TEMPORAL TRENDS OF FOREST INTERIOR CONDITIONS IN THE UNITED STATES

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Abstract.—Nature's benefits derived from forest interior environments cannot be sustained if the natural capital of forest interior area is not sustained. We analyzed the spatial patterns of forest loss and gain for the conterminous United States from 2001 to 2006 to determine whether forest interior environments were maintained at five spatial scales. A 1.1 percent net loss of total forest area translated to net losses of 3.2 percent to 10.5 percent of forest interior area over spatial scales of 4.41 ha to 5,310 ha. At the 65.6-ha scale, the reduction of forest interior area was 50,000 km^2—almost double the net loss of total forest area. The geographically pervasive discrepancy between total forest loss and forest interior loss indicates a widespread shift of the extant forest to more fragmented conditions, even in regions exhibiting small net changes in extant forest area. Forest dynamics could be monitored spatially to better understand the potential impacts of fragmentation on the sustainability of forest interior.

INTRODUCTION

Most forests are naturally extensive, and as they become fragmented a variety of physical and biological mechanisms begins to limit their capability to support the ecological attributes and functions that depend on interior environments (Laurance 2008, Murcia 1995, Ries et al. 2004). Continental to global forest monitoring tends to focus on trends in the absolute area of forest, but forest interior is a contextual attribute that depends on the spatial arrangement of forest area at multiple spatial scales (Riitters et al. 1997). Trend assessments should account for the initial spatial patterns and the patterns of forest loss and gain to more accurately reflect trends in forest interior area (Kurz 2010, Wickham et al. 2008). Riitters and Wickham (2012) analyzed the spatial patterns of forest loss and gain for the conterminous United States from 2001 to 2006 to determine whether forest interior environments were maintained at five spatial scales. This paper highlights the results and calls for spatial monitoring of forest dynamics using land cover maps to better understand the potential impacts of fragmentation on forest conditions.

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METHODS

Forest interior was measured on the 2001 and 2006 National Land Cover Database (NLCD) land cover maps (Fry et al. 2011), which identify 16 land cover classes at a spatial resolution of 0.09 ha/pixel. 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). At each date, the spatial context of each forest pixel was measured by its forest area density (FAD), defined as the proportion of all pixels in a surrounding fixed-area neighborhood that were forest. A given forest pixel was called forest interior if FAD $\geq$ 0.9. The analysis was repeated at five spatial scales with neighborhood sizes[†] of 4.41, 15.2, 65.6, 590, and 5,310 ha (Riitters et al. 2002). Thus, maps of FAD at a spatial resolution of 0.09 ha/pixel were produced for each date and neighborhood size. The corresponding maps of forest interior comprised the subset of all extant forest pixels which met the criterion defining forest interior.

To relate forest area gains and losses to the dynamics of forest interior area from 2001 to 2006, the NLCD forest maps from 2001 and 2006 were overlaid, on a pixel-by-pixel basis, upon the maps of FAD. Pixels that were forest in 2001 but not in 2006 represented forest area loss, and pixels that were forest in 2006 but not in 2001 represented forest gain. Pixels of forest loss were evaluated in relation to FAD in 2001 to determine whether forest area losses were also removing forest interior. Pixels of forest gain were evaluated in relation to FAD in 2006 to evaluate whether forest area gains were adding forest interior. The differences between gross gains and gross losses for FAD $\geq$ 0.9 represent the net changes of forest interior area.

RESULTS

The total forest area[††] in 2001 was 2,352,000 km^2. Forest area losses and gains were 54,000 km^2 and 27,000 km^2, respectively, resulting in a net loss of 27,000 km^2 (1.1 percent of total forest area). In comparison, the net loss of forest interior area was at least 29,000 km^2 with a maximum loss of 50,000 km^2 for the 65.6-ha neighborhood size (Table 1). The rate of loss of forest interior area increased with neighborhood size and was approximately 3 to 9 times larger than the rate of loss of total forest area.

The disproportionate loss rates are explained by the patterns of original forest area, forest loss area, and forest gain area in relation to FAD in 2001 and 2006 (Fig. 1). Overall forest losses tended to follow the distribution of all forest area in relation to FAD in 2001, but the area lost at high FAD values exceeded the area gained by 2006 at high FAD values. As a result, a smaller percentage of the extant forest area qualified as forest interior in 2006. Regional analyses of 36 ecological provinces (Bailey 1995) showed that these observations were typical of a wide range of initial forest conditions (Riitters and Wickham 2012).

In terms of total forest area, most of the naturally forested ecological sections (Cleland et al. 2007) exhibited a net loss while net gains were concentrated in sections where forest is not the dominant land cover (Fig. 2a). In comparison, for the 65.6-ha neighborhood size there was a net loss of forest interior area in 175 of 190 ecological sections, and 74 sections exhibited losses greater than 5 percent (Fig. 2b). In naturally forest-dominated regions, forest interior area losses greater than 5 percent were typical in the Pacific Northwest and Southeast but were less common elsewhere. The Intermountain and Great Plains

[†] Rounded to three significant digits; exact sizes were 4.41, 15.21, 65.61, 590.49, and 5,314.41 ha.

[††] Area estimates differ from official statistics because of differences in the definitions of forest.

Table 1.—Change in forest interior area in the conterminous United States from 2001 to 2006 for five neighborhood sizes

Neighborhood Size[a] (ha)	Forest Interior Area 2001 (1,000 km^2)	2006 (1,000 km^2)	Change (1,000 km^2)	Change (%)
4.41	1,419	1,374	-45	-3.2
15.2	1,151	1,102	-49	-4.3
65.6	867	817	-50	-5.8
590	523	482	-41	-7.8
5,310	277	248	-29	-10.5

[a] Rounded to three significant digits.

regions had relatively low total forest area and the forest interior area changes there had relatively little influence on national statistics. The nearly national extent of differences between total forest loss and forest interior loss (Fig. 2) suggests a widespread shift in the spatial pattern of the extant forest to a more fragmented condition, including regions exhibiting relatively small net changes in extant forest area.

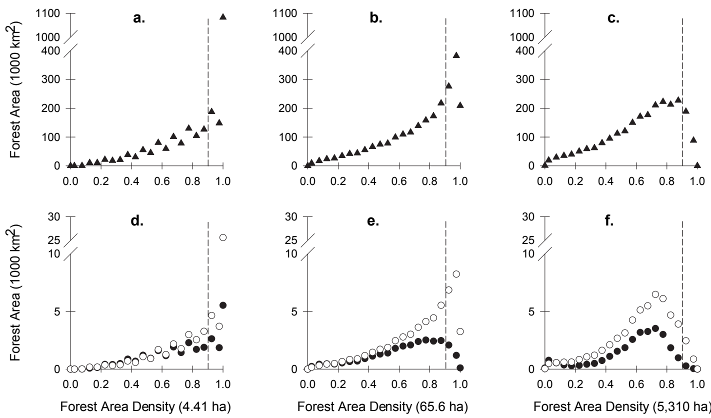

Figure 1.—The area distributions of initial forest, forest gains, and forest losses in relation to forest area density in 2001 or 2006 for three representative neighborhood sizes. Top row: initial forest area in relation to initial forest area density in 2001 (triangles) for neighborhood sizes of (a) 4.41 ha, (b) 65.6 ha, and (c) 5,310 ha. Bottom row: gross forest area lost in relation to initial forest area density in 2001 (open circles) and gross forest area gained in relation to final forest area density in 2006 (closed circles), for neighborhood sizes of (d) 4.41 ha, (e) 65.6 ha, and (f) 5,310 ha. The net change for each value of forest area density is the difference between gross loss and gross gain. Forest interior area for each data series includes the three symbols to the right of the dotted vertical reference lines.

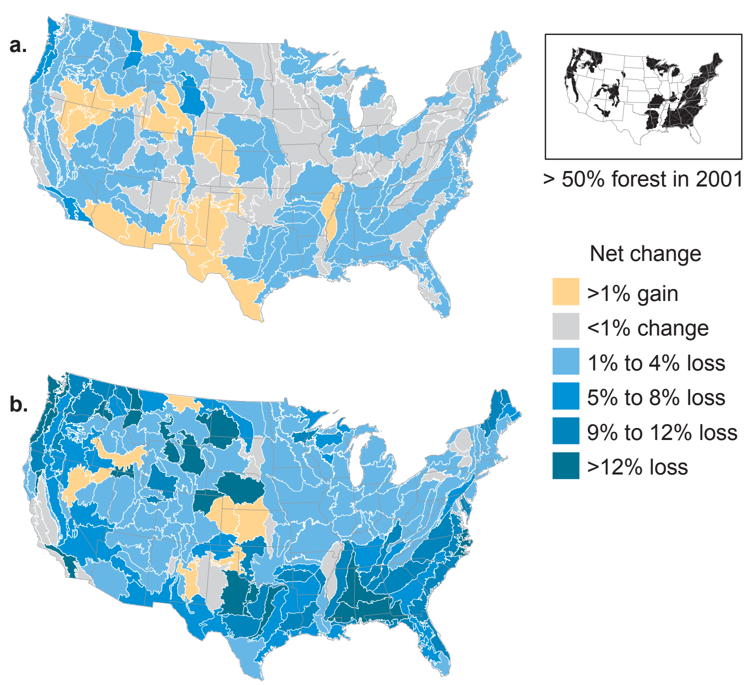

Figure 2.—Net change in forest area from 2001 to 2006. (a) All forest. (b) Forest interior in a 65.6-ha neighborhood. Ecological sections are shaded and State boundaries are shown for comparison. In the inset map, forest-dominated ecological sections are those that contained more than 50 percent forest in 2001.

DISCUSSION

The unavoidable dependence of perceived pattern on measurement scale requires analysis of forest interior at multiple spatial scales. Knowledge of forest interior at a single scale is required to understand the ecological attributes and functions which interact with the forest environment at that scale. A multiple-scale analysis can inform a wider range of ecological questions and identifies the range of spatial scales over which forest interior can be said to exist. Furthermore, from an inventory perspective forest interior may exhibit net gains, net losses, or equilibrium depending on the scale at which it is measured. Thus, a multiple-scale analysis is more useful than a single-scale analysis when the goal is to assess forest interior as a generic constraint affecting many ecological attributes and functions.

The recent spatial patterns of forest gains and losses have not maintained forest interior area in the conterminous United States. Forest losses tended to follow the distribution of all forest area in relation to FAD in 2001, indicating that preservation of forest interior was not usually an important consideration when forest was removed. Conversely, forest gains tended to occur where the gains did not create new forest interior, indicating that creation of forest interior was not usually an important consideration when forest was added. The dispersed and non-compensating patterns of forest losses and gains resulted in rates of net change of forest interior area that were at least 3 times larger than the rate of net change of total forest area. While the identity of forest interior is naturally scale-dependent, the multi-scale analysis showed that the non-compensating pattern of forest loss and gain was exhibited over a wide range of spatial scales from 4.41 ha to 5,310 ha. If the recent patterns of change continue, the extant forest interior area will become smaller in the future. As a result, maintaining the benefits derived from forest interior environments will become more difficult and fewer options will be available to natural resource managers.

Some degree of forest fragmentation is a natural condition, and the loss of interior forest per se does not imply an anthropogenic cause. Our analysis did not distinguish between natural and anthropogenic loss and gain, nor did it compare conditions in 2001 with the patterns of potential natural vegetation absent human influences. Knowledge of potential natural vegetation is helpful for understanding specific impacts of fragmentation, but it is not essential when evaluating trends of forest interior area within the human dominated era. More information is needed to evaluate quantitatively the relative importance of the causes of fragmentation in different parts of the United States. As a first approximation, the principal drivers of forest area change appear to be human activities in the East and intense, yet relatively local (relative to the scale of the study area), biotic and abiotic disturbances in the West (Riitters and Wickham 2012).

National land cover maps provide the synoptic perspective needed to identify indicators of forest interior consistently over large regions through time. These are coarse-scale indicators of dependent ecological changes, yet the specific impacts of forest interior loss will naturally depend upon local circumstances such as the vegetation type experiencing the forest loss, the proximate causes of loss, and anthropogenic land uses in the vicinity. Some of those details can be incorporated by spatially linking the synoptic maps of forest interior and other contextual pattern information (e.g., land cover adjacency metrics) to in situ inventory systems such as Forest Inventory and Analysis that provide better thematic resolution of forests and land uses (Riitters et al. 2011). Sustainable natural resource stewardship must account for fluxes in the natural capital that provides the desired benefits, and this research has demonstrated how forest patterns could be monitored to better understand the impact of human activities on the sustainability of forest interior.

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