Landscape Changes in Nine Rural Counties in Georgia

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ABSTRACT: Changing patterns of land use/land cover were studied in nine rural counties (Atkinson, Baker, Emanuel, Heard, Monroe, Oglethorpe, Rabun, Tattnall, and Walker) in the state of Georgia from the 1930s through the 1980s. Historical black-and-white aerial photography was analyzed for six 2,116-ha areas in each county during three time periods. Photographs were digitized in raster format (1-ha resolution) using eight land-cover categories: urban, agricultural, transitional, pasture, coniferous forest, upland deciduous forest, lower deciduous forest, and water. Landscape patterns were quantified by using a spatial analysis program written in FORTRAN. Forest increased in overall abundance, and coniferous forest increased in all counties. Transitional lands and lower deciduous forests generally decreased. Agricultural land increased in coastal plain counties but declined in the mountain and piedmont counties. Spatial pattern analyses (number, and mean and maximum size of patches; fractal dimension of patch perimeters; and indices of dominance and contagion) demonstrated that the Georgia landscape is less fragmented than it was in the 1930s. Patches have generally decreased in number and increased in size, although trends in each cover type varied among counties. Changing landscape patterns may have important ecological implications. Information regarding past changes in the rural landscape and the associated effects on ecological processes may be useful in future policy decisions. The linkage of remote sensing and GIS technologies with landscape ecological research can provide a sound basis for assessing broad-scale changes in rural landscapes.

INTRODUCTION

THE RURAL LANDSCAPE is a mosaic of natural and human-managed patches that vary in size, shape, and arrangement (Burgess and Sharpe, 1981; Forman and Godron, 1986; Urban *et al.*, 1987). These spatial patterns in the landscape may influence a variety of ecological phenomena (Turner, 1989) such as the distribution and persistence of populations (Van Dorp and Opdam, 1987; Fahig and Paloheimo, 1988), the horizontal flow of materials such as sediment or nutrients (Peterjohn and Correll, 1984; Ryszkowski and Kedziora, 1987; Kesner and Meentemeyer, 1989), the spread of disturbance (Romme and Knight, 1982; Franklin and Forman, 1987; Turner 1987a, Turner *et al.*, 1989), and other important processes such as net primary production (Sala *et al.*, 1988). Therefore, the analysis of changing landscape patterns is an important component of understanding ecological dynamics.

Substantial changes have occured in rural landscapes in many regions of the country (Hett, 1971; Bowen and Burgess, 1981; Healy, 1985; Iverson, 1989). The southern United States has seen dramatic changes in agriculture, forestry, and rural settlement during the past 50 years (Cowdry, 1983; Healy, 1985). Farming ceased on millions of hectares of hilly and degraded farmland, and farm abandonment was followed by natural reforestation. There was a massive shift of people out of the rural south and into southern cities and northern factories (Healy, 1985). Soybeans replaced cotton as a primary crop, and intensively managed forestry grew into a tremendous industry. These changes should be reflected in the temporal dynamics of rural landscape patterns.

Land-use and land-cover patterns integrate both the natural and human-developed environments and, therefore, are a good focal point for studies of the rural landscape. This paper examines landscape changes in nine rural counties in Georgia from the 1930s to the 1980s. Landscape dynamics were studied by using historical aerial photographs and measures of spatial pattern. This analysis was part of a broader study of changes in the landscape and resources of the state of Georgia during a 50-year time period (see also Hoover, 1986; Turner, 1987b, 1987c, 1988; Turner and Ruscher, 1988; Turner *et al.*, 1988; Odum, 1989; Odum and Turner, 1990). My purpose is to demonstrate some simple but effective methods to examine the changing rural landscape. These methods can be easily applied to data in a geographic information system and to more recent remotely sensed imagery.

METHODS

STUDY AREA

Georgia encompasses three major physiographic regions, each of which has undergone substantial changes in land use during the past two centuries (Nelson, 1957; Brender, 1974; Healy, 1985). These regions include the mountains (1,470,310 ha), piedmont (4,606,139 ha), and coastal plain (8,971,206 ha) (Figure 1). The mountain region ranges in elevation from 183 to 1432 m, with mean annual temperature ranging from 12.8° to 16.1°C and annual rainfall ranging from 132 to 229 cm. The Georgia piedmont consists of foothills underlain by acid crystalline and metamorphic rock. Elevation ranges from 152 to 457 m. Mean annual rainfall is 112 to 142 cm, and mean annual temperature ranges from 15.0° to 17.8°C. The large coastal plain region has gentle to moderate slopes and sandy soils underlain by marine sands,

FIG. 1. Map of Georgia showing physiographic regions and sample counties used in the study.

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loam, and/or clays. Elevation ranges from sea level to 300 m; mean annual rainfall ranges from 112 to 135 cm, and mean annual temperatures range from 18.9° to 21.1°C. The coastal plain region may also be divided into an upper coastal plain with rolling topography and a lower coastal plain which is relatively flat.

Forests once covered the state Georgia, with the exception of coastal salt marshes and grassy areas in the Okefenokee Swamp (Nelson, 1957; Plummer, 1975). The potential natural vegetation of Georgia (Kuchler, 1964) was suggested to an be an oak forest (*Quercus*) in the northeastern mountains and an oak-hickory-pine forest (*Quercus-Carya-Pinus*) in the northwestern mountains, the piedmont, and the upper coastal plain. Major forest types in the lower coastal plain are longleaf-slash pine (*P. palustris* and *P. elliotti*) and loblolly-shortleaf pine (*P. taeda* and *P. echinata*), except where southern floodplain forest (*Quercus-Nyssa-Taxodium*) would prevail along the bottomlands.

The Georgia landscape has been modified by human activities for centuries. Native Americans commonly used fire to clear fields for agriculture, to hunt, and to increase production of browse, berries, and other wild food plants (Stewart, 1956). Extensive clearing and farming accompanied European settlement of the region. Between 1773 and 1823, for example, the Georgia piedmont was converted from stands of virgin timber to agriculture (Bond and Spillers, 1935; Brender, 1974), and cotton was the dominant crop by 1793. Nearly all the original topsoil was lost from 47 percent of the uplands, and gullying was apparent on 44 percent of the piedmont (Hartman and Wooten, 1935). Large amounts of cropland were abandoned following invasion of the boll weevil (*Anthonomus grandis*) in the 1920s. Most abandoned land reverted through natural succession to pine (*primarily Pinus taeda* and *P. echinata*), and this old-field pine comprised more than two-thirds of the total forest area in 1930. The rate of cropland abandonment has decreased substantially since the early part of the century and, although natural succession still contributes to the dynamics of Georgia's forests, the many processes associated with an urban-agricultural society predomiant (Johnson and Sharpe, 1976).

Aerial Photo Interpretation

Historical black-and-white aerial photography was used to quantify changes in the rural landscape of Georgia. Nine counties (Atkinson, Baker, Emanuel, Heard, Monroe, Oglethorpe, Rabun, Tattnall, and Walker) were selected for analysis, including three in the piedmont and two each in the mountains, upper coastal plain, and lower coastal plain (Figure 1). These nine counties were chosen using a random selection modified by the availability of adequate photo coverage. Aerial photography for all sites was obtained from the library collections of the University of Georgia for three time periods: (1) the earliest available photos, ranging from 1937 to 1942; (2) an intermediate time period, with photos ranging from 1950 to 1963; and (3) the most recent photos available, ranging from 1978 to 1983. Nominal scales were 1:20,000 for the first two time periods and 1:40,000 or 1:60,000 for the last time period. For convenience these three time periods will hereafter be referred to as the 1930s, 1950s, and 1980s.

Six 230- by 230-mm black-and-white aerial photos at a nominal scale of 1:20,000, or an equivalent area at other scales and formats, were used in each county. This provided ground coverage of 4.6 by 4.6 km (2,116 ha) for each photo, or 12,696 ha for each county. If the nominal scale of a photograph was less than 1:40,000, the photo was enlarged to a scale of 1:40,000 before being digitized. The actual average scale for each photo was calculated, and the percent error in scale ranged from 0.1 percent to 4.5 percent. The photographs were arranged in a rectangular two column by three row pattern and were adjacent, but not overlapping (Figure 2). This arrangement alleviated double sampling, but there was a gap in coverage in both the endlap and sidelap directions because the photos did not overlap; this gap never exceeded 900 m. Essentially the same area was analyzed for each time period, although exact registration between photographs was not done. Therefore, a pixel-by-pixel comparison through time cannot be done with these data. The objective of the study was to analyze broad changes in pattern rather than temporal changes on a per pixel basis. Each photo was viewed with adjacent photography under a mirror stereoscope to produce stereoimages and magnification of the land cover. The land cover was delineated on transparent sheets of acetate overlain on each photograph. A transparent grid with cells representing 1 ha was then placed over the land-use acetate sheet. The data were manually digitized in raster format by assigning to each cell an integer representing the land cover occupying the greatest proportion of the cell. Eight land-use/land-cover categories were used (Table 1), following the classification of Anderson *et al.* (1976). A total of 162 data files (nine counties, three time periods, six sites) were created.

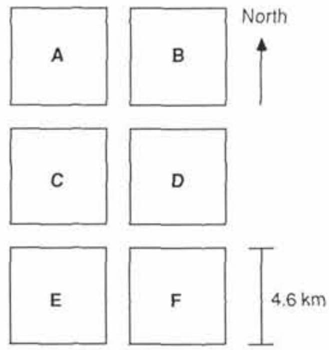

FIG. 2. Arrangement of the six aerial photographs interpreted for each county. Each photo encompasses an area of 2,116 ha at a nominal scale of 1:20,000.

Landscape Pattern Analysis

A spatial analysis computer program (SPAN) was developed in the programming language FORTRAN to quantify landscape patterns and their changes in an ecologically meaningful manner (Turner and Ruscher, 1988) and to evaluate the predictions of a spatial simulation model (Turner, 1987c, 1988). SPAN is a grid-cell based analysis program that can be applied to any kind of categorical data rasterized at an appropriate level of resolution (note that SPAN is not related to the commercially available geographic information system, SPANS). The program provides printed output with some summary statistics and computerized output in the form of data files that can be statistically analyzed using SAS (SAS Institute, 1982).

SPAN incorporates a series of measures of spatial pattern (Table 2). The fraction of the landscape area, p, occupied by each cover type is calculated. The probabilities, $q_{i,j}$, represent the probability of cells of land-use type i being adjacent to cells of land use type j. The $q_{i,j}$ values are calculated by dividing the number of cells of type i that are adjacent to type j by the total number of cells of type i. The amount of edge between each land use, $E_{i,j}$, is determined by summing the number of interfaces between adjacent cells of different land uses, then multiplying by the length of a cell (e.g., 100 m for 1-ha cells). The amount of edge between all categories is tabulated, and the edge data files can be statistically analyzed using SAS.

Each patch in the landscape matrix is identified. A patch is defined as contiguous, adjacent (horizontally or vertically) cells of the same land cover; diagonal cells are not considered to be

TABLE 1. LAND-COVER CATEGORIES USED IN THE AERIAL PHOTO INTERPRETATION.

Key	Category	Description
1	Urban	Cities, housing developments, major transportation routes wider than 100 m, golf courses, cemeteries.
2	Agricultural	Land currently under cultivation, orchards, chicken houses, and farm houses and outbuildings.
3	Transitional	Land changing from one category to another, generally the early successional stages following cropland abandonment; clear cut areasd which have not been replanted were also included.
4	Improved pasture	Distinguished by smooth texture, fencelines, large barns, watering holes, and cow trails; grazed woodlots were not included.
5	Coniferous forest	Pine forest with a canopy cover of at least 50 percent and with an estimated average tree height of at least 3 m; pine plantations were included.
6	Upper deciduous forest	Upland hardwood forest not along stream courses with a canopy cover of at least 50 percent and with an average tree height of at least 3 m.
7	Lower deciduous forest	Bottomland hardwood forest and associated vegetation found along or in stream courses.
8	Water	Natural or man-made water bodies including rivers, lakes, and farm ponds.

TABLE 2. MEASUREMENTS OF LANDSCAPE PATTERN THAT ARE CALCULATED IN THE SPATIAL ANALYSIS PROGRAM, SPAN.

Variable	Description
p_k	Proportion of the landscape occupied by each category
S, l	Size (s) and perimeter (l) of each patch
d	Fractal dimension of patch perimeters
$E_{i,j}$	Edges between each pair of land-cover types
$q_{i,j}$	Probabilities of adjacency between land-cover types
H	Diversity index
D	Dominance index
C	Contagion index

contiguous. Each patch in the landscape matrix is located and its size (s) and perimeter (l) are recorded. The number and mean size of patches by any cover type can then be calculated for each matrix using SAS (SAS Institute, 1982). The complexity of patch perimeters is measured using fractal dimensions (Mandelbrot, 1983). The fractal dimension is calculated for grid cell data using an edge to area relationship (Burrough, 1986; Gardner *et al.*, 1987) in which $l/4$) is the length scale used in measuring the perimeter. To calculate an overall fractal dimension for each or all data categories in a matrix, a linear regression of $\log(l/4)$ against $\log(s)$ is done using SAS. The fractal dimension of the patch perimeters is equal to twice the slope of the regression line (Burrough, 1986). In this analysis, the fractal dimension can theoretically range from 1.0 to 2.0, with 1.0 representing the linear perimeter of a perfect square and 2.0 representing a very complex perimeter encompassing the same area.

Two landscape indices, adapted from O'Neill *et al.* (1988) are calculated in SPAN and reported here. The first index, D, is a measure of dominance, calculated as the deviation from the maximum possible landscape or habitat diversity: i.e.,

$$D = [H_{max} + \sum_{i=1}^{m} (P_k)\log(P_k)]/H_{max}, \qquad (1)$$

where m = number of land-use types observed on the map, P_k is the proportion of the landscape in land use k, and $H_{max} = \log(m)$, the maximum diversity when all land uses are present in equal proportions. The terms in the summation in the numerator are negative, so Equation 1 expresses the deviation from the maximum. Dividing through by H_{max} in Equation 1 normalizes the index to range between zero and one and allows landscapes with differing numbers of cover types to be compared. Higher values of D indicate a landscape that is dominated by one or a few land uses, and lower values indicate a landscape that has many land uses represented in approximately equal proportions. The index is not useful in a completely homogeneous landscape (i.e., $m = 1$) because D then equals zero.

The second index, C, measures contagion, or the adjacency of land-cover types. The index is calculated from an adjacency matrix, Q, in which $q_{i,j}$ is the proportion of cells of type i that are adjacent to cells of type j, such that

$$C = [K_{max} + \sum_{i=1}^{m}\sum_{j=1}^{m} (q_{i,j})\log(q_{i,j})]/K_{max}, \qquad (2)$$

where $K_{max} = 2\, m \log(m)$ and is the absolute value of the summation of $(q_{i,j}) \log (q_{i,j})$ when all possible adjacencies between land-cover types occur with equal probabilities. The summation term is negative, and Equation 2 gives the deviation from the maximum possible contagion. Dividing through by K_{max} again normalizes the value to range between 0 and 1, allowing comparisons of landscapes with differing values of m. The index C will be zero when $m = 1$ or all possible adjacencies occur with equal probability. When $m \geq 2$, values of C approaching 1 will indicate a landscape with a clumped pattern of land-cover types.

LANDSCAPE CHANGES

The proportion of the landscape in each land-cover category varied through time in each county (Table 3). Urban land increased in seven of the counties, although urban area never exceeded 1 percent in five of the counties. Walker and Monroe counties had the most urban land (6.9 percent and 7.6 percent, respectively, in the 1980s). Land in agriculture ranged from 11.5 percent to 43.6 percent among the study counties during the 1930s. Agricultural land declined in the mountain and piedmont counties and generally increased in the coastal plain counties (Figure 3). In Baker County, agriculture encompassed nearly 50 percent of the landscape in 1982 (Table 3). Transitional lands, primarily abandoned croplands, were a dominant component of most counties during the 1930s, encompassing more than 60 percent of the landscape in Emanuel and Monroe counties. Rabun and Walker counties had the least transitional land in the 1930s, probably reflecting their lesser suitability for the agriculture that had dominated the rest of the state. In all counties except Rabun, transitional lands declined during the past 50 years as natural successional processes converted these lands to forest or humans put the lands to other uses.

Forest area increased in overall abundance during the past 50 years, with coniferous forests increasing in all counties (Table 3). In the 1930s, the percentage of pine forest was less than 20

LE 3. PERCENTAGE OF LAND IN EACH COVER TYPE BY COUNTY AND YEAR. DATA ARE FOR THE SIX AERIAL PHOTOGRAPHS CONSIDERED TOGETHER (SAMPLE AREA IS 12,696 HA) IN EACH COUNTY.

nty	Year	Urban	Agricultural	Transitional	Pasture	Coniferous Forest	Upper Deciduous Forest	Lower Deciduous Forest	Water
					Mountains				
.abun	1941	0.5	17.7	5.7	0.6	12.0	63.5	0.0	0.0
	1963	1.2	12.9	4.5	0.6	21.6	59.2	0.0	0.1
	1980	2.5	13.1	6.0	0.4	26.1	51.9	0.0	0.1
Walker	1938	0.6	36.9	16.3	2.7	17.3	25.9	0.3	0.0
	1950	1.6	27.8	18.2	1.4	21.9	28.6	0.5	0.1
	1980	6.9	17.3	8.8	4.9	43.8	17.6	0.7	0.1
					Piedmont				
Heard	1942	0.0	26.6	42.8	0.0	3.6	25.9	1.0	0.0
	1958	0.0	8.6	42.3	0.2	13.7	32.7	2.4	0.0
	1978	0.0	10.0	22.9	0.1	27.2	37.2	2.3	0.2
Monroe	1938	1.5	19.4	66.0	0.1	4.7	5.0	3.4	0.0
	1958	2.6	18.2	49.2	0.2	19.7	6.3	3.6	0.2
	1980	7.6	10.9	21.6	0.4	42.9	13.6	2.8	0.2
Oglethorpe	1942	0.1	43.6	43.4	0.0	7.6	1.8	3.4	0.0
	1955	0.5	35.5	41.1	0.6	12.9	5.2	4.2	0.0
	1980	0.9	15.3	28.5	0.7	52.2	1.3	0.8	0.3
					Upper Coastal Plain				
Baker	1937	0.8	27.6	41.0	0.0	13.5	9.1	4.6	3.4
	1953	1.0	25.2	44.1	0.6	15.6	8.0	4.7	0.8
	1982	2.1	49.4	14.6	0.3	25.1	2.4	5.3	0.9
Emanuel	1940	0.3	21.5	60.3	0.0	2.9	14.6	0.4	0.0
	1963	0.2	9.5	32.9	0.0	35.3	21.3	0.4	0.4
	1981	0.8	22.9	9.3	0.2	48.7	16.8	0.8	0.8
					Lower Coastal Plain				
Atkinson	1938	0.1	11.5	32.5	0.0	17.6	0.0	38.1	0.2
	1952	0.1	12.0	20.7	0.4	34.7	0.0	31.7	0.4
	1983	0.1	16.3	10.0	0.0	40.9	0.0	31.5	1.2
Tattnall	1939	0.0	21.1	42.3	0.1	16.2	0.2	20.0	0.1
	1952	0.0	22.9	21.6	0.1	31.9	0.3	23.1	0.1
	1981	0.5	30.3	9.3	0.7	44.0	0.0	14.4	0.8

percent in all counties, and four of the nine counties had less than 10 percent. By the 1980s, the percentages of coniferous forest (including pine plantations) ranged from 25 percent to greater than 50 percent. In contrast, changes in upper deciduous forests varied among counties. Upland hardwood forests increased in Heard and Monroe counties, but decreased in Rabun, Walker, and Baker counties. In the piedmont, many lands are not replanted following pine harvesting, thereby encouraging the development of hardwood stands (Figure 3). The net loss of hardwood forest in the mountains and coastal plain (Figure 3) may occur because hardwoods are frequently harvested and the area then replanted in pines or crops. Lower deciduous forest (i.e., bottomland hardwoods) were a major landscape component only in Atkinson and Tattnall counties, and both counties showed a decline in these riparian forests.

The spatial patterns of land-cover types have also varied through time, as indicated by changes in the number and sizes of patches (Table 4). The number of separate patches of agriculture generally declined during the past 50 years. The mean size of agricultural patches increased in Baker, Emanuel, Atkinson, and Tattnall counties, with Baker county having the largest mean patch size (120.7 ha) (Table 4). The maximum size of an agricultural patch also increased in Baker, Atkinson, and Tattnall counties. In the other six counties, the mean and maximum agricultural patch size declined or showed little change (Table 4).

The number of patches of coniferous forest varied differently among the counties, but the general trend was a decline (Table 4). The mean patch size of coniferous forests increased in all counties. In the 1930s, the mean patch size of coniferous forest ranged from 2.4 to 6.0 ha; by the 1980s, pine forest patches ranged from 6.5 to 53.8 ha. The maximum size of pine forest patches also increased, from 281 ha in the 1930s (Walker County) to 1,361 ha in the 1980s (Tattnall County). Rabun County had the most fragmented coniferous forests in the 1980s, with a total of 510 patches and the lowest mean patch size. The trends in upper deciduous forests differed from trends in coniferous forests. In most counties, the number of upper deciduous forest patches decreased as mean patch size increased, and maximum patch size changed differently among the counties. However, in Rabun and Walker counties, the number of patches of upland hardwoods increased, and the mean and maximum patch size declined.

The complexity of patch shapes, as measured by fractal dimensions, showed an overall decline in the Georgia landscape (Turner and Ruscher, 1988). The piedmont counties exhibited the greatest changes, and the land-cover types in the piedmont responded differently (Figure 4). The fractal dimension of coniferous forests in the piedmont decreased from 1.36 to 1.24, and transitional land, which originally showed the greatest complexity, declined from 1.51 to 1.36 (Figure 4). The decline in the fractal dimension indicates that the patches have become more

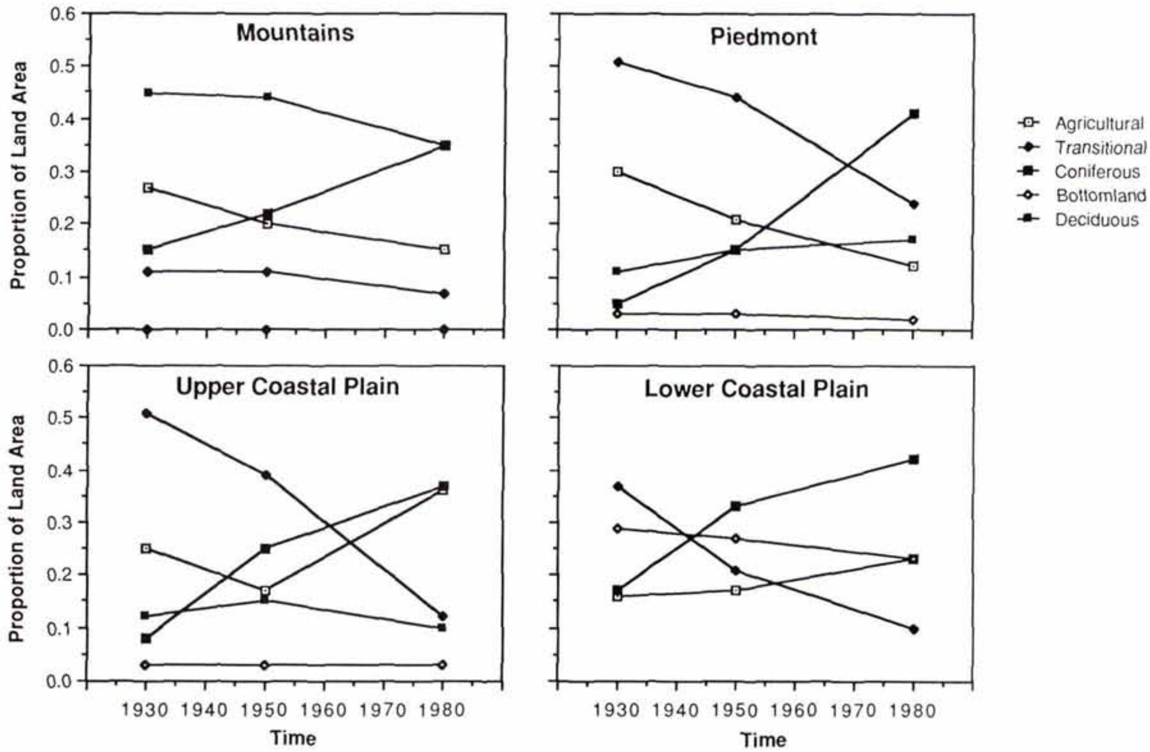

FIG. 3. Proportion of the landscape occupied by different cover types in the four physiographic regions of Georgia. Data are based on aerial photo interpretation for sample counties in each region (see Methods).

geometric in shape. In contrast, the fractal dimension of upper deciduous forest increased from 1.39 to 1.41 (Figure 4), indicating increased complexity in the shapes of patch perimeters.

Values of the dominance and contagion indices are presented for each county in Table 5. The dominance index ranged between 0.28 and 0.52, and differences were significant through time and among counties (Turner and Ruscher, 1988). The value of the index declined in Rabun, Walker, Heard, Monroe, Oglethorpe, and Emanuel counties, indicating a transition toward a more equitable distribution of cover types. Dominance increased in Baker County, which became dominated by agriculture (49.4 percent) by the 1980s. Atkinson and Tattnall counties showed little change. The lowest dominance value was obtained for Walker County, indicating a more even distribution among cover types than the other counties.

The contagion index differed significantly by county but not by time period (Turner and Ruscher, 1988). Values of the contagion index ranged between 0.77 and 0.87, a more narrow range than the dominance index. Walker and Oglethorpe counties had the lowest value for contagion, indicating a slightly more dissected distribution of cover types than the other counties. The highest value of contagion was found in Atkinson County, indicating a more clumped distribution of cover types.

DISCUSSION

This study has documented spatial and temporal changes in the rural landscapes of Georgia during the past 50 years. The extensive changes in land cover in Georgia involved not only the proportion of land that is farm, forest, and so on, but also the spatial patterns. During the 1930s, the landscape was dominated by a few cover types, primarily transitional lands, agriculture, and upland hardwood forest. However, the landscape was also very fragmented, having many small patches of different land uses. This fragmentation declined during the past 50 years. For example, the number of forest patches decreased, but the total amount of forest increased in all regions. Thus, the individual tracts of forest land increased in average size, and forests are now more connected. The size of crop fields changed in different ways among the nine counties. In the piedmont, where cropland has been declining, the average size of crop fields stayed the same. However, in the upper coastal plain, where most of today's agriculture is located, the average size of crop fields increased.

Changes in many ecologically important processes accompanied the land-use changes that occurred in Georgia. Net primary production in the Georgia landscape was extremely low through the 1960s but has increased substatially with natural reforestation, the removal of marginal lands from agriculture, and the adoption of improved agricultural and forestry practices (Turner, 1987b). Indeed, southern forests are now accumulating carbon and serving as a "sink" for carbon dioxide; secondary forests in the southeast now store 75 percent of the total carbon within the terrestrial biota (Delcourt and Harris, 1980; Schiffman and Johnson, 1989). Wildlife populations also varied with land cover. For example, several bird species that occupy old-field habitat (i.e., transitional lands) have declined in number during the past 20 years and these declines parallel the decrease in abandoned cropland (H. R. Pulliam, unpublished data). Water quality and quantity have also changed through time. Water use in Georgia increased rapidly from 1950 to 1970 and has generally leveled off since then (Odum and Turner, 1990). Nonpoint-source pollution, as indicated by nitrates and nitrites, has increased (Odum and Turner, 1990), a trend that is nationwide (Smith *et al.*, 1987).

Landscape patterns, such as those described here for Georgia, and their implications for ecological processes are primary research foci in landscape ecology (Risser et al., 1984; Forman and Godron, 1986; Turner, 1989). With its emphasis on large areas, landscape ecology integrates natural and human features in the environment (Naveh and Lieberman, 1984). Specifically, land-

TABLE 4. TOTAL NUMBER OF PATCHES, MEAN PATCH SIZE, AND MAXIMUM PATCH SIZE OF AGRICULTURAL LAND, CONIFEROUS FOREST, AND UPLAND DECIDUOUS FOREST IN A 12,696 HA AREA IN EACH STUDY COUNTY AND EACH TIME PERIOD. STANDARD DEVIATION OF THE MEAN IS SHOWN IN PARENTHESES.

Land	1930s				1950s				1980s			
cover	*n*	Mean	(s.d.)	Max	*n*	Mean	(s.d.)	Max	*n*	Mean	(s.d.)	Max
					MOUNTAINS							
					Rabun County							
Agricultural	98	22.9	(88.2)	599	81	20.3	(70.2)	485	84	19.7	(69.0)	463
Coniferous	574	2.6	(3.8)	35	685	4.0	(7.8)	92	510	6.5	(15.7)	193
Deciduous	150	53.8	(236.5)	1745	172	43.7	(202.1)	1502	231	28.5	(143.0)	1482
					Walker County							
Agricultural	274	17.1	(69.0)	599	318	11.1	(43.6)	460	169	13.0	(32.9)	329
Coniferous	400	5.5	(16.2)	281	437	6.4	(25.7)	449	263	21.1	(75.7)	702
Deciduous	299	11.0	(36.0)	355	284	12.8	(45.2)	573	410	5.4	(11.9)	134
					PIEDMONT							
					Heard County							
Agricultural	345	9.8	(23.2)	234	150	7.3	(20.1)	204	151	8.4	(12.7)	69
Coniferous	189	2.4	(2.1)	12	401	4.3	(8.0)	66	312	11.1	(30.3)	341
Deciduous	316	10.4	(4.3)	527	302	13.7	(44.7)	582	228	20.7	(63.4)	652
					Monroe County							
Agricultural	374	6.6	(15.1)	189	226	10.1	(36.6)	485	141	9.8	(22.4)	196
Coniferous	212	2.8	(5.4)	64	374	6.7	(19.1)	224	192	28.3	(88.4)	1037
Deciduous	285	2.2	(2.4)	21	252	3.1	(4.4)	39	244	7.1	(17.4)	156
					Oglethorpe County							
Agricultural	227	24.4	(95.2)	1093	242	18.6	(64.5)	567	155	12.5	(32.3)	273
Coniferous	376	2.6	(3.8)	40	428	3.8	(6.1)	64	180	36.8	(133.2)	1050
Deciduous	107	2.2	(2.8)	25	218	3.0	(4.2)	32	60	2.8	(3.6)	20
					UPPER COASTAL PLAIN							
					Baker County							
Agricultural	118	29.7	(57.7)	340	131	24.4	(79.3)	822	52	120.7	(330.5)	1460
Coniferous	307	5.6	(11.2)	93	332	6.0	(12.9)	106	167	19.0	(57.5)	622
Deciduous	101	11.4	(23.7)	177	106	9.5	(19.6)	135	37	8.1	(15.5)	87
					Emanuel County							
Agricultural	163	16.7	(38.0)	349	125	9.6	(14.8)	88	149	19.5	(17.2)	45
Coniferous	154	2.4	(3.7)	36	300	14.9	(46.2)	560	115	53.8	(161.0)	1115
Deciduous	553	3.3	(5.7)	66	474	5.7	(16.1)	208	269	7.8	(18.4)	169
					LOWER COASTAL PLAIN							
					Atkinson County							
Agricultural	112	13.0	(19.0)	99	135	11.3	(15.0)	89	100	20.7	(32.6)	178
Coniferous	370	6.0	(13.4)	212	234	18.8	(79.1)	884	116	44.8	(113.8)	694
Deciduous	0	0.0	(0.0)	0	2	1.0	(0.0)	1	0	0.0	(0.0)	0
					Tattnall County							
Agricultural	141	19.0	(33.4)	257	120	24.2	(60.9)	617	147	26.1	(101.9)	1187
Coniferous	352	5.9	(14.8)	180	279	14.5	(99.8)	1420	249	22.4	(110.7)	1361
Deciduous	5	5.8	(4.3)	12	9	4.2	(4.6)	14	0	0.0	(0.0)	0

scape ecology considers (1) the development and dynamics of spatial heterogeneity, (2) interactions and exchanges across heterogeneous landscapes, (3) the influences of spatial heterogeneity on biotic and abiotic processes, and (4) the management of spatial heterogeneity. Considerable progress has been made in analyzing and interpreting changes in landscape structure (e.g., Romme and Knight, 1982; Krummel *et al.*, 1987; Milne, 1988; O'Neill *et al.*, 1988; Turner and Gardner, in press.) The linkage of pattern and process and the development of predictive models are active areas of current research. Landscape data from remote imagery can also be used to test or run simulation models. For example, some of the historical data described here have been used to compare simulated and actual patterns in the rural landscape (Turner, 1987c, 1988). The use of remotely sensed imagery and geographic information systems will play an increasingly important role in landscape ecological research.

The rural landscape will certainly continue to change. In the southern United States, there is a very broad range of potential levels of demand on the land (Healy, 1985). Future demands for cropland, wood production, and urban areas will depend upon a complicated set of factors, many of which are interna-

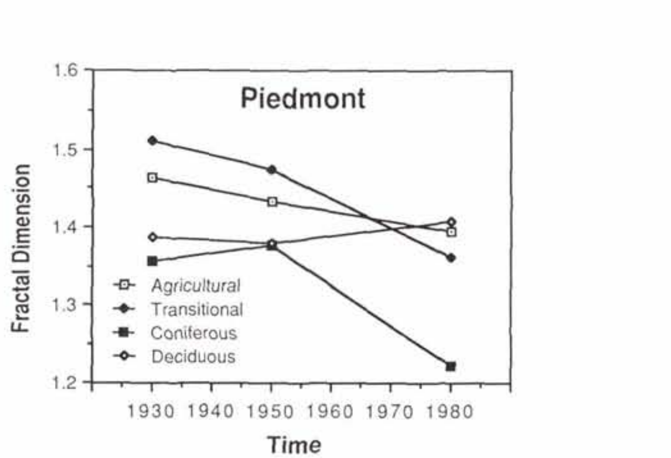

FIG. 4. Fractal dimensions (d) of patch perimeters of major land uses in the Georgia piedmont. A simple, linear perimeter has $d = 1$, whereas a convoluted perimeter surrounding the same area has d approaching 2.

TABLE 5. LANDSCAPE INDICES FOR STUDY COUNTIES IN GEORGIA

	Landscape Dominance			Landscape Contagion		
County	1930s	1950s	1980s	1930s	1950s	1980s
Mountains						
Rabun	0.51	0.48	0.43	0.83	0.84	0.82
Walker	0.31	0.29	0.28	0.80	0.79	0.77
Piedmont						
Heard	0.42	0.39	0.36	0.86	0.83	0.85
Monroe	0.45	0.39	0.36	0.66	0.82	0.81
Oglethorpe	0.47	0.38	0.45	0.84	0.79	0.79
Upper Coastal Plain						
Baker	0.33	0.36	0.42	0.82	0.82	0.82
Emanuel	0.52	0.38	0.39	0.87	0.83	0.83
Lower Coastal Plain						
Atkinson	0.40	0.40	0.40	0.86	0.86	0.86
Tattnall	0.40	0.40	0.42	0.85	0.84	0.81

tional in scope and difficult to predict. Understanding past changes in the rural landscape and their relationship to ecological processes provides information that may be useful in future policy decisions. For example, only 8 percent of the Georgia landscape is in public ownership, that is, in national, state, and municipal forests or parks, wildlife refuges, or wilderness areas. However, less than 2 percent of the piedmont region is preserved, even though the analyses described here demonstrate a substantial increase in forest cover. Because large areas of the Georgia landscape are not yet under strong economic pressure for urban-industrial or agricultural development, Odum and Turner (1990) suggested a statewide goal of placing 20 percent of the landscape under some form of protection. Odum and Turner (1990) also recommended a statewide effort directed toward the protection of river corridors and freshwater wetlands.

Continued development of methods to analyze and predict change is crucial to improving our understanding of rural landscape dynamics. The quantitative measures presented here can be easily appplied to any raster data and can be repeated through time. The linkage of remote sensing and GIS technologies with landscape ecological research, which integrates the spatial patterns of land cover and ecological processes, can provide a sound basis for assessing broad-scale changes in the rural landscape and developing strategies for land management.

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Forum

Miss-Precis

In outlining the distinctions between cartography, remote sensing, and geographic information systems, Fisher and Lindenberg (*PE&RS*, October 1989, pp. 1431-1434) have provided us with a most useful pedagogic framework. When defining remote sensing, they drew upon a note that had been published in the *PE&RS* Forum (Curran, March 1987, pp. 305-306). In this note, I discussed remote sensing as a technique within science and technology. The fourth paragraph started like this: "A browse through *Photogrammetric Engineering and Remote Sensing* reveals that many **researchers are not in pursuit of knowledge** by means of induction or deduction. **Rather,** they are using **remotely sensed** data to **solve problems** by means of a technological approach. Those scientific researchers who are in pursuit of knowledge are faced with many difficulties because inductive and deductive methodologies, although being the best that science has to offer, are far from ideal... ."

The words in bold were selected by Fisher and Landenberg in order to attribute me with the general view that remote sensing "researchers are not in pursuit of knowledge but rather use remote sensing to solve problems."

This statement is neither in the spirit or the wording of my note to Forum.

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