Use of FIA Data and GIS to Characterize the Effects of Fragmentation on the Forests of New Hampshire

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Abstract

Urbanization, and the resulting fragmentation of forest land, are of great concern across the world and continues to affect many facets of natural ecosystems. Due to development pressure, this is especially true in the northeastern United States. Assessments of regional and national forest fragmentation highlight where forest fragmentation has occurred at one point in time, but there is little information on the composition, structure, and health of fragmented forests at state or regional scales. We used a raster land-cover classification of New Hampshire to characterize the level of fragmentation and urbanization in the local neighborhood surrounding each forested Forest Inventory and Analysis (FIA) plot. FIA inventory data were used to characterize forests in New Hampshire that were more and less fragmented with respect to forest-type group, stand-size class, tree species richness, tree species diversity, and forest health. Findings highlight the forest-type groups that are in the most fragmented and urbanized conditions, and make comparisons between fragmentation metrics and stand characteristics. For example, forest land in the oak/hickory, oak/pine, and white/red/jack pine forest-type groups is, on average, four times closer to urban land cover than forest land in the spruce/fir and aspen/birch forest type groups and twice as close as that of the maple/beech/birch forest-type group.

Keywords: forest fragmentation, urbanization, forest inventory, forest health, land cover, forest composition, forest structure

Introduction

Forest fragmentation and habitat loss are threatening biological conservation due to the diminishing levels of biodiversity that are often associated (Honnay et al. 2005). Fragmentation of forests also is recognized as a major threat to animal populations worldwide (Rosenberg et al. 1999) and particularly for bird species that are sensitive to habitat fragmentation (Donovan and Lamberson 2001). Habitat fragmentation also is expected to affect several biological processes, including population size, species dispersal, structure and quality of habitat, and the probability of invasion (Pardini 2004). Additionally, the increase in edge that is associated with forest fragmentation can make a forest parcel more susceptible to invasion by nonnative plant species (Hobbs and Huenneke 1992, Pardini 2004, Yates et al. 2004).

Fragmented landscapes are complex, heterogeneous systems influenced by factors apart from the size of forest fragments. Fragmentation encompasses several components: (1) loss of habitat; (2) reduction of patch size; and (3) increasing spatial isolation of the remnant habitats (Andrén 1994). Conversion of land from forest to other land uses and covers (grass, impervious, shrub, etc.) by both humans and natural processes influences animal behavior, plant-seed dispersal, hydrological processes, and local weather conditions (Forman 1995). Decreasing fragment size increases the edge length of habitat fragments, which allows potentially negative edge effects to influence the long-term viability of the occurring species (Honnay et al. 2005), possibly resulting in changes in the composition and structure of the forest including increased potential of invasion by exotic species (Haskell 2000, Trombulak and Frissell 2000). Increasing isolation of patches means increasing distances from neighboring suitable habitats, affecting the ability of both plants and animals to successfully disperse and/or recolonize, and determining the long-term persistence of animal populations (e.g. Rosenberg et al. 1999, Hames et al. 2001).

The expansion of developed land uses that accompany human population growth often results in the fragmentation of natural habitat (Wilcox and Murphy 1985). In fact, human activity is currently the driving force behind changes in fragmentation patterns (Butler et al. 2004). In addition, as Honnay et al. (2005) point out, the spatial/physical fragmentation of habitats is only one of the human-induced processes affecting natural habitats and their biodiversity. Increasing proximity of people to natural habitats and the ways in which humans use those natural habitats can also lead to over-exploitation of species, environmental/habitat deterioration, and the introduction of exotic species.

In addition to the potential negative effects on forested ecosystems themselves, the fragmentation and urbanization of forest land may have direct economic and social effects as well (e.g., Wear et al. 1998). Smaller patches of forest are less likely to be managed for forest products and are more likely to be posted (i.e., not open for public use) (Butler et al. 2004), potentially affecting forest and tourism industries as well as outdoor recreation opportunities.

National, regional, and state assessments of forest fragmentation at one point in time have been published (e.g., Riitters et al. 2002, Heilman et al. 2002, Riemann and Tillman 1999), and Lister et al. (2004) summarized fragmentation indicators by county, watershed, and ecoregion. In this study we build upon a previous paper by Morin et al. (2006) to further characterize the current conditions in fragmented and contiguous forests in New Hampshire with respect to forest type, stand size, geographical location, diversity, and health, and describe a methodology that can be applied in other states and/or regionally.

Methods

New Hampshire was chosen as the study area because of the rapidly expanding population and associated development in that state. In addition, New Hampshire's dependence on healthy and accessible forest land for its forest-based economy, tourism industry, and outdoor recreation opportunities, makes it particularly interested in the extent, location, and magnitude of forest fragmentation/urbanization and the characteristics of the forest resource affected.

A 98.43-ft. (30-meter) resolution land use/land-cover image of New Hampshire from the 2006 National Oceanographic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) (Klemas et al. 1993, NOAA 2009) was acquired and the number of land-cover groups collapsed into five broader categories (developed, agriculture, forest, natural nonforest, and barren land) (Fig. 1). Water was considered background and did not contribute to edge/diversity and other metric calculations. Fragmentation statistics were generated for a 0.62-mile (1-kilometer) radius circular area around each of the 860 forested inventory plots using either APACK[5] software (Mladenoff and DeZonia 2001) or standard spatial analyses to quantify landscape composition and pattern and provide information on the extent of urbanization and the types of fragmentation occurring. The radius was selected because it represents a large block of contiguous forest (approx. 775 acres) if the area is largely or completely forested. Examples of these metrics (most of which are described in Mladenoff and DeZonia [2001]) include landscape composition measures (e.g., amount of agriculture or developed land in the local neighborhood), patch size distribution, clumpiness/connectedness (e.g., contagion, etc.), landscape diversity/heterogeneity measures (e.g., angular second moment, diversity, dominance, etc.), forested patch size, distance to developed (urban) land cover, whether a plot occurred on the forest edge, and edge measures (e.g., edge density, etc). Examples of two FIA plots, one surrounded by highly contiguous and one by highly fragmented forest, are shown in Figure 2 along with the calculated fragmentation statistics for the circular area surrounding them.

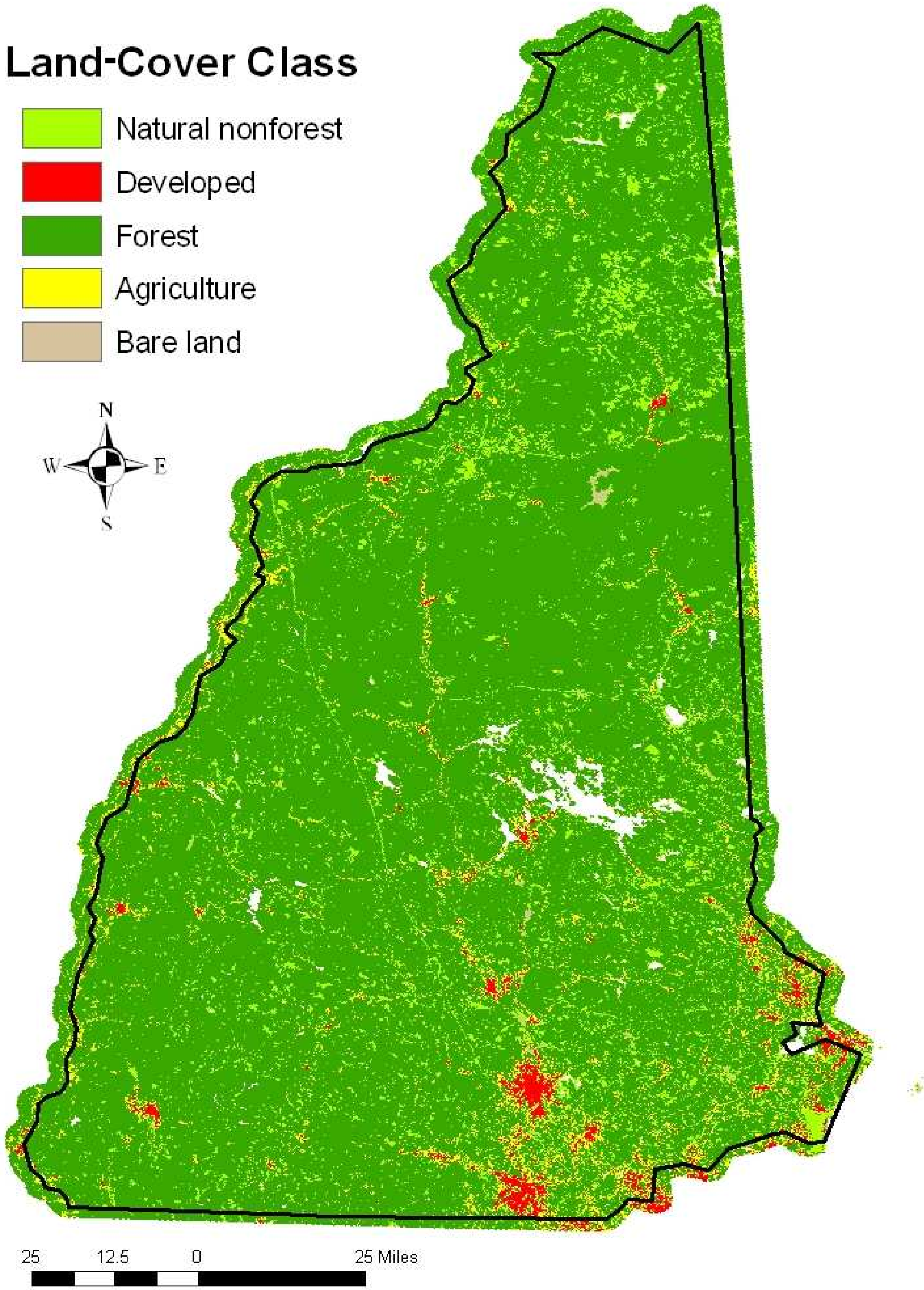
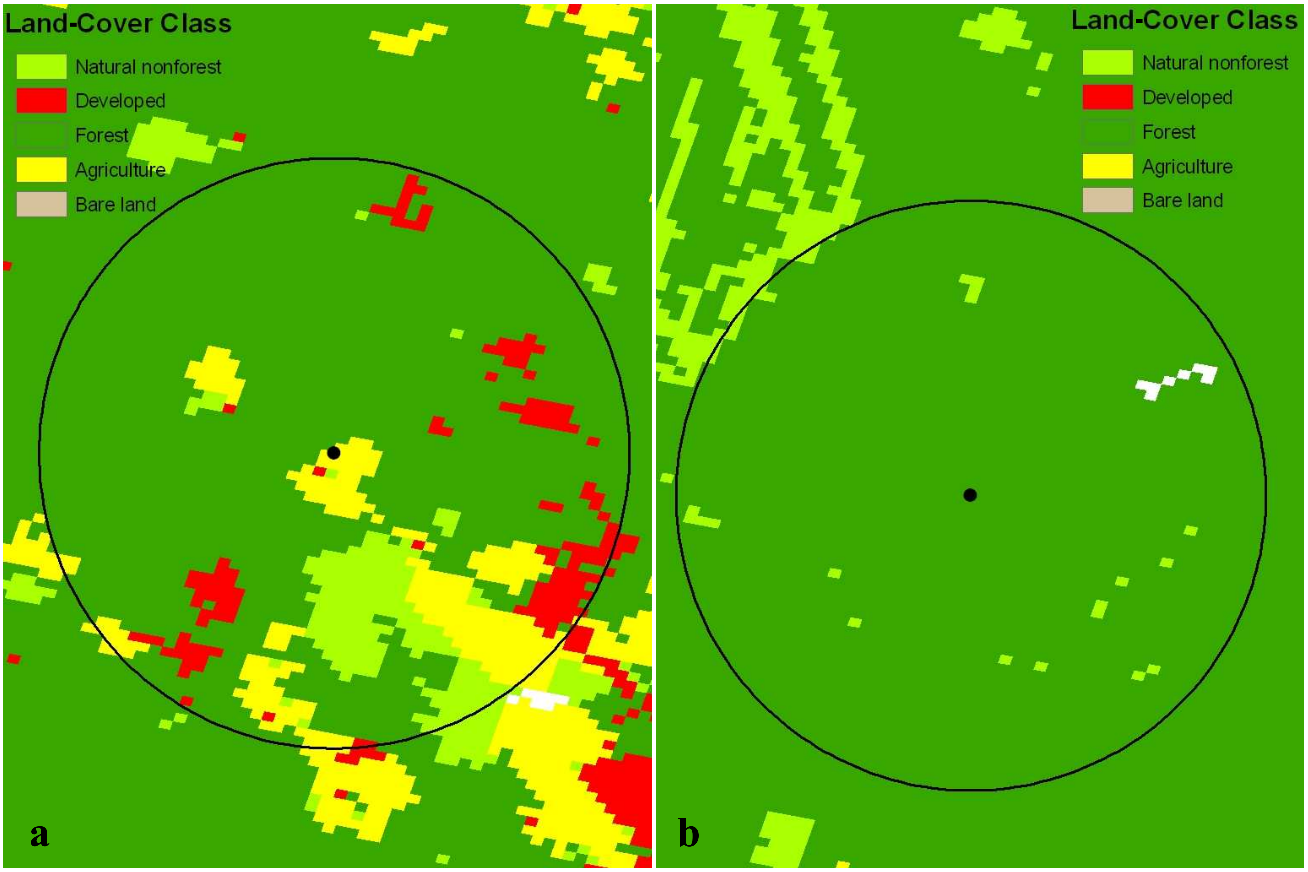


Figure 1. Classified land-cover image of New Hampshire from 2006 (Klemas et al. 1993, NOAA 2009).



Fragmentation variable	Value (a)	Value (b)
Distance to urban land cover	67 meters	1934 meters
Dominance	0.67 (unitless)	0.544 (unitless)
Edge density of forest patches	0.008 (unitless)	0.004 (unitless)
Distance to forest edge	42.4 meters	384.2 meters
Landscape diversity	0.716 (unitless)	0.149 (unitless)

Figure 2. Examples of FIA plots surrounded by highly fragmented (a) and highly contiguous (b) forest patches along with the calculated fragmentation statistics for the 1-km circular area surrounding them New Hampshire, 2006 (Klemas et al. 1993, NOAA 2009).

The FIA Program of the U.S. Department of Agriculture, Forest Service, the only congressionally mandated national inventory of U.S. forests, conducts a three-phase inventory of forest attributes of the country (Bechtold and Patterson 2005). The FIA sampling design is based on uniform sampling areas comprised of 6,000-acre hexagons with at least one permanent plot established in each. In phase 1, the population of interest is stratified and plots are assigned to strata to increase the precision of estimates. In phase 2, tree and site attributes are measured for forested plots established in each hexagon. Phase 2 plots consist of four 24-ft fixed-radius subplots on which standing trees are inventoried. The most recent published inventory of New Hampshire was completed in 2006 (Morin and Tansey 2008). The following variables were selected or calculated from the inventory plot data and analyzed with respect to fragmentation and urbanization characteristics:

- Stand size (large, medium, or small based on average diameter).
- Tree-species richness (number of species tallied on trees ≥ 5 inches d.b.h. per FIA plot).
- Stems density per acre (calculated for trees ≥ 5 inches d.b.h.).
- Shannon Diversity Index (calculated for trees ≥ 5 inches d.b.h.).
- Dead basal area per acre (calculated for trees ≥ 5 inches d.b.h.).
- Forest-type group (Fig. 3).

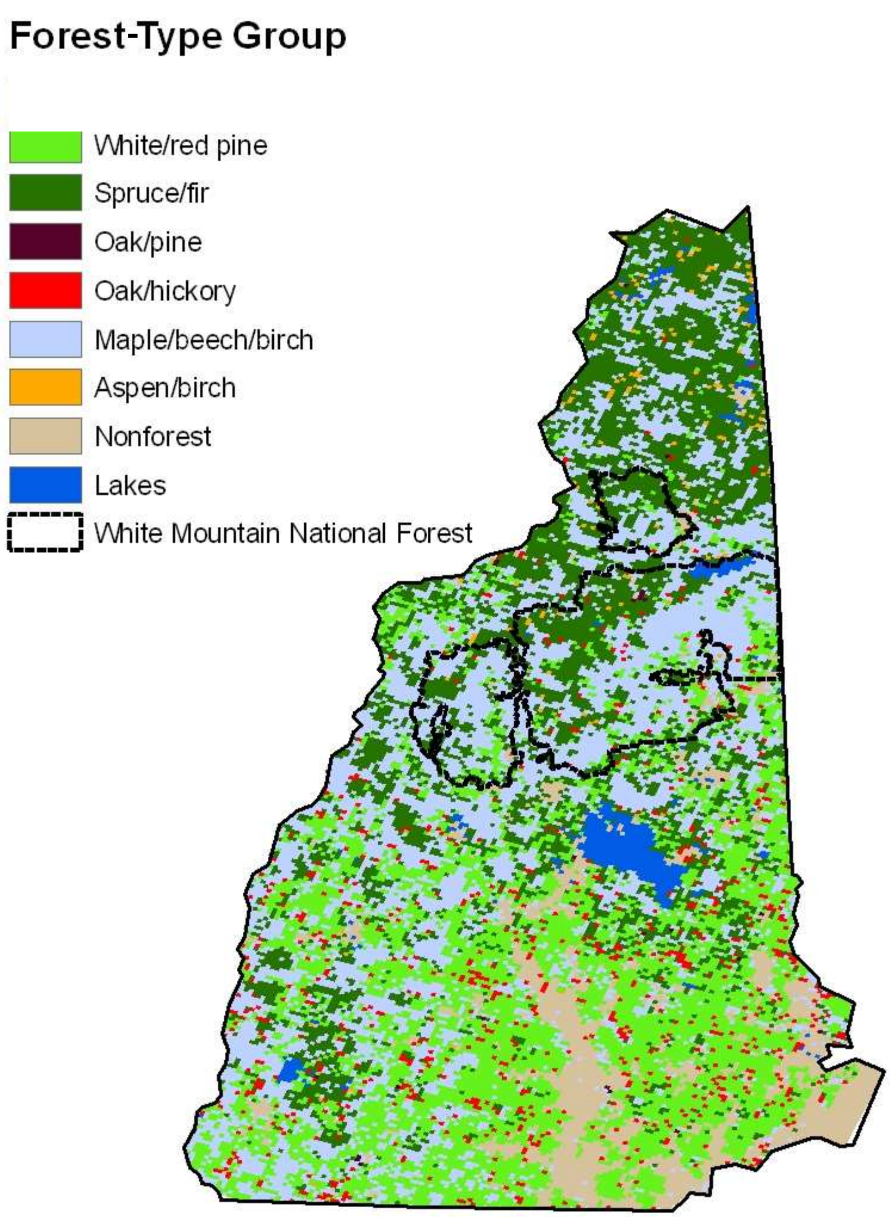


Figure 3. Forest cover type map of New Hampshire (Zhu and Evans 1994).

To characterize the level of development pressure on the different forest-type groups and stand sizes in New Hampshire, graphs of mean distance from each FIA plot to an urban land cover pixel were generated. Correlations between selected fragmentation metrics and FIA variables were examined using the Pearson correlation coefficient ($\alpha = 0.05$) (PROC CORR, SAS 2004). Sample size is included in all correlation tables because it has a large impact on the *r*-values and *p*-values (Sokal and Rohlf 2003). Therefore the results of the correlation analysis need to be interpreted carefully because a statistical difference does not infer a biological difference especially when dealing with a large sample.

Results and Discussion

Distance to urban land cover from forested FIA plots varied considerably by forest-type group. The six most prevalent forest-type groups in New Hampshire were divided into three distinct groupings when comparing the mean distance from each forested FIA plot to an urban land cover pixel (Fig. 3). Note that the terminology for the forest-type groups comes from FIA's national standards and, therefore, may have tree species in the forest-type group name which are not actually sampled on the FIA plots. For example, the white pine forest type is in the white/red/jack pine forest-type group. The oak/hickory, oak/pine, and white/red/jack pine forest type groups fall into the group with the shortest average distance to urban land cover, four times shorter than for the spruce/fir and aspen/birch forest type groups and twice as short as that of the maple/beech/birch forest type group. Those type groups in the shortest group were in the most fragmented condition because they are predominately located in southern New Hampshire where the rapid growth and development is occurring. In fact, the State's population is growing at twice the rate of the rest of New England, with most of that growth in the southeastern counties (SPNHF 2006). By contrast, the spruce/fir and aspen/birch forest-type groups are generally present in the northern part of the state where less growth and development is occurring. These forest-type groups are generally farther from urban land cover. The forests containing the maple/beech/birch type group are more widely distributed across the State and, therefore fall in the middle of this distance to urban land cover gradient. Distance to urban land cover also varies by stand-size class; the mean distance to urban land cover increases as stand size-class (in diameter) decreases (Fig. 4). The working forests in northern New Hampshire that contain the majority of the spruce/fir and aspen/birch type groups have more small-diameter stands because harvesting on existing and future forest land is occurring. By contrast, the oak and pine type groups to the south are more likely to be harvested in association with land-use change as urban and suburban growth continues. Although the proportions of the forest-type groups are similar across New Hampshire and on the White Mountain National Forest, some results may be impacted by differences between private and public ownerships (e.g., larger forest parcels and less harvest on public land).

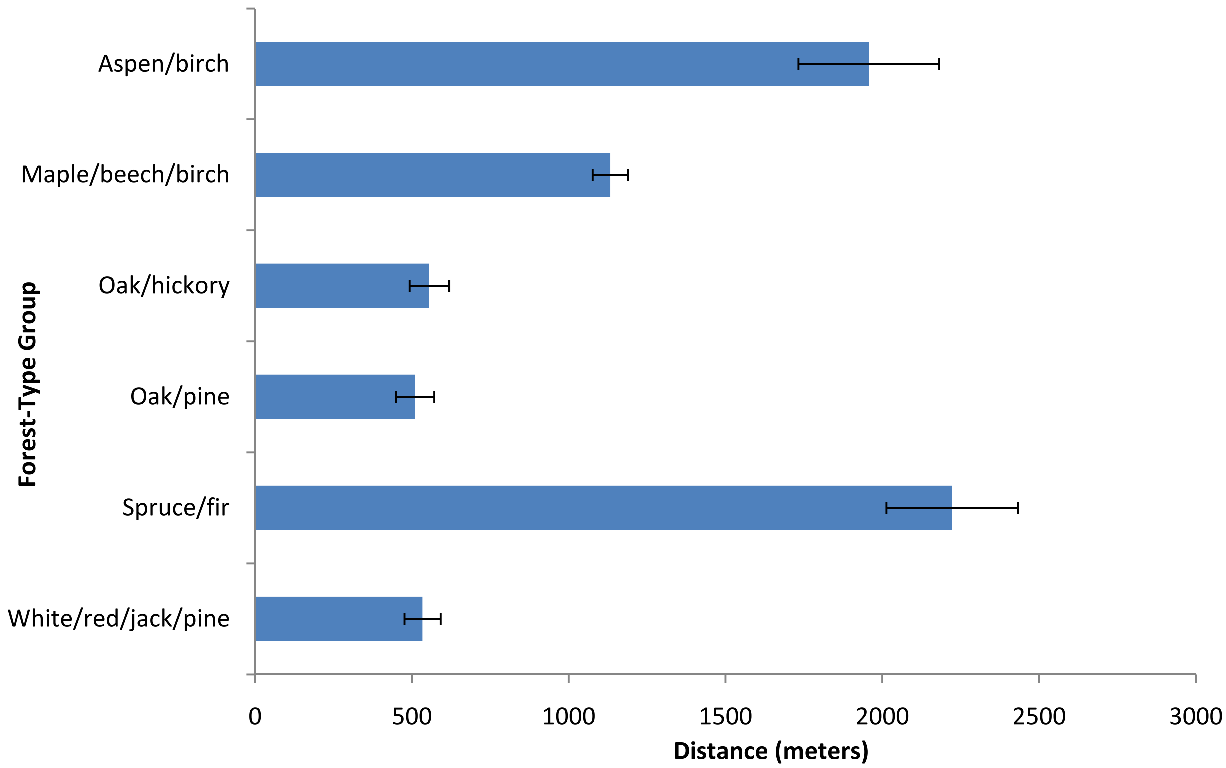


Figure 3. Mean distance to urban land cover value by forest-type groups (67-percent confidence intervals are shown).

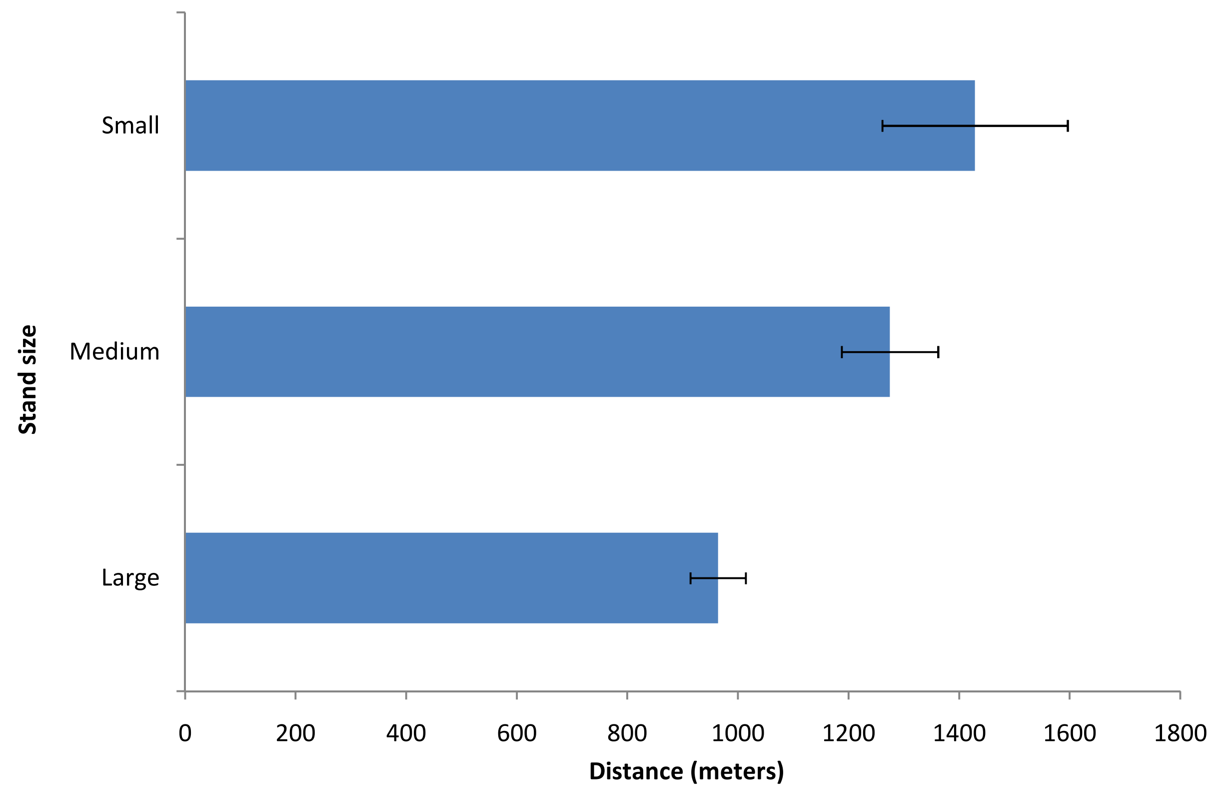


Figure 4. Mean distance to urban land cover value by stand size category (67-percent confidence intervals are shown).

Overstory tree-species diversity (Shannon Index), tree species richness, stem density, and standing dead basal area were significantly correlated with several fragmentation metrics but associations were weak (Table 1). Shannon Diversity Index and species richness were both positively, but weakly, associated with the landscape fragmentation metric dominance (r = 0.21 and r = 0.22,[(both $p<0.05$] respectively). Dominance represents the degree to which a landscape departs from the maximum diversity of cover classes. Large dominance values arise from landscapes with few land-cover classes, and low dominance values are the result of a landscape made up of many different land-cover classes in equal proportions. Since the study includes only forested plots, the dominance value for the 1-km neighborhood surrounding an FIA plot would increase as the amount of forest in that neighborhood increases. The positive correlations with dominance suggest that species richness and diversity could be positively affected by larger tracts of forest in the landscape surrounding an FIA plot, but these results are confounded by differences in potential diversity and species richness between forest type groups (ie. the spruce/fir forest type group is typically more homogeneous and less diverse than the oak/hickory forest type group). Therefore, these relationships are examined further by breaking up the forest type groups (Tables 2-7).

Stem density and standing dead basal area were both negatively associated with landscape diversity (r = -0.19795 and r = -0.24134, respectively) (Table 1). Landscape diversity reports the heterogeneity of the landscape where a high value (range is 0-1) implies a neighborhood with many land-use classes in nearly equal proportions, and a low value implies a neighborhood dominated by a single land-use class. Since the analysis includes only forested plots, those surrounded by high-diversity neighborhoods are presumably in more fragmented areas than plots surrounded by a neighborhood with low-diversity values, although this fragmentation may be due to agriculture, barren/cleared, or areas of natural nonforest vegetation as well as developed land uses. The relationship of stem density and standing dead basal area with edge density of forest patches is similar. Increasing values of landscape diversity and edge density of forest patches represent forest parcels that exist in smaller patches with more edge area. This suggests that more fragmented forests may have sparser tree cover including fewer standing dead trees. By contrast, stem density and standing dead basal area were positively correlated with distance to forest edge (r = 0.20516 and r = 0.2329, respectively) suggesting that stem density and dead tree density increase as a forest becomes more "interior" (i.e., farther from the forest edge).

Table 1. Correlation of overstory tree (> 5 inches d.b.h.) variables and fragmentation metrics, where r is the Pearson correlation coefficient and P is the significance (n=860).

	Overstory tree variable							
	Shannon diversity		Species richness		Number of stems		Standing dead basal area	
Fragmentation variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Dominance	0.21148	<.0001	0.2232	<.0001	0.03963	0.246	-0.1016	0.003
Edge density of forest patches	-0.07696	0.024	-0.08531	0.012	-0.18365	<.0001	-0.20123	<.0001
Distance to forest edge	-0.10514	0.002	-0.09202	0.007	0.20516	<.0001	0.2329	<.0001
Landscape diversity	-0.0601	0.078	-0.05702	0.095	-0.19795	<.0001	-0.24134	<.0001

To further explore the relationships between overstory tree variables and fragmentation metrics, correlations were analyzed by forest-type group. Within the white/red/jack pine forest type group the only marginally significant correlation was between landscape diversity and species richness (Table 2). This negative association indicates that more fragmented forest parcels in the pine type-group have lower numbers of species in the overstory.

Table 2. Correlation of overstory tree (> 5 inches d.b.h.) variables and fragmentation metrics for plots in the white/red/jack pine forest type group, where *r* is the Pearson correlation coefficient and *P* is the significance (*n*=86).

	Overstory tree variable							
	Shannon diversity		Species richness		Number of stems		Standing dead basal area	
Fragmentation variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Dominance	0.05316	0.627	0.0474	0.665	0.11755	0.281	0.10388	0.341
Edge density of forest patches	-0.15816	0.146	-0.18587	0.087	-0.04741	0.665	-0.05566	0.611
Distance to forest edge	-0.01165	0.915	-0.10483	0.337	0.099	0.365	0.02604	0.812
Landscape diversity	-0.16635	0.126	-0.20111	0.063	-0.1202	0.27	-0.09602	0.379

Within the spruce/fir forest type group overstory tree-species diversity (Shannon Index), tree-species richness, stem density, and standing dead basal area were significantly correlated with several fragmentation metrics (Table 3) and most associations were stronger than reported for all forested plots (Table 1). While the directions of many of the relationships were similar to what was reported for all plots, there are some interesting differences as well. The Shannon Diversity Index and species richness were positively associated with edge density of forest patches (r = 0.3791 and r = 0.2744, respectively). These correlations with edge density suggest that tree species richness and diversity in the spruce/fir type is positively affected by increasing patchiness of forest parcels.

Table 3. Correlation of overstory tree (> 5 inches d.b.h.) variables and fragmentation metrics for plots in the spruce/fir forest-type group, where *r* is the Pearson correlation coefficient and *P* is the significance (*n*=63).

	Overstory tree variable							
	Shannon diversity		Species richness		Number of stems		Standing dead basal area	
Fragmentation variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Dominance	0.2181	0.074	0.20232	0.098	-0.06348	0.607	-0.2163	0.0765
Edge density of forest patches	0.3791	0.001	0.2744	0.024	-0.23933	0.049	-0.37471	0.0016
Distance to forest edge	-0.37335	0.002	-0.20764	0.089	0.25503	0.036	0.41995	0.0004
Landscape diversity	0.3551	0.003	0.34832	0.004	-0.13335	0.278	-0.41474	0.0004

Within the oak/pine forest-type group, the only significant correlation was between dominance and standing dead basal area (Table 4). The association is positive, indicating that oak/pine plots set in a more heavily forested landscape have more standing dead basal area. This is similar to what was reported for all plots across New Hampshire.

Table 4. Correlation of overstory tree (> 5 inches d.b.h.) variables and fragmentation metrics for plots in the oak/pine forest-type group, where *r* is the Pearson correlation coefficient and *P* is the significance (*n*=65).

	Overstory tree variable							
	Shannon diversity		Species richness		Number of stems		Standing dead basal area	
Fragmentation variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Dominance	-0.01283	0.919	0.04458	0.724	0.00807	0.949	0.25266	0.0423
Edge density of forest patches	-0.20423	0.103	-0.19405	0.121	0.06969	0.581	-0.19569	0.1182
Distance to forest edge	0.09192	0.467	0.24006	0.054	0.19956	0.111	0.115	0.3617
Landscape diversity	-0.10621	0.4	-0.12653	0.315	0.02395	0.85	-0.15721	0.211

Within the oak/hickory forest-type group, Shannon diversity and species richness were significantly correlated with landscape diversity ($r = 0.2421$ and $r = 0.2344$, respectively) (Table 5). These correlations suggest that tree species richness and diversity in the oak/hickory forest-type group is positively affected by a heterogeneous landscape that includes other land covers interspersed with forest.

Table 5. Correlation of overstory tree (> 5 inches d.b.h.) variables and fragmentation metrics for plots in the oak/hickory forest type group, where *r* is the Pearson correlation coefficient and *P* is the significance (*n*=72).

	Overstory tree variable							
	Shannon diversity		Species richness		Number of stems		Standing dead basal area	
Fragmentation variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Dominance	-0.12849	0.282	-0.11784	0.324	-0.10795	0.367	-0.13338	0.264
Edge density of forest patches	0.22567	0.057	0.14637	0.22	0.05189	0.665	-0.05554	0.6431
Distance to forest edge	-0.07177	0.549	-0.04205	0.726	-0.04366	0.716	-0.03929	0.7432
Landscape diversity	0.24213	0.04	0.23436	0.048	0.26724	0.023	-0.05745	0.6317

The correlations for the plots in the maple/beech/birch and aspen forest type groups are the most similar to what was reported for all plots (Table 1, Table 6, and Table 7). Since the maple/beech/birch forest-type group is the most widespread geographically in New Hampshire, it follows that the relationships would be the most similar to the State as a whole.

Table 6. Correlation of overstory tree (> 5 inches d.b.h.) variables and fragmentation metrics for plots in the maple/beech/birch forest-type group, where *r* is the Pearson correlation coefficient and *P* is the significance (*n*=439).

	Overstory tree variable							
	Shannon diversity		Species richness		Number of stems		Standing dead basal area	
Fragmentation variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Dominance	0.18171	0.0001	0.19518	<.0001	0.09844	0.039	-0.1028	0.0313
Edge density of forest patches	-0.02533	0.5966	0.00425	0.929	-0.09105	0.057	-0.04498	0.3471
Distance to forest edge	-0.07646	0.1097	-0.11693	0.014	0.08595	0.072	0.04164	0.3841
Landscape diversity	0.0225	0.6383	0.05291	0.269	-0.12599	0.008	-0.08332	0.0812

Table 7. Correlation of overstory tree (> 5 inches d.b.h.) variables and fragmentation metrics for plots in the aspen/birch forest-type group, where *r* is the Pearson correlation coefficient and *P* is the significance (*n*=55).

	Overstory tree variable							
	Shannon diversity		Species richness		Number of stems		Standing dead basal area	
Fragmentation variable	*R*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Dominance	0.4602	0.0004	0.46178	0.0004	0.08165	0.5534	-0.17158	0.2104
Edge density of forest patches	-0.0673	0.6254	-0.10508	0.4452	-0.4648	0.0004	-0.4189	0.0015
Distance to forest edge	-0.1895	0.1658	-0.19596	0.1516	0.28183	0.0371	0.27803	0.0399
Landscape diversity	-0.20855	0.1265	-0.2118	0.1206	-0.507	<.0001	-0.43535	0.0009

This statewide summary provides an informative perspective on the magnitude of fragmentation and urbanization facing the different forest-type groups in New Hampshire's forests. Additionally, the addition of fragmentation context information to FIA inventory allows analysts and consumers to examine relationships between forest fragmentation and forest composition, structure, and health. A quantitative assessment as presented provided information about the magnitude of potential effects of forest fragmentation on different forest types and stand sizes. Forest types that are particularly sensitive to urbanization and/or fragmentation due to their location or inherent ecology should be watched closely for any further encroachment. Forest products, wildlife habitat, recreation potential, etc., could also be negatively affected.

Conclusions

The impacts of fragmentation have been discussed extensively in the literature but corresponding descriptions of the forests that have been fragmented are lacking. FIA data offer a unique opportunity to characterize the types of forests affected the most by fragmentation when used in conjunction with a classified, remotely sensed land-cover data layer. Additionally, FIA inventory data would allow for quantitative measurement of impacts over broad areas. An assessment of this type could be used in the future to monitor fragmentation trends and their effects at both state and landscape scales. Our study did not include all currently collected FIA attributes that could be used to further explore the effects of urbanization and fragmentation on timber attributes. For example, future work could examine the amount of volume in tree grades 1 and 2 among different levels of fragmentation and urbanization. The collection of additional variables on inventory plots, such as shrub and herbaceous species and densities which change more quickly than the overstory in response to fragmentation and urbanization pressures, will enable earlier examination of impacts.

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