Assessing Patch Shape in Landscape Mosaics

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ABSTRACT: The shapes of patches in classified landscape digital images can be characterized, for each land-cover class of interest, by quantifying the spatial contiguity and clustering of the pixels within each patch. In a study of the Finger Lakes National Forest in central New York State, patch-level contiguity and clustering indices were used in conjunction with the fractal dimension to assess changes, between 1938 and 1988, in forest patch morphology. Contiguity and clustering data may prove most useful, for landscape planning and management decision-making, however, as layers in raster geographic information systems (GISs).

INTRODUCTION

LANDSCAPE ECOLOGISTS are interested in the processes influencing the development and dynamics of landscape spatial heterogeneity, and in the influence of landscape spatial pattern on biotic and abiotic processes (Risser *et al.*, 1984; Forman and Godron, 1986; Turner, 1987). Remote sensing data are increasingly utilized in analyzing the spatial arrangement and shapes of patches in landscape mosaics (Sharpe *et al.*, 1986; Krummel *et al.*, 1987; O'Neill *et al.*, 1988; Turner and Ruscher, 1988; DeCola, 1989).

Demonstrated in this paper is a method for characterizing the shapes of grid-cell patches, in classified digital images, by quantifying the spatial contiguity and clustering of the pixels within each aggregation or patch. Patch level indices derived from these data complement other existing indices of landscape spatial pattern. Contiguity and clustering data may prove most useful for landscape planning and management decision-making, however, as layers in raster geographic information systems (GISs).

ECOLOGICAL SIGNIFICANCE OF LANDSCAPE STRUCTURE

Several spatial parameters define landscape structure. These include patch size, shape, and number; the distance between land-cover patches of the same type; and the juxtaposition of land-cover patches of different types (Burgess and Sharpe, 1981; Forman and Godron, 1986). Landscape connectivity, in contrast to landscape structure, has been defined as the potential flow, or movement, of seeds, animals, materials, water, or mineral nutrients within, and between, the patches, corridors, and networks of a landscape (Baudry and Merriam, 1988; Janssens and Gulinck, 1988).

Although patch shape has received relatively little attention in the ecological literature, the interaction of patch shape and size influences a number of important ecological processes. The forest "edge effect," for example, results primarily from differences in wind, light quality, and light intensity reaching a forest patch (Ranney *et al.*, 1981). The proportion of a forest patch that is edge habitat is substantially dependent, therefore, upon patch shape and orientation, and by adjacent land cover. A very large but linear patch, for example, could be entirely edge habitat.

Plant species indigenous to forest patch edges are commonly short-lived pioneer species; in contrast, longer-lived, and typically more threatened, forest species are generally found in patch interiors (Ranney *et al.*, 1981). Forest patch shape, therefore, influences within-patch species diversity and composition (Diamond, 1975; Carlton and Taylor, 1983), as well as inter-patch processes such as small mammal migration (Buechner, 1989) and woody plant colonization (Hardt and Forman, 1989).

Although landscape structure is the manifestation of various biotic and abiotic processes, the fragmentation of forested areas can be expected to influence ecological processes at the local, forest patch level (Forman and Godron, 1986; Franklin and Forman, 1987; Klein, 1989; Turner, 1989; Wiens, 1989). Within a hypothetical, half-forested landscape, for example, the forested area might be spatially arranged in a variety of configurations (Figure 1), each posing a unique set of ecological implications. The forest might be a plantation, existing entirely within a single rectangular patch (Figure 1a); or it could be a native forest remnant, fragmented into several irregularly shaped patches (Figure 1b). Alternatively, the forested area could be an interconnected, geometric network of woodlots and hedgerows (Figure 1c); or a riparian ecotope, meandering within the landscape (Figure 1d). These four patterns would not be uncommon within the human-dominated landscapes of the eastern United States.

INDICES OF SHAPE DERIVED FROM THE AREA TO PERIMETER RATIO

In landscape ecological research, patch shapes are increasingly characterized with the fractal dimension (Iverson, 1989;

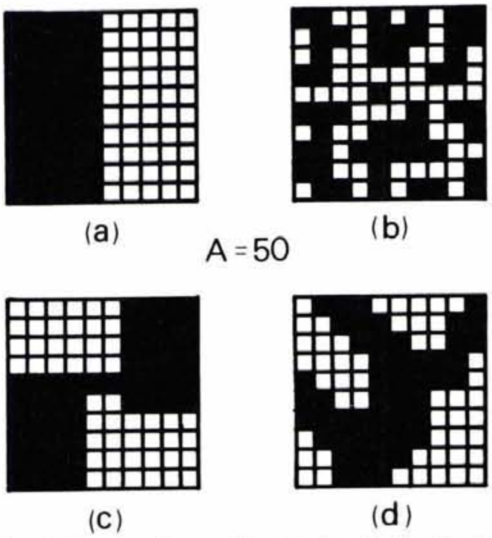

FIG. 1. Forest patterns within four hypothetical, half-forested landscapes. (a) Plantation. (b) Fragmented native remnants. (c) Woodlots and hedgerows. (d) Riparian ecotope. (Adapted from Figure 1, Baudry and Merriam (1988)).

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Krummel *et al.*, 1987; Turner and Ruscher, 1988). For a population of two-dimensional shapes or patches, the fractal dimension (D), at a given measurement scale, is proportionate to the slope of the regression line when the logarithm of the perimeter is regressed on the logarithm of the area (Equation 1) (Mandelbrot, 1977; Lovejoy, 1982; Krummel *et al.*, 1987).

$$\log(\text{perimeter}) \approx 1/2\, D \log(\text{area}) \qquad (1)$$

Shapes with highly convoluted, plane filling perimeters produce a fractal dimension approaching 2.0. Squares or circles, with very simple perimeters, yield a fractal dimension approaching 1.0.

For landscape analyses spanning a range of spatial scales, a constant fractal dimension reflects self-similarity in the component patch shapes (Milne, 1988). Substantial changes in patch shape, therefore, should be reflected by significant changes in the fractal dimension (Krummel *et al.*, 1987; Wiens, 1989). For a given landscape mosaic, understanding the behavior of the fractal dimension over a range of spatial scales may help in choosing appropriate sampling sizes and spacings for subsequent ecological research (Krummel *et al.*, 1987; Palmer, 1988; Wiens, 1989).

Shape, however, is a difficult parameter to concisely quantify numerically. As indices of shape, the area to perimeter ratio and the fractal dimension are insensitive to not so subtle differences in patch morphology. The four simple patches in Figure 2, for example, have identical areas and perimeters, yet they are considerably different in shape.

INFORMATION PRESERVING TWO-DIMENSIONAL SHAPE ANALYSIS

Shape analysis is a well-developed area within the pattern recognition literature (Pavlidis, 1980; Shapiro, 1985; Toussaint, 1988). Applications invoking shape analysis include automated finger print matching, aircraft recognition, and a broad assortment of manufacturing applications (Pavlidis, 1980). For these purposes, shape analysis algorithms must produce descriptions of shape that are size invariant, translation invariant, and rotation invariant (Shapiro, 1985). Moreover, the algorithms must be information preserving (Pavlidis, 1980), or capable of reproducing the shapes exactly. Although important for the purposes of shape matching, these features are not critical in many landscape ecological applications, particularly when supported by a GIS.

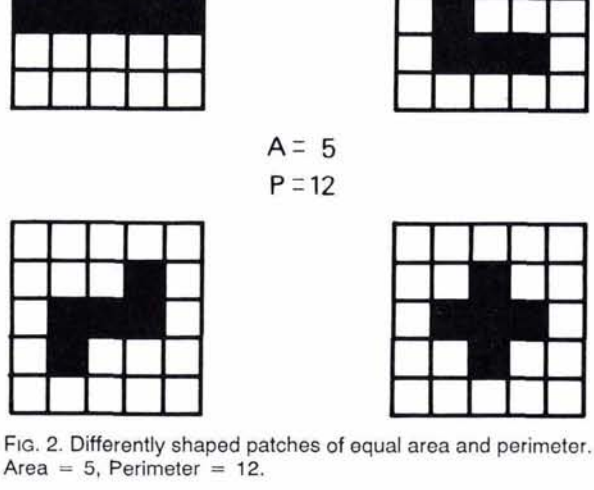


FIG. 2. Differently shaped patches of equal area and perimeter. Area = 5, Perimeter = 12.

ASSESSING PATCH SHAPE IN LANDSCAPE MOSAICS

Landscape spatial data arise in two basic forms: the variate values for a series of points, or areas, within a region; and the location of the points, or areas, themselves (Haggett *et al.*, 1977). Spatial autocorrelation and trend surface models are appropriate techniques for analyzing spatial pattern in variate values, while nearest neighbor, quadrat count, or Thiessen polygon methods can be used to evaluate the pattern in locations (Haggett *et al.*, 1977). Because patch shape is determined, in a digital image, by the spatial arrangement of the pixels within each patch, information about patch shape can be derived by characterizing the pattern of within-patch pixel locations using a nearest neighbor approach.

Several indices having considerable utility in wildlife habitat management have been developed to quantify or graphically accentuate spatial pattern within multiple-class landscape maps and images (Table 1). The spatial complexity of a map or classified digital image, however, is compounded by increases in the number of classes into which the data are divided, and by increases in spatial variation of the data within each class (Muller, 1976; MacEachern, 1982). Using a single index to characterize the spatial pattern within a multiple-class map or image unavoidably reflects, therefore, the complexity of the underlying classification system. If a multiple-class grid-cell image is decomposed into a series of binary images, however, separately displaying each component class, the spatial arrangement and the shapes of patches within each class can be explicitly analyzed.

SPATIAL CONTIGUITY

Assessing the spatial connectedness, or contiguity, of cells within a grid-cell patch provides useful information on boundary configuration, and thus on patch shape. For the following example, a patch is defined as an aggregation of pixels joined vertically, horizontally, or diagonally.

Patch contiguity is quantified by convolving a 3- by 3-pixel template, or mask (Richards, 1986), with a binary digital image in which the pixels within the class of interest are assigned a value of one, and the background pixels given a value of zero. A template value of 2 is assigned to quantify horizontal and vertical pixel relationships within the image, and a value of 1 is assigned to quantify diagonal relationships (Figure 3a). This combination of integer values weights orthogonally contiguous pixels more heavily than diagonally contiguous pixels, yet keeps computations relatively simple.

The value of each pixel in the output image, computed when at the center of the moving template, is a function of the number and location of pixels, of the same class, within the nine cell image neighborhood (Figure 3b). Specifically, the contiguity value for a pixel in the output image is the sum of the products, of each template value and the corresponding input image pixel value, within the nine cell pixel neighborhood.

The center pixel in the template is assigned a value of 1 to ensure that a single-pixel patch in the output image has a value of 1, rather than zero. This is important if the contiguity image will be displayed or plotted. For example, through an iterative process, the contiguity images for all land-use or land-cover classes could be reassembled, using conventional GIS overlay operations, to produce an overall landscape contiguity image. Thirteen contiguity sub-classes would then exist within each land-cover class.

In a quantitative analysis of patch shape, a contiguity index can be computed for each grid-cell patch using the following algorithm:

TABLE 1. SPATIAL INDICES FOR MULTIPLE-CLASS IMAGES

Index	Characteristic Measured	Source
Fragmentation	spatial complexity in a multi-class map or image	Monmonier, 1974
Interspersion	number of cells of a class unlike the center pixel within a pixel neighborhood	Mead *et al.*, 1981
Juxtaposition	edge combinations between different classes within a pixel neighborhood	Mead *et al.*, 1981
Diversity	number of pixels of different classes within a pixel neighborhood	Robinove, 1986
Dominance	dominance of one or more classes in an image	O'Neill *et al.*, 1988
Contagion	spatial aggregation of classes in an image	O'Neill *et al.*, 1988

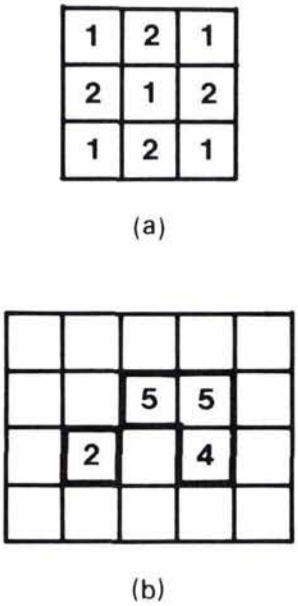


FIG. 3. Contiguity index. (a) 3-pixel by 3-pixel template. (b) Contiguity values for a 4-pixel patch.

$$C(j) = \frac{\left[\left(\sum_{i=1}^{n} C'(i,j)/n(j)\right) - 1\right]}{(m - 1)} + 1 \qquad (2)$$

where

$C(j)$ = contiguity index for a patch of class (j),

$C'(i,j)$ = contiguity value for pixel (i) of class (j),

$n(j)$ = total number of pixels of class (j), and

m = sum of the template values.

One is subtracted from both the numerator and denominator to confine the index to a range of 1.0, for a one pixel patch, to a limit of 2.0. Although a range from 0.0 to 1.0 could be utilized as well, this range facilitates transformation of the data. Index values increase, therefore, as patch contiguity, or connectedness, increases.

Morphological differences between four patches of equal perimeter and area illustrate the potentially useful information that is gained by quantifying patch contiguity (Figure 4a). Although these patches have identical area to perimeter ratios, they are considerably different in shape. The contiguity indices (Figure 4a) and the contiguity class frequency distributions (Figure 4b) reflect marked differences in the spatial arrangement of the pixels within each patch.

SPATIAL CLUSTERING

Characterizing the spatial clustering of pixels within each patch provides information on patch shape that is not obtained in assessing patch contiguity. A pixel neighborhood larger than 3 by 3 is used to detect, in the vicinity of each image pixel, the presence of nearby non-contiguous pixels of the class being analyzed. Sensitivity to clustering of both contiguous and non-contiguous pixels is achieved by decreasing the template values outward from the central pixel (Figure 5a).

For any given pixel, the clustering value reflects that pixel's proximity to other pixels within the same class. Although more computationally intensive, a pixel neighborhood larger than 5 by 5 increases sensitivity to image pixels more distant from the template center. Substituting K for C, the clustering index (K) is derived by the same procedure used to quantify contiguity (Equation 2).

If the pixel aggregations, or patches, can be conveniently isolated from one another prior to the convolution, the clustering index is a measure of intra-patch pixel clustering. If this is not feasible, as in most landscape research where the geographic location of each patch, and the spatial relationships between patches, are important, the index then reflects both intra-patch and inter-patch pixel clustering.

INDEX LIMITATIONS

Because measurements of spatial pattern and distance are a function of the size of the measuring units (Mandelbrot, 1967; Goodchild, 1980; Kappraff, 1986; Meentemyer and Box, 1987), contiguity and clustering indices derived for separate landscapes, or for a landscape at different points in time, are meaningfully compared only when equal pixel sizes are used in the analyses. Current research is exploring index behavior over a range of spatial scales, however, and is assessing procedures for deriving additional spatial information from the contiguity and clustering data.

Because the pixel contiguity and clustering values within a patch are summed, and the order in which the values occur is not utilized, these indices may correspond to more than one unique shape. To reduce the influence of internal pixels in large, highly contiguous patches, contiguity and clustering indices could be computed using the boundary pixels alone, although this would not increase index sensitivity to differences in the shapes of patches with equally "contiguous" or "clustered" boundaries. In the opinion of several spatial analysts, however, an index yielding a single, unique value for every conceivable shape is unattainable (Lee and Sallee, 1970; Pavlidis, 1980; Austin, 1984).

A FOREST MANAGEMENT APPLICATION

STUDY AREA

Between 1938 and 1941, over 100 farms in central New York State were purchased by the federal Resettlement Administration to remove marginal farmland from production, and to relocate farmers to better land or other jobs (U.S. Forest Service,

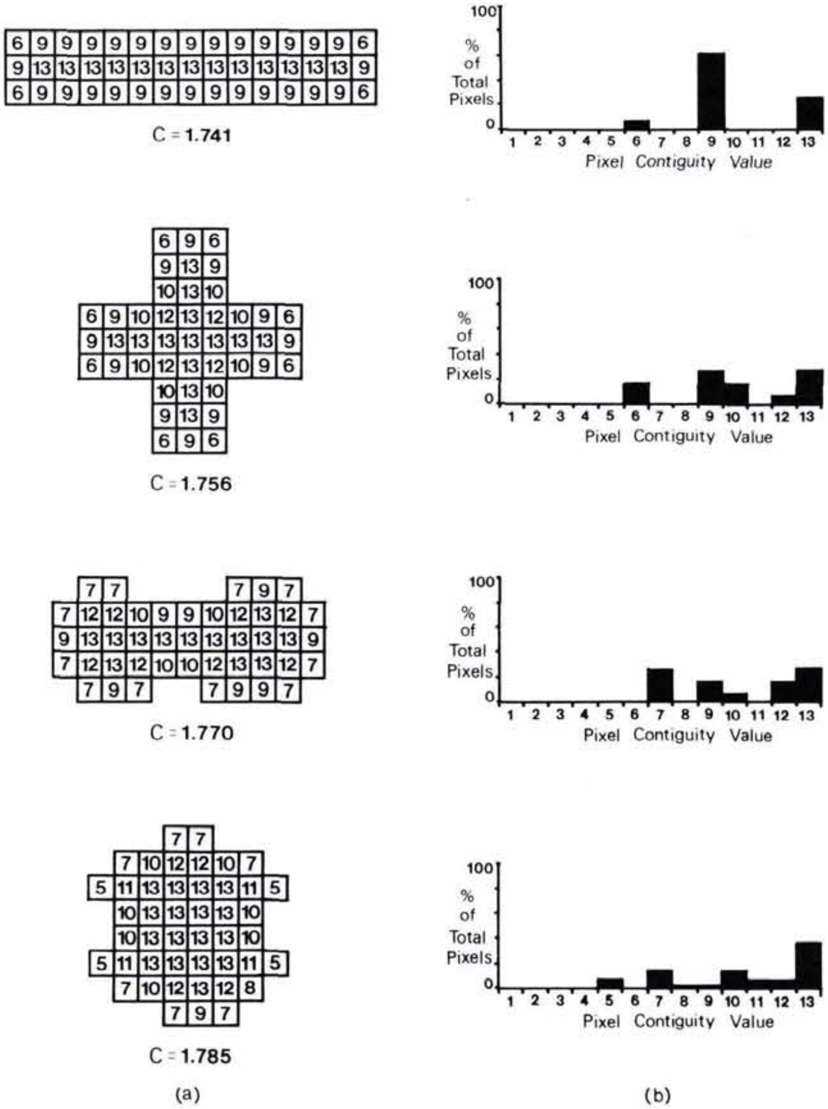


FIG. 4. Pixel contiguity values for differently shaped patches with the same area and perimeter. Area = 45, Perimeter = 36. (a) Patches. (b) Pixel contiguity frequency distributions.

1986). Highly erodible soils were stabilized by planting conifers, and by converting many cultivated fields to improved pastures. Other cropland was allowed to revert to forest. Because many farmers in the area chose not to participate in this program, however, the resulting federal ownership pattern was, and remains, highly fragmented.

Ten discrete areas, totaling 13,232 acres (5355 hectares) of temperate forest, pasture, and shrubland, were designated the Finger Lakes National Forest (FLNF) in 1982 (U.S. Forest Service, 1986) (Figures 6 and 7). Consistent with the administering agency's multiple-use mandate, the forested areas within the FLNF are managed to provide wildlife habitat, timber and firewood, hiking and camping opportunities, and landscape scenic amenity. An analysis of the forest patches (Figure 8), comprising both deciduous and coniferous forest, is used here to illustrate the potential utility of the indices in landscape planning and management.

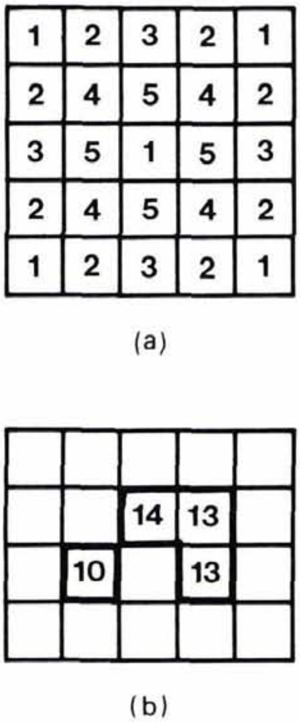
METHODS

Land-cover data for 1938 and 1988 were interpreted, respectively, from 1:20,000-scale panchromatic aerial photographs and from NHAP 1:58,600-scale color infrared photographs using a 3x stereoscope. For each date, seven classes were interpreted: cropland, pasture, deciduous forest, coniferous forest, wetland, water, and shrubland. These land-cover data were delineated, with a minimum mapping unit of about one acre (63.6 metres by 63.6 metres), on 1:24,000-scale mylar base maps using a Bosch and Lomb Zoom Transfer Scope. The two maps were manually digitized and the resulting vector data were converted to two grid-cell images. The pixel size used in the analysis was equivalent to an area on the ground of 0.25 acres (31.8 by 31.8 metres).

For this study, the two forest classes were combined to form a single forest class equivalent to the USGS Level I forest land category (Anderson *et al.*, 1976). By recoding, the forest class was isolated as a binary image, and this was then convolved with the appropriate template to generate the contiguity and clustering values for each forest pixel. These image processing and GIS operations were completed using commercially available software (ERDAS, Inc., Version 7.3, Release 1988), operating on an IBM AT personal computer.

RESULTS

Between 1938 and 1988, the number of forest patches remained relatively constant (Table 2). Positively skewed patch size class



1	2	3	2	1
2	4	5	4	2
3	5	1	5	3
2	4	5	4	2
1	2	3	2	1

(a)

		14	13	
	10		13	

(b)

FIG. 5. Clustering index. (a) 5 pixel by 5 pixel template. (b) Clustering values for a 4 pixel patch.

FIG. 6. Location of Finger Lakes National Forest in New York State.

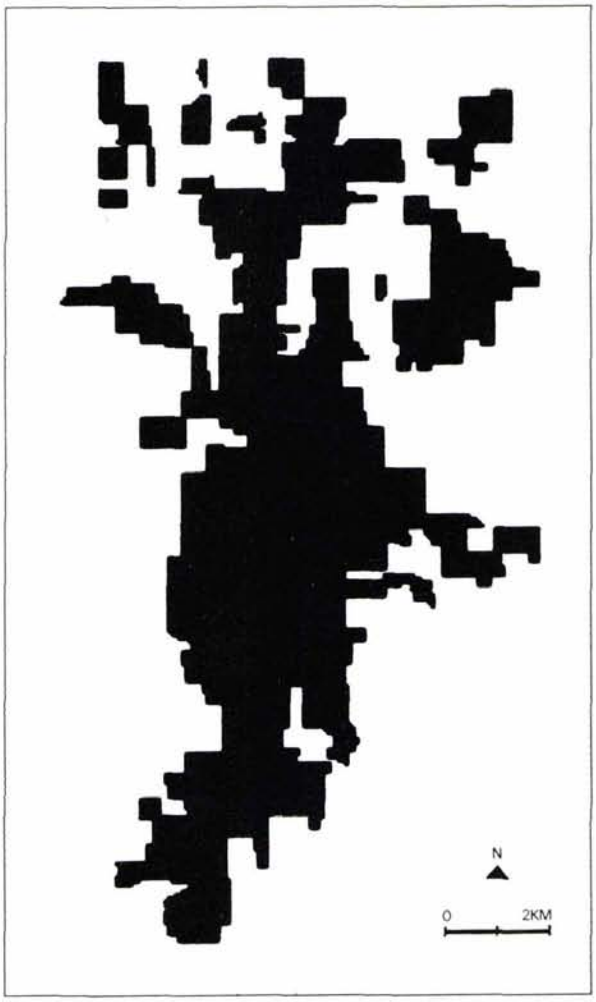


FIG. 7. Finger Lakes National Forest.

distributions reflect, for both years, many small patches and relatively few large patches (Figure 9). The large number of internal pixels within two large patches in the 1988 landscape is reflected in the frequency distributions of individual pixel contiguity values (Figure 10). At the pixel level, therefore, greater contiguity exists within the forest class in 1988 than in 1938 (average pixel contiguity increased from 10.9674 in 1938 to 11.7590 in 1988).

Patch level contiguity and clustering index distributions are somewhat negatively skewed. By the central limit theorem, the frequency distribution of repeated sample means from any population will be normal, if the sample size is adequately large (Snedecor and Cochran, 1980). Therefore, 30 randomly selected samples ($n=5$) were drawn, with replacement, from each population of contiguity and clustering index values. These resulting sample distributions were, indeed, approximately normal. Student's t-tests for the differences between sample means substantiate a significant ($p<0.05$) decline in mean contiguity and clustering indices over the 50-year study period. The fractal dimensions for the two populations of forest patches were not significantly ($p=0.20$) different.

DISCUSSION

In assessing patch contiguity, the pixels within a straight-sided segment of a patch boundary are assigned a contiguity value of 9 (Figure 4a). In the FLNF data, the high frequency of this contiguity class value (Figure 10) reflects the substantial presence of straight boundaries in both populations of forest patches. Although average patch size more than doubled from 9.68 hectares to 22.77 hectares between 1938 and 1988, patch boundaries remained largely defined by straight-edged roads, fencerows, and woodlots. This morphological feature of the FLNF forest patches is reflected, in both years, by a low fractal dimension.

While holding patch shape constant, however, patch contiguity and clustering increase asymptotically with increases in patch area. The decline in the mean patch contiguity and clustering indices could reflect, therefore, either an overall decline in patch compactness, or simply the proportionately larger influence of small patches on the population mean. A comparison of contiguity indices for patches of the same size yielded mixed results. While many size classes decreased substantially in spatial contiguity between 1938 and 1988, other classes exhibited greater spatial contiguity.

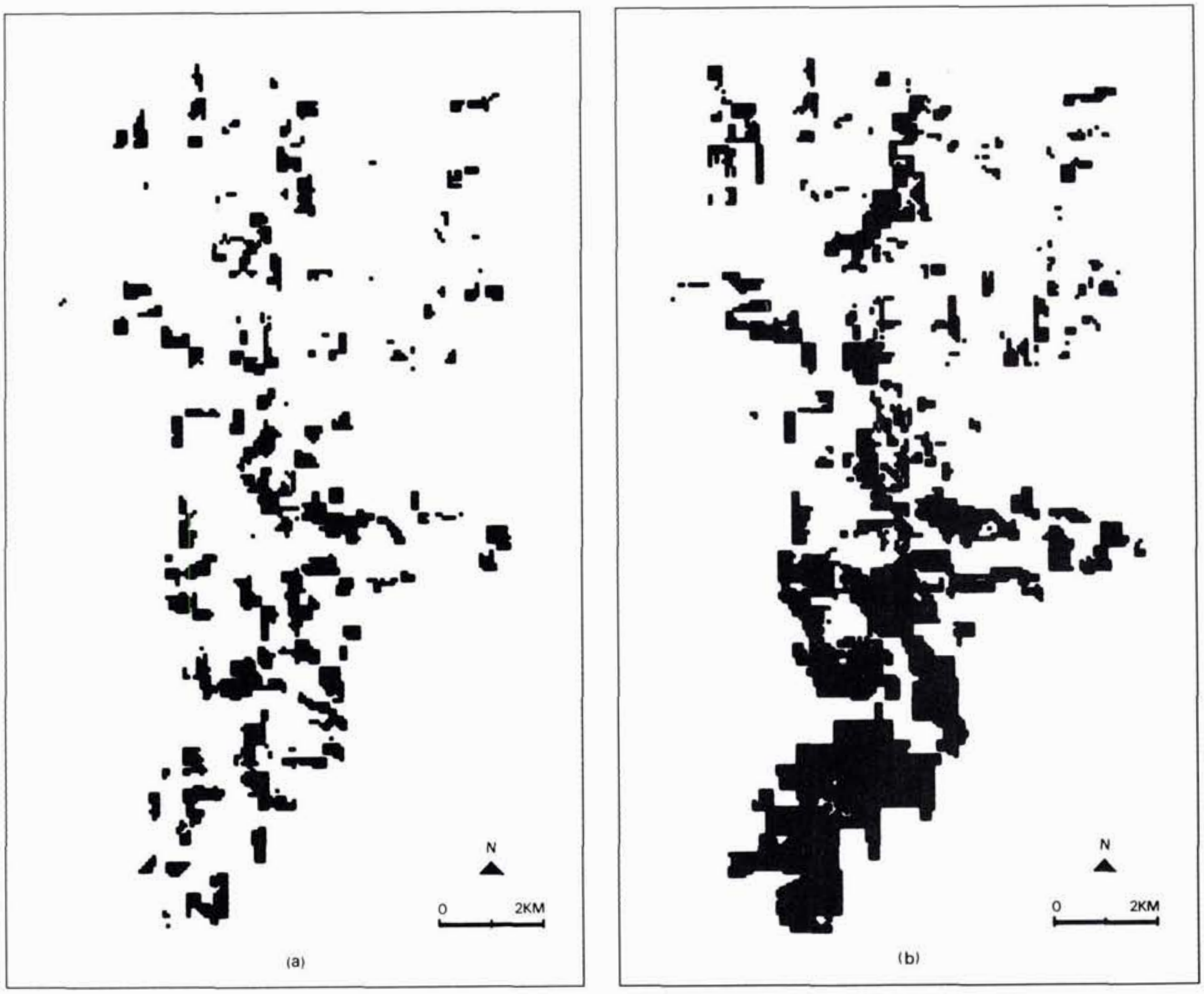


FIG. 8. Combined deciduous and coniferous forest patches within the Finger Lakes National Forest boundaries. (a) 1938 forest class. (b) 1988 forest class.

TABLE 2. FOREST PATCH STATISTICS
FINGER LAKES NATIONAL FOREST

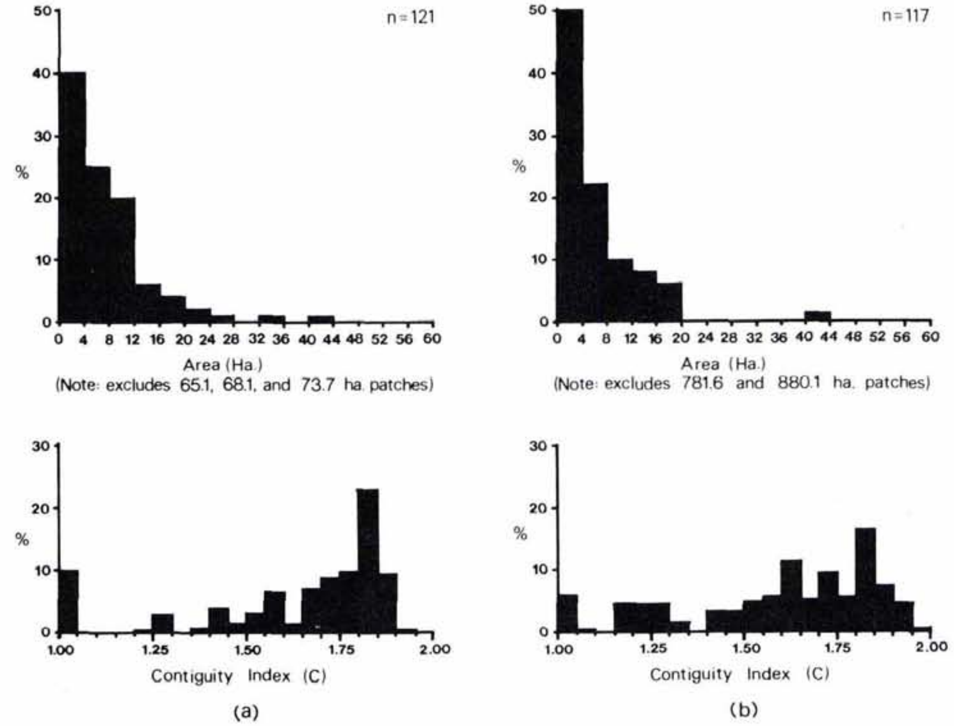
	1938	1988
Number of Patches	121	117
Total Forest Area (ha)	1171.6	2664.5
Contiguity Index (C)		
Mean	1.6579	1.5890
Range	1.0000–1.8999	1.0000–1.9582
Standard Deviation	0.2521	0.2602
Clustering Index (K)		
Mean	1.5688	1.4900
Range	1.0000–1.8533	1.0000–1.9390
Standard Deviation	0.2420	0.2558
Fractal Dimension (D)	1.2221	1.2434
Adjusted R-Squared	0.9642	0.9671

These results underscore the need for caution in characterizing landscape pattern, including patch shape, with spatial indices. They also suggest that indices derived from the area to perimeter relationship can be insensitive to changes in landscape pattern when those changes are not attributable to morphological transformations, but simply to changes in patch size.

MANAGEMENT IMPLICATIONS

Although not uncharacteristic of biological reserves (Schonewald-Cox and Bayless, 1986), the boundaries of the Finger Lakes National Forest are delineated by prior land ownership patterns, rather than by inherent ecological distributions. Two objectives stated in the FLNF management plan, however, are to protect and improve existing wildlife habitat, and to consolidate land ownership patterns (U.S. Forest Service, 1986).

As layers in a raster GIS, these contiguity and clustering data could facilitate ecologically and economically sound land acquisition and management decisions. The contiguity of pixels within two patches in the 1988 FLNF forest class image, for example, is depicted in Figure 11. Connectivity within the larger, highly fragmented, forest could be enhanced through habitat restoration (Noss, 1987) by increasing the size and contiguity of selected patches, and by linking isolated patches with corridors of similar habitat (Diamond, 1975). Strategically sited reforestation efforts could also help buffer the relatively rare, and vulnerable, old growth forests from disturbance (Harris, 1984). Conversely, logging could be managed to create forest stand sizes and shapes that would contribute to specific wildlife management objectives (Marcot and Meretsky, 1983; Franklin and Forman, 1987). Because the perception of landscape visual quality is highly dependent upon landscape spatial pattern (Kaplan and Kaplan, 1982),



(a) (b)

FIG. 9. Forest patch area and contiguity index frequency distributions. (a) 1938. (b) 1988.

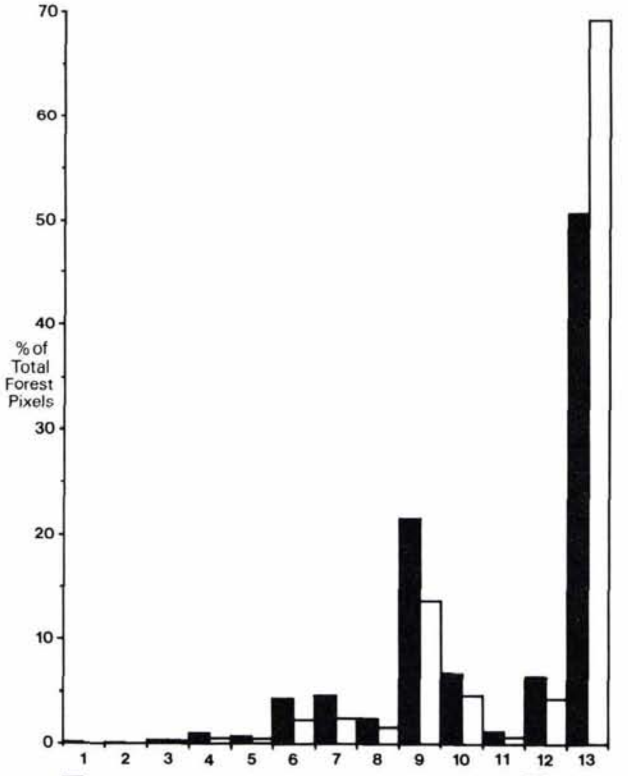


FIG. 10. Pixel contiguity frequency distributions for the 1938 and 1988 forest class.

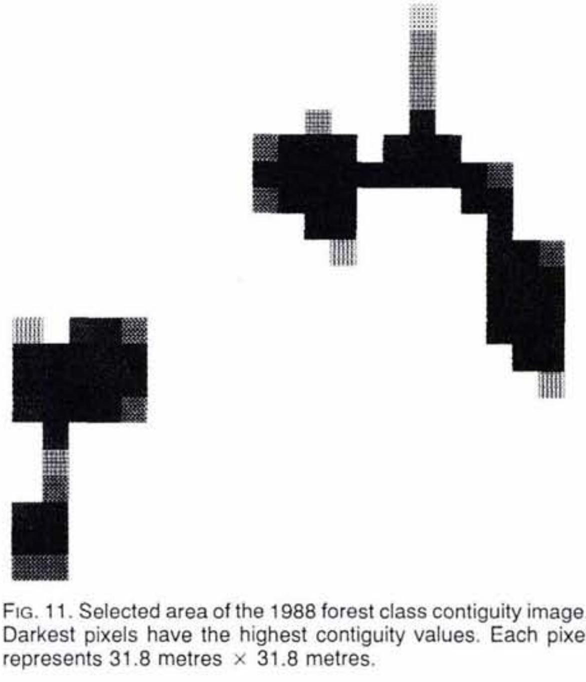


FIG. 11. Selected area of the 1988 forest class contiguity image. Darkest pixels have the highest contiguity values. Each pixel represents 31.8 metres × 31.8 metres.

additional applications might include scenic resource assessment and management.

CONCLUSIONS

Computer-based geographic information systems are now well-proven tools for organizing, storing, retrieving, and manipulating diverse spatial data (Burrough, 1986; Ripple, 1987). In a raster GIS, patch contiguity and clustering data could provide potentially useful overlay information for landscape ecological research, particularly for studies bearing on island biogeographic theory. These data layers could also improve the quality of information supporting landscape planning and management decision-making.

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BOOK REVIEWS

Commercial Observation Satellites and International Security, by Michael Krepon, Peter D. Zimmerman, Leonard S. Spector, and Mary Umberger (author-editors). St. Martin's Press, 175 Fifth Avenue, New York, NY 10010 (also available from ASPRS, 5410 Grosvenor Lane, Suite 210, Bethesda, MD 20814-2160). 230 p, 10 plates, hard cover. May 1990. $45.00

THIS IS THE FIRST BOOK to be published which systematically considers the benefits and problems associated with the use of commercial satellites. It is timely because high quality images from space (i.e., images having good enough spatial and spectral resolution to offer significant international benefits and thereby to pose international problems) are now available on a "pay-per-view" basis, for anyone who can afford them.

The images of primary concern in this book are those acquired in digital form by various commercial observation satellites that are owned and operated by foreign (non-U.S.) governments and corporations. Emphasis throughout the book is on how international relations may change as a result of the use of such images.

The book has been prepared, with major sponsorship of the Carnegie Corporation of New York, as a result of the establishment of a Commercial Observation Satellite Program under the Carnegie Endowment for International Peace. Aided by that support, a three-day conference on the subject matter dealt with in this book was held in Washington, D.C. in January 1989.

The book is divided into five major parts dealing, respectively, with International Politics, International Conflict, International Cooperation, Open Skies and the Role of the Media, and Photo Interpretation of Commercial Satellite Imagery. Topics include observation-satellite capabilities, imagery analysis, implications in relation to cross-border conflicts, monitoring nuclear proliferation, verification of arms-control agreements, and implications with respect to crisis decision-making, alliance relations, and public diplomacy.

Of the book's 25 authors, four also served as co-editors. They did a masterful editorial job of integrating into a single volume the book's multifaceted contents—always an important consideration when so many writers, collectively expert in such a wide variety of overlapping fields, are the co-authors of a single book.

Ten black-and-white plates are used to illustrate the book. It is acknowledged in the text that *multispectral* imagery is important in that "the more channels or colors a satellite system has, the greater the detail that can be revealed." Yet no color illustrations or other means of documenting the validity of this important point are included. To the contrary, spatial resolution (mostly ranging from 10 to 20 metres) rather than spectral resolution appears to have been the determining factor in selecting all of the illustrations. In this connection, speculation is given in the book to the likelihood that *military*-acquired satellite imagery that is "widely acknowledged to have a resolution far superior to one metre" will soon become available on a selective basis for public use.

Because this book places such great emphasis on spatial resolution, the fact that properly acquired images can be viewed *stereoscopically*, and sometimes to great benefit, might well have been stressed and illustrated. (It has long been known that, through "binocular reinforcement," the interpreter's "stereoscopic acuity" is in most instances two to four times greater than his "vernier acuity." In addition, of course, stereoscopic study of overlapping photos permits perception of the three-dimensional configuration of objectives and topographic features.) These highly important stereoscopic aspects seem to have been inadequately recognized, however, both in the text and in the book's illustrations.

Superficially, it might seem that an overall summary, complete with a set of conclusions, might well have been included by the co-editors at the end of this wide-ranging book. It was not. That potential deficiency is largely overcome, however, by the inclusion early in the book of Admiral B.R. Inman's very perceptive and remarkably comprehensive "Introduction."

As suggested by the book's title, it is concerned with various aspects of international security. One aspect of such security, according to the United Nations' Food and Agriculture Organization (FAO), is "food security"—i.e., ensuring that adequate food supplies for humans are available year-by-year, country-by-country, and crop-by-crop. The use of remote sensing by commercial observation satellites offers great promise for helping to ensure such food security each year, primarily through crop-monitoring during the growing season. Rather than largely overlooking such use, it would seem that this book might well have given a degree of treatment to it, in this reviewer's opinion, comparable to that given to other potential applications.

Seemingly adverse comments, such as the few just given, come pretty cheaply these days and often do much to obscure the greatly offsetting merits of a book. Therefore, let it be said that, overall, this is an excellent and timely book. Almost any remote sensing scientist, whether within the fold of the ASPRS or not, would do well to become familiar with it.

—Robert N. Colwell
RADAM, USNR (Ret.)