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How are America's private forests changing? An integrated assessment of forest management, housing pressure, and urban development in alternate emissions scenarios

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ABSTRACT

Private forests are a vital component of the natural ecosystem infrastructure of the United States, and provide critical ecosystem services including clean air and water, energy, wildlife habitat, recreational services, and wood fiber. These forests have been subject to conversion to developed uses due to increasing population pressures. This study examines the changing patterns in the private forests across the urban–rural gradient in 36 states in the eastern United States. We combine observed forest management activities, housing pressure, and 50-year projections of development pressures under alternate IPCC emission scenarios (A1, A2, B1, and B2) to produce a forest pressures index for a total of 45,707 plots located on privately owned land. We find evidence of continued forest loss in suburban/urban regions, and imminent pressure on private forests in exurban regions, while forests in rural regions are found to be relatively stable in next 50 years. Patterns of forest pressures differ depending on the sub-regions, which can be attributed to differing socio-ecological context of these sub-regions. Forest pressures also differ depending on the alternate scenarios considered, as projected increases in impervious surfaces is higher for the A1 and A2 scenarios as compared to the B1 and B2 scenarios. Land owners, often influenced by changing economic, demographic, and environmental trends, will play an important role in managing goods and services provided by these private forests. While it remains challenging to model forest owner attributes, socio-economic factors appear to be critical in shaping the future forested landscape in the United States.

Introduction

Land use change is a major contributor to global environmental change (Foley et al., 2005; Millennium Assessment, 2005). Many assessments of climate and land use dynamics report their coupled effects on global environment, as decoupling of changing climate and land use issues is difficult (Millennium Assessment, 2005; Jetz et al., 2007; Brook et al., 2008; Lee and Jetz, 2008; Clavero et al., 2011). Forests play an important role in this climate change–land-use dynamic as they sequester carbon and help to reduce the amount of carbon dioxide in the atmosphere. Approximately 200 million metric tons of carbon are sequestered by forests in the United States (U.S.) each year (Heath and Smith, 2004), offsetting approximately 10% of current U.S. carbon emissions (Woodbury et al., 2007). While deforestation worldwide contributes 18% of all carbon dioxide emissions (Stern, 2006), this number is likely to change depending on future development patterns. To facilitate further research in alternate global climate change scenarios, the Intergovernmental Panel on Climate Change (IPCC) has developed the Special Report on Emissions Scenarios (SRES) with social, economic, and demographic storylines (Nakicenovic et al., 2000), which can be directly linked to global climate models. Since private forests in the U.S. are collectively controlled by approximately 11 million private owners (Butler, 2008), the maintenance and conservation of these forests are critical in mitigating greenhouse gas emissions and global climate change.

Private forests comprise approximately 56% (approximately 171 million hectare) of the total forested land in the U.S. (Butler, 2008). These forests not only provide many critical ecosystem services, including timber, water, and recreational facilities, but are also important for at-risk species whose habitats are a patchwork of

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public and private lands (Robles et al., 2008). Aesthetics, family legacy, and land investment have been identified as the principal reasons for owning lands among families in the U.S. (Butler, 2008) and it is challenging to predict future trends in ownership objectives which depend on demography, economy, personal preferences, and other factors. Increasing numbers of private forest owners pose a particular challenge for sustainable forest management. Increasing parcelization, resulting from ownership changes, can also lead to increased housing densities (Theobald, 2005; Stein et al., 2006) and deleteriously affect biodiversity (Hansen et al., 2005). Coupled effects of climate change and land use change are only expected to create additional challenges for these forests in near future.

In an effort to explore future developments in world regions with special reference to the production of greenhouse gases and aerosol emissions, SRES was published by the IPCC in 2000. The SRES scenarios, or alternative futures, include a wide range of driving forces, to reflect integrated influence of future demographic, economic, and technological development (Nakicenovic et al., 2000). These storylines describe scenarios along two major axes, economic versus environmentally driven development (A–B) and global versus regional development (1–2), which constitute the four combinations of storylines, A1, A2, B1, and B2. All these storylines have different implications for private forests, as the priorities of the private landowners are likely to change depending on the scenario which will in turn affect the fate of the private forest lands.

The A1 storyline represents rapid economic development, in which affluence is correlated with long life and small families (low mortality and low fertility) and regional economic averages converge resulting from advances in communication and transport technology, changes in national policies on immigration and education, and international cooperation in the development of national and international institutions. The A2 storyline is characterized by uneven economic growth, slower technological change, and less emphasis on economic, social, and cultural interactions between regions. The highlight of the B1 storyline is a high level of environmental and social consciousness and a globally coherent approach toward sustainable development. Like A1, the B1 storyline depicts a fast-changing and convergent world with balanced economic and technological change. However, the priority of a B1 world is improved efficiency of resource use to limit the effects of deforestation, soil depletion, over-fishing, and global and regional pollution, and not just further economic growth as in the A1 scenario. The B2 storyline is one of increased concern for social and environmental sustainability compared to A2, with more emphasis on community-based environmental response strategies. Technological convergence is weaker than in A1 and B1, with a strong local and regional focus on technological development, land use management, and urban and transport development, leading to less urban sprawl and food self-reliance.

While it remains challenging to model the priorities of private land-owners based on alternative scenarios or the decisions they are likely to make regarding their forest lands, it is possible to project the likelihood of development pressures on these private forests in the near future. The U.S. Environmental Protection Agency (EPA) has developed Integrated Climate and Land-Use Scenarios (ICLUS) based on the SRES storylines. The IPCC SRES storylines are highly aggregated into four world regions (Nakicenovic et al., 2000), and do not provide outlines for downscaling to regional or national levels. The ICLUS project interpreted and adapted these storylines for the specific case of the U.S., following several assumptions, such as domestic and international migration patterns more adapted to the U.S. scenario, resulting in estimated housing density and impervious surface cover for the conterminous U.S. at a spatial scale of 1 ha by decade through 2100 for these scenarios (U.S. Environmental Protection Agency, 2009).

In this study, we integrate past land cover changes (specifically forest conversion and modification through harvesting), current housing density, and estimated future impervious surface cover development for next 50 years on private forests to derive a comprehensive change trajectory for these valuable natural resources. Previous studies, such as the U.S. Department of Agriculture (USDA) Forest Service-sponsored Forests on the Edge Reports, have projected residential development on private lands in next 30 years (Stein et al., 2005), examined projected housing development on private lands around national forests (Stein et al., 2007), conducted case-studies of residential development in rural regions (White and Mazza, 2008), and analyzed the relative contributions of private forest land to ecosystem services including water quality, timber volume, at-risk species habitat, and interior forest (Stein et al., 2009). These studies, however, do not consider the combined effects of current housing pressure, recent land use activities (such as land clearing or harvesting), and projected development under alternate scenarios during next 50 years on the private forests. Here we first examine the spatial distribution of harvesting activities on private forests across the urban–rural gradient. We also quantify the amount of impervious surface that is projected to be developed within these areas between 2010 and 2060. Then we develop an index that combines the various pressures on these forests. Finally we discuss our findings in the context of changing socio-economic realms under the various scenarios and how that is likely to change private land-owner attributes which will have significant implications for the private forests in the U.S.

Materials and methods

Forest plot data

The USDA Forest Service's Forest Inventory and Analysis (FIA) program maintains an ongoing detailed national estimate of the Nation's forest condition and extent by collecting and analyzing data from all ownerships (Bechtold and Patterson, 2005). FIA has established a permanent set of inventory plots, each with a footprint of approximately 0.01 ha, across the U.S. using a systematic sample design. A grid of approximately 2400-ha hexagons was established and within each hexagon, a sample point was randomly selected. Aerial photography is used to identify forested plots that are visited by forestry technicians. On each field plot, information is collected on the species, diameter, and height of the trees, general environmental attributes such as slope, and ownership. The plots are re-measured once every 5–7 years in the East and every 10 years in the West with the sample evenly distributed (spatially and temporally) across the inventory cycle. In order to improve the precision of estimates, satellite imagery or aerial photography remote sensing products are used to post-stratify the sample producing stratified estimates.

We analyzed data from 45,707 complete or partial forested FIA plots in 36 eastern states (Table 1) that were privately owned, including corporate, non-governmental conservation/natural resources organization, unincorporated local partnership/association/club, Native American (Indian), individual, and undifferentiated private forest lands (Fig. 1). These plots cover the entire eastern U.S., except Louisiana. We included plots which were either identified as forested during the latest measurement cycle, or were identified as converted from forest to non-forest, when re-measured during the latest measurement cycle. No forest plot records were available for the rest of the states in the U.S. based on these criteria. This limited data availability can be attributed to the fact that we are only using data obtained through the new FIA annual inventory design that was first implemented in most states in the late 1990s and early 2000s with some not coming online until

Table 1
Number of forest plots analyzed in the eastern United States by sub-region, and state.

Sub-region	State	No. of forest plots
Northeast	Connecticut	119
	Delaware	13
	Maine	2798
	Maryland	54
	Massachusetts	133
	New Hampshire	329
	New Jersey	34
	New York	836
	Pennsylvania	1669
	Rhode Island	34
	Vermont	343
	West Virginia	305
Northeast total		6667
North central	Illinois	441
	Indiana	614
	Iowa	411
	Michigan	3213
	Minnesota	2438
	Missouri	1896
	Ohio	704
	Wisconsin	3537
North central total		13,254
Great Plains	Kansas	286
	Nebraska	180
	North Dakota	86
	South Dakota	89
Great Plains total		641
Southeast	Florida	784
	Georgia	3713
	North Carolina	2444
	South Carolina	1896
	Virginia	2163
Southeast total		11,000
South central	Alabama	3333
	Arkansas	2430
	Kentucky	1836
	Louisiana	–
	Mississippi	808
	Oklahoma	163
	Tennessee	1951
	Texas	3624
South central total		14,145
Eastern U.S. total		45,707

the late 2000s, especially in the west. With this new annual design, there are different re-measurement cycles in the west versus the east (10 years versus 5–7 years, respectively). Hence there is no re-measurement data yet available for the western states. The latest measurement cycle for the plots used in this study differed by state, with approximately 98% of plots measured between 2005 and 2010, although 2001 is the earliest inventory year. These data were then analyzed along with housing density to identify forest conversion and anthropogenic modification trends across urban–rural gradient. Data for housing density categories with fewer than 20 plots were excluded.

Housing density data

Housing density data for the conterminous U.S. were acquired from the EPA for the year 2000 (U.S. Environmental Protection Agency, 2009). This spatial dataset was compiled from the 2000 census and population and housing units for census blocks. Housing density was then computed for each 1 ha cell of the spatial dataset (Theobald, 2005). This spatial dataset represents the urban–rural continuum through unitless grid values ranging from 0 to 24,710, but do not include undevelopable lands (protected areas of different categories), or commercial lands. We believe that in spite of having negligible housing density, presence of protected land or, at the other extreme, commercial areas in the vicinity of the private forest lands can affect the forest change trajectories. Hence, we created two spatial datasets to fill the gap in the housing density dataset for 2000 – one for the undevelopable land, and the other for the commercial areas. ICLUS project provides a classified housing density dataset for 2000 with commercial areas as a separate class. This classified dataset was used to extract a dataset for commercial regions, which we recoded with a grid value of 13,591 (mid-point of the suburban/urban grid value range) in order to assign a moderate weight to the commercial areas. Then we extracted the undevelopable lands from the ICLUS housing density dataset, and recoded these cells with a grid value of 0. We then merged the original housing density dataset, the commercial areas dataset (now with a grid value of 13,591), and the undevelopable lands (now with a grid value of 0) to create a modified spatial dataset for 2000 housing density. We used this dataset to compute mean housing density within a 5 km radius of each of the centers of the FIA central subplot (area for each location = 78.5 km^2). A radius of 5 km was chosen based on the coefficient of variation values involving multiple distances, such as 1 km, 2 km, 5 km, and 10 km. The mean housing density values were then used to assign the locations to one of the three broad categories across the urban–rural gradients – suburban/urban, exurban, and rural, defined as less than 0.008 km^2 per housing unit (<2 acre/unit), less than 0.162 km^2 per housing unit (<40 acre/unit), and greater than 0.162 km^2 per housing unit (>40 acre/unit), respectively (Bierwagen et al., 2010). Further, 10 sub-categories of housing density (Table 2) were used to capture the continuous change in forest attributes across the urban–rural gradients.

Table 2
Housing density categories adapted from the US EPA ICLUS project. This table explains housing density cutoff values (km^2/housing unit) for each of the ten categories grouped under three broad categories, i.e. rural, exurban, and suburban/urban.

Housing density category	km^2/housing unit	No. of FIA forest plots	
1	≥2.020	2419	Rural
2	0.810–2.019	2356	Rural
3	0.405–0.809	5411	Rural
4	0.162–0.404	12,564	Rural
5	0.080–0.161	9729	Exurban
6	0.040–0.079	6560	Exurban
7	0.020–0.039	3546	Exurban
8	0.008–0.019	2224	Exurban
9	0.004–0.007	658	Suburban/Urban
10	<0.004	240	Suburban/Urban

Impervious surface data

The EPA ICLUS project developed projections of impervious surface cover for each decade through 2100 based on the IPCC SRES social, economic, and demographic storylines (U.S. Environmental Protection Agency, 2009). Future estimates of impervious surface were calculated at a spatial scale of 1 ha as a function of housing density based on statistical relationships between 2000 housing density and 2001 percent urban imperviousness derived from the National Land Cover Dataset (Theobald et al., 2009) for A1, A2, B1, and B2 scenarios (Nakicenovic et al., 2000). We acquired these spatial datasets for percent impervious surface for each decade from 2010 to 2060 for all 4 scenarios. We estimated mean percent impervious surface and total impervious surface area within a 5 km radius of FIA forest subplot centers (both for forest and recently converted plots) for each decade up to 2060. Differences between the

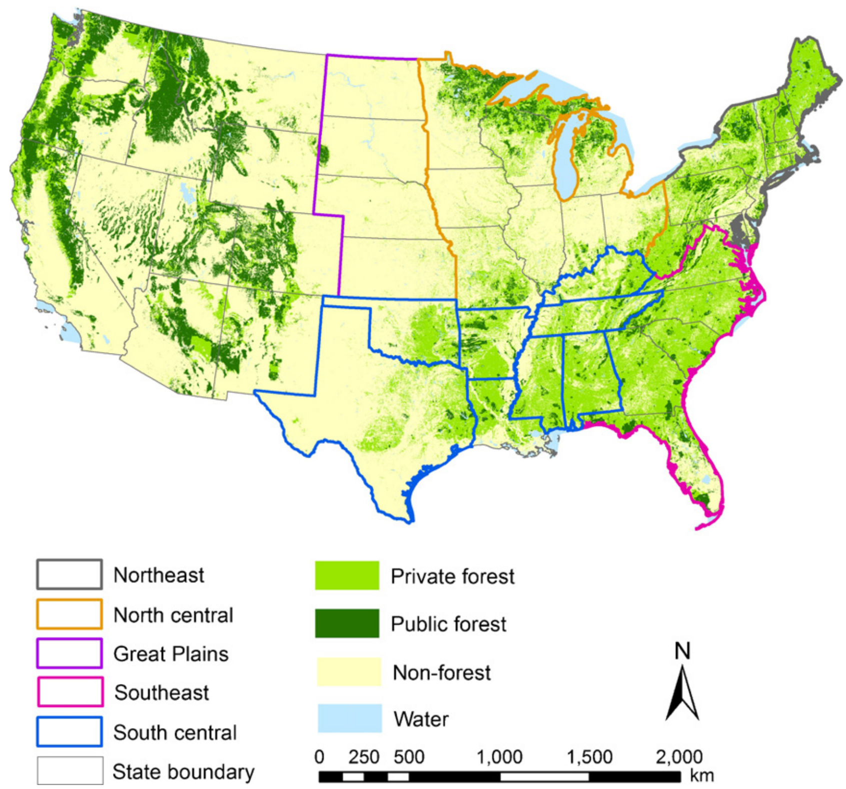

Fig. 1. Spatial distribution of private forests across the U.S. (data source: Nelson et al., 2010), and boundaries of five sub-regions included in this study covering 36 states in the eastern U.S.

percent impervious cover for two dates were then calculated for each location. So, for example, the difference between the percent impervious cover for 2010 and 2060 for a particular location would indicate projected percent development within 5 km surrounding each of the FIA forest plot center during the next 50 years. Total area in each location projected to develop under different scenarios was then calculated.

Forest pressures index

We first developed three categorical indices – one each for: changing land use/cover, 2000 housing density, and change in impervious surface cover between 2010 and 2060. All these indices have lower values for no/negligible change/projected change, with increasing values for higher level of changes. The *land use/cover index* has a value of 0 for the forest plots that did not undergo any harvesting activities during the latest measurement cycle; a value of 1 was assigned to modified forest plots where harvesting has been recorded (we considered only sawtimber harvesting to exclude other low-intensity forest products removal), but the plots remained as forest; a value of 2 was assigned to converted forest plots, where a forest to non-forest conversion occurred. The *housing density index* has a value of 0, 1, or 2 when the forest plots are located within the rural, exurban, and suburban/urban region respectively, as explained in Table 2. The *impervious surface index* builds upon the cumulative change in percent impervious surface cover between 2010 and 2060. If there is no change predicted, the impervious surface index has a value of 0. A value of 1 is assigned when the increase in impervious surface cover within 5 km vicinity is $\leq$1%. A value of 2 is assigned to the plots which are projected to have >1% but $\leq$5% increase in impervious cover within 5 km vicinity; and a maximum value of 3 is assigned to the plots which are predicted to have $\geq$5% increase in impervious surface cover within 5 km vicinity during next 50 years. Class break values were selected based on sample distribution to ensure sufficient representation in each of the four categories (i.e. at least 20 plots in each of the categories).

We then developed a *forest pressures index* (FPI), to represent the cumulative effect of forest management activities and resulting changes in land use/cover, current housing density, and future development potential on the FIA private forest plots and their surroundings. FPI is an additive measure of the individual indices described above, where all the components carry equal weight (see Eq. (1)). It should be noted, however, that the impervious surface area is somewhat related to housing density, resulting in housing density index with relatively higher weight than the other two indices.

$$\text{FPI} = \left(\text{land use/cover index} + \text{housing density index} + \text{impervious surface index}\right) \quad (1)$$

FPI has a range of 0–7. A lower FPI value indicates forest plots in rural regions which are likely to undergo negligible/no change in terms of development in next 50 years. A higher FPI value indicates forest plots located in either exurban or suburban/urban regions, hence already under pressure from potential development, or plots which have already been converted to non-forest, and have higher chances of development in next 50 years.

Results

Forest conversion and modification

FIA data for harvesting (forest modification) and land clearing (forest conversion), when reported against current housing density, exhibit varied patterns across the sub-regions (Fig. 2).

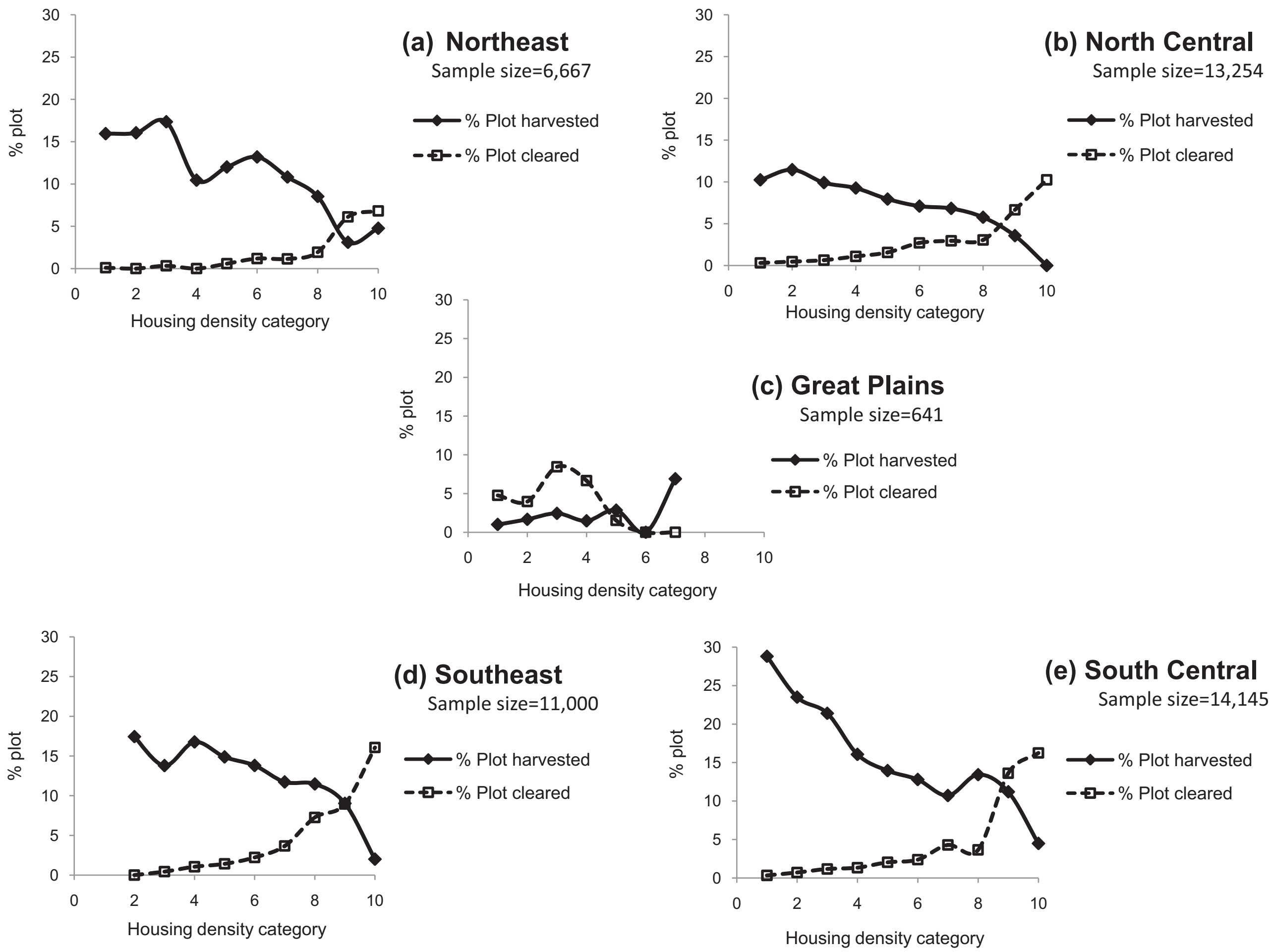

Fig. 2. Trends in sawtimber harvesting activities across the urban–rural gradient in five sub-regions in the eastern U.S. by housing density category (1 = most rural, 10 = suburban/urban). *Y*-axis and legend refer to fraction of number of plots that was harvested or cleared.

The suburban/urban housing density category (Table 2) has fewer observations for all of these sub-regions as non-forest plots are dominant in this category. These graphs corroborate our argument that private forests in exurban regions are at higher risk for conversion than those in rural regions, whereas rural private forests are more likely to be modified through harvesting.

Forest modification through harvesting in the northeastern sub-region is more frequent within the rural categories (Fig. 2a), probably due to rural Maine with a lot of industrial forest land (Table 1). Harvesting activities in this sub-region are stable (15–17%) within rural housing category, then decreases to 10% in exurban areas with lowest housing density, followed by an intermittent increase to 13%, and then steady decrease to 4% with increasing housing density. Unlike the northeast, the north central sub-region exhibits an almost steady decrease from 10% harvesting in the rural regions to no detectable harvesting in the highest housing density category (Fig. 2b). The southeastern sub-region has fewer than 20 forest plots in its most rural region (category 1: Table 2), hence was not reported. This sub-region exhibits a decreasing trend from 17% to 3% of the plots harvested with increasing housing density (Fig. 2d). The south central sub-region, like the north central, shows a decreasing trend in harvesting with increasing housing density (Fig. 2e). Harvesting proportion, however, is the highest in this sub-region, ranging between 29% and 4%. Harvesting proportion in the Great Plains ranges between 1% and 7% (Fig. 2c). Unlike other sub-regions, the pattern is not clear, possibly due to fewer plots in this sub-region (Table 1), and harvesting propensity appears to increase with housing density in this sub-region.

We expected to see more conversion in exurban and suburban/urban areas, as private forests are subject to more pressure at the edges of growing towns and cities. We found supporting evidence in our study which shows that a majority of the rural (and lower ends of exurban) housing density categories for three out of five sub-regions witnessed forest conversion of less than 5% of the plots in each of these housing categories when re-measured during the latest measurement cycle (Fig. 2). These converted plots will most likely contribute toward the rural/exurban–urban shifts as suggested by previous studies (Stein et al., 2005), or agricultural shifts in the Great Plains. Without any exception though, conversion took place in suburban/urban areas or exurban areas with high housing density, probably as a result of urban sprawl, and higher commercial gains associated with forest to non-forest conversion. In the southeast and south central sub-regions, for example, conversions were recorded in as high as 16% of the forest plots measured in the most suburban/urban category (housing categories 9 and 10). Northern and southern sub-regions show similar trends with highest conversion rates in the housing density category 10 (Table 2), and varying degree of increasing conversion rates (Fig. 2a,b and d,e). The conversion scenario in the Great Plains differs from both these groups (Fig. 2c), as most plots were converted in housing density categories 3 and 4 (Table 2). Since comparatively fewer records were found for category 7 onwards, it is difficult to confirm whether this trend is distinctive of this region or due to the absence of enough forest plots in this sub-region.

Development threats under different SRES storylines

Average cumulative increases in impervious surface cover within 5 km of private forest plot centers show similar trends for all five sub-regions, differing only in magnitudes and variability (Fig. 3). All the sub-regions show maximum development under the A2 scenario in the next 50 years, albeit only slightly for the southeast (Fig. 3), while the scenario with lowest predicted development varies by sub-region. With the exception of Great Plains where the A1 scenario has the least development projection by 2060, all other sub-regions are projected to have the least development under one of the two B scenarios. Besides, there is no notable difference in the B storylines, which are considerably different than the A storylines except Great Plains. Maximum average development per plot projected for the next 50 years ranges between 0.035 km^2 per plot in the Great Plains for the A2 storyline and 0.42 km^2 per plot in the southeastern sub-region for the A2 storyline. However, this summarization at the sub-regional level masks plot-level findings due to finer level driving factors. The highest projected percent impervious cover increase within 5 km of a currently forested FIA plot for northeast, north central, Great Plains, southeast, and south central sub-regions are 12.88% (A1), 15.54% (A2), 4.83% (A2), 27.56% (A1), and 15.49% (A1), respectively.

Forest pressures index distribution for five sub-regions

The distributions of FPI values are highly skewed for all the five sub-regions under different climate scenarios (Fig. 4). For the north central and the Great Plains sub-regions, 95–98% of plots have FPI values between 0 and 2 for all the four storylines. For the northeast and south central sub-regions, 91–94% of the plots are within the FPI value range of 0–2 depending on the SRES storylines. For the southeast, 83–87% plots have FPI values between 0 and 2. Fig. 5 shows one such FPI distribution for all the sub-regions, with evident effects of varying sampling intensity (Table 1).

Irrespective of the storylines, the Great Plains and north central sub-regions have more than 50% of the plots in the least pressured category (Fig. 4), meaning these plots are located in rural areas with negligible housing pressure, are undisturbed in terms of harvesting, and are not projected to have significant development in the next 50 years. For the rest of the three sub-regions, however, the plurality of the plots have an FPI value of 1 (Fig. 4), meaning these plots are either disturbed or under pressure from current housing density/projected development. None of the sub-regions exhibit a high proportion of the plots under the higher pressure categories. For example, the highest proportion of the plots in FPI categories of 5–7 is 1.4% for the southeastern sub-region under the A2 storyline. This resistance to pressure can partly be attributed to the largely rural locations of these plots.

Discussion

Changing private forests – implications for ecosystem services

Private forests in the U.S. have long been identified as increasingly being converted for residential and other development uses, parcelized, and simplified in ecological structures and functions (Best, 2002), despite their often rural location. Approximately 62% of private forest lands are owned by families who own these lands for various non-commercial reasons, such as beauty/scenery, privacy, nature protection and others (Butler, 2008). Yet over 11% of private forests across the conterminous U.S. are projected to experience substantial increase in housing density by 2030 (Stein et al., 2005). This is mainly because ecosystem services provided by private forests are becoming less economically competitive compared to other uses of private land. While loss of forestland to pasture, and cropland might be reversible, that is often not the case for forests converted to urban and suburban development (Masek et al., 2011). In the last two decades of the twentieth century alone, over 10 million ha of private forest lands were lost to development (USDA NRCS 1999). Our study adds to this knowledge by describing the pattern of loss/harvest across the urban–rural gradient. While, our study presents continued evidence of suburban/urban clearing, it also highlights the potential threats of land clearing in exurban areas (Fig. 2). The argument that increasing amounts of forests in the rapidly urbanizing southeastern states, such as Georgia, Florida, and Alabama will be lost (Best, 2002) is also corroborated by our analyses of past forest activities (Fig. 2) and future impervious surface development (Fig. 4), and is highlighted in Fig. 5. While it has also been suggested that in the New England states forestland will increasingly be converted to accommodate second homes and recreational activities (Best, 2002), we only found evidence of mildly significant forest conversions in this area (Fig. 2) at the scale of our study. Little increase in developed land (e.g. 1–5%), however, could be substantial when translates into acres. In addition, with approximately 20% of family forest lands in the U.S. owned by someone who plans to sell or subdivide the land in near future (Butler, 2008), there is increasing pressure on timber supply to meet the growing demand. Timber supply is further considered to suffer from the decreasing size in land holdings, as previous studies have suggested positive relationship between the two (Kittredge et al., 1996; Munn et al., 2002).

Approximately 8 million out of 11 million private landowners of the U.S. have relatively small holdings of less than 20 ha each, and approximately 61% of family forest owners have less than 4 ha each (Butler, 2008). High costs for maintaining and conserving forest lands, and development pressure leading to high demand for forest lands often drive these private landowners to sell their land. Such decisions, along with changes in tax code, shifts in forest land market values, and business decisions might result in changes in ownership patterns, e.g. sub-division of larger forested tracts into multiple parcels owned by several owners, a process known as parcelization. Both parcelization, and land use change may contribute toward forest fragmentation (Haines et al., 2011), i.e. reduction of contiguous forest in smaller patches, which is one of the greatest threats to biodiversity. Moreover, smaller parcels tend to be more fragmented by residential units, driveways, cultivation, and recreational facilities, which lead to diminished forest functionality for important ecosystem services, such as wildlife, watershed protection, and timber (Foley et al., 2007; Radeloff et al., 2010). A wide variety of variables, such as increasing population density, death rates, urbanization, and income have been identified as driving factors of parcelization (Mehmood and Zhang, 2001; Zhang et al., 2009). Our findings show that a major portion of the rural lands are still under negligible pressure (Fig. 4). Increasing population density and corresponding demand for development, however, will inevitably affect these rural forest lands, once potential lands in suburban/urban and exurban regions are consumed. Our findings also suggest that different patterns exist depending on regional location. Hence, multiple policy strategies might be required to address the issues of parcelization and fragmentation.

Probable ownership attribute changes under different SRES storylines

Several aspects of the SRES storylines have major implications for the ownership attributes, sometimes with contradicting outcomes, in spite of having increasing impervious surface projected for all the scenarios. For example, under the A1 storyline higher economic growth would translate into more disposable income to invest in acquiring land (Mehmood and Zhang, 2001).

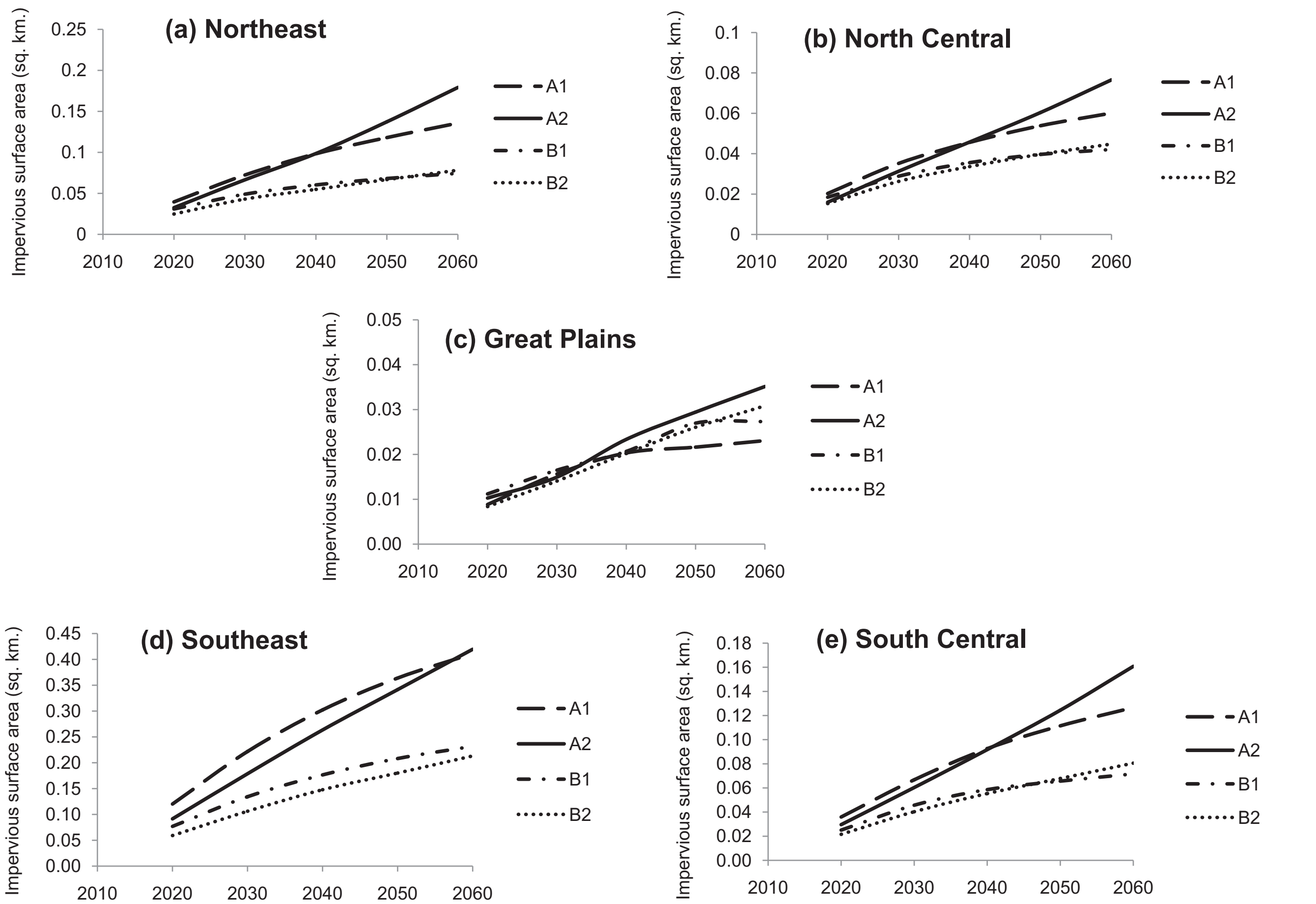

Fig. 3. Projected average changes in cumulative impervious surface cover per plot as measured in and around private plots ($n = 45,707$) in five sub-regions in the eastern U.S. between 2010 and 2060 by SRES storylines (A1, A2, B1, and B2).

Hypothetically, with increasing demand for second homes, desire (and ability) to live in a rural setting, and/or an investment, more families/individuals would have a piece of rural land ultimately leading to parcelization. Under the same storyline, shifts in family structures and low fertility would lead to fewer heirs in the future, i.e. fewer decision-makers – probably leading to less parcelization. Overall, these circumstances probably would give rise to steady/increased forest loss/conversion, and division/sale of lands, compared to the status quo of today. Due to high domestic migration, number of absentee landowners would probably increase.

Slower economic convergence between regions under the A2 storyline might translate into a slower rate of sale of family forest lands, yet impervious surface development is projected to be highest under this storyline. Since A2 represents a world with continued economic development, more forest lands can be expected to be developed to accommodate increased primary residences, along with second homes, and associated development. This will ultimately increase the number of decision-makers, making the forest lands more vulnerable to economy and private preferences. In a slow economy, older owners would hypothetically have more reliance on land for income, due to inadequate financial planning and resources for income. This will translate to more parcelization, as the families would be selling off pieces of land, while retaining the core of ownership.

Both B1 and B2 storylines emphasize environmental sustainability, only differing in the rate of economic development. In these scenarios, the information-oriented economy increases demand for specialized labor pools, which in turn will increase number of high-paying jobs in urban centers. In addition, increased focus on sustainability would result in subsidy reduction for development in rural regions. These factors, combined with minimized domestic migration, would lead to less interest in rural lands. With less financial benefits to subdivide and sell rural lands, land ownership would be more stable in rural areas, whereas more forest lands are expected to convert into residential areas in exurban regions to accommodate the suburban/urban shift.

Sustainable forestry – what's in store for future?

The relative stability in the area of total forestland in the U.S. in the last century can be attributed to reforestation resulting from agricultural abandonment (Birdsey and Lewis, 2003), in spite of significant forest loss to other, primarily developed, land uses (Smith et al., 2009). Annual removals through harvesting, however, have witnessed an approximate 10% increase between 1976 and 2006 (Smith et al., 2009). In addition, there has been a significant shift in harvesting by owner class. Removals from national forests have been reduced to approximately 15% of the level in 1976 with a corresponding increase in private lands harvest, resulting in a shift in timber production from the West to the South (Masek et al., 2011). While shifts in public policy have reduced rates of harvesting on federal lands (Healey et al., 2008), private timberlands are now facing even more pressure to compensate for these reduced harvesting rates. However, smaller parcel sizes (<10 acres) controlled by the majority (61%) of the family forest owners, who own approximately 62% of private forests (Butler, 2008), may be deemed inadequate for sustainable forestry (Kittredge et al., 1996; Munn et al., 2002). Sustainable commercial forestry is also likely to be affected by

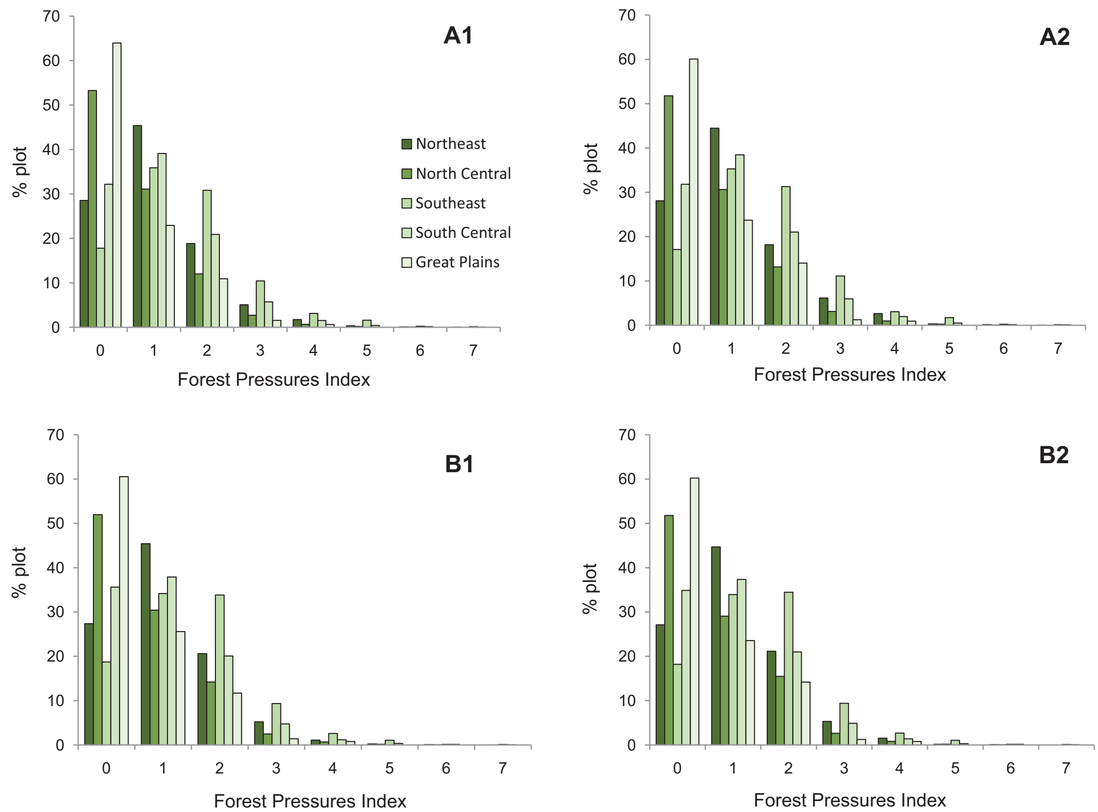

Fig. 4. Distribution of privately owned forest plots ($n = 45{,}707$) in different Forest Pressures Index (FPI) categories under four SRES storylines (A1, A2, B1, and B2) in the eastern U.S. *Y*-axis and legend refer to fraction of number of plots that was harvested. FPI is a combined measure of land use activities, current housing density pressure, and projected changes in impervious surface cover during 2010–2060.

the inevitable population growth and the resulting changes in urban–rural interface (Wear et al., 1999; McDonald et al., 2006).

Our findings suggest that private forests in rural regions will most likely experience negligible changes. This can be partially attributed to 'the illusion of preservation', as growing demands for timber are often satiated by resource extraction from other parts of the world without perturbing public or private forest resources closer to home (Berlik et al., 2002). In alternate scenarios,

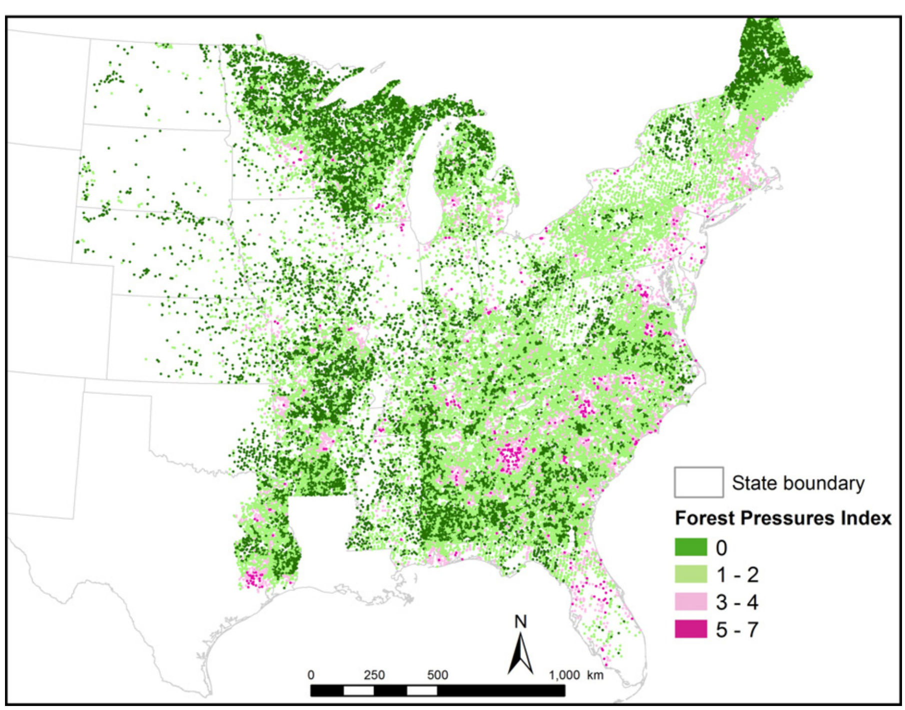

Fig. 5. Spatial distribution of Forest Pressures Index (FPI) for 45,707 FIA plots on privately owned lands (approximate locations) in the eastern U.S. under SRES A2 storyline. Dark green represents areas with no/negligible pressure, light green represents low pressure, light pink represents moderate pressure, and dark pink represents high pressure.

however, the nature-society dynamics might as well change with growing environmental awareness, changing demands, advancing technology, and international trade. Sustainability will also be controlled by the way owners adapt to the biophysical changes caused by climate change, such as changing patterns of drought/flood, insect/disease outbreak, and species migration. While it remains challenging to predict how private landowners will adapt to the regional trends of the global environmental and economic changes, it will not be surprising if anthropogenic activities emerge as more significant controlling factors of global environmental changes than the bio-climatic factors.

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