Quantifying Forest Fragmentation Using Geographic Information Systems and Forest Inventory and Analysis Plot Data

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Abstract.—Fragmentation metrics provide a means of quantifying and describing forest fragmentation. The most common method of calculating these metrics is through the use of Geographic Information System software to analyze raster data, such as a satellite or aerial image of the study area; however, the spatial resolution of the imagery has a significant impact on the results. Forest Inventory and Analysis (FIA) plot data also provide a way of quantifying fragmentation using measurements collected on the ground. In this study, the relationship between fragmentation metrics (total edge length, edge density, and forest proportion) calculated using FIA plot data and satellite imagery at two different spatial resolutions, 30 m and 250 m, is compared. Results for total edge length and edge density showed that estimates derived from the 30-m data were consistently larger than those from the FIA data, while estimates from the 250-m data were consistently smaller than those from the FIA data. For forest proportion, the percent forest values found using FIA plot data were very similar to those calculated using satellite imagery.

Introduction

Forest fragmentation is the breaking up of large, contiguous tracts of forest into smaller, more isolated patches. Fragmentation has many negative impacts on vegetation and wildlife; therefore, it is important that fragmentation be accurately quantified for management and monitoring purposes. This task can be accomplished through the use of fragmentation metrics, which are measurements that quantify and describe landscape pattern. The most common method of calculating fragmentation metrics is through the use of Geographic Information System (GIS) software to analyze raster data, such as a satellite or aerial image of the study area; however, the spatial resolution of the imagery has a significant impact on the results of the fragmentation metric calculations, and it is not known which spatial resolution produces the most accurate results. We believe that Forest Inventory and Analysis (FIA) plot data can offer some insight into this problem. In this study, we compare the relationship between fragmentation metrics calculated using FIA plot data and satellite imagery at two different spatial resolutions (30 m and 250 m). The fragmentation metrics include total edge length, edge density, and forest proportion. Fragmentation is indicated by longer total edge lengths, higher numbers of edge density, and lower amounts of forest proportion.

Data

Study Areas

Three study areas (fig. 1), ranging from heavily to sparsely forested, were selected in Michigan. These particular areas were chosen because they each are adjacent to one of the Great Lakes, do not contain any large tracts of Federal land, and, finally, do not contain any large urban or metropolitan areas. Study area 1 is Marquette County, which is located in the Upper Peninsula and is bordered by Lake Superior to the north; study area 2 is a group of three neighboring counties (Alpena, Montmorency, and Presque Isle) in the northeast portion of the Lower Peninsula and is bordered by Lake Huron to the east; and study area 3 is also a group of three neighboring counties (Berrien, Cass, and Van Buren) in the southwest corner of the Lower Peninsula and is bordered by Lake Michigan to the west.

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FIA Plots

The national plot configuration (fig. 2) consists of four circular subplots, each with a 24-ft radius. The centers of subplots 2, 3, and 4 are located 120 ft from the center of subplot 1, and the azimuths to subplots 2, 3, and 4 are 360, 120, and 240 degrees, respectively. The national plot configuration also requires mapping the different conditions (forest land, nonforest land, noncensus water, or census water) that occur on any of the four subplots if the area of the condition is at least 1 acre in size.

Plots from the first annual cycle of Michigan (2000 to 2004) were used in this study. More specifically, only plots where both forest and nonforest conditions occurred on the same subplot(s) were selected from the FIA database for the three study areas. Since both forest and nonforest conditions were present, this condition indicated that there was at least one forest/nonforest edge on each selected plot. Additionally, edges between forest and water and edges that occurred outside the subplot boundary were not included. Out of a possible 1,313 field plots, 150 were selected for this study based on the criteria described previously.

Imagery

The first set of satellite imagery was from the 1992 National Land Cover Dataset (Vogelmann *et al*. 2001) and has a spatial resolution of 30 m. This data set was previously corrected using a roads layer from the TIGER 2000 data (U.S. Census Bureau 2000) to update the urban class because a number of urban areas were initially classified as forest. The imagery was then reclassified into two categories, forest and nonforest, from the original 24 land cover classes.

The second set of satellite imagery was Moderate Resolution Imaging Spectroradiometer imagery with 250-m spatial resolution. Originally, the pixels in this imagery contained percent forest values ranging from 0 to 100, so a threshold of 36 percent was used to classify the pixels into forest and nonforest categories (Nelson *et al.* 2005). Pixels with values between 0 and 35 percent were classified as nonforest, while pixels with values greater than 35 percent were classified as forest.

Figure 1.—*Study area locations in Michigan (ESRI 2002).*

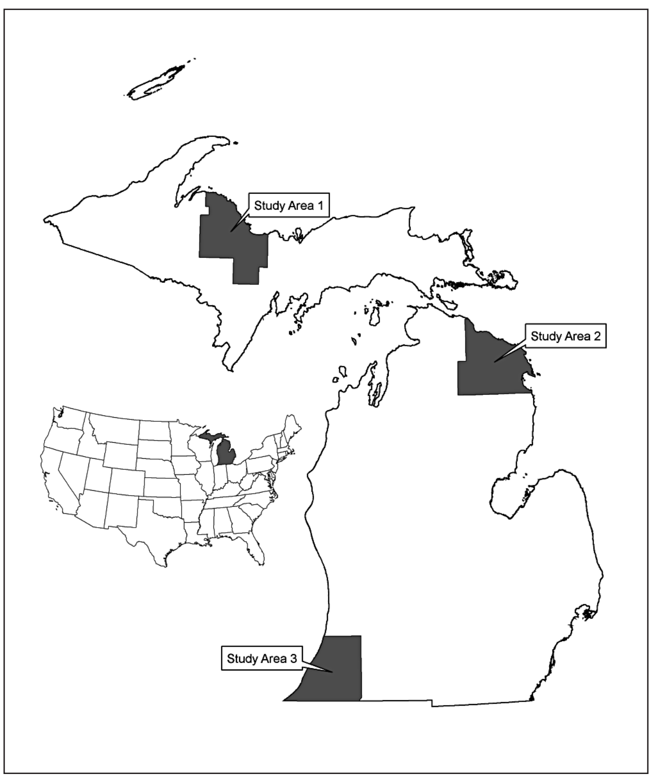
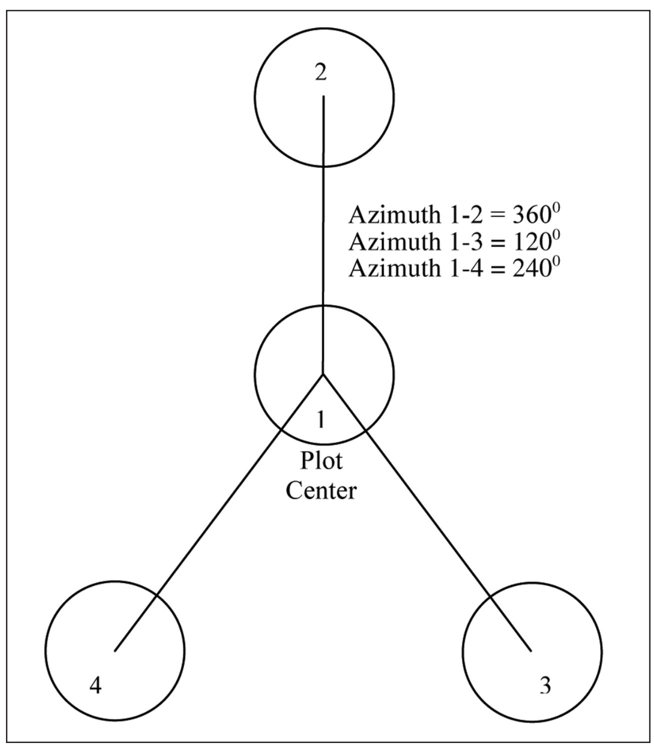


Figure 2.—*Forest Inventory and Analysis phase 2 plot configuration.*



Methods

Metric Calculations

Total Edge Length. The requirement to map different condition classes on subplots allows the boundary, or edge length, between the conditions to be obtained. For this study, however, the edge length was only obtained between forest and nonforest condition classes. This edge length may be measured as a straight line (fig. 3) or as two lines that meet at a corner (fig. 4). When two different conditions are encountered on a subplot and the edge is a straight line, the right and left azimuths are recorded, from subplot center, where the different conditions intersect the subplot circumference. Given that the radius of the subplot is fixed at 24 ft, the edge length has a maximum length of 48 ft. If the edge between the two conditions is not a straight line and contains a corner, however, a corner azimuth and a corner distance from the subplot center are also recorded. When this condition occurs, the total edge length may be longer than 48 ft, so, with the azimuth, radius, and/or corner distance information, the total edge length for both types of edges was calculated using the law of cosines:

$$a^2 = b^2 + c^2 - 2bc*\cos A$$

where a is the edge length and b and c are the length of the radii, or, when a corner is present, b and c are the lengths of the segments from the corner to the subplot circumference. The angle A is the angle in the triangle (opposite the straight-line edge) at the subplot center. When a corner was present, two angles were found and the law of cosines was used to find the two edge lengths, which were then summed to find the total edge length. After the edge lengths were obtained for each subplot, they were summed (if there was more than one subplot containing a forest/nonforest edge) to find the plot-level edge length total, which was then multiplied by the plot expansion factor. Finally, these expanded plot estimates were summed to find the total edge length for the study area.

To find the total edge length using the satellite imagery and GIS software, a short ARC Macro Language program was written to count the number of edges between the forest and nonforest pixels in the study area. Starting in the upper left corner of the image, all forest/nonforest pixel edges that occurred to the east and south of the subject center pixel were counted and the value was assigned to that pixel in an output grid. The numbers of edges in the output grid were summed and the total was multiplied by the spatial resolution to find the total edge length in meters. Meters were then converted to miles to reduce the large results and make it easier to compare the results.

Figure 3.—*How a straight boundary is measured on a subplot (USDA Forest Service 2005).*

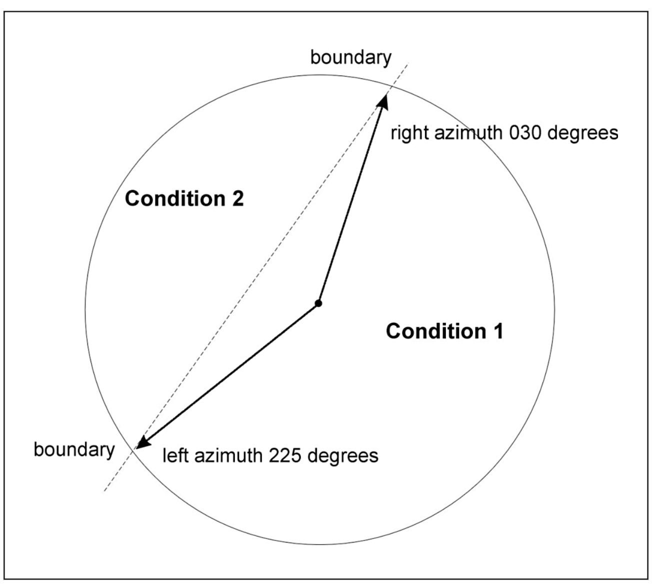
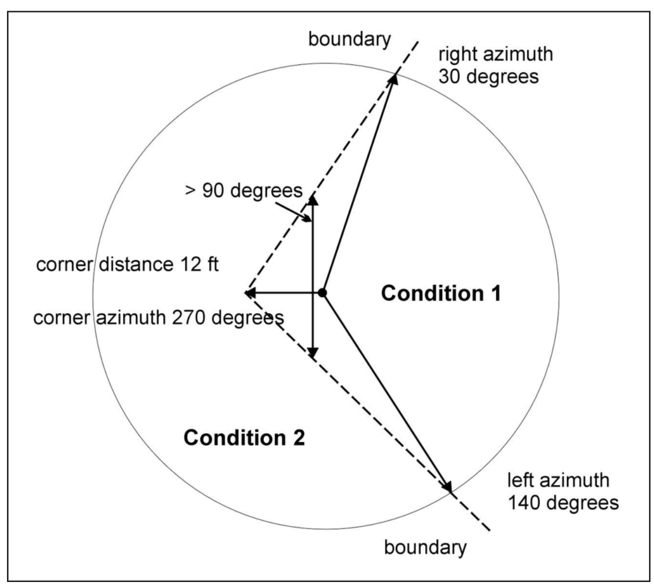


Figure 4.—*How a boundary with a corner is measured on a subplot (USDA Forest Service 2005).*



Edge Density. In an attempt to make the total edge length metric results more meaningful, they were converted to an edge density measurement: miles of edge per square mile of forest land. This procedure was accomplished by converting forest land area from acres to square miles. The total edge length in miles was then divided by the forest land area in square miles to obtain edge density.

Forest Proportion. The estimates of forest proportion found using FIA plot data were obtained by using two algorithms that expanded condition-level data (e.g., accessible forest, nonforest, noncensus water) from the FIA database to population estimates (Miles *et al.* 2001). Because each study area was considered a population, both algorithms were run for each area. The first algorithm calculated the area, in acres, of accessible forest land and the second calculated the total area of all land and noncensus water. The forest land area was then divided by the total area to find the proportion of forest. Estimates of forest proportion found using the satellite imagery were obtained by dividing the number of forest pixels by the total number of forest and nonforest pixels in each study area.

Results. The values obtained using FIA plot data and the satellite imagery approaches similarly separated the study areas into different levels of fragmentation through the use of the edge density and forest proportion metrics, but the approaches differed for total edge length (table 1). Study area 1, the most heavily forested, had the shortest total edge length. Study area 3, the most sparsely forested, had the longest total edge length according to the results found using the satellite imagery. The FIA plot data results showed that study area 2 had the longest total edge length (table 1), however. Overall, for all three study areas, the 30-m resolution imagery produced the longest edge lengths while the 250-m resolution imagery produced the shortest edge lengths.

In terms of edge density, in all cases, study area 1 had the lowest edge density and study area 3 had the highest edge density (table 2). Furthermore, the 30-m and 250-m images produced the highest and lowest results, respectively, as occurred with total edge length (table 2).

The results found for forest proportion (table 3) were similar for each study area using all three approaches. The proportion of forest in study area 1 differed by only 3 percent, but the FIA plot data and the 250-m imagery approaches produced the same result. The results for study area 2 were the most similar, and study area 3 had the widest range of results (table 3).

To further illustrate the degree of fragmentation in the three study areas, the percentages of field plots that were fragmented were also found by dividing the number of field plots that had forest and nonforest conditions by the total number of field plots in the study area. In study area 1, 6.4 percent of the field plots were fragmented. In study areas 2 and 3, 12.8 percent and 20.7 percent of the field plots, respectively, were fragmented.

Table 1.—*Total edge length metrics (miles) for three study areas in Michigan using three different approaches: (1) FIA plot data, (2) satellite imagery with 30-m spatial resolution, and (3) satellite imagery with 250-m resolution.*

Study area	FIA plot data	30-m resolution	250-m resolution
1	6908	14985	3578
2	11462	17912	6167
3	9135	23327	6710

FIA = Forest Inventory and Analysis.

Table 2.—*Edge density metrics (mile/mile2 of forest land) for three study areas in Michigan.*

Study area	FIA plot data	30-m resolution	250-m resolution
1	4.3	9.3	2.2
2	8.3	13.0	4.5
3	20.6	52.5	15.1

FIA = Forest Inventory and Analysis.

Table 3.—*Forest proportion metrics (percent) for three study areas in Michigan using three different approaches: (1) FIA plot data, (2) satellite imagery with 30-m spatial resolution, and (3) satellite imagery with 250-m resolution.*

Study area	FIA plot data	30-m resolution	250-m resolution
1	89	86	89
2	75	75	74
3	27	30	25

FIA = Forest Inventory and Analysis.

Summary

The objective of this study was to compare the fragmentation metric values calculated using FIA plot data with those calculated using satellite imagery obtained at two different spatial resolutions. Generally, the use of FIA plot data and 30-m and 250-m satellite imagery successfully separated the study areas into varying levels of fragmentation. In addition, forest proportion was similar among all approaches. The 250-m resolution imagery underestimated fragmentation, while the 30-m resolution imagery overestimated fragmentation, especially in study area 3, the most sparsely forested study area. This observation indicates that FIA plot data would produce other metric values similar to those found using satellite imagery with a spatial resolution somewhere between 30 and 250 m. Therefore, FIA data could potentially provide an answer to the question of which spatial resolution is the most appropriate for calculating fragmentation metric values. Accurate quantification of fragmentation would be valuable information that could be included in annual and 5-year State reporting.

Future work on this study will include calculating fragmentation metrics at a range of spatial resolutions, from less than 30 m. (e.g., 10 m) to resolutions between 30 and 250 m (e.g., 60 m, 90 m, 120 m), and will also include calculating additional metrics, such as average patch size. In addition, the relationship between metric values calculated using FIA plot data and those calculated at all of the various spatial resolutions will be further analyzed to find out exactly how spatial resolution impacts metric results. Finally, we hope this process will lead to useful conclusions about which spatial resolution is the most accurate and reliable for quantifying forest fragmentation.

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