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# Landscape patterns in a disturbed environment

J. R. Krummel, R. H. Gardner, G. Sugihara, R. V. O'Neill and P. R. Coleman

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Deciduous forest patterns were evaluated, using fractal analysis, in the U. S. Geological Survey 1: 250,000 Natchez Quadrangle, a region that has experienced relatively recent conversion of forest cover to cropland. A perimeter-area method was used to determine the fractal dimension; the results show a different dimension for small compared with large forest patches. This result is probably related to differences in the scale of human versus natural processes that affect this particular forest pattern. By identifying transition zones in the scale at which landscape patterns change this technique shows promise for use in developing hypotheses related to scale-dependent processes and as a simple metric to evaluate changes on the earth's surface using remotely sensed data.

*J. R. Krummel, R. H. Gardner, G. Sugihara and R. V. O'Neill, Environmental Science Div., Oak Ridge National Lab., Oak Ridge, TN 37831, USA. P.R.Coleman, Computing and Telecommunications, Oak Ridge National Lab., Oak Ridge, TN 37831, USA (present address of JRK: Energy and Environmental Systems Div., Argonne National Lab., Argonne, IL 60439, USA).*

Natural land cover patterns occur as a result of complex interactions between climate, terrain, soil, water availability, and biota (Whittaker 1975). The alteration of natural land cover patterns by humans is well known (Curtis 1956): through urbanization, agriculture, and forestry, part of the natural vegetation is removed and replaced with managed systems of altered structure. The resulting landscape is a mixture of natural and human-managed patches of different sizes and shapes. The size-shape relationships of the altered land cover can influence a number of important ecological and environmental phenomena (Burgess and Sharpe 1981, Beasley and Huggins 1981) such as animal dispersal, surface water runoff, speciation, and extinction. Understanding how the geometric shape and size of the land cover patterns are related to natural and human processes can help in determining the appropriate spatial scales to use in studying ecological or environmental systems (Wilson and Willis 1975, Loehle 1983).

Quantifying environmental heterogeneity has been an ongoing objective of ecology and other branches of environmental science (Patil et al. 1971, Pielou 1977). However, natural boundaries are so complex that most techniques developed to date detect only certain kinds of patterns (Loehle 1983). Mandelbrot's (1977) development of fractals has made it possible to quantify complex boundaries or patch shapes and relate these patterns to the underlying processes that may affect pattern complexity. Mandelbrot introduced fractal analysis as a method to study spatial phenomena that are partially correlated over many scales and are continuous but not differentiable. In this paper we present the results of a perimeter-area method (Mandelbrot 1977, Lovejoy 1982) to determine the fractal dimension of deciduous forest patches in the U. S. Geological Survey (USGS) Natchez, Mississippi, 1: 250,000 Quadrangle. The results show a different fractal dimension for small compared with large patches of deciduous forests. These differences imply spatial scale changes in the underlying processes that control the shape complexity of forest patches in this region. Changes in the fractal dimension are most likely related to differences in the scale of human versus natural processes that control this particular forest pattern.

The Natchez Quadrangle incorporates the Mississippi Floodplain of central Louisiana and southern Missis-

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sippi and a portion of the uplands in southern Mississippi. According to the potential vegetation map of Küchler (1969), the dominant type of deciduous forest in this region would be Southern floodplain forest with a band of oak-hickory forest along the western edge of the Mississippi uplands. However, over the last 30 yr much of the deciduous forest in the Mississippi floodplain has been cleared for agricultural crop production (USGS 1950, 1973). Thus, this region has experienced extensive alteration of the natural land cover patterns by humans.

The USGS digital land use and land cover data base (Fegeas et al. 1983) provides perimeter-area data of the deciduous forest patches in the Natchez Quadrangle. The data originate from NASA U2/RB-57 high-altitude aerial photo coverage in 1973, and from these photos land cover types are delineated into 1 of 37 Level II land cover categories. The Natchez land cover data set contains 505 separate patches of deciduous forest. The minimum polygon (patch) size is set at approximately 16 ha, based on the provision that the minimum width of a polygon must be greater than 400 m. The median patch size is 74 ha, with the largest patch totaling 62,866 ha. The resolution of the internal coordinate units used in the calculation of the perimeter and area is 10 m. Because the original USGS data set divides the 1: 250,000 Natchez Quadrangle into 24 separate sections, a special computer program was written to reformat the arc and node topological elements of the polygons and remove section boundaries that arbitrarily dissect polygons along those boundaries. This allows, for the first time, an analysis of the entire quadrangle as one complete landscape data set.

Mandelbrot (1977) proposed and Lovejoy (1982) used a perimeter-area method to calculate the fractal dimension of natural planar shapes. The perimeter-area method quantifies the degree of complexity of the planar shapes. The degree of complexity of a polygon is characterized by the fractal dimension D, such that the perimeter P of a patch is related to the area A of the same patch by $P \approx \sqrt{A^D}$ (i.e., $\log P \approx 1/2D \log A$). For simple Euclidean shapes (circles and rectangles), $P \approx \sqrt{A}$ and $D = 1$ (the dimension of a line). As the polygons become more complex, the perimeter becomes increasingly plane filling and $P \approx A$ with $D \rightarrow 2$. If the deciduous forest patches have structures of well defined length scale, then one can compare large and small characteristic lengths. This would lead to different A-P relationships for large and small structures and thus to different values of D, indicating scale distinctions in the underlying processes that generate the shapes. However, if the A-P relationship can be described only by one value of D, this would indicate the absence of characteristic length scale of the processes generating the shapes of the patches. If sufficient data are available, the perimeter-area method for calculating fractal dimensions is to regress log(P) on log(A) and evaluate D, the slope of the line (Lovejoy 1982).

The hypothesis that the fractal dimension D differs for small compared with large patches of deciduous forest was tested by separately regressing log(P) on log(A) for the smallest patches (area $< 55.7$ ha, $N = 200$)[a] and the largest patches (area $> 100.4$ ha, $N = 200$). The value of D for the smaller patches was $1.20 \pm 0.02$ ($R^2 = 0.78$), whereas D for the larger patches was $1.52 \pm 0.02$ ($R^2 = 0.90$). A t-test for the differences was significant at $P < 0.001$. This comparison was done with the areas of all other land cover types removed from within each patch. The presence of these "holes" in the patches increased the perimeter and decreased the area of patches that contain holes. A second analysis was done with the areas of the other land cover types included in each patch. In the absence of these holes, the area increased and the perimeter decreased. This second analysis resulted in D values for the same groups of small and large patches of $1.20 \pm 0.02$ ($R^2 = 0.78$) and $1.38 \pm 0.02$ ($R^2 = 0.88$), respectively. A t-test showed significance at $P < 0.001$. While the presence of holes in the larger patches increases the fractal dimension, more importantly, significant differences in shape complexity exist between large and small deciduous forest patches. This result suggests that two processes control the pattern of deciduous forest in the Natchez Quadrangle: one operating on small patches and the other on larger forested areas.

Alternatively, as the perimeter-area of small patches approaches the size of the "ruler" used to measure the patches, one would expect the measured shapes to become more Euclidian ($D \rightarrow 1$). However, in the present analysis the minimum patch area is set at approximately 160,000 $m^2$, while the internal coordinate unit (ruler size) is set at 10 m (grid size of 100 $m^2$). Thus, even the smallest patches of deciduous forest are 3 orders of magnitude larger than the ruler with a resulting negligible ruler size effect on the regression used to determine the fractal dimensions.

The continuous behavior of D over the entire range of forest patches is illustrated in Fig. 1. The 306 estimates of D used to create this figure were produced by successive regressions of log(P) on log(A). The first estimate of D is obtained from the slope of the regression of the 200 smallest forest patches, with successive regressions formed by removing the smallest and adding the next largest patch. Thus, the successive values of D show the smooth, continuous change of values estimated in this fashion, but with a distinct break between log area 13.3–13.5 $m^2$ (60–73 ha).

Changes in D in Fig. 1 show that the deciduous patches below the break region have smoother or more regular boundaries compared with patches of forest above the break line. Fig. 2 shows two areas (both at the same scale) from the Natchez Quadrangle that illustrate

[a]Forcing the intercept of the regression to equal zero is inappropriate for these analyses because it removes the local effect of scale and results in inappropriate estimates of D.

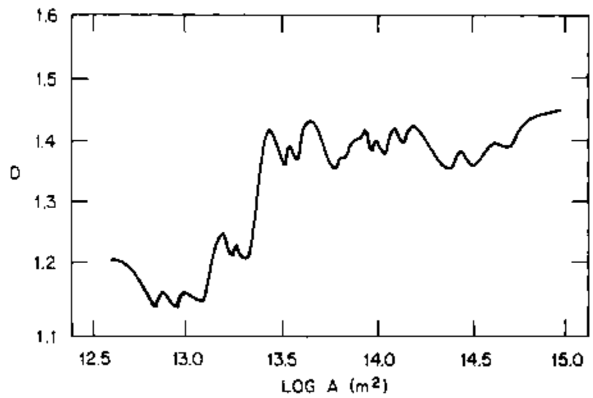


Fig. 1. Changes in fractal dimension (D) values as the log of area (A) increases; as determined by successive regressions of the log of perimeter (P) on log of A.

the differences in the geometry of small and large patches. In Fig. 2a, a floodplain area consists of small patches of deciduous forest that have perimeters of rectangular shape. These shapes are characteristic of forest patches found in agricultural areas in which land ownership is based on survey and township divisions that impose regular land use patterns (Burgess and Sharpe 1981). The larger patch in Fig. 2b is a forested area along a transition from floodplain to upland terrain east of the Mississippi River. The shape of this large patch is more irregular compared with the "woodlot" shape occurring within the floodplain.

Terrain and hydrology/moisture factors are primary determinants of vegetation associations, such as floodplain forest, forested wetland, and mixed forest (Whittaker 1975). Topographic and hydrological patterns are generated by diffusion and turbulence processes that can produce fractal dimensions greater than 1.5 (Mandelbrot 1977). If these factors were controlling the large forest patterns, one would expect to observe higher fractal dimensions for the large natural areas than for the smaller patches that result from agricultural development. The deciduous forest in the Natchez region has been altered by humans, and the current pattern of forest reflects the overlaying of many relatively small scale human disturbances on the large-scale factors that control the major successional patterns of natural vegetation.

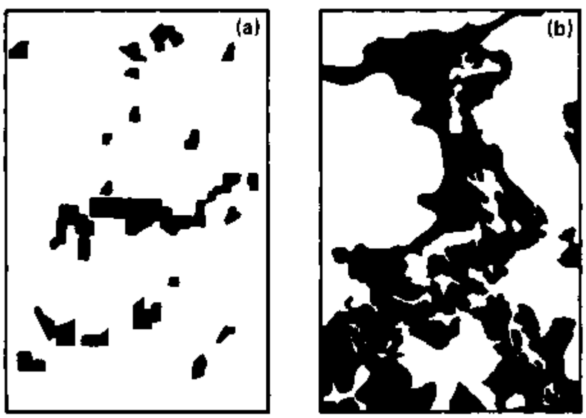


Fig. 2. Computer plots (both at same scale) of deciduous forest in two different areas of the Natchez Quadrangle that illustrate the differences in shape complexity between small forest patches in the Mississippi flood-plain (a) and a larger forested area on the eastern edge of the floodplain (b).

Understanding how landscape patterns relate to the processes that generate these patterns is fundamental to developing sound theory in landscape ecology. Burrough (1981) has suggested that while many natural phenomena display statistical self-similarity over many spatial scales, there are others that may be structured and show clustering of variability at certain scales. Both he and Mandelbrot consider the fractal concept applicable to phenomena that have distinct dimensions connected by transition zones. Indeed, the presence of transition zones may have important biological implications for ecosystem structure (Bradbury et al. 1984). For landscape systems analysis, identifying such spatial scale ranges and transition zones can have enormous practical value in adjusting sampling and modeling schemes and the resultant interpolations.

By examining the fractal dimension of the forest patches in this region, we have shown that this technique can help formulate hypotheses concerning the spatial scale of process-pattern interactions. This should prove extremely useful for developing appropriately scaled studies to correlate ecological, hydrological, and anthropogenic processes operating at different spatial hierarchies. The technique should also be of particular interest to the analysis of remotely sensed data, as it provides a simple metric, D, that indicates the scale at which processes are occurring on the ground. Changes in values of D, determined with remotely sensed data, would have immediate implications for changes in environmental conditions over large areas of the earth.

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**Area-Perimeter Relation for Rain and Cloud Areas**

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