9. The Georgia Landscape: A Changing Resource

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Albert E. Cowdrey (1983) comments that poverty is no friend of natural resources which "typically are devoured piecemeal to sustain existence." Unbridled prosperity is also no friend of natural resources, which tend to be despoiled in the rush to accumulate material wealth. Georgia, along with the rest of the southern U.S.A., has experienced both poverty and prosperity. In the early 1900s, Georgia was poor as measured by most economic and cultural indices and as compared with northern states of the U.S.A. Much of its soil was "devoured" in an effort to scratch out an agrarian existence, and human-resource potential was chronically underachieved as a result of low income and poor education. During the past 50 years the tables have turned. Southern states have made a remarkable recovery from decades of depression, and economic and cultural measures now approach those of the rest of the nation. However, little planning has been done to cope with the changes. Land use, for example, changed dramatically. Once forested, Georgia became primarily agricultural, then made a transition to its present diversity of forests, farms, and cities. The South, including Georgia, now has a relatively large land reserve for which a variety of uses may compete in the future (Healy, 1985).

To provide a background for future planning and management, we studied changes in the landscape and in resource use from 1935 to 1985 in Georgia. We began with the 1930s because the late Howard W. Odum published his masterwork, *Southern Regions of the United States*, in 1936. This book documented the condition of the region's human and natural resources, the reasons for the

...may be protected by ...

"chasm between the potentialities and the actualities" (Odum's words), and what needed to be done. Our goal in this study was to compile a sort of "Southern Regions Revisited," with a focus on the state of Georgia as a microcosm of the region. In this chapter, we will describe changes in land and resource use within Georgia and assess some of the ecological implications of these changes.

Georgia is a good microcosm for the southern USA because its topographic gradient from mountains to the sea and its climate (moist, warm temperate) are representative of the region. Human population density, the ratio of urban to rural inhabitants (60/40), and per capita income are also close to the regional average. Accordingly, we can compare Howard Odum's southern regions of the 1930s with Georgia of the 1980s. In the 1930s the chief problems were social and economic; now they are demographic (rapid population growth due to immigration) and environmental. To assess change, we first compiled numerous charts and tables from existing data bases to document changes in the Georgia landscape and its plant, animal, and other natural resources during the past 50 years. For some studies, it was not possible to analyze the whole state during our 2-year project, so representative sample counties were selected for study (Figure 1).

Georgia encompasses three major physiographic regions (Figure 1); the mountains (1,470,310 ha), the piedmont (4,606,139 ha), and the coastal plain (8,971,206 ha). The mountain region ranges in elevation from 183 to 1432 m,

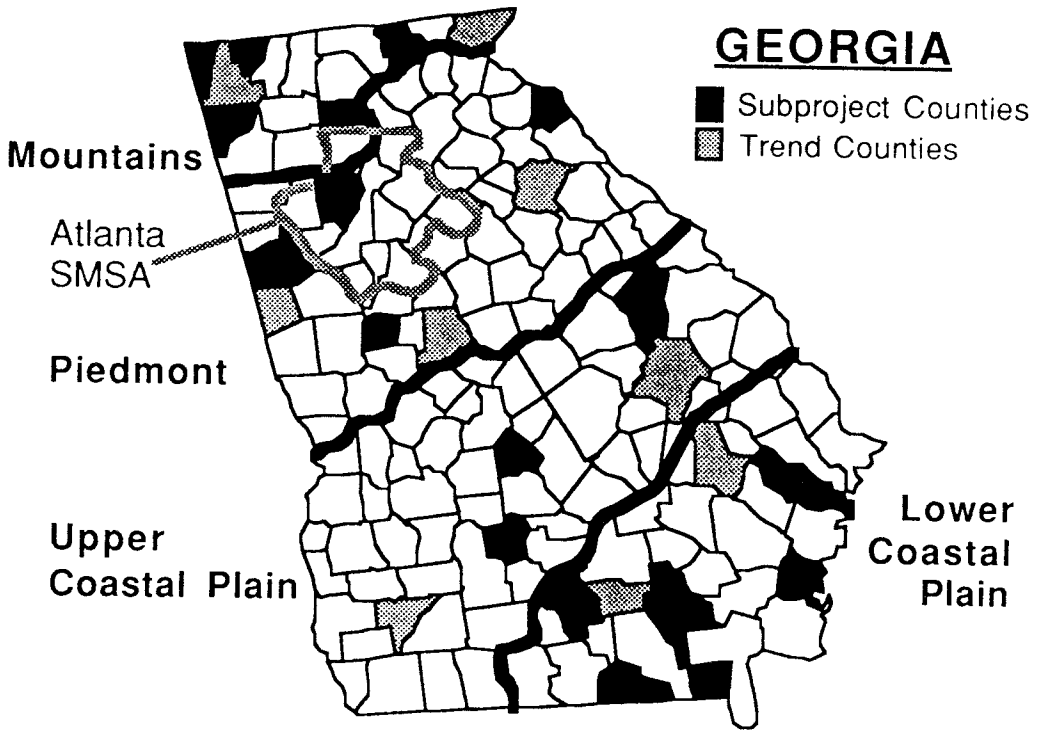

Figure 1. Map of Georgia showing physiographic regions and sample counties used in our study. The nine *trend counties* were used for the analysis of changes in landscape patterns; these plus the other *subproject counties* were used in other portions of the study.

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, loam, and/or clays. Elevation ranges from 0 to 300 m; mean annual rainfall ranges from 112 to 135 cm, and mean annual temperatures range from 18.9 to 21.1°C.

Historical Perspective

Forests once covered the state of 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 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. Plummer (1975) used survey maps from the early 1800s to identify the species composition of the early forests. The virgin forest had been modified for centuries by Native Americans, who commonly used fire as a hunting technique, as a means to increase production of browse, berries, and other wild food plants, and to clear fields for agriculture (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 by 1793 cotton was the dominant crop. Subsequently, 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). Following invasion of the boll weevil *(Anthonomus grandis)* in the 1920s, large amounts of cropland were abandoned. 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.

Structure of the Georgia Landscape

Most landscapes, including Georgia, are heavily influenced by human land use. The resulting landscape mosaic is a mixture of natural and human-managed patches that vary in size, shape, and arrangement (e.g., Burgess and Sharpe, 1981; Forman and Godron, 1986; Urban et al., 1987). These spatial patterns can influence a variety of ecological phenomena (Turner, 1989), 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), or the spread of disturbance (e.g., Franklin and Forman, 1987; Turner, 1987a; Turner et al., 1989). Thus, our ability to quantify changes in landscape structure through time may be crucial to our understanding of the dynamics of the Georgia landscape. We discuss several different approaches to analyzing these changes.

Changes in Land Use

Land use patterns integrate both the natural and human-developed environments and thus were an important focal point in our study. The extensive changes in land use in Georgia involved not only the *proportion* of land that is farm, forest, urban, and so on, but also the *spatial patterns*, such as patch size and complexity. For the state as a whole, the area in farmland (which includes the fields, pastures, small woods, etc., that are on farms) decreased, with the most rapid change occurring between 1950 and 1970. In the coastal plain, however, cropland increased during the past two decades (Figure 2). Forests of varying age and composition have covered more than 60 percent of the state throughout the half-century period. This included frequent cutovers, but nevertheless there was a tendency for the total forest area to increase. Coverage today is about 65 percent statewide, but varies up to 85 percent in some mountain counties and to as low as 40 percent in some agricultural counties of southwestern Georgia. The greatest changes in land use occurred in the piedmont region (Figure 2), where the majority of Georgians live today.

Since the 1930s, the area in urban-industrial use (including transportation corridors) has increased rapidly. In 1930, Atlanta was the only officially recognized Standard Metropolitan Statistical Area (SMSA, a census bureau term for major cities and their surrounding suburban areas). By 1985, the Atlanta SMSA comprised 15 counties (see Figure 1) and one-third of the state's human population. Now there are seven other SMSAs of two to four counties each, so that 22 percent of Georgia's 159 counties are included in metropolitan districts. The total length of state and federal highways in Georgia has more than doubled since 1935, from 5,400 to 12,000 km (9,000 to 20,000 mi). Southern cities are not as densely populated as many older cities of the Northeast; for example, human density in Atlanta is about 3,000 persons per square mile compared with 10,000 or more in some eastern cities.

Despite the increased urbanization in Georgia, the ground actually occupied by towns and cities remains only about 6 percent of the whole land area of the state (Figure 2), with an additional 2 to 3 percent in transportation corridors. However, because of the very large energy and resource demands of urban-industrial areas, the impact of cities on surrounding cropland, forests, rivers, and aquifers is enormous. In the pie-diagram of Figure 3, we weighted the three major environments (agricultural, natural, and urban) according to **energy density,** that is, how much fossil-fuel energy is consumed for human activities per

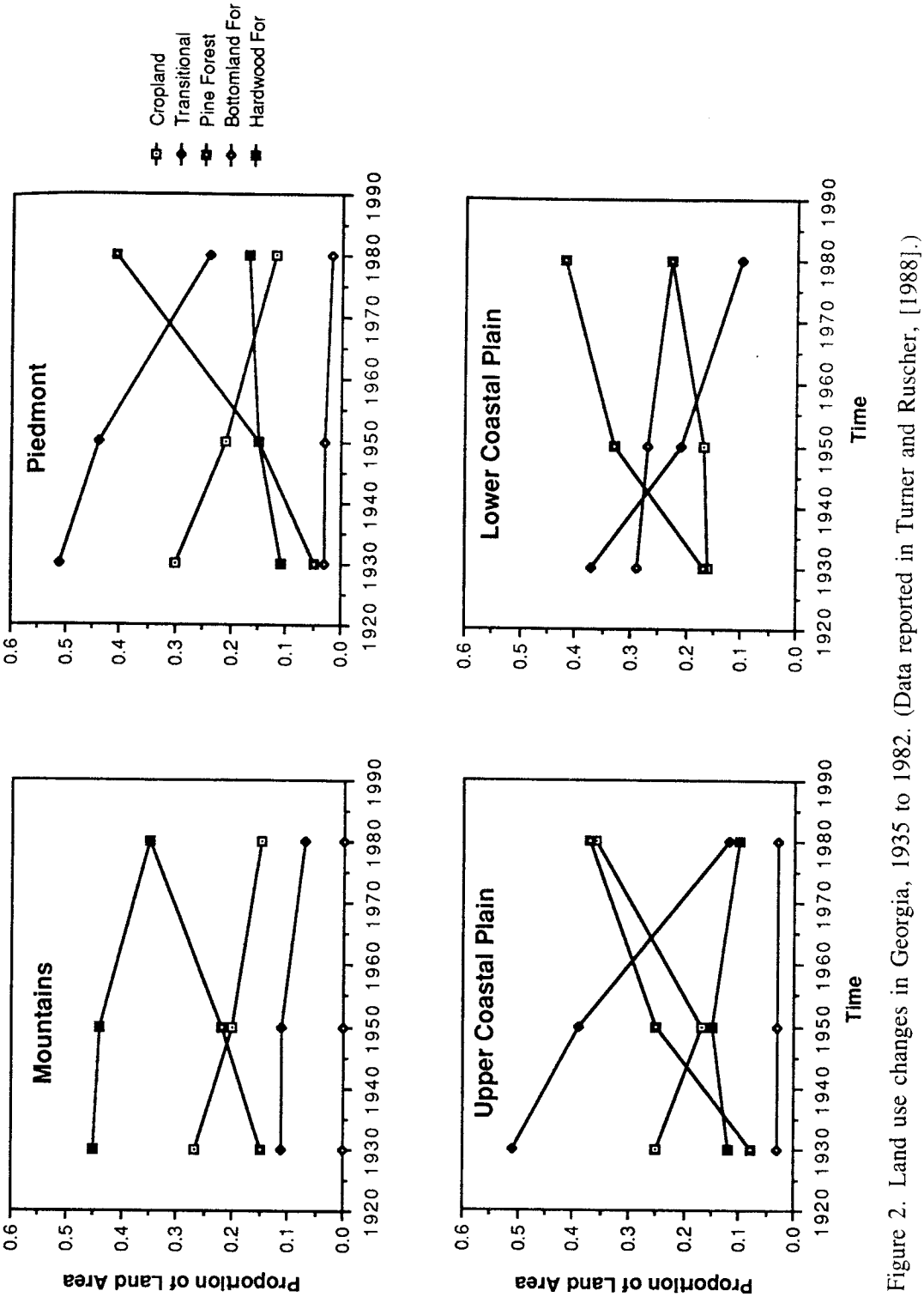

Figure 2. Land use changes in Georgia, 1935 to 1982. (Data reported in Turner and Ruscher, [1988].)

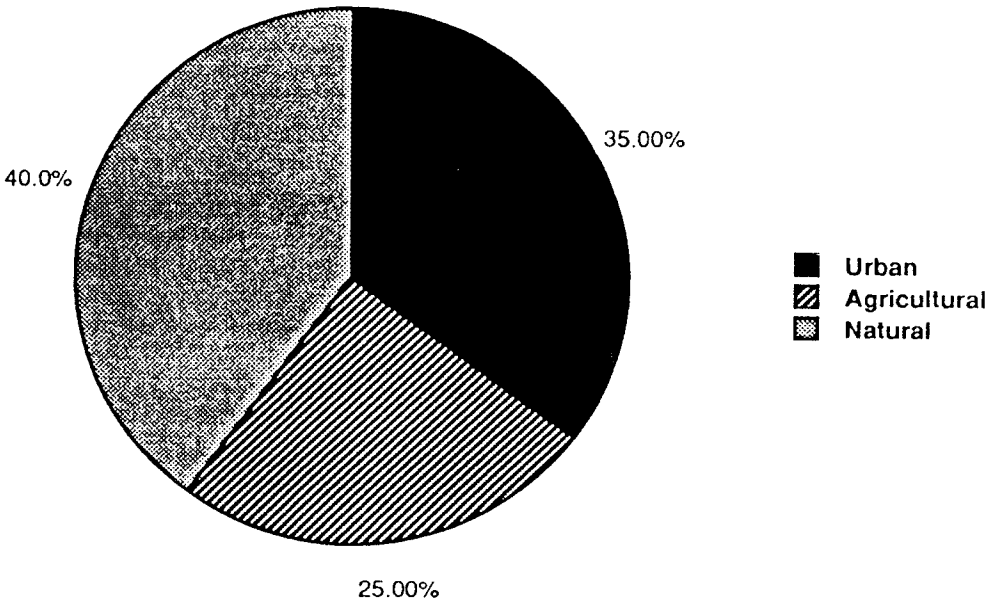

Figure 3. Percent of energy consumed in Georgia in three major land uses. Calculations were based on energy density and the area in each land use. Energy density of agricultural areas is considered to be twice as high as natural environments; that of urban areas ten times as high.

unit of area. Urban areas in Georgia average 10 times the energy density (as estimated from consumption of electricity which is 38 percent of the total), and cropland 1.5 times the energy density of forests and other natural areas. If we multiply these ratios by the area occupied by the three land uses, the percentage of energy consumed in each land use can be estimated (Figure 3). This illustrates the true importance of the urban landscape in terms of energy flow, and, indirectly, its impact on the rural landscape.

Spatial Patterns in the Landscape

The amount of land in various uses has thus changed, but what about the spatial arrangement of the landscape components? The complexity or fragmentation of the pattern may also be important. Historical black-and-white aerial photography was used to analyze the spatial patterns of land use (Turner and Ruscher, 1988). Nine sample counties (included in the trend counties in Figure 1) from different nonurban regions were selected by a stratified random sample: Atkinson, Baker, Emanuel, Heard, Monroe, Oglethorpe, Rabun, Tattnall, and Walker. Photographs encompassing a 12,696-ha rectangular study area in each county were analyzed for three time periods (1930s, 1950s, 1980s), and eight land uses were identified: urban, cropland, abandoned cropland, pasture, pine forest, upland hardwood forest, bottomland hardwood forest, and water. Land use data were digitized manually at a resolution of one ha (see Turner and Ruscher, 1988 for details).

During the 1930s, the landscape was very fragmented, meaning that there were many small patches of different land uses. This fragmentation declined during the past 50 years. For example, the number of forest patches of one hectare in size 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 in the different physiographic regions. 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.

To assess changes in the complexity of the patch shapes, fractal dimensions (Mandelbrot, 1983) of patch perimeters were calculated (Turner and Ruscher, 1988). In general, the fractal dimensions declined during the past 50 years, reflecting a decrease in the complexity of the landscape pattern (Turner and Ruscher, 1988). However, there was some variance among land-cover categories. For example, fractal dimensions in the piedmont generally declined with time (Figure 4), indicating that tracts of cropland, abandoned cropland, and pine forest have become more regular and less convoluted in shape. Hardwood forest was an exception, however, reflecting the increase in patch size and the relatively lower human influence.

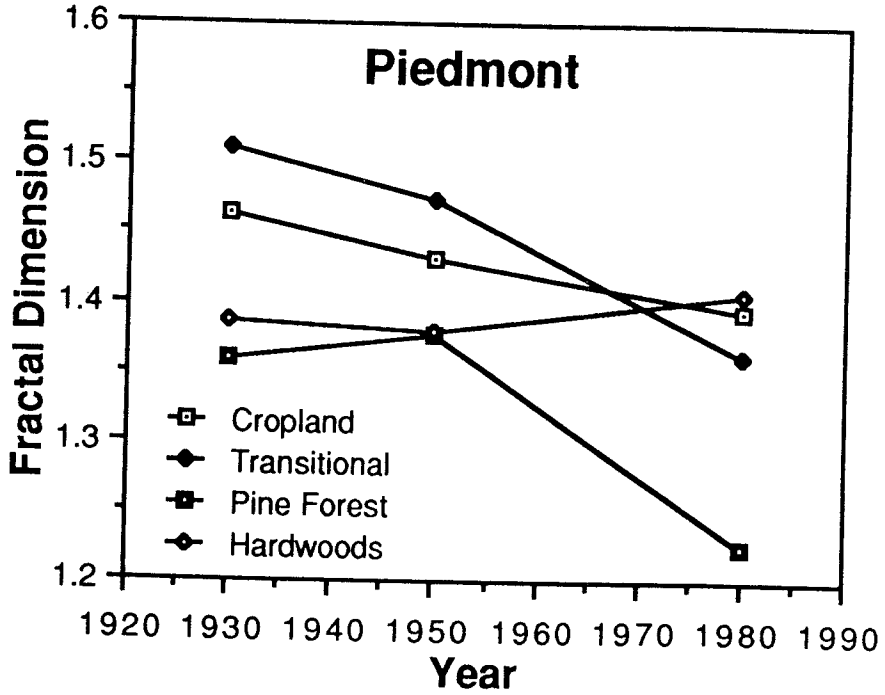

Figure 4. Fractal dimensions *(D)* of patch perimeters of major land uses in the Georgia piedmont. A simple, linear perimeter has $D = 1$, whereas a convoluted perimeter surrounding the same area has D approaching 2. (Data reported in Turner and Rusche, [1988].)

Edges between land types are important for certain species of animals and may affect water runoff and erosion from one land use to another. The total length of edge between cropland and abandoned cropland decreased in all regions, whereas edge between cropland and forest increased in all regions (Turner and Ruscher, 1988). This suggests that the boundaries of crop fields have become more permanent than they were in the 1930s. The total amount of edge between all land uses decreased in all sample counties between 1930 and 1980, again emphasizing that the Georgia landscape has become less fragmented.

Landscape Diversity

Landscape pattern can also be studied by looking at the diversity of units or patches in the landscape. The diversity concept has been applied in many ways to species, but the application of this concept to landscapes is fairly new (Romme, 1982; Romme and Knight, 1982). Commonly used measures of species diversity include species richness, the number of different species in a specified area, and evenness, the equitability of the abundance of each species. By merging the study of species diversity with the geometry of biotic communities, the concept of landscape diversity emerges. For terrestrial studies landscape diversity may be defined as the richness and evenness of the habitats or cover types that make up the landscape mosaic.

Hoover (1986) studied comparative diversity of plant comunities and species across the physiographic regions of Georgia by using the indices developed by Romme (1982). Six sample areas located in counties without extensive agricultural or urban features were studied: two each from the mountains, the piedmont, and the coastal plain. Vegetation maps of the sample counties previously prepared by the state Department of Natural Resources were used to identify the sizes and shapes of natural vegetation communities and agriculture. Vegetation was classified as matrix, corridor, or patch (after Forman and Godron, 1981). Community types were verified in field studies, and species diversity determined from strip censuses conducted in each community type.

Species diversity increased from the coastal plain to the mountains (Hoover, 1986). Landscape diversity, however, exhibited the reverse trend with highest diversity in the coastal plain. The mountains generally exhibited low landscape diversity, having both low evenness and richness. The piedmont landscapes expressed an intermediate level of landscape diversity, with a high degree of evenness but the lowest value for richness. The relatively even distribution of community types might be attributed to the extensive human impacts and prior fragmentation. The coastal plain had the most diverse landscape. The trend in landscape diversity was unexpected, since we had hypothesized that both species and community diversity should increase from south to north because of increasing topographic relief. Hoover's research suggested that the complex drainage patterns of the coastal plain may create more natural diversity than hills and mountains. These results underscore the concept that patterns at one level of

scale are not necessarily the same as patterns at another level. Thus, diversity at the species, community, and landscape levels may differ.

For the state as a whole, xeric communities tended to behave as patch components embedded in the matrix of dominant vegetation. In contrast, mesic areas, such as stream courses, behaved as corridors, the most linear feature in the landscape. Corridors join the landscape together and function as vital networks of animal movement and plant dispersal within the landscape. For these and other reasons (water quality, for example) improved statewide protection of stream and river corridors was emphasized among the recommendations that emerged from our research.

Simulating Changes in Landscape Structure

Along with quantifying changes in landscape patterns, the prediction of such patterns would be useful. The application of simulation modeling to landscapes represents a powerful approach. Most ecological modeling, however, has focused on temporal changes and excluded spatial dynamics. Transition models have been used to predict changes in vegetation or land use, but these models have not been spatially explicit. Accordingly, spatial simulation models were developed by Turner (1987b; 1988) to predict changes in land use patterns in the piedmont county of Oglethorpe, adjacent to the Athens metropolitan area. Five land use categories were included: urban, cropland, abandoned cropland, pasture, and forest. Three different types of spatial simulation were compared using cells in a grid:

1. random simulations based solely on transition probabilities
2. spatial simulation in which the nearest four neighbors (adjacent cells only) influence the transition
3. spatial simulations in which the eight nearest neighbors (adjacent and diagonal cells) influence the transition

Models and data were compared using the mean number and size of patches, fractal dimensions of patches, and amount of edge between land types. The random model simulated a highly fragmented landscape having numerous small patches with complex shapes. The two versions of the spatial model simulated the pattern for cropland well, but simulated patches of forest and abandoned cropland were fewer, larger, and less convoluted than those in the real landscape. To improve predictability, several possible modifications of model structure were proposed. This approach has potential generality for simulating human-influenced landscapes and may prove quite useful, particularly if socioeconomic factors can also be included (e.g., Parks, in press).

Ecological Effects of Land Use Changes

With these striking changes in structure of the Georgia landscape quantified, we now turn to the ecological implications of land use change. Here we focus on

patterns of primary productivity of the whole landscape, and then more specifically on trends in agricultural production, on forests, and on certain wildlife populations.

Net Primary Production of the Landscape

In natural landscapes, net primary production (NPP) provides the energetic and material basis for all other processes, because every food chain begins with some kind of plant production. NPP also provides an important resource base for human economic activity. NPP includes yield, the merchantable part of plant production, plus all the other organic matter produced by the plants.

A sample of 20 counties, with four to six in each physiographic region (Figure 1), was used to quantify both land use and NPP for the time period 1935 to 1982 (Turner, 1987c). Data on yield of food and fiber harvested from cropland, pastures and forests for each county were converted to estimates of NPP using appropriate conversion factors (harvest ratios, for example). Estimates for NPP of urban areas and wetlands were obtained from the literature.

The NPP for the whole Georgia landscape has more than doubled between 1935 and 1982 (Figure 5), increasing from 2.5 to 6.4 tonnes/ha, a remarkable recovery when one considers the "wasted" land of the 1930s. The pattern of increase varied among land uses and physiographic regions, but followed a general sigmoid growth form with the most rapid increase occurring between 1960 and 1970. The increase in productivity of agricultural lands reflects soil recovery as well as increased fertilization and irrigation, and the increase in forest productivity reflects natural soil-building processes and improved silviculture.

Rates of potential natural NPP predicted by world models are 16 to 18 tonnes/ha for a forested region with the temperature–rainfall pattern of Georgia (Turner, 1987c). The average NPP estimated for Georgia forests was 8.3 tonnes/ha, approximately two-thirds of the predicted rate. Some cropland approximated the predicted rate, but the average was much lower (5.1 tonnes/ha.). Accordingly, Georgia remains below its potential productivity.

Agriculture

Crops

To determine the 50-year trends in Georgia crop production, we converted the yields (bushels and pounds per acre) of all major crops (corn, soybeans, grain, vegetables, cotton, etc.) as reported by the U.S. Agricultural Reporting Service into the common denominator of calories. This allows us to add up all "the apples and oranges as fruit," so to speak. During the five decades since 1935, the area in crops has decreased by half while crop yield (cal/ha) has quadrupled (Figure 6). Thus, total food production in Georgia has doubled. In other words, in the present decade, Georgia grows twice as much food on half as much land as in the decade 1935–1944. This remarkable achievement (in view of the degraded

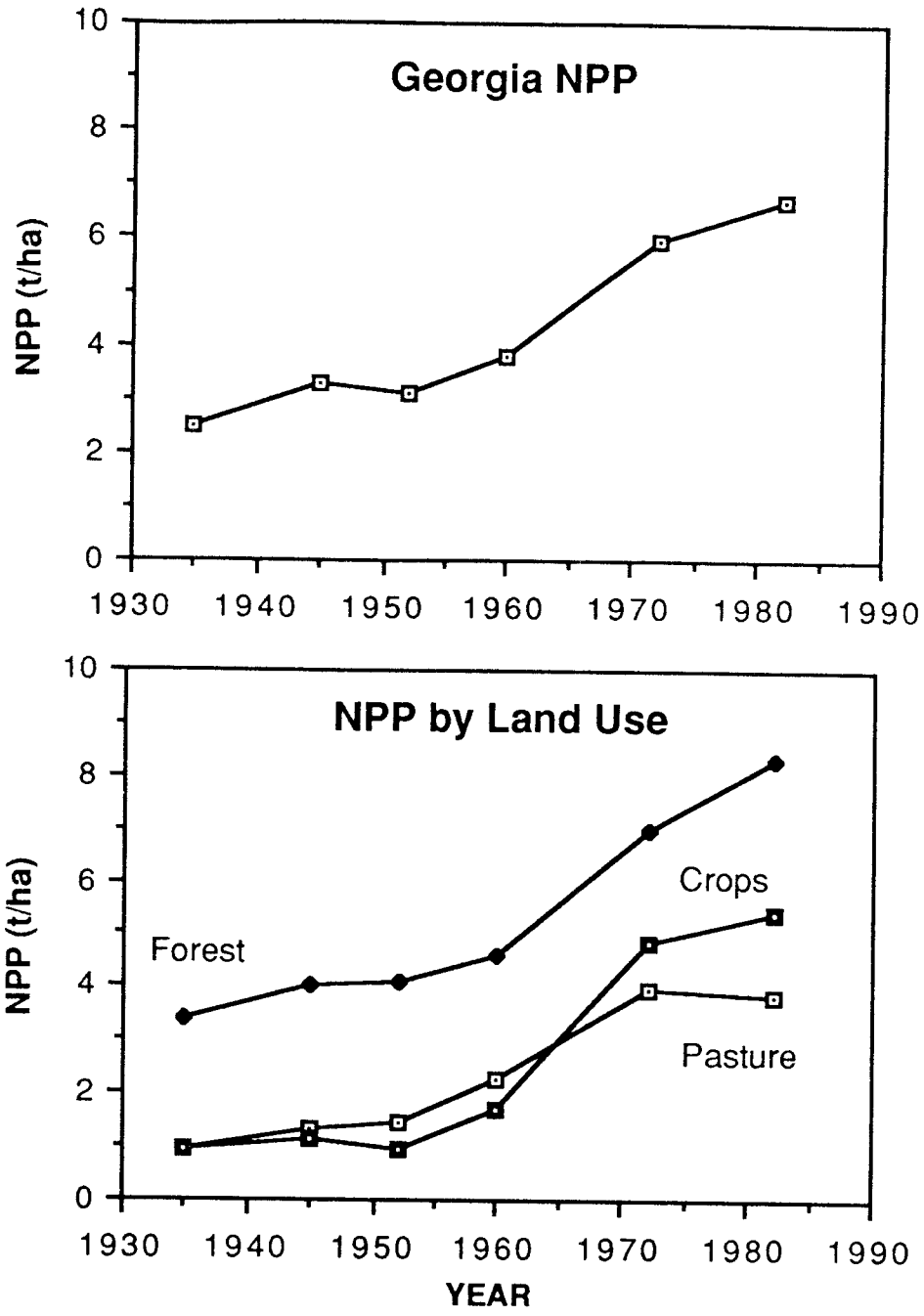

Figure 5. Net primary production of the Georgia landscape, 1935 to 1982. (From Turner, [1987c].)

state of the land in the 1930s) was accomplished partly by development of improved crop varieties (cultivars) and farm machinery, but mostly by increased use of fertilizers, pesticides, herbicides, and (in recent years) irrigation. General mineral fertilizer use increased seven-fold and nitrogen use increased eleven-fold over the half century (Figure 6). Pesticide and herbicide use showed similar trends.

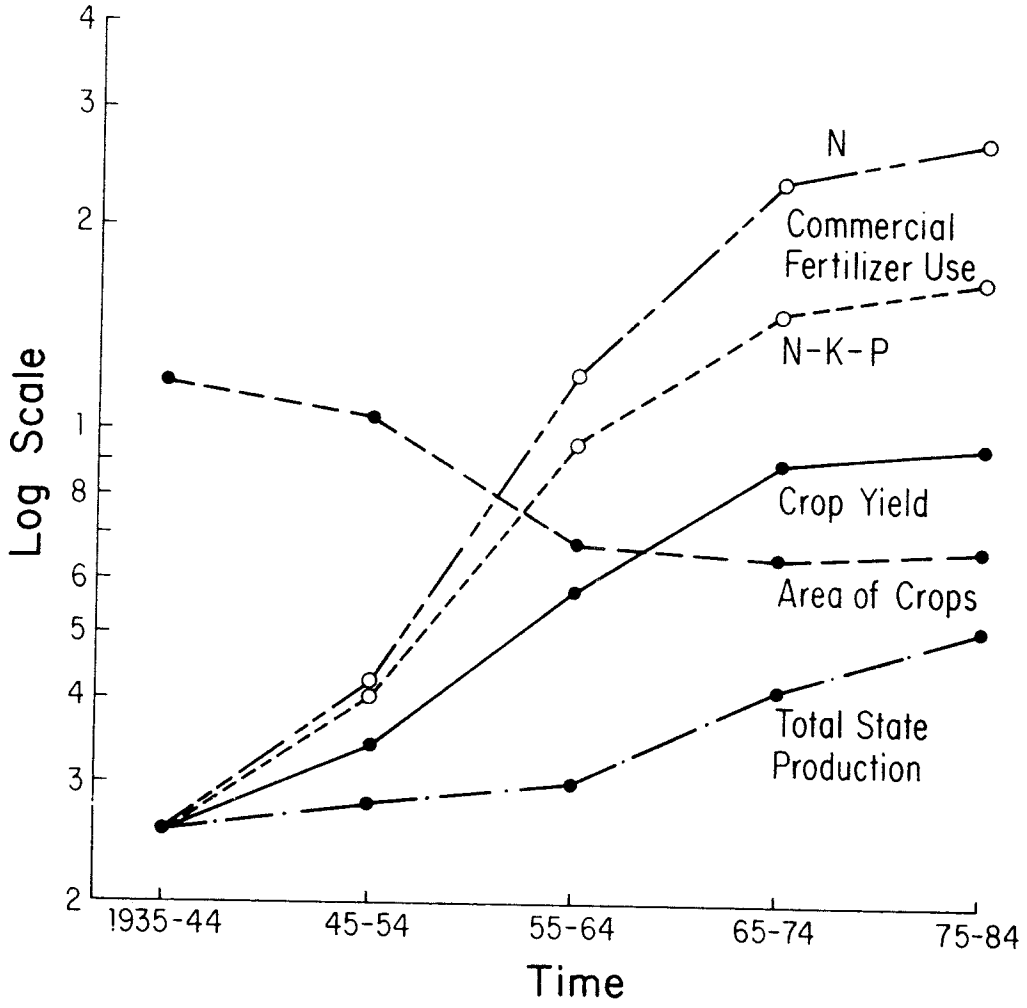

Figure 6. Changes in commercial fertilizer use (10^3 tons/yr), crop yields (cal/ha), area in crops (ha), and total crop production (cal/yr) in Georgia, 1935 to 1985.

The curves in Figure 6 all appear S-shaped, or sigmoid, with the most rapid change occurring between about 1950 and 1970. The fact that yields have essentially leveled off during the past 10 years suggests diminishing returns with agricultural practices that rely on raising yields by increasing chemical subsidies. Much of the fertilizer and pesticide now applied to crops runs off or leaches out of the crop fields, and contaminates surface and ground water. This non-point-source pollution (that is, unwanted and deleterious materials that do not originate from a concentrated or point source, such as a discharge pipe) poses a great threat to our global life-support systems (e.g., effects of acid rain, ozone, greenhouse gases, and so on). Reducing inputs, or input management, may be most important for future non-point-pollution control, but it should also be coupled with "output side" control techniques, such as the best management practices used for erosion control and urban runoff (Odum, 1989). Current research here in Georgia and elsewhere on "reduced-input agriculture," "conservation tillage" and other

systems that maintain reasonable yields, but reduce damage to our life-support systems, will contribute to improvements in our agricultural production systems (Odum, 1987; 1989).

In sharp contrast to major cash crops (corn, grains, soybeans), vegetable production in Georgia has declined. The area devoted to growing commercial vegetables declined by about three-fourths since the 1930s, and there has been no improvement in yield. Thus, total production has declined. To an increasing extent, vegetables consumed in Georgia are produced in other states (California and Florida, especially). As transportation costs rise in the future, a revival of agriculture centered on vegetables, especially near large urban areas, seems likely. Also, a greenhouse agriculture, common in European countries such as The Netherlands and Italy, that would provide fresh beans, tomatoes, and other products year round, could be in Georgia's future.

Domestic Animals

Most people are unaware that there are more domestic animals in Georgia than people, and these animals also consume more food. We compared the growth of human and domestic animal populations by converting numbers of cattle, chickens, pigs, turkeys, and so on, to human population equivalents. To do this, we took the calories of food consumed annually by an individual animal (information supplied by animal science nutritionists at the University of Georgia) and scaled this to the one million calories per year required by a human in Georgia. Thus, on an annual basis a beef cow would be equal in energy consumption to three people, while about 73 broiler chickens (which only live a few weeks) would be equivalent to one person. Over the 50-year period, domestic animals in population equivalents tripled while the number of people doubled (Figure 7). The growth of the poultry population has been spectacular, a ten-fold increase since 1935. Broiler chickens as well as laying hens and eggs are major Georgia cash crops. At the present time, chickens alone consume a quantity of corn and soybeans approximately equivalent to the entire state production of these crops. In other words, most of Georgia's crop production could go to feed animals, while most human plant food needs to be imported from out of state!

Aquaculture, chiefly catfish (*Ictalurus* spp.) farming, has increased in the state in recent years. In warm-water regions such as southern Georgia, fish (and shellfish) theoretically convert plant to animal food more efficiently than cattle or poultry, because the fish are cold-blooded and do not divert energy to maintaining a high body temperature. Many people predict that fish farming in artificial ponds will become a major industry in the state; much will depend on the availability of labor and water and the cost of building and maintaining impoundments.

Forests

For the whole state, slightly less than half of the forest land is in pine (less in northern Georgia, more in southern Georgia), a little more than a third is in

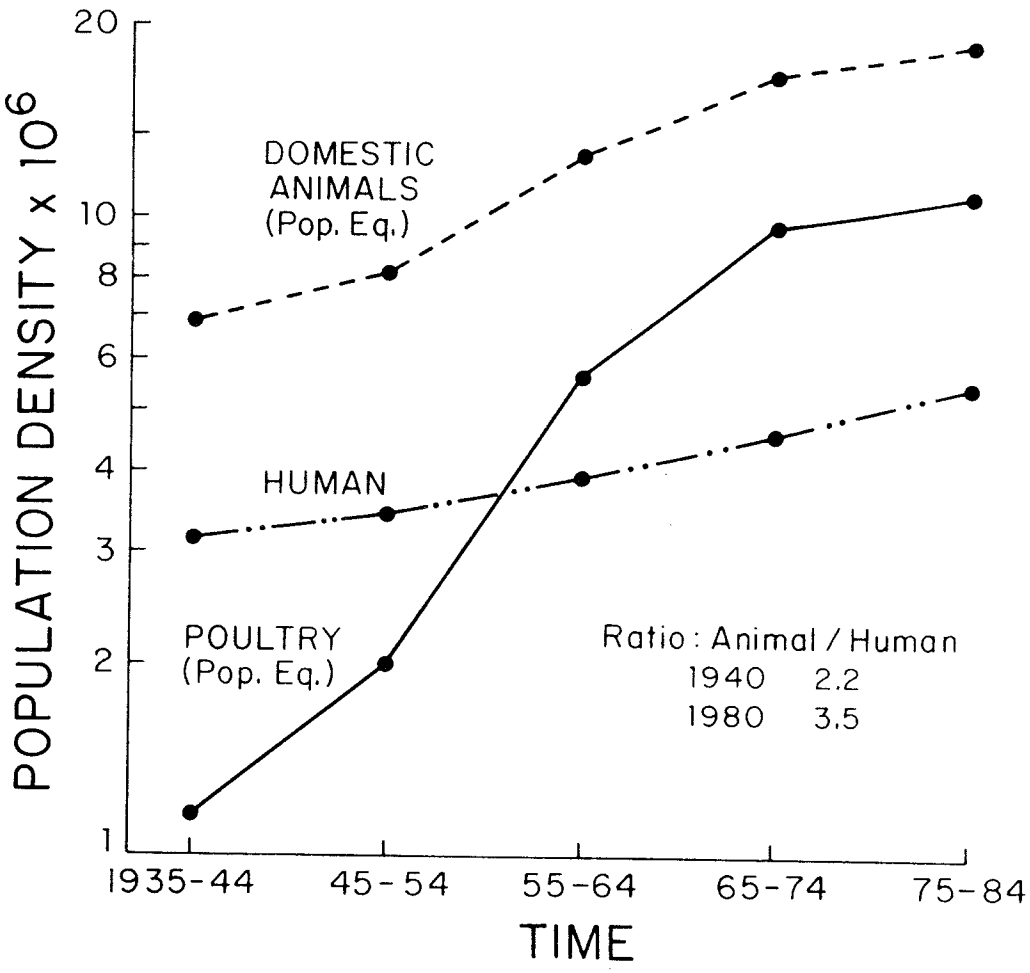

Figure 7. Changes in human population (in millions of individuals) and domestic animals in Georgia, 1935 to 1985. Domestic animals are expressed in human population equivalents calculated on the basis of food consumption in calories. See text.

upland hardwood or in transition to hardwood (oak–pine), and about 15 percent is in bottomland hardwoods (Table 1). Only 15 percent of Georgia forests are in pine plantations, that is, trees planted in rows and harvested and replanted at short intervals, but this type of forest (really a crop) is expected to increase in the future.

Land ownership is an important consideration if we are to project future trends. Less than 7 percent of Georgia forests are in public ownership, about 25 percent are owned by forest industries, and 66 percent are in numerous small to medium-sized tracts owned by individual private citizens (Table 1).

Questions about future forest trends are two-fold: (1) How much of the approximately 400,000 ha (1,000,000 acres) now in private (noncommercial) ownership will remain as such, and how much will be converted to urban or farmland, or be preserved? and (2) How will the competition between pine and hardwood on the Piedmont turn out? Pine currently has a higher market value

Table 1. Forest cover in nine sample counties in Georgia and in the whole state. Data are for 1982 and expressed as acres $\times 10^3$.

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County	All land	All forest	Forest Types: Pine: Plantation	Forest Types: Pine: Natural	Forest Types: Oak Pine (transition)	Forest Types: Upland hardwood	Forest Types: Bottomland hardwood	Ownership: National forests	Ownership: Other public	Ownership: Forest industry	Ownership: Other private
Union (MTS)[a]	198	171 (86.7%)	4.4	53.2	8.9	102.2	—	89.1	0.34	3.4	76.0
Chattooga (MTS)	203	149 (73.5%)	2.8	31.8	48.7	65.7	—	15.5	—	17.0	116.5
Cobb (Pied)	222	105 (47.5%)	—	73.0	12.7	12.8	3.2	—	3.0	0.14	98.5
Oglethorpe (Pied)	278	221 (79.3%)	42.5	67.7	11.8	64.7	33.8	3.8	0.34	96.3	120.2
Monroe (Pied)	255	204 (79.9%)	16.3	86.1	28.8	61.2	10.9	—	0.18	59.2	143.9
Emanuel (UCP)	439	285 (64.9%)	61.9	107.7	24.1	29.5	60.9	—	16.0	6.5	48.3
Turner (UCP)	188	82 (44.0%)	10.7	40.1	10.1	6.7	15.0	—	0.08	12.3	70.0
Barrien (LCP	300	181 (60.5%)	15.7	71.2	27.1	14.3	52.9	—	2.6	21.0	157.7
Glynn (LCP)	270	157 (58.2%)	57.1	27.7	11.4	19.9	37.0	—	3.9	112.1	37.1
Totals	2,353	1,555	211.4	558.5	183.5	357.0	203.7	108.4	25.4	327.8	867.2
Percentages		66	14	36.9	12.1	23.6	13.5	8.2	1.9	24.7	65.2
State	37,167	24,242	3,592	7,847	2,960	5,805	3,530	765	819	5,936	16,214
Percentages		65.2	15.1	33.1	12.5	24.5	15	3.2	3.5	26.0	68.3

[a]MTS—Mountain Region; Pied—Piedmont; UCP—Upper Coastal Plain; LCP—Lower Coastal Plain (see Figure 1).

than hardwood, and most of the large Georgia forest industry is based on pine. Johnson and Sharpe (1976) reported that despite silvicultural efforts to maintain pine in the Georgia piedmont, the area occupied by hardwoods increased. Using a 30-year model, they projected this trend to continue, although at a slower rate than if only natural succession was involved. Urbanization and suppression of fire, both of which favor hardwoods over pines, were important factors in the model projection. Healy (1985) noted that urbanites are purchasing an increasing amount of land in the vicinity of cities, and unlike farmers or foresters, they do not obtain their main income from the land. Such owners are more interested in the second home or recreational value of their land, and less interested in managing for pine production; many, in fact, would rather see the hardwoods take over.

Because of these trends, some foresters worry that future demand for pine may exceed supply, because few private land owners are replanting after the very large stands of naturally regenerated pine are cut. Demand projections often are based not only on human population increase, but on an increase in per capita consumption as well. However, paper recycling and more efficient use of wood in home construction could reduce per capita needs. For example, the number of municipalities with paper recycling programs in Georgia has increased from one in 1975 to 17 in 1983. If by the year 2000 most cities and towns in this and other states recycle paper, there should be plenty of pine to meet both local and export demands for paper.

Wildlife Populations

The effect of land use changes on bird populations was examined by Ronald Pulliam (University of Georgia) and associates who analyzed long-term census data collected by the U.S. Fish and Wildlife Servive (Pulliam, 1987, unpublished). Several species that occupy old-field habitat (i.e., recently abandoned crop fields) have declined during the past 20 years. These declines parallel the decline in abandoned or idle cropland (Figure 2). Other bird species have increased in number and extended their ranges southward in Georgia. This group includes the robin *(Turdus migratorius)*, house wren *(Troglodytes aedon)*, song sparrow *(Melospiza melodia)*, house finch *(Carpodacus mexicanus)*, and grackle *(Quiscalus quiscula)* that thrive in urban and suburban habitat.

The large growth of white-tailed deer *(Odocoileus virginianus)* populations in Georgia (Figure 8) is a result not only of the shift in land use from agriculture to second-growth forest, but also a successful restocking and management effort by the Georgia Department of Natural Resources. The increase in deer since 1940 has been exponential, and the one million deer now populating the state have detrimental effects on crops, home gardens, and auto accidents. Strong measures (increasing hunting, large scale removal, etc.) will probably be required to halt this growth and establish some desirable equilibrium. Beaver *(Castor canadensis)*, which were once almost exterminated in the state, have also made a comeback as a result of state protection and changes in land use.

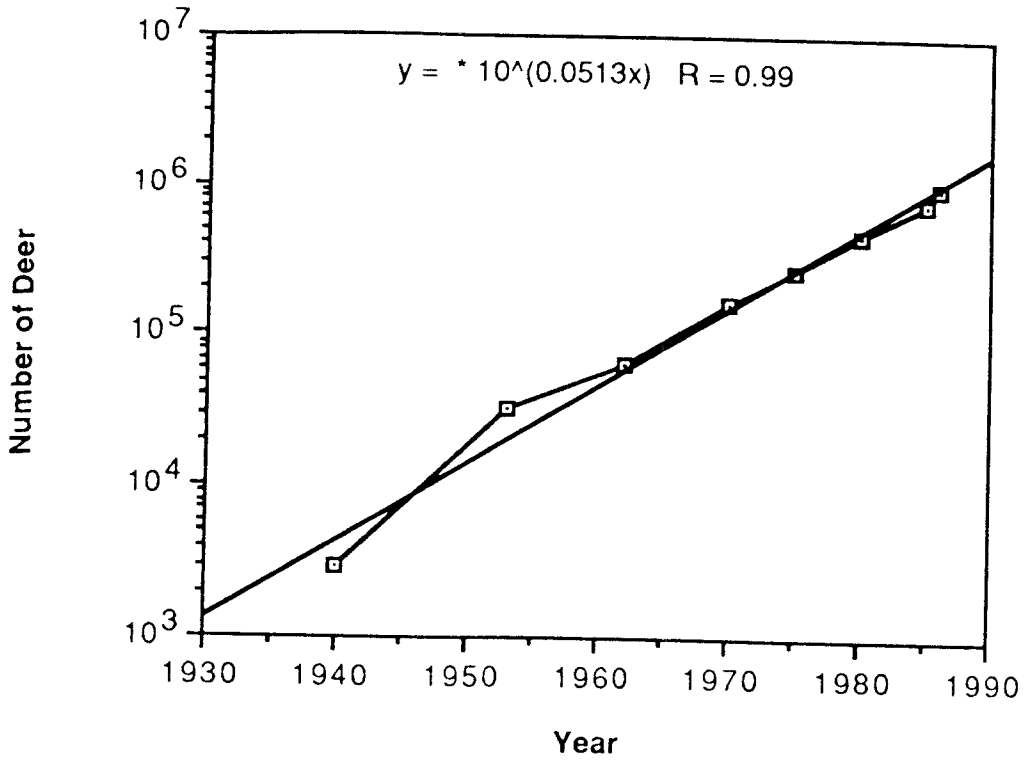

Figure 8. Deer population growth in Georgia, 1940 to 1985. Data provided by the Georgia Department of Natural Resources. The straight line is the exponential curve fitted to the data.

Trends in Resource Use

As land use and human population size both change, the demand for and consumption of resources also changes. In assessing the implications of landscape changes, therefore, it is instructive to assess the trends in resource use and quality. Land planning, or growth management, requires an understanding of such trends and, furthermore, should aim toward maintaining both availability and quality of the resources. Here we focus on two resources, energy and water.

Energy

Per capita energy consumption in Georgia was about 60 percent lower than the national average in 1960, but increased rapidly to approach the national level by 1980 (Table 2, Figure 9). This reflects increasing urbanization and prosperity in the state. Between 1980 and 1985, per capita consumption declined both in the United States as a whole and in Georgia—a result of the rise in energy prices and concurrent energy conservation. A recent report released by the International Energy Agency (cited in Anonymous, 1987) indicated that conservation efforts have increased the efficiency of energy use in western industrialized nations by

Table 2. Energy consumption in Georgia and the United States.

	Total Energy	Population	Per Capita Energy	END USES (BTU × 10^{12})					Sources (% of total)			
	BTU × 10^{12}	× 10^{3}	BTU × 10^{6}	Residential	Commercial	Industrial	Transportation	Electric	Coal	Natural Gas	Petroleum	Fossil Fuel
Georgia												
1983	1,666	5,732	291	348	228	524	567	630	35.2	18.3	41.9	95.4
				21%	14%	31%	34%	37.8%				
1980	1,681	5,463	316	344	207	580	550	600	31.1	19.2	44.6	94.9
				20%	12%	34%	33%	35.7%				
1975	1,454	4,900	296	297	192	478	487	485	21.5	22.9	41.1	92.4
				20%	13%	32%	34%	33.4%				
1970	1,252	4,590	273	255	147	450	400	370	15.4	27.4	42.6	90.4
				20%	12%	36%	32%	29.6%				
1965	876	4,250	206	167	91	361	257	213	17.4	25.0	48.6	90.8
				19%	10%	41%	29%	24.3%				
1960	651	3,943	165	128	68	247	208	144	13.7	29.0	49.4	92.0
				20%	10%	38%	32%	22.1%				
United States												
1960	43,806	180,270	243	18.9%	10.8%	46.0%	24.2%	18.8%	22.5	28.3	45.5	96.3
1983	70,508	234,250	301	20.9%	15.2%	36.7%	27.2%	35.4%	22.5	24.6	42.6	89.7

Source: State Energy Data Report.
1960–1983. U.S. Energy Information Administration.

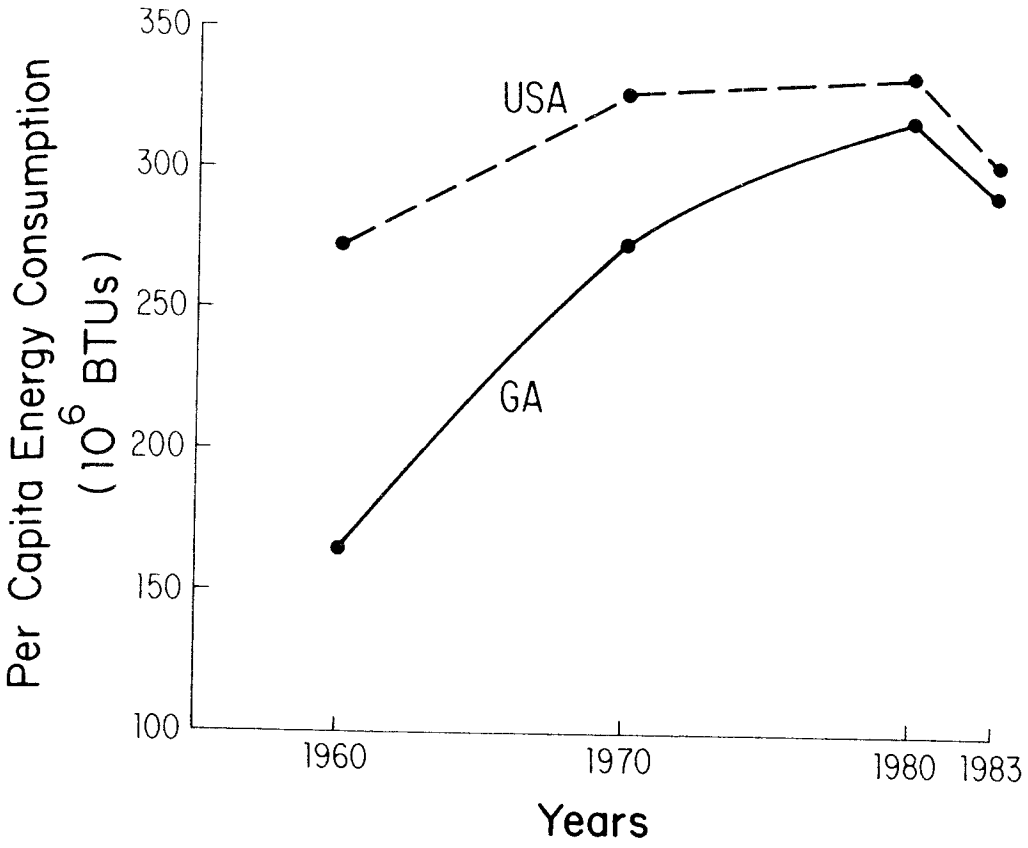

Figure 9. Changes in per capita energy consumption in Georgia and the United States, 1960 to 1983. (From the State Energy Data Report, U.S. Energy Administration.)

Source: State Energy Data Report.
1960–1983. U.S. Energy Information Administration.

about 20 percent since 1970. In the U.S., gross production increased almost 32 percent between 1973 and 1985, but energy consumption increased only 5 percent. The result was a saving of the equivalent of 880 million tons of oil a year—more than the total oil production of western nations (Anonymous, 1987). Accordingly, the downward trend in per capita energy consumption in Georgia parallels the worldwide trend.

Residential, commercial, industrial and transportation energy uses as percentages of the total energy consumption have not changed much over the past 23 years (Table 2). However, electric use increased from 22 percent to 38 percent of the total for Georgia, and 19 percent to 35 percent for the nation. Georgia's dependence on coal as an energy source increased from 14 percent to 35 percent compared to no increase for the nation. Georgia has a 95 percent dependence on fossil fuels (all imported from out-of-state), about average for the nation.

In view of Georgia's dependence on coal, the burning of which in power plants is a major cause of air pollution (e.g., Bormann, 1987), it would seem that power companies should invest in known technology for cleaning coal (removing sulfur and other pollutants) before it is burned. A coal gasification combined power plant rated as the cleanest coal-fired power plant in the U.S. has been

operating successfully, and competitively with conventional power plants, in California since 1984 (Spencer et al., 1986). Tax and other incentives could be used to promote this.

The potential for further energy conservation is also very large. The president of a company specializing in designing and retrofitting buildings for energy efficiency estimates that a 40 percent saving in energy consumption can be achieved with today's technology (Milton Bevington, personal communication). If all new buildings in Georgia were 40 percent more energy efficient than conventional construction, much new economic growth could occur with only a modest increase in energy consumption.

While rising costs will undoubtedly result in further reductions in per capita energy use, the state could encourage needed reductions. For example, tax deductions could be provided for the cost of energy-efficient new or retrofitted construction. We strongly recommend that the state become actively involved in energy conservation, not only to save fossil fuels but because reductions in the burning of coal, oil, and gasoline will also reduce the considerable costs of non-point pollution.

Water Quantity

Reliable figures on water consumption were not available before 1950. Water use (both total withdrawals and consumptive use) in Georgia increased rather rapidly from 1950 to about 1970, and has generally leveled off during the past 15 years (Figure 10). Per capita use of water has even declined since 1970 (Figure 10), suggesting that rising costs and droughts have resulted in some water conservation.

The proportions of the public water supply that come from surface water and ground water have not changed markedly over the 35-year period (Figure 10). State-wide, 65 percent is from surface water and about 35 percent from groundwater. In the piedmont, where groundwater is limited, some 90 percent of the public water supply comes from surface water. Water conservation will be extremely important for the future welfare of Atlanta and other rapidly growing urban areas of the piedmont. Water use for irrigation increased about ten-fold between 1970 and 1980, and most of this was from ground water in the prime agricultural areas of the upper coastal plain. The water levels in many shallow wells throughout the state have declined, but water levels in deep wells in the coastal plain have been reduced only slightly. Many artesian wells in the vicinity of paper mills and other heavy water users, however, no longer flow, and salt intrusion is a problem in several coastal counties.

The amounts of water impounded by large reservoirs and smaller lakes and ponds (many built under the supervision of the U.S. Soil Conservation Service) exhibit sigmoid growth patterns, with the most rapid increase between 1950 and 1970. Because many of the best sites on streams and rivers have now been impounded, and because U.S. government funds will be more difficult to obtain for this purpose, the benefit–cost ratio for proposed future impoundments must

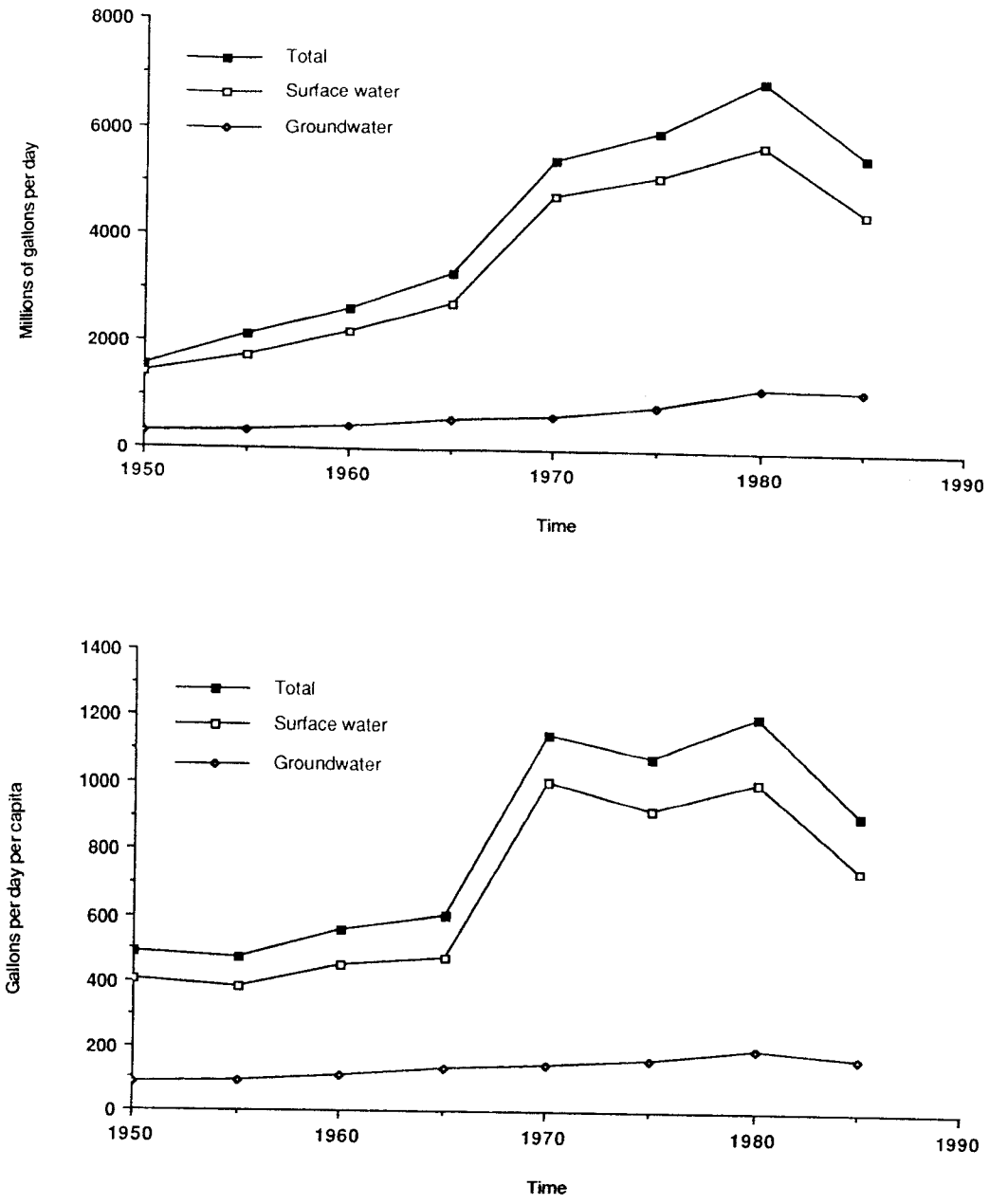

Figure 10. Total freshwater withdrawals (top) and per capita use of freshwater (bottom) in Georgia, 1950 to 1985. (From R. T. James [1987, unpublished report].)

be carefully researched. Many impoundments were originally constructed to promote hydroelectric power and/or recreation, but these are now more important as a water supply for metropolitan areas. Probably the greatest need for new small and medium-sized impoundments will be to store water for cities during droughts. Housing, industrial, and agricultural development on watersheds of such new reservoirs must be restricted if sedimentation is to be minimized and water quality is to be maintained.

Water Quality

Environmental monitoring of Georgia rivers has not been consistent, and information on key aspects was often not available for long periods of time. Nevertheless, some important trends were revealed by data on four rivers (Savannah, Ocmulgee, Oconee, and Yellow Rivers). Coliform bacteria, an index of sewage pollution, have decreased in the Savannah River (Figure 11) and the other rivers since 1970. State and municipal governments have done an excellent job of reducing this point-source pollution, so Georgia rivers in 1985 were more "swimmable and fishable" than they were 15 to 20 years ago. However, non-point pollution as indicated by nitrates and nitrites has increased (Fig. 11), a trend that is nationwide (Smith et al., 1987). Non-point-pollution threats (which include toxic wastes) to water quality can be controlled primarily by reducing the inputs of chemicals into agriculture and industry. As we have already noted, input management as a means of reducing pollution also reduces costs, and is something that mandates statewide (and worldwide) attention.

Nonmarket Values and Natural Area Preservation

Most people are unaware that croplands, forests, and watersheds not only provide material goods like food, fiber, and water, but also provide life-support goods and services. These services (such as air and water purification, recycling and tertiary waste treatment, recreation, and scenic beauty) all are vital to maintaining the economics and quality of life of the urban dweller. It is for this reason that we have included natural-area preservation and nonmarket valuation as important components of this study.

Nonmarket Values in the Georgia Landscape

Landscapes produce many services that historically have been grossly undervalued (Alig, 1983) and presently are not adequately reflected as market values. These nonmarket values may be quite large, but they must be measured indirectly (DeLorme and Wood, 1974) and can be difficult to determine (Westman, 1977; Healy, 1985). Wise and rational management of natural areas requires that these values be incorporated into the decision-making process, and the valuation of the benefits of nonmarketed resources and services has been identified as a major research need (e.g., Odum, 1977; Westman, 1977; Alig, 1983; Costanza, 1984; Loomis and Hof, 1985; Loomis and Walsh, 1986).

Details of our attempts to estimate the nonmarket value of the entire Georgia landscape are reported elsewhere (Turner et al., 1988). Contingent Valuation (an economic approach) and Energy Analysis (an ecological approach) were used, and both approaches yielded similar estimates. The annual value of nonmarketed natural services in Georgia was estimated as $2.6 billion in 1982 dollars, which compares with an annual value of marketed agricultural products of $2.8 billion, and a marketed timber production of $4.5 billion. Assuming a constant stream of

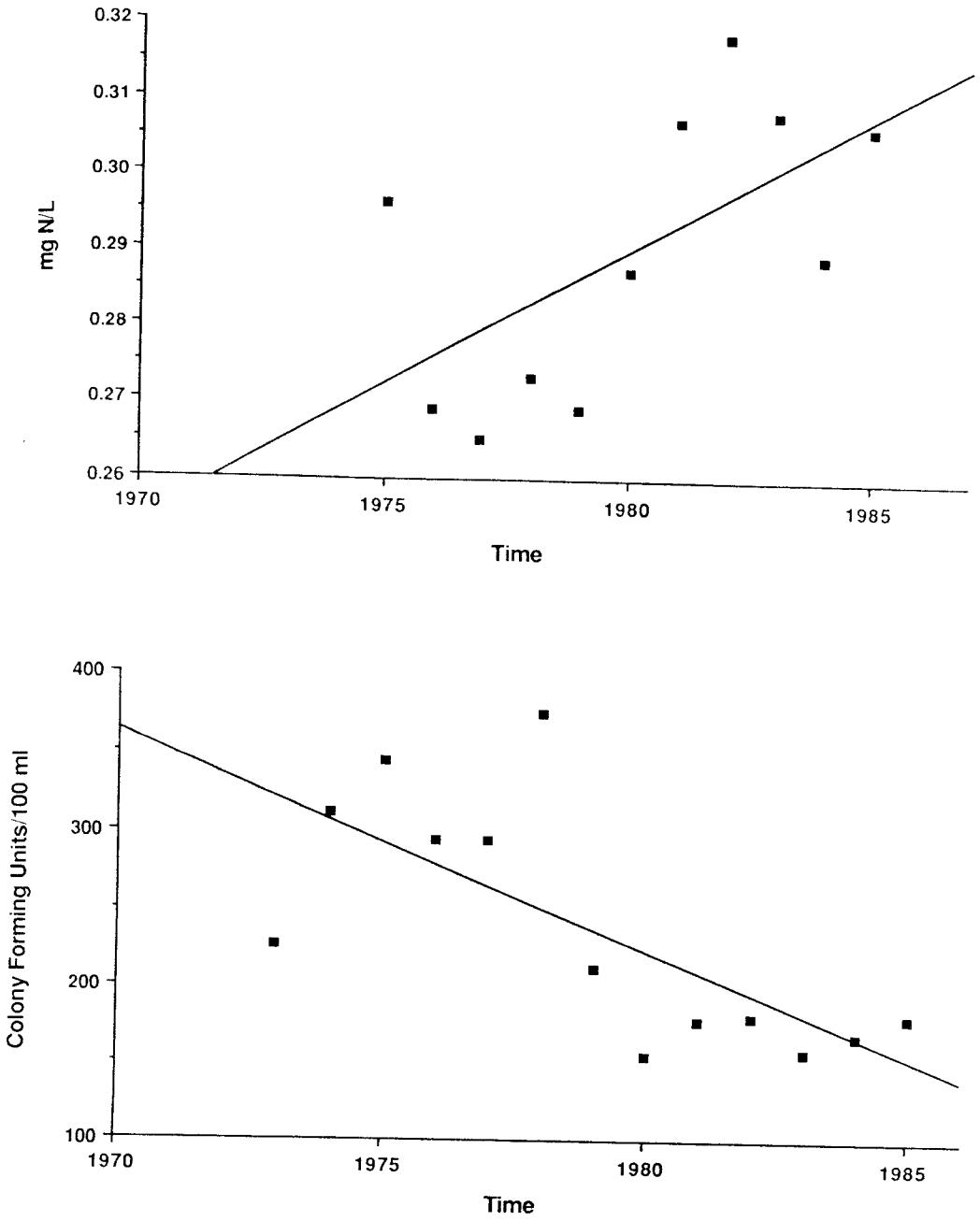

Figure 11. Total nitrate–nitrite nitrogen (top) and fecal coliform bacteria counts (bottom) in the Savannah River, 1970 to 1985. Graphs are five-year moving averages weighted for river flow rate. Data were obtained from the STORET data base of the U.S. Environmental Protection Agency.

services into the indefinite future at a 4 percent discount rate, the total present value of nonmarket goods and services comes to $65.7 billion. This is an estimate of the worth of the state's life-supporting services provided mostly by the natural environment.

Within Georgia, urban lands are of mostly market, whereas wetlands are mostly of nonmarket value (Figure 12). Forests have a high value in both

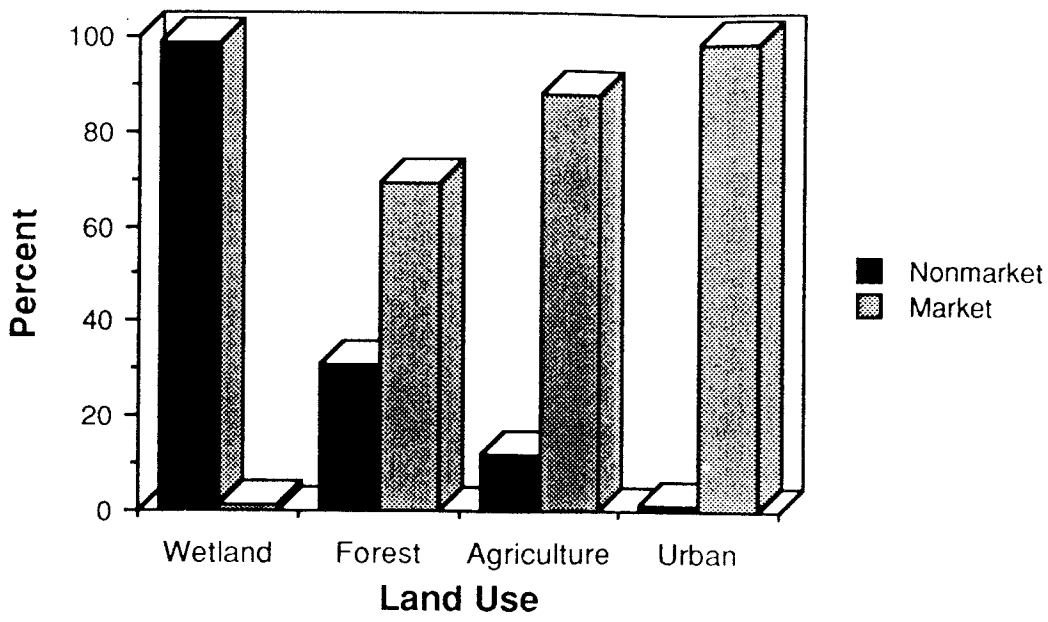

Figure 12. Importance of market and nonmarket values of major land use in Georgia. (Data reported in Turner et al. [1988].)

categories. Thus, changing land use patterns in Georgia and elsewhere will be accompanied by shifts in the relative importances of market and nonmarket values. We believe that the evaluation of nonmarket values is useful, because it demonstrates their magnitude and importance in units (e.g., dollars) that decision makers and the public can readily understand.

Natural Area Preservation

The preservation of large areas in Georgia began in 1836–1837 with the establishment of the Chattahoochee National Forest in the mountains and the Okefenokee Swamp National Wildlife Refuge in the southeastern corner of the state. In both areas, most of the valuable old-growth timber had been removed before the land was acquired by the U.S. government. In the Okefenokee, an unsuccessful attempt was made to drain the swamp to convert it to agricultural use. In the 1950s, abandoned farmland in the eastern piedmont was included in the Oconee National Forest. Between 1965 and 1975, five of the large and unique coastal barrier islands in Georgia were acquired by the U.S. or state government from wealthy families who had purchased the islands after 1865. Acquisition of the Chattahoochee, Okefenokee, and Oconee sites followed resource extraction, which left market values of the lands relatively low. The resilience of these areas has allowed them to recover into valuable resource bases today. Future land acquisition might include currently degraded areas which can be restored.

Despite these acquisitions, only 8 percent of the Georgia landscape is in public ownership, that is, in national, state or municipal forests or parks, wildlife refuges, wilderness areas, etc. For southern states, 8 percent is about average (Parker et al., 1981), but it is less than Florida and far less than all western states in the USA. The Georgia piedmont is especially lacking in preserved areas; less than 2 percent of this physiographic region is preserved. Because large areas of the Georgia landscape are not yet under strong economic pressure for urban-industrial or agricultural development, and because recent opinion surveys indicate strong public support for preserving more natural areas, a once-in-a-century opportunity is here. We suggest a goal of 20 percent preserved land for the year 2000. Accomplishing this would protect critical resources and reduce pollution and congestion, thus improving the quality of life for all Georgians.

Implications for Landscape Management

Based on the results of our research, we offer the following strong recommendations for growth management (i.e., land use planning) in Georgia, giving high priority to maintaining environmental quality:

1. Statewide effort is urgently needed to increase natural-area preservation, especially in the piedmont region, with a goal of placing 20 percent of the state under some form of protection (parks, national and state forests, wildlife refuges, nature preserves, etc.).
2. Statewide effort is needed for the protection of river corridors and freshwater wetlands. Conservation easements and other measures already on the legal books should be encouraged, and new legislation, perhaps similar to the U.S. Coastal Marsh Protection Act of 1970, should be enacted.
3. Educational campaigns are needed to increase public awareness of the: (i) value of the life-supporting environment (nonmarket goods and services of nature); (ii) nature and seriousness of nonpoint pollution; (iii) need for more preserved area; and (iv) need for more effective economic and political infrastructure for planning. Our surveys indicate that large segments of the public are not aware of the significance of changes in the Georgia landscape, and do not perceive the need to take any action to maintain the environmental quality that the state is fortunate to have (Westmacott and Roos, 1987, unpublished).
4. By providing tax and other incentives, state and local governments should encourage power companies to invest in clean coal technology, now economically feasible, to reduce air pollution.
5. In view of the increasing potential for water shortages and declines in water quality, state and municipal governments should actively promote water conservation before there are shortages. To ensure water quantity and quality, all housing, industrial, and agricultural development should be prohibited around all new reservoirs built to store water for urban areas.

6. A central data base for geographical and environmental information should be established, so that decision makers and resource managers will have the continuously updated information needed for managing growth and maintaining environmental quality.

The changes we have documented in Georgia may be useful to those less developed countries that wish to evaluate the processes and effects of changing to a "developed country." In the 1930s, Georgia was largely agrarian, with both low per capita income and low educational levels. Quality industry was lacking, and soil-destroying agricultural practices were prevalent. Today, Georgia is well on its way to becoming developed, with all the problems that come with that status.

Conclusion

In this study, we have followed a *top-down* approach. We examined the patterns of land and resource use for the Georgia landscape as a whole as well as for the major physiographic regions and showed how these patterns changed during the past 50 years. Both spatial and temporal changes were documented. The Georgia landscape has become less fragmented, and forests have increased in area and connectivity. However, although urban areas comprise only 6 percent of the landscape, their impact on energy consumption and use of other resources is several times greater. Landscape diversity varies by physiographic region, but plant species diversity follows a different trend, suggesting that diversity varies with spatial scale. In the Georgia landscape, net primary productivity, as an indicator of functional change associated with land use, is increasing, but still remains below predicted rates for natural land. We conclude that landscape ecological research, which integrates both structure and function, can provide a sound conceptual base for assessing large-scale changes, and in developing strategies for land management.

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