Measuring Sprawl's Consequences: Linking Biodiversity Change with Development Planning

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Abstract

Sprawl has been identified as a process where the development spread outpaces population growth. In researching sprawl, quantification of the impacts or changes has been limited. The research focus has been measuring the indicators of sprawl. Assessing the consequences requires true environmental measurement. This paper examines an approach to land use change detection to aid decision-making. It discusses the implications at the watershed level. The paper focuses on quantifying land use change and biodiversity impacts of sprawl. The process can aid in monitoring ecosystems and urban development. Change detection is useful in assessment of deforestation, changes in vegetation phenology, agricultural lands and water quality. The study ties satellite imagery with census information. It uses ArcGIS Spatial Analyst to analyze biodiversity by watershed catalog units. The research explores land use changes around Greenville, South Carolina. Greenville is characterized as the fifth most sprawling metropolitan area in the country.

Keyword: GIS; Remote Sensing; Sustainable Development Planning, Biodiversity, Change Detection

Introduction

The icons of sprawl – a landscape of similar low-density suburbs, strip malls, and highways spreading across the landscape – are hot topics. Sprawl's consequences are endless driving to work, frequent traffic jams, aggravated air and water pollution as well as lost agriculture and degraded biodiversity. While these effects are visible, sprawl may place fiscal burdens on towns to extend services and infrastructure – sewers, schools, police and fire service – to outlying areas, even if the older core areas are drained of economic vitality. Arguments can be made on both sides of the issues as to whether these development patterns are what Americans desire. Concerns about sprawl reflect a general frustration that suburban life does not always live up to the expectations. Suburbanites complain about constant gridlock, long commutes and overcrowded schools. At the same time, families cherish the open spaces, safer streets, better schools, and convenient shopping that they may not get living in the city. People want solutions to congestion without taking away the conveniences and freedoms that suburban life offers them.

Issues of Sprawl

Historically most urban growth has been outward. In the modern era, the trend is accelerating because of rapidly falling communications and transportation costs. Favorable public policy has encouraged growth with funded highway networks, special tax treatment of residential mortgage interest, zoning codes, and low gasoline taxes. (Gordon, 2001). In the US, the populace preference is for suburban living, reliance on the automobile for personal mobility, and being closer to the natural environment. Cheaper development costs result in larger homes on larger parcels. European and Canadian urban policies favor compact development and more sustainable development.

According to Robert Burchell, sprawl can be characterized by unlimited outward expansion of development. The growth is primarily low-density residential and commercial settlements. The result is using more land for fewer people. Widespread strip commercial development is the new development form. There are no downtowns or village centers. Sprawl leapfrogs over existing development (Burchell, 1998). It results in an abundance of roads with the dominance of private automobiles for transportation. Sprawl research has focused on the pattern of land use in an urban area. Studies suggest there are different types of sprawl. It exhibits low levels of some combination of eight distinct dimensions:

- Density
- Centrality
- Continuity
- Nuclearity
- Concentration
- Mixed Uses
- Clustering and
- Proximity (Galaster 2001)

Reid Ewing and others in *Measuring Sprawl and its Impact* identified sprawl as the process in which the spread of development outpaces population growth. They developed a sprawl index based on four factors that can be measured and analyzed:

- Residential density
- Neighborhood mix of homes, jobs, and services
- Strength of activity centers and downtowns
- Accessibility of the street network. (Ewing 2002)

In researching sprawl, quantification of the impacts or changes has been limited. The focus is measuring/identifying the pattern or indicators of sprawl. The only real measure of consequence has been traffic congestion. Environmental issues, the catalyst for sustainable development, generally have been conjectured. There needs to be monitoring and evaluating of policies, plans and programs. It requires true environmental measurement and accountability. Linking environmental assessment with sustainable development or sprawl can address the measurement issues.

Environmental Assessment in the United States

Environmental assessment was developed in the 1960s and made into US law in 1970 with the National Environmental Policy Act (NEPA). It was designed to evaluate the environmental consequences of proposed federal actions and to minimize resulting environmental damage. Over the years, biodiversity has become a part of Environmental Assessments (EA). It has been used as a threshold to determine need for an Environmental Impact Statement (EIS). Additionally, US Laws include the Endangered Species Act, Clean Air and Water Acts, Wetland, Critical Areas, and Floodplain laws. The states have seized on the opportunities presented in these laws as biodiversity conservation tools (Environmental Law Institute 2003).

American Planning Association (APA) completed the *Growing Smart*℠ *Legislative Guidebook*. Growing Smart is APA's seven-year project to draft the next generation of model planning and zoning legislation. The project involved a wide variety of partners and advisors and has produced multiple research and education products related to the revision of state enabling legislation for planning and land use (APA 2002). Reform envisioned and enabled by Growing Smart will provide improved predictability in the planning and development process. It starts at the State level with the State Biodiversity Conservation Plan and continues with the Regional Plan. If needed, Urban Growth Boundaries are determined at that level. Protection of biodiversity identified at the State level is one of the criteria. Finally, at the Local level, the Comprehensive Plan requires a monitoring of buildable lands and the carrying capacity within the urban growth boundary. It should occur every five years. This kind of predictability aids the development and construction industry. It also should create a better climate for all stakeholders. Similarly, the kind of state and local planning processes proposed by the optional statutory models promotes efficiency in the investment of public funds in the location of government facilities and in transportation and utility infrastructure and strong public participation. In other words, this is the US's answer to sustainable development planning.

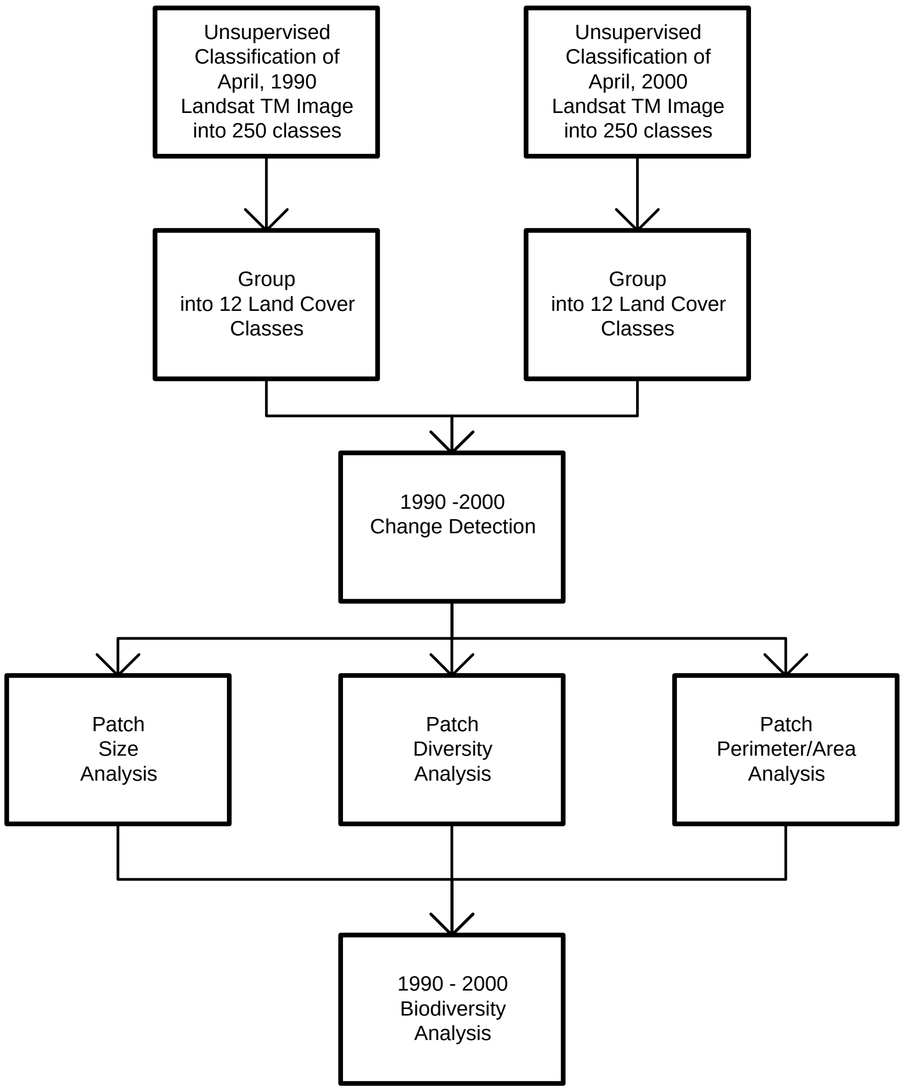
Study Methodology

In reviewing the literature, assessment terms and intents are well defined. The processes for determining a project are clear. However, the measuring and monitoring of the environment are not obvious. Biodiversity is an important indicator. This study addressed monitoring and the quantification issues of assessing sprawl, using an increasingly common application of remotely sensed data for change detection. Change detection is the process of identifying differences in landscape at different periods. Change detection is an important process in monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution of the population of interest. Change detection is useful in such diverse applications as land use change, deforestation assessment, changes in vegetation phenology, lost agricultural lands, as well as biodiversity degradation (Singh, 1989).

The study centered on the Greenville-Spartanburg Metropolitan Area located in Upstate South Carolina (Greenville, Spartanburg, Pickens, and Anderson counties). Oconee County was added to the study area. Greenville-Spartanburg is the fifth most sprawling metropolitan region in the US (Ewing, 2002). The effort focused incorporating change detection into an environmental assessment process. The results are part of longer-term research on Sprawl and Smart Growth in exurbia. The work looked at portions of Greenville-Spartanburg for urban sprawl and the Lake Keowee area in Oconee County for exurbia development. Lake Keowee is becoming a retirement haven. The development is expensive low-density lakeside housing with septic development. Oconee County has the highest land consumption rate in the region. The study addressed land use and land cover changes over a 10-year period. The effect of forest and agricultural land conversion on biodiversity was the primary focus of this study (see Figure 1). The study addresses three aspects of change detection to monitoring natural resources and urban growth:

1. Detecting the change
2. Identifying the nature of the change in biodiversity
3. Quantifying the areal extent and mean index of the change by watershed

Figure 1. Study Methodology



The basic premise in using remote sensing data for change detection is that changes in land cover result in changes in light reflectance values that are monitored. Techniques to perform change detection with satellite imagery have become numerous because of increasing versatility in manipulating digital data and increasing computing power.

Watershed as the Primary Environmental Measurement Unit

From an environmental perspective, watersheds are the natural mapping unit for regional monitoring. As John Wesley Powell said: "(A watershed is) *that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part* *of a community." Watersheds come in all shapes and sizes. They cross county, state, and national boundaries. No matter where you are, you're in a watershed!"* (Saber 1987). The United States has divided nation's drainage network into successively smaller hydrologic units – regions, sub-regions, accounting units, and cataloging units. The hydrologic units are arranged within each other, from the smallest (cataloging units) to the largest (regions). The study used the cataloging units to measure the quality of biodiversity. It is a geographic area representing part or all of a surface drainage basin (Seaber 1987). Nationally the units average 4000 Ha in size. In the five-county study area there are 150 subwatersheds averaging 6000 Ha in size. Thirty subwatersheds are located in more than one county.

Land Cover Classification and Change Detection

With rapid changes in land use/land, cover occurring in the US, remote sensing technology is an essential tool in monitoring urban development and environmental conditions. From a strategic perspective, remote sensing, using multispectral imagery such as Landsat Thematic Mapper, offers timely monitoring methods for extensive land areas. Arrays of techniques are available to detect land cover changes from multi-temporal remote sensing data sets (Jensen, 1996; Coppin and Bauer, 1996). Initiatives to monitor land cover and land use change are increasingly relying on information derived from remotely sensed data. It is cost effective. Such information provides the data link to other techniques designed to understand the human processes behind environmental changes. The analysis goal is to characterize those areas of important change (e.g. forest clearing or land cover / land use change) between two or more image dates. One method, image differencing, is simply the subtraction of the pixel digital values of an image recorded at one date from the corresponding pixel values of the second date. The histogram of the resulting image depicts a range of pixel values from negative to positive numbers, where those clustered around zero represent no change and those at either tail represent reflectance changes from one image date to the next (Jensen, 1996). This method has been documented widely in change detection research (Singh, 1986; Stow and Sperry, 1990; Green *et al*., 1994; and Coppin and Bauer, 1996). This method is accurate, simple in computation, and easy to interpret. Image differencing, although mathematically simple, does not allows identified change to be separated into multiple classes. For this study, multispectral images classified into land cover classes were the preferred method of change detection. This image type is has robust capability to identify vegetation and development classes.

Classification Scheme

The study used Landsat TM and ETM+ scenes that covered the five county study area. Dual dates for the scene were acquired for the change detection. The period selected was late April in 1990 and 2000. This time was preferred for early leaf-on conditions, but no dense canopy to obscure urban development. In addition, the scenes were cloud free. The 1990 Landsat 5 TM and 2000 Landsat ETM+ data were geometrically corrected by the EROS Data Center (Sioux Falls, SD) to less than 1/2 pixel root mean square error, registered to Universal Transverse Mercator coordinates, zone 17, North American Datum 1983, and resampled to 30-meter pixels by cubic convolution. All six reflective bands from both dates were used for the classification. Land cover mapping was conducted for the study area using both satellite imagery and other geospatial data sets. Briefly, the classification used unsupervised clustering program ISODATA to generate 250 classes. The resulting spectral clusters were grouped into 12 classes using ancillary data sources (e.g., census, slope/aspect/elevation, orthophotography etc.) as required. The 12 thematic classes resemble the well-established Anderson land use/cover classification system (Anderson et al. 1976). The thematic classes are:

11. Open Water - All areas of open water with total vegetative cover less than 25 percent.

21. Developed, Open Space (Parks, Golf Courses, Open Space) - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Impervious surfaces account for less than 20 percent of total cover. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-50 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-80 percent of the total cover. These areas most commonly include single-family housing units.

24. Developed, High Intensity - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.

30. Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material. Vegetation is less than 20 percent of total cover.

41. Deciduous Forest - Areas dominated by trees where greater than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest (Coniferous) - Areas dominated by trees where greater than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest Areas dominated by trees where neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

81. Open Fields/Pasture – Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle.

82. Cultivated Crops - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton, typically on an annual cycle.

91. Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 25 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

The classification followed the new 2001 National Land Cover Data (NLCD) scheme. It is a modification of the previous 1992 NLCD classes. The new scheme uses percent of impervious surfaces for development classes as opposed to the land uses such as commercial and transportation. Impervious surface is more consistent with the capability of satellite imagery. This new scheme is being used for the National Land Cover Characterization 2001 project. It is a cooperative effort involving several US Federal agencies – USGS, EPA, USFS, and NOAA. They will compile land cover data (NLCD 2001) across all 50 states and Puerto Rico and update the 1992 NLCD classification.

Urban Classification

Steps were taken in processing the data to stratify urban or high intensity classes from rural stratification or cultivated crops. The grouping of the unsupervised classification used the ERDAS Imagine Grouping Tool. Table 1 shows the conflict among the 12 classes. Developed areas, due to confusion with bare soil, can be classified more accurately if done separately from agricultural or rural areas (Robinson & Nagel, 1990). For this reason, road data were overlaid on the imagery to aid visual identification of urban areas. High intensity development was separated from cultivated by careful manual delineation around large urban areas approximately over 100 contiguous pixels. Digital orthophotography were visually checked for this delineation.

Table 1. The Most Frequent Conflict Between Mapped Land Cover Classes.

Class name	Primary conflict	Secondary conflict
Open water	Woody wetlands	Coniferous forest
Developed open space	Open field/pasture	Mixed forest
Low Inten. Development	Mixed Forest	Open field/pasture
Med. Inten. Development	High Inten. Development	Low Inten. Development
High Inten. Development	Med. Inten. Development	Cultivated cropland
Deciduous forest	Mixed forest	Coniferous forest
Coniferous forest	Mixed forest	Woody wetlands
Mixed forest	Coniferous forest	Deciduous forest
Open field/pasture	Cultivated cropland	Low Inten. Development
Cultivated cropland	High Inten. Development	Open field/pasture
Woody wetlands	Coniferous forest	Open water

In comparing the grouping of the classes there were some conflicts. Major factors that have contributed to disagreements between mapped land cover include:

1) 1990 Landsat TM data quality and mapping error,
2) Early Spring time period – clear-cut, bare earth vs. paved urban areas(open fields/pasture, cultivated crops, and high intensity development)
3) Spatial uncertainty, such as geo-registration error.

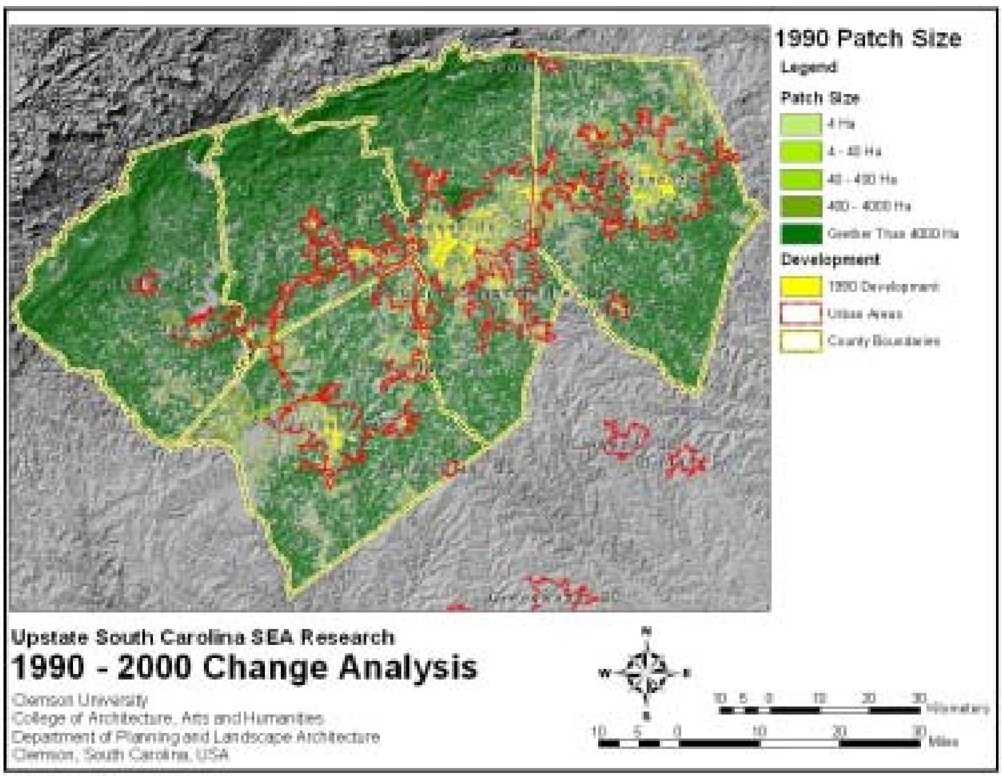
Measurement Process for Biodiversity

The challenge of the study is to monitor an environmental program's trends and consequences. Such process requires a common baseline as well as having efficient and effective analysis techniques. This process should integrate environmental concerns in land use policy. It can stimulate participation and action of stakeholders from business to citizens in the development process. If all parties are involved, having better and more accessible information on the environment can streamline the development process benefiting all stakeholders. A quality environmental assessment process informs planners, decision makers and affected public on the sustainability of strategic decisions, facilitates the search for the best alternative and ensures a public decision making process. The process can enhance the credibility of decisions, as long as it is integrated, focused and accountable.

To demonstrate the process, this study assessed the biodiversity quality of the five counties and monitored the trend over a 10-year period. For the purposes of this study, biodiversity information is defined as data on the location, status, and history of vegetation and ecosystems. In monitoring biodiversity, ecosystem degradation is more difficult to measure than habitat loss. The subtle effects of changing vegetation diversity and fragmentation of habitats into smaller patches can have significant impacts on biodiversity. It is a generally assumed among ecologists that smaller patches provide lower quality habitat than larger patches (Calhoun and Klemens, 2002). This study used both ERDAS Imagine for processing satellite imagery in land cover classes and ESRI's ArcGIS for generating statistics representing the number or density of landscape patches, the size and variability metrics of patches, the diversity metrics of the landscape and the variation in patch shape at the class and watershed levels. These metrics are best considered as representing landscape configuration. Generating mean values at the watershed level are good for determining the trend of the condition over time. The number of patches of a particular habitat type may affect a variety of ecological processes, depending on the landscape context; for example, they may determine the number of subpopulations in a spatially dispersed population, or metapopulation, for species exclusively associated with that habitat type. The number of subpopulations could influence the dynamics and persistence of the metapopulation (Gilpin and Hanski 1991). In addition, habitat subdivision, as indexed by the number of patches, may affect the propagation of disturbances across a landscape (Franklin and Forman 1987). Consequently, habitat fragments may suffer higher rates of disturbance for some disturbance types than do contiguous habitats.

The number of patches in a landscape can serve as an index of spatial heterogeneity of the entire landscape pattern. Although the number of patches in a class or watershed may be fundamentally important to various ecological processes, often it does not have any interpretive value by itself because it conveys no information about area, distribution, or the quality of patches. If total landscape area and class area are held constant, then the number of patches conveys the same information as the mean patch size and it could be a useful index to interpret. Number of patches is probably most valuable as the basis for computing other interpretable metrics. The size, diversity and shape of patches in the entire landscape can serve as a good biodiversity index because a watershed or landscape with greater variety and constant shape would have more spatial stability and in theory support more species. Another class and watershed index based on the number of patches is mean patch size (see figure 2). Again, the area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. The area comprised by each patch type is equally important; for example, progressive reduction in the size of habitat fragments is a key component of habitat fragmentation. Thus, a watershed with a smaller mean patch size for the target patch type than another watershed might be considered more fragmented. Mean patch size at the class level is a function of the number of patches in the class and total class area (McGarigal and Marks 1995). Therefore, at the class level, these two indices represent slightly different aspects of class structure. For example, two watersheds could have the same number and size distribution of patches for a given class and thus have the same mean patch size; yet, if total watershed area differed, patch density or canopy quality could be very different between the watersheds. In addition, two watersheds could have the same number of patches and total watershed area, thereby having the same patch density. Yet, if class area differed, mean patch size could be very different between watersheds. This study did not address density directly and further research on density and canopy quality needs to be conducted. Higher resolution imagery is required for canopy assessment. For this study, the mean size by watershed is a key value.

Figure 2. Identifying the Natural landscape as Habitat Patches and Determining Their Size



Diversity is another measurement of Biodiversity. Diversity measures a patch's richness or variety of classes (see Figure 3). It measures the number of vegetation types present; but it is not affected by the relative abundance of each vegetation type. In this application, it helps in evaluating the edge condition. Because richness does not account for relative abundance of each patch type, rare patch types and common patch types contribute equally to richness. Patch diversity, nevertheless is an important element of landscape structure because the variety of elements present in a landscape can have an important influence on several ecological processes. With many organisms being associated with a single patch type, patch diversity often correlates well with species richness. Diversity richness is partially a function of scale. Larger areas are generally richer, and they have greater heterogeneity over large areas than over comparable smaller areas (McGarigal and Marks 1995). Therefore, comparing diversity among watersheds of different sizes can be problematic. The mean of diversity over a watershed standardizes diversity to a per area basis that facilitates comparison among watersheds.

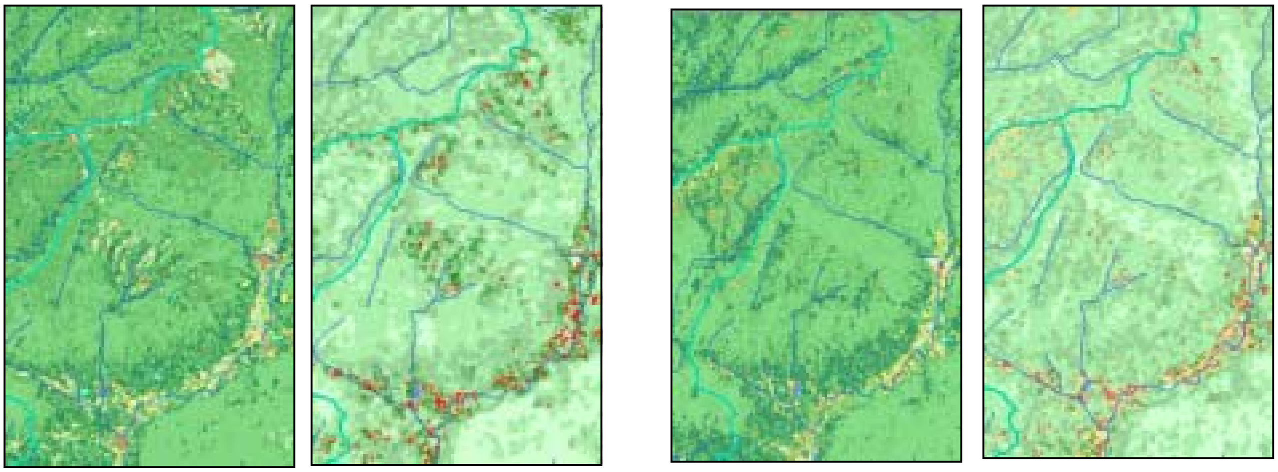
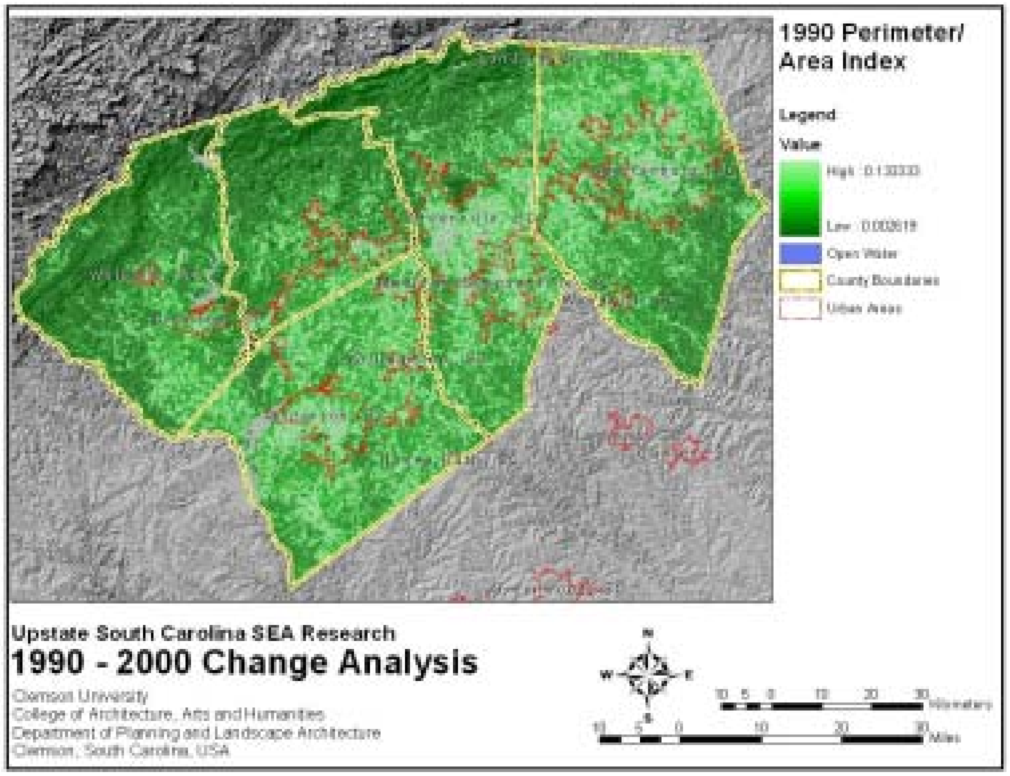


Figure 3 Shows the change in diversity over the 10-year period. The images from left to right are 1990 land cover and diversity followed by 2000 landcover and diversity. Notice the pasture area in the center of the image changing to forest over the decade.

The final variable to quantify a landscape configuration is the complexity of patch shape at the class, and watershed levels (see Figure 4). The lower index number is a better shape because the area is large and the perimeter is small. The interaction of patch shape and size can influence a number of important ecological processes. Patch shape has been shown to influence inter-patch processes such as small mammal migration (Buechner 1989) and woody plant colonization (Hardt and Forman 1989). It may influence animal foraging strategies (Forman and Godron 1986). Shape is a difficult parameter to quantify concisely in a metric. The study used a mean shape index to measure the average patch shape, or the average perimeter-to-area ratio, for a particular patch type (class) and all patches in a watershed. Although there are other means of quantifying patch shape (Lee and Sallee 1970), this shape index is applicable and used in landscape ecological research (Forman and Godron 1986).

The final analysis categorized each index into five value levels based on standard deviation (see figures1 and 5). The three indexes were added to determine the biodiversity for 1990 and 2000 by watershed. The final trend analysis was determined by subtracting the mean values of 1990 from the 2000 mean values.

Figure 4 Classifying Shape by Mean Perimeter/Area Index



Results and Discussion

Tables 2 through 8 present the land cover and biodiversity change from April 1990 to April 2000. Within the study area, medium intensity development grew 191% from 370 square kilometers to 1076 kilometers. High intensity development grew 79% from 124 square kilometers to 281 square kilometers. Finally, since deciduous forest grew 38% and coniferous forest expanded 8%, the study area patches improved. These changes came at the expense of agricultural areas. Over 1000 square kilometers were lost. In 2000, cultivated crops are essentially nonexistent, and pasture decline by 689 square kilometers. While the growth pattern in Greenville and Spartanburg was outward, the expansion in Anderson and Oconee were more significant. The growth showed more of a leapfrog pattern and had significant impact on exurbia. Urban growth in Greenville and Spartanburg was more concentrated and contiguous to the 1990 development.

The relationship between sprawl and the quality of life shows that development is far outpacing population growth. Population in the region grew by 12.7%, but the area of new development grew 48.9% (see table 8). In Anderson and Oconee counties, the developed land increased even faster at 63.4% and 77.4%. In the northern portion of the study area, the outward growth resulted in a decline in the biodiversity of the Appalachian foothills. Biodiversity near existing built-up areas generally showed improvement. Biodiversity degradation does not match the development change. In fact, several watersheds showed improvement. While 33% of the 150 watersheds declined in biodiversity, another 42% improved. Eighty five percent of the agricultural land changed from pasture and cultivated crops to development and forest vegetation. The result is the natural patches increased in size over the 10-year period. There appears to be a strong locational association of new forest land and the development pattern (see Table 7 and Figure 7). It suggests that these old fields while adding to the natural habitats may in fact be "development in waiting". In other words, over the next 10 years many of the old fields may become new development (see figures 9 and 10). The changes were not expected for the type of sprawl the study area showed. These results suggest that after initial development the vegetation/habitats can improve. The development of cul-de-sacs roads and cluster housing may actually offer more opportunities for patches to remain connected than previously thought.

Table 2. 1990 – 2000 Land Cover Change

2000 Land Cover	Anderson	Oconee	Pickens	Spartanburg	Greenville	Total	Percent
Open Water (11)	105	118	41	27	20	311	3%
Open Space Developed (21)	51	23	16	18	17	125	1%
Low Intensity Development (22)	217	116	96	183	175	788	9%
Medium Intensity Development (23)	252	137	126	276	284	1,076	12%
High Intensity Development (24)	45	23	24	80	109	281	3%
Barren (30)	-	-	-	-	-	-	0%
Deciduous Forest (41)	585	444	374	618	568	2,589	28%
Evergreen Forest (Coniferous) (42)	231	366	251	400	351	1,599	17%
Mixed Forest (43)	286	396	308	372	419	1,782	19%
Open Fields/Pasture (81)	179	94	75	128	102	579	6%
Cultivated Crops (82)	-	-	-	-	0	0	0%
Woody Wetlands (91)	10	27	13	20	17	86	1%
Total Sq Km	1,962	1,744	1,324	2,121	2,064	9,216	100%

1990 Land Cover	Anderson	Oconee	Pickens	Spartanburg	Greenville	Total	Percent
Open Water (11)	108	121	39	23	19	309	3%
Open Space Developed (21)	74	32	22	33	34	195	2%
Low Intensity Development (22)	184	92	89	226	199	791	9%
Medium Intensity Development (23)	66	33	39	119	114	370	4%
High Intensity Development (24)	22	11	14	50	60	157	2%
Barren (30)	-	4	-	-	-	4	0%
Deciduous Forest (41)	378	373	285	379	454	1,870	20%
Evergreen Forest (Coniferous) (42)	249	294	231	377	330	1,481	16%
Mixed Forest (43)	392	538	397	449	496	2,271	25%
Open Fields/Pasture (81)	380	172	144	332	241	1,268	14%
Cultivated Crops (82)	95	49	43	91	85	363	4%
Woody Wetlands (91)	13	25	22	42	32	135	1%
Total Sq Km	1,961	1,745	1,324	2,120	2,063	9,214	100%

Changed Land Cover	Anderson	Oconee	Pickens	Spartanburg	Greenville	Total	Percent
Open Water (11)	(3)	(3)	2	4	1	2	0%
Open Space Developed (21)	(23)	(9)	(5)	(16)	(17)	(70)	-36%
Low Intensity Development (22)	33	24	6	(42)	(23)	(3)	0%
Medium Intensity Development (23)	187	105	87	157	171	706	191%
High Intensity Development (24)	23	11	10	30	49	124	79%
Barren (30)	-	(4)	-	-	-	(4)	-100%
Deciduous Forest (41)	206	71	89	239	114	720	38%
Evergreen Forest (Coniferous) (42)	(18)	72	21	22	21	118	8%
Mixed Forest (43)	(106)	(141)	(88)	(77)	(76)	(489)	-22%
Open Fields/Pasture (81)	(200)	(78)	(68)	(204)	(139)	(689)	-54%
Cultivated Crops (82)	(95)	(49)	(43)	(91)	(84)	(363)	-100%
Woody Wetlands (91)	(3)	2	(10)	(22)	(16)	(49)	-36%
Total Sq Km	0	(0)	0	1	1	2	0%

Area in Square Kilometers

Figure 5. Watershed Change in Patch Size, Diversity, and Perimeter/ Area Index were added together to determine the Biodiversity Values

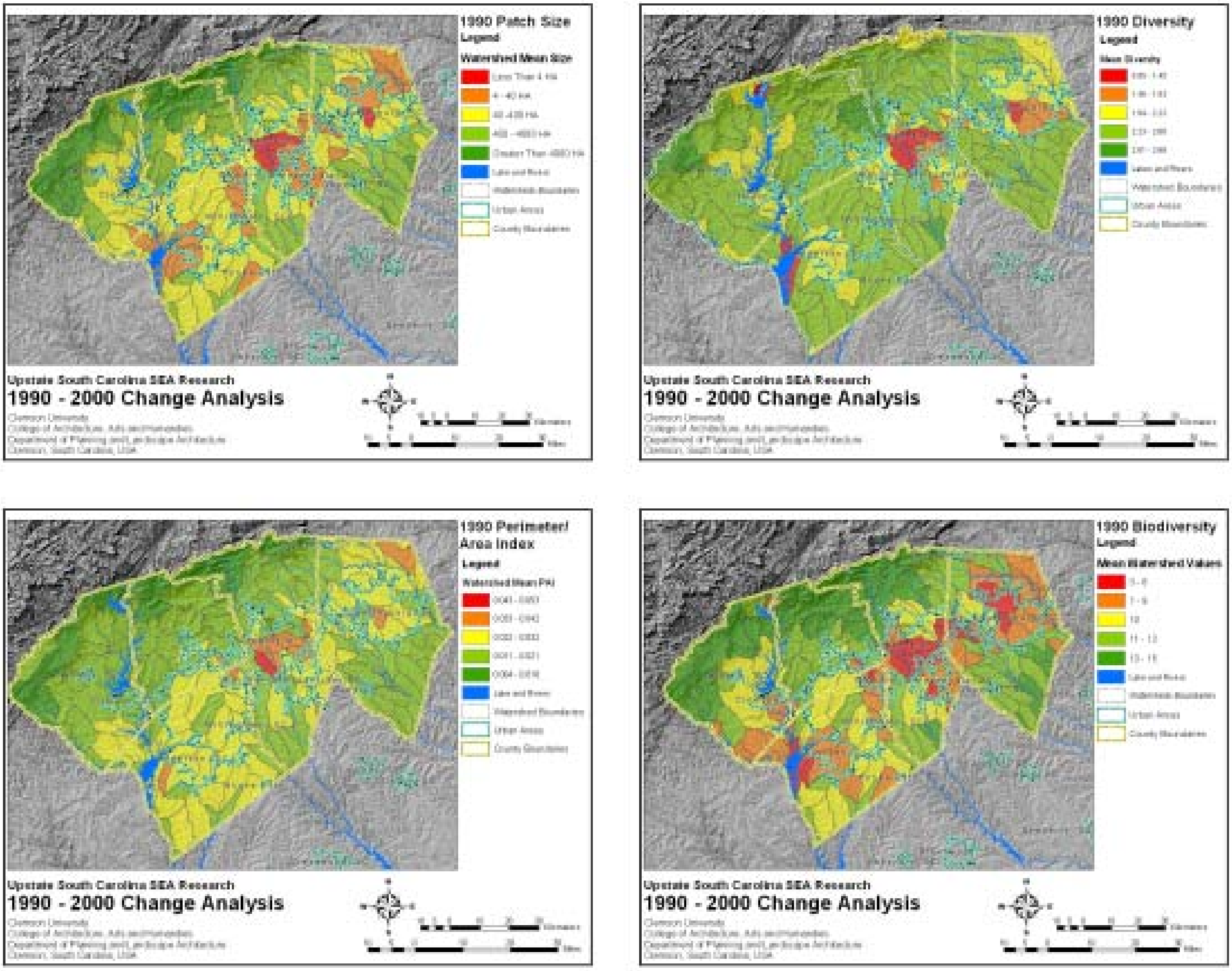


Table 3. 1990 – 2000 Patch Size Change

County	2000		1990		Change	
Anderson						
Size	**Patches**	**Percent**	**Patches**	**Percent**	**Patches**	**Percent**
< 4 Ha	2,488	88.7%	3,235	88.4%	(747)	-23%
4-40 Ha	253	9.0%	347	9.5%	(94)	-27%
40-400 Ha	50	1.8%	66	1.8%	(16)	-24%
400-4000 Ha	12	0.4%	11	0.3%	1	9%
>4000 Ha	2	0.1%	1	0.0%	1	100%
	2,805		3,660		(855)	-23%
Oconee						
Size	**Patches**	**Percent**	**Patches**	**Percent**	**Patches**	**Percent**
< 4 Ha	929	88.5%	1,070	89.4%	(141)	-13%
4-40 Ha	99	9.4%	107	8.9%	(8)	-7%
40-400 Ha	20	1.9%	16	1.3%	4	25%
400-4000 Ha	1	0.1%	2	0.2%	(1)	-50%
>4000 Ha	1	0.1%	2	0.2%	(1)	-50%
	1,050		1,197		(147)	-12%
Pickens						
Size	**Patches**	**Percent**	**Patches**	**Percent**	**Patches**	**Percent**
< 4 Ha	896	90.4%	983	90.3%	(87)	-9%
4-40 Ha	79	8.0%	93	8.5%	(14)	-15%
40-400 Ha	14	1.4%	10	0.9%	4	40%
400-4000 Ha	1	0.1%	1	0.1%	-	0%
>4000 Ha	1	0.1%	1	0.1%	-	0%
	991		1,088		(97)	-9%
Spartanburg						
Size	**Patches**	**Percent**	**Patches**	**Percent**	**Patches**	**Percent**
< 4 Ha	1,989	88.3%	3,442	89.4%	(1,453)	-42%
4-40 Ha	215	9.5%	343	8.9%	(128)	-37%
40-400 Ha	34	1.5%	56	1.5%	(22)	-39%
400-4000 Ha	11	0.5%	8	0.2%	3	38%
>4000 Ha	4	0.2%	3	0.1%	1	33%
	2,253		3,852		(1,599)	-42%
Greenville						
Size	**Patches**	**Percent**	**Patches**	**Percent**	**Patches**	**Percent**
< 4 Ha	2,209	98.0%	2,686	69.7%	(477)	-18%
4-40 Ha	308	13.7%	293	7.6%	15	5%
40-400 Ha	48	2.1%	53	1.4%	(5)	-9%
400-4000 Ha	6	0.3%	3	0.1%	3	100%
>4000 Ha	5	0.2%	2	0.1%	3	150%
	2,576		3,037		(461)	-15%

Table 4. Patch Area Change

		2000			1990			Change			
Counties	**County Size**	**Patches**	**Area***	**Percent**	**Patches**	**Area***	**Percent**	**Patches**	**Percent**	**Area***	**Percent**
Andesrson	196,122	2,805	109,312	55.7%	3,660	101,108	51.6%	(855)	-23%	8,204	8%
Oconee	174,465	1,050	122,616	70.3%	1,197	122,189	70.0%	(147)	-12%	427	0%
Pickens	132,425	991	93,919	70.9%	1,088	92,708	70.0%	(97)	-9%	1,211	1%
Spartanberg	212,021	2,253	139,469	65.8%	3,852	122,458	57.8%	(1,599)	-42%	17,011	14%
Greenville	206,322	2,576	134,069	65.0%	3,037	129,383	62.7%	(461)	-15%	4,687	4%
Totals	921,354	9,675	599,386	65.1%	12,834	567,846	61.6%	(3,159)	-25%	31,539	6%

Table 5. 1990 – 2000 Diversity Change

2000 Diversity Level	Anderson	Oconee	Pickens	Spartanburg	Greenville	Total	Percent
Level 1- Lowest	15,629	9,642	8,226	14,149	13,323	60,969	9.0%
Level 2	52,851	58,282	43,511	57,352	61,094	273,091	40.4%
Level 3	51,472	55,169	42,549	68,934	60,891	279,015	41.3%
Level 4	13,009	10,958	8,778	14,009	11,283	58,037	8.6%
Level 5	1,229	966	717	1,054	882	4,849	0.7%
Level 6	30	17	12	29	23	111	0.0%
Level 7 - Highest	1	0	0	1	0	2	0.0%
Total Hectares	134,220	135,034	103,795	155,527	147,497	676,073	100.00%
Mean	2.489	2.522	2.521	2.553	2.494	2.516	
Std. deviation	0.857	0.774	0.788	0.808	0.788	0.804	

1990 Diversity Level	Anderson	Oconee	Pickens	Spartanburg	Greenville	Total	Percent
Level 1- Lowest	12,108	9,157	7,693	12,223	13,937	55,119	8.2%
Level 2	46,460	48,576	36,995	51,461	52,924	236,416	35.0%
Level 3	65,508	63,026	47,080	73,247	68,074	316,934	46.9%
Level 4	28,342	23,358	18,726	28,336	26,812	125,574	18.6%
Level 5	5,391	4,337	3,559	4,793	5,054	23,134	3.4%
Level 6	338	285	225	299	338	1,485	0.2%
Level 7 - Highest	8	6	5	6	8	34	0.0%
Total Hectares	158,156	148,747	114,282	170,365	167,146	758,697	100.00%
Mean	2.807	2.772	2.774	2.782	2.744	2.776	
Std. Deviation	0.948	0.901	0.921	0.915	0.941	0.926	

Change Diversity Level	Anderson	Oconee	Pickens	Spartanburg	Greenville	Total	Percent
Level 1- Lowest	3,521	484	534	1,926	(614)	5,850	10.6%
Level 2	6,391	9,706	6,516	5,891	8,170	36,675	15.5%
Level 3	(14,036)	(7,857)	(4,530)	(4,313)	(7,183)	(37,920)	-12.0%
Level 4	(15,334)	(12,400)	(9,948)	(14,327)	(15,529)	(67,538)	-53.8%
Level 5	(4,162)	(3,371)	(2,841)	(3,739)	(4,172)	(18,285)	-79.0%
Level 6	(308)	(268)	(213)	(270)	(315)	(1,374)	-92.5%
Level 7 - Highest	(8)	(6)	(4)	(6)	(8)	(32)	-94.1%

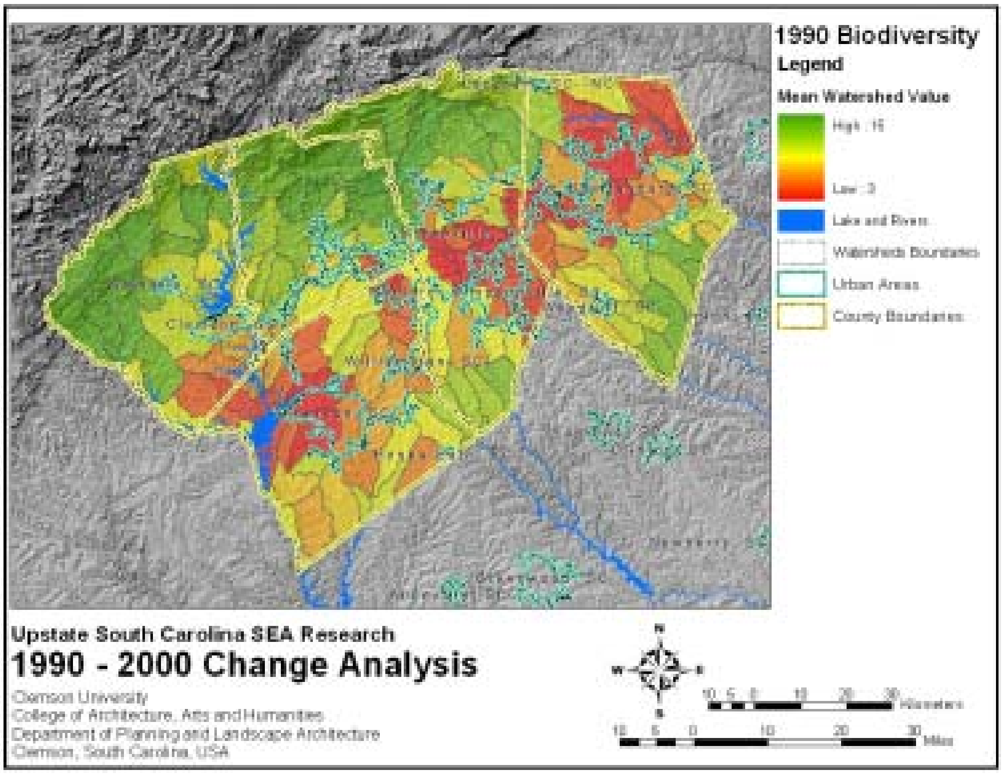
Table 6. 1990 – 2000 Patch Perimeter/Area Index

Counties	Watersheds	Hectares	Kilometers	Sq Miles	1990 PAI	2000 PAI	Changed PAI
Anderson	41	196,067.5	1,960.7	757.0	0.02367	0.02517	(0.00129)
Oconee	27	174,383.4	1,743.8	673.3	0.01278	0.01520	(0.00241)
Pickens	29	132,389.3	1,323.9	511.2	0.01566	0.01748	(0.00166)
Spartanburg	46	212,005.3	2,120.1	818.6	0.02337	0.02026	0.00336
Greenville	42	206,269.1	2,062.7	796.4	0.02256	0.02197	0.00102
Study Area Watershed Average		1,228.2	12.3	4.7	0.02088	0.02076	0.00039

Counties	No Change	Improved	Degraded	Total*	No Change	Percent Improved	Percent Degraded
Anderson	0	10	31	41	0%	24%	76%
Oconee	0	2	25	27	0%	7%	93%
Pickens	0	6	23	29	0%	21%	79%
Spartanburg	1	40	5	46	2%	87%	11%
Greenville	0	23	19	42	0%	55%	45%
Total Study Area	1	69	80	150	1%	46%	53%

* Portions of 30 Watersheds are in multiple counties

Figure 6. 1990 and 2000 Biodiversity Analysis



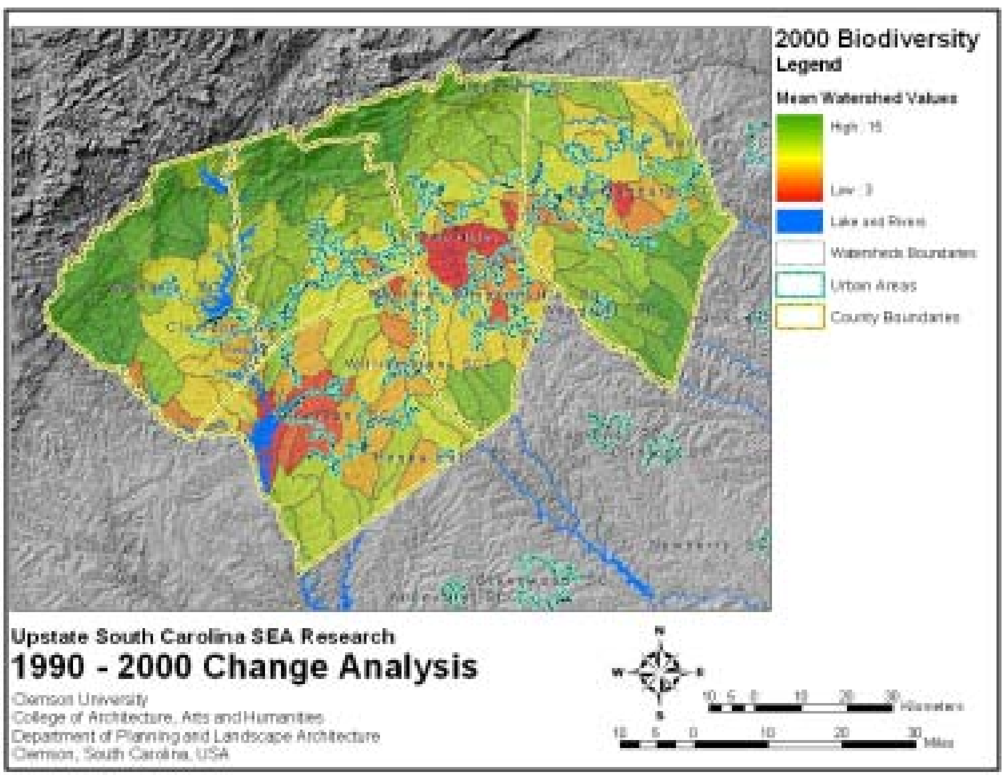


Figure 7. 1990 – 2000 Biodiversity Change by Watershed

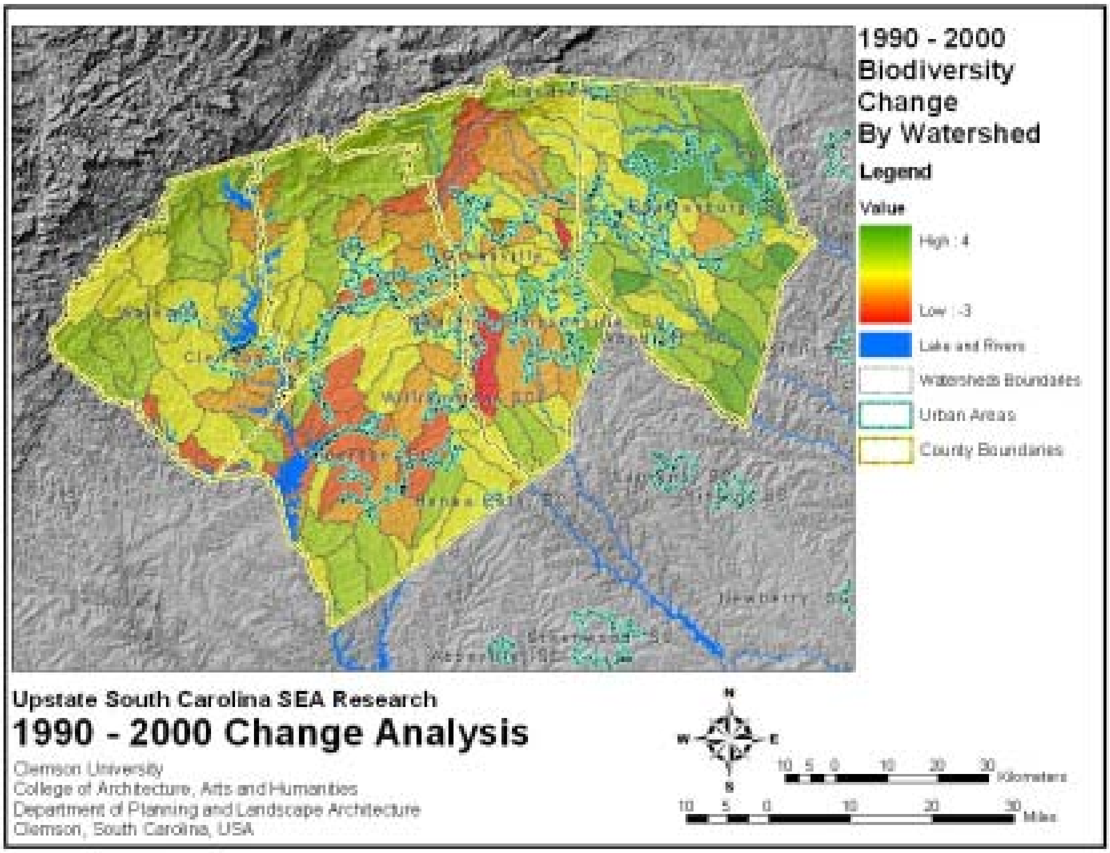


Table 7. 1990 – 2000 Biodiversity Change by County

Counties	Watersheds	Hectares	Sq Kilometers	Sq Miles	1990 Biodiversity	2000 Biodiversity	Biodiversity Change
Anderson	41	196,067.5	1,960.7	757.0	9.1	8.7	(0.4)
Oconee	27	174,383.4	1,743.8	673.3	12.0	12.3	0.2
Pickens	29	132,389.3	1,323.9	511.2	11.5	11.3	(0.2)
Spartanburg	46	212,005.3	2,120.1	818.6	9.6	10.8	1.2
Greenville	42	206,269.1	2,062.7	796.4	9.4	9.3	(0.1)
Study Area Watershed Average		6,141.4	61.4	23.7	10.0	10.3	0.3
Highest Biodiversity Average		6,996.5	17,288.7	27.0	15.0	14.3	(0.7)
Lowest Biodiversity Average		2,556.4	6,317.0	9.9	3.0	3.1	0.1

Counties	No Change	Improved	Degraded	Total*	No Change	Percent Improved	Percent Degrades
Anderson	15	7	19	41	37%	17%	46%
Oconee	12	11	4	27	44%	41%	15%
Pickens	8	9	12	29	28%	31%	41%
Spartanburg	10	33	3	46	22%	72%	7%
Greenville	13	14	15	42	31%	33%	36%
Total Study Area	49	63	38	150	33%	42%	25%

* Portions of 30 Watersheds are in multiple counties

Figure 8. Biodiversity With Development

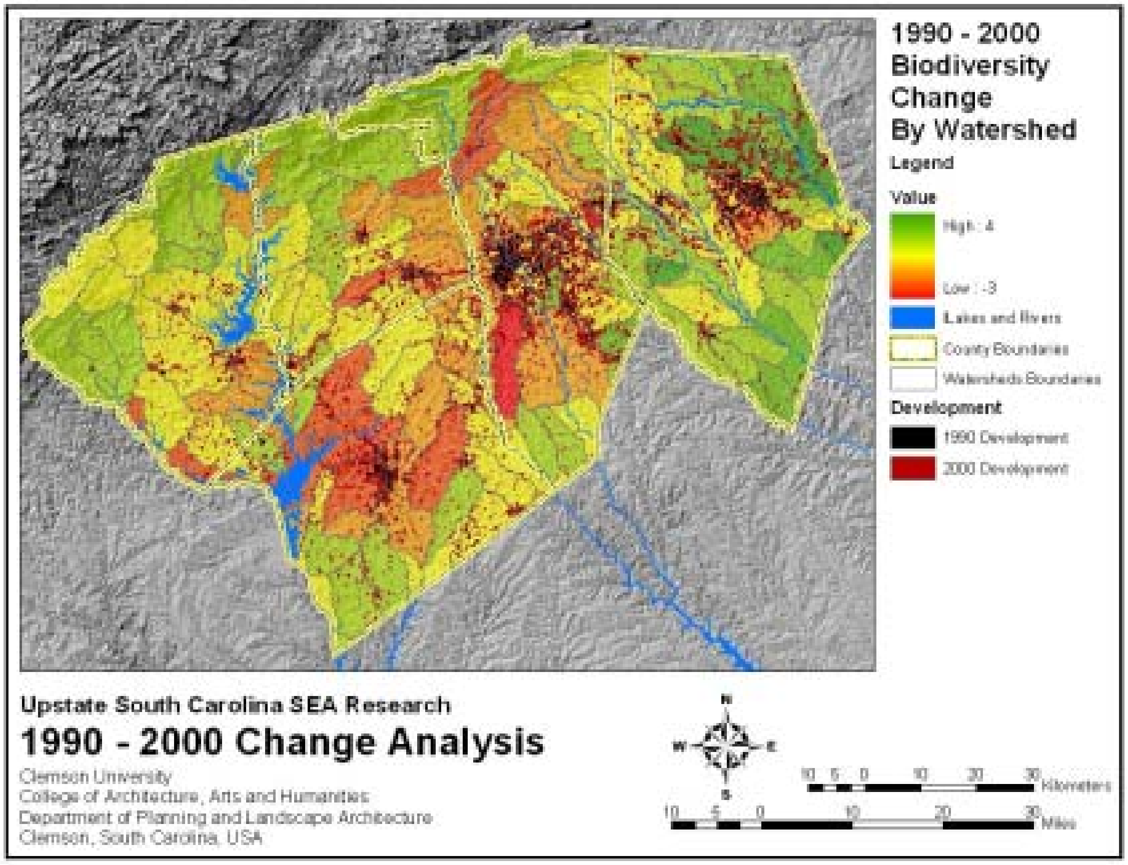


Table 8. Population Growth Verses Development Growth

County	Area / Sq Km	1990 Population	Area / Sq Km	Density/ Sq Km	Percent of County	2000 Population	Area / Sq Km	Density / Sq Km	Percent of County	Population Growth	Land Growth
Anderson	1,961.22	145,196	346.38	419.19	17.7%	163,654	565.9	289.2	28.9%	12.7%	63.4%
Oconee	1,744.65	57,494	168.53	341.15	9.7%	65,435	299.0	218.8	17.1%	13.8%	77.4%
Pickens	1,324.25	93,894	164.12	572.10	12.4%	110,394	245.5	449.7	18.5%	17.6%	49.6%
Spartanburg	2,120.21	226,800	427.38	530.67	20.2%	252,842	557.0	453.9	26.3%	11.5%	30.3%
Greenville	2,063.22	320,167	406.71	787.22	19.7%	358,012	585.8	611.1	28.4%	11.8%	44.0%
Total	9,213.54	843,551	1513.12	557.49	16.4%	950,337	2,253.3	421.8	24.5%	12.7%	48.9%

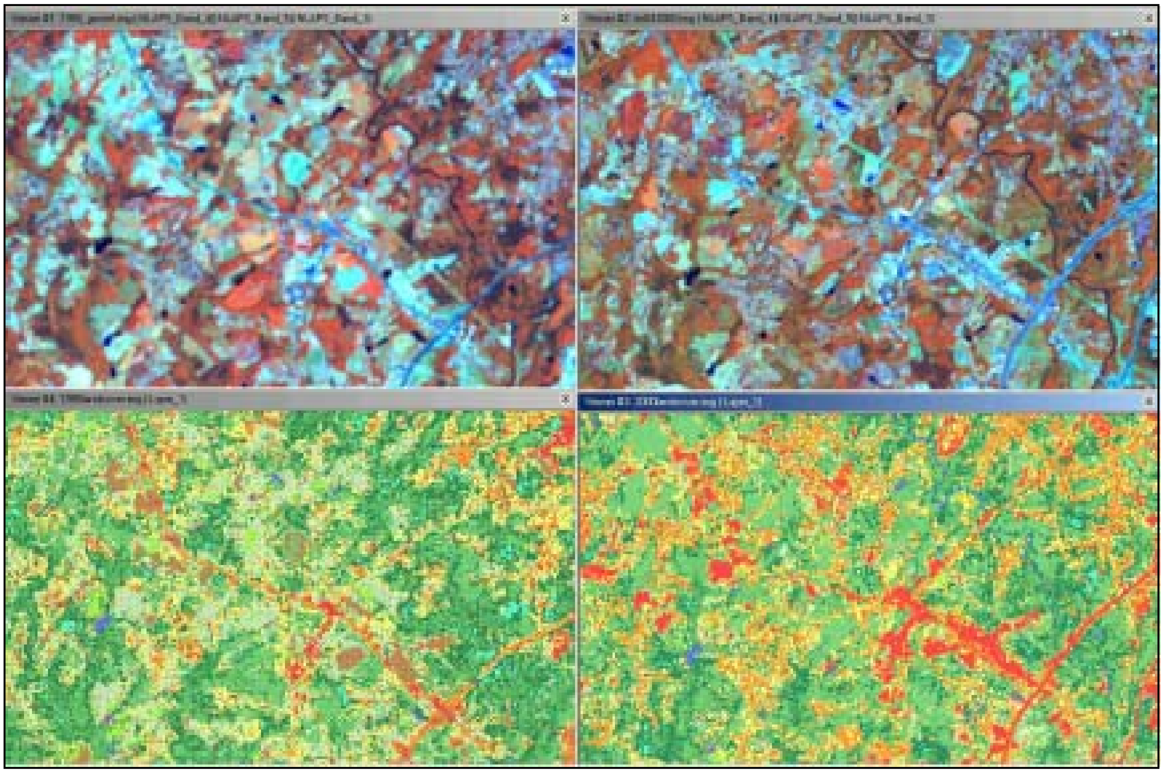


Figure 9. Shows the 1990 land cover classification on the left and the 2000 classification on the right. Notice the change in pasture from open field to new development and forestland.

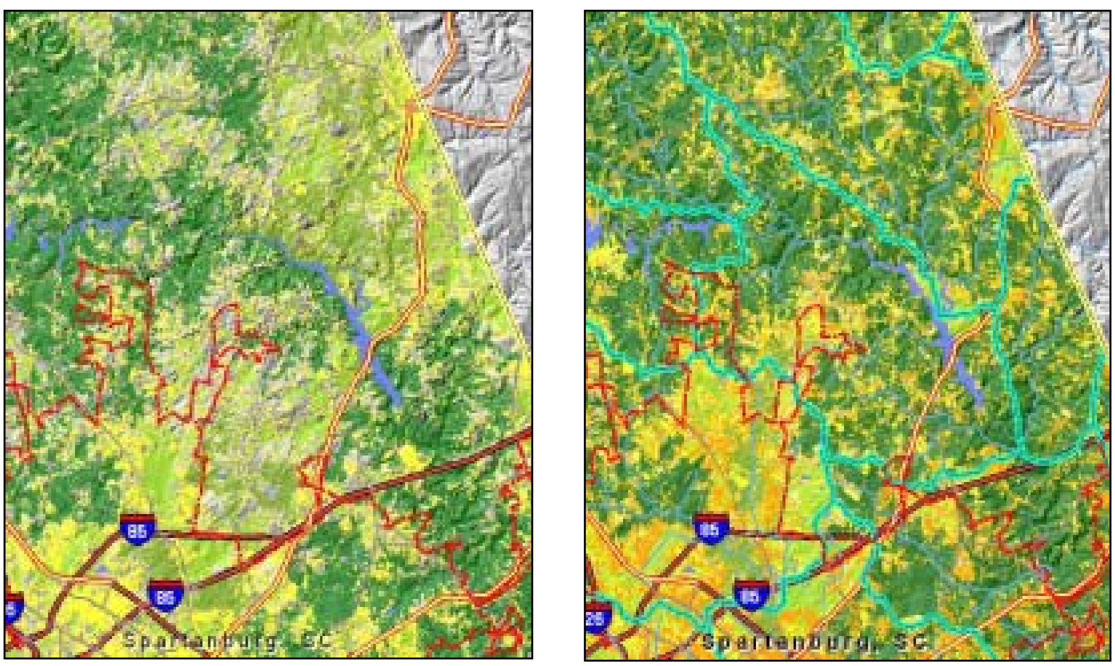


Figure 10. Shows the changes in patch size near Spartanburg, SC over the 10-year period. The increase in size results from the conversion of cultivated farmland to forestland. While this improved the 2000 biodiversity results, these forestlands are more likely land in holding for future development.

Future Research

Readers are cautioned these are preliminary results. The assessment process was the primary research objective. The classification accuracy still needs to be conducted. Initial indication of biodiversity improvement near existing built-up areas raises some interesting questions. After accuracy assessment is performed, some reclassification may be required to verify the biodiversity trends and the development patterns. The study area needs to ground-truthed. It has been four years since the imagery was acquired. Reviewing new Landsat TM imagery and visiting Spartanburg County can verify if the open fields has changed and is development continuing in these areas. Using either a fuzzy tolerance classifier or a knowledge-based classifier may improve the results. Using new high-resolution data will also be explored for determining impervious surfaces and tree canopy density. Finally acquiring additional change detection data such as road pattern density from imagery will be assessed.

Conclusion

Change detection is a tool that can promote sustainable development. With cheaper data, better software and more powerful computers, remote sensing produces reliable monitoring data. Change detection using Landsat TM imagery is a very useful to assess planning decisions. At 30-meter resolution, the imagery works well at map scales of 1:75,000 to 1:250,000 or larger. These are good scales for regional assessments. In assessing the quality and vision of sustainable development, the process tests the environmental/sustainability standards. A process, based on land cover information, can assess development patterns and their affect of the environmental quality. For the process to work on n a national level requires the following:

- Governments offering land cover information just as they supply census data.
  - They should be responsible to establish and update land cover data.
  - Programs, such as the NLCD program in the US, should perform the classifications to establish a consistent baseline.
  - International standards for the land classes would offer consistency for worldwide environmental trend analysis.
- Monitoring needs to be on a regular basis, with data collection happening every five years and matching census estimates.
- Environmental statistics should be mapped by watershed boundaries
- Matching census tract boundaries with cataloging watersheds units would allow demographic and environmental data to be used together.

The assessment can become a transparent and flexible process. Thinking strategically about land cover change and biodiversity at a regional level, stakeholders can review and monitor the effectiveness of policy decisions for development. The process allows assessment of both positive and negative affects of planning decisions. The broad-brush or qualitative nature of the process allows program changes to be altered quickly. It offers enough detail to highlight the regional development trends and the environmental consequences. It is a red flag approach whereby the worst areas are easily identified. Change detection can allow stakeholders to act quickly and only focus where detail analysis is required. It can clarify for politicians, planners, developers and the public the political priorities and judgments that are less easily realized by the existing development process. Less conjecture and more facts on both sides of the sustainable development issue may become a reality

Acknowledgments

The author gratefully acknowledges Clemson University's College of Architecture, Arts, Humanities, and The Innovative Funding Grant Program for their financial support of this research project.

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