

INTRODUCTION

As humans introduce competing land uses into natural landscapes, the public concerns regarding landcover patterns are expressed through headline issues such as urban sprawl, forest fragmentation, water quality, and wilderness preservation. The spatial arrangement of an environment affects all human perceptions and ecological processes within that environment, but this usually happens in competing ways, so the task for resource managers is to maintain appropriate amounts and patterns of different landcover types to provide the desired balance of social and ecological benefits. A prerequisite for informed management actions at local, regional, and national scales is reliable information about landcover patterns at those scales. National assessments of landcover patterns make it possible to identify national strategies to achieve particular objectives. To the extent that national data are also able to capture local details, the same information can be used for local planning as well.

Previous reports by the Forest Health Monitoring Program of the Forest Service, U.S. Department of Agriculture, (e.g., Ambrose and others 2008; Conkling 2011; Coulston and others 2005; Potter and Conkling 2012a, Potter and Conkling 2012b) have addressed different aspects of forest, grassland, and landscape spatial patterns. The objective of this chapter is to characterize and compare the fragmentation of forest, grassland, and shrubland landcover types by using assessment protocols which have

been used before in national assessments of forest fragmentation (Riitters and others 2002, EPA 2008, USDA Forest Service 2004, USDA Forest Service 2011, Wickham and others 2008). The measurements were taken on the 2001 National Land Cover Database (NLCD) national landcover map.

METHODS

Briefly, a landcover pattern metric known as “area density” was applied separately to the forest, grassland, and shrubland components of the national landcover map. For a given location, area density was the proportion of a surrounding neighborhood that was a given landcover type, i.e., forest, grassland, or shrubland. Six measurement scales were defined as the sizes of the neighborhoods within which the measurements of area density were taken. The results were mapped at the same spatial resolution as the input map, permitting summaries by landcover type and by assessment region.

Landcover Maps

The landcover map from the 2001 NLCD (Homer and others 2004, 2007) covers the 50 States plus the District of Columbia and Puerto Rico (fig. 5.1). It has a spatial resolution of 0.09 ha per pixel (i.e., each pixel is 30 m x 30 m). For this analysis, the landcover classification was condensed from 16 to 8 landcover types (table 5.1) including the forest, grassland, and shrubland types of interest. The distribution of

CHAPTER 5.

Fragmentation of Forest, Grassland, and Shrubland

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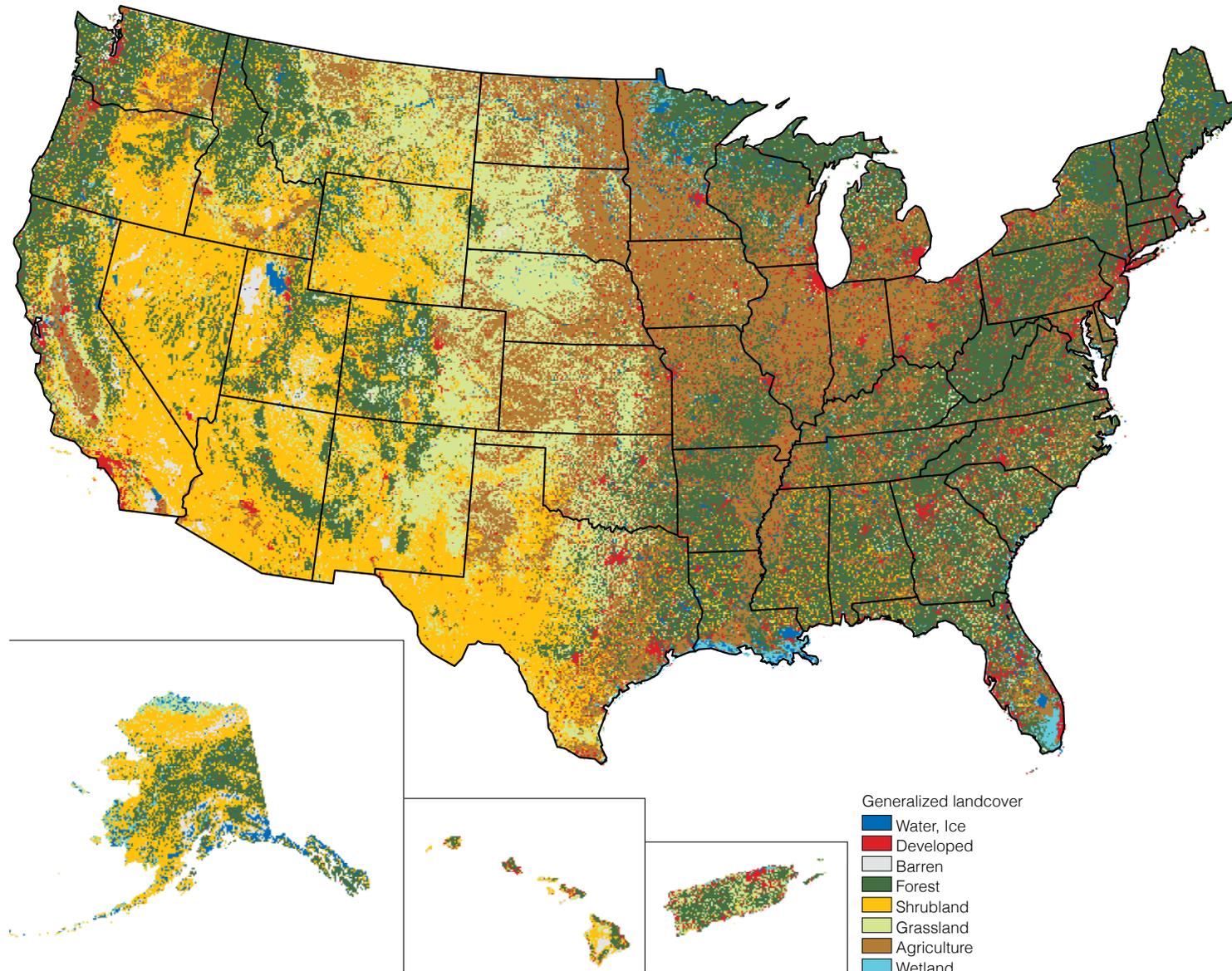


Figure 5.1—The input data was an eight-class version of the 2001 National Land Cover Database (NLCD) landcover map. Note the scale differences for Alaska, Hawaii, and Puerto Rico (insets) in comparison to the conterminous United States.

Table 5.1—The original National Land Cover Database (NLCD) landcover legend as condensed to an eight-class legend

NLCD landcover legend	Eight-class legend
Water Perennial ice/snow	Water
Developed, open space Developed, low intensity Developed, medium intensity Developed, high intensity	Developed
Barren land (rock/sand/clay)	Barren
Deciduous forest Evergreen forest Mixed forest Woody wetlands	Forest
Shrub/scrub	Shrubland
Grassland/herbaceous	Grassland
Pasture/hay Cultivated crops	Agriculture
Emergent herbaceous wetlands	Wetland

total area among those eight classes is shown in table 5.2. Ocean area adjacent to land was included in the measurements, but data summarization was limited to the boundaries of detailed State maps (fig. 5.1) (ESRI 2005).

Area Density

Area density is a measure of landcover dominance that describes a given location on a landcover map by the proportion of a surrounding neighborhood that is a specified landcover type. For this analysis, three specific types of area density were defined by looking separately at forest pixels (forest area density), grassland pixels (grassland area density), and shrubland pixels (shrubland area density). Six measurement scales were defined by six neighborhood sizes² of 10.9 acres (4.41 ha; 7 pixels x 7 pixels), 37.6 acres (15.21 ha; 13 x 13), 162 acres (65.61 ha; 27 x 27), 1,460 acres (590.49 ha; 81 x 81), 13,100 acres (5 314.41 ha; 243 x 243), and 118,000 acres (47 829.69 ha; 729 x 729). Six measurement scales were used because fragmentation naturally is scale-dependent, because the effects of fragmentation may be scale-dependent, and because knowledge of fragmentation as manifested at different scales is required to inform resource management as practiced at those different scales.

For a given landcover type and measurement scale, a measurement was taken separately for each location defined by the 10.4 billion subject

²The neighborhood sizes are hereafter shown in acres with three significant digits.

Table 5.2—Percent of total area covered by eight generalized landcover types, national and by Resource Planning Act (RPA) region, according to the 2001 National Land Cover Database landcover map

	Land cover type							
	Water	Developed	Barren	Forest	Shrubland	Grassland	Agriculture	Wetland
RPA regions ^a	Percent of total area							
Alaska	8.92	0.09	8.41	28.97	43.05	7.27	0.02	3.26
North	2.57	8.90	0.24	42.63	1.15	1.95	40.90	1.64
Pacific Coast	1.26	5.23	3.32	32.32	37.33	9.13	10.78	0.62
Rocky Mountain	1.13	2.11	1.86	16.26	33.86	27.25	16.84	0.70
South	2.17	7.07	0.38	39.17	15.19	10.96	23.22	1.84
National	2.91	4.50	2.40	30.08	25.21	13.84	19.51	1.55

^aRPA regions are illustrated in figure 5.3.

pixels on the landcover map. The result of a given measurement was stored in a new map at the location of the subject pixel, with the same pixel size. A pixel value on such a map describes the area density within the surrounding neighborhood. Eighteen new maps were created by repeating the process for each combination of six measurement scales and three focal landcover types. All of the measurements for a given landcover type were then converted from a continuous variable to a categorical variable by using a classification model (table 5.3) that identified seven classes called intact, interior, dominant, transitional, patchy, rare, and none. For example, on a map of grassland area density measured at the 10.9-acre scale, a transitional

Table 5.3—All measurements for a given landcover type were converted from a continuous area density proportion to an area density class categorical variable using a classification model

Area density (p) measurement	Area density class
$p = 1.0$	Intact
$0.9 \leq p < 1.0$	Interior
$0.6 \leq p < 0.9$	Dominant
$0.4 \leq p < 0.6$	Transitional
$0.1 \leq p < 0.4$	Patchy
$0.0 \leq p < 0.1$	Rare
$p = 0.0$	None

pixel was surrounded by a 10.9-acre neighborhood that contained 40 percent to 60 percent grassland landcover. This example emphasizes that area density is a measure of the neighborhood context of a given location.

The 18 maps of area density were then post-stratified by geographic overlays upon the original landcover map, to extract 6 maps of forest area density values for the pixels that were forest on the landcover map, 6 maps of grassland area density values for the grassland pixels, and 6 maps of shrubland area density for the shrubland pixels. The area density class called “none” never appears on those extracted maps because there is always at least one pixel in a neighborhood (i.e., the subject pixel itself) which is the focal landcover type.

Figure 5.2 illustrates the classification and post-stratification of forest area density. For clarity, a portion of the NLCD landcover map was converted to a legend showing forest and nonforest pixels (fig. 5.2A). For each pixel on that map, the proportions of forest pixels in surrounding neighborhoods of size 37.6 acres and 1,460 acres were calculated and converted to forest area density class values (figs. 5.2B and 5.2C, respectively). In comparison to larger neighborhoods, smaller neighborhoods portray more local detail of area density (or, equivalently, are more sensitive to higher-frequency variation in the spatial domain). In figures 5.2B and 5.2C, every pixel has a forest area density class, including pixels that were nonforest on the input

map (fig. 5.2A). The results of post-stratifying figures 5.2B and 5.2C by geographic overlays with figure 5.2A are shown as figures 5.2D and 5.2E, respectively. The post-stratification retained only the area density class values for pixels that were forest landcover, and necessarily did not include any of the area density class called “none.”

For data summaries, the Resources Planning Act (RPA) assessment regions (fig. 5.3) were selected for consistency and comparability with other Forest Service national resource assessments. The area density class values for the maps illustrated in figures 5.2D and 5.2E were summarized within RPA regions by the percentages of all forest (or grassland or shrubland) pixels in the six remaining area density classes. Note that a percentage was based on the total area of forest (or grassland or shrubland) that was actually present in a given region, not the total area of the region itself. The process of post-stratification followed by geographic aggregation focuses interpretations on the relative fragmentation of the existing landcovers, as distinguished from differences in the absolute amounts or historic losses of landcover in different regions. Comparisons may be made across geographic units even though the units are different sizes, and across landcover types even though there are different absolute amounts of those landcover types. Selected statistics were summarized by county to illustrate geographic trends nationally in map format.

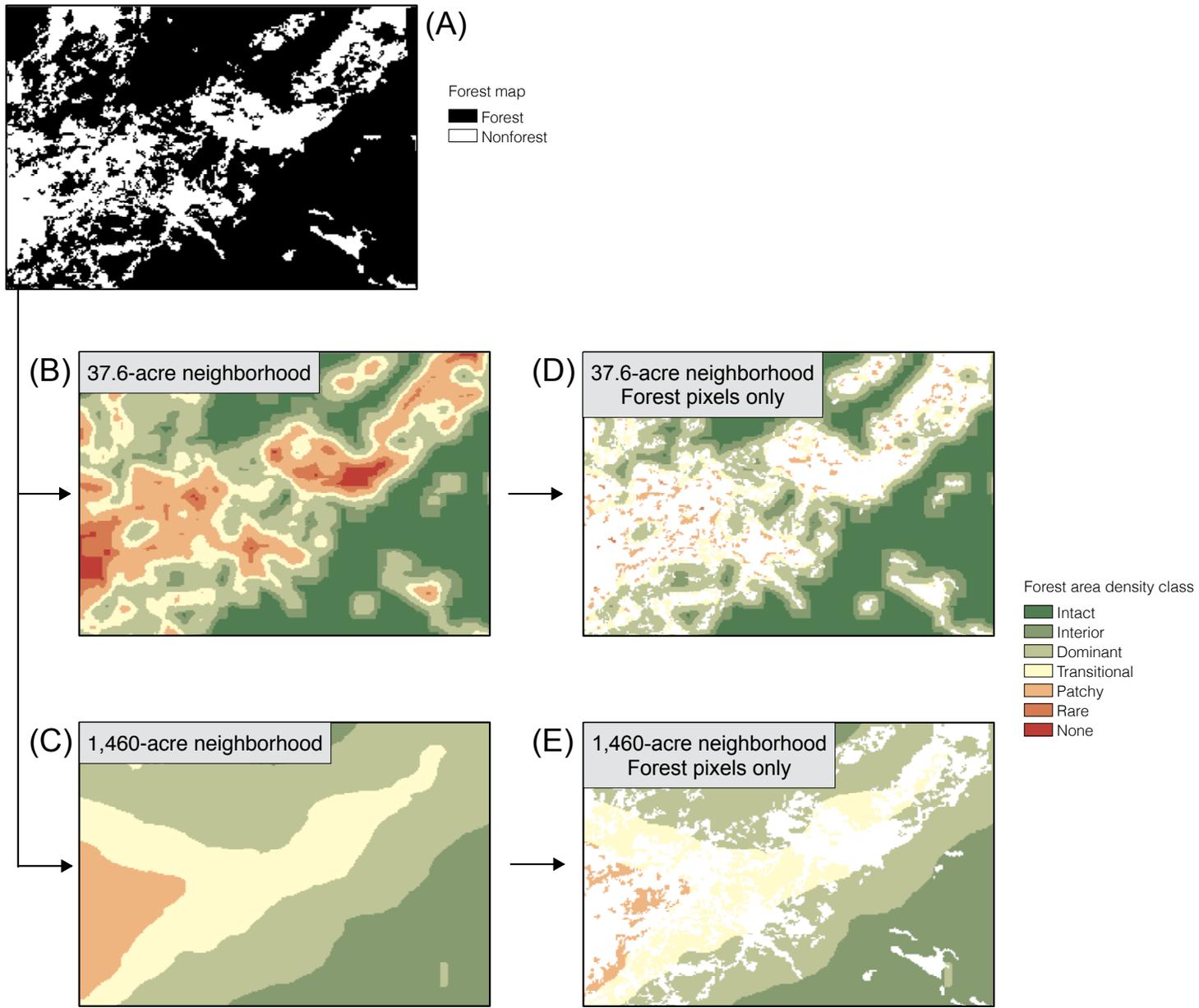


Figure 5.2—Illustration of input and output maps for forest area density mapping. See text for explanation.

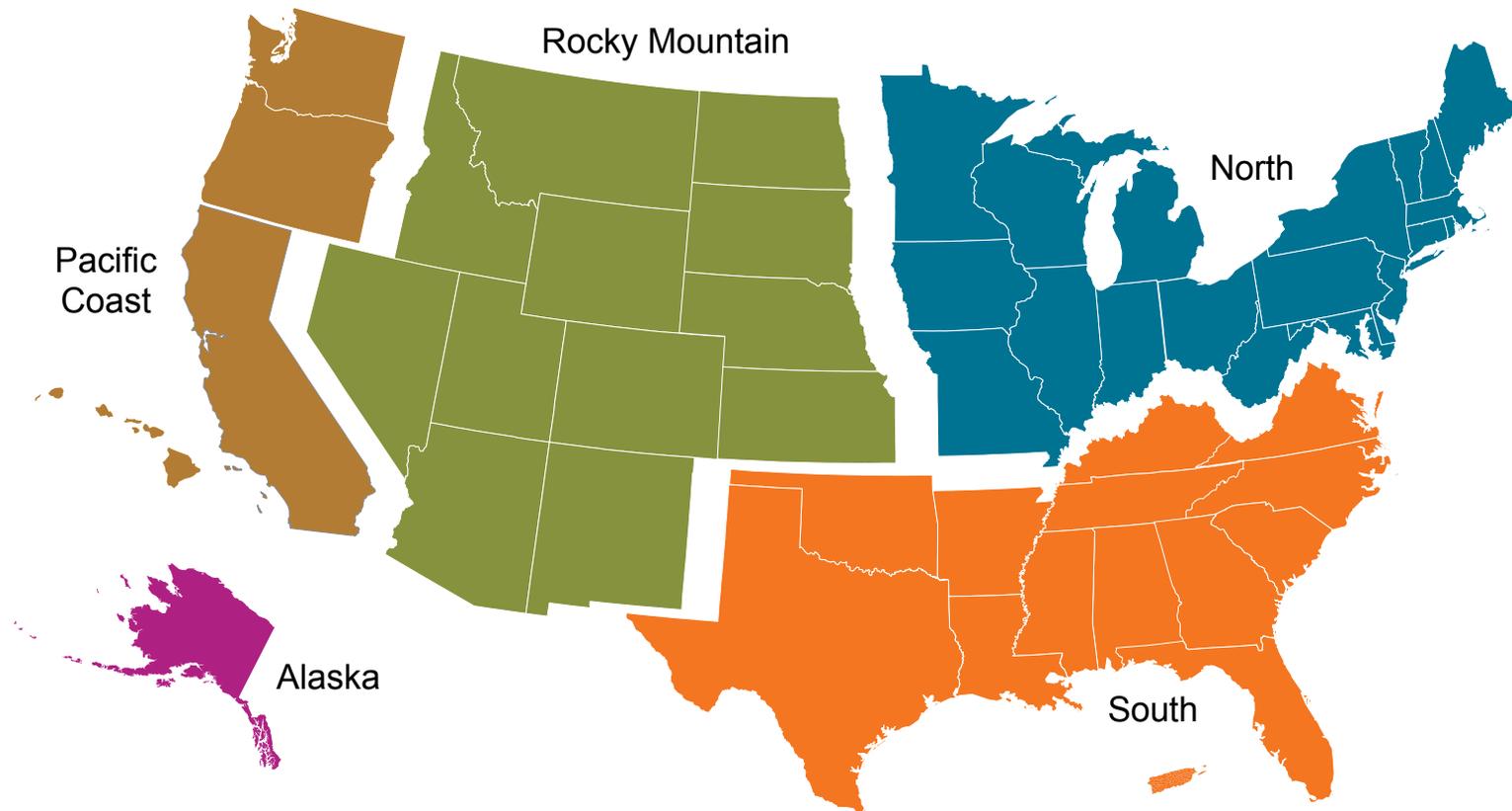


Figure 5.3—Illustration of Resources Planning Act (RPA) assessment regions. Note: Alaska is not shown to scale with map of the conterminous United States.

RESULTS AND DISCUSSION

The percentages of total forest, grassland, and shrubland in each of six area density classes, nationally and by region, are shown in figure 5.4 for each of six measurement scales. In the following discussion, the six area density classes are interpreted as a gradient of fragmentation from low fragmentation (intact class) to high fragmentation (rare class). The results for grassland and shrubland in the North region are often quite different from other regions only because the North region contains very small percentages (< 2 percent) of those two landcover types (table 5.2).

Considering first the general trends of intact and interior landcover with increasing neighborhood size, there is more intact landcover in smaller neighborhoods and less intact landcover in larger neighborhoods, for all three types of landcover considered. That is because of a high degree of spatial autocorrelation of each landcover type, which results in locally intact forest, grassland, or shrubland. At the national scale, approximately one-half of all forest, one-half of all grassland, and one-half of all shrubland are labeled as either interior or intact at 10.9-acre scale, and the smaller percentages observed for grassland and shrubland in the North and South regions may be attributed to the relative scarcity of grassland or shrubland in those regions (table 5.2). However, over larger neighborhoods the pervasiveness of human land uses (e.g., roads) prevents the occurrence of large intact regions of natural landcover types (Riitters and Wickham 2003). As a result, the percentages

of interior plus intact forest and grassland decrease rapidly with increasing neighborhood size; decreases are also observed for shrubland but they are less dramatic in comparison to forest and grassland. Nationally, within neighborhoods 1,460 acres and larger, < 1 percent of total forest and total grassland are characterized as intact, and < 25 percent are characterized as interior. The comparable percentages for shrubland are approximately twice the values obtained for forest and grassland.

In comparison to interior plus intact landcover, the percentages of intact plus interior plus dominant landcover exhibit smaller decreases with increasing neighborhood sizes. That is because each landcover type tends to dominate in the areas where it occurs, even if it is fragmented. That can be seen, for example, by noting on the original landcover map (fig. 5.1) the existence of large geographic regions that appear to be mostly-forested, mostly-grassland, or mostly-shrubland, as driven by regional climate differences that favor one or another of those landcover types. While competing human land uses remove natural landcover and introduce some degree of fragmentation almost everywhere, most of the remnant forest, grassland, and shrubland still exists in landscapes where that same natural landcover still dominates the landscape (Riitters and others 2002). Human land uses tend to occur either as inclusions on a background of natural landcover, or they have removed so much of the natural landcover in a given area, e.g., a city, that the remnant natural landcover has a minor influence on aggregate regional and

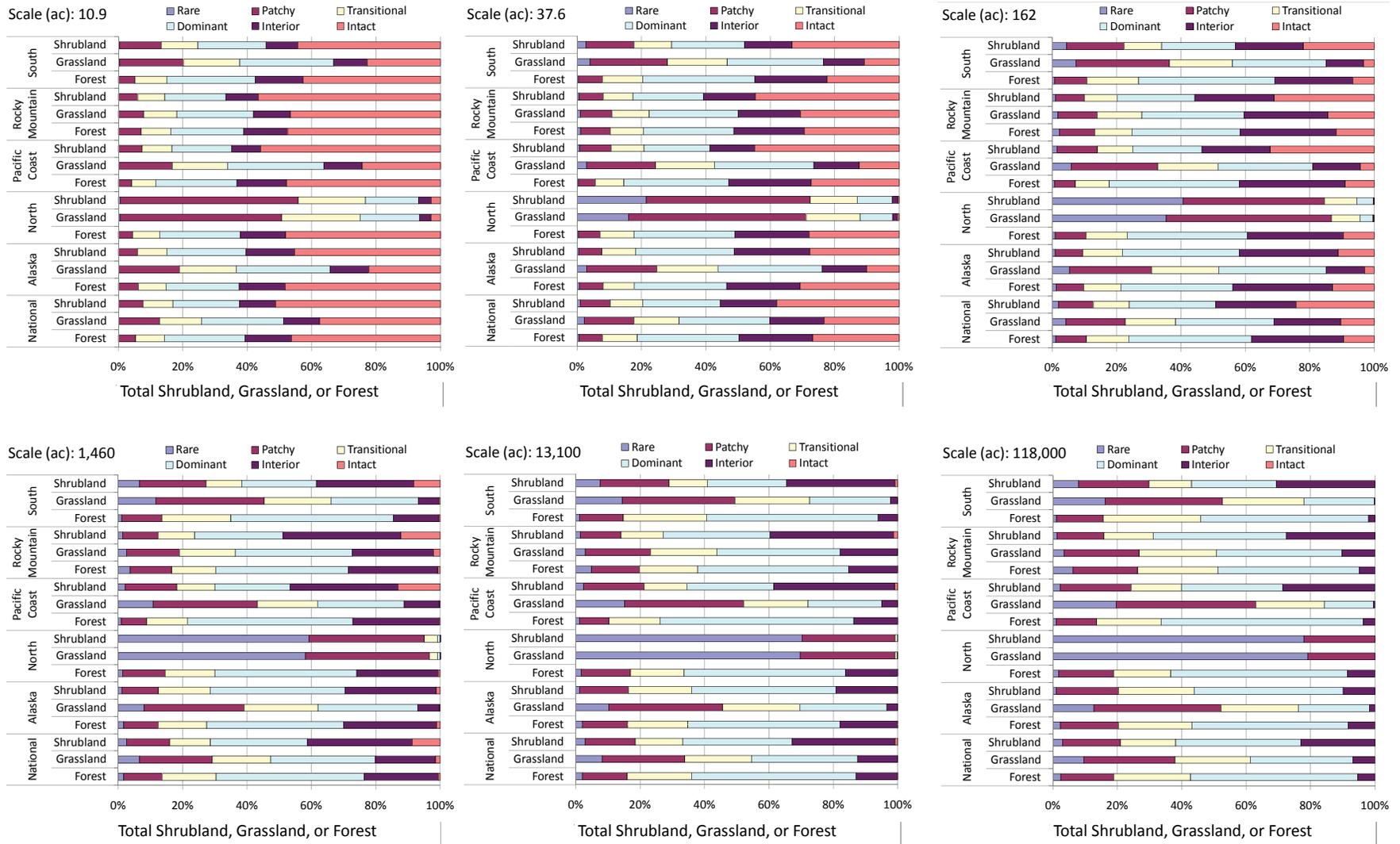


Figure 5.4—The percentage of total forest, grassland, and shrubland in each of six area density classes, for six measurement scales, nationally and by region (“ac” in the figure means acre).

national statistics (Riitters and others 2009). Thus, grassland is more heavily fragmented than forest or shrubland landcover over the largest neighborhood size; approximately 40 percent of grassland is contained in 118,000-acre neighborhoods labeled as intact plus interior plus dominant, in comparison to approximately 60 percent of forest and shrubland.

Another way to interpret the summary statistics is in terms of the likely mechanisms by which different types of fragmentation effects may be caused. For example, a wildlife habitat quality model may distinguish the effects of “edge” (Murcia 1995), “matrix” (Ricketts 2001), or “isolation” (MacArthur and Wilson 1967). In terms of the summary statistics in figure 5.4, edge effects may be expected anywhere the landcover is not in the intact class, and the influence of different “edge widths” can be gauged because of the correspondence between neighborhood size and minimum edge width in an intact neighborhood (Riitters and others 2002). For an edge width of approximately 550 feet (an intact 10.9-acre neighborhood), at least half of all area of the existing forest, grassland, and shrubland in the United States is habitat edge and is therefore subject to potential edge effects. In contrast, matrix effects are likely when habitat is not dominant within a neighborhood. In comparison to potential edge effects in 10.9-acre neighborhoods, potential matrix effects likely impact less than one-quarter of the total forest, grassland, or shrubland area because those landcover types tend to be dominant if they occur at all in a neighborhood. Finally, isolation effects occur when habitat is physically separated

from other habitat, which is most common when landcover is in the rare and patchy area density class. On that basis, isolation effects are likely relevant for even smaller proportions of overall habitat area, with the exception of those places where overall habitat area is itself low.

Whether or not landcover patterns can be interpreted in specific habitat terms, public attention is often focused on identifying the locations with relatively unfragmented forest, grassland, and shrubland. Those locations may be considered priority areas for the conservation of relatively intact landcover patterns, or as demonstration regions where the existing landcover is arranged into relatively compact patterns even if there is not much of that landcover. To illustrate these locations, the maps of area density classes were re-aggregated by county and the statistics were summarized as maps showing the percentage of existing forest, grassland, or shrubland that were in the intact plus interior area density classes. Figures 5.5 and 5.6 show the results for the 37.6-acre and 1,460-acre neighborhood sizes, respectively. These figures illustrate trends noted earlier; the proportions of intact plus interior forest and grassland are much more sensitive to neighborhood size than the same proportions for shrubland.²

As might be expected, counties containing a high proportion of a given landcover type must contain relatively high proportions of intact plus

²A complementary analysis of area density statistics without post-stratification by landcover type is presented in Riitters (2011).

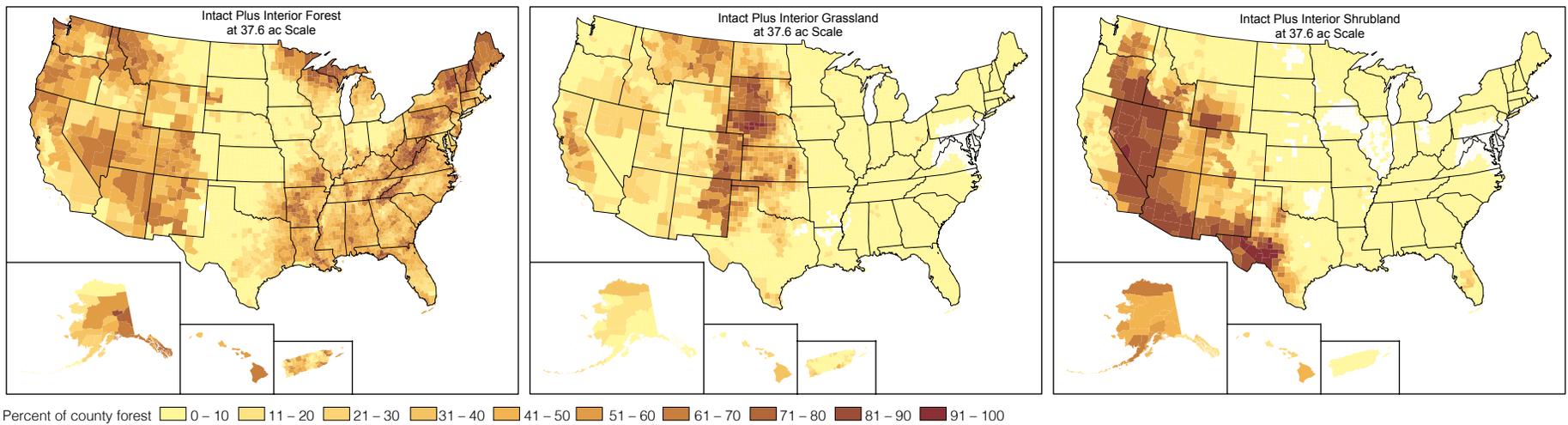


Figure 5.5—The percentage of total county forest, grassland, and shrubland that was labeled as intact or interior, for the 37.6-acre measurement scale. Counties lacking a given landcover type are not shaded.

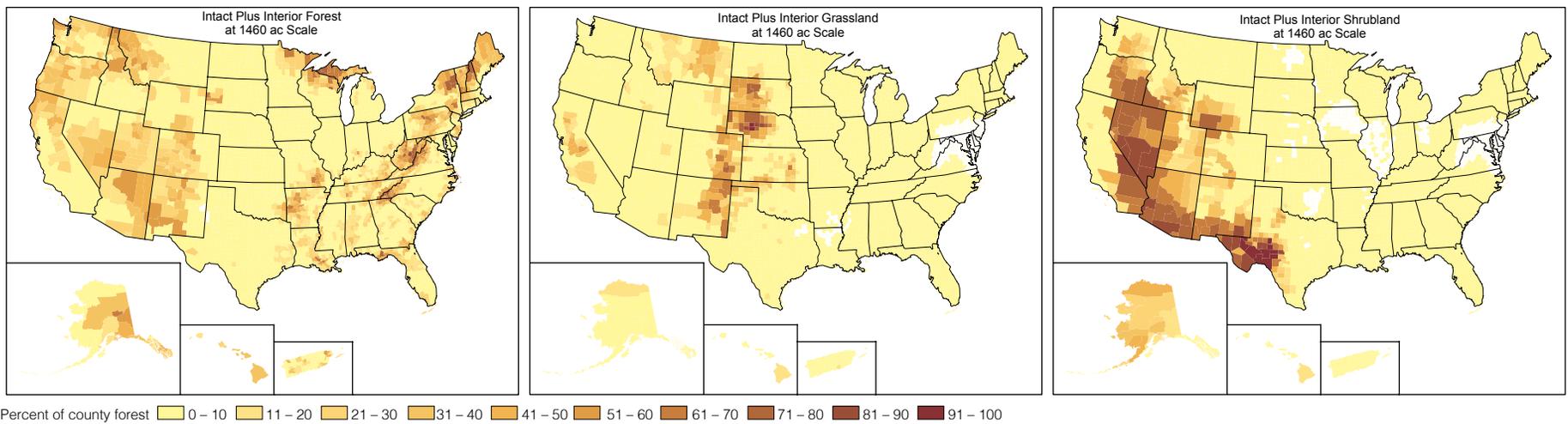


Figure 5.6—The percentage of total county forest, grassland, and shrubland that was labeled as intact or interior, for the 1,460-acre measurement scale. Counties lacking a given landcover type are not shaded.

interior of that landcover type (compare to fig. 5.1). However, it is not obvious from looking at the landcover map (fig. 5.1) that some counties exhibit high proportions of intact and interior landcover even if they contain relatively small amounts of that landcover. For example, many counties in the Intermountain West, e.g., in Nevada and Utah, contain relatively high proportions of intact plus interior forest because the existing forest, while relatively less abundant, is spatially concentrated in the higher-elevation parts of those counties.

In summary, landcover patterns affect many social perceptions and ecological processes within a landscape. Assessments of area density at multiple scales from national landcover maps provide insights about the fragmentation of forest, grassland, and shrubland that are not evident by just looking at a landcover map. Most of the existing forest, grassland, and shrubland in the United States is relatively intact at fine spatial scales and highly fragmented at coarser scales. By all measures the grassland landcover type is more fragmented than the other two, and the shrubland landcover type is least fragmented at coarser scales.

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