Indicator 1.03:

Fragmentation of forests

Kurt H. Riitters

July 1, 2022

What is the indicator and why is it important?

Indicator 1.03 provides information on the extent to which human activities and natural processes fragment forests, as measured at five spatial scales and for three fragmentation thresholds. The fragmentation of forest area into smaller pieces can change ecological processes, alter biological diversity, and ultimately reduce the capacity of a forested area to function as a forest. Fragmentation can be transient or essentially permanent, and natural or anthropogenic. The effects of fragmentation can be positive or negative depending on the circumstances.

What does the indicator show?

The most recent (2016) national land cover data show that forest is usually the dominant land cover where it occurs, but also that fragmentation is pervasive. For landscapes up to 13,000 acres in size, at least 60 percent of forest land is in forest-dominated landscapes (fig. 3-1, "Dominant"). However, since blocks of forest land are often separated by inclusions of nonforest land, the percentage of forest land that is relatively unfragmented decreases rapidly as landscape size increases from 10.9 acres to 13,000 acres (fig. 3-1, "Interior"). Fragmentation is so pervasive that only 8 percent of forest land occurs in 162-acre landscapes that are completely forested (fig. 3-1, "Core"); the "core" statistics imply that 54 percent of forest land is within 185 yards of forest-nonforest edge, 75 percent is within 330 yards, and only 0.3 percent is more than 1,900 yards (1.1 miles) from forest-nonforest edge.

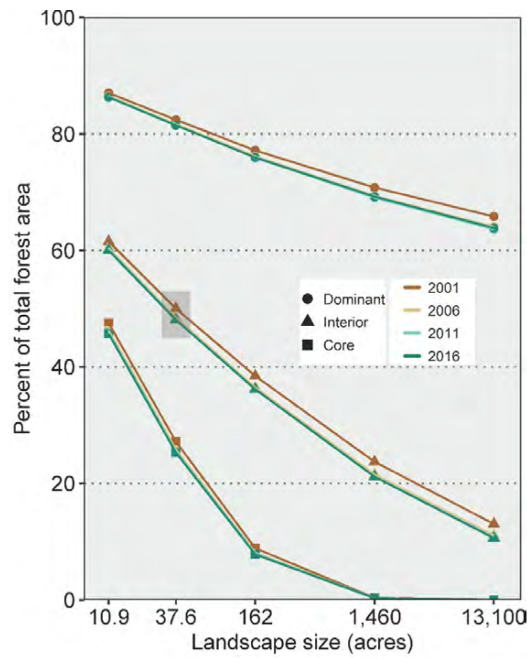

Figure 3-1—Forest land cover fragmentation from national land cover maps. The chart shows the percentage of forest cover in the conterminous United States that is considered core (at the center of a completely forested landscape), interior (landscape is more than 90 percent forested), or dominant (landscape is more than 60 percent forested), and how those proportions changed over time and with increasing landscape size. Note that that core is a subset of interior, which is a subset of dominant, which is a subset of total forest cover area in the indicated year. The highlighted symbols identify conditions mapped in figure 3-3.
Source: National Land Cover Database. See Technical Appendix for additional details on data sources and analysis methods.

Citation: Riitters, K.H. 2022. Sustainable Forest Indicator 1.03. https://www.fs.usda.gov/research/inventory/sustainability

Changes in forest cover and fragmentation

Between 2001 and 2016, the spatial patterns of forest losses and gains increased levels of fragmentation of the extant forest area (fig. 3-1). The net loss of interior forest was between 5.0 and 20.7 percent of the original interior forest area, and that percentage increased with increasing landscape size (table 3-1). In comparison, the conterminous United States experienced a 2.6 percent net loss of total forest land cover area during that time (table 3-1). The annualized net loss rates of interior forest cover and total forest cover decreased during the three 5-year intervals between 2001 and 2016 (table 3-1).

Table 3-1—Annual percentage rates of net change in conterminous United States interior forest cover area at five landscape sizes, for three time periods. Changes of all forest cover area are shown for comparison. Source: National Land Cover Database. See Technical Appendix for additional details on data sources and analysis methods.

				Compound annual rate of net change		
Interior forest cover	2001	2016	Net change	2001 to 2006	2006 to 2011	2011 to 2016
Landscape size (ac)	million ac	million ac	(percent)	(percent)		
10.9	363	345	-5.0	-0.78	-0.19	-0.05
37.6	295	276	-6.4	-1.04	-0.23	-0.05
162	227	208	-8.4	-1.46	-0.27	-0.02
1,460	140	122	-13.1	-2.33	-0.42	-0.04
13,100	77	61	-20.7	-3.61	-0.73	-0.24
All forest cover	590	575	-2.6	-0.41	-0.11	-0.01

Are there important regional differences?

Regional differences are illustrated by changes in forest cover and interior forest cover for the 37.6-acre landscape size (table 3-2). The overall (15-year) rates of both types of change were substantially higher in the West (Pacific Coast and Rocky Mountain Regions) than in the East (North and South Regions). In all four regions the compound annual rates of change were highest from 2001 to 2006 and declined over the next two time periods. In the North and South Regions, the net changes of both forest cover and interior forest cover were small after 2006, and the South Region exhibited increases in forest cover and interior forest cover after 2011. Similar regional differences were obtained for other landscape sizes, and for dominant and core forest (fig. 3-2).

For most counties, relatively small net changes from 2001 to 2016 in total forest area translated to larger net changes in interior forest area (fig. 3-3). Of 3,109 counties, 2,054 experienced a net loss of interior forest; 334 counties exhibited net losses larger than 15 percent. Relatively few counties experienced increases in interior forest area, and interior forest area was reduced even in some counties where total forest area increased. In forest-dominated areas of the Nation, interior forest cover losses greater than 5 percent were typical in the West but less common in the East, where many counties exhibited net gains of interior forest cover. Interior forest cover percent changes were commonly large in the Intermountain and Great Plains areas, but those areas had relatively low total forest cover and therefore had little influence on national statistics.

Why can't the entire indicator be reported at this time?

The available data permit an analysis of overall forest land cover fragmentation, which is the scope of this indicator. It is known that some of the proximate causes of fragmentation (e.g., water, ice) are usually not anthropogenic and may therefore be considered a natural attribute of some forest communities. While the origin of fragmentation by developed or agriculture land cover is clearly anthropogenic, land cover data alone cannot resolve the origin by other proximate causes (e.g., grass, shrub, barren). Regional baseline conditions and the specific ecological implications of observed levels of fragmentation are mostly unknown. To improve the interpretation of the proximate causes of fragmentation, supplemental indicator 1.03.1 summarizes the typology of forest-nonforest edges according to forest community types in the conterminous United States.

Table 3-2—Annual percentage rates of net change in interior forest cover area at five landscape sizes, for three time periods, by region. Changes of all forest cover area are shown for comparison.
Source: National Land Cover Database. See Technical Appendix for additional details on data sources and analysis methods.

Region	Interior forest cover for landscape size:	2001 million ac	2016 million ac	Net change (percent)	Compound annual rate of net change (percent)		
					2001 to 2006	2006 to 2011	2011 to 2016
North	10.9 ac	118	114	-2.9	-0.54	<0.01	-0.04
	37.6 ac	97	93	-4.0	-0.77	<0.01	-0.05
	162 ac	77	72	-5.9	-1.18	0.01	-0.04
	1,460 ac	52	47	-9.9	-2.08	0.02	-0.02
	13,100 ac	33	28	-15.7	-3.30	-0.14	0.08
	All forest cover:	187	185	-1.1	-0.24	<0.01	0.01
Pacific Coast	10.9 ac	44	39	-10.6	-1.32	-0.63	-0.28
	37.6 ac	37	32	-12.8	-1.65	-0.77	-0.31
	162 ac	30	25	-16.1	-2.21	-0.94	-0.33
	1,460 ac	20	16	-21.8	-3.18	-1.13	-0.55
	13,100 ac	12	8	-28.1	-4.49	-1.07	-0.91
	All forest cover:	67	63	-6.2	-0.75	-0.37	-0.15
Rocky Mountain	10.9 ac	73	66	-10.3	-0.91	-0.71	-0.56
	37.6 ac	62	54	-12.3	-1.10	-0.86	-0.64
	162 ac	50	43	-15.0	-1.40	-1.08	-0.75
	1,460 ac	34	27	-21.8	-2.13	-1.64	-1.11
	13,100 ac	18	11	-37.1	-3.79	-2.90	-2.44
	All forest cover:	118	111	-5.7	-0.49	-0.38	-0.30
South	10.9 ac	128	126	-2.1	-0.76	0.06	0.27
	37.6 ac	100	97	-2.7	-1.02	0.10	0.39
	162 ac	70	68	-3.2	-1.49	0.24	0.60
	1,460 ac	33	32	-4.0	-2.40	0.48	1.14
	13,100 ac	14	13	-5.7	-3.40	0.71	1.60
	All forest cover:	218	215	-1.2	-0.41	0.01	0.17

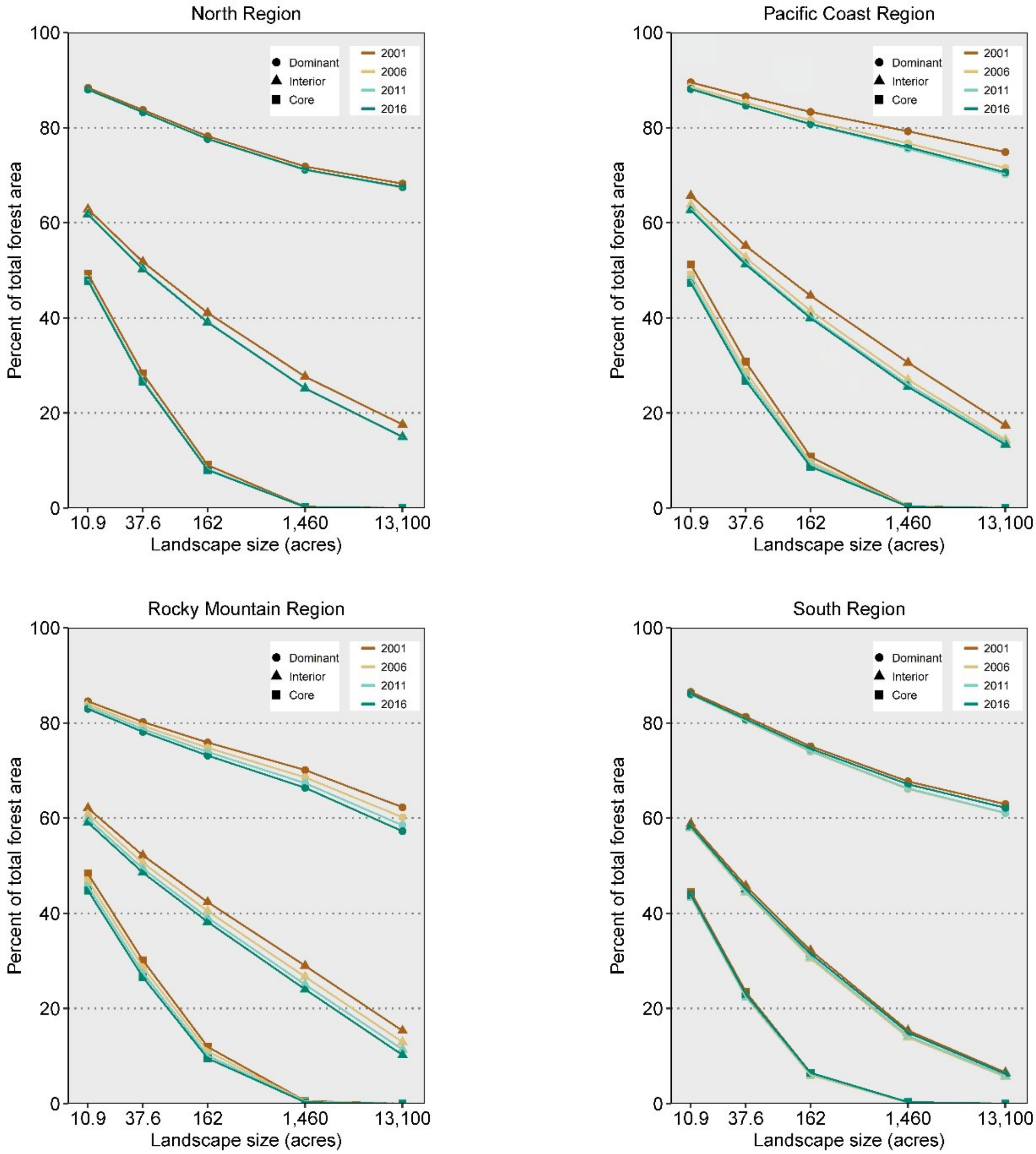

Figure 3-2—Forest land cover fragmentation by region from national land cover maps. The charts show the percentage of forest cover in the region that is considered core (at the center of a completely forested landscape), interior (landscape is more than 90 percent forested), or dominant (landscape is more than 60 percent forested), and how those proportions changed over time and with increasing landscape size. Note that that core is a subset of interior, which is a subset of dominant, which is a subset of total forest cover area in the indicated year.
Source: National Land Cover Database. See Technical Appendix for additional details on data sources and analysis methods.

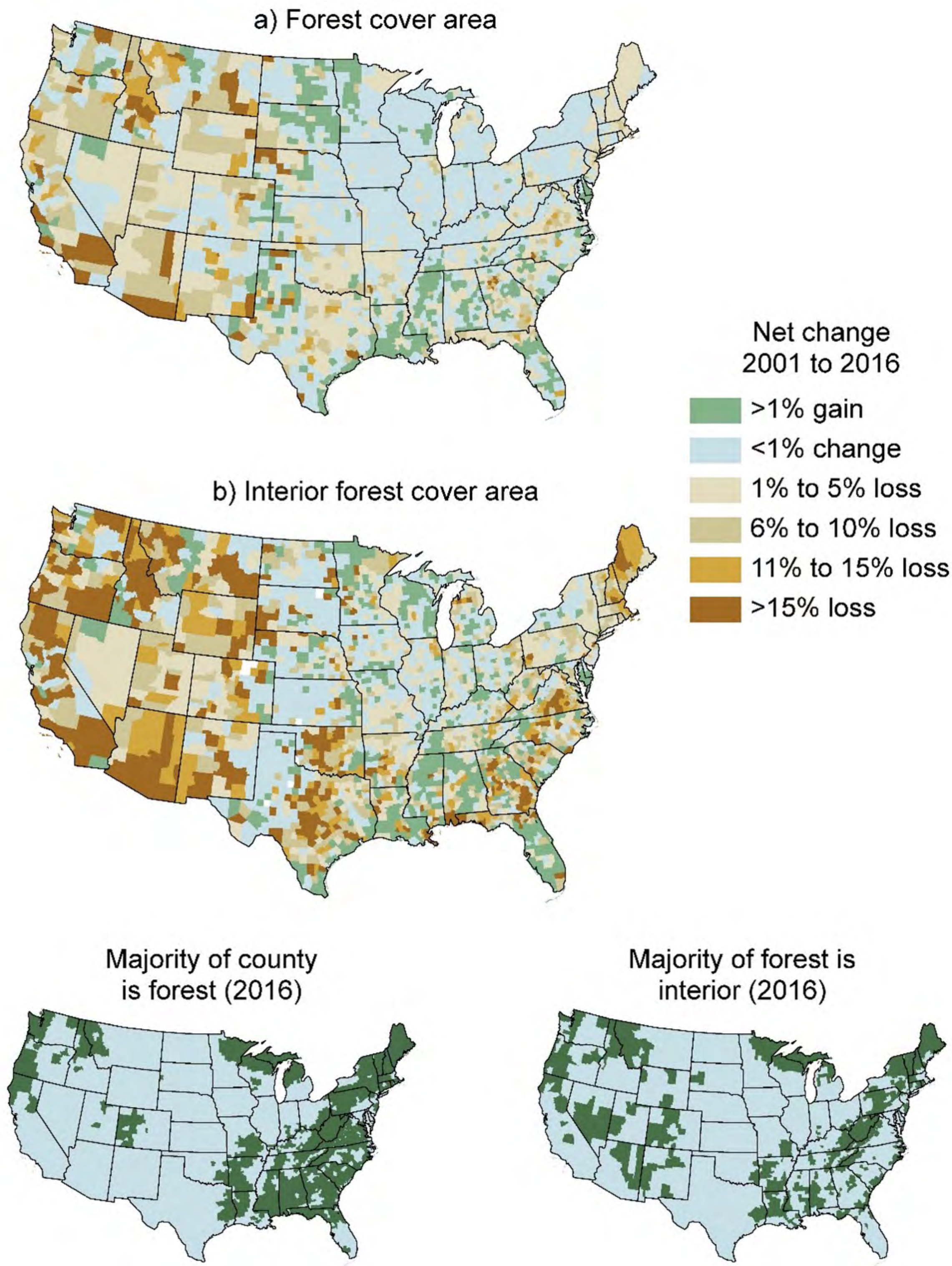

Figure 3-3—**(a)** The net change in total forest land cover in a county from 2001 to 2016, expressed as a percentage of the total forest area in 2001. **(b)** The net change in interior forest land cover in a county from 2001 to 2016, when analyzed with a 37.6-acre landscape size, expressed as a percentage of the total interior forest area in 2001 (corresponding to the highlighted symbols in figure 3-1). Because the same legend applies to both maps, it is possible to compare net percent changes in total forest area and interior forest area at the county level. The two inset maps identify counties where more than 50 percent of total area was forest land cover in 2016, and where more than 50 percent of the extant forest land cover in 2016 was interior.
Source: National Land Cover Database. See Technical Appendix for additional details on data sources and analysis methods.

Supplemental Indicator 1.03.1:

Forest-nonforest edge typology

Kurt H. Riitters

July 1, 2022

What is the indicator and why is it important?

This supplemental indicator documents the types of forest-nonforest edge in different forest types. This information addresses, but does not fully resolve, whether observed fragmentation is natural or anthropogenic, and temporary or permanent. This indicator does not quantify the degree of fragmentation but rather the relative importance of different forest-nonforest edges where fragmentation exists.

What does the indicator show?

The forest-nonforest edge typologies of 124 forest types (fig. 3-4) are broadly consistent with the distribution of forest types in relation to their typical biophysical settings. For example, there is a higher proportion of forest-water edge in riparian or wetland forest types (e.g., black spruce, mangrove), a higher proportion of forest-barren edge in forest types typical of high-elevation (e.g., mountain hemlock, subalpine fir) or pioneer forests (e.g., gray birch, black locust), and a higher proportion of forest-agriculture edge for forest types typical of agricultural areas (e.g., black walnut, bur oak). The proportion of forest-shrub/grass edge tends to be higher in forest types with a higher degree of "natural" fragmentation (e.g., pinyon/juniper woodland, Oregon white oak) but is also higher in commercially important forest types (e.g., Douglas-fir, loblolly pine) for which shrub and grass are transitional land covers following harvest. Because developed land cover includes impervious road surfaces, the proportion of forest-developed edge can be relatively high just due to roads in forest types that are typically remote and not naturally fragmented (e.g., redwood, Sitka spruce).

The occurrences of forest-developed and forest-agriculture edges clearly indicate human influence. The median share of developed edge was 16 percent, with the largest shares in the pitch pine (63 percent) and redwood (57 percent) types. Including those two, 32 forest types exhibited more than 30 percent developed edge. The median share of agriculture edge was 10 percent with the largest shares in the black walnut (67 percent), river birch / sycamore (48 percent), and elm / ash / black locust (48 percent) types. Including those three, 27 forest types exhibited more than 30 percent agriculture edge. Conversely, most of the forest-water edge is arguably natural and was the most common type of edge in seven forest types (mangrove, black spruce, tamarack, baldcypress/water tupelo, baldcypress/pondcypress, and palms). The forest-barren edge was significant only for high elevation forest types in the West (e.g., whitebark pine, foxtail pine/bristlecone pine, subalpine fir, and mountain hemlock) where it is arguably natural, and on poor or reclaimed sites in the East (e.g., gray birch, black locust).

Are there important regional differences?

Except for forest-developed edge in the Pacific Coast Region, almost all forest-nonforest edge in the two western regions is forest-shrub/grass edge (fig. 3-5). Most of the forest-agriculture edge is in the two eastern regions, which also exhibit the largest percentages of forest-developed and forest-water edges. Regional differences may also be explored by comparing figure 3-4 with tree species' range maps.

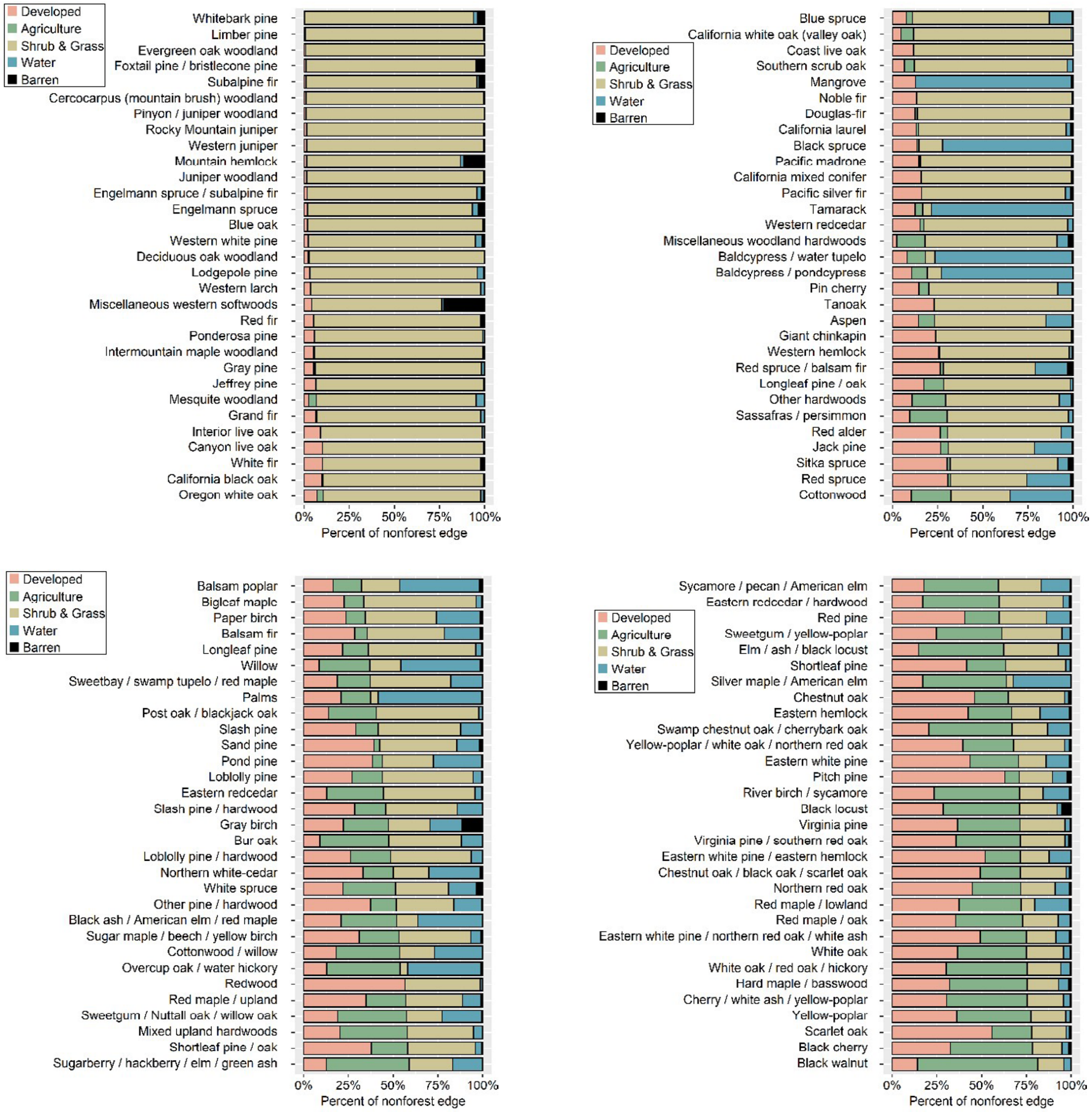

Figure 3-4—Mean shares of forest-nonforest edge within a 37.6-ac neighborhood of Forest Inventory and Analysis (FIA) forest land in 2016, by FIA forest type. Forest types are sorted in ascending order by the sum of developed and agriculture shares of nonforest edge.
Source: Forest Inventory and Analysis Database; National Land Cover Database.

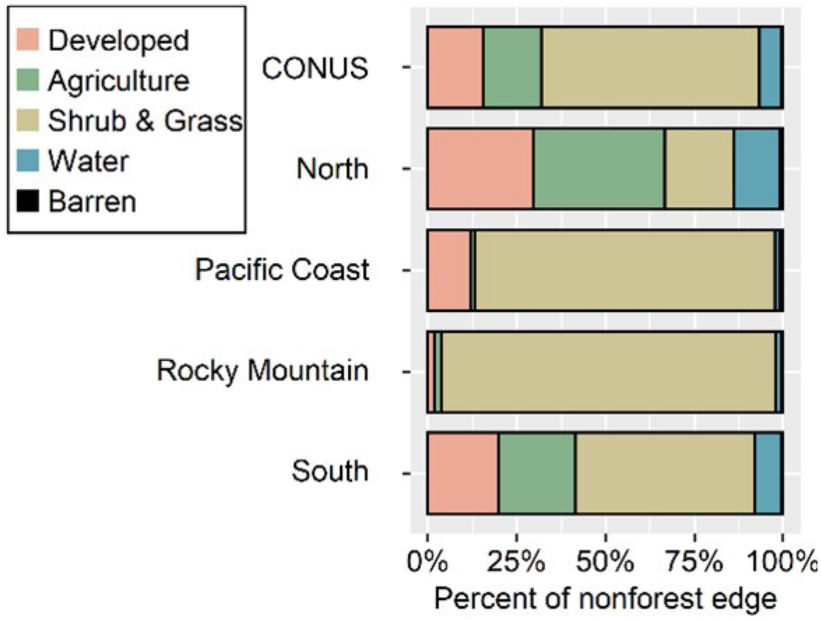

Figure 3-5—Mean shares of forest-nonforest edge within a 37.6-ac neighborhood of FIA forest land in 2016, by RPA Region and conterminous United State.

CONUS = Conterminous United States
FIA=Forest Inventory and Analysis
RPA = Resource Planning Act

Source: Forest Inventory and Analysis Database; National Land Cover Database.

Why can't the entire indicator be reported at this time?

Regional baseline conditions and the specific ecological implications of observed forest-nonforest edges are mostly unknown. Forest edge typology cannot be reported for all forest cover—only for the forest cover near inventory plots that are considered to be "forest land" (a type of land use), because there is no forest type information where there is no "forest land." Forest edge typologies apply to "forest land" as of 2016; temporal change from 2001 to 2016 cannot be reported by forest types because the inventory plot data are insufficient to perform a comparable stratification in 2001.

Technical appendix

Data sources. Information about fragmentation and forest edge was derived from the National Land Cover Database (NLCD; Homer et al. 2020) for 2001 (USGS 2019a), 2006 (USGS 2019b), 2011 (USGS 2019c), and 2016 (USGS 2019d). The NLCD land cover maps identify 16 land cover classes at a spatial resolution of 0.22 ac per pixel (30m X 30m) for the conterminous United States. For the analysis of forest cover fragmentation (Indicator 1.03), the 16 NLCD land cover classes were combined into two generalized classes called forest (the NLCD deciduous, evergreen, mixed forest, and woody wetlands classes) and nonforest (all other NLCD classes). For the analysis of forest edge typology (Indicator 1.03.1), the 16 NLCD land cover classes were combined into six classes called developed (NLCD class codes 21, 22, 23, 24; includes most impervious roads), agriculture (81, 82), shrub and grass (52, 71), water (11, 95; includes herbaceous wetlands), barren (11, 12; includes permanent ice), and forest (41, 42, 43, 90; includes woody wetlands). The CONUS-wide 2016 NLCD map has an overall accuracy of 72.1 percent (± 0.9 percent); the combined forest cover class has a producer's accuracy of 87 percent and a user's accuracy of 91 percent (calculated from Table 4 in Wickham et al. 2021).

The forest type information that was used for stratification of Indicator 1.03.1 came from a statistically representative set of Forest Inventory and Analysis (FIA) forest land plots used for the FIA 2016 area evaluations in the conterminous United States (Burrill et al 2018). The analysis used a subset of FIA plots representing 96 percent of all forest land (as defined by FIA; Burrill et al 2018) in 2016, comprising 124 forest types on 660 million ac of forest land. Excluded were non-stocked forest land (22.2 million ac), eight exotic forest types (2.47 million ac), 17 forest types that occupied less than 100,000 acres each, and forest land with an unassigned forest type.

Forest fragmentation analysis. Riitters (2019) provided the general rationale for using forest area density as a fundamental measure of forest fragmentation. Forest area density (FAD) is defined as the proportion of all NLCD land cover pixels within a fixed-area neighborhood that are forest. The interpretation of FAD in terms of fragmentation is straightforward—if forest was not fragmented, then FAD equaled 1.0 in that neighborhood, and fragmentation was therefore the departure from that condition. To account for the fact that fragmentation is scale-dependent, FAD measurements were taken using five measurement scales defined by neighborhood sizes equal to 10.9 ac (7 pixels X 7 pixels), 37.6 ac (13 X 13), 162 ac (27 X 27), 1,459 ac (81 X 81), and 13,132 ac (243 X 243). A set of five FAD values was associated with each pixel by centering the neighborhoods on its location. FAD values were summarized by considering only the pixels that were forest each year. Each forest pixel was then labeled as "dominant" forest (surrounded by a landscape that is at least 60 percent forested), "interior" forest (at least 90 percent forested), or "core" forest (100 percent forested). The labeling was done at each of the five landscape sizes such that the overall "scale of fragmentation" refers to both thematic scale (the thresholds defining fragmentation labels) as well as spatial scale (the size of the neighborhood over which FAD was measured). The indicator report refers to neighborhood size as "landscape size" and shows the values rounded to three significant digits (10.9, 37.6, 162, 1,460, and 13,000 ac). Examples of interpreting FAD in terms of the status and change of forest cover fragmentation are provided by Riitters et al. (2002) and Riitters and Wickham (2012). Inferences about the distance to nonforest edge are possible by noting the relationship between the size of the largest neighborhood that is "core" at a given location and the implied minimum distance to the nearest nonforest edge for that size (Riitters and Wickham 2003).

To prepare figures 3-1 and 3-2, the FAD values associated with all forest pixels were summarized over the conterminous United States (fig. 3-1) and over four assessment regions (fig. 3-2). Separate summaries were prepared for each year. A given forest pixel was labeled as ''core forest'' at a given measurement scale if the associated FAD equaled 1.0, as "interior forest" if FAD ≥0.9, and as "dominant forest" if FAD ≥0.6. Note that a forest pixel that meets the "core" criterion also qualifies as "interior" and "dominant," and one which meets the "interior" criterion also qualifies as "dominant." For each year, the percentages of forest pixels meeting those three criteria are based on the extant forest at that time.

To prepare figure 3-3(a), the total area of forest land cover in each county was calculated using the 2001 and 2016 NLCD forest maps, and the difference was expressed as percentage change from the base year 2001. To prepare figure 3-4(b), the total area of "interior forest" at a 37.6 ac measurement scale was calculated for 2001 and 2016, and the difference was expressed as a percentage change from the base year of 2001.

Tables 3-1 and 3-2 show compound annual rates of net change for three 5-year time periods between 2001 and 2016. The rate was calculated as:

$$rate = 100 * \left(\left(\frac{Final\ area}{Starting\ area} \right)^{\frac{1}{5}} - 1 \right)$$

Forest-nonforest edge typology analysis. Forest-nonforest adjacencies are fundamental measures of the proximate causes of fragmentation (Riitters 2019). This analysis overlaid the forest plot locations on the national land cover map (USGS 2019d), tabulated the frequencies of different types of forest-nonforest edges in a surrounding neighborhood, and summarized results by forest type. Riitters et al (2012) provides examples of interpreting forest-nonforest adjacencies in terms of the proximate causes of fragmentation.

Within the 37.6-ac neighborhood of each FIA plot, there are 169 pixels of NLCD land cover and 312 "edges" between adjacent pixels. That neighborhood size is the same as was used to illustrate the geography of fragmentation in figure 3-3. Each edge in a neighborhood was characterized by the land cover on the two sides of the edge, for example as "forest-forest" edge (two adjacent forest pixels) or "forest-agriculture" edge (forest pixel adjacent to agriculture pixel). The relative proportions of the forest-nonforest edges (i.e., forest-developed, forest-agriculture, forest-shrub/grass, forest-water, and forest-barren) were calculated for each FIA plot. Note that by ignoring the forest-forest edge, this supplemental indicator does not indicate the magnitude of fragmentation but instead focuses on the relative importance of different forest-nonforest edges near plots where there is fragmentation.

The results of a neighborhood analysis were assigned to each forest type contained within a given plot, and population estimates were generally formed by using standard FIA "expansion factors" for each "condition class" defined by forest type within each plot (Burrill et al. 2018). Those estimates were area-weighted (by the same expansion factors) because the relative proportions of different forest-nonforest edges vary with the area of forest in a neighborhood (Riitters et al 2012) and individual plots do not have the same area of forest in a neighborhood. The area-weighting was applied in two steps, first to derive mean values for all plots with a given area of forest in the neighborhood and second to derive mean values across plots with different areas of forest in the neighborhood. A similar procedure was used to summarize results by geographic region, except the "condition class" was defined as the Resource Planning Act Region that contained the plot; the regional results were similarly aggregated to the CONUS level.

Because the analysis is based on forest land locations (plots with forest land use) in 2016, the results are not necessarily indicative of all forest cover fragmentation. For example, locations near urban areas may exhibit more forest cover fragmentation, with higher proportions of forest-developed edges, but such areas are often excluded from the FIA sample because they do not qualify as forest land if they have a different primary land use. In contrast, some nonforest land cover pixels (NLCD) are considered FIA forest land use (with temporary absence of tree canopy cover). Future work could extend this supplemental indicator, for example to evaluate all plot locations defined by the FIA design (forest land or not, which would provide a closer link to the main fragmentation indicator results), or to incorporate plot-level changes in forest-nonforest edges or forest types (when sufficient data become available).

Issues and concerns. To ensure consistency with current maps, new releases by the NLCD program also update previous years' maps. As a result, the statistics for the years 2001, 2006, and 2011 differ from comparable statistics presented in earlier Sustainability Reports.

Prognosis and comfort level. These indicators essentially reformat and extend earlier analysis protocols that have been reported in earlier Sustainability Reports and peer-reviewed publications. The accuracy of the analysis depends on the accuracy of the underlying NLCD forest maps, the minimum mapping unit size, the scale of analysis (neighborhood size), and possibly other factors.

References

Burrill, E.A.; Wilson, A.M.; Turner, J.A.; Pugh, S.A.; Menlove, J.; Christiansen, G.; Conkling, B.L.; David, W. 2018. The Forest Inventory and Analysis Database: database description and user guide version 8.0 for Phase 2. U.S. Department of Agriculture, Forest Service. 946 p. http://www.fia.fs.usda.gov/library/database-documentation/.

Homer, C.G.; Dewitz, J.A.; Jin, S.; Xian, G.; Costello, C.; Danielson, P.; Gass, L.; Funk, M.; Wickham, J.; Stehman, S.; Auch, R.F.; Riitters, K.H. 2020. Conterminous United States land cover change patterns 2001–2016 from the 2016 National Land Cover Database. ISPRS Journal of Photogrammetry and Remote Sensing. 162: 184–199. DOI: 10.1016/j.isprsjprs.2020.02.019.

Riitters, K.H.; Wickham, J.D.; O'Neill, R.V.; Jones, K.B.; Smith, E.R.; Coulston, J.W.; Wade, T.G.; Smith, J.H. 2002. Fragmentation of continental United States forests. Ecosystems. 5: 815–822. DOI: 10.1007/s10021002-0209-2.

Riitters, K.H.; Wickham, J.D. 2003. How far to the nearest road? Frontiers in Ecology and the Environment. 1: 125–129. DOI: 10.1890/1540-9295(2003)001[0125:HFTTNR]2.0.CO;2

Riitters, K.H.; Coulston, J.W.; Wickham, J.D. 2012. Fragmentation of forest communities in the Eastern United States. Forest Ecology and Management. 263: 85–93. DOI: 10.1016/j.foreco.2011.09.022.

Riitters, K.; Wickham, J. 2012. Decline of forest interior conditions in the conterminous United States. Scientific Reports. 2: 653. DOI: 10.1038/srep00653.

Riitters, K. 2019. Pattern metrics for a transdisciplinary landscape ecology. Landscape Ecology. 34: 2057-2063. DOI: 10.1007/s10980-018-0755-4.

USGS. 2019a. NLCD 2001 Land Cover (2016 Edition). Sioux Falls, SD: U.S. Department of the Interior, U.S. Geological Survey, Earth Resources Observation and Science Center, Multi-Resolution Land Characteristics Project.

USGS. 2019b. NLCD 2006 Land Cover (2016 Edition). Sioux Falls, SD: U.S. Department of the Interior, U.S. Geological Survey, Earth Resources Observation and Science Center, Multi-Resolution Land Characteristics Project

USGS. 2019c. NLCD 2011 Land Cover (2016 Edition). Sioux Falls, SD: U.S. Department of the Interior, U.S. Geological Survey, Earth Resources Observation and Science Center, Multi-Resolution Land Characteristics Project.

USGS. 2019d. NLCD 2016 Land Cover (2016 Edition). Sioux Falls, SD: U.S. Department of the Interior, U.S. Geological Survey, Earth Resources Observation and Science Center, Multi-Resolution Land Characteristics Project.

Wickham, J.; Stehman, S.V.; Sorenson, D.G.; Gass, L.; Dewitz, J.A. 2021. Thematic accuracy assessment of the NLCD 2016 land cover for the conterminous United States. Remote Sensing of Environment. 257:112357.