Land Use Policy 32 (2013) 230–238

Contents lists available at SciVerse ScienceDirect

Land Use Policy

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

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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ARTICLE INFO

Article history:
Received 2 May 2012
Received in revised form 16 October 2012
Accepted 16 October 2012

Keywords:
Private forest
Land use
Urban–rural interface
Forest ownership
Socio-economic context
Emission scenario

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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http://dx.doi.org/10.1016/j.landusepol.2012.10.014

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