

TECHNIQUES AND CONSIDERATIONS FOR FIA FOREST FRAGMENTATION ANALYSIS

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ABSTRACT.—The Forest Inventory and Analysis unit of the Northeastern Research Station (NEFIA) is charged with inventorying and monitoring the Nation's forests. NEFIA has not gathered much information on forest fragmentation, but recent developments in computing and remote sensing technologies now make it possible to assess forest fragmentation on a regional basis. We describe several options for calculating landscape statistics and provide guidelines on their use.

The forests of the Eastern United States have been subjected to decades of conversion and regrowth due to human activity, insects and diseases, fire and wind damage, and other factors. This pattern of change has led to a mosaic of forest patches of varying sizes across the region. Forest patches vary in quality with respect to watershed protection, biomass sequestration, wildlife habitat, species richness maintenance, forest product production, aesthetic values, recreation opportunities, and other amenities. Forest fragmentation can thus greatly affect ecological systems and human activities.

Forest Inventory and Analysis (FIA) of the USDA Forest Service conducts periodic assessments of the quantity, quality, distribution and health of the Nation's forests (USDA Forest Service 1992). The Northeastern Research Station's FIA unit (NEFIA) periodically remeasures nearly 30,000 field survey plots across the Northeast. For each plot, data are collected on the size and distribution of trees, land use, productivity, ownership, and tree quality (USDA Forest Service 2000). From these data, statistical summaries are created and statistical reports are produced. Also published are resource bulletins (e.g., Widmann 1995), which provide more extensive interpretation of the data than do the statistical reports.

References to forest fragmentation are conspicuously absent from, or occur very infrequently in, most NEFIA statistical

and analytical reports because the FIA plot design is such that a given ground plot is meant to represent 6,000 acres. The plots are thus considered to be sparsely distributed if the goal is to characterize landscape features that occur at scales finer than this. Also, no data directly related to forest patch size are collected on the NEFIA plots, so any attempt to make inferences about forest fragmentation based on the plot data alone is questionable.

It is unfortunate that FIA does not report on the spatial distribution of contiguous areas or patches of forest in a detailed manner. Much depth of analysis is lost when only coarse-scale patterns are mentioned and generalizations about the distribution of forest across a State are given. As the Forest Service unit charged with reporting on the quantity, distribution, use and health of the Nation's forest resource, FIA should include in its reports detailed information on the spatial distribution and configuration of forest patches.

In this paper we present a methodology and offer guidelines for developing a protocol for FIA reporting on forest fragmentation using classified Landsat Thematic Mapper imagery from the USGS National Land Cover Dataset (NLCD) (Vogelmann and others 2001). This data set provides continuous coverage of land cover information across the United States and can be analyzed using well-defined spatial statistical methods that were, until very recently, impractical to implement at the State or regional scale. The choice of specific metrics, considerations of patch definition (a critical component of any fragmentation study), and the choice of specific data sources are described in Riemann and others (2001). Here we review currently existing, free, and commercially available software for conducting the spatial analysis, and we provide guidelines for implementing the assessment and interpreting the results.

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Review of Available Software

Fragstats

Developed as a shareware software utility for analyzing and quantifying landscape structure (McGarigal and Marks 1995), FRAGSTATS has since been incorporated into other shareware as well as commercial landscape analysis programs. The vector implementation of the program was written as a suite of Arc/Info Arc Macro Language (AML) programs (ESRI, Redlands, CA 92373). The raster implementation was written in the C programming language. There is currently a newer, GUI-based version of FRAGSTATS produced by programmers at the University of Massachusetts and available as shareware on the Web, but we do not have experience using it. Since raster data are the most widely available sources for raw fragmentation data on a regional scale, we will hereafter refer only to the raster capabilities of the software described here. A discussion of the full range of metrics that FRAGSTATS returns is beyond the scope of this paper; see McGarigal and Marks (1995) for specifics.

The most useful version of FRAGSTATS for landscape analysis at the coarse scale is the compiled DOS version of the raster implementation or the C version available for compilation on UNIX platforms. The program requires command line entry of parameters and prompts the user in a relatively straightforward manner for inputs. It accepts various image formats as well as ASCII text files in a special format. Program output is the fragmentation statistics in well-formatted tabular format and optional output images that assign each patch a unique patch-id. Indeed, this "patch grid" and its cross-reference to the original raster file form the basis for most of the programs and analyses described here. Although the raster implementation of the program is written in C, our experience is that for large landscapes; e.g., 20 by 20 km, FRAGSTATS is extremely slow or does not run at all. Because of this limitation and the difficulties associated with formatting input and output files, we did not choose FRAGSTATS as the software solution for regional assessments of fragmentation. The program can be useful, however, for assessments at a finer scale (e.g., townships).

Created by Elkie and others (1999), Patch Analyst is a shareware graphical interface for FRAGSTATS that runs as an extension to ArcView GIS (ESRI, Redlands, CA 92373)². The parameter entry is GUI-based and the user manual is written

clearly. One of the benefits of Patch Analyst is the ability to use ARC grid format raster files directly rather than the images that are required by the native FRAGSTATS implementation. The tabular output is formatted for quick import into a spreadsheet package, and any raster outputs are saved as Arc/Info grids. The major disadvantage, however, is that the user must operate within the confines of ArcView and its associated sluggish use of memory. As a result, processing time is much greater with Patch Analyst than with DOS FRAGSTATS, even though the basic programs are the same.

ARCVIEW AND ARC/INFO

The ARC software packages do not provide for analysis of landscape fragmentation analysis directly, but with a limited amount of knowledge of the command syntax, users can create many custom analyses that perform some of the same analyses as other bundled landscape fragmentation software. The commands that follow are very useful for fragmentation analysis. Each must be used with the ARC grid file format and in the GRID program within Arc/Info unless otherwise specified. When multiple areas within an image, such as counties, are to be analyzed, the command **gridclip** can be incorporated into an AML macro to create subsets of the original image. If gridclip does not perform well, a grid with binary values can be created from a vector representation of the study area using the ARC command **polygrid**, and this grid can be combined additively or multiplicatively with the image grid so as to create a subset that encompasses the study area. Contact the senior author for example code and for other ways to automate the following procedures.

- 1. regiongroup:** **Regiongroup** is the most fundamental of the grid commands for generating a landscape. It takes an integer ARC grid file (e.g., a classified satellite image converted to a grid using the **imagegrid** command) and assigns groups of contiguous pixels a unique patch-id (e.g., figure 1). There is a contiguity rule to define; i.e., the user must ask if he or she wants to include diagonal pixels or only pixels that are directly adjacent on the long side of the pixel to be evaluated. In figure 1, diagonal

pixels were considered to be members of a patch. Once the region coverage (hereafter, patch grid) has been created, one can simply examine its value attribute table (.vat) to derive information. The ARC commands **statistics** or **frequency** can be used to summarize the .vat when there are too many records for practical export to a statistical software package. The first part of table 1 is the .vat from the patch grid

(right) of figure 1. Note that 11 patches were formed from the input binary grid. Table 1 shows the patch-id, the count of pixels in that patch, and the value of the original grid that each patch represents (link). With this information, one can calculate an average patch area. Note that there are a large number of pixels for patch #2, which is actually the matrix, or nonforest background of the landscape, so including it in any

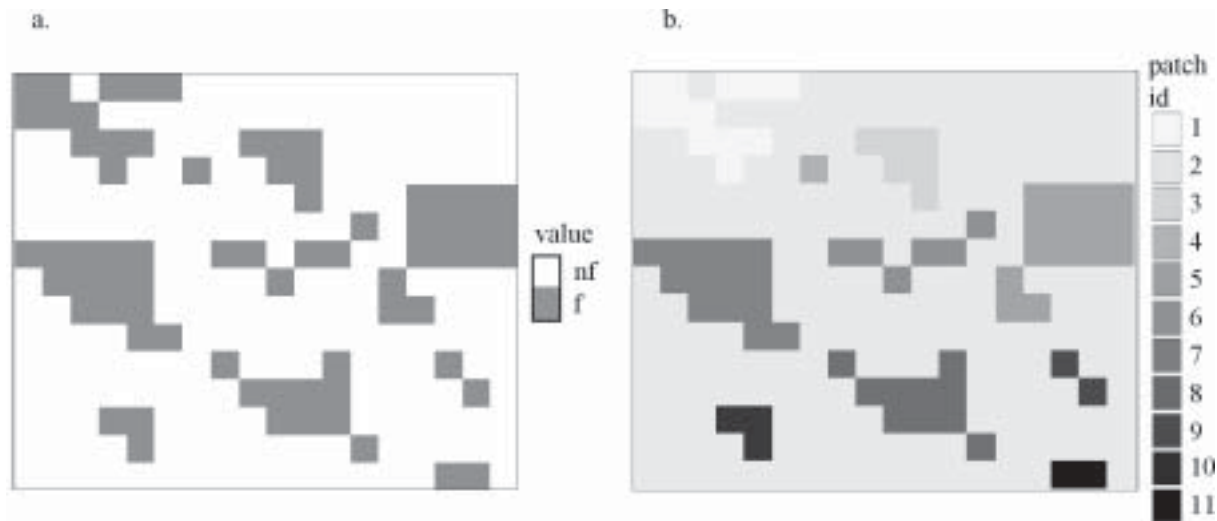


Figure 1.—a: Portion of an NLCD image that has been reclassified to forest (gray) and nonforest (white) using the Arc Grid command **reclass**; b.: Output of the **regiongroup** command (see text). Note that the contiguous areas of forest were assigned unique patch id values 1-11, and that contiguity was defined by the 8-neighbor rule (diagonal pixels are considered adjacent). Patch 2 is the matrix, or nonforest background. This patch should be excluded from analyses that might be skewed by its inclusion (e.g., average patch area).

Table 1.—Example of .vat of the output grid generated by **regiongroup** (Value, Count, and Link), merged to the output table from **zonalgeometry** (Area, Perimeter, Thickness, Xcentroid, Ycentroid, Major and Minor Axis, and Orientation)

Value	Count	Link	Area	Perimeter	Thickness	Xcentroid	Ycentroid	Major_Axis	Minor_Axis	Orientation
1	12	1	10800	780	15	2006588	2392070	73	46	173
2	199	0	179100	5640	51	2006776	2391882	259	219	16
3	6	1	5400	360	15	2006798	2392020	54	31	135
4	1	1	900	120	15	2006698	2392010	16	16	90
5	15	1	13500	660	45	2006970	2391934	87	49	43
6	6	1	5400	600	15	2006803	2391920	78	22	10
7	14	1	12600	600	45	2006599	2391885	89	44	147
8	10	1	9000	660	15	2006812	2391761	77	36	157
9	2	1	1800	240	15	2006983	2391785	41	13	135
10	3	1	2700	240	15	2006628	2391730	38	22	135
11	2	1	1800	180	15	2006983	2391680	33	16	0

calculation will bias patch metrics that are constructed by averaging individual patch values.

2. **zonalgeometry:** **Zonalgeometry** is a command for assessing the geometry of each patch in the patch grid. Table 1 shows the area, perimeter, thickness (radius of the largest circle that can be completely contained by the patch), and various parameters that describe the ellipse that best approximates the patch's shape and location (centroid coordinates, major and minor axis length, and orientation). Average patch perimeter and area are common landscape metrics that help analysts better understand the composition of a landscape. Thickness and average axis length ratios can suggest the value of a landscape's patches for maintaining interior forest-dwelling species. Average distance between patch centroids can be calculated by converting the centroid coordinates to a point coverage using the ARC **generate** function, and then summarizing the output table from the ARC command **pointdistance**. Be advised that irregularly shaped patches and landscapes with a clumpy distribution of patches can confound this measure.

3. **core areas:**

Core areas are the internal portions of the patches that are not affected by edges, or interfaces between; e.g., forest and nonforest. They are probably the most useful landscape units with which to conduct an analysis because they are the most biologically meaningful. To create a core area grid, the user must first define an edge width of interest. A somewhat arbitrary choice might be 30 m for a classified Landsat Thematic Mapper data set; this would suggest that the analyst assumes that there is a 30-m buffer of questionable forest around the edge of a forested patch found on the original patch grid. Once this is decided, a user-defined filter can be created using ARC grid's **focal functions** or the **shrink** command, which shrinks the size of patches composed of specific classes; e.g., forest, by a specified number of pixels. The result is a grid for which the boundaries of the patches of interest are converted to either no data or the value of the matrix. As illustrated in figure 2, the patch-level statistics that are derived when examining only core areas derived with the shrink function will differ greatly from those derived when the entire landscape is used.

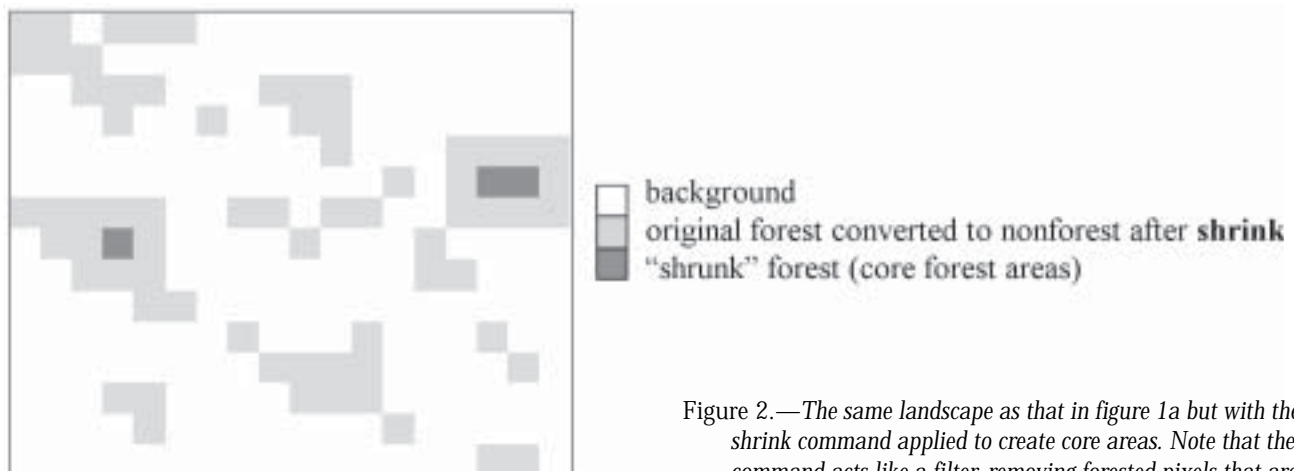


Figure 2.—The same landscape as that in figure 1a but with the *shrink* command applied to create core areas. Note that the command acts like a filter; removing forested pixels that are within 1 pixel of a nonforest boundary.

One also might wish to define meaningful areas of forest or create core areas by clipping out forest patches using roads. It is possible to convert U.S. Census Bureau Tiger Line Files (U.S. Census Bureau 2000) into grids by converting Arc coverages into grids using the **linegrid** command. Next, using one of the grid reclassification functions (e.g., **reclass**), each pixel is assigned a value of no data for road, 0 for no road. This new grid can serve as a mask for excluding analyses on tree-covered areas affected by roads (by using **setmask**) or as a way to split contiguous forest patches into smaller, more meaningful units (Heilman and others 2001)².

ArcView scripts and extensions that perform these analyses (e.g., Grid Transformation Tools and Grid Generalization Tools) can be downloaded free of charge from the ESRI Web site. They require Spatial Analyst, a commercial ArcView extension, however. Although it is appealing and convenient to work within the GUI framework of ArcView, it is not as stable as UNIX Arc/Info when processing large ARC grid file formats.

APACK

APACK was created at the University of Wisconsin's Forest Landscape Ecology lab as a shareware tool for processing large raster data sets consisting of landscape information (e.g., classified satellite imagery). It calculates many or most of the landscape statistics available from FRAGSTATS and some additional ones (see Mladenoff and DeZonia (2001) for details). Like FRAGSTATS, APACK has a command line parameter entry. Unlike FRAGSTATS, it does not interactively prompt the user for information, but this is only a slight inconvenience because the program's command reference manual is very easy to use.

² Heilman, G.E.; Strittholt, J.R.; Slosser, N.C.; DellaSala, D. [In prep.]. Forest fragmentation of the conterminous United States: assessing forest intactness through road density and spatial characteristics. In review; data and publication on file at the Conservation Biology Institute, Corvallis, OR 97333.

The authors of APACK report that its outputs compare closely with those of FRAGSTATS (we have verified this with our own tests), suggesting that the software is well written compared to FRAGSTATS. However, the primary advantage of APACK over FRAGSTATS is that the processing time is reduced dramatically. For example, with APACK, a 30-m NLCD image encompassing an area consisting of several tens of thousands of square kilometers can be processed in less than 15 minutes using a Pentium 500 MHz computer with 256 Meg of RAM. When the same analysis was run with FRAGSTATS, we experienced unexplained crashes and freezes. We later confirmed from discussions with colleagues that FRAGSTATS is not well suited for analyzing areas that are this large in a reasonable amount of time.

Another advantage of APACK is the flexibility and suitability of its output for direct transfer into a spreadsheet for processing. Formatting poorly organized output files is time consuming when hundreds of landscapes are analyzed in batch mode with FRAGSTATS or APACK. The following is a sample section of an APACK batch file that creates one run of APACK for each of several Massachusetts counties (coded 1, 3, and 5):

```
apack -f(gis) -UL(M) -UA(HA) -P(-) -
b(0) maforest1.gis maforest1.gisout aa
aan ai ap asm co col cor do dor ed pa
swd aa aan ai ap ar ed ede pa pac ps ra
sp
```

```
apack -f(gis) -UL(M) -UA(HA) -P(-) -
b(0) maforest3.gis maforest3.gisout aa
aan ai ap asm co col cor do dor ed pa
swd aa aan ai ap ar ed ede pa pac ps ra
sp
```

```
apack -f(gis) -UL(M) -UA(HA) -P(-) -
b(0) maforest5.gis maforest5.gisout aa
aan ai ap asm co col cor do dor ed pa
swd aa aan ai ap ar ed ede pa pac ps ra
sp
```

This batch file can be created easily in a spreadsheet by sequentially increasing the cell values containing the file names and copying the remainder. Note that in the previous example the general processing parameters precede the input and output file names, followed by a list of the desired metrics (see Mladenoff and DeZonia 2001 for a description

of the parameter entry). Note also that the input file extension is .gis, or ERDAS 7.x file format. This file format can be created directly in an image processing package like ERDAS Imagine (ERDAS, Atlanta, Georgia 30329) or by using the **gridimage** and/or **imagegrid** commands in Arc/Info.

Another advantage of APACK over other programs is that it provides adjacency matrices. The rows and columns of these matrices are the land use classes and the entries are the length of shared boundary between each combination of land uses. This information alone can dramatically increase a data consumer's understanding of the relationships between forested areas and their surroundings. For example, it is clear that two counties with equal areas of forest land can have a very different length of forest-agriculture and forest-urban boundary. A clear understanding of this difference will aid decisionmakers.

CONCLUSIONS

Analyzing the spatial distribution of forest cover is an essential component of reports by FIA and other Forest Service units that describe the distribution, quantity, use, and health of forest resources. With freely available software like APACK, one can rapidly produce fragmentation summaries for different-sized areas. NEFIA plans to produce county-level summaries of the APACK statistics and to make them available to both the FIA analysts and the public. As new data sources become available (e.g., the revision of the 1992 NLCD product (Yang and others 2001)), it will be possible to assess changes in fragmentation through time. Our aim is to increase the value of FIA statistical and analytical reports, to create new opportunities for analysis, and to broaden understanding of the forests in the Northeastern United States.

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