Relationships Between Major Ownerships, Forest Aboveground Biomass Distributions, and Landscape Dynamics in the New England Region of USA

Daolan Zheng · Linda S. Heath · Mark J. Ducey · Brett Butler

Abstract This study utilizes remote sensing derived forest aboveground biomass (AGB) estimates and ownership information obtained from the Protected Areas Database (PAD), combining landscape analyses and GIS techniques to demonstrate how different ownerships (public, regulated private, and other private) relate to the spatial distribution of AGB in New England states of the USA. "Regulated private" lands were dominated by lands in Maine covered by a Land Use Regulatory Commission. The AGB means between all pairs of the identified ownership categories were significantly different ($P < 0.05$). Mean AGB observed in public lands (156 Mg/ha) was 43% higher than that in regulated private lands (109 Mg/ha), or 30% higher than that of private lands as a whole. Seventy-seven percent of the regional forests (or about 9,300 km^2) with AGB >200 Mg/ha were located outside the area designated in the PAD and concentrated in western MA, southern VT, southwestern NH, and northwestern CT. While relatively unfragmented and high-AGB forests (>200 Mg/ha) accounted for about 8% of total forested land, they were unevenly proportioned among the three major ownership groups across the region: 19.6% of the public land, 0.8% of the regulated private land, and 11.0% of the other private land. Mean disturbance rates (in absolute value) between 1992 and 2001 were 16, 66, and 19 percent, respectively, on public, regulated private, and other private land. This indicates that management practices from different ownerships have a strong impact on dynamic changes of landscape structures and AGB distributions. Our results may provide insight information for policy makers on issues regarding forest carbon management, conservation biology, and biodiversity studies at regional level.

Keywords Biomass accumulation · Forest carbon storage · Forest management · Land conservation · Ownership behaviors

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Introduction

Forest aboveground biomass (AGB) is an important ecosystem property related to carbon cycles, fuel loading, and biodiversity of flora and fauna (Cleary and others 2005; Houghton 2005; Ryu and others 2006; Smith and Heath 2007; Zheng and others 2008a). Remote sensing techniques have become prevalent in estimating AGB in recent years at various scales (Nelson and others 1988; Franklin and Hiernaux 1991; Lefsky and others 2002; Zheng and others 2004; Lu 2005; Muukkonen and Heiskanen 2007; Zheng and others 2007). Continuous AGB maps derived from RS observations include all forest conditions, and are needed to identify spatial distribution and variation of regional forest AGB to provide information to support biodiversity conservation. For example, late-developmental forests are relatively rare in the Northern Forest region because of land-use history and have high conservation value, but they are sparsely represented, especially in sample-based,

broad-scale inventories such as that of the USDA Forest Service, Forest Inventory and Analysis (FIA) program. Thus, spatially identifying these late-developmental forests associated with their ownerships could provide necessary information for ecological and biodiversity studies at regional levels (Askins and others 1987; Richards and others 2002).

The spatial pattern of high-conservation-value lands may vary due to forest ownership. Public and private owners may consider values of forests from multiple perspectives, such as production, conservation, family legacy, ecological biodiversity, and aesthetics. While private industrial owners are more likely to emphasize short-term financial goals, opportunistic harvesting and other financially motivated behaviors can characterize other private landowner groups (Jones and others 1995; Egan 2007). Consequently, owners implement different strategies in managing their forestlands. Even within private ownership in the New England (NE) region, individuals owning relatively small forested tracts behave differently from those individuals and organizations with larger holdings (Butler 2008).

Previous studies have demonstrated that spatial distributions of forest AGB vary substantially with human introduced disturbances, and various management strategies (Johnson and others 2000; Khera and others 2001). It is of particular interest to understand the geographic relationship between late-developmental forests, other relatively high-biomass forests (including younger unmanaged forests), and their ownership in the NE region. Such understanding may help inform policy that would influence landscape management over substantial areas, with implications for regional biodiversity conservation and carbon stocks. In addition, a great deal of time, money, and effort has been invested in the development of spatially explicit techniques for identifying candidate areas for conservation assessment and action (Knight and others 2008; Wallace and others 2008). These techniques enhance the effectiveness of implemented conservation actions and provide scientifically defensible information for better management of natural resources, which is ecologically and socially beneficial to the environment and communities.

The overall goal of this study is to examine relationships between forest AGB stocks and major ownership groups in the six NE states to examine if forest AGB differs by owner group, including landscape dynamics and distribution patterns of AGB. This information could help identify opportunities for improved management of regional forest ecosystems. Detailed steps include: (1) stratifying a MODIS-derived 1-km AGB map based on the Protected Areas Database (PAD) and comparing AGB distribution patterns among different ownerships; (2) quantifying landscape structures for different ownerships based on National Land Cover Dataset (NLCD) and their relationships to regional AGB distribution; (3) examining owner effect on different management practices and therefore on landscape dynamics between 1992 and 2001; and (4) illustrating how scaling process can influence landscape pattern analyses.

Materials and Methods

This study was conducted in the 6 NE states of the USA: Connecticut (CT), Massachusetts (MA), Maine (ME), New Hampshire (NH), Rhode Island (RI), and Vermont (VT). Forestland covered approximately 84% of this total territory based on the 2001 MODIS land-cover map. Major inputs for this study include the biomass map, PAD map, and land-cover maps from different sources.

Biomass Map

The 2001 AGB map used in this study was developed by Zheng and others (2008b) for the region at 1-km resolution using multi-scale methodology. In their study, ground-based measurements from FIA were linked to remotely sensed spectral information within a 30-m Landsat 7 Enhanced Thematic Mapper plus scene (ETM + , about 180×180 km in size) to develop an empirical AGB model. The model was applied to the entire region using 1-km MODIS data after spectral calibrations with the ETM + data. The resulting spatially-explicit biomass map takes advantage of integrity of spatial variation from RS and unbiased county means of AGB observations developed from the larger sample sizes of FIA plots. The estimated total regional forest AGB was 1,867 teragram (10^{12}, dry weight) in 2001, with a mean AGB density (dry weight) of 120 Mg/ha (Standard deviation = 54 Mg/ha) ranging from 15 to 240 Mg/ha within a 95% percentile (Zheng and others 2008b). At the state level, the average difference in mean AGB densities between simulated and FIA (as reference) was −2.0% ranging from 0% to −4.2% with a standard error of 3.2% in absolute value.

High-AGB late-developmental secondary forests are of particular conservation interest in the Northern Forest region because centuries of land use history have left them relatively scarce. However, current land use and management is leading to an increasing representation of high-AGB forests, including some forests with more advanced developmental characteristics, as well as passively managed forests of moderate age. These two categories of forests may experience different AGB trajectories in the future, depending not only on stand dynamics but on landowner objectives and behavior. Spatially identifying those high-AGB forests associated with major ownership groups across the region is useful information.

Ownership Identification

General ownership information was obtained from the PAD map (2006 version 4) that was the result of a collaborative effort between the Conservation Biology Institute and the World Wildlife Fund U.S. (DellaSala and others 2001). The database was developed as a geographic information system (GIS) dataset that identifies protected areas including publicly and privately owned lands in the conterminous United States (http://www.consbio.org/cbi/projects/PAD/index.htm). The PAD-US Partnership (www.protectedlands.net) defines protected areas as, "lands dedicated to the preservation of biological diversity and to other natural, recreation and cultural uses, and managed for these purposes through legal or other effective means". In other words, protected areas are in general protected from land development (permanent conversion to developed land use) but not from unplanned disturbances or related to management. The PAD is a national database with somewhat generalized definitions that may be interpreted differently from region to region across the country.[1] Regrouping original ownership categories may be necessary depending on study purposes because a perfect naming system may not even exist. We aggregated the original PAD ownership classes that occurred in our region into four broader groups: (1) public (federal, state, and local), (2) regulated private (protected-private), (3) other private (private-inholding, tribal, and all other forested lands not designated in the PAD), and (4) others (joint ownership and unknown) based on our best knowledge about the regional land-use history and ownership behavior (Table 1). For example, "Tribal" land was considered to be similar to other private than to the public and regulated private categories based on ownership behavior (not the name). Our analyses were focused on the first three groups since the last one represented very small proportion of regional forestland (0.02%). Such generalization simplified the analyses because we were not interested in differences of forest AGB distributions within the public land owned by government agencies at various levels. In some regions, differences between government agencies would be apparent; in this region there is little Federal land ($\approx$ 4%). Our analyses, instead, were focused on (1) the difference between public (as a whole) and private in general; and (2) within the privately owned forests, what are the differences, in terms of landscape characteristics and AGB distribution, between the categories of "regulated private" and "other private". Our study design reflects that (1) these

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[1] A new version of PAD (although numbered version 1) was released as this manuscript was through the review process.

Table 1 Cross-walk table between original categories in the PAD and reclassified classes involving forested lands in New England region

Original records	Reclassified classes
Federal	Public
State	Public
Local	Public
Private-protected	Regulated private
Private-inholding	Other private
Tribal	Other private
Forestlands not designated in PAD	Other private
Joint Ownership	Others
Unknown	Others

three general groups owned more than 99% of the regional forested land; and (2) more than 90% of the regional forestland were privately owned (Irland 1999).

Landsat-Derived Land-Cover Maps Used for Landscape Pattern Analyses

We used NLCD 1992 and 2001 maps, developed from Landsat 5 and 7 imagery at 30-m resolution under the Multi-Resolution Land Characteristics Consortium (MRLC) project (http://www.mrlc.gov/). The two maps were not used for pixel-to-pixel change detection, rather, they were used for distinguishing forestland from non-forestland after being aggregated to these 2 very broad categories for the purposes of (1) landscape pattern analysis in 2001 to link the AGB distribution patterns in 2001; (2) quantifying landscape dynamics between 1992 and 2001, and (3) examining how scaling process (from 30 m to 1 km) can affect landscape pattern analyses. Landscape pattern related analyses for all three ownerships were conducted using FRAGSTATS after the NLCD maps were stratified by the regrouped PAD map. It was noted that detailed land-cover classes between the 1992 and 2001 NLCD maps were not identical for non-forest categories at Anderson level II (Anderson and others 1976) with slightly adjustment for agriculture, urban, and barren, but the impact of these differences in our heavily forested region was supposed to be very limited, especially at the broad categories (i.e., forest versus non-forest) (Vogelmann and others 2001; Homer and others 2004). We downloaded the 1992 and 2001 NLCD maps for the conterminous U.S. (http://landcover.usgs.gov/natllandcover.php, www.mrlc.gov/nlcd_multizone_map.php) and extracted the NE area for this study. We aggregated the Level II land-cover types of 41, 42, 43 into forest, and all other types into non-forest for both years.

Quantifying Landscape Patterns and Dynamics Using FRAGSTATS

Landscape structures among the ownerships were quantified using FRAGSTATS – a spatial pattern analysis program (version 3.3) (www.umass.edu/landeco/research/fragstats/downloads/fragstats_downloads.html). Landscape characteristics and patterns were evaluated in terms of four representative indices at the class level: (1) patch density (PD, number per 100 hectares, >0 without limit) calculated as patch number within the corresponding status or ownership divided by total landscape area, larger PD indicating more fragmented landscape; (2) edge density (ED, meters per hectare, ≥0, without limit), as ED increases the landscape becomes more fragmented; (3) landscape shape index (LSI, unitless, ≥1, without limit), LSI = 1 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type; LSI increases without limit as the landscape becomes more irregular; and (4) mean patch size (MPS, hectare, >0 without limit), larger MPS indicating less fragmented landscape. The above indices, along with others, are widely used for quantifying landscape dynamics and spatial patterns (Zheng and others 1997; Buyantuyev and Wu 2007).

Illustration of Scaling Effects on Landscape Pattern Analyses

A subarea in Maine was used to demonstrate how scaling process could affect quantifications of landscape characteristics among the ownership categories (Fig. 1a). First, the 30-m NLCD 2001 map for the subarea (forestland only) was overlaid with our reclassified PAD map. Second, landscape characteristics within each of the ownerships were quantified using FRAGSTATS. The same procedures were repeated for the analyses after the 30-m NLCD map was aggregated to 1-km pixel size. Three represented landscape indices quantified within the subarea based on different pixel resolutions (30 m versus 1 km) were compared to evaluate scaling effects on landscape pattern analysis. Majority rule was used for spatial aggregation from 30-m to 1-km resolution (ESRI 2008), which found the value that appeared most often within the specified windows (e.g. 1×1 km^2 cells) and sent it to each of the corresponding cells as the output grid.

Data Analyses and Statistics

Our initial tests in the subarea indicate that scaling process can substantially affect landscape pattern analyses and conclusions. Consequently, an appropriate pixel size should be determined for the entire region. It is also recognized that there is always a trade off between accuracy and efficiency in landscape studies by choosing an appropriate pixel resolution that is consummated with the study extent and purpose (Wu 1999). Previous studies have demonstrated that the 'noise' in 30-m classified image can be reduced by applying a certain cutting value for patch size (e.g. ≥1 ha) for landscape structure analyses after a rule-based merging algorithm is performed to eliminate the 'salt and pepper' effect (Ma 1995; Zheng and others 1997). In forests, a patch is generally equivalent to a stand with a homogeneous mixture of species, ages, sizes, and/or stocking of trees (Waring and Running 1998). Heilman and others (2002) applied minimum of 1 ha in size for assessing forest fragmentation across the conterminous U.S. For the above reasons, we aggregated the 30-m NLCD maps to 90-m resolution (<1 ha) for the entire study area to quantify landscape characteristics in 1992 and 2001 among the 3 ownership groups using FRAGSTATS. Landscape pattern analyses resulting from 90-m resolution data retained the original patterns obtained from the 30-m data while decreasing the time required for data processing and simulations, and simplified the analyses. The FRAGSTATS results for the 2001 landscape were linked to the 2001 AGB map to examine the relationships between AGB distribution and landscape characteristics among the three ownership groups. The FRAGSTATS results for the 1992 and 2001 landscapes were compared to illustrate differences in landscape dynamics among the 3 ownerships.

Image processing and spatial analyses were performed using GIS packages (e.g. Imagine, ArcInfo, ArcView, ArcMap). The Kruskal–Wallis test was used to test overall significance of AGB distributions among groups, using a = 0.05. Then, the Wilcoxon rank sum test was used to evaluate differences between each possible pair of groups. Significance of the Wilcoxon tests was evaluated using a Bonferroni-adjusted a = 0.0083 (three pairs; experiment-wise error rate was maintained at 0.05). Disturbance rates in this study were defined as the relative changes for representative indices calculated by FRAGSTATS between the years 1992 and 2001. They are calculated as (Value$_{2001}$/Value$_{1992}$ − 1), and demonstrate how disturbance rates caused by different management practices can affect landscape dynamics.

Results

Privately owned forests accounted for about 90% of the NE forested land whereas public land (e.g. owned by Federal, state, and local governments) occupied 9% based on the PAD map. This is very similar to the estimation of 87% private ownership from FIA. Within the publicly owned forest, federal ownership accounted for about 42% based

Fig. 1 a Reclassified regional
ownership map based on the
national PAD. A sub area in the
rectangular box was used for
testing scaling effects on
landscape pattern analyses; and
b 2001 forest aboveground
biomass (dry weight) map at
1-km resolution (Zheng and
others 2008b)
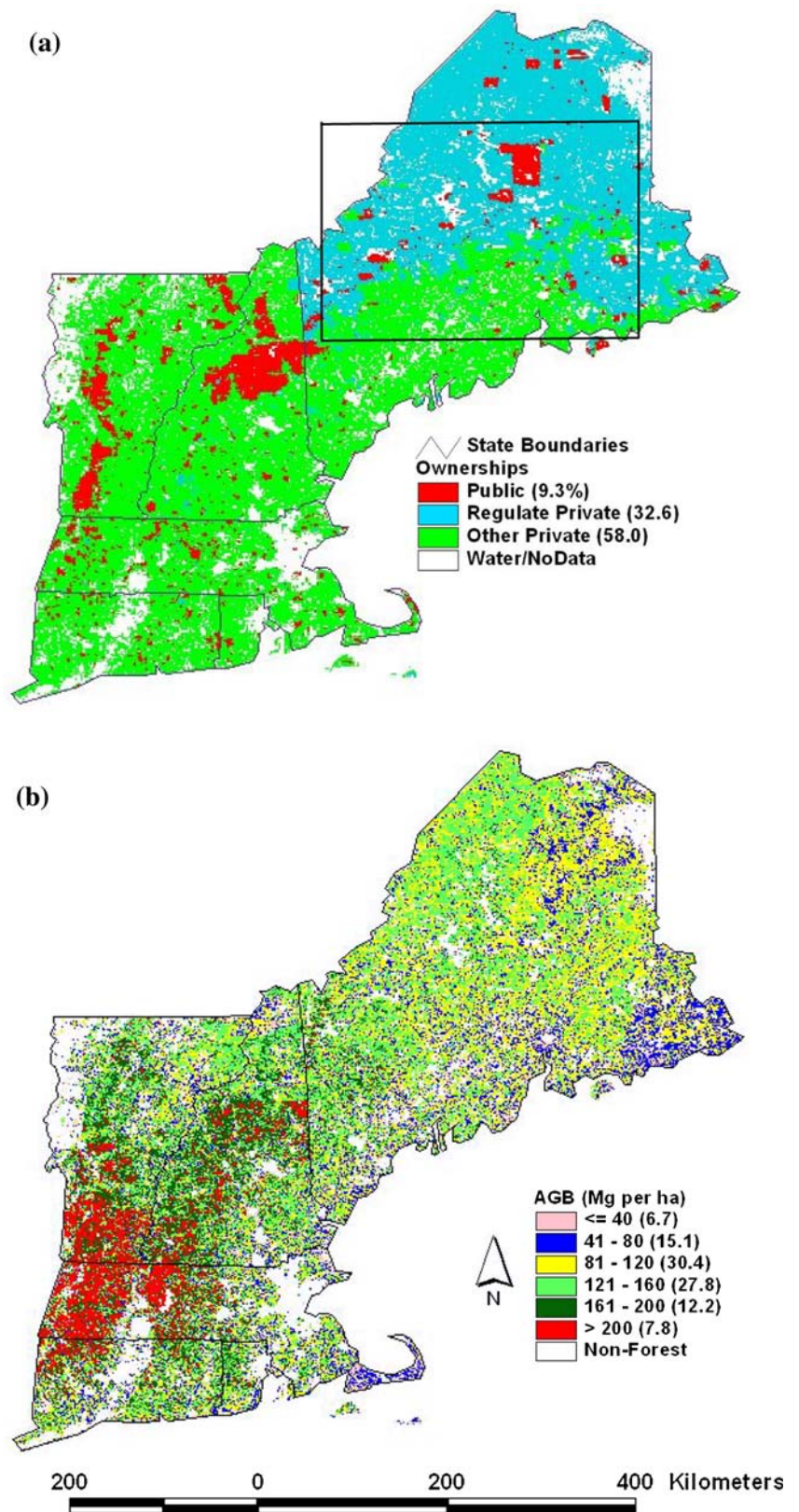
on the PAD. Spatially, 82% of regional public lands were within the 3 northern states with the maximum percentage of 29.2% in NH, followed by 28.8% in ME, and 24.1% in VT. In the meantime, 98% of regional regulated private forests were concentrated in northern ME and 71% of other private forests were in the 3 northern states (30%, 21%, and

20% for ME, NH, and VT respectively) followed by 17% in MA, 11% in CT, and 2% in RI (Fig. 1a).

Clear trends of negative relationship were observed between AGB values and degrees of landscape fragmentation in 2001 between publicly and privately owned lands in general, but less clear between regulated private and other private (see discussion). The highest mean AGB was observed in the public lands (156 Mg/ha), which was 43% higher than the lowest AGB mean (109 Mg/ha) observed in regulated private lands, or 30% higher than that in privately owned lands on average (120 Mg/ha, after area weighting) (Table 2). Within the private forests, however, mean AGB density in other private forests was 19% greater than that in regulated private forests. Mean AGB density in other private forests featured the highest spatial variation, followed by public forestland, with regulated private land showing the lowest variation where more even-age management could be expected. Our results agreed with the general landscape ecological concept that higher forest biomass is usually associated with more intact and less disturbed forestlands (Chhetri 1999). A Kruskal–Wallis test suggested that overall difference among AGB groups was highly significant (K–W chi-squared = 13693.64, df = 2, P-value < 0.05) (Table 3). All pairs of groups were also significantly different ($P < 0.05$).

The forested lands with AGB density >200 Mg/ha represented 7.8% of the total forested area (Fig. 1b). Of these, 77% or 9,300 km^2, were located outside the areas designated in the PAD. These high-AGB forests were mainly distributed in MA (41%), followed by VT (26%), NH (19%), CT (11%), ME (3%), and RI (1%). Specifically, they were concentrated in western MA, southern VT, southwestern NH, and northwestern CT (Fig. 1b). Furthermore, these high-AGB forests were unevenly proportioned among the three major ownership groups across the region: 19.6% of the public land, 0.8% of the regulated private land, and 11.0% of the other private land. This suggests potential impact of ownership behaviors on forest

Table 2 Relationships between forest aboveground biomass (AGB, Mg/ha) and landscape characteristics (resulting from the FRAG-STATS) among major and ownership group in New England region

	Public	Regulated private	Other private
ED[a]	2.0	7.5	16.4
PD[b]	0.015	0.022	0.066
LSI[c]	56.4	116.4	189.7
MPS[d] (km^2)	7	15	9
AGB (Mg/ha)	156 (54)	109 (35[e])	127 (59)
AGB range	1–483	1–376	1–363

[a] Edge density, [b] Patch density, [c] Landscape shape index, [d] Mean patch size, [e] Standard deviation

Table 3 Comparisons of aboveground biomass frequency distributions among major ownership groups using Kruskal–Wallis test

	Public	Regulated private	Other private
Public		*	*
Regulated private			*
Other private			

* Indicates a significant difference at P value < 0.05. We only marked half of the matrix because of its symmetry

carbon storage, conservation biology, and biodiversity studies in the region.

Scaling processes could substantially affect landscape pattern analysis. Three representative indices calculated from 30-m and 1-km based maps within the subarea differed significantly in magnitude and showed inconsistent patterns among the ownerships (Fig. 2). For example, 30-m based results indicated that public land had lower PD than that of other private land whereas the results from 1-km based calculations showed an opposite pattern. Also 30-m based results suggested that landscape shape was more complex in regulated private land than that in other private land but only differed slightly based on 1-km calculations. Furthermore, values calculated from a 1-km map were much smaller than those calculated from the 30-m map; thus, a multiplier had to be used for comparison purposes (Fig. 2).

Our landscape pattern analyses demonstrated that public land in 2001 across the region had lower values of ED, PD, and LSI than those in the private lands (Table 2), indicating a less fragmented landscape. Between the 2 private ownerships, other private owned lands tended to be more fragmented than those in the regulated private category. This may reflect fragmentation and parcelization due to residential and other development; the regulated private forests occur in a portion of the region with relatively low population density, and the regulating authority (Maine 2009) exercises some control over residential conversions and other land use change.

Similarly, public forests on average experienced the least disturbances between 1992 and 2001 while the greatest disturbances were observed in regulated private forests (Fig. 3). The disturbance rates expressed by the 4 indices in public land ranged from 12% in LSI to 19% in PD with an average of 16% during the period whereas the rates in regulated private land ranged from 38% in MPS (in absolute value) to 85% in ED with an average of 66%. Meanwhile, disturbance rates in other private land (unprotected and non-industry related) ranged from 15% (absolute value) in MPS to 24% in ED averaging 24%. These results suggested substantial impact of ownership and different forest management practices on landscape dynamics in the region.
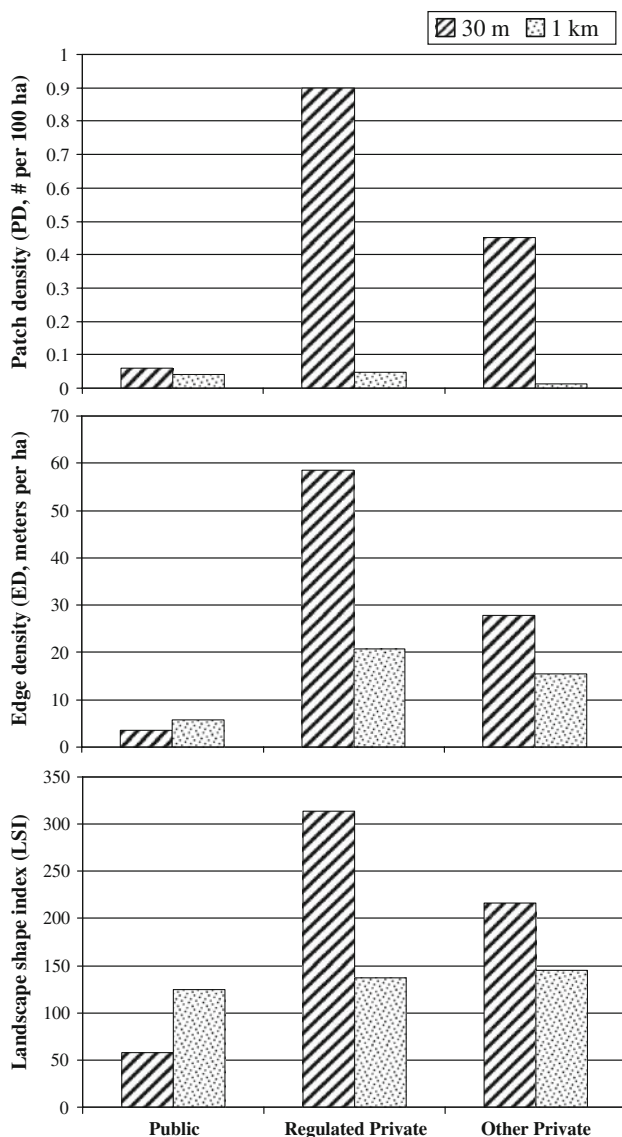
Fig. 2 Evaluation of scaling effects (30 m vs. 1 km) on landscape pattern analyses among major ownerships in a sub area of Maine, USA by comparing the relative changes in some representative landscape indices calculated from FRAGSTATS. Because the index values calculated from different pixel resolutions are not at the same magnitude, the values at 1 km have been multiplied by 10 for the presentation purpose

Discussion

Our results agreed well with a previous study that about 90% NE forests were privately owned (Irland 1999). Linkage between landscape pattern and AGB analyses should be evaluated with caution due to scaling effects. Similar results were also reported from other studies in North America that forest disturbance rates were generally lower in public lands than in private lands (Spies and others 1994; Turner and others 1996; Sachs and others 1998).

Although the MPS value in public land was smaller (more fragmented according to the usual definition) than the values in regulated and other private lands (Table 2), there was a particular reason for this. Public lands represented a small portion (9%) of the region, and they were selected purposively for various considerations including watershed protection, conservation value, historical significance, national forest/park/monument/landmark, and recreational and scenic values. This selection process has led to public lands occurring as individual small patches scattered across the region, and some public lands are interwoven with private owner inholdings. By contrast, the 90% of regional forests held by private owners were relatively continuous and dominant over the landscape.

Forest disturbances included harvests in the regeneration phase of even-aged silvicultural systems, which typically lead to rapid redevelopment of forest cover and biomass in this region, and terminal harvests for land use clearing due to development and associated land cover changes, which did not. The data used in this study did not allow unambiguous separation of the two types of disturbance, though clearly they implied very different scenarios for future AGB development in the region.

Between the 2 private ownership groups, forests within the other private ownership category were more fragmented but had higher mean AGB than those in the regulated private category. One should be cautious about causal inferences, however. A partial explanation may be that most regulated forests in Maine have in the past been owned by industrial concerns that usually purchased lands in large blocks (or aggregated ownerships by assembling smaller holdings), while many other private forests were owned by individuals holding small parcels. There has been a trend in the region (as in the rest of the U.S.) since the 1980s for industrial lands to be purchased by non-industrial corporate owners, such as timber investment management organization (TIMOs) and real estate investment trusts (REITs). The continuation of the observed pattern will depend on the future harvesting and ownership decisions of these organizations. Second, whereas individual owners more likely used their properties for multiple purposes (including forest harvest), forestland under industrial ownership was managed with a different set of financial objectives. One would expect a shorter harvesting interval in such forests. For example, the harvest interval of spruce-fir in northern ME has been about 70-year old (http://www.state.me.us/doc/mfs/pubs/htm/supply.htm). More intense and systematic harvesting pressure would certainly attenuate high standing biomass accumulation. AGB frequency curves clearly indicated that many fewer hectares of forest in the regulated forestlands than in other private land and public land currently reach AGB values larger than 200 Mg/ha (Fig. 4).

Fig. 3 Relative disturbance rates of forest landscapes between 1992 and 2001 among major ownerships across the region by comparing four representative class-level indices calculated from FRAGSTATS
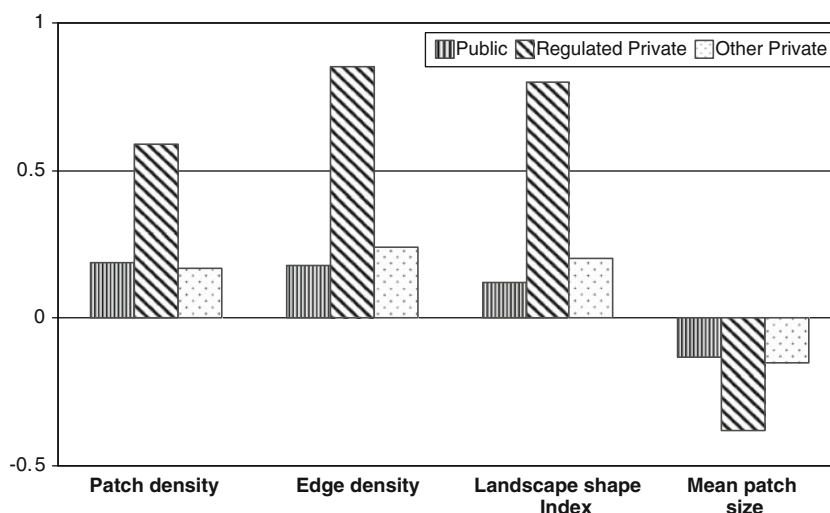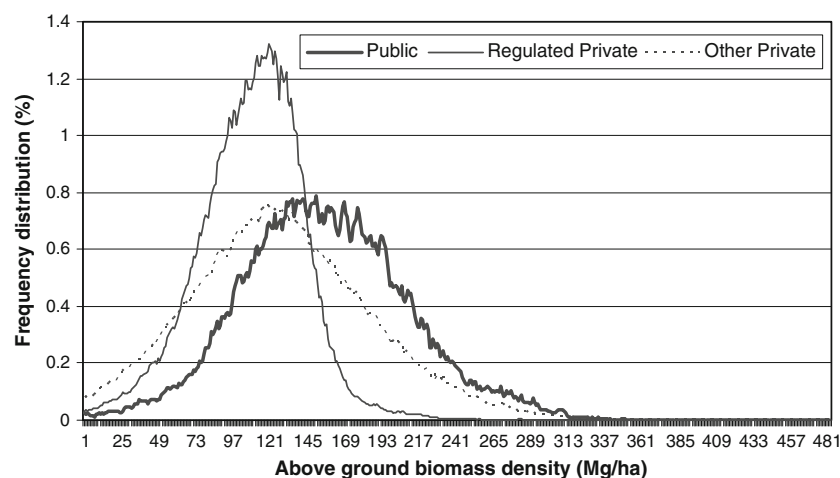

Fig. 4 Frequency distributions of forest aboveground biomass density within major ownerships in New England region, USA. Statistical analyses were based on raw data and the curves drawn based on a 5-point running average

Another factor affecting AGB distributions is forest type and composition. Most regulated private forests in northern ME mainly consists of spruce-fir and northern hardwoods with a lower expected productivity than in the oak and pine forests occurring farther south. However, an influence of ownership and forest practices on AGB distribution remains evident because most of public forested lands that have high AGB values are located in the 3 northern NE states, and share their dominant forest types with the regulated private forests (Irland 1999). Partitioning the effects of ownership, forest composition, and land use history on the regional AGB distribution is necessarily difficult, as these factors are intertwined in the New England landscape.

One source of potential error for this study is the use of 2 NLCD maps at different years (1992 and 2001), due to different classification schemes applied in each year (Vogelmann and others 2001; Homer and others 2004). In general, water, urban, and forestedland covers have relatively high classification accuracies while wetland, rangeland, and barren have low accuracies (Hollister and others 2004). Accuracies tend to increase as the classification level becomes more broad (Stehman and Wickham 2006). For example, overall accuracies in different regions across the eastern U.S. increase from 43%–66% at Anderson Level II to 70%–83% at Level I whereas from 38%–70% to 74%–85% in different regions across the western U.S. according to the 1992 NLCD map (Stehman and others 2003; Wickham and others 2004). We expect even smaller uncertainty from this perspective for this study because our related analyses are conducted at even broader categories (forest versus nonforest).

There are also some limitations in the national PAD (V4) dataset used in this study. First, ideally and theoretically it should include protected private lands (such as those under easements or held in fee by conservation organizations), but it is difficult to maintain consistency due to differences in various definitions among states. This

remains true even in the newly available updated PAD-V1, just released after this study was conducted (http://www.protectedlands.net/padus/). Second, the PAD is not designed to distinguish between industrial and non-industrial private owners, although this distinction may be inferred by forest type in our study in the State of Maine. Further investigation on the strengths and limitations of the PAD are needed but they are beyond the scope of this study. Our experience with this study suggests that labeling of a management choice in a national dataset should be carefully implemented at the regional level, especially with the designation "protected".

Ownership composition in the region is extremely unevenly distributed, which tends to create confounding between biophysical and ownership factors in understanding the pattern of AGB distributions. This study, however, illustrates how different broad ownership categories are associated with regional landscape dynamics and AGB distributions. Our results can also be used for comparison with similar analyses for other regions in the country.

Conclusions

Our results have clearly revealed the impact of major ownerships on regional biomass accumulation and landscape pattern dynamics. Uneven distributions (both spatially and statistically) of high-AGB forests among the major ownerships provide insight information on regional forest resources management and policy implication. These high-AGB forests can contribute important social and ecological benefits to the community and society as a whole including: (1) flood and erosion control and management of water quantity and quality while increasing carbon storage in forest ecosystems; and, (2) preserving unique aesthetic value and habitats of late successional forest for recreational and biodiversity considerations. The uneven distribution of high-AGB forests by ownership suggests on the one hand that maintaining such forests on the landscape may be a worthwhile conservation goal, but also suggests there may be significant opportunities both to conserve existing high-AGB forests and to create young forests on privately-owned lands to provide goods and services to meet societal demands. In terms of research methodology, we found that determining a suitable pixel resolution on raster-version FRAGSTATS simulations is necessary to achieve meaningful and efficient analyses on linking regional landscape characteristics and ecosystem properties (e.g., AGB).

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