Estimating Number and Size of Forest Patches From FIA Plot Data

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Abstract.—Forest inventory and analysis (FIA) annual plot data provide for estimates of forest area, type, volume, growth, and other attributes. Estimates of forest landscape metrics, such as those describing abundance, size, and shape of forest patches, however, typically are not derived from FIA plot data but from satellite image-based land cover maps. Associating image-based land cover metrics with FIA plot-based attributes is problematic due to differences in definitions between FIA land use and image-based land cover, temporal inconsistencies between plot and image acquisitions, and spatial misregistration between plots and map pixels. We assess an existing approach for using FIA field plot data directly for estimating the number and mean size of forest patches within estimation units typically reported by FIA (e.g., counties, States, or other geographic extents of moderate to large area). Comparison analyses reveal that FIA plot-based estimates of mean patch size are larger, and estimates of the number of patches are smaller than estimates derived from a satellite image-based land cover map.

Introduction

Scientists in the Forest Inventory and Analysis (FIA) program developed a standard plot and sample design to produce nationally consistent estimates of forest area, volume, and other attributes over moderate- to large-sized estimation units, (e.g., counties and States) (Bechtold and Patterson 2005). These estimates provide useful information about many forest resources, including amount of wildlife habitat. The suitability of forest land for wildlife habitat is dependent not only upon local characteristics and total area but also on the landscape pattern of forest habitat. For example, some neotropical migratory bird species require patches of forest habitat measuring at least several hundred hectares in area (Wenny *et al.* 1993). The number and size of individual forest patches and other metrics of landscape pattern typically are not estimated from FIA plot data, however (Riemann *et al.* 2003); such metrics are routinely derived from land cover maps by using spatial pattern analysis computer programs (Lister *et al.* 2003, McGarigal and Marks 1995). Associating independently acquired satellite image-based landscape metrics with FIA plot attributes is problematic due to differences in definitions between FIA forest land use and image-based forest land cover, temporal inconsistencies between plot and image acquisitions, and spatial misregistration between plots and map pixels. Thus, it is necessary to obtain estimates of landscape metrics that are more consistent with FIA estimates of standard forest attributes.

Although not designed specifically for estimating spatially explicit attributes such as landscape metrics, FIA plots do contain spatial information inherent in inventory cluster plot designs. This spatial information occurs within subplots, between subplots, and between plots (Kleinn 2000). Using between-subplot spatial information, inventory cluster plots can provide for estimates of the number and size of forest patches and the length and area of forest/nonforest buffers (Kleinn 2000). Kleinn (2000) described an approach for estimating metrics of landscape pattern, involving the assignment of subplot center points to forest or nonforest class, or other classes of interest. These estimates are most meaningful when the size of cluster plots is smaller than the size of forest patches and smaller than the distance between patches (Kleinn 2000), a requirement generally met by FIA's plot design. Van Deusen (2005) described a similar approach for estimating average patch size; he stated, "The possibility of making patch size estimates is unique to the mapped plot design." Kleinn (2000), however, previously demonstrated that nonmapped cluster plots provide for estimates of landscape metrics, including patch size.

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Because FIA cluster plots are mapped, they can be used with either Kleinn's (2000) or Van Deusen's (2005) approach, both of which require an assumption of typical patch shape. Kleinn's (2000) approach also allows for the analysis of other inventory data obtained from nonmapped cluster plots.

In this article, we apply Kleinn's (2000) approach to produce estimates of forest patch size and number, using nonmapped data from FIA annual inventory cluster plots. We then compare these FIA plot-based estimates with satellite image-based pixel estimates of forest patch size and the number of patches.

Data and Methods

FIA Plot Data

The study was conducted in Michigan, USA, a State that has 83 counties and 14.7 million ha of land area. According to FIA estimates from Michigan's first annual inventory (2000 to 2004), approximately 7.8 million ha of forest land occur within the State and constitute about half of the total land area.

At base Federal sampling intensity, one FIA annual inventory plot is established per approximately 2,400 ha. Each FIA ground plot comprises a cluster of four points, each surrounded by a 7.32-m (24-ft) fixed radius subplot within which subplot center points are assigned a land use class, land use conditions are mapped, and trees are measured (Bechtold and Scott 2005). FIA's four subplots consist of one central subplot and three peripheral subplots. Peripheral subplot centers are spaced 36.58 m (120 ft) from the center of the central subplot, at azimuths of 0, 120, and 240 degrees from the central subplot. Thus, the outer three subplots of FIA cluster plots form an equilateral triangle with a circumcircle through subplot centers of 73.152 m (240 ft) in diameter.

During Michigan's first annual inventory, FIA plots were sampled at an intensity three times greater than the base Federal sample intensity, resulting in 18,952 measured plots. Of these plots, 18,233 were fully sampled and had land use conditions recorded for all four subplots. Forty-five percent of these plots (8,211) had forest condition at all four subplot centers and 44 percent (8,015) had nonforest condition at all four subplot centers. Plots containing a mixture of forest and nonforest conditions at subplot centers constituted 11 percent (2,007) of the total number of plots, ranging from 3 to 22 percent across Michigan counties.

Landscape metrics were estimated following the approach defined by Kleinn (2000).

In short, Kleinn's (2000) approach uses an inventory cluster plot's shape and size to determine the probability of intersecting an imaginary forest/nonforest buffer, from which one can estimate mean patch size and the number of patches from observations of subplot center conditions. In this study, we knew FIA's cluster plot shape and circumcircle diameter, but we did not know typical patch shape; therefore, we calculated metrics using various assumptions of patch shape.

The triangular shape of FIA's three peripheral subplots determines a conditional probability of plot intersection with a forest/nonforest border, $P_{is} = \frac{3\sqrt{3}}{2\pi} = 0.82699$. The proportion of area in an estimation unit within an imaginary forest/nonforest buffer is $\hat{p}_s / P_{is}$, where $\hat{p}_s$ is the proportion of plots having a mixture of forest and nonforest subplot center conditions. A relationship between forest area and buffer area is defined as $\hat{k} = \frac{\hat{F}_{Forest}}{\hat{F}_{Buffer}} = \frac{\hat{p}}{\hat{p}_s} P_{is}$, where $\hat{p}$ is the estimated forest cover proportion. An estimate of mean forest patch size follows, $\hat{a} = \frac{1}{v}\hat{k}^2 d^2$, given the constant *v*, which relates to typical patch shape, and the FIA cluster plot circumcircle diameter $d = 73.152$ m , which was converted to $d = 0073152$ km to maintain the consistency of units of patch area estimates. We applied multiple constants of *v*, assuming shapes of forest patches to be circular, square, or one of several rectangular shapes with various length/width ratios. A standardized measure of relative patch size, independent of patch shape, is defined as $\hat{k}^2_{s\tan d} = \hat{k}^2 d^2$. The mean number of forest patches was estimated as $\hat{b} = \frac{\hat{p}F}{\hat{a}}$, where *F* is the known total area of an estimation unit. See Kleinn (2000) for additional explanation and for metrics of forest/nonforest perimeter length, buffer area, and estimates of precision.

Satellite Image-Based Land Cover Data

We used the National Land Cover Dataset (NLCD) of 1992 as our satellite image-based source of forest landscape metrics (fig. 1). The NLCD of 1992 has the following characteristics: thematic land cover data set of the conterminous United States, 30-m spatial resolution, derived from Landsat Thematic Mapper satellite imagery circa 1992, comprising 21 land cover classes, and produced by the U.S. Geological Survey (Vogelmann *et al.* 2001). Prior to calculating patch metrics, we updated the NLCD to capture recent development that had occurred since 1992 and we conducted additional processing to more closely conform with FIA's definitions of forest patch minimum area and width. To accomplish these preprocessing steps, we performed the following five sets of activities: (1) converted a vector data set of road networks to a 30-m raster data set; calculated road density using a convolution filter (moving window) with a circular, 7-pixel radius circle; and reassigned NLCD pixels within areas of high road density into one of five new "developed" classes, following the procedure of Lister *et al.* (2005); (2) aggregated the NLCD classes and five new developed classes into either forest or nonforest class; (3) clumped and eliminated isolated forest and nonforest pixel clusters such that the resulting data set contained no pixel clusters with fewer than four 30-m pixels; (4) bisected forest pixel clusters with Topologically Integrated Geographic Encoding and Referencing System (TIGER) roads data such that resulting forest patches would be bounded and constrained in size by roads; and (5) masked nonforest pixels to exclude them from subsequent analyses. Hereafter, this enhanced NLCD 1992 data set is referred to as NLCD+.

Figure 1.—*Landsat Thematic Mapper-based 30-m forest cover data set, Michigan, USA.*

Estimates of mean patch size and the number of forest patches were produced as follows. Unique patches of forest were identified using the REGIONGROUP command in the ArcInfo GRID software package. The command works by grouping adjacent pixels of the same class into discrete regions, assigning a unique number to each region, assigning a region's unique number to every pixel within that region, and producing a summary table that lists all regions and the count of pixels within each region. The number of forest patches is equivalent to the number of regions. The size of each patch was calculated as the product of the number of pixels per region multiplied by the size of each 30-m (0.09-ha) pixel. Per-county estimates of the number and mean size of forest patches were obtained by assigning each region to one county, based on the location of the geographic centroid of each region, and summarizing the regions within each county.

Comparison of Plot- and Image-Based estimates

Plot- and image-based estimates of per-county forest area, mean patch size, and the number of patches were compared using linear regression analyses. Estimates of the relative number of patches and relative patch size were computed as the ratio of county estimates to the statewide estimate for both patch size and the number of patches. Regressions of relative patch size were produced before and after applying a lognormal transformation to the per-county estimates.

Results

Michigan forest area estimates from FIA and NLCD+ were 78,155 and 79,392 km^2, respectively. The FIA estimate of Michigan forest land was about 52 percent of total land area, which includes noncensus water and inland census water, ranging from 9 to 88 percent among counties. The comparison of per-county forest area estimates from FIA and NLCD+ is described by the regression equation y = 0.9456x + 66.129, with R^2 = 0.9909. About 11 percent of Michigan FIA plots have a mixture of forest and nonforest among the three peripheral subplot center conditions, ranging across counties from 3 to 22 percent. The FIA estimate of Michigan area within a forest/nonforest buffer of 73.152 m (the diameter of the FIA plot circumcircle) in width was 13 percent, ranging across counties from 4 to 26 percent. FIA and NLCD+ estimates of mean size and the number of Michigan forest patches and corresponding county minimums and maximums are reported in table 1. When patch shape was assumed to be circular, FIA and NLCD+ estimates of patch size were 0.91 and 0.29 km^2, respectively, and estimates of the number of patches were 86,095 and 276,143, respectively. FIA estimates grew substantially larger for patch size and substantially smaller for the number of patches as patch shape parameters diverged from an assumption of circular patch shape (table 1). An estimate of $\hat{k}^2_{s\tan d}$, the standardized metric related to mean patch size, was 0.0722 for Michigan, ranging from 0.0042 to 0.7254 among Michigan counties when circumcircle diameter was measured in kilometers.

FIA estimates of per-county relative forest patch size (fig. 2) were moderately positively correlated with NLCD+ estimates before applying a lognormal transformation, y = 0.6783x + 0.4761, R^2 = 0.483, and more strongly positively correlated after applying a lognormal transformation, y = 0.7176x + 0.1207, R^2 = 0.8457.

Figure 2.—*Ratio of Forest Inventory and Analysis plot-based per-county mean forest patch size to statewide mean forest patch size, Michigan, USA.*

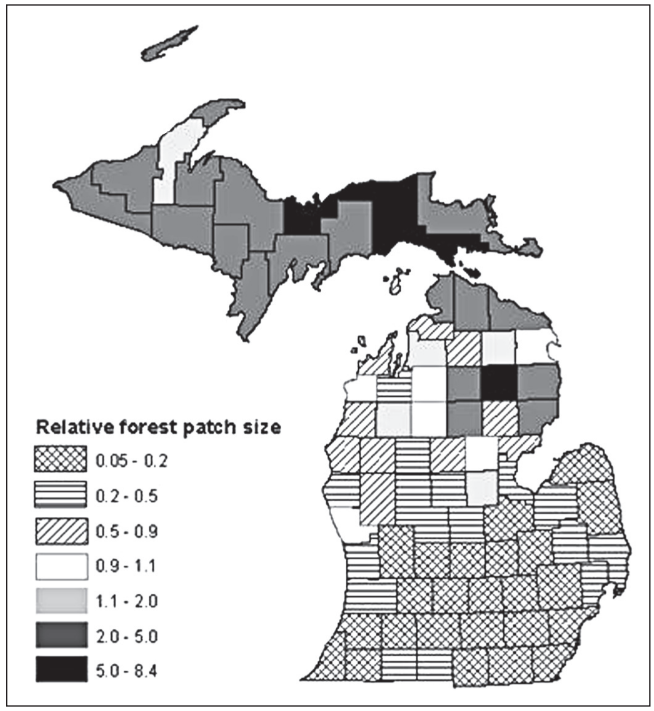

Table 1.—*Mean size and number of forest patches estimated from three peripheral subplot centers of FIA annual inventory cluster plots (per Kleinn 2000) and from an enhanced NLCD data set, MI, USA.*

Data source	Patch shape	Length/width factor	Patch size (km2)		Number of patches	
			MI	(County range)	MI	(County range)
FIA	circular	NA	1.06	(0.05 – 9.11)	73,719	(216–4303)
FIA	square	1	1.35	(0.07 – 11.61)	57,897	(169–3379)
FIA	rectangular	2	1.52	(0.08 – 13.06)	51,464	(150–3004)
FIA	rectangular	4	2.11	(0.11 – 18.13)	37,054	(108–2163)
FIA	rectangular	8	3.42	(0.17 – 29.38)	22,873	(67–1335)
FIA	rectangular	10	4.08	(0.20 – 35.11)	19,140	(56–1117)
FIA	rectangular	20	7.44	(0.37 – 63.98)	10,503	(31–613)
FIA	rectangular	50	17.56	(0.88 – 150.93)	4,452	(13–260)
NLCD	pixel region	NA	0.29	(0.04 – 2.98)	276,143	(429–7958)

FIA = Forest Inventory and Analysis. MI = Michigan. NA = Not applicable. NLCD = National Land Cover Dataset.

Discussion

In this study, we produced estimates of Michigan county mean forest patch area and the number of patches from FIA annual inventory subplot center condition data. Compared with NLCD+ estimates summarized by county, FIA estimates were comparable in total forest area, fewer in number of forest patches, larger in size of forest patches, and similar in relative size of forest patches. These results are similar to those of Riemann *et al.* (2003), who reported that NLCD-based estimates of Massachusetts forest patch size were smaller than estimates derived from aerial photo interpretation.

Although FIA estimates were closest to NLCD+ estimates when patch shape was assumed to be circular, these estimate pairs for both patch size and the number of patches still differed from each other by a factor of three. Explanations for this discrepancy are yet unknown but following are possible reasons. First, it was observed that the smallest NLCD+ forest patch size was 4 pixels for all Michigan counties, equivalent to 0.36 ha or 0.0036 km^2, which is the smallest region of pixels constrained by our preprocessing steps. These 4-pixel patches are slightly smaller than FIA's 0.4-ha (1-acre) definition of minimum forest area, resulting in a possible source of bias. Furthermore, except for 2x2-pixel configurations, 4-pixel clusters are narrower (30 m) than FIA's minimum width requirement of 36.576 m (120 ft). Forest patches 1 pixel wide and more than 4 pixels in length exceed FIA's minimum size requirement, but not the minimum width requirement. Within larger patches of forest, unimproved roads and nonforest strips narrower than 36.576 m or smaller than 1 ha are considered to be forest land, according to FIA definitions. Improved roads of any size are considered to be nonforest. We assumed all roads in the TIGER data set to be improved roads, thus nonforest. Further investigation is required to determine the distribution of these small pixel clusters and their effect on the discrepancy with FIA estimates of forest patch size and the number of patches.

Both Kleinn (2000) and Van Deusen (2005) require prior knowledge of patch shape, a parameter that is not derived from the inventory plot data themselves. Estimates of mean patch size and the number of patches vary greatly with patch shape. Sources of patch shape could include other field data (e.g., forest stand maps), analysis of remotely sensed data, or literature. A metric of relative patch size that is independent of patch shape was described by Kleinn (2000); such metrics allow for comparison between estimation units and inventories, independent of cluster plot configuration or patch shape, although they do not provide the specific information needed for assessing minimum area requirements of wildlife habitat.

FIA cluster plots contain only four subplots and results reported here are for estimates produced when using only the three peripheral subplots. Although estimates of precision are not reported here, we speculate that lower precision of patch size estimates may occur when using Kleinn's (2000) approach with FIA cluster plots than could be achieved with Van Deusen's (2005) mapped plot or with alternate cluster plot designs having more subplots. The comparison of estimates and the precision of those estimates from multiple approaches are recommended. Additional investigations are needed to develop operational protocols for integrating metrics of landscape and FIA attributes, which would provide for additional data, information, knowledge of our Nation's forests and their spatial pattern, and suitability for wildlife habitat and other ecological functions. Additionally, these metrics could be integrated with non-FIA inventory data obtained from nonmapped cluster plots of various designs.

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