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Changes in landscape patterns in Georgia, USA

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Abstract

The objectives of this study were to determine how landscape patterns in Georgia, USA have changed through time and whether the spatial patterns varied by physiographic region. Historical aerial photography was used to analyze spatial patterns of land use from the 1930's to the 1980's. Land use patterns were quantified by: (1) mean number and size of patches; (2) fractal dimension of patches; (3) amount of edge between land uses; and (4) indices of diversity, dominance, and contagion. Forest cover increased in aerial extent and in mean patch size. The mean size of agricultural patches increased in the coastal plain and decreased in the mountains and Piedmont. Edges between land uses decreased through time, indicating less dissection of the landscape. Fractal dimensions also decreased, indicating simpler patch shapes. Indices of diversity and dominance differed through time but not among regions; the contagion index differed among regions but not through time. A geographic trend of decreasing diversity and increasing dominance and contagion was observed from the mountains to the lower coastal plain. Landscape patterns exhibited the greatest changes in the piedmont region. Overall, the Georgia landscape has become less fragmented and more connected during the past 50 years. Changing patterns in the landscape may have implications for many ecological processes and resources.

Introduction

The patterns of landscape development in time and space result from complex interactions of physical, biological and social forces (Risser *et al.* 1984; Urban *et al.* 1987). Human land use has influenced most landscapes, resulting in a landscape mosaic of natural and human-managed patches that vary in size, shape and arrangement (e.g., Burgess and Sharpe 1981; Forman and Godron 1986; Krummel *et al.* 1987). This patterning in the landscape can influence a variety of ecological phenomena, including animal movements (e.g., Fahrig and Merriam 1985; Henderson *et al.* 1985; Freemark and Merriam 1986), water runoff and erosion (e.g., White *et al.* 1981; Peterjohn and Correll 1984; Kesner 1984), the spread of disturbance (e.g., Franklin and Forman 1987; Turner 1987a), or boundary phenomena in general (Wiens *et al.* 1985). Thus, changes in the spatial patterns of land use through time may be crucial to the understanding of landscape dynamics.

Historical aerial photography was used to analyze spatial patterns of land use in Georgia, USA, from the 1930's to the 1980's. Land use patterns were quantified in several ways, including: (1) mean number and size of patches; (2) fractal dimension of patches; (3) amount of edge between land uses;

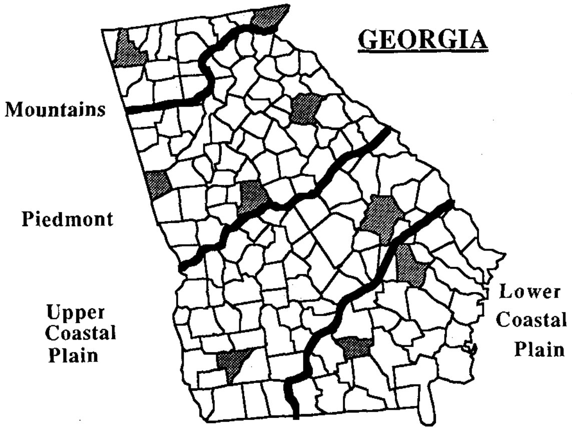

Fig. 1. Map of Georgia showing major physiographic regions and locations of sample counties used in this study.

and (4) indices of diversity, dominance, and contagion. The objectives of the study were to determine how the landscape pattern had changed and whether the spatial patterns varied by physiographic region.

The Georgia landscape

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 (Fig. 1) include the mountains (1,470,310 ha), piedmont (4,606,139 ha) and coastal plain (8,971,206 ha). The mountain region ranges in elevation from 183 to 1432 m, with mean annual temperatures from 12.8 to 16.1°C and annual rainfall from 132 to 229 cm. The predominant forest types are oak-hickory *(Quercus-Carya)* and oak-pine (*Quercus-Pinus*). 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 between 15.0 and 17.8°C. Major forest types are loblolly-shortleaf pine (*Pinus taeda* and *P. echinata)* and oak-pine. The large coastal plain region has gentle to moderate slopes and sandy soils underlain by marine sands, loam and/or clays. Elevation ranges from 0 to 300 m; mean annual rainfall ranges between 112 and 135 cm and mean annual temperatures range from 18.9 to 21.1 "C. The dominant forest types are longleaf-slash pine *(P. palustris* and *P. elliotti)* and loblolly-shortleaf pine, with oak-gum-cypress (*Quercus-Nyssa-Taxodium*) occurring along river flood plains. The coastal plain region may be divided into an upper coastal plain having rolling topography and a lower coastal plain which is relatively flat.

The presettlement vegetation of Georgia was primarily forest, with the exception of coastal salt marshes and grassy areas in the Okefenokee Swamp (Nelson 1957; Plummer 1975). The virgin forest was modified for centuries by the American Indians (Stewart 1956), but more extensive modification of the landscape accompanied European settlement. Coastal plain forests were cut between 1866– 1890, and virgin pine timber was exhausted by 1895 (Plummer 1975). Extensive clearing and farming also occurred during the 1800's on the Georgia piedmont (Brender 1952, 1974), where the lands were worn out, abandoned, and new lands cleared almost continuously for more than a century (Hartman and Wooten 1935). By 1930, more than 80% of the lower Piedmont region had been cleared at some time (Bond and Spillers 1935), and much of it had been cleared two or three times (Hartman and Wooten 1935). Most abandoned land reverted through natural succession to pine, primarily loblolly and shortleaf, and old-field pine comprised more than two-thirds of the total forest area in 1930 (Hartman and Wooten 1935). 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 predominate (Johnson and Sharpe 1976).

Methods

Aerial photo interpretation

Data on land use patterns in Georgia were obtained from historical black and white aerial photography.

Nine counties were selected for analysis (Fig. 1), including three in the piedmont and two each in the mountains, upper coastal plain, and lower coastal plain. These nine counties were chosen using a random selection modified by the availability of adequate photo coverage. Aerial photography for all sites was obtained for three time periods: (1) the earliest available photos, ranging from 1937 to 1942; (2) photos from the 1950's; 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. Six 23-cm² (9-in²) 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 x 4.6 km (2,116 ha) for each photo, or 12,696 ha for each county. Essentially the same area was analyzed for each time period, although exact registration between photographs was not done. The photographs were arranged in a rectangular two column by three row pattern and were adjacent, but not overlapping. 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.

Each photo was viewed with adjacent photography under a mirror stereoscope to produce stereo-images and magnification of the land cover. Photos were overlain with transparent sheets of acetate upon which the land cover was delineated. 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 using the land cover occupying the greatest proportion of each cell.

Eight land use/land cover categories were used, following the classification of Anderson et *al.* (1976). These are summarized as follows:

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 areas 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% and with an estimated average tree height of at least 3 m; pine plantations were included.

6. *Upper deciduous forest.* Deciduous forest not along stream courses with a canopy cover of at least 50% and with an average tree height of at least 3 m.

7. *Lower deciduous forest.* Deciduous forest and associated vegetation found along or in stream courses.

8. *Water.* Natural or man-made water bodies including rivers, lakes, and farm ponds.

Spatial pattern analyses

A spatial analysis computer program (SPAN) was developed to quantify landscape patterns and compare patterns through time. The fraction of the landscape occupied by each land cover type was calculated. Patch size and complexity, the amount of edge in the landscape, and several indices (O'Neill *et al.*, in press) based on information theory (Shannon and Weaver 1962) were used to describe landscape patterns.

A patch was defined as contiguous, adjacent (horizontally or vertically) cells of the same land cover; diagonal cells were not considered to be contiguous. Each patch in the landscape matrix was located, and its size (s) and perimeter (I) were recorded. The number and mean size of patches were calculated for each matrix using SAS (SAS Institute 1982). The complexity of patch perimeters was measured using fractal dimensions (Mandelbrot 1983), which can be used to compare the geometry of landscape mosaics (Milne in press). The fractal 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. Linear regression analysis of log $(l/4)$ against log(s) of each patch was done for each land use in a matrix using SAS. The fractal dimension of the patch perimeters is equal to twice the slope of the regression line. 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 sqare and 2.0 representing a very complex perimeter encompassing the same area.

The amount of.edge between each land use was determined by summing the number of interfaces between adjacent cells of different land uses, then multiplying by 100 m (the length of a cell). Edge data ware analyzed with SAS using ANOVA, and means were differentiated using Bonferroni t-tests.

Three indices based on information theory were also used. The first index, H, is a measure of diversity:

$$H = -\sum_{k=1}^{m} (P_k) \log (P_k), \qquad (1)$$

where P_k is the proportion of the landscape in cover type k, and m is the number of land cover types observed. The larger the value of H, the more diverse the landscape.

The second index, D, is a measure of dominance, calculated as the deviation from the maximum possible diversity:

$$D = H_{\max} + \sum_{i=1}^{m} (P_k) \log (P_k), \qquad (2)$$

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. Inclusion of $H_{\max}$ in Equation 2 normalizes the index for differences in numbers of land cover types between different landscapes; the terms in the summation are negative, so Equation 2 expresses the deviation from the maximum. Large values of D indicate a landscape that is dominated by one or a few land uses, and low values indicate a landscape that has many land uses represented in approximately equal proportions. However, the index is not useful in a completely homogeneous landscape (i.e., $m = 1$) because D then equals zero.

Table 1. Proportion of the landscape occupied by each cover type (P_k) by physiographic region in Georgia.

Land use	1930's	1950's	**1980's**
		Mountains	
Urban	0.01	0.01	0.05
Agricultural	0.21	0.20	0.15
Transitional	0.11	0.11	0.01
Improved pasture	0.02	0.01	0.03
Coniferous forest	0.15	0.22	0.35
Upper deciduous forest	0.45	0.44	0.35
Lower deciduous forest	0.00	0.00	0.00
Water	0.00	0.00	0.00
		Piedmont	
Urban	0.01	0.01	0.03
Agricultural	0.30	0.21	0.12
Transitional	0.51	0.44	0.24
Improved pasture	0.00	0.00	0.00
Coniferous forest	0.05	0.15	0.41
Upper deciduous forest	0.11	0.15	0.11
Lower deciduous forest	0.03	0.03	0.02
Water	0.00	0.00	0.00
		Upper coastal plain	
Urban	***0.01***	0.01	0.01
Agricultural	0.25	0.17	0.36
Transitional	0.51	0.39	0.12
Improved pasture	0.00	0.00	0.00
Coniferous forest	0.08	0.25	0.37
Upper deciduous forest	0.12	0.15	0.10
Lower deciduous forest	0.03	0.03	0.03
Water	0.02	0.01	0.01
		Lower coastal plain	
Urban	***0.00***	***0.00***	***0.00***
Agricultural	0.16	0.17	0.23
Transitional	0.37	0.21	0.10
Improved pasture	0.00	0.00	0.00
Coniferous forest	0.17	0.33	0.42
Upper deciduous forest	0.00	0.00	0.00
Lower deciduous forest	0.29	0.27	0.23
Water	0.00	0.00	0.01

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

$$C = K_{\max} + \sum_{i=1}^{m} \sum_{j=1}^{m} (Q_{ij}) \log (Q_{ij}), \qquad (3)$$

were $K_{\max} = 2m \log(m)$ and is the absolute value of the summation of $(Q_{ij}) \log (Q_{ij})$ when all pos-

Table 2. Number of patches (n) and mean patch size (ha) by physiographic region in Georgia.

Land use	1930's			1950's			1980's		
	n	mean size	s.d.	n	mean size	s.d.	n	mean size	s.d.
Mountains (total study area = 25,392 ha)									
Urban	17	8.06	8.10	28	12.64	19.67	110	10.81	31.89
Agricultural	372	18.61	74.48	399	12.96	50.24	253	15.25	48.03
Transitional	796	3.52	6.35	638	4.51	9.38	385	4.86	8.78
Improved pasture	119	3.47	3.07	67	3.70	3.70	90	7.52	11.34
Coniferous forest	974	3.82	10.88	112	4.92	17.23	773	11.47	46.45
Upper deciduous forest	49	25.29	140.97	456	24.40	129.80	641	13.76	87.07
Lower deciduous forest	20	1.65	1.14	24	2.62	2.43	30	2.83	2.96
Water	3	1.33	0.58	14	1.00	0.00	16	1.50	0.97
Piedmont (total study area = 38,088 ha)									
Urban	11	18.45	51.30	12	33.33	93.05	23	47.00	182.78
Agricultural	946	12.02	50.03	618	12.80	47.27	447	10.28	23.97
Transitional	901	21.44	108.13	894	18.84	75.91	658	14.09	35.44
Improved pasture	3	4.33	2.52	35	3.60	4.65	31	4.61	3.86
Coniferous forest	777	2.61	4.03	1203	4.88	12.21	684	22.70	85.93
Upper deciduous forest	708	5.86	23.37	772	7.25	28.61	532	12.45	43.16
Lower deciduous forest	210	4.74	8.46	237	5.48	13.62	70	10.60	23.67
Water	0	–	–	22	1.45	1.50	58	1.71	1.77
Upper coastal plain (total study area = 25,392 ha)									
Urban	7	19.57	36.67	7	22.86	40.19	7	51.57	93.59
Agricultural	281	22.18	47.65	256	17.20	58.03	201	45.10	174.91
Transitional	462	21.85	135.24	587	16.66	76.91	291	10.41	26.44
Improved pasture	0	–	–	8	9.50	15.47	6	9.17	5.91
Coniferous forest	461	4.52	9.53	632	10.22	33.47	282	33.25	112.98
Upper deciduous forest	654	4.60	11.05	580	6.40	16.82	306	7.88	18.10
Lower deciduous forest	83	7.51	12.03	71	9.15	13.62	73	10.49	15.09
Water	56	7.70	12.89	73	2.11	2.32	102	2.07	2.07
Lower coastal plain (total study area = 25,392 ha)									
Urban	3	4.61	5.51	6	3.33	3.93	16	4.60	4.32
Agricultural	253	16.35	28.09	255	17.37	43.58	247	23.92	81.29
Transitional	670	14.16	63.17	654	8.20	24.78	262	9.33	19.30
Improved pasture	3	2.33	1.53	6	10.67	18.79	24	3.83	4.62
Coniferous forest	722	5.95	14.1	513	16.47	90.93	365	29.56	112.02
Upper deciduous forest	5	5.80	4.21	11	3.63	4.32	0	–	–
Lower deciduous forest	769	9.59	38.90	754	9.23	43.19	508	11.48	51.01
Water	18	2.20	2.44	22	3.09	5.93	105	2.35	2.99

sible adjacencies between land cover types occur with equal probabilities. The summation term is negative, and Equation 3 gives the deviation from the maximum possible contagion. K_{max} normalizes landscapes with differing values of m and causes C to be zero when $m = 1$ or all possible adjacencies occur with equal probability. When $m \geq 2$, large values of C will indicate a landscape with a clumped pattern of land cover type.

Results

The proportion of land in each cover type varied throughout the study period (Table 1). Forests increased in overall abundance, with coniferous forests increasing in all regions. Upland deciduous forest declined in the mountains and upper coastal plain, but increased in the Piedmont. Agricultural land declined in all regions except the upper coastal plain, where it increased. Transitional land declined in all regions. Urban area increased in the mountains and Piedmont, although major metropolitan areas (e.g., Atlanta) were not included in the study.

The number and size of patches (Table 2) generally varied through time and among physiographic regions. Forest patches were numerous and small in the 1930's (Table 2), with many forest islands of only 1 ha in size. Forest patches were generally fewer in number and larger in size in the 1980's. The largest mean forest patch sizes (29-33 ha) were observed in the coastal plain for coniferous forests, which frequently are pine plantations; forest patch sizes were significantly smaller in the piedmont and mountains (p c 0.05, Bonferroni t-tests). The greatest increases in mean forest patch sizes were observed for coniferous forests in the piedmont (from 2.6 to 13.6 ha) and upper coastal plain (from 4.52 to 33.25 ha). Patches of upper deciduous forest were largest in the mountains, although they decreased in mean size from 25 to 13 ha. Patch size of upper deciduous forest increased in the piedmont and upper coastal plain. Agricultural patches decreased in number in the mountains, Piedmont, and upper coastal plain, but remained almost constant in number in the lower coastal plain. The mean size of agricultural patches doubled to 46 ha in the upper coastal plain and was significantly larger in the upper coastal plain than in the other regions ($p < 0.05$, Bonferroni t-tests). Agricultural patch size also increased in the lower coastal plain, but decreased in the mountains and Piedmont.

The complexity of patches, as measured by fractal dimensions across all cover types, declined in the Georgia landscape (Fig. 2), with the' piedmont showing the greatest change. Land cover types most influenced by humans (e.g., urban, agricultural land, pine plantations) tended to have lower fractal dimensions, indicating less complex shapes (Table 3). Deciduous forests frequently had higher fractal dimensions than other land uses. The highest fractal dimensions were observed for lower deciduous forest in the mountains (1.566) and the piedmont (1.539). The lowest fractal dimensions were observed for coniferous forest in the piedmont (1.224) and for urban areas in the piedmont (1.27 1) and upper coastal plain (1.258). The fractal dimension of hardwood forests in the upper coastal plain increased notably, probably because these deciduous forests are generally residual and not managed, occurring on less productive lands whose boundaries may follow physiographic contours. Transitional lands exhibited relatively high fractal dimensions in the 1930's, probably reflecting both large patch sizes and decreasing human influence on the land.

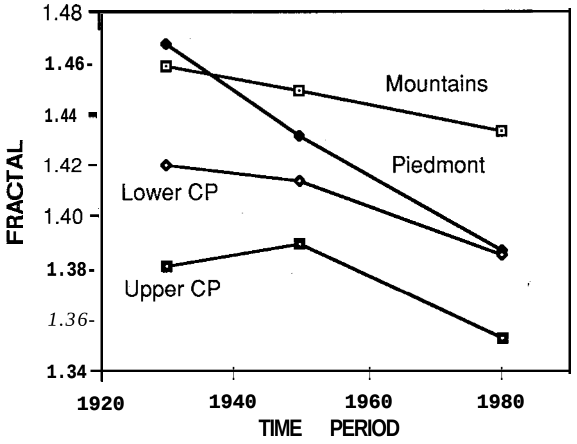

Fig. 2. Fractal dimension for patches of all land cover types by physiographic region in Georgia. Fractals were calculated by regression analysis (see Methods); all $r^2 > 0.95$.

Amounts of edge in the landscape (Table 4) varied among regions (p c 0.001, ANOVA) and through time ($p < 0.001$, ANOVA). Edge between agricultural land and pine forest increased significantly through time, whereas edge between agricultural land and other land uses decreased. The lower coastal plain had the most edge between agricultural land and forest types ($p < 0.05$, Bonferroni t-tests), but the piedmont had the most edge between agricultural and transitional lands ($p < 0.05$). Edge between coniferous and upper deciduous forest was greatest in the mountains, but it increased through

Table 3. Fractal dimensions (r^2) for major land cover types by physiographic region in Georgia.

Land use	1930's	1950's	1980's
		Mountains	
Agricultural	1.487 (0.99)	1.413 (0.98)	1.386 (0.98)
Transitional	1.423 (0.98)	1.420 (0.97)	1.326 (0.97)
Coniferous forest	1.453 (0.98)	***1.458 (0.98)***	1.479 (0.98)
Upper deciduous forest	1.468 (0.98)	1.490 (0.99)	1.466 (0.98)
Lower deciduous forest	1.519 (0.99)	1.310 (0.96)	1.566 (0.99)
Urban	1.312 (0.97)	***1.400 (0.96)***	1.374 (0.98)
		Piedmont	
Agricultural	1.464 (0.98)	1.432 (0.98)	1.394 (0.97)
Transitional	1.511 (0.98)	1.474 (0.98)	1.362 (0.98)
Coniferous forest	1.358 (0.97)	1.377 (0.97)	***1.224 (0.96)***
Upper. deciduous forest	1.387 (0.98)	1.380 (0.98)	1.407 (0.98)
Lower deciduous forest	1.499 (0.99)	1.539 (0.99)	1.449 (0.99)
Urban	1.271 (0.99)	1.408 (0.99)	1.294 (0.98)
		Upper coastal plain	
Agricultural	1.344 (0.97)	1.325 (0.97)	1.345 (0.98)
Transitional	1.471 (0.98)	1.438 (0.98)	1.353 (0.97)
Coniferous forest	1.337 (0.98)	1.386 (0.98)	1.354 (0.98)
Upper deciduous forest	***1.390 (0.98)***	1.408 (0.98)	1.463 (0.98)
Lower deciduous forest	1.306 (0.95)	1.325 (0.97)	1.333 (0.97)
Urban	1.327 (0.99)	1.310 (0.96)	***1.258 (0.99)***
		Lower coastal plain	
Agricultural	1.356 (0.97)	1.361 (0.98)	1.373 (0.97)
Transitional	1.479 (0.99)	1.417 (0.98)	1.372 (0.98)
Coniferous forest	***1.419 (0.97)***	1.462 (0.98)	1.419 (0.98)
Upper deciduous forest	1.351 (0.91)	1.413 (0.95)	-
Lower deciduous forest	1.424 (0.98)	1.427 (0.98)	1.376 (0.98)
Urban	-	-	1.466 (0.98)

time in all regions. All other edges between dominant land uses decreased in each region, except for the edge between transitional land and upper deciduous forest in the mountains, which increased by 600% between the 1950's and 1980's (Table 4). Transitional - forest edges were greatest in the piedmont and upper coastal plain. The total amount of edge among all land cover types decreased during the study period.

Values for the indices of diversity, dominance, and contagion are shown in Table 5. Indices of diversity and dominance differed through time and by county but did not differ significantly by region (Table 6). The diversity and dominance indices exhibited the greatest net changes in the Piedmont. Diversity increased in the mountains and piedmont but remained constant in the lower coastal plain. In the upper coastal plain, diversity increased between the 1930's and 1950's but decreased in the 1980's, corresponding to the increase in agricultural land (Table 1). The dominance index generally decreased (mountains, Piedmont, upper coastal plain) or did not change (lower coastal plain) through time. However, dominance increased in the upper coastal plain in the 1980's. The index of contagion differed by region and among counties, but did not differ significantly through time (Table 6). The mountain region had the lowest values and the upper and lower coastal plain had higher values (Table 5), indicating more clumped patterns on the coastal plain.

Table 4. Mean and standard deviation of edge (km) between land uses in a 2116 ha area of the Georgia landscape.

Land uses	1930's		1950's		1980's	
			Mountains			
Ag-bottom	0.6	(1.2)	0.6	(1.2)	0.8	(1.2)
Ag-hardwood	19.8	(8.9)	12.7	(6.9)	7.6	(29.7)
Ag-pine	12.6	(9.6)	12.4	(6.5)	15.5	(8.9)
Ag-transitional	23.9	(18.2)	20.0	(15.0)	6.0	(3.3)
Pine-hardwood	42.1	(23.6)	60.2	(29.1)	63.2	(25.1)
Transitional-hardwood	16.4	(6.4)	12.9	(7.7)	81.2	(4.4)
Transitional-pine	9.3	(5.9)	12.2	(9.9)	11.3	(6.2)
			Piedmont			
Ag-bottom	2.0	(1.7)	1.5	(1.7)	0.6	(1.4)
Ag-hardwood	8.3	(7.7)	4.9	(2.9)	5.2	(4.8)
Ag-pine	6.7	(6.2)	11.1	(8.4)	17.6	(11.4)
Ag-transitional	65.8	(13.8)	35.2	(19.3)	10.7	(6.5)
Pine-hardwood	2.8	(2.8)	12.6	(11.4)	25.7	(18.2)
Transitional-hardwood	24.8	(19.6)	25.2	(17.3)	13.4	(11.0)
Transitional-pine	16.9	(9.2)	32.2	(11.5)	31.8	(13.9)
			Upper coastal plain			
Ag-bottom	1.0	(1.9)	0.5	(0.8)	1.3	(1.3)
Ag-hardwood	9.4	(8.7)	5.4	(3.9)	10.3	(12.4)
Ag-pine	5.6	(4.8)	9.7	(4.4)	23.1	(5.1)
Ag-transitional	34.4	(9.8)	21.3	(15.7)	10.8	(7.1)
Pine-hardwood	3.9	(3.4)	18.9	(13.7)	16.6	(16.5)
Transitional-hardwood	33.2	(24.4)	25.6	(17.4)	5.8	(5.4)
Transitional-pine	19.3	(12.2)	37.2	(10.4)	13.5	(13.9)
			Lower coastal plain			
Ag-bottom	11.8	(8.0)	11.0	(8.9)	9.8	(6.8)
Ag-hardwood	0.2	(0.6)	0.2	(0.6)	0.0	(0.0)
Ag-pine	12.5	(9.6)	17.4	(9.4)	26.5	(14.3)
Ag-transitional	14.3	(9.6)	12.0	(10.4)	8.0	(4.0)
Pine-hardwood	0.1	(0.3)	0.1	(0.3)	0.0	(0.0)
Transitional-hardwood	0.1	(0.5)	0.2	(0.3)	0.0	(0.0)
Transitional-pine	31.0	(12.1)	25.0	(8.5)	11.4	(7.6)

Discussion

Spatial patterns of land use in Georgia have changed during the past 50 years. Edges, fractal dimensions, contagion, and dominance generally decreased; thus, the landscape has become less fragmented and more connected. Forests, the natural vegetative cover, increased in aerial extent and in mean patch size. Qualitative changes in the dominant types of edge (from transitional-agricultural and transitional-hardwood to agricultural-pine and pine-hardwood) reflect the successional changes that followed cropland abandonment. The changes observed in Georgia contrast with the decreased connectivity observed in other areas of the U.S. (Burgess and Sharpe 1981, Sharpe et *al.* 1987) and many European countries (e.g., Van Dorp and Opdam 1987).

Regional differences in landscape patterns were also identified. The piedmont and mountain regions were most patchy, whereas the coastal plain had fewer and larger patches. Fractal dimensions were greatest in the mountains and Piedmont, whereas simpler shapes were indicated in the coas-

Table 5. Landscape pattern indices (mean, sd) by physiographic region in Georgia.

Index	1930's	1950's	1980's
	Mountains		
Diversity	1.22 (0.24)	1.26 (0.25)	1.33 (0.22)
Dominance	0.86 (0.24)	0.81 (0.25)	0.74 (0.22)
Contagion	27.10 (0.95)	27.07 (1.39)	26.45 (1.45)
	Piedmont		
Diversity	1.10 (0.12)	1.27 (0.09)	1.26 (0.15)
Dominance	0.94 (0.10)	0.81 (0.91)	0.81 (0.15)
Contagion	26.15 (3.10)	27.21 (1.08)	27.17 (1.91)
	Upper coastal plain		
Diversity	1.19 (0.25)	1.31 (0.17)	1.23 (0.16)
Dominance	0.89 (0.25)	0.77 (0.17)	0.84 (0.16)
Contagion	28.18 (1.18)	27.49 (1.21)	27.47 (1.24)
	Lower coastal plain		
Diversity	1.23 (0.12)	1.23 (0.14)	1.22 (0.24)
Dominance	0.84 (0.12)	0.84 (0.14)	0.85 (0.14)
Contagion	28.64 (0.82)	28.32 (1.10)	27.72 (1.20)

Table 6. Two-way **ANOVA** results for variation of landscape diversity, dominance and contagion.

Source of variation	df	Index Diversity		Dominance		Contagion	
		F	*P>F*	*F*	*P>F*	*F*	*P>F*
Region	3	1.66	0.179	0.94	0.424	13.80	0.001
Time	2	7.53	0.001	5.35	0.006	0.90	0.408
County	5	14.70	0.001	14.56	0.001	15.71	0.001
Region x time	6	1.84	0.095	1.29	0.268	3.06	0.008
County × time	10	2.96	0.002	2.39	0.012	8.50	0.001
Error	135	–	–				

tal plain. The mountains currently have the most edge and highest diversity, and there is a geographic trend of decreasing diversity and increasing dominance and contagion from the mountains to the lower coastal plain. Thus, land use patterns in Georgia may reflect broad-scale topographic patterns.

Land use classes that are less influenced by humans (e.g., hardwood forests) tend to be more complex in shape than those which receive greater human influence (e.g., urban or agricultural lands). Similar results have been reported for other sections of the United States (Krummel et al. 1987). The observed complexity of patches of transitional land and lower deciduous forest may reflect topographic or edaphic patterns. Most transitional lands were derived from agricultural lands. Crop fields were typically abandoned first from the perimeters, creating complexly shaped patches of early successional lands. The complexity of the lower deciduous forest patches probably reflects the sinuosity of stream courses.

Hoover (1986) also studied the structure of the Georgia landscape, but 14 vegetation types were used. Sections of a vegetation map (Georgia DNR 1974) representing 10x 10 km areas in each of six rural counties were analyzed, and field study was conducted to describe species composition in selected stands. Hoover reported higher landscape diversity in the lower coastal plain, decreasing to the mountains. These results describe pattern at a finer resolution (e.g., 14 plant communities) than the present study, and may also reflect the wide range of moisture conditions in the lower coastal plain (Hoover 1986). Thus, broad-scale land use patterns may reflect topographic conditions, whereas finer-scaled vegetation patterns may reflect more local edaphic variability.

A small number of landscape indices can discriminate among major landscape types (O'Neill *et al.* in press). Significant changes in diversity and dominance were observed through time in this study, but differences among regions were not detected. In contrast, significant differences in contagion, which identifies finer-scaled aspects of pattern (O'Neill *et* al. in press), were observed among regions but not through time. Edges and patch sizes, which describe even finer detail, varied significantly both through time and among regions. Thus, broad-scale measures of pattern may be useful to detect large temporal changes but may be less useful to differentiate spatial patterns within a biotic province.

Analyses of landscape pattern are dependent upon the spatial scale of the data, which encompasses both grain (the resolution of the data) and extent (the total size of the study area) (Turner *et al.* submitted). The data used in this study had a grain size (S_g) of 1 ha and a spatial extent (S_e) of 12,696 ha per county. Extrapolation or comparison of results obtained at different spatial scales may not be straightforward (Turner *et al.* submitted).

Changing patterns in the landscape will have implications for many ecological processes and resources in Georgia (Odum and Turner in press; Turner *et al.* 1988). Net primary production of the landscape, which is both ecologically and economically important, has changed with land use during the past 50 years (Turner 1987b). The abundance and distribution of wildlife species might also vary with changing spatial patterns in the landscape. For example, species that favor or require particular edge types may decline if the amount of edge declines, whereas species requiring extensive tracts of forest may benefit from the increasing size and connectivity of forest patches. Changes in landscape patterns may also relate to the flows of material or energy across landscapes. For example, erosional processes and sediment movement across landscapes might be predictable using indices of landscape pattern. Quantification of the relationship between changing landscape patterns and functional processes would be particularly informative and provide a more complete understanding of landscape dynamics.

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