CHAPTER 5

Updating the Sustainability Indicators of Forest Cover Fragmentation for the United States From 2001 to 2019

Kurt Riitters, Jennifer K. Costanza, and Karen G. Schleeweis

How to cite this chapter:

Riitters, K.; Costanza, J.K.; Schleeweis, K.G. 2024. Updating the sustainability indicators of forest cover fragmentation for the United States from 2001 to 2019. In: Pandit, K.; Conkling, B.L., eds. Forest Health Monitoring: national status, trends, and analysis 2023. Gen. Tech. Rep. WO-105. Washington, DC: U.S. Department of Agriculture, Forest Service: 101–111. Chapter 5. https://doi.org/10.2737/WO-GTR-105-Chap5.

INTRODUCTION

International forest sustainability reporting by the U.S. Department of Agriculture, Forest Service is pursuant to the Montréal Process Criteria and Indicators (C&I; Montréal Process Liaison Office 2015). That framework includes measures of forest fragmentation that have evolved substantially over three decades of reporting (Riitters and Robertson 2021). The most recent report, for the years 2001 to 2016, indicated that fragmentation continued to increase but at a decreasing rate over that time interval (Riitters and Robertson 2021). The objective of this chapter is to update the fragmentation information by incorporating new land cover data for the year 2019 and the accompanying revisions to the earlier land cover data. Unlike the 5-year reporting of conterminous United States (CONUS) conditions in the most recent report, this chapter evaluates changes over 2- and 3-year time intervals and evaluates conditions within eight regions (fig. 5.1) and by county.

Relatively fine-scale, wall-to-wall forest maps are ideal for measuring and mapping forest fragmentation. As in earlier reports, forest is defined here by national land cover maps (see below). This definition, which is based on land cover, should be distinguished from other forest definitions that are based on land use (Nelson and others 2020). Forest land cover is more dynamic than forest land use because temporary losses of forest cover do not change the underlying forest land use. Thus, land cover data provide a more sensitive measure of fragmentation, and fragmentation can increase or decrease with the loss or gain of forest cover over time.

The reporting is based on a metric called "forest area density" (FAD)—roughly, how much forest is surrounded by how much other forest—which is measured and mapped at multiple measurement scales. Specifically, the percentage of forest within a fixed-area neighborhood of each forest pixel is compared to minimum threshold values of 60, 90, and 100 percent to identify the forest pixels that are "dominant," "interior," or "core," respectively. Measurement scales are varied by using several neighborhood sizes such that a given forest pixel could be, for example, "core" at a small scale and "dominant" at a larger scale. The reporting format thus accounts for the well-known dependence of fragmentation on scale and observer.

The FAD metric provides a transparent and sensitive indicator of the location, scale, and degree of fragmentation at a given time (Riitters 2019). If no fragmentation, then all forest pixels would meet all FAD thresholds for all neighborhood sizes. Fragmentation is therefore relative to a baseline corresponding to a completely forested condition. Scale-dependent deviations from the 100-percent-forested baseline arise from natural (and endemic) fragmentation as well as anthropogenic fragmentation, which different observers can interpret for their chosen threshold. Absent meaningful baselines describing natural (or endemic) fragmentation, the spatial and temporal changes in FAD are meaningful indicators of landscape changes. Furthermore, the same results can be interpreted in different policy contexts (e.g., forest conservation, forest biodiversity, urban sprawl) simply because wall-

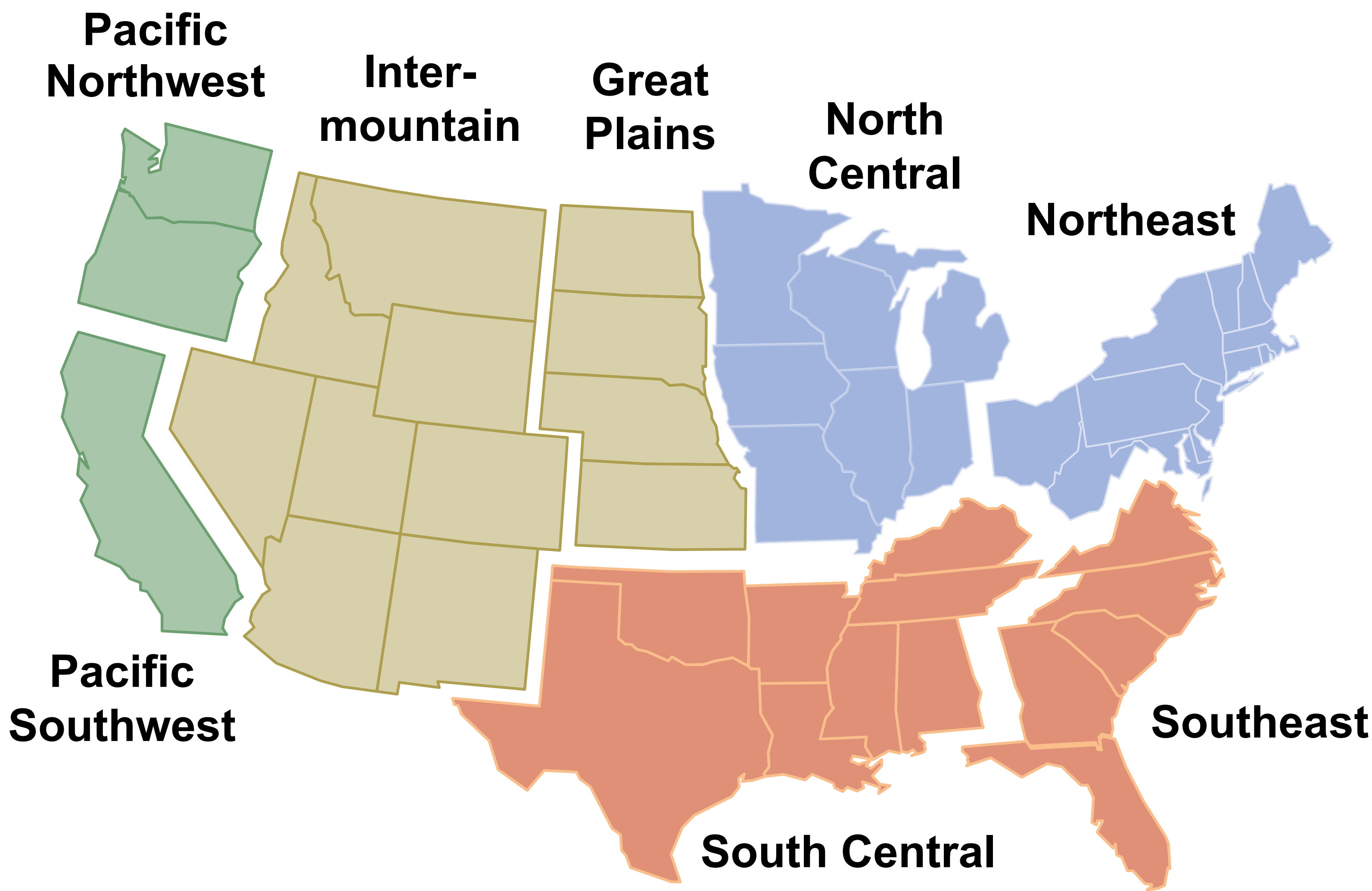

Figure 5.1—The eight geographic regions for which results are reported in this chapter. For literature comparisons, the colors indicate a set of four larger regions used in other Forest Service assessment reports. (Source: adapted from fig. 2-1 in USDA Forest Service (2023))

to-wall mapping of FAD with multiple thresholds and neighborhood sizes provides flexibility for and thus consistency among different applications. While the tension between the parsimony sought by the Montréal Process C&I approach, which comprises just one metric per indicator, and the amount of information needed to evaluate complex phenomena may never be resolved, starting with nationally consistent metrics that can be unambiguously interpreted with respect to fragmentation is essential. Subsequent interpretations can address the causes or consequences of changing fragmentation in specific circumstances.

METHODS

CONUS forest maps were derived from the National Land Cover Database (NLCD) for the nominal years 2001, 2004, 2006, 2008, 2011, 2013, 2016, and 2019 (Dewitz and USGS 2021). The NLCD land cover maps identify 16 land cover classes at a spatial resolution of 0.09 ha/pixel (30 x 30 m). For this analysis, 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). The combined forest classification accuracy has not been formally evaluated for this NLCD dataset but is expected to approximate previous estimates (Nelson and others 2020) of 84 percent (producer's accuracy) and 88 percent (user's accuracy). This analysis did not address measurement errors.

FAD is defined as the percentage of forest pixels within a fixed-area neighborhood. This analysis used five neighborhood sizes of approximately 4.41 ha (7 x 7 pixels), 15.2 ha (13 x 13), 65.6 ha (27 x 27), 590 ha (81 x 81), and 5310 ha (243 x 243). In each year, five FAD values were associated with each forest pixel by centering the five neighborhoods on their locations. For each neighborhood size, a forest pixel was labeled as "core forest" if the associated FAD equaled 100 percent, as "interior forest" if FAD was at least 90 percent, and as "dominant forest" if FAD was at least 60 percent. Note that a forest pixel that meets the "core" criterion also qualifies as "interior" and "dominant," and one that meets the "interior" criterion also qualifies as "dominant." Data summaries were prepared for each year by calculating the area and proportion of forest pixels that met each of the three FAD criteria, for each neighborhood size.

Temporal changes were generally calculated as net area change. Percent changes were expressed either as the net percent change over a specific time interval, or as the annual percent rate of change over *N* years (*N* = 2, 3, or 18) in a time interval.

$$net\ percent\ change = 100 * \frac{Final\ area - Initial\ area}{Initial\ area}$$

$$annual\ percent\ rate\ of\ change = 100 * \left[\left(\frac{Final\ area}{Initial\ area} \right)^{\frac{1}{N}} - 1 \right]$$

The annual percent rate of change is not available for the year 2001 because the initial area before 2001 is unknown. The two equations calculated percent changes for interior forest, and for all forest as a basis for comparison with the interior forest results.

This study also examined how the proportion of all forest that was labeled as core, interior, and dominant forest changed depending on neighborhood size for three of the NLCD map years, 2001, 2011, and 2019.

RESULTS

Because forested places tend to be clustered in proximity to one another, forest is usually the dominant land cover in these areas. Thus, for landscapes up to 5310 ha in size, >60 percent of all forest area is in forest-dominated landscapes (fig. 5.2). However, because larger blocks of forest land are increasingly subject to inclusion of at least some nonforest land (natural or anthropogenic), the percentage of forest land that is relatively unfragmented (i.e., interior) decreases rapidly as neighborhood size increases from 4.41 ha to 5310 ha (fig. 5.2). Fragmentation is so common that almost no forest qualifies as core for the two largest neighborhood sizes in all regions (fig. 5.3).

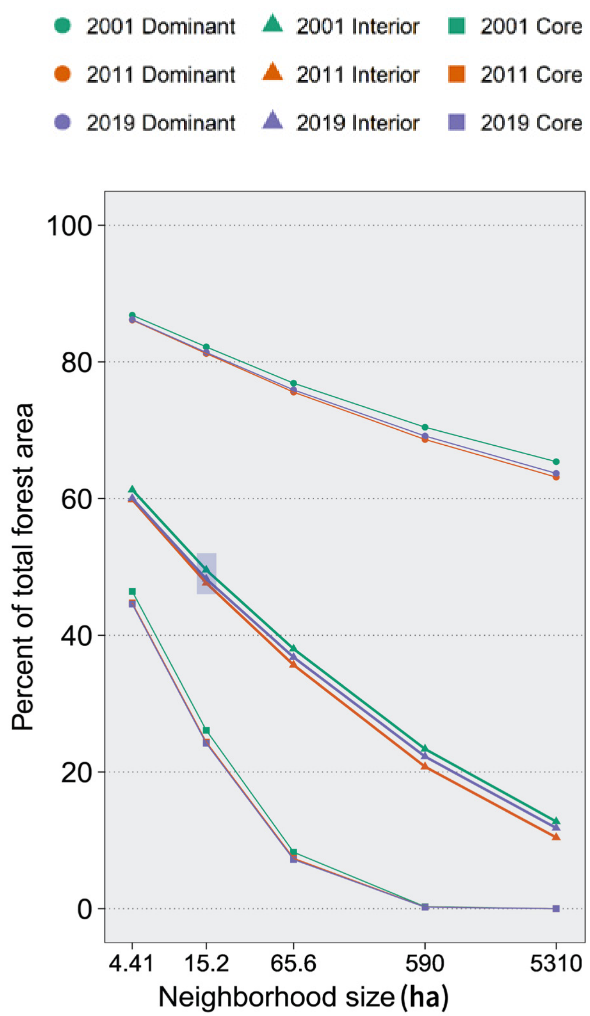

Figure 5.2—Forest fragmentation in the conterminous United States (circa 2001, 2011, and 2019) derived from measurements of forest area density. The shaded blue rectangle identifies the conditions mapped at the county level in figure 5.4. Note the logarithmic scale for neighborhood size.

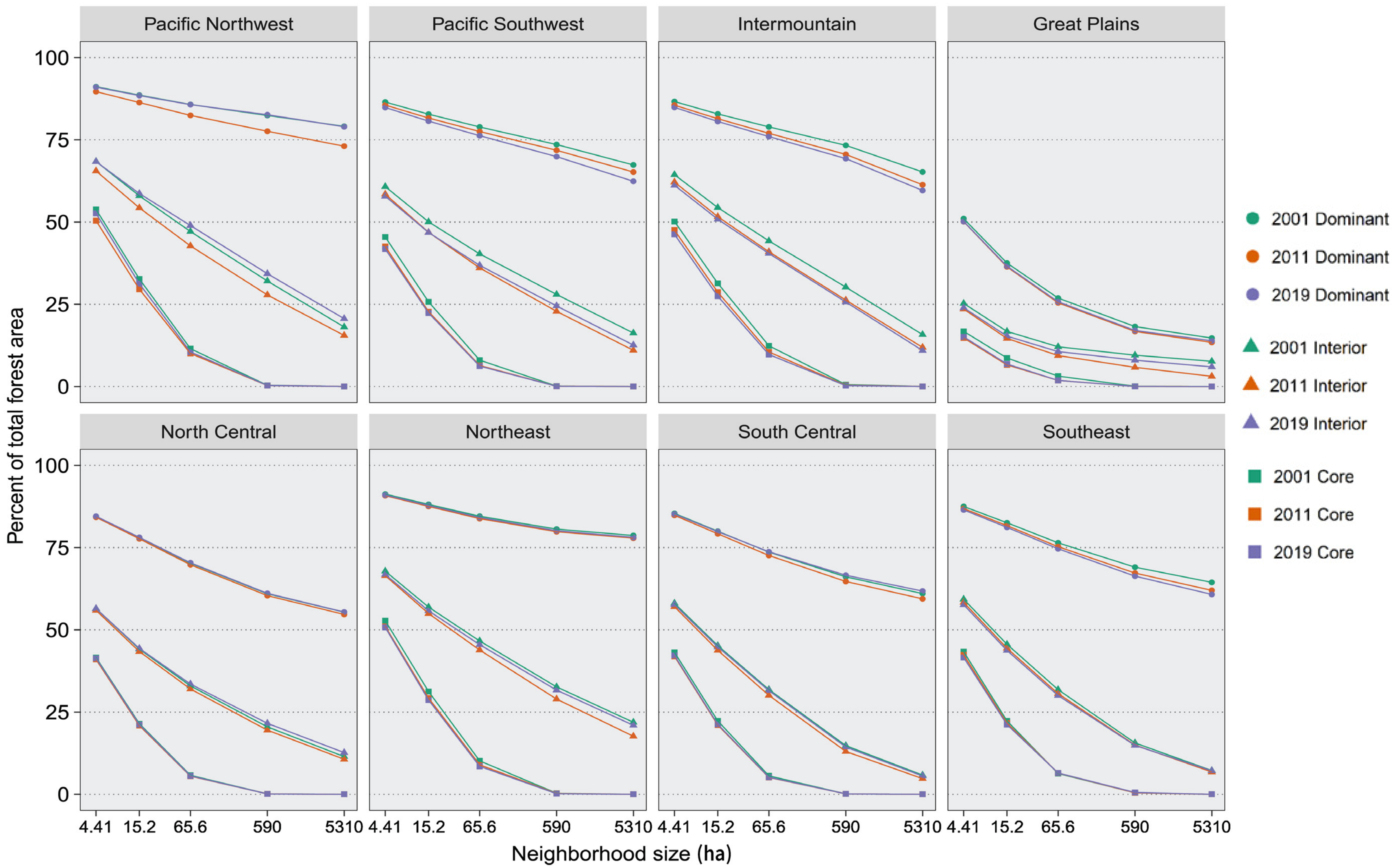

Figure 5.3—Forest fragmentation (circa 2001, 2011, and 2019) derived from measurements of forest area density, by region. Note the logarithmic scale for neighborhood size.

Between 2001 and 2019, the CONUS experienced a 2.3-percent net loss of total forest land cover area (table 5.1). In comparison, the net loss of interior forest was between 4.3 and 9.5 percent depending on neighborhood size. The net area loss of interior forest decreased with neighborhood size, consistent with the patterns of relatively local forest loss in heavily forested areas and forest gain in less-forested areas (Riitters and Wickham 2012). The percent loss of interior forest increased with neighborhood size largely due to less interior area for larger neighborhood sizes in 2001.

Shifting to a county-level analysis, changes in interior forest area for the 15.2-ha neighborhood size were used to illustrate comparisons with total forest area change. The overall geographic distribution of net percent changes (gains and losses) from 2001 to 2019 was similar for total forest area (fig. 5.4A) and interior forest area (fig. 5.4B). Except for counties within the Great Plains region, the net percent gains and losses of total forest area generally translated to larger net percent changes (gains or losses) of interior forest area. Notable gains of interior forest area occurred along the Gulf Coast and west of the Cascade Mountains in the Pacific Northwest region. Notable losses occurred throughout most of the rest of the Western States, in the Piedmont and Coastal Plain areas in the Southeast, and elsewhere near major metropolitan areas. CONUS-level summaries are driven mainly by changes in the counties that contain most of the total forest area (fig. 5.4 inset).

The regional differences suggested by the county-level analysis are consistent with the 18-year changes in different regions (table 5.2). The Intermountain region exhibited the largest net area losses of total forest and interior forest, but the Pacific Southwest region exhibited the largest annual percent rates of losses. The North Central region was the only region to exhibit a net gain of interior forest area, while the Pacific Northwest region was the only region where the annual percent rate of interior forest loss was less than the rate of total forest loss. Net losses in terms of both area and rate were large in the Southeast region when compared to other eastern regions.

Table 5.1—Status and trend of interior forest area in the conterminous United States for five neighborhood sizes from 2001 to 2019, with change of total forest area shown for comparison

Neighborhood size (ha)	2001 (million km^2)	2019 (million km^2)	Net area change (thousand km^2)	Net percent change
4.41	1.45	1.39	-63	-4.3
15.2	1.18	1.12	-58	-4.9
65.6	0.90	0.85	-50	-5.5
590	0.55	0.52	-39	-7.0
5310	0.30	0.27	-29	-9.5
Total forest area	2.37	2.32	-55	-2.3

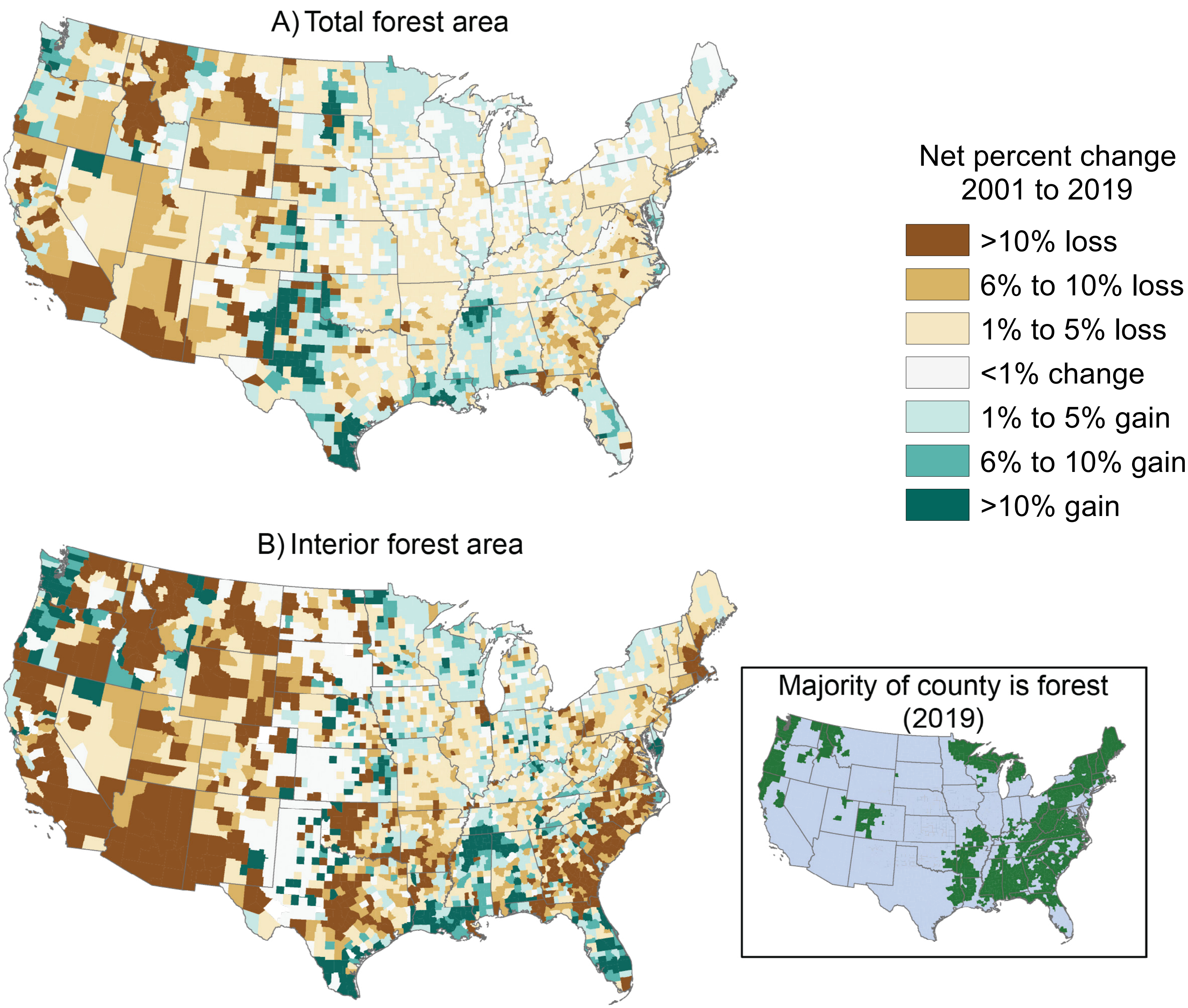

Figure 5.4—The net percent change from 2001 to 2019, by county, in (A) total forest area and (B) interior forest area (15.2-ha neighborhood). The same legend applies to both maps, and the inset map identifies counties with at least 50 percent forest area in 2019.

Table 5.2—Cumulative net changes of forest area and interior forest area (15.2-ha neighborhood) from 2001 to 2019, in the conterminous United States (CONUS) and by region

Region	Net area change (thousand km^2)		Annual percent rate of net change	
	All forest	Interior forest	All forest	Interior forest
CONUS	-55.4	-57.9	-0.13	-0.28
Pacific Northwest	-3.1	-0.6	-0.10	-0.04
Pacific Southwest	-9.2	-7.5	-0.54	-0.91
Intermountain	-30.0	-31.3	-0.38	-0.76
Great Plains	-0.5	-0.5	-0.10	-0.59
North Central	0.2	0.8	0.00	0.03
Northeast	-3.5	-6.4	-0.05	-0.16
South Central	0.1	-1.9	0.00	-0.05
Southeast	-9.5	-10.6	-0.15	-0.38

The annual percent rates of change of total forest and interior forest area between 2001 and 2019 are shown in figure 5.5. Overall, changes at the CONUS scale were generally smaller than changes in some regions. In the Intermountain and Pacific Southwest regions, annual percent rates of change were typically negative for all time periods. The Pacific Northwest region was notable because of the apparent trend of improving conditions (less loss, or more gain) there; the South Central region exhibited a similar but less apparent trend. In the Great Plains region, the relatively large annual percent rates of interior forest area change are probably related to the relatively small interior forest area in that region. Other regions showed no obvious trends, but the annual percent rates of change in the North Central and Northeast regions appeared to be somewhat less variable over time compared to the South Central and Southeast regions. The changes after 2016 are of particular interest because the objective is to update the fragmentation statistics to incorporate the 2019 land cover data. In that regard, note that six of the eight regions exhibited net gains of total forest area, and six regions also exhibited net gains of interior forest area. The relatively large post-2016 gains in the Pacific Northwest are particularly striking.

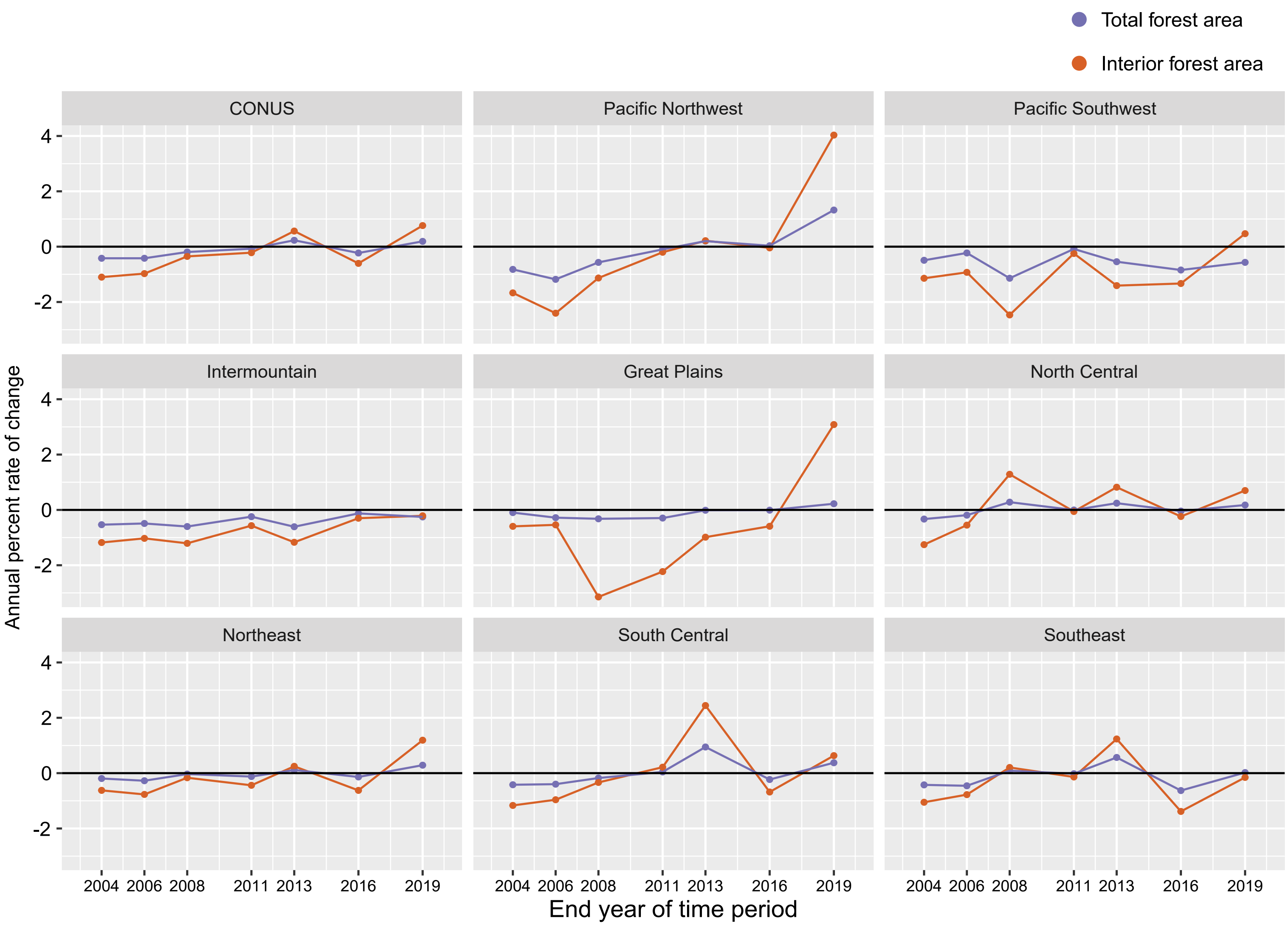

Figure 5.5—Annual percent rate of change of total forest area and interior forest area (15.2-ha neighborhood) over seven time periods from 2001 to 2019, in the conterminous United States (CONUS) and by region. Note that the interval ending in 2004 began in 2001.

DISCUSSION

Direct comparisons of these results with the results for 2001 to 2016 presented by Riitters and Robertson (2021) are not possible for several reasons. Regarding the input data for these analyses, the NLCD data for all years were updated for consistency with the release of the new data for 2019. As a result, the forest area that was newly mapped for the base year of 2001 was 17 300 km^2 less than the previous (2016) edition of the 2001 NLCD data. The change in base year forest area was certain to affect both the FAD calculations and the calculated rates of change of total forest and interior forest after that base year. Similarly, revisions of the NLCD data for the intervening years of 2006, 2011, and 2016 complicate comparisons with previous results presented for those years.

Considering the overall CONUS changes in dominant, interior, and core forest area, figure 5.2 indicates across the board net losses from 2001 to 2011 followed by evidence of stabilization or recovery until 2019. This contrasts with earlier reports (e.g., fig. 2 in Riitters and Robertson 2021) that indicated the same pattern of losses after 2001, with evidence of stabilization until 2016, but without much evidence of recovery. The new results presented here may reflect the widespread increase in both total forest and interior forest areas between 2016 and 2019 (fig. 5.5). The new results do not indicate complete recovery to 2001 conditions; forest loss and fragmentation have continued in most regions but at slower rates than previously reported.

Given the policy concerns related to wildfire, drought, and insect outbreaks in the Western States, this analysis supports the concerns for net loss of total forest area and increased fragmentation of the remainder in the Intermountain and Pacific Southwest regions. Similar concerns about wildfire and harvesting in the Pacific Northwest may allow speculation about the post-2016 increase in forest area and decrease in fragmentation, which may signal that relatively slow but ultimately successful regeneration was responsible for previous reports of increasing fragmentation west of the Cascade Mountains. In the Eastern States, forest area dynamics are largely driven by land use changes involving forest, agriculture, and developed land. This study's finding of decreasing fragmentation in the South Central region is generally consistent with previous reports of forest area increases due to conversion of former agricultural land (e.g., Nelson and others 2020). The finding of increasing fragmentation in the Southeast region and near major metropolitan areas elsewhere is consistent with previous reports of large expansions of urban area on former forest land in those areas (e.g., Nelson and others 2020).

ACKNOWLEDGMENTS

The authors thank Evan Brooks and Todd Schroeder for their helpful reviews.

LITERATURE CITED

Dewitz, J.; U.S. Geological Survey (USGS). 2021. National Land Cover Database (NLCD) 2019 products (ver. 2.0, June 2021): U.S. Geological Survey data release. https://doi.org/10.5066/P9KZCM54.

Montréal Process Liaison Office. 2015. The Montréal Process criteria and indicators for the conservation and sustainable management of temperate and boreal forests. 5th ed. https://montreal-process.org/documents/publications/techreports/MontrealProcessSeptember2015.pdf. [Date accessed: May 23, 2023].

Nelson, M.D.; Riitters, K.H.; Coulston, J.W. [and others]. 2020. Defining the United States land base: a technical document supporting the USDA Forest Service 2020 RPA Assessment. Gen. Tech. Rep. NRS-191. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 70 p. https://doi.org/10.2737/NRS-GTR-191.

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

Riitters, K.; Robertson, G. 2021. The United States' implementation of the Montréal Process indicator of forest fragmentation. Forests. 12: 727. https://doi.org/10.3390/f12060727.

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

U.S. Department of Agriculture (USDA), Forest Service. 2023. Future of America's forests and rangelands: Forest Service 2020 Resources Planning Act Assessment. Gen. Tech. Rep. WO-102. Washington, DC. 348 p. https://doi.org/10.2737/WO-GTR-102.