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Evaluating Anthropogenic Risk of Grassland and Forest Habitat Degradation using Land-Cover Data

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Abstract

The effects of landscape context on habitat quality are receiving increased attention in conservation biology. The objective of this research is to demonstrate a landscape-level approach to mapping and evaluating the anthropogenic risks of grassland and forest habitat degradation by examining habitat context as defined by intensive anthropogenic land uses at multiple spatial scales. A landscape mosaic model classifies a given location according to the amounts of intensive agriculture and intensive development in its surrounding landscape, providing measures of anthropogenic risks attributable to habitat isolation and edge effects at that location. The model is implemented using a land-cover map (0.09 ha/pixel) of the conterminous United States and six landscape sizes (4.4, 15.2, 65.6, 591, 5300, and 47800 ha) to evaluate the spatial scales of anthropogenic risk. Statistics for grassland and forest habitat are extracted by geographic overlays of the maps of land-cover and landscape mosaics. Depending on landscape size, 81 to 94 percent of all grassland and forest habitat occurs in landscapes that are dominated by natural land-cover including habitat itself. Within those natural-dominated landscapes, 50 percent of grassland and 59 percent of forest is within 590 m of intensive agriculture and/or intensive developed land which is typically a minor component of total landscape area. The conclusion is that anthropogenic risk attributable to habitat patch isolation affects a small proportion of the total grassland or forest habitat area, while the majority of habitat area is exposed to edge effects.

Keywords:

landscape mosaic, patch isolation, edge effect, land-cover map, geographic information system, model, island biogeography theory

1 Introduction

It is the custom of humans to farm and build things, often in otherwise natural environments, and conversely to preserve and create natural environments within human-dominated landscapes. Society views the resulting anthropogenic interface zones from a variety of utilitarian perspectives such as security from wildfire or access to green space, and ecological perspectives are equally diverse and observer-dependent. As a result, while most people may agree that assessments of the spatial patterns of land use and land cover are important, there is no general agreement on how to conduct an assessment of land-cover patterns. Ecologists often focus assessments by adopting a ‚biodiversity' perspective such that land-cover approximates habitat with land-cover patterns representing different aspects of habitat quality such as distance from patch edge and connections among land-cover patches. From that perspective, popular pattern metrics of land-cover edge, patch size, and patch isolation are motivated by concerns for habitat edge effects (Murcia 1995, Harper et al. 2005) and habitat isolation (MacArthur & Wilson 1967). However, when those metrics are applied to large-area land-cover maps, it is difficult to interpret them with respect to land-cover patterns (Hargis et al. 1998; Tischendorf 2001; Neel et al. 2004; Riitters et al. 2004), let alone habitat quality or biodiversity (Bissonette & Storch 2002; McGarigal & Cushman 2002). To achieve a synthesis of anthropogenic risks to habitats and ultimately biodiversity across species and biomes, there is a need for better ways to use and interpret the available land-cover data at continental to global scales.

The need for improved procedures is also demonstrated by emphasis on the habitat matrix in conservation biology, which until recently was largely ignored in standard ecological theory (Haila 2002; Laurance 2008). Following Ricketts' (2001) declaration that "the matrix matters," the signs of an emerging landscape perspective include recommendations for a "landscape mosaic approach" (Murphy & Lovett-Doust 2004), a "matrix-inclusive approach" (Kupfer et al. 2006), and a "pattern-oriented approach" (Fischer & Lindenmayer 2007). Debinski (2006) suggests that the conservation biologist's first question should be about the habitat matrix, not the habitat itself. Only seven years after Ricketts (2001), a communiqué by 37 scientists (Lindenmayer et al. 2008) clearly indicates that the focus of conservation biology has shifted from the habitat content of landscapes to the landscape context of habitats.

The goal of this paper is to demonstrate a landscape mosaic approach to mapping and evaluating the risks of habitat degradation that are caused by intensive anthropogenic land uses which make a habitat matrix inhospitable for species that are adapted to natural environments. To illustrate continental-scale applications and inferences, a landscape mosaic classification model is applied to a national land-cover map in a way that describes the anthropogenic context of each location at several spatial scales. The results for grassland and forest habitats are interpreted by evaluating the relative risks of habitat isolation and edge effects arising from intensive anthropogenic land uses. The first objective is to estimate how much grassland (or forest) is contained in landscapes that are dominated by natural, agricultural, or developed land-cover types. Then, considering only the natural-dominated landscapes, the second objective is to estimate how much grassland (or forest) resides within landscapes with different types and amounts of human land uses. Achieving those objectives with the creation of high-resolution maps of landscape mosaics will better inform society of the interface zones that have been created by intensive human uses of the land, and will permit conservation biologists to identify opportunities for protecting habitat in natural landscapes, managing habitat changes in transitional landscapes, and preserving habitat in anthropogenic landscapes.

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2 Methods

The landscape mosaic classification model comes from the 'landscape pattern type' model (Wickham & Norton 1994) which has been modified as a landscape context indicator for applications using land-cover maps (Riitters et al. 2000). Landscape mosaic classes have been used to model direct forest loss or gain in dynamic landscapes (Riitters et al. 2009), and a modified version of landscape mosaic is the core indicator of landscape pattern in a recent ecological report card for the United States (Heinz Center 2008). The landscape mosaic model classifies landscape context according to land-cover composition in a neighborhood, and it is sensitive to composition, diversity, and dominance, all of which are essential components of landscape context for biodiversity studies (Murphy & Lovett-Doust 2004). Landscape mosaic is also a direct measure of land-cover pattern in the sense that composition is a fundamental indicator of pattern (O'Neill et al. 1988; Li & Reynolds 1994; Gardner and Urban 2007). To highlight interface zones arising from relatively intensive anthropogenic land uses, landscape mosaic classes are defined in terms of agricultural, developed, and 'natural' (i.e., neither agricultural nor developed) land-cover types. The model is implemented by classifying the landscape surrounding each pixel of land-cover, and mapping the landscape mosaic at the pixel level, which enables subsequent geographic overlays to extract grassland and forest statistics. Several landscape sizes are used because landscape context naturally varies as more or less of a surrounding area is considered and because those differences are informative of the spatial scales at which anthropogenic risks to habitat can be said to occur.

2.1 Landscape Mosaic Model

The landscape mosaic classification model is analogous to vegetation community classification based on the identity and relative abundance of species within a plot. The differences between vegetation classification and landscape mosaic classification are first, the classification is based on land-cover composition instead of species composition, and second, a location is classified according to its surroundings instead of its contents. A tri-polar (ternary) chart of the classification scheme (Fig. 1(a)) is analogous to the 'soil triangle' (e.g., Gee & Bauder 1986) which classifies soil texture based on the proportions of sand, silt, and clay in a soil sample. In the landscape mosaic model, the proportions of three generalized land-cover types (agriculture, developed, natural) replace the proportions of soil components along the three axes, and the classes refer to landscape mosaic instead of soil texture.

The full model illustrated in Fig. 1(a) identifies 19 landscape mosaic classes using the threshold values of zero, ten, 60, and 100 percent along each axis. Classification threshold values are always at least partly arbitrary and those choices are reasonable for stratifying landscapes for comparative analyses of habitat in anthropogenic interface zones. For example, Gagné & Fahrig (2007) used a 50 percent threshold to classify landscapes as 'urban' or 'forested' and a 70 percent threshold to classify landscapes as 'agricultural.' The selected threshold values distinguish between landscape mosaics on the basis of the presence (zero percent), substantial presence (ten percent), dominance (60 percent), and exclusivity (100 percent) of the three generalized land-cover types.

The landscape mosaic labels in Fig. 1(a) are coded as follows. A lower-case letter (a, d, n) appears in a label if the corresponding land-cover type (agriculture, developed, natural, respectively) comprises at least ten but less than 60 percent of a landscape. An upper-case letter (A, D, N) appears if that land-cover type comprises at least 60 but less than 100 percent of the landscape. A letter does not appear if that land-cover type comprises less than ten percent of the landscape. The labels AA, DD, and NN indicate landscapes that

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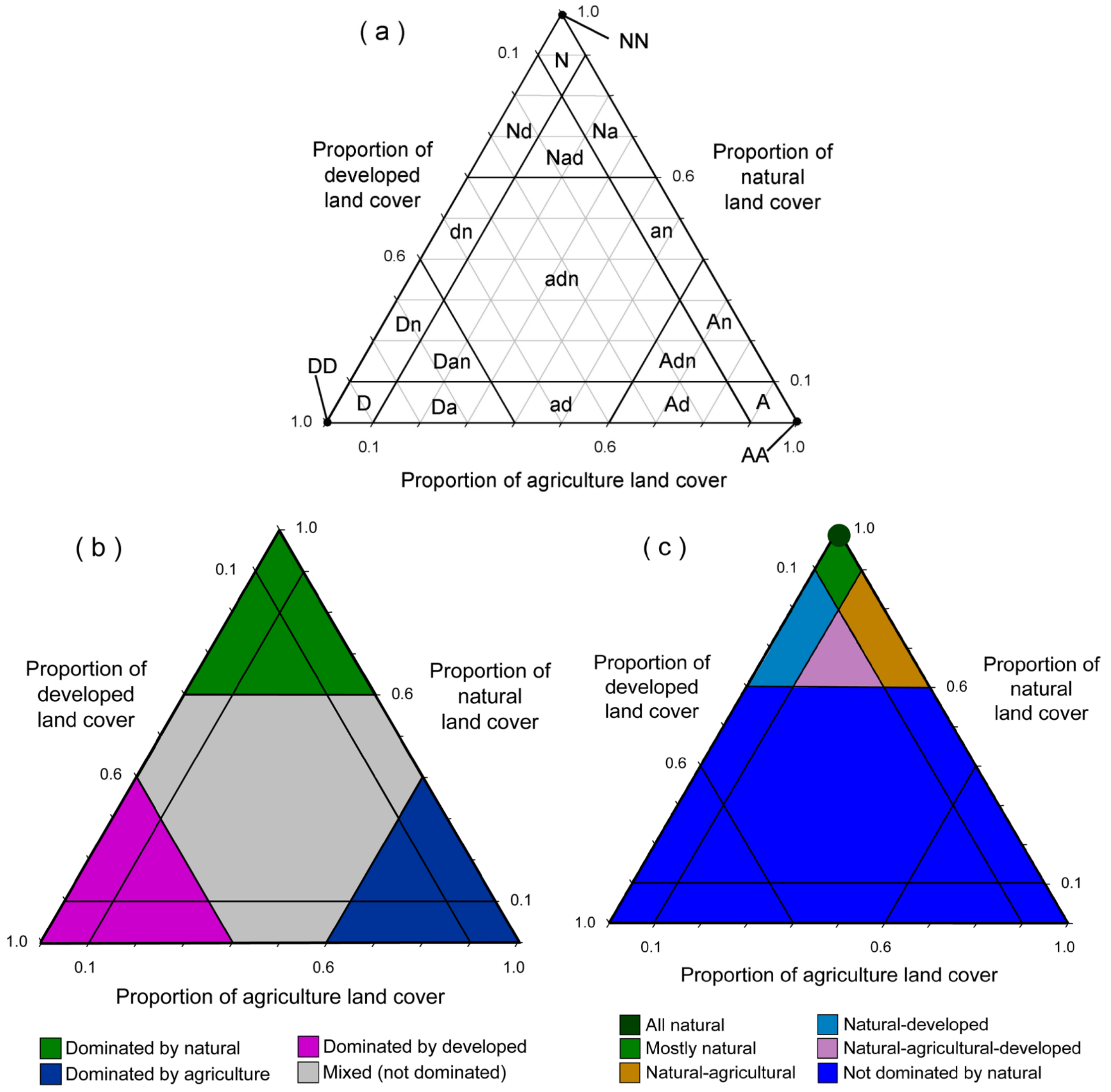

Figure 1: (a) The tri-polar landscape mosaic classification model identifies 19 mosaic classes from the proportions of agriculture, developed, and natural land-cover types in a landscape. The labels shown in the figure are a code that describes the relative amounts of the three land-cover types, as explained in the text. (b) The 19 mosaic classes were condensed into four classes to highlight landscape background. (c) The 19 mosaic classes were condensed into six classes to highlight landscape mosaics within natural background.

contain exactly 100 percent of the corresponding land-cover type. To address the first objective, the 19 landscape mosaic classes are aggregated into four 'landscape background' classes (Fig. 1(b)) which identify locations dominated by (i.e., surrounded by at least 60 percent of) one of the three generalized land-cover types, and locations not dominated by any one land-cover type. The second objective is addressed by focusing on the five landscape mosaic classes within natural landscape backgrounds (Fig. 1(c)).

2.2 Implementation of the landscape mosaic model

The landscape mosaic model is implemented by using the conterminous United States portion of the 2001 National Land-Cover Database (NLCD; Homer et al. 2007), a land-cover map with a spatial resolution of 0.09ha/pixel and a thematic resolution of 16 land-cover types. The NLCD land-cover map was prepared using regression tree modelling of Landsat Thematic Mapper images and several ancillary data sources (Homer et al. 2004). A formal thematic accuracy assessment is underway and unpublished preliminary results indicate accuracy of approximately 85% for the generalized urban, agriculture, and natural land-cover classes that are used in the present study. The 2001 NLCD may be described as the United States equivalent of the CORINE land-cover map of Europe (Bossard et al. 2000).

The 16 NLCD land-cover types are condensed into three generalized types called agriculture, developed, and natural as follows. 'Agriculture' includes the original NLCD land-cover types called cultivated crops and pasture, which refer to intensive agriculture. 'Developed' includes the original high, medium, and low intensity development, and developed open space types, which refer to intensive development. 'Natural' includes all other land-cover types including water, forest, shrub/scrub, grassland, and wetland, which refer to locations that are not used by humans for intensive agriculture or development. After excluding land and water area outside the boundaries of detailed State maps (ESRI 2005), there are approximately 8.65 x 10^9 pixels on the land-cover map of the conterminous United States, and the overall percentages of the generalized land-cover types are 23.3 percent agriculture, 5.3 percent developed, and 71.4 percent natural.

The landscape mosaic containing each pixel is classified at six spatial scales defined by six landscape sizes. At a single scale, a fixed-area square window (hereafter, a 'landscape') is placed around a focal pixel on the land-cover map, the land-cover is evaluated within the landscape, and the corresponding landscape mosaic class is mapped at the location of the focal pixel. A new map of landscape mosaics is obtained by repeating the procedure for all pixels on the land-cover map. The process is then repeated at different scales (landscape sizes), yielding six landscape mosaic maps at scales of 4.4 ha (7 x 7 pixel landscape), 15.2 ha (13 x 13), 65.6 ha (27 x 27), 591 ha (81 x 81), 5300 ha (243 x 243), and 47800 ha (729 x 729). Those choices make it possible to evaluate the ranges of scales over which different landscape mosaics exist. The window sizes used cover four orders of scale magnitude. Near international boundaries, the landscape may contain missing data and in those cases the landscape mosaic is classified from the non-missing data.

Standards for comparisons may be defined as follows. Maximum distance to 'anthropogenic edge' is inferred from the size of the smallest landscape that contains more than the generalized natural land-cover type (Riitters & Wickham 2003). For 30-m pixels, the maximum distances corresponding to the six landscape sizes in this study are approximately 170, 300, 590, 1740, 5180, and 15500 meters, respectively. As the landscape size approaches the pixel size, the landscape mosaic map approaches the generalized land-cover map because the landscape mosaic necessarily approaches AA, DD, or NN. As the landscape size approaches the total extent of the conterminous U.S. land-cover map, the landscape mosaic approaches a single mosaic class (here, 'Na') corresponding to the overall proportions of agriculture, developed, and natural in the full extent of the land-cover map. If land-cover distribution is completely random, then a landscape larger than a single pixel, anywhere, will yield the mosaic 'Na' provided that the landscape is large enough to reliably estimate the three generalized land-cover proportions. The meaning of "large enough" depends in part on the classification threshold values relative to the overall proportions of each generalized land-cover type. A simulation study (not shown here) indicates that if land-cover is randomly distributed, the five largest landscape sizes are large enough in the sense that the expected mosaic ('Na') is obtained in more than 99 percent of 25000 random samples with sample sizes equal to the number of pixels in a landscape (i.e., 169, 729, 6561, 59049, and 531441 pixels). The smallest landscape (with a sample size of 49 pixels) yields the expected mosaic in 85 percent of the samples.

Mapping the landscape mosaic as a contextual measure at the pixel level preserves options to stratify or aggregate the information in many ways. For example, for questions related to water quality, a geographic stratification based on catchment boundaries may be appropriate, whereas an administrative stratification may be appropriate for regional planning. The focus of this study is on grassland and forest habitat, and therefore a thematic stratification is used in which the landscape mosaic maps for each landscape size are intersected with the original land-cover map to extract the landscape mosaic pixel values

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that are specific to grassland only, and to forest only.

3 Results

The national map of the landscape mosaic classification from 15.2-ha landscapes may be visualized at local, regional, and national scales by using a geographic browser to access a compressed keyhole markup language (KMZ) file (Appendix 1). Here, the three States of Colorado, Kansas, and Missouri illustrate geographic gradients of natural land cover from forest (west; Rocky Mountains), through grassland (Great Plains) to forest again (east; Ozark Plateau). In Fig. 2, the landscape background for three landscape sizes is illustrated, including an enlarged sub-region to portray spatial detail, and national maps to show continental trends. Similarly, Fig. 3 illustrates the landscape mosaic of grassland and Fig. 4 illustrates the landscape mosaic of forest. Figs 3 and 4 also illustrate the sub-populations of pixels extracted by geographic overlay that are included in the summary statistics for grassland and forest habitat. The pie charts in Figs 3 and 4 do not reflect differences in total area of grassland and forest among the indicated regions.

Approximately 70 percent of the total area of the conterminous United States exists in a landscape

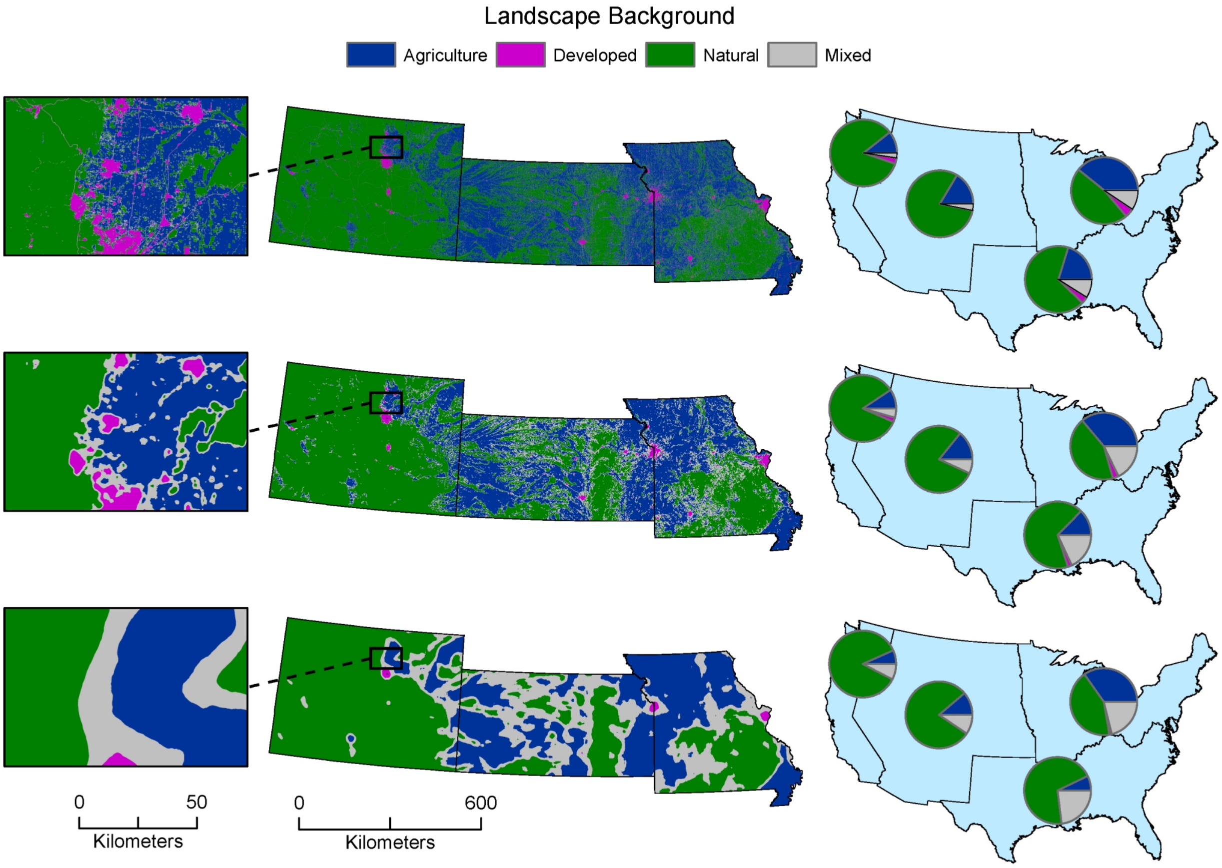

Figure 2: The landscape background describes the dominant land-cover in a landscape. Center: Landscape background exhibits both fine-scale and coarse-scale patterns in the States of Colorado, Kansas, and Missouri. The three landscape sizes shown are 4.4 ha (top row), 591 ha (middle row), and 47800 ha (bottom row). Left: Illustrations of spatial detail at each scale near the city of Denver. Right: the relative proportions of landscape backgrounds in each of four regions are shown by the pie charts.

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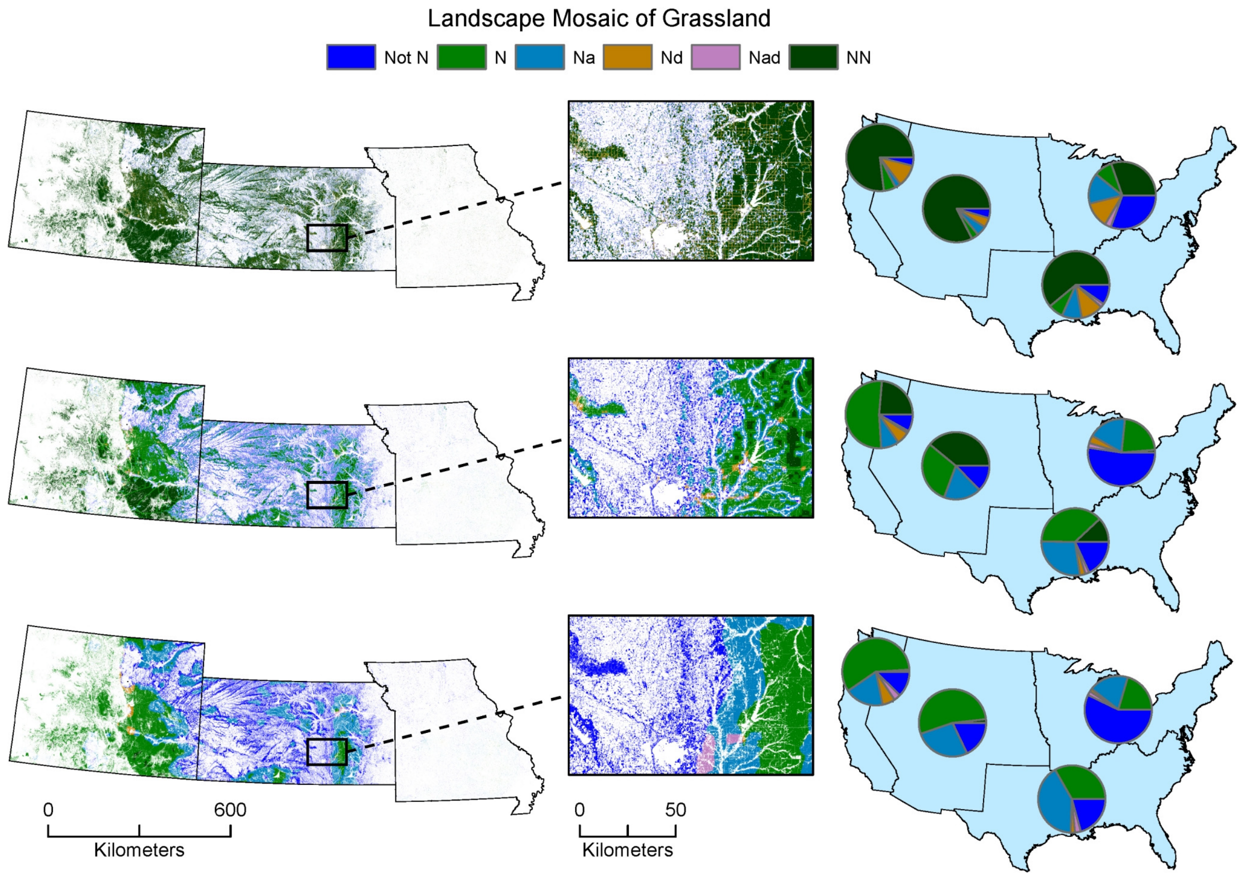

Figure 3: The landscape mosaic of grassland, in landscapes that are dominated by natural land-cover. Left: Grassland distribution is indicated by the colored pixels, and the color of a pixel indicates its landscape mosaic context in landscapes of size 4.4 ha (top), 591 ha (middle), and 47800 ha (bottom). Center: Illustrations of spatial detail near the city of Wichita. Right: The relative proportions of grassland area in anthropogenic interface zones in each of four regions are shown by the pie charts. Note: „Not N" refers to landscape backgrounds not dominated by natural land-cover types.

background dominated by natural land-cover, over four orders of magnitude of landscape size (Tab. 1a). The area dominated by agriculture decreases with increasing landscape size from 22 to 15 percent while the area with a developed land-cover background decreases from three to one percent. The percent of total area residing in a mixed landscape background exhibiting no dominant land-cover increases with landscape size from six to 16 percent. Addressing the first objective of this study, at least 81 percent of grassland (Tab. 1b) and 84 percent of forest (Tab. 1c) occurs in a natural landscape background, and those percentages increase to 94 percent with decreasing landscape size. Where grassland and forest occur in non-natural landscape backgrounds, they are two to three times as likely to be found in landscapes with mixed backgrounds as in landscapes with either agriculture or developed backgrounds. For all landscape sizes, less than one percent of all grassland and forest occurs in a developed landscape background.

The second objective of this study is addressed by using the model shown in Fig. 1(c) to partition the proportions for the natural landscape background (Tab. 1(b) and Tab. 1(c)) into proportions for five landscape mosaic classes for grassland (Tab. 2(a)) and forest (Tab. 2(b)). Approximately three-fourths

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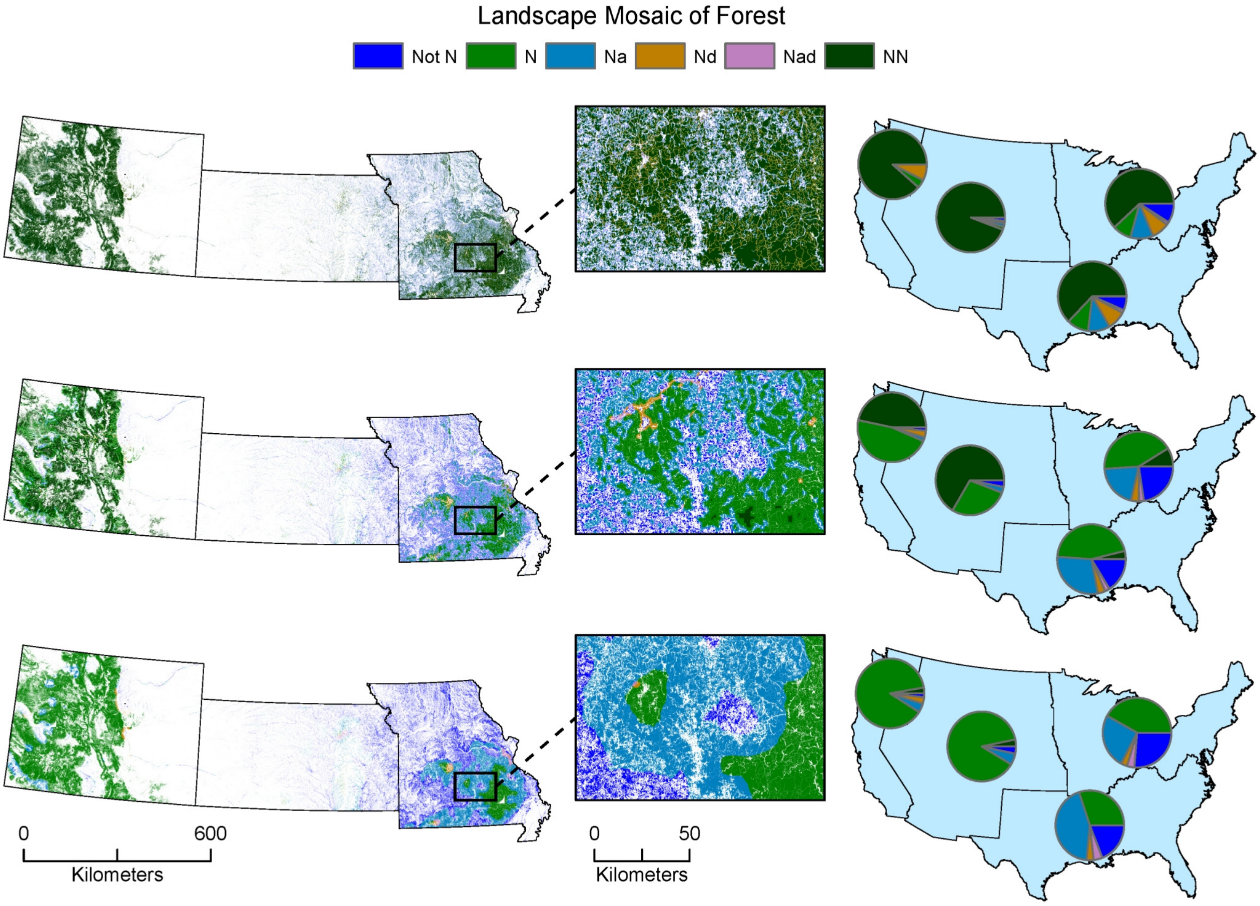

Figure 4: The landscape mosaic of forest, in landscapes that are dominated by natural land-cover. Left: Forest distribution is indicated by the colored pixels, and the color of a pixel indicates its landscape mosaic context in landscapes of size 4.4 ha (top), 591 ha (middle), and 47800 ha (bottom). Center: Illustrations of spatial detail near the Ozark Plateau. Right: The relative proportions of forest area in anthropogenic interface zones in each of four regions are shown by the pie charts. Note: „Not N" refers to landscape backgrounds not dominated by natural land-cover types.

of all grassland and forest exists in 4.4-ha landscapes with no evidence of an anthropogenic interface zone (landscape mosaic NN), but that proportion decreases rapidly with landscape size such that at least 50 percent of total area is contained in a landscape mosaic that is not NN in 65.6-ha landscapes and at least 87 percent of total area is contained in a landscape mosaic other than NN in 5300-ha landscapes. Those statistics imply that approximately one-fourth of all grassland and forest is within 170 m of anthropogenic edge, and at least half is within 590 m. For all landscape sizes, grassland is less likely than forest to be contained in an interface zone and therefore tends to be more remote from anthropogenic edge. The most common interface zone containing grassland and forest depends on landscape size. At local scale, the landscape mosaic is more likely to include a substantial presence (more than ten percent) of agriculture or developed land-cover (mosaics Na, Nd, Nad) whereas at larger scales the landscape mosaic is more likely to include a less substantial presence (less than ten percent) of those land-cover types (mosaic N). Landscape mosaics are approximately as likely to be characterized by a substantial presence of developed land-cover (Nd) as agriculture land-cover (Na) in 4.4-ha landscapes, but in larger landscapes those landscape mosaics are predominantly agricultural (Na).

ISSN 1865-1542

Table 1: The distribution of (a) total area, (b) total grassland area, and (c) total forest area among landscapes characterized by different background for six landscape sizes. The model of landscape background is defined in Fig. 1(b).

	Landscape size (ha)					
Landscape Background	4.4	15.2	65.6	591	5300	47800
	(a) Proportion of total area					
Natural	0.70	0.69	0.69	0.68	0.68	0.69
Developed	0.03	0.02	0.02	0.02	0.01	0.01
Agriculture	0.22	0.21	0.20	0.18	0.16	0.15
Mixed	0.06	0.07	0.09	0.12	0.14	0.16
	(b) Proportion of total grassland area					
Natural	0.94	0.92	0.89	0.85	0.83	0.81
Developed	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	0.02	0.02	0.03	0.05	0.05	0.05
Mixed	0.04	0.05	0.07	0.10	0.12	0.14
	(c) Proportion of total forest area					
Natural	0.94	0.92	0.89	0.86	0.85	0.84
Developed	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	0.01	0.02	0.03	0.03	0.04	0.04
Mixed	0.04	0.06	0.08	0.10	0.11	0.12

Table 2: The distribution of (a) total grassland area and (b) total forest area among landscape mosaics in natural landscape backgrounds, for six landscape sizes. Except for rounding errors, the sum over landscape mosaics for a given landscape size and land-cover type equals the value the for natural landscape background shown in Tab. 1.

	Landscape size (top; ha) Minimum distance to edge (bottom; m)					
Landscape Mosaic	4.4 170	15.2 300	65.6 590	591 1740	5300 5180	47800 15500
	(a) Proportion of total grassland area					
NN	0.76	0.65	0.50	0.31	0.13	0.01
N	0.04	0.13	0.22	0.33	0.44	0.49
Na	0.06	0.09	0.13	0.19	0.24	0.29
Nd	0.06	0.04	0.03	0.01	0.01	0.01
Nad	0.01	0.01	0.01	0.01	0.01	0.01
	(b) Proportion of total forest area					
NN	0.72	0.58	0.41	0.23	0.10	0.01
N	0.07	0.18	0.30	0.41	0.49	0.52
Na	0.08	0.10	0.13	0.18	0.21	0.25
Nd	0.07	0.06	0.04	0.03	0.03	0.03
Nad	0.01	0.01	0.01	0.02	0.02	0.03

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4 Discussion

If land-cover distribution was completely random, then only the natural landscape background would have been obtained for all landscape sizes, and all grassland and forest would have appeared in the landscape mosaic 'Na.' The conclusion that land-cover is not distributed randomly is trivial since it is well-known that land uses are structured spatially by natural constraints (e.g., biophysical parameters) and human preferences (e.g., economics, aesthetics). The actual results obtained are an indication of the types of anthropogenic landscape structure which have been created by those constraints and preferences, and the spatial scales over which they exist. Considering the landscape background of all land area, the results indicate that developed and agriculture land-covers tend to be locally dense and spatially pervasive (Tab. 1(a)), where 'local' refers to a larger landscape size in the east than in the west (Fig. 2).

The mental image of isolated habitat patches only applies in landscapes where the overall proportion of habitat is low (Gardner & Urban 2007). Where such patches exist in an inhospitable matrix, ecological effects can arise from patch isolation (MacArthur & Wilson 1967) as well as from edge influences (Murcia 1995; Harper et al. 2005; Laurance 2008). While the definition of inhospitable is species-dependent, a first approximation for grassland- and forest-obligate species is that intensive agricultural or intensive developed landscape backgrounds are inhospitable for species adapted to natural environments. The amount of grassland or forest habitat in those landscape backgrounds is low (<40 percent) by definition, but that does not indicate the proportion of the existing habitat that actually exists in those backgrounds. The answer to that question indicates that the mental image of isolated habitat patches in an inhospitable landscape mosaic probably applies to less than five percent of total grassland area (Tab. 1(b)) or total forest area (Tab. 1(c)). Depending on landscape size, that mental image applies to an additional four to 14 percent of habitat area if a mixed landscape background is considered to be inhospitable, but in that case the existence of isolated patches is less certain (Gardner & Urban 2007). In summary, the majority of grassland and forest habitat is either the matrix itself or is embedded in a landscape matrix dominated by shrubland, water, and other non-anthropogenic land-cover types. These statistics suggest that the risks associated with habitat isolation probably apply to only a small percentage of total grassland or total forest habitat.

The results also indicate that the risk of habitat degradation from anthropogenic edge effects is of more concern than the risk from patch isolation effects where the matrix is hospitable and the identity or isolation of individual habitat patches is less relevant. Reviews of experimental evidence for biotic and abiotic edge effects (Murcia 1995; Harper et al. 2005; Laurance 2008) indicate edge influence distances of 500 to 600 m in some cases. Riitters & Wickham (2003) found that approximately 65 percent of all land in the conterminous United States is within 590 m of the nearest road, which indicates a pervasive exposure of all land to road-mediated edge effects. The present study confirms that exposure of grassland and forest habitat to anthropogenic edge is pervasive even where grassland and forest habitat occur within natural landscape backgrounds. Fifty percent of grassland (Tab. 2(a)) and 59 percent of forest (Tab. 2(b)) is not contained in the landscape mosaic 'NN' at 65.6-ha scale and is therefore within 590 m of an edge involving either agriculture or developed land-cover. For that landscape size, approximately half of the exposure of total habitat area is attributable to a less than substantial (less than ten percent) presence of agriculture or developed land-cover (i.e., landscape mosaic N), five percent or less is attributable to a substantial (more than ten percent) presence of developed land-cover (Nd, Nad), and 14 percent is attributable to a substantial presence of agriculture (Na, Nad). Considering other landscape sizes, there is less exposure to anthropogenic edge in smaller landscapes, and the proportion of total exposure attributable to substantial presence of developed land-cover decreases with increasing landscape size.

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The risk of habitat degradation from both patch isolation and edge influences is probably large in inhospitable landscapes. However, those landscapes would not exist except as a result of conversion of natural land-cover and furthermore, anthropogenic land uses tend to expand over time (e.g., urban sprawl) which usually results in additional direct loss of nearby grassland and forest. Therefore, it may be expected that over the long term, the risk of direct loss of habitat in agricultural, developed, and mixed landscape backgrounds probably exceeds the risk of habitat degradation from patch isolation or edge effects. The exception is habitat that is protected from conversion (e.g., parks), unsuitable for development (e.g., riparian zones), or created for utilitarian purposes (e.g., forested windbreaks and grassland buffer strips), but that comprises a low proportion of overall habitat area. Taken together, the results indicate that the risk of degradation of existing grassland and forest habitat attributable to anthropogenic land-cover is not typically imposed 'from the outside' on isolated fragments of grassland or forest, because grassland and forest do not typically occur as isolated fragments within an inhospitable matrix. Instead, risk typically arises 'from within' otherwise intact natural landscapes as a result of human land uses that create relatively small inclusions of anthropogenic land-cover.

While it may be an open question if and how land-cover pattern and landscape mosaics affect particular species, it is not an open question that humans create risks to forest and grassland habitats through creation of adjacent agriculture and developed land-cover. Characterizing habitat in terms of anthropogenic context is essential since conservation strategies must incorporate areas dominated by human land uses (Margules & Pressey 2000; Fischer et al. 2006). The landscape mosaic model is a scalable representation of habitat, matrix and edge conditions that may prove useful for habitat management and biodiversity assessments. But biodiversity applications are only a first step towards interdisciplinary, landscape-level risk assessments and there is a need to test applications of the landscape mosaic model involving other ecological values (e.g., water quality) and social issues (e.g., parcellation of ownership). The landscape mosaic model is an intuitive, flexible, and transparent approach to measuring landscape context in a way that indicates the composition, diversity, and dominance of different land uses that create landscape context. The same general approach could use different partitions of the landscape mosaic triangle, different definitions of the three axes of the triangle along with other types of input maps, geometric objects other than triangles for classification, or other landscape sizes, all selected on the basis of criteria deemed relevant to a particular investigation.

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Appendix 1

A supplementary online resource is a compressed keyhole markup language (KML) file that can be opened in a geographic browser (e.g., Google Earth, version 4 or later) to visualize landscape mosaics at 15.2-ha scale in relation to recent aerial photographs as provided by the geographic browser service (e.g., Fig. 5). Instructions for locating and using the file ‚mosaics.kmz' are located at http://forestthreats.org/tools/landcover-maps/lcm-instructions (date 08.12.08). Note that this application is designed for illustrative and educational purposes only; mention of trade names and/or copyrights does not constitute endorsement or recommendation for use by the

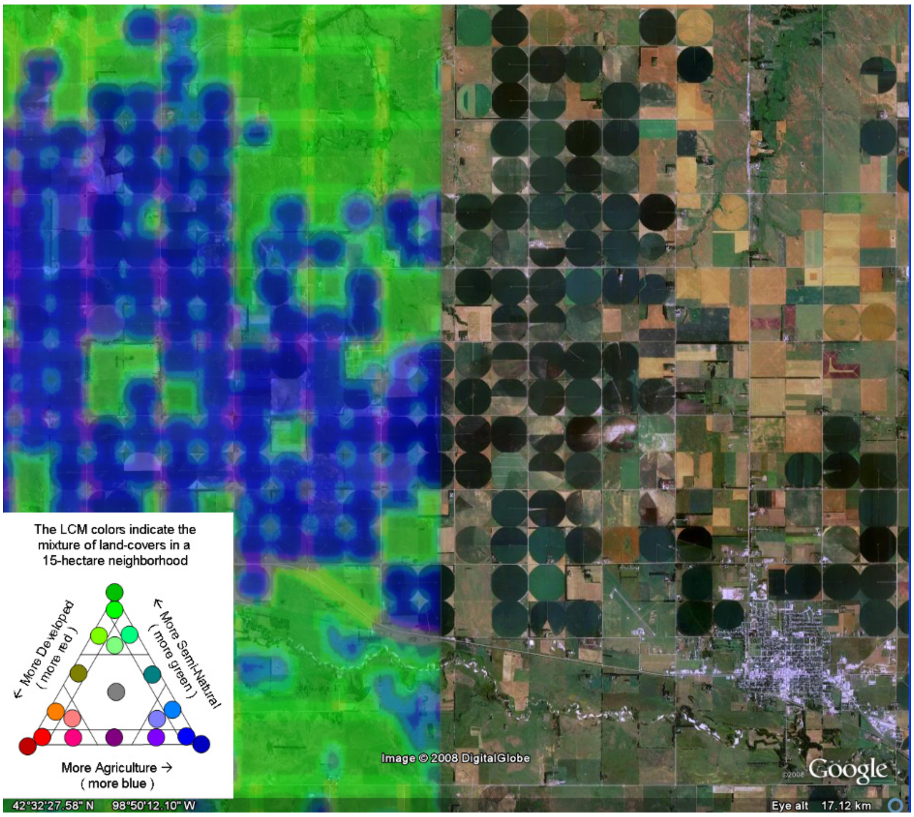

Figure 5: Illustration of viewing landscape mosaics with a geographic browser. The landscape mosaic map at left is partly transparent to reveal the underlying aerial photograph which continues without the landscape mosaic overlay at right. The circular features are irrigated croplands, embedded in a mostly-natural landscape mosaic in the Great Plains region of the United States.