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Short communication

Global survey of anthropogenic neighborhood threats to conservation of grass-shrub and forest vegetation

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ABSTRACT

The conservation value of natural vegetation is degraded by proximity to anthropogenic land uses. Previous global assessments focused primarily on the amount of land protected or converted to anthropogenic uses, and on forest vegetation. Comparative assessments of extant vegetation in terms of proximity to anthropogenic land uses are needed to better inform conservation planning. We conducted a novel comparative survey of global forest and grass-shrub vegetation at risk of degradation owing to proximity of anthropogenic land uses. Using a global land cover map, risks were classified according to direct adjacency with anthropogenic land cover (adjacency risk), occurrence in anthropogenic neighborhoods (neighborhood risk), or either (combined risk). The survey results for adjacency risk and combined risk were summarized by ecoregions and biomes. Adjacency risk threatens 22 percent of global grass-shrub and 12 percent of forest vegetation, contributing to combined risk which threatens 31 percent of grass-shrub and 20 percent of forest vegetation. Of 743 ecoregions examined, adjacency risk threatens at least 50 percent of grass-shrub vegetation in 224 ecoregions compared to only 124 ecoregions for forest. The conservation threats posed by proximity to anthropogenic land cover are higher for grass-shrub vegetation than for forest vegetation.

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1. Introduction

Land use conversion is the primary global driver of natural vegetation loss (Turner et al., 1990; Meyer and Turner, 1994) and ranks among the top five global anthropogenic drivers of overall ecosystem condition (Nelson et al., 2006). Croplands and pastures now occupy approximately 40 percent of the global land surface area (Foley et al., 2005), and more than 75 percent of the ice-free land area shows evidence of alteration as a result of human residence and land use (Ellis and Ramankutty, 2008). There is no doubt that expanding human populations will require more land cover conversions in the future (Balmford and Bond, 2005).

Land use conversion degrades the conservation values of natural vegetation, for example its capability to support ecosystem services such as clean water and biodiversity. The loss of natural vegetation is an obvious direct effect; less obvious are the indirect effects which degrade the remnant vegetation (DeFries et al., 2004). At local scale, a variety of biotic and abiotic "edge effects" can extend hundreds of meters into intact vegetation (Murcia, 1995; Forman and Alexander, 1998; Weathers et al., 2001; Houlahan and Findlay, 2004; Harper et al., 2005; Laurance, 2008; Berber et al., 2009). At landscape scale, the cumulative impact of land use conversion is a transformation of the ecosystem itself (O'Neill et al., 1997) such that anthropogenic "matrix effects" permeate entire landscapes (Ricketts, 2001; Ewers and Didham, 2006). Efforts to conserve natural ecosystem services must consider edge and matrix effects for the simple reason that much of the remaining natural vegetation resides in anthropogenic landscapes (Margules and Pressey, 2000; Luck et al., 2004; Fischer et al., 2006).

Land cover maps derived from remotely sensed data support meaningful global assessments of vegetation, but systematic analyses are needed to better inform conservation planning (Leper et al., 2005). Most of the available global assessments have been conducted by examining the absolute area of natural vegetation, converted land, or protected land, which addresses the direct effects of land use conversions. The spatial arrangement of remnant natural vegetation in relation to converted land must be evaluated to address indirect effects of land use conversions. Spatial arrangement is a key observation that can be made from global land

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cover data (Wade et al., 2003; Townshend et al., 2008), and such observations can inform conservation planning by evaluating anthropogenic threats from edge and matrix effects.

Previous global assessments of the spatial arrangement of vegetation have focused on forest land cover (e.g., Riitters et al., 2000; Wade et al., 2003). The motivations for complementary global assessments of grass-shrub lands are equally as compelling (Millennium Ecosystem Assessment, 2005) but such assessments are generally lacking. In this study, we conduct a novel global comparative survey of grass-shrub and forest vegetation in terms of conservation threats posed by direct adjacency to anthropogenic land cover (risk of edge effects) and by occurrence in anthropogenic neighborhoods (risk of matrix effects). We summarize spatial analyses of the GLOBCOVER global land cover map (Defourny et al., 2006) within the biomes and ecoregions (Olson et al., 2001) that are often used for global conservation assessments (e.g., Millennium Ecosystem Assessment, 2005). The results identify the ecoregions which contain relatively small or large proportions of extant forest and grass-shrub vegetation at risk from anthropogenic edge and matrix effects.

2. Materials and methods

2.1. Global land cover and ecoregion maps

We use version 2.2 of the GLOBCOVER land cover map (Defourny et al., 2006; Bicheron et al., 2008a, 2008b) which is derived from 300-m resolution satellite images from December 2004 to June 2006. The map identifies 22 land cover classes which are consistent with the UN/FAO Land Cover Classification System (LCCS) (Di Gregorio and Jansen, 2000). We condensed the 22 land cover classes into four generalized land cover types called "anthropogenic," "forest," "grass-shrub," and "other" as described in the online supplement.

The World Wildlife Fund (WWF) global map of terrestrial ecoregions (World Wildlife Fund, 2004) is derived from historical maps, published references, and expert advice, and it defines boundaries of biomes and ecoregions (Olson et al., 2001). The 14 biomes portray major vegetation zones including eight "forest" biomes and four "grass-shrub" biomes. Ecoregions are nested within biomes and depict the original boundaries of relatively large land units containing distinct assemblages of natural communities and species prior to major land use changes (Olson et al., 2001).

As described in the online supplement, all maps were converted to comparable equal-area projections and the WWF map was used to post-stratify land cover analyses according to biomes and ecoregions. Biome summaries included all terrestrial area within biomes, but ecoregion summaries were prepared only for the 743 ecoregions which were larger than 25 km^2 and contained terrestrial land cover. As illustrated in the online supplement, each of the 743 ecoregions contained at least some grass-shrub land cover, but 23 contained no anthropogenic land cover, and nine contained no forest land cover.

2.2. Anthropogenic threat analysis

Each 9-ha pixel of forest and grass-shrub land cover was examined to determine if it was adjacent to a pixel of anthropogenic land cover, and if it was located within an anthropogenic neighborhood. Anthropogenic adjacency was defined by the presence of anthropogenic land cover in one or more of the eight pixels surrounding a given pixel. As explained in the online supplement, anthropogenic neighborhood status was indicated by the presence of at least 20 percent anthropogenic land cover in the surrounding 137 km^2 (11.7 km $\times$ 11.7 km) neighborhood centered on a given pixel. Since the adjacency and neighborhood tests were applied globally, pixels near an ecoregion boundary may be adjacent to, or in the neighborhood of anthropogenic land cover in a different ecoregion. That was desirable because anthropogenic influences extending up to 50 km are important in conservation (DeFries et al., 2005), and because the ecoregion boundaries are only approximate (Olson et al., 2001).

The resulting maps were combined such that each pixel of forest and grass-shrub land cover was described by the ecoregion and biome which contained it, by its anthropogenic adjacency status (yes or no), and by its anthropogenic neighborhood status (yes or no). For a given biome or ecoregion, "adjacency risk" was measured by the percentage of extant grass-shrub (or forest) area with positive adjacency status, "neighborhood risk" by the percentage of area with positive neighborhood status, and "combined risk" by the union of adjacency risk and neighborhood risk. The use of extant land cover percentages permitted comparisons between regions, and between forest and grass-shrub land cover, but it obscured differences in geographic region size and total areas of different land cover types. That was desirable because our objective was to characterize the remnant fractions of forest and grass-shrub land cover in relation to current anthropogenic land cover. The online supplement illustrates the calculation of combined risk and describes the correlations between adjacency risk and neighborhood risk that led to focusing this report on adjacency risk and combined risk.

3. Results and discussion

Anthropogenic and grass-shrub land cover each occupy approximately one-fifth of total area (excluding water, ice, and snow) and forest land cover occupies approximately one-third (Table 1). Anthropogenic land cover is the most abundant land cover in three biomes, and in five other biomes it is more common than one of the other two land cover types. Anthropogenic land cover occupies more than one-third of total area in five of the 14 biomes, and occupies less than ten percent of total area only in three biomes that are too cold or too dry to support substantial conversions to agricultural land uses. The potential adjacency of anthropogenic and other land cover types is necessarily related to the amounts of anthropogenic and other land cover types in a region, but direct measurements of adjacency provide spatial information that is not apparent from area data alone. At the biome-level, for example, there are no clear trends of adjacency risk in relation to land cover composition (Table 1; see also online supplement). Knowledge of land cover composition alone is insufficient for assessing the potential for edge and matrix effects.

Substantial percentages of the existing forest and grass-shrub land covers are subject to anthropogenic risks. Overall biomes, 12 percent of forest is subject to adjacency risk compared to 22 percent of all grass-shrub, and 20 percent of forest is subject to combined risk compared to 31 percent of grass-shrub (Table 1). On a per-biome basis the forest percentages range from less than one to 31 percent for adjacency risk and to 46 percent for combined risk. The per-biome grass-shrub percentages range from less than one to 41 percent for adjacency risk and to 54 percent for combined risk. In eight biomes, at least one-fifth of forest is subject to adjacency risk, and in 11 biomes at least one-fifth is subject to combined risk. For grass-shrub land cover, at least one-fifth is subject to adjacency risk and combined risk in 11 biomes.

Biomes with the lowest risk percentages typically are those with the lowest percentages of anthropogenic land cover (Temperate Conifer Forests, Boreal Forests/Taiga, and Tundra). On the other hand, biomes with the largest risk estimates are not always the ones with the largest percentages of anthropogenic

Table 1
Land cover composition and anthropogenic risks to existing forest and grass-shrub land cover, by biome.

Biome[a]	Percent of total area[b]			Percent of total forest area		Percent of total grass-shrub area	
	Anthropogenic	Grass-shrub	Forest	Adjacency risk[c]	Combined risk[c]	Adjacency risk	Combined risk
	(%)	(%)	(%)	(%)	(%)	(%)	(%)
TSMBF	30	62	8	16	25	37	52
TSDBF	49	31	19	22	36	26	38
TSCF	21	55	25	21	30	39	47
TBMF	38	45	9	20	33	41	52
TCF	11	67	12	9	13	35	45
BFT	1	76	12	1	1	<1	1
MFWS	39	20	14	22	41	26	41
M	35	52	12	22	36	29	42
TSGSS	24	30	35	14	22	21	32
TGSS	43	15	23	31	46	41	54
FGS	17	27	39	12	19	19	29
MGS	24	10	36	26	41	30	41
T	<1	20	15	<1	<1	<1	<1
DXS	8	2	17	27	38	11	17
All biomes	21	34	18	12	20	22	31

[a] Biome nomenclature after Olson et al. (2001) as follows. TSMBF – Tropical and Subtropical Moist Broadleaf Forests; TSDBF – Tropical and Subtropical Dry Broadleaf Forests; TSCF – Tropical and Subtropical Coniferous Forests; TBMF – Temperate Broadleaf and Mixed Forests; TCF – Temperate Conifer Forests; BFT – Boreal Forests & Taiga; MFWS – Mediterranean Forests, Woodlands and Scrub; M – Mangroves; TSGSS – Tropical and Subtropical Grasslands, Savannas, and Shrublands; TGSS – Temperate Grasslands, Savannas, and Shrublands; FGS – Flooded Grasslands and Savannas; MGS – Montane Grasslands and Shrublands; T – Tundra; DXS – Deserts and Xeric Shrublands.
[b] Excludes area of water, ice, snow, and missing land cover. Values do not sum to 100 because bare and sparse land cover types are not shown. See the online supplement for definitions of anthropogenic, forest, and grass-shrub land cover types.
[c] See Section 2.2 for explanation of adjacency risk and combined risk.

land cover. Forest exceptions include the Desert and Xeric Shrublands, and Montane Grasslands and Shrublands biomes, and grass-shrub exceptions include the Tropical and Subtropical Moist Broadleaf Forests, and Tropical and Subtropical Coniferous Forests biomes.

There is also substantial variation of adjacency risk and combined risk among ecoregions. Excluding the Tundra and Boreal Forest & Taiga biomes, the per-ecoregion percentages of forest and grass-shrub land cover subject to combined risk vary from almost zero to almost 100 percent (Fig. 1). Table 2 shows the median

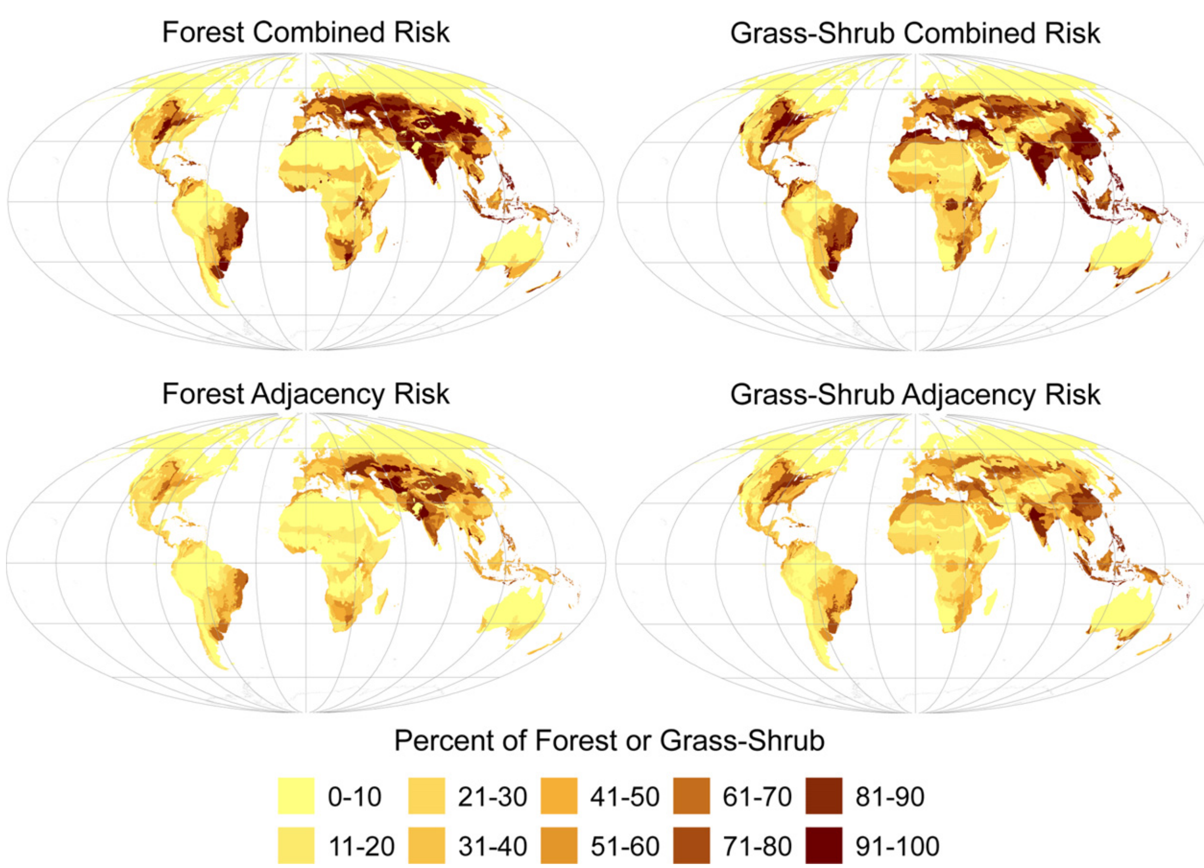

Fig. 1. Ecoregional percentages of existing forest or grass-shrub land cover that are threatened by combined risk and adjacency risk (Mollweide map projection).

Table 2
Median ecoregion percentage of forest and grass-shrub land cover area threatened by adjacency risk and combined risk, by biome.

Biome[a]	Number of ecoregions	Forest		Grass-shrub	
		Adjacency risk[b]	Combined risk[b]	Adjacency risk	Combined risk
	(number)	(%)	(%)	(%)	(%)
TSMBF	191	30	50	44	65
TSDBF	46	34	57	40	61
TSCF	15	20	28	37	46
TBMF	78	24	40	43	60
TCF	53	10	11	27	35
BFT	27	<1	<1	<1	<1
MFWS	39	23	45	29	54
M	18	21	34	39	58
TSGSS	42	16	26	20	32
TGSS	40	38	55	50	71
FGS	23	19	34	23	35
MGS	48	28	50	31	45
T	32	<1	<1	<1	<1
DXS	91	20	27	12	16
All biomes	743	22	35	32	46

[a] See footnote in Table 1 for definitions of biomes.
[b] See Section 2.2 for explanations of adjacency risk and combined risk.

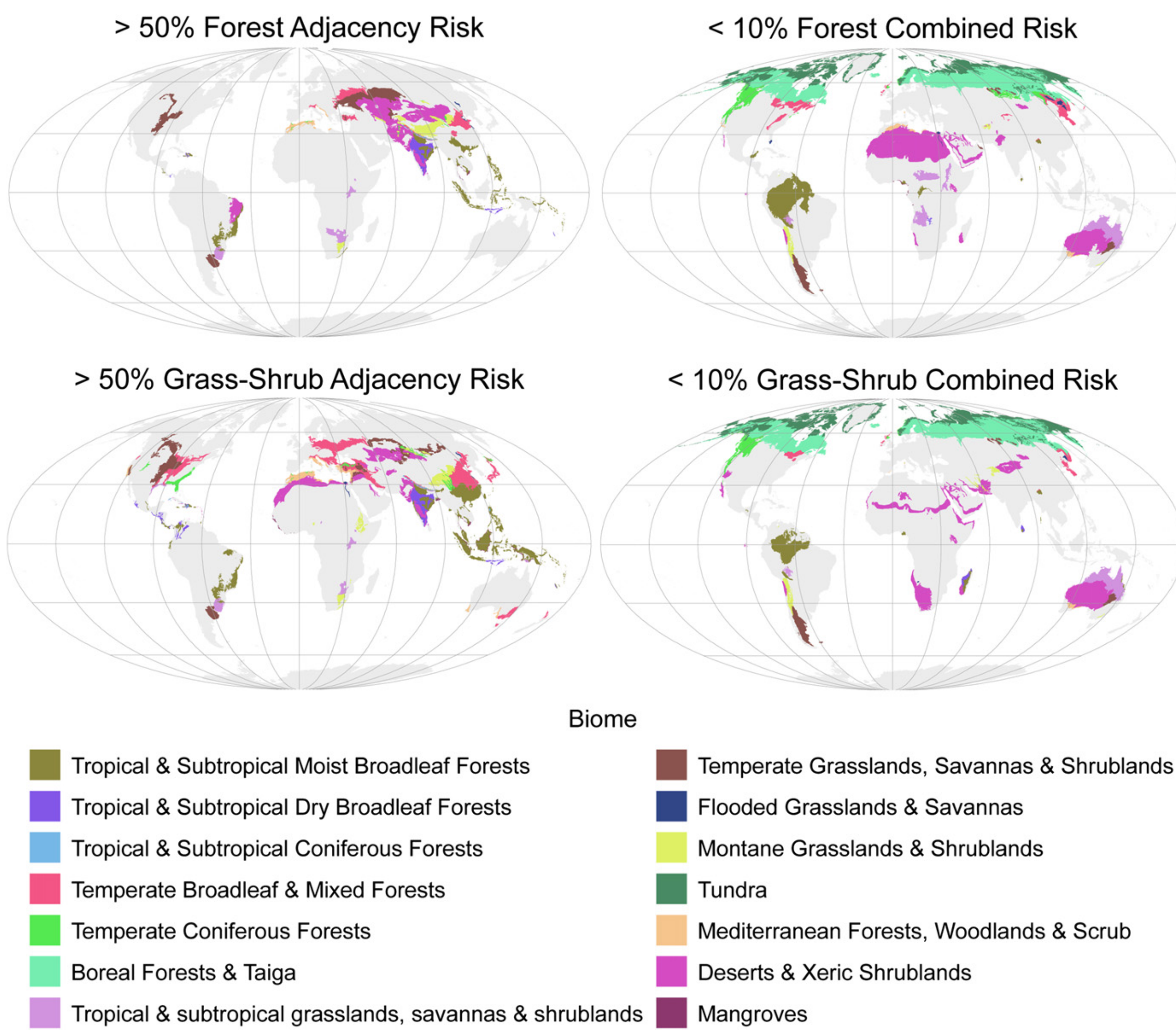

Fig. 2. Left: ecoregions with more than 50 percent of current forest or grass-shrub land cover threatened by adjacency risk. Right: ecoregions with less than 10 percent of existing forest and grass-shrub land cover threatened by combined risk. Ecoregions are shaded according to biome identity. See Fig. 1 in Olson et al. (2001) for comparable map of biome boundaries (Mollweide map projection).

ecoregion risk estimates within each biome. For example, the median ecoregion in the Tropical and Subtropical Moist Broadleaf Forests biome has 30 percent of its forest adjacent to anthropogenic land cover (adjacency risk), and 50 percent of its forest either adjacent to anthropogenic land cover or contained in an anthropogenic neighborhood (combined risk). Within a given biome, the median ecoregion risk estimates (Table 2) are often much larger than the corresponding overall biome risk estimates (compare with Table 1). That occurs because ecoregions containing larger proportions of anthropogenic land cover usually have larger risk estimates, but those same ecoregions receive less weight in biome-level summaries because there is relatively less forest or grass-shrub in those ecoregions.

Global assessments typically examine the absolute area of natural vegetation, converted land, or protected land as a basis for identifying ecoregions with conservation opportunities. Such assessments could also consider the potential for anthropogenic edge and matrix effects, for example, the ecoregions where the existing vegetation has relatively high or low risk. Ecoregions with relatively high (>50 percent) values of adjacency risk and relatively low (<10 percent) values of combined risk are identified in Fig. 2. Adjacency risk exceeds 50 percent in 224 of the 743 ecoregions for grass-shrub land cover, and in 124 ecoregions for forest land cover (including 94 ecoregions for both land cover types). Combined risk is less than 10 percent in 171 ecoregions for grass-shrub land cover, and in 189 for forest land cover (including 112 ecoregions for both land cover types).

The results shown in Table 1 may be used to calculate indices of relative area at risk as the product of land cover percentages and at risk percentages of grass-shrub and forest land cover. While the grass-shrub risk percentages are larger than the forest risk percentages, the total global area threatened by each type of anthropogenic risk is approximately the same because there is less grass-shrub area. On a per-biome basis, there is more forest area at risk in biomes that are naturally forested (e.g., the first eight biomes listed in Table 1), and more grass-shrub area at risk in biomes that are naturally grass-shrub vegetation (e.g., the next four biomes listed in Table 1). That occurs because the remnant vegetation is still dominated by the same land cover type that was dominant before anthropogenic conversions.

Ecoregions are a useful framework for global assessments, but exclusive usage of that framework may lead to an emphasis on conserving ecoregions, which implies an emphasis on conserving dominant vegetation. Yet forest is present in relatively small amounts in grass-shrub biomes, just as grass-shrub vegetation occurs in forest biomes. Non-dominant vegetation in any biome probably requires more conservation effort than dominant vegetation simply because there is less of it. For example, a larger percentage of forest is at risk in grass-shrub biomes than in forest biomes, so global forest conservation would not be achieved by targeting forest vegetation in forest ecoregions only.

Global land cover maps may have limited temporal, spatial and thematic resolutions, but they are at least a feasible alternative for a consistent global census of land cover patterns. Our risk estimates are conservative because human influences are pervasive and incorporating higher resolution data would almost certainly show higher anthropogenic risk (Riitters et al., 2004). While absolute risk may vary with data resolution, we expect the relative risks to forest and grass-shrub vegetation would be similar. An advantage of pixel-level risk mapping is that it permits post-stratification of at risk land cover according to many frameworks (e.g., ecoregions, catchments, countries, or land cover types) while ensuring comparability of the underlying statistics across those frameworks.

4. Conclusion

This research contributes the first global comparative assessment of grass-shrub and forest vegetation in terms of conservation threats posed by proximity to anthropogenic land cover. The results quantify earlier perceptions of relative conditions among ecoregions and biomes which were drawn mainly from knowledge of historical land cover conversions and human population concentrations as summarized in meta-analyses such as the Millennium Ecosystem Assessment (2005). Substantial portions of the remnant global forest and grass-shrub land cover are at risk from edge effects and matrix effects. Conservation threats exhibit spatial variation that is related to original vegetation and to historic patterns of anthropogenic land cover conversions, such that nearly all forest and grass-shrub land cover is threatened in some ecoregions. Overall, and within most biomes and ecoregions examined, a larger proportion of grass-shrub than forest land cover is threatened by proximity to anthropogenic land cover.

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Appendix. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jenvman.2011.11.009.

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