.29		51.2	1.72	
G200 (N)	In	20.1	0.35	NS	56.2	1.93	NS
	Out	12.7	0.27		46.5	1.53	
MC (N)	In	12.5	0.24	<0.001	51.2	1.79	NS
	Out	18.0	0.37		50.1	1.62	
HBWA (P)	In	58.9	0.35	NS	89.3	3.57	NS
	Out	13.9	0.30		44.9	1.42	
FF (P)	In	40.7	0.21	NS	91.0	3.82	NS
	Out	15.1	0.31		47.7	1.55	
LW (P)	In	38.7	0.25	NS	88.3	3.73	NS
	Out	14.8	0.31		46.8	1.49	
Reactive	In	12.4	0.28	<0.001	40.7	1.25	<0.001
	Out	23.5	0.35		66.7	2.42	
Proactive	In	45.0	0.29	NS	85.4	3.37	NS
	Out	13.6	0.30		43.6	1.36	
World	In	15.6	0.30		50.6	1.70	

Percentage (%) of the area of each global biodiversity conservation priority schemes that was affected by uncertainty about the area covered by agriculture in 2000 and from 2010 to 2100 according to the Integrated Model to Assess the Global Environment version 2.2. Value of uncertainty mean score (US) of the cells of each conservation scheme resulted from the sum of the 6 maps (possible value = 0–6). Value of probability (*P* value) that the priority area was more affected by uncertainty than the portion of the world that was convertible to agriculture (see text). See abbreviations and references in Table 1

Proactive approaches that take into account only wilderness (i.e., the lack of human presence), such as Last of the Wild (LW) and Frontier Forests (FF), were virtually unaffected in 2000 and during the twenty-first century were likely to have just relatively small increases, reaching about 18 and 34%, respectively, of agriculture extent inside their area when all scenario were combined. The other approaches (Global 200 ecoregions, G200; Megadiversity Countries, MC; Endemic Bird Areas, EBA; and Centers of Plant Diversity, CPD) showed different results, ranging from proactive to reactive approaches. As shown in previous research (Scharlemann et al. 2004), EBA was also highly affected, similarly to a reactive approach.

Since an effective conservation priority scheme should be able to anticipate threats for the foreseeable future, one of the most interesting findings of our analyses was the results obtained for HBWA. This is a proactive approach whose areas were affected in only 11% of their extension in 2000, but which could see up to 75% used by 2100 under certain land use scenarios, as if it were a reactive approach. This assumes great importance given that HBWA is the only proactive scheme that considers irreplaceability, defined by high levels



**Fig. 3** Map of uncertainty value in the global extent of agriculture in 2000 (a) and from 2010 to 2100 (b) simulated by the Integrated Model to Assess the Global Environment version 2.2 with six SRES scenarios

of plant endemism (Mittermeier et al. 2003). HBWA are composed of North American deserts, savannas of Miombo-Mapone and the tropical forests of Amazonia, Congo and Indonesia. Tropical forests are regions that contain most of the global biological diversity, play a vital role in providing ecosystem goods and services and have been under intensive destruction over the last decades (Laurance 1999). Further, they encompass most of the tropical ecosystems still offering significant options for successful broad-scale conservation action (Loyola et al. 2009a).

Agricultural expansion has been encouraged in these regions, which aims at local development and generation of capital for national industrialization, although such processes do not guarantee sustainable development (Rodrigues et al. 2009). Our projections show that a less vulnerable region today may not be so in the foreseeable future, and modeling future trends of land use/land cover change can help to anticipate threats to species and ecosystem. A good (or bad) example of this assumption was observed in the Islands of Eastern Melanesia. These islands have seen their land surface converted from an almost pristine environment to a situation in which less than 30% of its natural vegetation cover remains intact, in less than 10 years. The region ended up being classified as a Biodiversity Hotspot in 2004 (Mittermeier et al. 2004).

But what are the benefits of our approach? Human population density, the ultimate cause of species extinction worldwide, has been shown to be positively correlated to pressures on biodiversity, such as habitat alteration (Thompson and Jones 1999),

over-harvesting (Brashares et al. 2001) and biological invasion (McKinney 2001). However, Rangel et al. (2007) have shown that agriculture can represent a threat to biodiversity that is independent of the human population, as was found in the Brazilian “Cerrado” (the open savannas in the central part of the country), where species richness and complementarity is coincident with indicators of agriculture and cattle ranching, but not with human population per se. This pattern is explained by the increase in technology applied to agriculture in the Cerrado region of Central Brazil (Klink and Moreira 2002). To illustrate the implications of this process, in Brazil (one of the 16 megadiversity countries that also harbors two Biodiversity Hotspots), the cropland and the number of bovine heads doubled, while the number of people in agriculture reduced 6% and the number of tractors increased 475% from 1970 to 2006 (IBGE 2010). Associated with this process, there was a huge destruction in two Brazilian biomes prone to agricultural expansion: the Cerrado, where only 20% of the original vegetation remains intact (Myers et al. 2000), and the Amazon rainforest, which has been losing an average of 1.8 million hectares of forest per year during 1988–2008 period (INPE 2010). Moreover, 70% of Brazil’s population is concentrated in another biome, the Atlantic Forest (Metzger 2009). Therefore, we suggest that the agriculture area, the principal driving force of habitat destruction, should be investigated as an important indicator of the human impact for evaluating conservation conflicts, as shown by the Brazilian examples above. Also, as we found here, agriculture was capable of capturing differences among the prioritization approaches (reactive versus proactive schemes).

In addition, the use of the Global Biodiversity Conservation Priorities can be reasoned by the fact that these priorities represent large areas of the world that have directed conservation funds and efforts for on-the-ground conservation actions (Brooks et al. 2006). These several conservation schemes have been criticized as been developed due to a lack of agreement about the global conservation priorities at international level and as a cause of duplicate effort that difficult the rational application of conservation resources (Mace et al. 2000). However, our work helps demonstrate that once 74% of the world’s land area is covered by some biodiversity conservation priority templates, these schemes could play an important role as part of an effective conservation strategy against agricultural expansion. Some areas highlighted in these templates are, and certainly will be even more, put in jeopardy under different intensities of destruction if society does not take action.

Like other authors (Balmford et al. 2001; Dobson et al. 2001; Luck 2007), our work suggest that these different places need different conservation strategies. For example, reactive approaches need intensive and continuous conservation actions, like the identification, at higher spatial resolution, and protection of the remnants of natural areas in landscapes dominated by agriculture and other human uses, which implies in higher costs. Areas included in reactive approaches need strategies of coexistence of agriculture and biodiversity conservation, including the so-called conservation agriculture (Baudron et al. 2009) and the conservation of wildlife on private lands (Main et al. 1999). The systematic conservation planning in these areas can also be improved by strategies in which the economic costs of land acquisition are considered (e.g. Loyola et al. 2009a). Conversely, to conserve proactive areas, it is crucial (and still possible) to protect large areas (Peres 2005) because the land considered under such approaches is available and tends to be cheaper.

Assuming the agriculture data of IMAGE is correct, it remains at least three sources of uncertainty: (i) future scenarios; (ii) time and (iii) the ability of agriculture areas for maintain biodiversity. Conservation community should take advantage of this uncertainty since it could mean just lack of knowledge or a possible “leeway”. In the case of scenarios, our analysis shows that the uncertainty in future land use change related to agriculture is

higher under proactive approaches, which means that regions indicated as priorities under these schemes are likely to be affected only under certain future scenarios. Thus, the conservation community must pay attention to factors that influence the outcome of future scenarios, such as human population density (Cincotta et al. 2000), technological development (Reganold et al. 2001; Balmford et al. 2005; Ewers et al. 2009) and human per capita consumption (Myers and Kent 2003). However, the conservation community is not limited by the scenarios above, and people are free to build a future reality better than those suggested by available scenarios. In relation to time, the conservation actions may use the data about agriculture dynamic in an adaptive management (Salafsky et al. 2002) and conservation planning (see Pressey et al. 2007 for a review) to anticipate actions needed to choose areas less prone to be converted to agriculture, to work in agricultural areas, making it less harmful (uncertainty iii above), and planning the restoration actions to be implemented immediately after the agriculture areas are abandoned.

Conservation organizations must work together (Redford et al. 2003) in order to replace those unrelated initiatives that means duplicate efforts with an orchestrated mosaic of conservation strategies in which international efforts will be complementary (Loyola et al. 2009b). This cooperative work can be improved by the forecast of threats to biodiversity, such as agriculture, and its uncertainties. It seems that instead of a “silver bullet” (Myers 1983), the international conservation community needs a “utility belt” to deal with this changing world.

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