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The effects of forest fragmentation on forest stand attributes

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ABSTRACT

For two study areas in Minnesota, USA, one heavily forested and one sparsely forested, maps of predicted proportion forest area were created using Landsat Thematic Mapper imagery, forest inventory plot data, and a logistic regression model. The maps were used to estimate quantitative indices of forest fragmentation. Correlations between the values of the indices and forest attributes observed on forest inventory plots were estimated. One interesting result was a statistically significant negative correlation between total forest area and number of tree species per unit forest area.

Keywords and phrases: inventory plots, correlation, species richness

1.0 INTRODUCTION

Over the last decade, natural resources managers, the scientific community, and the general public have voiced serious concerns regarding the status of and emerging trends in the world's forests. In 1993, the Government of Canada initiated a series of meetings with the goal of developing scientifically rigorous methods for evaluating forest management. These meetings led to the Montreal Process criteria and indicators for environmental and ecological assessments of forest sustainability. A criterion is a category of conditions or processes by which sustainable forest management may be evaluated and is further characterized by a set of indicators that are monitored periodically to assess change. Four of the seven Montreal Process criteria deal with forest conditions and attributes: (1) conservation of biological diversity; (2) maintenance of productive capacity of forest ecosystems; (3) maintenance of forest ecosystem health and vitality; and (4) maintenance of forest contribution to global carbon cycles. Forest fragmentation is an indicator corresponding to several of these criteria.

The objectives of this study were to evaluate the effects of forest fragmentation on a variety of forest stand attributes. The study was conducted in two areas, designated St. Louis and St. Cloud, in the State of Minnesota, USA (Figure 1). The St. Louis study area encompasses most of St. Louis county, includes approximately 2.1 million hectares of which approximately 75 percent is forest land, and is dominated by Spruce-Fir associations. The St. Cloud study area contains the St. Cloud urban area, includes approximately 3.3 million hectares of which slightly more that 20 percent is forest land, and is characterized by prairie agriculture and a diverse mixture of both coniferous and deciduous species.

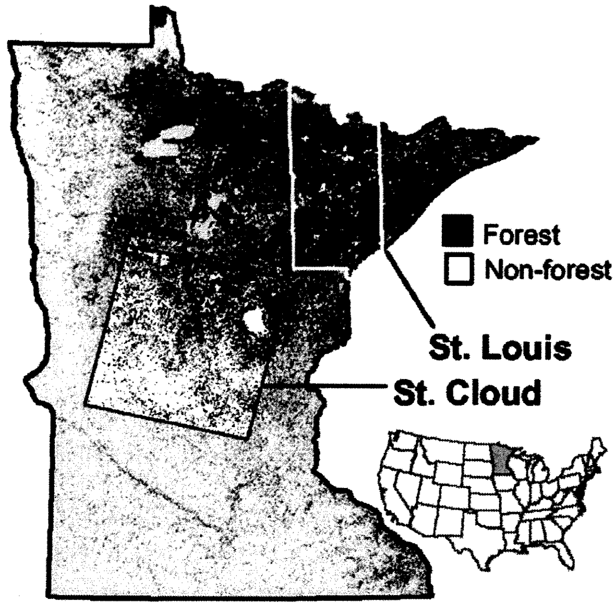

Figure 1. Minnesota study areas.

2.0 DATA AND METHODS

2.0 Inventory plot data

The Forest Inventory and Analysis (FIA) program of the Forest Service, U. S. Department of Agriculture, has established an array of field plots in permanent locations using a systematic sampling design. A fixed proportion of plots are measured each federal fiscal year (01 October – 30 September). Plots measured in the same year comprise a single panel of plots, and panels are selected for measurement on a rotating basis. In aggregate, over a complete measurement cycle of five years, a plot represents approximately 2,403 hectares. In general, locations of forested or previously forested plots are determined using global positioning system receivers, while locations of non-forested plots are determined using digitization methods. Each field plot consists of four 7.31-m radius circular subplots configured as a central subplot and three peripheral subplots with centres located at 36.58 m and azimuths of 0°, 120°, and 240° from the centre of the central subplot (Figure 2). For each tree, field crews obtain observations of species, live or dead status, and diameter at breast height (DBH) (1.37 m). Regression models are used with observed DBH as an independent variable to predict the volumes and biomasses for individual trees. In addition, field crews note evidence of disturbance due to both natural and human causes, estimate the number of seedlings, and estimate the proportions of each subplot that satisfy specific ground land use conditions. Subplot estimates of forest land proportions are obtained by aggregating these ground land use conditions into forest and non-forest uses. Plot-level estimates of number of species, number of live and dead trees, biomass in live and dead trees, live tree volume, number of seedlings per unit area, and average stand diameter were obtained by aggregating over individual trees and subplots. For both study areas, observations were available for the 1999 and 2000 panels of plots with 748 plots for the St Louis study area and 822 plots for the St. Cloud study area.

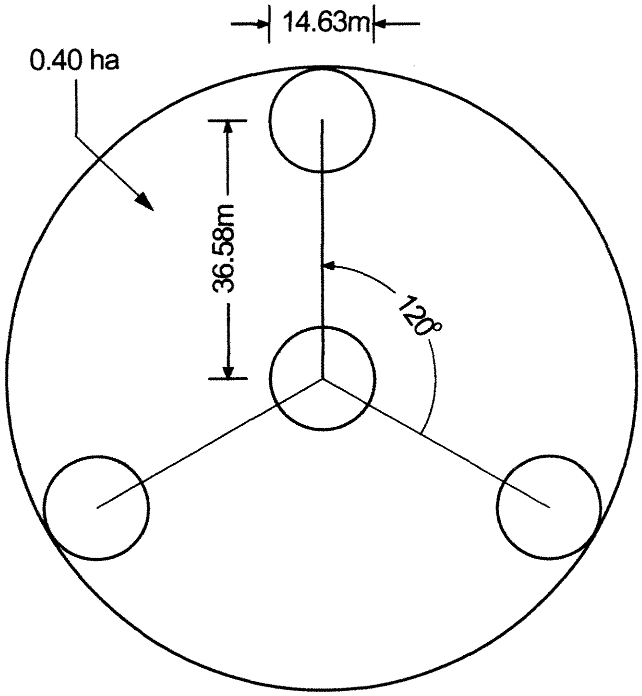

Figure 2. Forest inventory and analysis plot configuration

2.2 Satellite imagery classification

Landsat TM imagery, classified with respect to forest and non-forest, was used as the basis for quantifying fragmentation. The St. Louis study area is covered by the Landsat TM path 27, row 27 scene. For this scene images were obtained for three dates: 05 November 1999, 31 May 2000, and 05 July 2001. The St. Cloud study area is covered by the Landsat TM path 28, row 28 scene. For this scene images were also obtained for three dates: 23 July 1999, 27 October 1999, and 03 March 2000. For each scene, the images consisted of 30 m x 30 m pixels for bands 1-5 and band 7, were geo-referenced to Albers Equal Area projection, NAD 83, and for different dates were geo-referenced to each other.

The first step in the classification was to calibrate a model for predicting the proportion forest land for each image pixel. Because forest land proportions are always in the closed interval [0,1], it is appropriate to select a model with mathematical properties that restrict predictions to the same interval. The logistic model is often used with such data and was selected for this study to describe the relationship between observed forest land proportion for FIA subplots and the spectral values of the pixels containing the subplot centres,

$$E\left(Y_k\right) = \frac{1}{1 + \exp\left(\beta_0 + \beta_1 X_{1k} + \beta_2 X_{2k} + \ldots + \beta_p X_{pk}\right)}$$

where E(.) denotes statistical expectation, Y_k is the forest land proportion for the k^{th} subplot, X_{jk} is the spectral value for the j^{th} band for the pixel containing the centre of the k^{th} subplot, and the βs are parameters to be estimated. For each study area, all possible band combinations were compared with respect to root mean square error, and the combination with the smallest root mean square error was selected.

After calibration, the models were used to predict forest land proportion for each pixel in each study area. In accordance with the practice of other mapping agencies, pixels with proportion forest land predictions less that 0.25 were designated non-forest, and pixels with forest land predictions equal to or greater than 0.25 were designated forest. For the St. Louis study area, slightly more the 90 percent of the forest plots were correctly classified, while slightly less that 90 percent of the non-forest plots were correctly classified. For the St. Cloud study area, slightly more than 90 percent of the non-forest plots were correctly classified, while slightly less than 90 percent of the forest plots were correctly classified.

2.3 Correlation analyses

For the 0.4-ha circle circumscribing the four subplots of each FIA plot, four measures of forest fragmentation were obtained: forest edge length, edge forest area, interior forest area, and total forest area. Forest edge length was calculated as the total length within the 0.4-ha circle of the forest/non-forest boundary between pixels classified as forest and pixels classified as non-forest; edge forest was calculated as the total area within the circle of forest pixels within two pixel widths of the forest/non-forest boundary; interior forest area was calculated as the area within the circle of forest pixels greater than two pixel widths from the forest/non-forest boundary; and total forest area was calculated as the sum of edge and interior forest area. The three area measures were divided by the total area of the 0.4-ha circle and were analyses as proportions of that area.

The first stage of analysis consisted of simple correlation analyses between the estimates of forest attributes and the four measures of forest fragmentation (Table 2). Plots with no forest land within the 0.4-ha circle were excluded from the analyses as were plots with evidence of human-caused disturbance, leaving 504 plots for the St. Louis study area and 169 plots for the St. Cloud study area. The forest attribute measures previously described were all divided by the total forest area to scale estimates to a per unit forest area basis. The observed high negative correlations between number of species per unit forest area and total forest area were of particular interest and suggested that the number of species per unit of forest area may be greater when forest fragmentation is greater. This result warrants further investigation, because lesser fragmentation and greater species richness, defined as the number of species per unit area, are both generally viewed as having positive impacts on forest sustainability. The observed result, however, suggests that greater species richness is observed in conjunction with greater, not lesser, fragmentation.

Table 1. Estimated correlations between measures of forest fragmentation and forest stand attributes[1].

Forest attribute	St. Louis study area				St. Cloud study area			
	Edge length	Edge forest area	Interior forest area	Total forest area	Edge length	Edge forest area	Interior forest area	Total forest area
No. species	**0.393**	**-0.105**	-0.002	**-0.355**	**0.389**	**-.271**	-0.105	**-0.624**
No. trees	0.075	0.070	**-0.099**	-0.042	0.025	0.069	**-0.186**	-0.145
No. live trees	0.077	0.070	**-0.098**	-0.040	0.026	0.071	**-0.188**	-0.145
No. dead trees	0.038	**-0.088**	0.024	**-0.228**	-0.002	-0.022	-0.003	-0.043
Biomass-total	-0.001	**0.109**	**-0.121**	0.024	**0.356**	**-0.200**	-0.036	**-0.400**
Biomass-live	0.015	**0.133**	**-0.142**	0.024	**0.372**	**-0.214**	-0.027	**-0.413**
Biomass-dead	-0.069	-0.024	0.018	-0.027	0.035	0.015	-0.069	-0.073
Seedlings	**-0.094**	0.076	**-0.090**	0.000	**0.162**	-0.075	-0.134	**-0.323**
Volume-live	0.009	**0.101**	**-0.107**	0.035	**0.341**	**-0.225**	-0.010	-0.046
Mean DBH	0.027	-0.012	-0.011	-0.072	**0.274**	**-0.287**	-0.085	**-0.623**

[1] Estimates in bold are statistically significant at α=0.05.

The second stage of analysis focused on the relationships between total forest area in the 0.4-ha circle and number of tree species per unit of forest area on the four subplots. A graph of this data for the St. Cloud study area reveals that the number of species per unit of forest area declines as total forest area increases (Figure 3). Thus, there is reason to believe that the high, statistically significant negative correlation between tree species per unit forest area versus total forest area may be a genuine phenomenon and not simply an arithmetic artifact.

Summary

In brief summary, a forest/non-forest classification of satellite imagery provided a good means of estimating quantitative measures of forest fragmentation such as edge length, edge forest area, and interior forest area. Further, these measures may be easily correlated with estimates of forest attributes obtained from forest inventory plot data. A number of statistically significant results were obtained, including negative correlations for both study areas between total forest area and number of tree species per unit forest area, a measure of species richness. This correlation suggests that two positive indicators of forest sustainability, a small degree of forest fragmentation and a large degree of species richness perhaps should not be expected to occur simultaneously. However, checks must be made to determine if the number of different species that actually are observed on highly fragmented forest land is in the vicinity of 12 as indicated by Figure 3a.

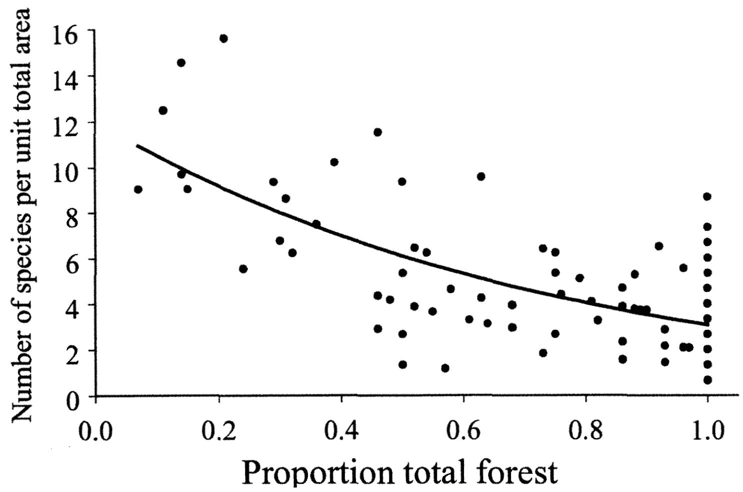

Figure 3. Number of species per unit forest area versus proportion of plot in forest.

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