ARTICLE IN PRESS

Landscape and Urban Planning xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

The landscape context of family forests in the United States: Anthropogenic interfaces and forest fragmentation from 2001 to 2011

Kurt Riitters[a,*], Jennifer Costanza[b]

[a] Southern Research Station, United States Department of Agriculture, Forest Service, 3041 Cornwallis Road, Research Triangle Park, NC 27709, USA
[b] Department of Forestry and Environmental Resources, North Carolina State University, Research Triangle Park, NC 27709, USA

ARTICLE INFO

Keywords:
Landscape pattern
Forest dominance
Landscape mosaic
Forest inventory
Wildland-urban interface
Neighborhood analysis

ABSTRACT

The capacity of family owned forests to sustain ecological goods and services depends on the landscape context within which that forest occurs. For example, the expansion of a nearby urban area results in the loss of adjacent forest, which threatens the ability of the family forest to sustain interior forest habitat. Our objective was to assess the status and change of the landscape context of family forests across the conterminous United States, as measured by interior forest status and anthropogenic (urban and agricultural) interface zones. We combined circa 2005 forest inventory data with land cover maps from 2001 and 2011 to evaluate changes in the vicinity of 132,497 inventory locations. We compared family forests to nonfamily private and public forests, and evaluated regional conservation opportunities for family forests. Between 2001 and 2011, 1.5% of family forest area experienced a change of anthropogenic interface zone, and 46% was in an interface zone by 2011. During that same time, there was a net decrease of 9.7% of family owned interior forest area, such that 27% of family forest was interior forest by 2011. The rates of forest fragmentation and occurrence in anthropogenic interface zones were higher for family and nonfamily private forests than for public forest, yet family forests contained 31% of the extant interior forest area. The geography of landscape patterns suggested where aggregate actions by family forest owners may have relatively large regional effects upon extant interior forest conditions.

1. Introduction

Family owned forests are an important component of United States landscapes. More than one-third of the total United States forestland area is family owned, the forestland area in family ownership is roughly twice that in nonfamily private ownership (e.g., corporations), and families own the majority of all forestland in 27 of 50 States (Butler et al., 2016a). It is not surprising that families play a pivotal role in achieving broad-scale, sustainable forest management goals (Butler, 2008). However, assessing the roles of family forests in regional sustainability is complicated because the characteristics of family forests differ from other privately owned forests as well as public forests. For example, family forest parcels tend to be smaller than other privately owned parcels (Butler et al., 2016b), and family forests are often managed for amenity values (e.g., beauty, wildlife habitat, nature protection) rather than commodity (e.g., timber) or conversion (e.g., development) values (Majumdar, Teeter, & Butler, 2008). In addition, assessments of the benefits provided by privately owned forests (e.g., Stein et al., 2009) and the future trends of those benefits (e.g., Mondal, Butler, Kittredge, & Moser, 2013) do not typically distinguish between family and nonfamily private ownership. All of those factors complicate understanding the specific roles that family forests play in sustaining the nation's forestland.

An assessment of broad-scale, sustainable forest management should include information about the status and trends of key ecosystem benefits provided by forests and the factors that can change those benefits (USDA Forest Service, 2011). Stein et al. (2009) evaluated privately owned forest benefits related to water quality, timber volume, habitat for at-risk species, and interior forest. They considered housing density, insect pests and diseases, wildfires, and air pollution as the main factors that reduce those benefits. In that study, interior forest was used as a measure of both forest fragmentation and forest habitat quality, and housing density trends measured the potential expansion of the wildland-urban interface zone which could increase fragmentation and reduce wildlife habitat quality (Radeloff et al., 2005; Theobald, Miller, & Hobbs, 1997). Stein et al. (2009) concluded that the cumulative effects of actions taken by many private landowners can determine broad-scale outcomes in some regions. In regions dominated by family forests, aggregate measures of privately owned forest may be sufficient to guide family forest conservation actions (e.g., Kittredge,

* Corresponding author.
E-mail addresses: kriitters@fs.fed.us (K. Riitters), jkcostan@ncsu.edu (J. Costanza).

https://doi.org/10.1016/j.landurbplan.2018.04.001
Received 14 August 2017; Received in revised form 19 February 2018; Accepted 10 April 2018
0169-2046/ Published by Elsevier B.V.

Short Gianotti, Hutyra, Foster, & Getson, 2015). However, in regions with several types of private and/or public ownerships, it is important to distinguish family from nonfamily forest in order to determine the potential of family forest management to affect broad-scale outcomes. Assessments must consider where family forest owners have relatively high leverage on ecological outcomes, which depends on ownership patterns in relation to ecosystem benefits.

To improve understanding of the potential roles of family forests in landscape conservation and sustainable forest management, our overall objective in this study was to evaluate the status and change of family owned "interior" (i.e., relatively less fragmented) forest and the occurrence of family forests in anthropogenic interface zones. We assumed that interior forest was a coarse-scale indicator of several forest benefits including wildlife habitat quality as well as an overall indicator of forest fragmentation (McIntyre & Hobbs, 1999). In contrast to typical studies of wildland-urban interface zones, we adopted a broader definition of wildland interfaces to consider forest interfaces with both agricultural and urban land uses. Many of the anthropogenic influences that occur in an urban interface zone (e.g., Bar-Massada, Radeloff, & Stewart, 2014) also occur in an agricultural interface zone (Theobald et al., 1997). Furthermore, compared to urban land use, agriculture in the vicinity of a forest stand is often a better predictor of processes such as fire ignition (Fusco, Abatzoglou, Balch, Finn, & Bradley, 2016) and exotic plant invasions (Riitters et al., 2017). By explicitly recognizing three general types of ownerships (family, nonfamily private, and public), we were able to assess the relative importance of family forest ownership in broad-scale conservation and management of interior forest land, and to quantify the extent of anthropogenic stresses on family forests owing to their occurrence in anthropogenic interface zones. We used that information to identify ecoregions where conservation or management strategies directed specifically at family forest owners may have relatively high leverage in effecting broad-scale outcomes for interior forest.

2. Methods

2.1. Forest inventory data

The USDA Forest Service Forest Inventory and Analysis Program (FIA) is the census of United States forests. The FIA uses a permanent, grid-based, equal probability sample of inventory plots across all land (Bechtold & Patterson, 2005). A sampling intensity of approximately one plot per 2400 ha of total area is designed to achieve a target precision of approximately 3% of total area (Bechtold & Patterson, 2005). That design adequately supports FIA summaries of forest area by ownership at the State level. Field plots are established at sample locations where the land use is "forestland" [i.e., land that has, or has had, at least 10% tree crown cover, and is at least 0.4 ha in size and 37 m wide (USDA Forest Service, 2015)]. Forestland includes temporarily cleared land, but excludes tree-covered areas in agricultural production settings (e.g., fruit orchards) and in urban settings. Hereafter, forestland will be called "forest."

We identified a set of 132,497 plots that were used by FIA analysts to prepare State-level forest area reports for 48 States circa 2005 (see Supplemental Material). From the FIA database (O'Connell et al., 2015) we obtained for each plot the type of ownership, the area expansion factors needed for area estimation, and the (actual) geographic coordinates needed to associate plots with ecoregions and land cover patterns (see below). The expansion factors accounted for plots that contained portions of non-forest land uses, and for plots that contained more than one type of ownership. We condensed the 17 types of land ownership recognized by FIA (see Supplemental Material) to three generalized types as follows. "Family forest" included forest held by families, individuals, trusts, estates, and family partnerships. "Nonfamily forest" included other privately owned forest held by corporations, Native American nations, universities, non-governmental organizations, and unincorporated partnerships or associations. "Public forest" included forest held by Federal, State, and local governments or agencies. Our use of the FIA definition of family forest permits comparisons with family forest statistics reported by the National Woodland Owner Survey (Butler et al., 2016a, 2016b).

2.2. Land cover pattern data

In the vicinity of each plot location, we measured land cover patterns on the 2001 and 2011 NLCD national land cover maps (USGS, 2014a, 2014b). The NLCD maps identify 16 land cover types with a spatial resolution of 30 m (Homer et al., 2007, 2015). To quantify interior forest and fragmentation, we measured forest dominance by the proportion of forest cover (P_F) in the surrounding 15.21-ha neighborhood (13 pixels × 13 pixels), where forest included the three NLCD upland forest classes and the woody wetlands class (Riitters et al., 2002). Thus, we evaluated forest cover dominance (from NLCD) in the vicinity of forest land use (from FIA). We then defined five classes of forest dominance called "interior" ($P_F \geq 0.9$), "dominant" ($0.6 \leq P_F < 0.9$), "transitional" ($0.4 \leq P_F < 0.6$), "patchy" ($0.1 \leq P_F < 0.4$), and "rare" ($P_F < 0.1$). We focused our attention on the interior dominance class because that class is indicative of fragmentation in otherwise continuous forest cover (e.g., McIntyre & Hobbs, 1999). Measurements of P_F are scale-dependent (Riitters et al., 2002); we used a 15.21-ha neighborhood because that is the measurement scale that best represents the national geographic patterns of forest cover fragmentation (USDA Forest Service, 2016).

To quantify interface zones, we measured the proportions of agriculture (P_A) and developed (P_D) land cover types in the surrounding 65.61-ha neighborhood (27 pixels × 27 pixels). Agriculture included the two NLCD agriculture cover classes, and developed included the four NLCD developed classes. Those measurements were used to identify three anthropogenic interface zones called "developed" ($P_D \geq 0.1$ and $P_A < 0.1$), "agricultural" ($P_D < 0.1$ and $P_A \geq 0.1$), and "developed & agricultural" ($P_D \geq 0.1$ and $P_A \geq 0.1$), along with a fourth zone called "none" ($P_D < 0.1$ and $P_A < 0.1$). The threshold value of 0.1 was used because it represents a substantial presence of developed or agricultural land use in a neighborhood, is indicative of the risk of forest conversion (Riitters, Wickham, & Wade, 2009), and is comparable to earlier national assessments of anthropogenic interface zones (e.g., USDA Forest Service, 2012). Like P_F, measurements of P_A and P_D are scale-dependent. We used a larger neighborhood size than was used to evaluate forest dominance because we were interested in a broader landscape context that could potentially include substantial area of both agriculture and urban cover. Smaller neighborhoods are typically used for evaluating only urban interfaces (e.g., Theobald & Romme, 2007).

2.3. Analysis

To facilitate geographical interpretations of results, we identified the ecological section and province (Bailey, 1995) which contained each inventory plot location. The ecological regions included 36 ecological provinces (Fig. 1) and 190 nested ecological sections. Thus, the final database included, for each plot, variables describing ownership type, area expansion factor, forest dominance class in 2001 and 2011, interface zone in 2001 and 2011, ecological section, and ecological province. We used the area expansion factors to estimate forest area by ownership type, which we assumed was fixed circa 2005. Each plot was labeled by land cover patterns in the neighborhood in both 2001 and 2011, and we analyzed the status and change of land cover patterns in the vicinity of different forest ownerships (circa 2005).

We used circa 2005 FIA data because the implementation of the current FIA sampling design did not support nationally-consistent forest area estimation in 2001. We use the term "circa 2005" because FIA defines a target year for reporting and uses measurements spanning

Fig. 1. Ecological provinces of the conterminous United States (data Source: Cleland et al., 2007).

several years (one measurement per plot) to prepare a State-level report, and because not all States had the same FIA target year. We assumed that "circa 2005" represented forest area and ownership in both 2001 and 2011, and that actual changes among the three ownership types were relatively small during that time period.

There is sampling error associated with FIA forest area estimates, but we analyzed the status and change of pattern metrics derived from NLCD land cover data, not the status and change of FIA forestland area. Our analysis of pattern simply partitioned the circa 2005 forest area into different categories of forest dominance and interface zone in 2001 and 2011. A change of pattern from 2001 to 2011 resulted in the relabeling of the same forest area, which did not introduce additional sampling error. The NLCD data have measurement errors (Wickham, Stehman, Fry, Smith, & Homer, 2010; Wickham et al., 2017), but estimates of per-pixel measurement errors do not translate directly to pattern measurement errors in a neighborhood of pixels (Smith, Stehman, Wickham, & Yang, 2003; Smith, Wickham, Stehman, & Yang, 2002; Wickham, O'Neill, Riitters, Wade, & Jones, 1997).

Our estimates of forest area by ownership may be compared to the FIA target precision of 3% of total area. Sampling error is expected to be higher in relatively small regions or in regions containing less forest area, and lower in relatively large regions or in mostly-forested regions. For other comparisons, Butler et al. (2016b) provided a comprehensive compilation of standard errors of family owned forest area by State and multi-State regions. However, those statistics were based on the National Woodland Owner Survey, not on the FIA inventory data. Comparisons may also be made with the ongoing series of State-level forest inventory reports produced by the FIA program. Those State-level reports often include estimates of family owned forest area with standard errors.

3. Results and discussion

3.1. Family forest area

Family owned forests are a significant component of conterminous United States landscapes. As of circa 2005, family forests occupied approximately 15% of the total surface area and comprised 118 Mha (million hectares) or 43% of the total forest area. In comparison, nonfamily forest comprised 59.2 Mha (21% of total forest area) and public forest comprised 100 Mha (36%). Family forest area varied substantially (from 0.03 Mha to 18.73 Mha) among ecological provinces and was concentrated in the eastern United States (Fig. 2). The family forest share of total forest area also varied substantially (from 6% to 81%) among provinces. Family forest comprised more than half of the total forest area in 12 of the 18 provinces, and more than three-fourths of the total in seven provinces.

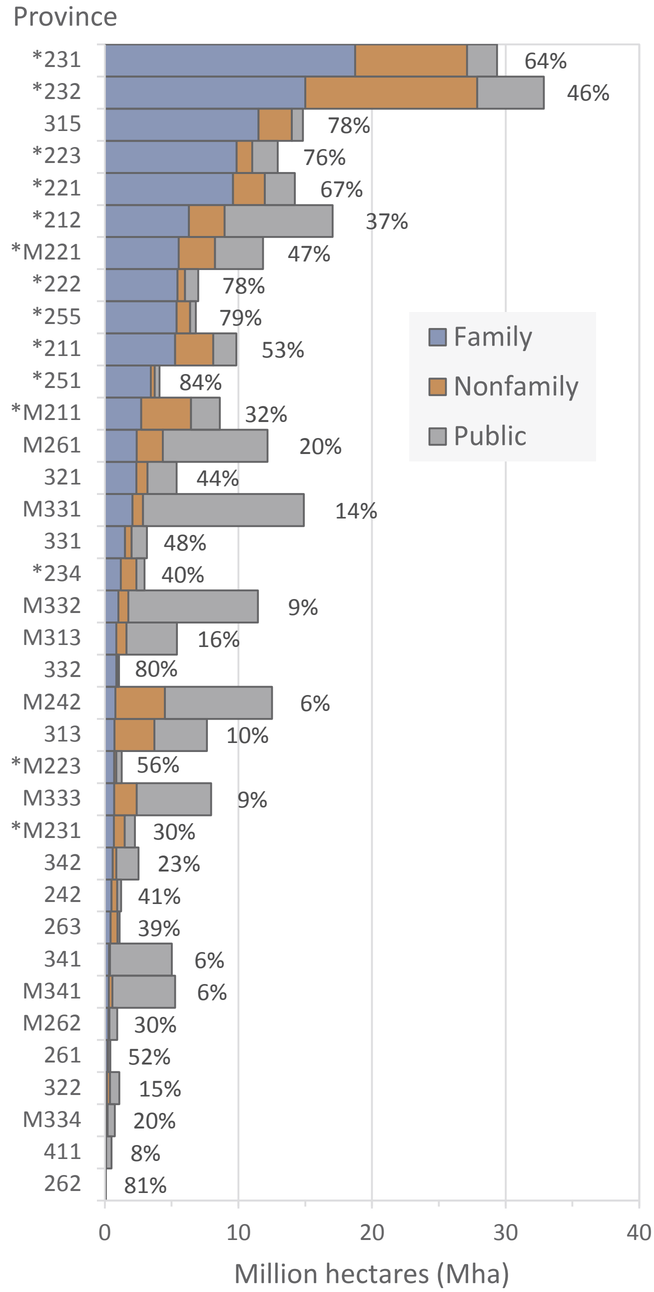

Fig. 2. Forest area by ecological province and ownership, circa 2005. Provinces are sorted in decreasing order by family forest area. An asterisk before a province label indicates an eastern province (see Fig. 1). The family forest share of total forest area is indicated at the end of each bar.

3.2. Anthropogenic interface zones

As of 2011, 71.5 Mha or 25.9% of total forest area was in an anthropogenic interface zone, whether agricultural, developed, or both. Nearly half (46%) of all family forest was in an anthropogenic interface zone, compared to 19% of nonfamily forest and 6% of public forest. Reflecting differences in total forest area among ownerships, family forest comprised the largest share (76%) of forest area in an anthropogenic interface zone, followed by nonfamily forest (15%) and public forest (9%). Our estimates of forest area in a developed interface zone represented minimum values because the NLCD data often do not measure houses, roads, and other developed features under a forest canopy.

Considering family forest area alone, one-third (33%) was in the agriculture interface zone in 2011, which was more than four times larger than the percentage in the developed (7%) or the developed & agricultural (6%) interface zones (Fig. 3). Overall, 39% (i.e., 33% + 6%) of all family forest was in a 65.61-ha neighborhood that contained at least 10% agriculture land cover, and 13% (7% + 6%) was in a neighborhood with at least 10% developed cover. From 2001 to 2011, there was a net decrease in the percent of total family forest area in the agricultural interface zone, and a net increase in the percent in the developed interface zone (Fig. 3). Similar changes for other ownerships suggested a net decrease in agricultural land cover and a net increase in developed land cover in the neighborhood of all forest area.

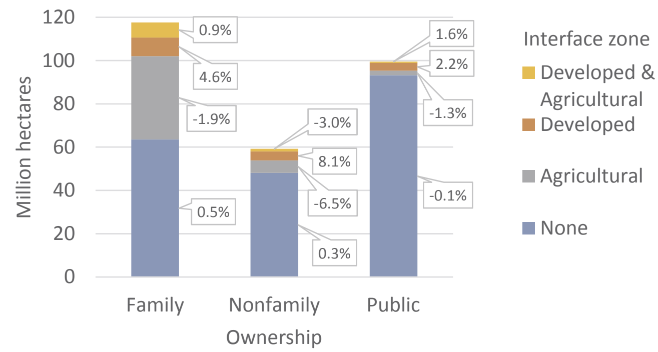

Fig. 3. Characterization of the interface zones containing forest area in 2011, by ownership. The percent change in zone area since 2001 is indicated.

Since the family forest area was fixed in this analysis, the observed transitions of family forest to and from interface zones represent a "shifting landscape mosaic" (Riitters et al., 2009). The information about gross gains and losses (Table 1) helps to interpret the net changes shown in Fig. 3. For example, about 20% (0.21 Mha) of the decrease in area in the agricultural interface zone was the result of accretion of developed land cover in the neighborhood, with a consequent shift into the developed & agricultural interface zone. About 76% (0.81 Mha) of that decrease represented loss of agricultural land cover with consequent shift out of an anthropogenic interface zone. Overall, the landscape mosaic shifted over 1.5% (1.78 Mha) of total family forest area. Expressed in terms of source/sink relationships, the agricultural interface zone and the non-anthropogenic zone ("none") acted as sources while the two interface zones with substantial developed land cover acted as sinks. The Supplemental Material contains similar tables for the nonfamily and public ownerships.

3.3. Interior forest

As of 2011, 101.3 Mha or 36.7% of total forest area was interior forest. The relatively low overall percentage of interior forest at that scale reflects the pervasiveness of forest cover fragmentation in the continental United States (e.g., Riitters & Wickham, 2012). Public forest contained the largest share (48%) of the total interior forest area, followed by family forest (31%) and nonfamily forest (21%). On a per-unit area basis, 29% of total family forest was interior forest compared to 36% and 48% of total nonfamily and public forest, respectively. While fragmentation rates are higher on private land than on public land, most of the interior forest area is still privately owned (family plus nonfamily) because most of the total forest area is privately owned (USDA Forest Service, 2016).

Considering family forest alone, the most common forest dominance class was dominant, followed by interior, transitional, patch, and rare, in that order (Fig. 4). Family forest differed from nonfamily and public forest in terms of the concentration of forest area in the intermediate (dominant, transitional, patch) classes, and in terms of a relatively even distribution of family forest across all five dominance classes. From 2001 and 2011, there was a net decrease in the percent of total family

Table 1
Transitions of family forest area among interface zones from 2001 to 2011. The Supplemental Material contains similar tables for the nonfamily and public ownerships.

		Interface zone in 2001				Total (Mha)
		None (Mha)	Developed (Mha)	Agricultural (Mha)	Developed & Agricultural (Mha)	
Interface zone in 2011	None	62.74	0.01	0.81	0.00	63.56
	Developed	0.20	8.16	0.04	0.17	8.57
	Agricultural	0.32	0.00	38.20	0.01	38.53
	Developed & Agricultural	0.00	0.02	0.21	6.75	6.98
	Total	63.26	8.19	39.26	6.93	117.64

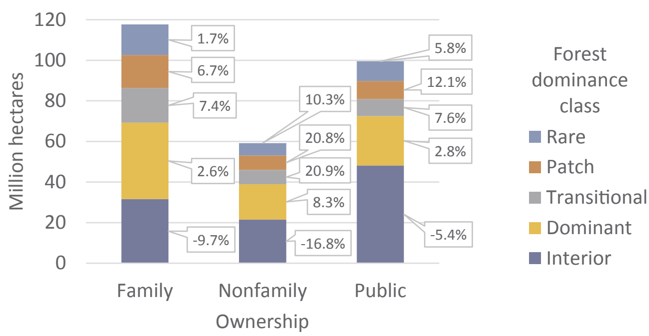

Fig. 4. Characterization of the forest dominance classes containing forest area in 2011, by ownership. The percent change in class area since 2001 is indicated.

forest area that was interior forest, and a net increase in all of the other dominance classes. The transitions among forest dominance classes may be explained by a pattern of forest cover change in which most forest cover is lost from previously interior forest while most forest cover gains, which occur in intermediate dominance classes, are not sufficient to create interior forest (Riitters & Wickham, 2012).

3.4. The geography of family forest dynamics

The geography of the status and change of the landscape patterns surrounding family forests is illustrated in Fig. 5. The overall percent of forest (Fig. 5A) and the share of total forest that is family owned (Fig. 5B) in each ecological section (Bailey, 1995) provide context with which to gauge the local and regional importance of family forest landscape dynamics. The regional patterns of extant interior forest (Fig. 5C) are similar to patterns reported earlier for all forest cover (USDA Forest Service, 2016), but the absolute values are lower for family forests than for all forests. For simplicity in this illustration, the developed interface zone includes all forest where $P_D \geq 0.1$, and the agricultural interface zone includes all forest where $P_A \geq 0.1$; in other words, the area in the developed & agricultural interface zone (where $P_D \geq 0.1$ and $P_A \geq 0.1$) was included in both of them. The percent of family forest in the developed interface zone (Fig. 5D) and in the agriculture interface zone (Fig. 5E) tend to follow the familiar regional distributions of human population and agricultural land, respectively.

Considering the change of landscape patterns, in every ecological section there was a net decrease in the percent of family forest that was interior (Fig. 5F), which reflects the pervasiveness of forest cover fragmentation from 2001 to 2011 (USDA Forest Service, 2016). Similarly, there was a net increase in the percent of family forest that was in a developed interface zone (Fig. 5G), which reflects the regional pattern of net gain of human populations (USDA Forest Service, 2016). In contrast, several ecological sections exhibited a net increase in the percent of family forest in an agricultural interface zone while others exhibited a net decrease (Fig. 5H). The decreases in the southern US are probably attributable to relatively large net reductions in cropland area from 2002 to 2012 (USDA, 2015), but the large percentage changes observed elsewhere in the US are probably artifacts attributable to a relatively small original area of family forest in agricultural interface zones.

3.5. Identifying conservation opportunities for family forests

We consider interior forest as an example of using landscape pattern data to identify regional conservation opportunities in family forests. To motivate this example, we assumed that interior forest represents relatively unfragmented forest cover, that unfragmented forest cover has social or ecological value, and that detrimental effects of fragmentation can be avoided by conserving (or restoring) a condition of interior forest cover. Of course, forest interior may not be the natural state of forests in some places, for example in sparsely-forested woodland or prairie regions. Furthermore, depending on the management goal, fragmentation can have positive as well as negative effects even in forest-dominated regions.

In this example, the objective is to identify ecological provinces where management of family forests has the potential to strongly affect a future change of interior forest area. We anticipate that the potential for family forests to influence change is highest where the family owned share of forest interior is > 30%. If the objective is to conserve interior forest where it is relatively rare, then attention is drawn to eight provinces representing the eastern Great Plains steppe and parkland, the Midwest broadleaf forest, and the California coast (Fig. 6). In these areas, actions by individual owners could have a relatively large impact on regional conditions. Similarly, if the objective is to conserve interior forest where it is relatively abundant, then attention is drawn to seven provinces covering most of the remainder of the eastern United States. In these regions, harmonized actions by many owners may be needed to have a large impact on regional conditions. Within a given province, a conservation strategy could focus on ecological sections where the family owned share of interior forest is relatively large (Fig. 5C), and that have exhibited high net loss rates of family owned interior forest (Fig. 5F). Family forest owners own < 30% of the extant forest interior area over most of the western United States (Fig. 6), where similar analyses could be used to assess the relative potential of public versus private ownerships to influence change of forest interior area. We used ecological provinces for this example, but similar procedures would support assessments of other types of geographic units such as counties or watersheds.

4. Summary and conclusion

Family owned forests play an important role in achieving sustainable forest management goals at broad scales (Butler, 2008). The capacity to continue to play that role depends on what happens in the vicinity of family forests. For example, a small family forest is less likely to function as interior forest when all other forest is lost from the surrounding neighborhood, and is less likely to be free of anthropogenic impacts when it is subsumed by an anthropogenic interface zone. We used metrics describing the status and change in family owned interior forest and forest interface zones surrounding family owned forests to help characterize the landscape context. Our results highlight that (1)

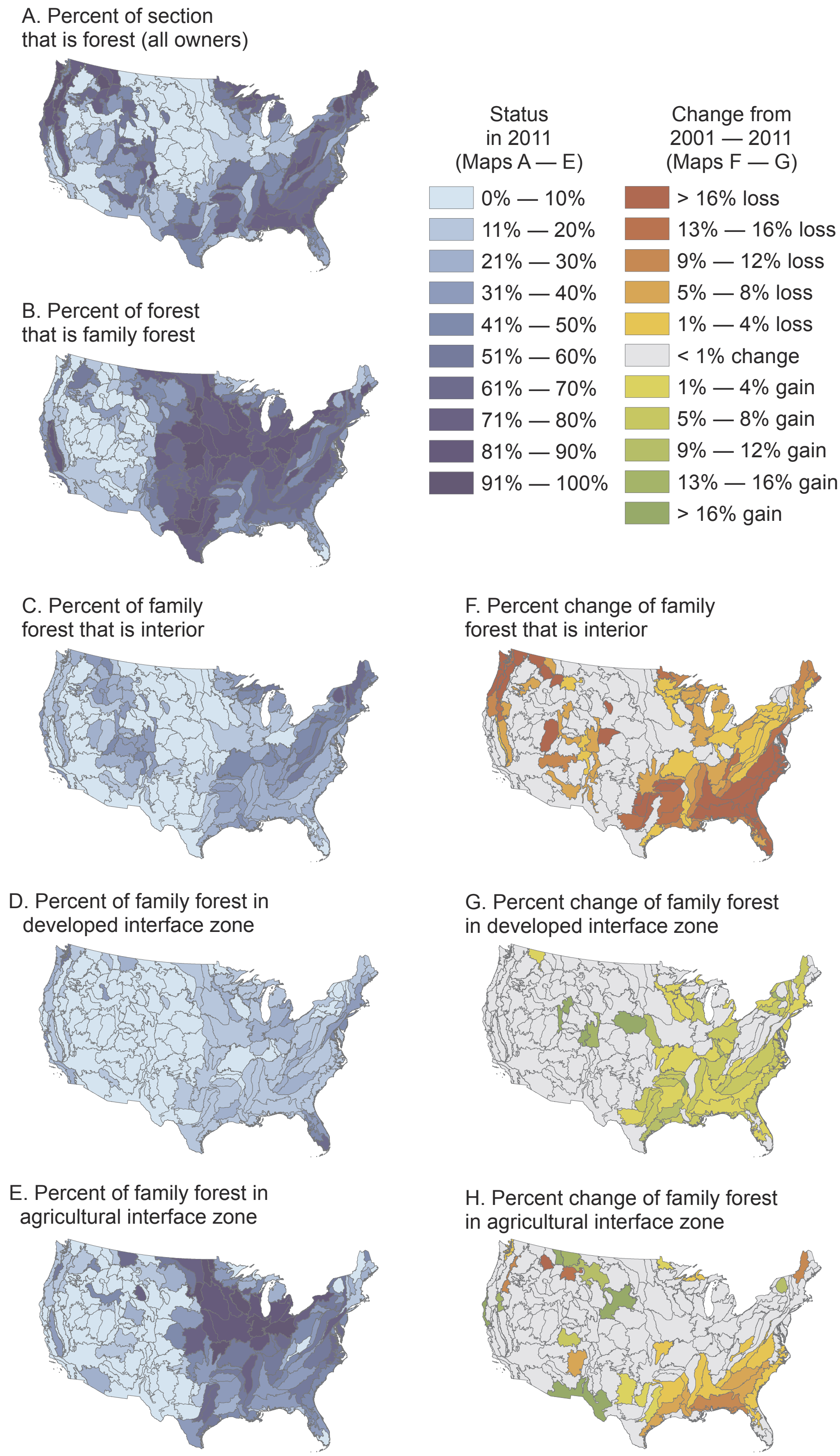

Fig. 5. Family forest status in 2011 and change from 2001 to 2011, by ecological section. See text for additional description.

compared with other ownerships, family owned forests existed more often within landscape mosaics of anthropogenic land uses; (2) family owned forests supported a substantial share of forest interior conditions in the conterminous United States, and; (3) these metrics could be considered to inform regional strategies for forest conservation and management. Furthermore, our results showed that the landscapes which contained family forests exhibited substantial changes over a relatively short period of time. The geography of the status and change of landscape patterns in relation to family owned forests indicated aggregate actions by family forest owners could have large effects on the

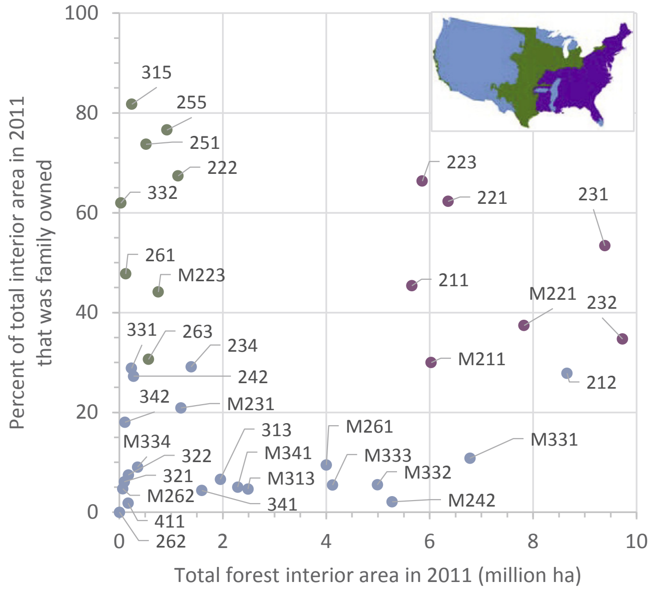

Fig. 6. Identifying conservation opportunities for family owned forests. In ecological provinces where more than 30% of the total interior forest area is family owned, green indicates provinces where interior forest is relatively rare, and purple indicates provinces where it is relatively abundant. Blue indicates provinces where less than 30% of the total interior forest is family owned. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

future status of interior forest conditions in some regions, and suggested regional land management strategies could be tailored to either restore, maintain, or enhance the capacity of family forests to supply ecological goods and services.

While most States have at least some regulations affecting family owned forests (Ellefson, Cheng, & Moulton, 1997), private forest policies are more typically non-regulatory and employ tools that emphasize incentives or information (Schaaf & Broussard, 2006). The early focus of national policy and information on private forest conditions [e.g., "forests on the edge" (Stein et al., 2005)] was soon translated to a commitment to conserve open space (USDA Forest Service, 2007) across ownership boundaries (USDA Forest Service, 2006). Such programs have recognized the importance of translating science into local, on-the-ground management plans.

Just as knowledge of the local landscape context is essential for any tract-specific action plan, regional strategies to restore, maintain, or enhance the flow of ecological goods and services from family forests require a macroscale evaluation of the types of landscapes that contain them. Knowledge of landscape patterns is essential when assessing forest sustainability because patterns create, mediate, facilitate, and impede ecosystem services that are essential for maintaining human well-being (Wu, 2013). We treated forest interior as an ecosystem benefit and anthropogenic interface zones as threats to family forests. That was an oversimplification because fragmented forests can also have ecosystem benefits, and forests in agricultural landscapes contribute substantially to human well-being in those landscapes. The desirable features of landscape pattern metrics like we used is that they are informative of patterns while being relatively simple and transparent, amenable to multiple scale implementation, and value-free in the sense of being interpretable with respect to more than one frame of reference or ecosystem service. Therefore, our analysis can be a first step toward assessing the sustainability of family forests and the ecological goods and services they support.

Acknowledgements

Mention of trade names does not imply endorsement or recommendation for use. We thank the many FIA staff who collected forest inventory data used in this study, Riccardo Tortini for reviewing an early draft of the manuscript, and John Coulston for invaluable advice and assistance in working with the FIA statistical design and database. This work was supported by an agreement between the USDA Forest Service, Southern Research Station and North Carolina State University in support of the 2020 RPA Assessment.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2018.04.001.

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Kurt Riitters is a research ecologist with the USDA Forest Service whose research focuses on macroscale assessments of forest fragmentation and landscape patterns.

Jennifer Costanza is a research assistant professor at North Carolina State University whose research aims to understand current and future threats to landscapes and forest ecosystems.