Identifying Areas of Relative Change in Forest Fragmentation in New Hampshire Between 1990 and 2000

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Abstract.—Forest fragmentation potentially can impact many facets of natural ecosystems. Numerous methods have been employed to assess static forest fragmentation. Few studies, however, have analyzed changes in forest fragmentation over time. In this study, we developed new classifications from Landsat imagery data acquired in 1990 and 2000 for New Hampshire, assessed fragmentation in both time periods, and created maps depicting the spatial extent of fragmentation change through time. Visual inspection of the resulting maps suggests the method successfully identifies areas of the State where fragmentation is occurring at a relatively high rate.

Introduction

Forest fragmentation continues to be a topic of great interest in the Northeastern United States. The conversion of land cover from forest to other uses by humans and natural processes affects animal behavior, plant-seed dispersal, hydrological processes, and local weather conditions (Forman 1995). When contiguous forest land is divided into smaller, more complex patches, increasing isolation of remaining patches and an increase in forest areas influenced by nonforest edge often results. These factors may lead to changes in the composition and structure of the forest, including an increased potential for nonnative species invasion (Haskell 2000, Trombulak and Frissell 2000).

The U.S. Department of Agriculture Forest Service's Forest Inventory and Analysis (FIA) program continuously inventories the Nation's forest resources. The data collected include information on the extent, condition, and character of U.S. forests. Recently, FIA also has included forest fragmentation information in their State reports (Barnett *et al.* 2002, Wharton *et al*. 2004). In a regional assessment of forest fragmentation in the Northeast, a suite of fragmentation indicators were summarized by county, watershed, and ecoregion (Lister *et al.* 2005, USDA Forest Service 2006). These data sets and other regional and national forest fragmentation assessments (e.g., Riitters *et al.* 2002, Heilman *et al.* 2002) provide information on forest fragmentation at one point in time. Information about the dynamic nature of fragmentation, including changes in the patterns and distribution of forest land, are less abundant in the scientific literature. Although this dynamic component of fragmentation is difficult to assess, it is critical to our understanding of the stability and health of forest ecosystems and to our ability to properly manage forest resources.

Recognizing the importance of forest land dynamics and fragmentation change to forest management, the New Hampshire Division of Forests and Lands is addressing these concerns in their latest revision of the Forest Resource Plan. This comprehensive Statewide plan summarizes the condition of New Hampshire's forests and discusses the desired future forest condition. As a potential input to the 2006 Forest Resource Plan, FIA agreed to conduct a spatial assessment of relative change in forest fragmentation. This ongoing assessment is designed to identify areas of the State where land class conversion is occurring at a relatively high rate, with the purpose of helping managers and policymakers make more

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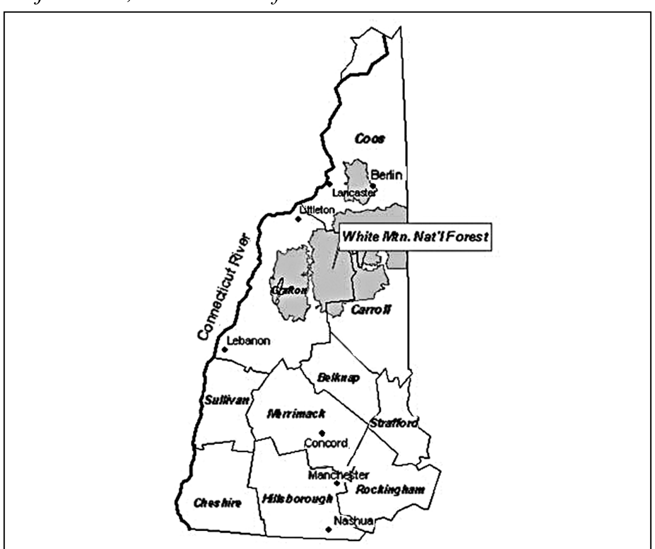
effective and appropriate management decisions. The goals of this article are to describe the methods used to produce the land cover base maps of New Hampshire, to provide a mapped summary of the fragmentation statistics calculated at two points in time, and to discuss preliminary interpretations of the data. Furthermore, this analysis serves as the first in a series of State-level land cover conversion analyses that could become part of the fabric of FIA analytical reports.

Methods

Description of Study Area

Forest land dominates New Hampshire's landscape, covering 84 percent of the total land area, making it second to Maine, the Nation's most forested State (Frieswyk and Widmann 2000). New Hampshire's 4.8 million acres of forest are relatively evenly distributed across the State with all 10 counties made up of at least 65 percent forest. A greater concentration of forest occurs in the northern half of the State, which includes the White Mountain National Forest (fig. 1). The lowest concentration of forest is in the more populated, southeastern section of the State (Frieswyk and Widmann 2000).

Figure 1.—*The State of New Hampshire showing counties, major cities, and national forests.*



New Hampshire's forest products industry adds more than $1.5 billion to the State's economy (NEFA 2001). Sawlogs are the primary industrial use of wood harvested, followed by pulpwood. According to FIA data, the area of forest land in New Hampshire decreased slightly between 1983 and 1997 (Frieswyk and Widmann 2000). An estimated 134,500 acres of forest were converted to other land uses during this period. The greatest decrease in the area of forest land occurred in the eastern part of the state, especially in Carroll and Strafford Counties.

Base Map Classification

Initially we hoped to use previously classified images from two different points in time that would serve as the basis for a moving window fragmentation analysis. The land cover maps that we compared included the Multi-Resolution Land Characterstics (MRLC) 1992 classification (Vogelmann 2001), and classifications created by David Justice (2002). Due to differences in the original images and classification methods, we determined that these classification maps were not comparable. We decided to perform our own classifications to reduce any methods-based discrepancies.

We found spectral differences between a Landsat satellite image collected in 1990 and one collected in 2000. The images used were clipped from Earthsat Geocover mosaics (Earthsat 2006), and consisted of leaf-on bands two, four, and seven. Spectral difference images were created by using band subtraction (band 7–band 7, band 4–band 4, and band 2–band 2) in Leica Imagine[4]. Spectral difference images were created by using band subtraction using Leica imagine[4]. For example, on a pixel-by-pixel basis, the spectral values of band 7 for the 1990 image were subtracted from the spectral values of band 7 for the 2000 image. Once the magnitude of the spectral differences between each of the corresponding bands from the two time periods was determined, we developed heuristics to identify areas of loss, increase, or no change in forest cover. This was done by iteratively thresholding the three band spectral difference image to create potential forest cover loss maps and comparing them visually with National Agricultural Imagery Program files from 2004 (USDA Aerial Photo Field Office 2006), U.S. Geological

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Survey (USGS) digital orthophoto quads from around 1997 (USGS 2006a) and NHAP (USGS 2006b) 1:40,000 aerial photographs from 1993. Photography that corresponded with the dates of the Landsat scenes would have been preferred, but was unavailable.

We then combined the resulting classified forest cover change image with a classification conducted by Justice *et al.* (2002) from 2000 (IM2000), and one conducted by the MRLC program (Vogelmann 2001) from 1990 (IM1990) to produce the land class base maps. Unique combinations of forest cover change and IM2000 allowed us to "backdate" the 2000 classification to create a new 1990 classification, based on IM2000, via a recoding procedure. For example, if IM2000 indicated an urban class and the forest change image indicated forest loss, then a new 1990 image was created by "backdating" IM2000 to a forest class. Similar logic was used for other classes. IM1990 was used primarily to detect areas of forest gain. For example, if IM2000 indicated a forest class, the land cover change image indicated forest gain, and the IM1990 image indicated a nonforest class (not including urban, residential or transportation, which was unlikely to revert to forest), then the new 1990 image was assigned a nonforest class at that location. If the forest cover change image indicated no change, then the IM2000 class was assigned to the new 1990 image.

We combined Geographic Information System coverages of roads from the U.S. Census Bureau's TIGER Line files (U.S. Census Bureau 2002) with both the new 1990 image and IM2000. We then applied a correction methodology described in Lister *et al.* (in press) to convert forested areas with a high road density to the developed class, under the assumption that these areas are probably either residential, or so impacted by the road density as to make them ecologically similar to developed areas.

Map Refinement and Land Class Descriptions

The final classification scheme for both IM2000 and the new 1990 image was based on a collapsing of the original IM2000 classes into six categories: water and background (which consisted of analysis unit edges and roads, and was not included in calculations), developed (residential, urban, forest that was relabeled developed based on road density, and transportation networks not coinciding with the census roads), agricultural areas (including pastures and orchards), forest (including forested wetlands), natural vegetated areas (including herbaceous wetlands, sand dunes, tundra, and exposed bedrock areas with stunted vegetation), and cleared areas that have not been converted to developed land cover classes. We applied a spatial filtering algorithm to these maps (Leica Imagine's "eliminate" procedure) to remove patches consisting of less than four contiguous pixels of the same class.

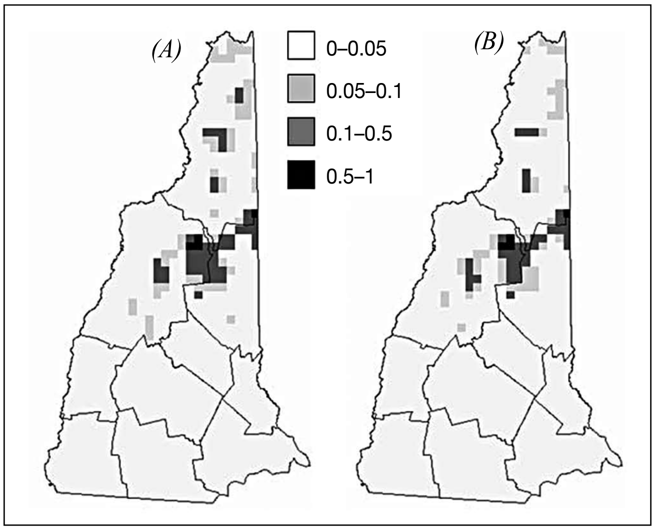
Fragmentation Assessment

Next, we clipped each image into 974 overlapping 10- by 10-km image tiles using Leica Imagine and calculated a suite of fragmentation statistics on the image tiles from each time period using APACK software (Mladenoff and DeZonia 2001). We then normalized each metric's value for each tile by dividing it by the maximum value of that metric across all the tiles. We did this to facilitate interpretation of the fragmentation difference analyses when the classifications from the two time periods varied due to classification error and not true land cover change. In other words, the fragmentation change analyses identify image tiles that show large relative differences, not absolute differences. We merged and joined these normalized datasets to the centroids of the overlapping tiles (which were 5 km apart), subtracted the new 1990 image's normalized fragmentation statistics from those of IM2000, and generated the fragmentation change maps.

Results and Discussion

Although a full suite of fragmentation metrics was estimated and mapped, the following discussion includes a small sample of only the most interesting fragmentation indices. Mean patch size is widely used to characterize forest patches and has been shown to be an important and applicable metric (Lausch and Herzog 2002). As described above, the mean forest patch size is presented as a relative value in figure 2, which shows the distribution of patch sizes in New Hampshire. Not surprisingly, the average patch size is largest in the White Mountains National Forest located in the eastern-central portion of the

Figure 2.—*Relative forest mean patch size calculated within overlapping 10- by 10-km image tiles in New Hampshire in 1990 (A) and 2000 (B).*



State. Although the distribution of average forest patch area is similar in 1990 and 2000, the change map (fig. 3) shows mostly patchy decreases and some increases in average forest patch area in the northern half of the State. A preliminary visual inspection of USGS digital orthophoto quads and aerial photographs at different time periods revealed that many of these areas of change are due to harvesting and forest regrowth.

The forest aggregation index estimates the degree to which forested pixels are clumped together in the landscape. This metric is calculated by dividing the number of forest cells that are adjacent to other forest cells by the total number of possible adjacent forest-forest edges. The more aggregated the forested pixels, the higher the aggregation index. As expected, the forest aggregation index is lowest in the southeastern portion of the State (fig. 4), which has the lowest percentage of forest cover yet hosts the greatest number of forest patches. The area surrounding Manchester also supports the greatest amount of urban land uses. The highest forest aggregation index values are found in Coos, Grafton, and Carroll Counties in the north. Figure 5 shows relatively little change in forest aggregation index between 1990 and 2000. The aggregation index shows some increases along the Connecticut River at New Hampshire's western border with Vermont. Decreases in forest aggregation index in central Coos County may correspond

Figure 3.—*Relative difference in forest mean patch size calculated within overlapping 10- by 10-km image tiles in New Hampshire.*

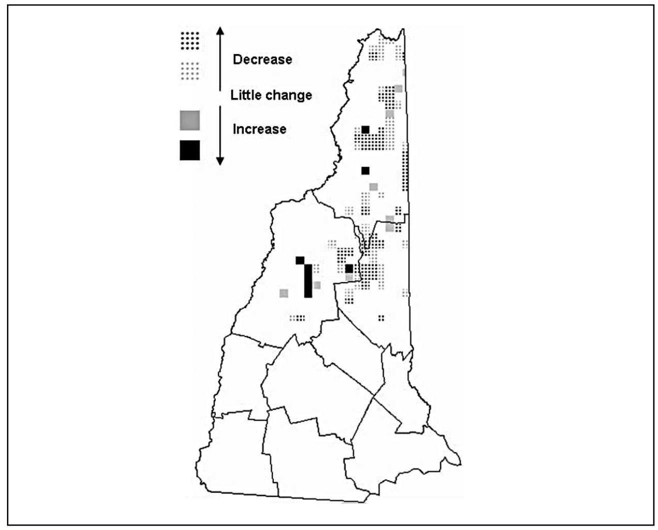
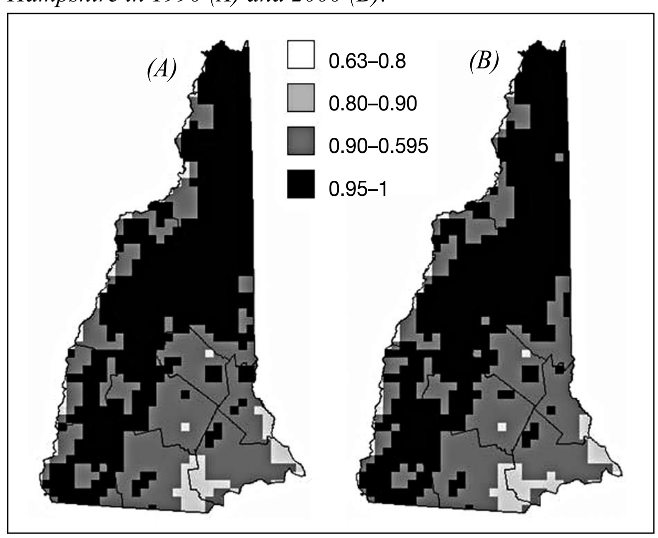


Figure 4.—*Relative values of forest aggregation index calculated within overlapping 10- by 10-km image tiles in New Hampshire in 1990 (A) and 2000 (B).*



with areas influenced by harvest activities as suggested by the images and photography we studied.

Up to this point the changes captured by our preliminary analyses have been attributed to land cover conversion due to harvesting activities as forested land is cleared and regrowth occurs. These changes are significant to evaluate, but generally do not represent a permanent loss of forest land; a change in

Figure 5.—*Relative difference in forest aggregation index calculated within overlapping 10- by 10-km image tiles in New Hampshire.*

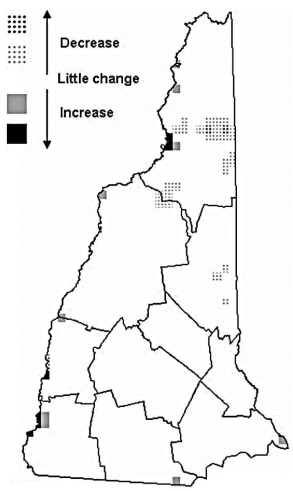
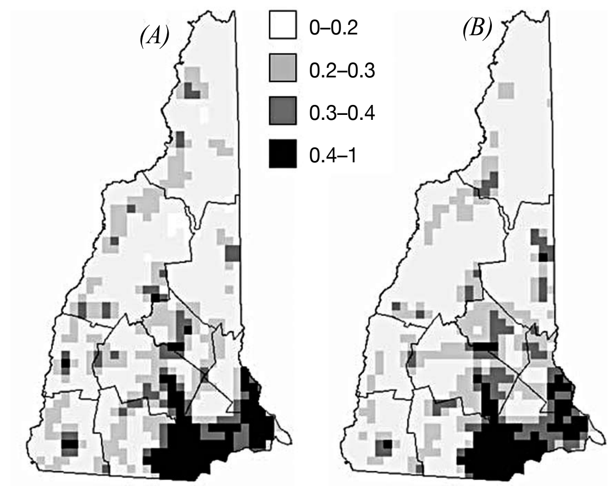


Figure 6.—*Relative values of the number of forest patches less than 10 ac in size calculated within 10- by 10-km image tiles in New Hampshire in 1990 (A) and 2000 (B).*

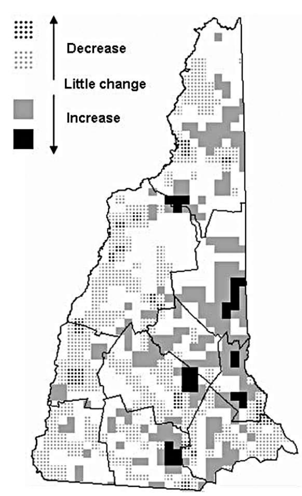


land use has not occurred, just a temporary change in land cover. In an attempt to capture forest loss and fragmentation changes due to urban pressures, we selected two metrics: the number of forest patches less than 10 ac in size, and the length of edge shared between urban and forest patches.

Figure 6 indicates that the more highly developed, southeastern portion of the State has the greatest number of small forest patches. One of the most impressive increases in the number of small forest patches occurred in the southern half of Carroll County (fig. 7). According to FIA data, Carroll County lost more than 10 percent of its forest land between 1983 and 1997 (Frieswyk and Widmann 2000). Forest loss in this county is most likely due to urban and residential growth to accommodate an expanding population. From 1990 to 2000, population in Carroll County increased 23 percent, which was higher than the State and national averages of 11 and 13 percent, respectively.

The influence of forest edge on habitat quality is a matter of great concern. The character of the edge effect depends on the type of land use or class that borders the forest patch. For this article, we were interested in evaluating changes in the amount of forest/urban edge. The length of edge shared by forest and urban land classes was greatest in the areas surrounding

Figure 7.—*Difference in relative values of the number of forest patches less than 10 ac in size calculated within 10- by 10-km image tiles in New Hampshire in 1990 (A) and 2000 (B).*



Manchester and Nashua (fig. 8). The Manchester and Nashua areas also experienced relatively large increases in the length of forest/urban edge between 1990 and 2000 (fig. 9). Southern Carroll County was also a site of relatively high increase in urban/forest perimeter. This finding is consistent with the possibility that urban pressure and population growth in Carroll County is affecting forest patterns and fragmentation. In the northern part of the State, some of the increases in length of

Figure 8.—*Length of edge shared between forest and urban, normalized to the maximum values in the landscape, calculated within overlapping 10- by 10-km image tiles in New Hampshire in 1990 (A) and 2000 (B).*

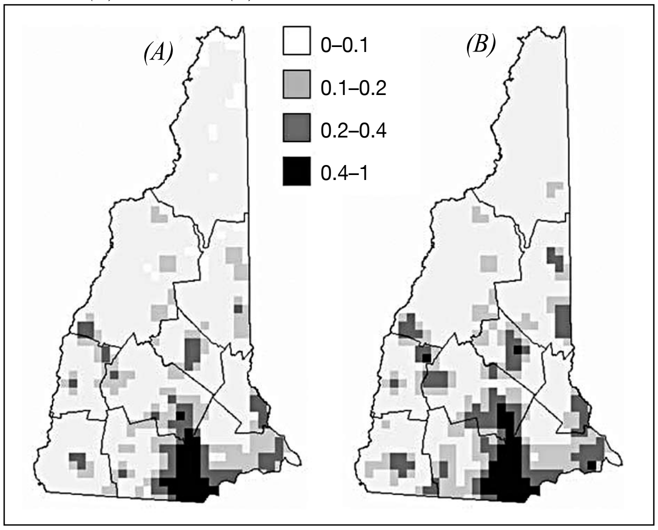
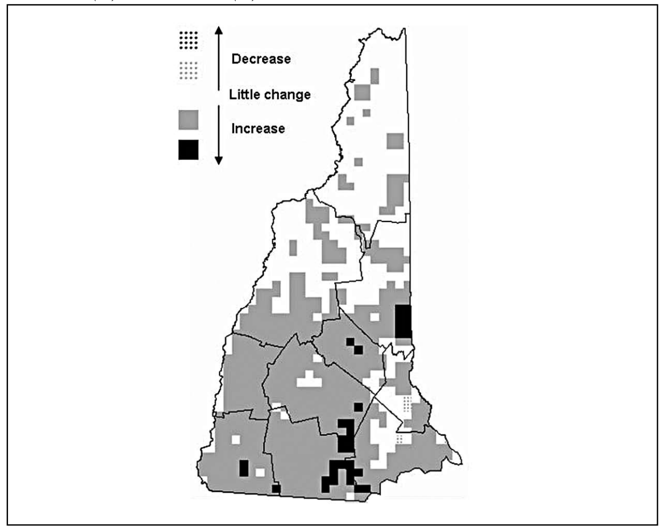


Figure 9.—*Length of edge shared between forest and urban, normalized to the maximum values in the landscape, calculated within overlapping 10- by 10-km image tiles in New Hampshire in 1990 (A) and 2000 (B).*



edge shared between forest and urban are centered on specific cities, including Littleton, Lancaster, and Berlin (fig. 9).

The utility of some fragmentation metrics and patch-based fragmentation metrics in general has been the subject of debate. For example, mean patch size can be misleading—many different landscape configurations can lead to the same mean value. Furthermore, our use of roads as patch-defining borders could lead to false interpretations of the results. Some small roads or land cover changes might not have a strong ecological impact. For example, forest and pasture have less ecological difference than forest and urban areas. We used relative differences in fragmentation metrics between the time periods because we wanted to identify areas of the State that showed anomalous changes in forest fragmentation compared to the rest of the State. If we assume that the classifications are similar to each other with respect to accuracy and have similar minimum mapping units, then we can infer that differences in the fragmentation metrics between the two time periods are the result of actual changes in the landscape, and not artifacts of the classification process or metric calculation algorithms. Future work will involve verifying the accuracy of these maps.

Literature Cited

Barnett, C.J.; Butler, B.J.; Dolan, P.; Dupree, T.A.; Emery, M.; Lister, A.; Lister, T.W.; Ricard, P.; Sparks, C.; Wharton, E.C.; Widmann, R.H. 2002. The forests of Rhode Island. Inf. Bull. NE-155. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 24 p.

Earthsat. 2006. Earthsat geocover mosaics. https://zulu.ssc.nasa.gov/mrsid/. (10 January 2006).

Forman, R.T.T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge, MA: Cambridge University Press. 632 p.

Frieswyk, T.S.; Widmann, R.H. 2000. Forest statistics for New Hampshire: 1983 and 1997. Resour. Bull. NE-146. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 130 p.

Haskell, D.G. 2000. Effects of forest roads on macroinvertebrate soil fauna of the southern Appalachian Mountains. Conservation Biology. 14: 57-63.

Heilman, G.E.; Strittholt, J.R.; Slosser, N.C.; Dellasala, D.A. 2002. Forest fragmentation of the conterminous United States: assessing forest intactness through road density and spatial characteristics. BioScience. 52: 411-422.

Justice, D.; Deely, A.; Rubin, F. 2002. New Hampshire land cover assessment final report. http://www.granit.sr.unh.edu. (10 January 2006).

Lausch, A.; Herzog, F. 2002. Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution, and interpretability. Ecological Indicators. 2: 3-15.

Lister, A.; Riemann, R.; Lister, T.; McWilliams, W. 2005. Northeastern regional forest fragmentation assessment: rationale, methods, and comparisons with other studies. Proceedings, fifth annual forest inventory and analysis symposium. Gen. Tech. Rep. WO-69. Washington, DC: U.S. Department of Agriculture, Forest Service. 222 p.

Mladenoff, D.J.; DeZonia, B. 2001. APACK 2.17 user's guide. Madison, WI: University of Wisconsin, Forest Landscape Ecology Lab. 52 p.

North East State Foresters Association (NEFA). 2001. The economic importance of New Hampshire's forests. North East State Foresters Association. 8 p.

Riitters, K.H.; Wickham, J.D.; O'Neill, R.V.; Jones, K.B.; Smith, E.R.; Coulston, J.W.; Wade, T.G.; Smith, J.H. 2002. Fragmentation of continental United States forests. Ecosystems. 5: 815-822.

Trombulak, S.C.; Frissell, C. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14: 19-29.

U.S. Census Bureau. 2000. Census 2000 TIGER/Line Files [machine-readable data files]. Washington, DC: U.S. Department of Commerce, Census Bureau.

U.S. Department of Agriculture (USDA) Aerial Photo Field Office. 2006. National aerial imagery program. http://www.apfo.usda.gov/NAIP.html. (10 January 2006).

USDA Forest Service. 2006. Remote sensing application center. http://www.fs.fed.us/eng/rsac/index.html. (10 January 2006).

U.S. Geologic Survey (USGS). 2006a. Digital orthophoto quadrangles fact sheet. http://www.usgsquads.com/downloads/factsheets/usgs_doq.pdf. (10 January 2006).

USGS. 2006b. National high altitude photography program. http://edc.usgs.gov/guides/nhap.html. (10 January 2006).

Vogelmann, J.E.; Howard, S.M.; Yang, L.; Larson, C.R.; Wylie, B.K.; Van Driel, N. 2001. Completion of the 1990s national land cover data set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering and Remote Sensing. 67(6): 650-662.

Wharton, E.H.; Widmann, R.H.; Alerich, C.L.; Barnett, C.H.; Lister, A.J.; Lister, T.W.; Smith, D.; Borman, F. 2004. The forests of Connecticut. Resour. Bull. NE-160. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 35 p.