

Where does the coast sprawl the most? Trajectories of residential development and sprawl in coastal North Carolina, 1971–2000

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Abstract

High levels of population growth in coastal U.S. settings give cause for concern about development's effects. Urban sprawl, a potential manifestation of development, is known for its negative environmental and social impacts; however, there have been few efforts to define and measure it in coastal regions where beach-oriented tourism and amenity-driven population growth and land development are prominent. This study describes residential expansion patterns and identifies trajectories for a set of sprawl metrics in New Hanover County, North Carolina over a 30-year time period. Using parcel data and GIS techniques, I developed a set of metrics for nine townships that nest within three township groups classified as: most coastal, transitional, and least coastal. Metrics measuring land consumption, leapfrog distance, land use diversity, and highway strip development are quantified and compared across regions. Most of the metrics were weakly correlated with each other suggesting that they capture different dimensions of sprawl. Results demonstrate that transitional settings located near estuaries between the oceanfront and the interior mainland were consistently the most sprawling. Behaviors of many metrics had complex, non-linear trajectories that would be invisible using either a cross-sectional or two-date approach. The approach can be extended to other regions, both coastal and non-coastal, to determine if there are differences in sprawl patterns that are unique to other environments.

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1. Introduction

Population growth and landscape change are features of coastal development that effect coastal ecosystems in various ways (Bartlett et al., 2000; Beach, 2002; Curran et al., 2002). Land use behaviors associated with coastal development contribute to land cover change that increases impervious surface; alters hydrological regimes; impairs water quality; disturbs natural habitats through areal reduction, fragmentation and degradation; alters aesthetic viewscales; and alters regional sense of place. Changes in social and ecological landscapes may also threaten the social sustainability of populations engaged in traditional fisheries economies as a result of market forces associated with amenity-driven migration and tourism (see Colgan, 2003 for a summary of coastal U.S. employment patterns).

In 1995, 39% of the global population lived within approximately 60 miles (100 km) of a coast line. Evidence suggests that coastal population is growing faster than in other regions prompting Hinrichsen (1998) to call population growth in the coastal zone the “ultimate threat” to coastal waters. Domestically, more than half of the U.S. population lives in coastal counties, and by 2010 it is projected that more the 75% of the U.S. population will live within 50 miles (80 km) of the coast (Culliton et al., 1990). The Pew Commission (2003) reported that coastal resident population will increase 25 million by 2015 and that nationally more than 20,000 acres (approximately 8000 ha) of coastal habitat is developed each year. Additionally, the U.S. Environmental Protection Agency reports that 35% of the nation's estuarine resources are impaired (poor condition), and 44% are threatened (USEPA, 2004).

North Carolina is no exception to the concern for population pressure on coastal ecosystems. According to calculations using U.S. decennial census data, from 1990 to 2000, population in North Carolina's coastal counties grew from approximately 658,000 to 773,000—an increase of 17.5%. By summing

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population counts of census block centroid points located within a 2-mile buffer of ocean or estuary shorelines, I calculated that 74% of this population resided within 2 miles (3.2 km) of ocean or estuary shorelines in 2000. These numbers do not include the effects of seasonal visitors associated with tourism which place even greater demands on coastal resources. In response to threats to coastal resources, the state legislature enacted the Coastal Area Management Act (CAMA) in 1974 to promote balance between preservation of coastal natural resources and economic development (Norton, 2005a,b). Features of CAMA included a mandate for local planning programs and a regulatory permitting program for defined “areas of environmental concern”.

Coastal development in North Carolina and elsewhere is driven to a large degree by attraction of natural and cultural amenities and consequent consumption of land resources by long-time and new residents and seasonal visitors. Land consumption implies land use change and figures prominently in debates concerning coastal development which often revolve around themes associated with “urban sprawl”. Alternatively, Smart Growth has emerged as a paradigm that is largely but not exclusively defined by principles opposite to those of sprawl such as: denser development, promotion of infill, mixed land use, preservation of open space, walkable neighborhoods, transportation alternatives, and community involvement (Danielsen et al., 1999; Smart Growth Network, 2002). Critiques of sprawl are often concerned with its negative economic (Burchell et al., 1998) and environmental impacts (Johnson, 2001) (Table 1). A growing literature has developed that seeks to identify signatures of sprawl using quantitative metrics. Largely absent from this literature are studies targeted specifically towards the issue of coastal sprawl over a long time period for relatively small urban coastal regions (in terms of population) such as those in coastal North Carolina.

1.1. Sprawl in coastal settings

Beach (2002, p. iii) defines coastal sprawl as “the expansion of low-density residential and commercial development scattered across large coastal land areas”. Issues of spatial scale complicate sprawl analyses focused explicitly on coastal settings due to varying definitions of “coastal”. The U.S. National Oceanic and Atmospheric Administration (NOAA) identifies 30 coastal states containing 673 coastal counties, with coastal counties defined as meeting at least one of the following criteria (Crosset et al., 2004): (1) at least 15% of land area is located within a coastal watershed which is defined by the US Geological

Survey (USGS) as an 8-digit cataloging unit bordering oceans or estuaries, or (2) land within the county accounts for at least 15% of a coastal watershed. This definition yields 37 coastal North Carolina counties (Fig. 1), 17 more than the 20 coastal counties defined by the North Carolina Coastal Area Management Act. This difference is likely due NOAA’s national scope compared to the more local scope of CAMA. Clearly, there are varying degrees of “coastal” if one considers locational, environmental, and cultural differences between Cape Hatteras and Cumberland County within North Carolina (Fig. 1). Most North Carolinians would not consider Cumberland County, located well to the interior and home of a major U.S. Army base (Fort Bragg) to be “coastal”.

Shifting scale to a smaller spatial extent may lessen ambiguities with the notion of “coastal” but does not do so completely. For example, New Hanover County (Fig. 2), the setting for this case study, contains barrier islands fronting the ocean, a stretch of the intra-coastal waterway, estuaries, tidal creeks, and estuarine portions of the Cape Fear River. Within the county, regions more proximal to the ocean or estuarine features arguably are more coastal than interior locations. Regional stratification along these or similar lines is necessary if we are to more precisely characterize sprawl in coastal settings while recognizing inherent difficulties in defining “coastal”.

Sprawl as a concept also suffers from difficulties in definition. Galster et al. (2001, p. 682) critiqued the conceptual ambiguity of sprawl observing that much of the existing literature is “lost in a semantic wilderness”. Their review of the literature found that sprawl can alternatively or simultaneously refer to: (1) certain *patterns* of land use, (2) *processes* of land development, (3) *causes* of particular land use behaviors, and (4) *consequences* of land use behaviors. It seems that sprawl is used both as a noun (condition) or verb (process) and suffers from a lack of clarity even though many would claim to “know it when they see it” (Galster et al., 2001, p. 682).

To help remedy this situation and employing a pattern-focused definition, Galster et al. (2001) defined eight conceptual dimensions of land use that characterize sprawl (Table 2). To operationalize this framework requires specification of appropriate data and methods with which to quantify sprawl metrics for empirical analysis (for example, see Torrens and Alberti, 2000; Hess et al., 2001; Ewing et al., 2002; Hasse and Lathrop, 2003a,b; Lopez and Hynes, 2003; Hasse, 2004). An important message to draw from this research is that sprawl can take on many dimensions as a region may exhibit high levels of sprawl for one or more metrics yet low levels for others (Cutsinger et al., 2005). For example, newly developed parcels may exhibit high land consumption (e.g. large lot sizes) yet be spatially contiguous with respect to prior existing residential development. Thus, there is no single blanket measure of sprawl and care must be taken to clarify which dimension (or related metric) one is referring to.

An innovative study by Hasse and Lathrop (2003a) used cadastral data, GIS techniques, and a housing-unit-level approach to characterize residential sprawl for a single New Jersey county. A unique feature of their study is that sprawl metrics were derived initially for individual land parcels newly devel-

Table 1
Environmental impacts of sprawl

| | |
|-----------------------------|---------------------------------|
| Loss of fragile lands | Excessive removal of vegetation |
| Reduced open space | Loss of farmland |
| Greater air pollution | Decreased aesthetics |
| Reduced species diversity | Ecosystem fragmentation |
| Increased stormwater runoff | Beach and shellfish enclosures |
| Increased risk of flooding | |

Modified after Johnson (2001).

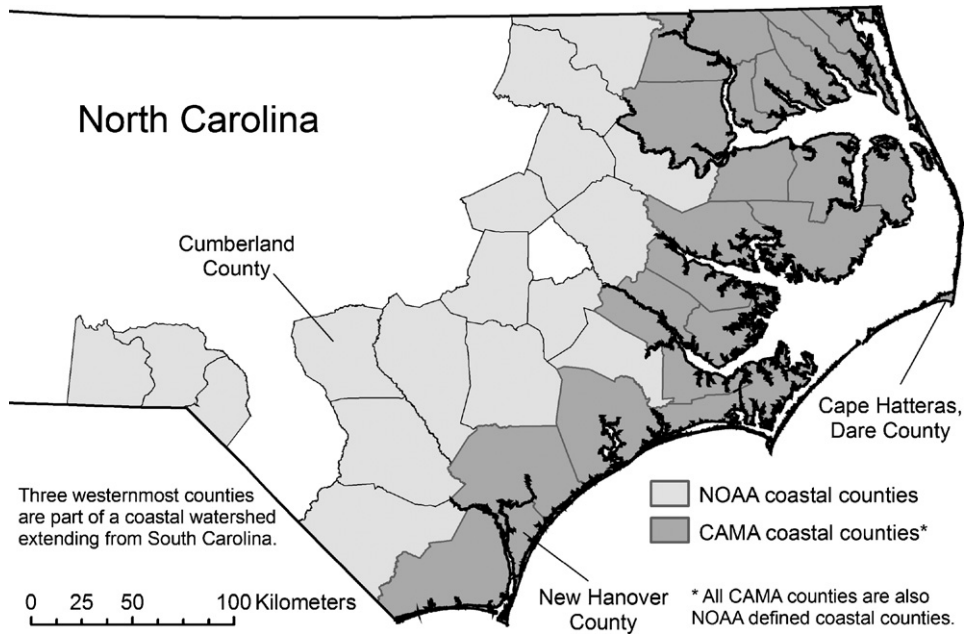


Fig. 1. North Carolina coastal counties defined by NOAA and the NC Coastal Area Management Act (CAMA) of 1974.

oped during the 10-year period 1986–1995 ($n = 9339$ residential parcels). A benefit is that subsequent aggregation enables characterization for any number of other defined spatial scales (e.g., blockgroups, counties, watersheds, etc.). This also portends correlative linkages with a rich set of socio-economic descriptors using census or sample data. Hasse and Lathrop (2003a) focused on some of what they deemed the most significant spatial characteristics of sprawl: *density*, *leapfrog*, *segregated land use*, and *highway strip*. Similar or identical metrics are used in the present analysis, and values at the parcel level are aggregated

first to townships and then to township groups to determine if regions with differing proximities to the coast exhibit different trajectories of sprawl.

1.2. Research objectives

In this study, I pursued two main goals. First, I sought to identify signatures of sprawl for a coastal region over a relatively long time period compared to prior research. Sprawl is a heated topic that has garnered the attention of environmentalists, develop-

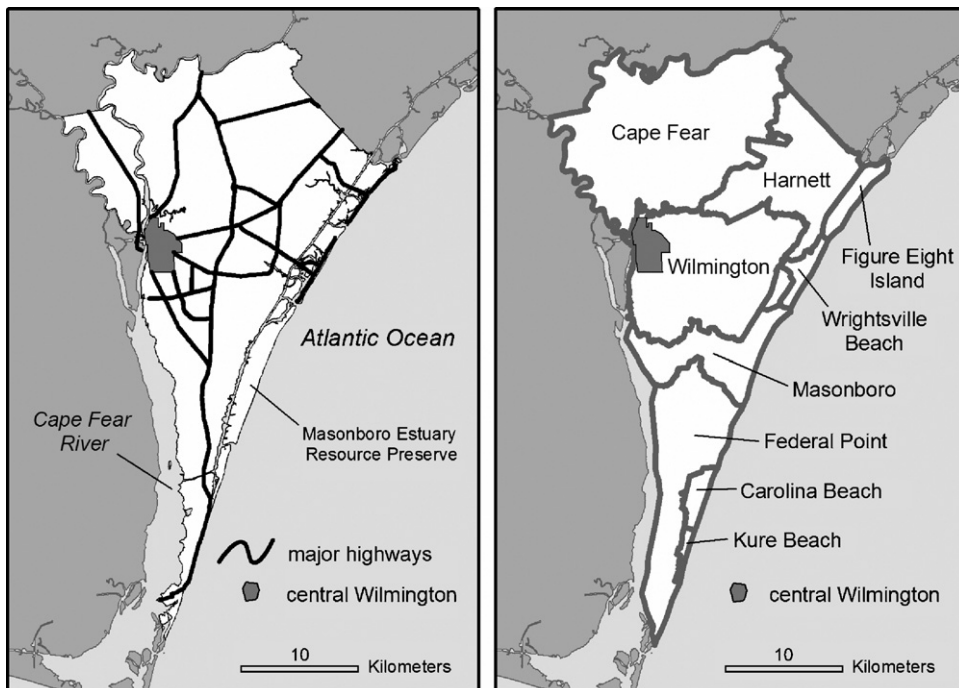


Fig. 2. New Hanover County study area townships and major roads.

Table 2
Dimensions of sprawl (Galster et al., 2001)

| Dimension | Definition |
|---------------|--|
| Density | The average number of residential units per square mile of developable land. |
| Continuity | The degree to which developable land has been built upon at urban densities in an unbroken fashion. |
| Concentration | The degree to which development is located disproportionately rather than spread evenly. |
| Clustering | The degree to which development has been tightly packed to minimize amounts of land occupied by residential or non-residential uses. |
| Centrality | The degree to which residential and/or non-residential development is located close to a central business district. |
| Nuclearity | The extent to which an area is characterized by a mononuclear development pattern (as opposed to polynuclear). |
| Mixed uses | The degree to which multiple land uses exist within the same small area and its prevalence throughout a region. |
| Proximity | The degree to which different land uses are close to each other. |

ers, planners, policy makers, academics, and the general public (Burchell and Shad, 1999; Nasser and Overberg, 2001; Harvey and Works, 2002; Bengston et al., 2005). Yet, to date relatively little research has been directed specifically towards measuring and analyzing sprawl in coastal regions where beach and marine-oriented amenities drive population growth and development. Second, this study seeks to extend the methodological utilities of existing sprawl measures for coastal applications through the use of digital parcel data and GIS techniques. In doing so, the study responds to researchers who have identified a need for conceptual clarity and refinement of measurement techniques in addition to demonstrating a micro-level approach towards analyzing sprawl. Specific research questions are outlined below:

1. Within New Hanover County, what are the magnitudes and trajectories of residential development during the period 1971–2000, and how do they vary by proximity to the coast?

Table 3
Regional population change, 1990–2000

| Region | 2000 population | 1990 population | % change | Coastal orientation/comments |
|---------------------|-----------------|-----------------|----------|--|
| Wilmington MSA | 274,532 | 200,124 | 37.2 | New Hanover and Brunswick counties |
| New Hanover County | 160,307 | 120,284 | 33.3 | |
| Wilmington | 89,451 | 73,080 | 22.4 | <i>Least coastal</i> , non-oceanfront |
| Harnett | 23,279 | 13,775 | 69.0 | <i>Transitional</i> , borders estuary |
| Cape Fear | 15,859 | 12,076 | 31.3 | <i>Least coastal</i> , non-oceanfront |
| Masonboro | 11,477 | 7,978 | 43.8 | <i>Transitional</i> , borders estuary ^a |
| Federal Point | 10,946 | 5,444 | 101.1 | <i>Transitional</i> , borders estuary ^a |
| Carolina Beach | 5,057 | 4,249 | 19.0 | <i>Most coastal</i> , borders estuary and ocean |
| Wrightsville Beach | 2,564 | 2,851 | −10.1 | <i>Most coastal</i> , borders estuary and ocean |
| Kure Beach | 1,514 | 720 | 110.3 | <i>Most coastal</i> , borders estuary and ocean |
| Figure Eight Island | 160 | 111 | 44.1 | <i>Most coastal</i> , borders estuary and ocean |

Source: U.S. Census (2000, accessed 2006).

^a Apparent oceanfront land is in protected reserve status.

2. Are there identifiable signatures of sprawl metrics for more ocean-proximal regions that are distinct from those for more ocean-distant regions?
3. How are sprawl metrics that capture different dimensions of sprawl correlated with each other (i.e. are redundancies present among a set of metrics)?

2. Regional context

New Hanover County and neighboring Brunswick County comprise the Wilmington metropolitan statistical area (MSA), the largest of North Carolina's two coastal MSAs (Jacksonville is the other). While not a large MSA, it experienced high levels of population growth during the 1990s. In 1997, the Wilmington MSA was ranked 153rd in terms of population size but had the 9th highest population growth rate from 1990 to 1997 (U.S. Department of Commerce, 1998). Nearly 60% of the MSA's population resided in New Hanover County in 2000 which grew 33.3% from 1990 to 2000 (Table 3). For comparison, North Carolina's population grew 21.4% and national population grew 13% from 1990 to 2000 (U.S. Census, 2000). Factors such as the availability of jobs and coastal amenities have been the major drivers of this growth. Another important factor was the completion of Interstate 40 in October 1990, connecting the region with the state's more heavily populated interior, particularly North Carolina's Triangle region (Raleigh, Durham, Chapel Hill).

New Hanover County government defines eight townships for the county (Fig. 2). Figure Eight Island is a special case not defined by the county that I separated from Harnett Township for the purposes of this research. It is a barrier island, gated community consisting of luxury residences and has a small population compared to the other regions. Its rather unique context warranted this spatial separation. Hereafter, all nine regions are referred to as townships.

Population size and growth rates varied across the townships for 1990–2000 (Table 3). The four oceanfront regions (Carolina Beach, Wrightsville Beach, Kure Beach, Figure Eight Island) are classified as *most coastal* townships and are the smallest in total population. This is largely an effect of their physical geogra-

phies whereby narrow barrier islands and peninsular oceanfront landforms limit land areas and population compared to interior regions. Masonboro, Federal Point, and Harnett are classified as *transitional* townships due to their intermediate locations between the oceanfront and less coastal interior. Masonboro and Federal Point appear geographically to be oceanfront. However, their ocean fronts are occupied by a federally-owned estuarine reserve and privately-owned conservation easements; although privately-owned, non-conserved parcels do in fact border its estuarine coasts, tidal creeks, and the intra-coastal waterway. Wilmington and Cape Fear are classified as *least coastal* townships due to their interior position; although both border the Cape Fear River which contains estuarine environments. The majority of population growth between 1990 and 2000 occurred away from the immediate oceanfront in *transitional* or *least coastal* townships. This is not surprising because undeveloped coastal land was already scarce by 1990. Based on differences in relative location as described above, the nine townships were grouped into the categories: *most coastal*, *transitional*, and *least coastal*.

3. Materials and methods

3.1. Data

Digital parcel and tax assessor data were acquired from New Hanover County in June 2005. Parcel boundary data were in ArcGIS shapefile format and contained all 85,820 parcel polygons located within the county. Related tabular tax assessor data contained information on land use, the year built for building improvements, and many other descriptive attributes. A subset of residential parcels containing single or multi-family residences was extracted for analysis yielding 50,238 parcels developed for residential use by 2000 (Fig. 3). Following Hasse and Lathrop (2003a), centroid points were derived for each parcel and served as the spatial location for each unit. The reported year built for parcel structures provides reasonably accurate information from which development trajectories can be constructed. A drawback is that this information reflects the year built for structures present at the time of data acquisition. It is reasonable to assume that in the vast majority of cases, the year built represents a tran-



Fig. 3. Orthophotos depicting selected parcels for a most coastal township (A), transitional townships (B and C), and a least coastal township (D). Thick white lines indicate parcels developed from 1996 to 2000. Thin white lines depict parcels developed previous to 1996.

Table 4
Description of sprawl metrics

| Metric | Interpretation | Range ^a | Relation to dimensions of sprawl ^b |
|---------------------|---|--|---|
| Land consumption | Mean parcel area. | >0 to total of region's area. | Density |
| Leapfrog distance | Mean distance to existing residential parcels. | >0 to approximately region's maximum diameter. | Density, clustering, nuclearity |
| Segregated land use | Degree of land use homogeneity in radial buffers around newly developed parcels; accounts for number of different land uses but not areal amounts of land uses. | 0 to ($X - 1$), where X equals the possible maximum number of different land uses. | Mixed uses, proximity |
| Land use diversity | Degree of land use homogeneity in radial buffers around newly developed parcels; accounts for number of different land uses and areal amounts of land uses. | 0–1. | Mixed uses, proximity |
| Highway strip | Percentage of newly developed parcels located within a highway buffer zone. | 0–1. | Clustering, nuclearity |

^a All metrics were constructed so that higher values are associated with higher sprawl and vice versa.

^b Dimensions of sprawl from Galster et al. (2001), see Table 2.

sition from undeveloped to residential. For a small minority of cases, the reported year built may represent new construction on a previously developed parcel. Resolution of this distinction was not feasible for this study because of the resources required to create individual parcel histories from courthouse records.

I used two levels of spatial aggregation: (a) townships and (b) township groups using the scheme of *most coastal–transitional–least coastal*. The temporal extent is 1971–2000, and 5-year increments within this extent define the temporal grain. This means that metrics were constructed for the temporal observations 1971–1975, 1976–1980, . . . , 1996–2000. For example, all units developed by 1970 were identified, and metrics were calculated for all new units developed between 1971 and 1975.

Other data included a detailed GIS roads layer and township boundaries acquired from New Hanover County. As with parcels, new roads clearly will have been built during the study period. However, only a subset of roads, federal, state, and county highways, present throughout the period was used in this analysis (Fig. 2). All sprawl metrics described below (Table 4) were constructed so that higher values are indicative of higher levels of sprawl.

3.2. Land consumption

The land consumption metric is an indicator of the average amount of land area occupied by each new residential unit with higher values being indicative of sprawl.

$$LC_{\text{town}} = \frac{\sum A_{\text{unit}}}{N_{\text{town}}}$$

where A_{unit} is the parcel area in acres for each new residential unit and N_{town} is the number of new residential units per region (this applies throughout) so that the metric represents average consumption.

3.3. Leapfrog

Residential growth occurring at a significant distance from existing residential units is considered *leapfrog*. This metric was

calculated for a given 5-year period by measuring the distance from the center of each new residential parcel to the center of the nearest residential parcel that existed in the year immediately preceding the period. New growth with higher leapfrog distances is considered more sprawling.

$$LF_{\text{town}} = \frac{\sum Df_{\text{unit}}}{N_{\text{town}}}$$

where Df_{unit} is the leapfrog distance in feet for each new unit. Here the complication of redevelopment is a potential factor that could impact results. I assumed this effect would be negligible because it is highly unlikely that an entire neighborhood would be redeveloped within the rather short 5-year time increment. One is more likely to find small numbers of scattered redeveloped units surrounded by existing developed units so that any redeveloped units would have low leapfrog distances. With aggregation, this is likely to have a small impact on average leapfrog distances. To the extent that there is an effect, it would be to slightly lower a township's value. LF_{town} represents an average leapfrog distance for each region.

3.4. Segregated land use

Mixed land use is exemplified by a mix of residential, commercial, industrial, or other land uses within a reasonable walking distance of residential settings. New residential growth exhibiting higher levels of segregated land use within walking distance is considered more sprawling than a more mixed land use pattern.

$$SL_{\text{town}} = \frac{\sum Seg_{\text{unit}}}{N_{\text{town}}}$$

where Seg_{unit} in this study is X minus the number of different developed urban uses within 1500 ft (457 m) of each new residential parcel centroid. X equals the maximum possible land use mix surrounding a given unit—in this case study $X=9$, although this may vary for other case studies. Possible land uses were generalized from detailed land use

descriptors in the tax assessor data and included the following nine classes: residential, service and retail businesses, lodging, restaurants, manufacturing/industrial, schools or public administration, church-related uses, transportation/utilities, and recreation. The 1500 ft distance was selected as the typical distance a pedestrian will walk 10 min to other types of land uses following Nelessen (1993). This metric was implemented by converting all parcels to a gridded format using a 50 ft (15.2 m) cell resolution. All gridded cells within a given parcel were assigned the parcel's reported land use even though actual land cover is differentiated within parcels. A 1500 ft buffer was extended around each parcel center and overlaid with the parcel grid to tabulate the number of different land uses. Averaging the number of surrounding land uses associated with each parcel for township regions yields a non-integer, continuous metric SL_{town} .

3.5. Land use diversity

This metric is similar in principle to *segregated land use* in that it measures degrees of land use heterogeneity. It differs by accounting for the areal amounts of different land uses within a parcel's neighborhood. As with the prior index, a 1500 ft (457 m) radial neighborhood was used. This metric is a version of Shannon's information entropy (Leitão et al., 2006).

$$DIV_{\text{town}} = 1 - \frac{-\sum(p_{i:\text{unit}} \log(p_{i:\text{unit}}))/\log(X)}{N_{\text{town}}}$$

where $p_{i:\text{unit}}$ is the percentage of land area in a particular land use class within a unit's neighborhood where i indexes the nine different land uses. Undeveloped land uses are excluded from each parcel's radial neighborhood so that the total land amount in a neighborhood may vary by parcel. $\log(p_{i:\text{unit}})$ is the base two logarithm of land use percentages. X is the maximum possible number of land uses—nine in this case as before. Dividing by $\log(X)$ acts to normalize resulting values

to range from 0 to 1. With Shannon's information entropy, a perfectly even distribution of the 9 land uses would result in a value of 1. A completely uneven distribution gives a value of 0 (i.e., all surrounding land area is residential). Hence, this entropy value was subtracted from the maximum possible value of 1 to enforce consistent interpretation with higher values indicative of sprawl. DIV_{town} represents the average land use diversity for each region although note that higher values of DIV_{town} actually mean lower diversity and hence higher sprawl.

3.6. Highway strip

Highway strip development is typified by fast food restaurants and retail malls and may also include single family or multi-family housing units lining regional highways or major arteries. Higher proportions of development occurring along highway strips are considered more sprawling. Federal, state, and county level highways outside the Wilmington central business district were selected and a 300 ft (91.4 m) buffer was applied following Hase and Lathrop (2003a). These roads were selected by consulting digital and hardcopy roadmaps and through familiarity with the region. I did not include Interstate 40 because it was not included until 1990, and I wanted to use the same set of roads throughout. Interstate 40 runs through Cape Fear Township and has only two access ramps. Inspection of recent air photos shows very little development within the buffer zone.

$$HS_{\text{town}} = \frac{\sum HB_{\text{unit}}}{N_{\text{town}}}$$

HB_{unit} takes on a value of 1 for newly developed units within the buffer and a value of 0 for those outside the buffer. N_{town} is the number of newly developed units in a township both inside and outside the buffer. HS_{town} is therefore a percentage that represents the probability of highway strip development for each township region.

Table 5
Newly developed residential parcels by period

| Region | 1971–1975 | 1976–1980 | 1981–1985 | 1986–1990 | 1990–1995 | 1996–2000 | 1971–2000 |
|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Least coastal | 2,300 | 1,668 | 2,151 | 3,444 | 3,887 | 2,790 | 16,240 |
| Wilmington | 1,780 | 1,039 | 1,699 | 2,736 | 3,011 | 2,218 | 12,483 |
| Cape Fear | 520 | 629 | 452 | 708 | 876 | 572 | 3,757 |
| Transitional | 2,206 | 1,485 | 1,055 | 1,763 | 3,539 | 3,507 | 13,555 |
| Harnett | 1,295 | 673 | 483 | 1,059 | 1,973 | 1,636 | 7,119 |
| Federal Point | 304 | 316 | 310 | 369 | 791 | 1,145 | 3,235 |
| Masonboro | 607 | 496 | 262 | 335 | 775 | 726 | 3,201 |
| Most coastal | 360 | 433 | 507 | 362 | 558 | 484 | 2,704 |
| Carolina Beach | 127 | 208 | 256 | 140 | 152 | 204 | 1,087 |
| Wrightsville Beach | 163 | 129 | 126 | 94 | 63 | 59 | 634 |
| Kure Beach | 29 | 37 | 37 | 67 | 277 | 181 | 628 |
| Figure Eight Island | 41 | 59 | 88 | 61 | 66 | 40 | 355 |
| Entire County | 4,866 | 3,586 | 3,713 | 5,569 | 7,984 | 6,781 | 32,499 |

Source: New Hanover County tax assessor data acquired June, 2005.

4. Results

4.1. Within New Hanover County, what are the magnitudes and trajectories of residential development during the period 1971–2000 and how do they vary by coastal proximity?

A total of 32,499 residential parcels were developed in New Hanover County during the period 1971–2000 (Table 5). This

amounts to 65% of the 50,238 residential parcels existing in 2000. *Least coastal* townships accounted for approximately half of this development and was most concentrated in the Wilmington Township. *Transitional* townships accounted for 42%, with roughly half of its development occurring in Harnett Township. Development in *most coastal* townships was much lower accounting for 8% of the county total. Fig. 4 depicts the spatial pattern of new residential development during successive decades.

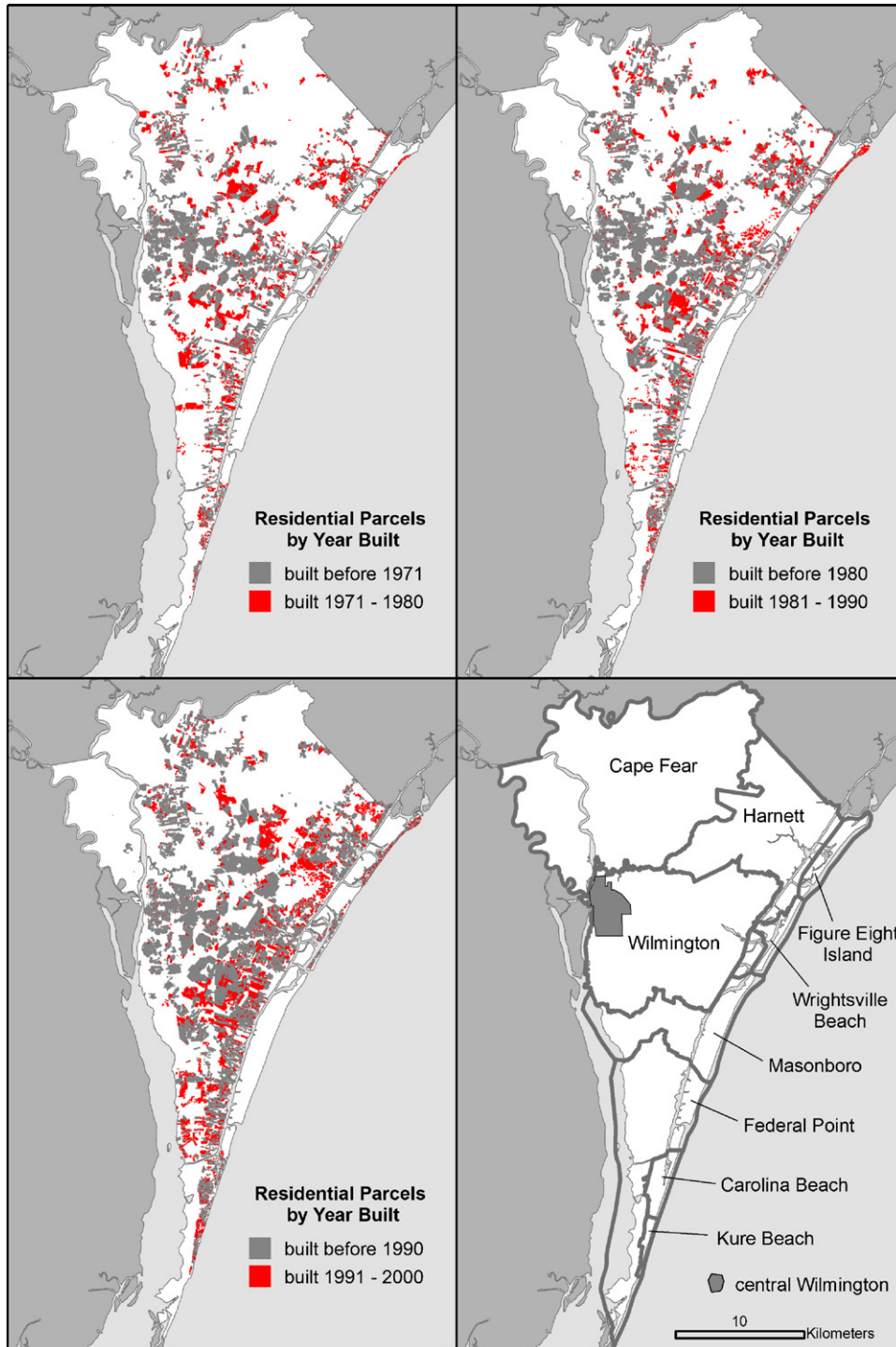


Fig. 4. Spatial pattern of new residential development (red) and existing residential development (dark gray) during the 1970s, 1980s, and 1990s. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

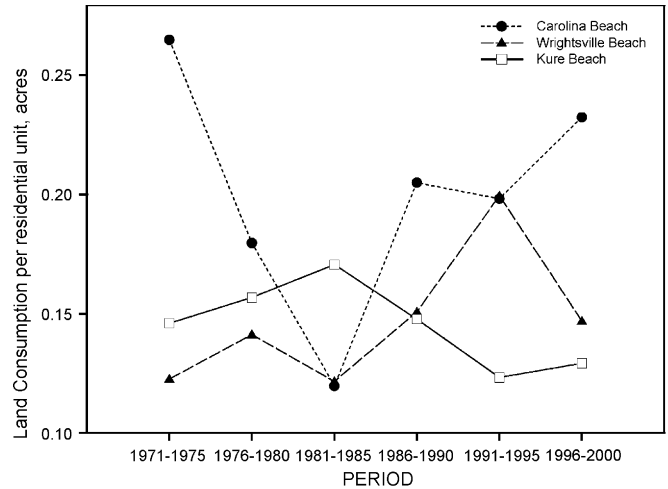
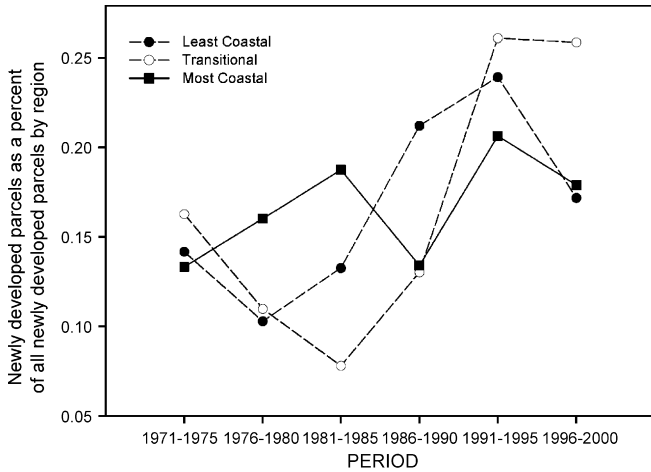


Fig. 5. Newly developed parcels as a percentage of total developed parcels from 1971 to 2000 by region.

To compare regional trajectories the number of newly developed parcels for each period were normalized by dividing by the total number of developed parcels for 1971–2000 per region (Fig. 5). Each data point represents the percentage of the region’s newly developed parcels in 1971–2000 that were developed in a particular 5-year period. Trajectories for the *least coastal* and *transitional* regions generally had similar behavior exhibiting an initial decline followed by a sharp increase to peaks near 25% during the 1991–1995 period. The *most coastal* region was different from the other two regions in that its trajectory initially increased after which it fluctuated.

4.2. How are metrics that capture different dimensions of sprawl correlated with each other?

This first correlation analysis revealed relationships between the five different sprawl measures (Table 6). All observations at the township level from the time series were pooled yielding 54 observations for each metric—9 townships times 6 time periods. Seven of the 10 correlations were significant at the $p < 0.01$ level (Spearman’s rank correlation); however, only 3 can be characterized as strongly correlated by having correlations of greater than 0.80 in absolute value. While several statistically significant correlations were present, the majority of metric combinations were only weakly related to each other suggesting that these metrics captured different aspects of sprawl.

Table 6
Correlation matrix for sprawl metrics at the township level, $n = 54$ (9 townships \times 6 periods)

| | Land consumption | Leapfrog | Segregated land use | Land use diversity |
|---------------------|-------------------|--------------------|---------------------|--------------------|
| Leapfrog | 0.43 ^a | 1.00 | | |
| Segregated land use | 0.84 ^a | 0.45 ^a | 1.00 | |
| Land use diversity | 0.84 ^a | 0.45 ^a | 0.95 ^a | 1.00 |
| Highway strip | −0.24 | −0.41 ^a | −0.12 | −0.22 |

^a $p < 0.01$, Spearman’s rank correlation.

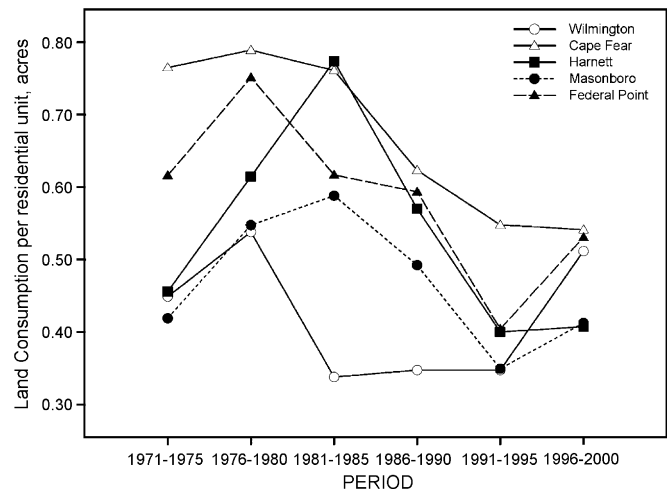


Fig. 6. Time series trajectory of land consumption, acres per newly developed residential parcel: (top) *most coastal* townships, (bottom) *least coastal* in open symbols and *transitional* townships in filled symbols.

4.3. Are there identifiable signatures of residential sprawl for more ocean-proximal regions that are distinct from those for more ocean-distant regions?

Trajectories over the six periods spanning 1971–2000 reveal striking differences in metric magnitudes between *most coastal* townships and *transitional* or *least coastal* townships (Figs. 6–9). Note the differently scaled y-axes where, with few exceptions, all metric values but those for highway strip were consistently much lower for the *most coastal* group. Table 7 reinforces this finding but with less temporal detail by reporting metric values over the entire 30-year period with parcels

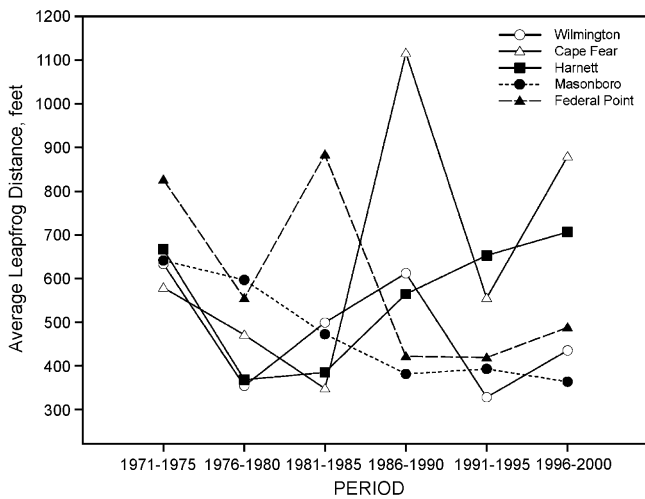
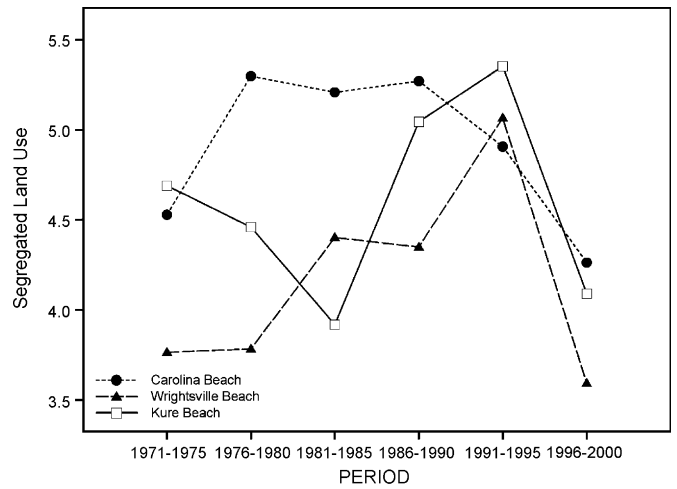
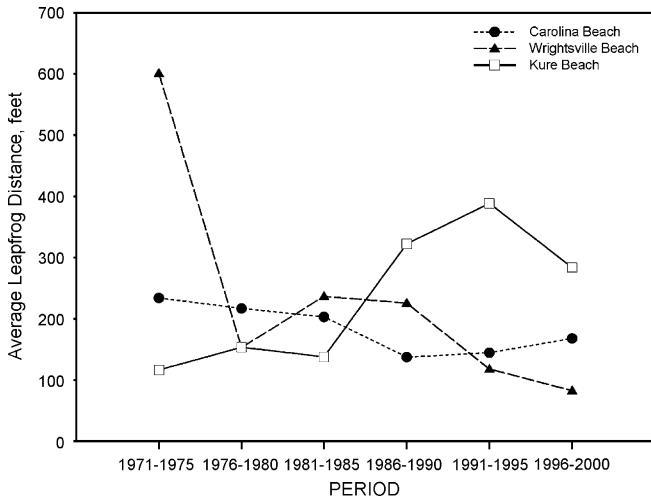


Fig. 7. Time series trajectory of leapfrog, mean distance in feet from newly developed residential parcels to prior existing residential parcels: (top) *most coastal* townships, (bottom) *least coastal* in open symbols and *transitional* townships in filled symbols.

Fig. 8. Time series trajectory of segregated land use, mean segregation value of surrounding land use for newly developed residential parcels that can range from 0 (least segregated) to 8 (most segregated): (top) *most coastal* townships, (bottom) *least coastal* in open symbols and *transitional* townships in filled symbols.

aggregated into their respective grouped township regions. On average, *most coastal* parcels consumed half as much land, exhibited less leapfrogging behavior, and had more diverse (less segregated) land uses in close proximity compared to *transitional* parcels which were the most sprawling for these metrics. Figure Eight Island, an exclusive gated community, is excluded from graphs for the *most coastal* group because it has much higher values for every metric than the other *most coastal townships*. Note, however, that it is the most sprawling of any region by far for three of the four metrics (Table 7).

Few of the trajectories have consistent trends, and most are often complex and non-linear with frequent inflection points and intersections between trajectories. In many cases, there is little apparent difference in beginning and ending point values yet fairly dramatic shifts during intermediate periods—see, for example, Harnett Township’s land consumption trajectory which contrasts with the more discernable downward trend in consumption for Cape Fear (Fig. 6). Simultaneous with Cape Fear’s downward consumption trend is its spikey “W” shaped pattern for leapfrog distance (Fig. 6) which demonstrates how at cer-

Table 7
Sprawl metrics for the entire 1971–2000 period for township groups and Figure Eight Island

| Region | Number of parcels | Land consumption | Leapfrog | Segregated land use | Highway strip |
|---------------------|-------------------|------------------|----------|---------------------|---------------|
| Most coastal | 2,704 | 0.24 | 281 | 5.03 | 26.3 |
| Transitional | 13,555 | 0.49 | 560 | 6.11 | 3.3 |
| Least coastal | 16,240 | 0.35 | 523 | 5.77 | 3.5 |
| Figure Eight Island | 355 | 0.74 | 514 | 7.40 | 56.3 |

Land use diversity not shown due to redundancy with segregated land use.

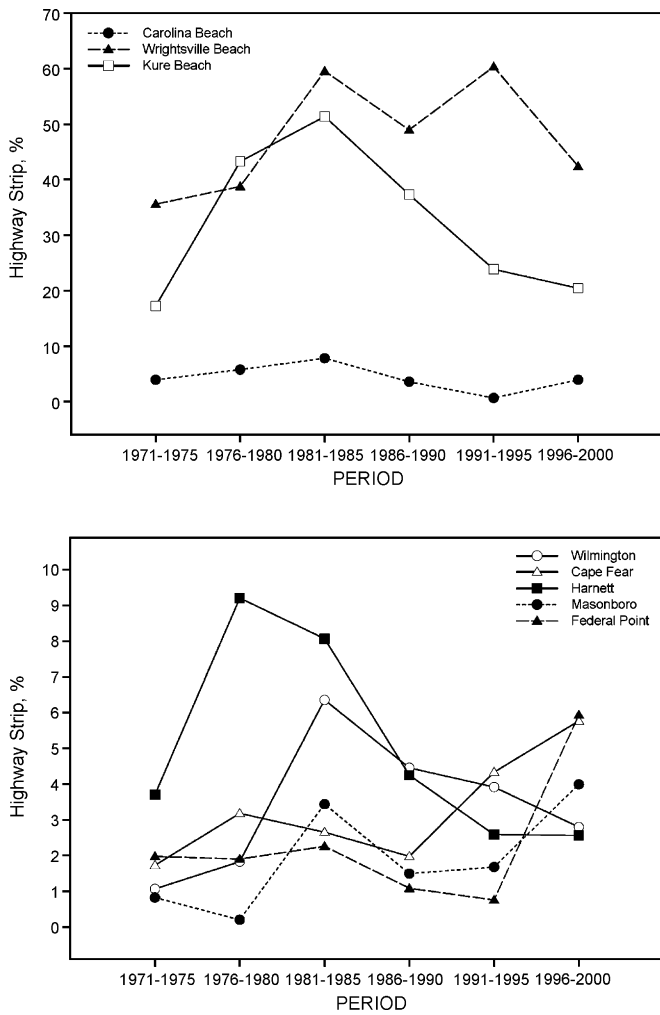


Fig. 9. Time series trajectory of highway strip development, the percent of newly developed residential parcels located within 300 ft (91.4 m) of a major road: (top) *most coastal* townships, (bottom) *least coastal* in open symbols and *transitional* townships in filled symbols.

tain periods it behaved less sprawling for one metric yet more sprawling for another.

Regarding leapfrog distance for the *most coastal* townships, Kure Beach experienced a general upward trend which contrasted with the downward trends for Carolina Beach and Wrightsville Beach (Fig. 7). For segregated land use (Fig. 8),

Carolina Beach (*most coastal*) had similar starting and ending values but substantially higher values in between resembling an inverted “U”. Through 1995, Wrightsville Beach (*most coastal*) increased greatly but in a punctuated fashion after which it dropped sharply. Kure Beach (*most coastal*) was highly non-linear with alternating periods of decline and increase.

Highway strip (HS) was remarkably stable and low for Carolina Beach (Fig. 9) and roughly on par with townships in the *transitional* and *least coastal* regions. One explanation is that Carolina Beach has a much wider uninterrupted ocean front land area than the other ocean front townships thereby permitting more land for development away from the highway. Results for *transitional* and *least coastal* townships were non-linearly complex with trajectory intersections at various periods.

To more rigorously compare sprawl metrics between the regional groupings, I used Wilcoxon Rank Tests on all metrics except highway strip which was excluded due to its binary (inside/outside the buffer) nature at the parcel level. Results from these multiple comparisons revealed statistically significant differences ($p < 0.01$) for all test metrics (Table 8). Compared to *least coastal* and *transitional* settings, residential development in *most coastal* areas had significantly lower sprawl values for all but one of the metric/time period combinations. The *most coastal* group was less sprawling than the *transitional* group for every metric/year combination. The *transitional* region had significantly higher values than the *least coastal* region for 23 of the 28 metric/year combinations. These and the prior results demonstrate that the *transitional* region intermediate between the ocean coast and the interior was consistently the most sprawling for these four metrics—land consumption, leapfrog, segregate land use, and land use diversity. Residential development in the *most coastal* region was clearly the least sprawling.

For highway strip, a reverse pattern exists where parcels in the *most coastal* region were more likely to be located along major transportation arteries (Table 7)—an indicator of sprawl. The fact that disproportionately more land area is located close to major roads for oceanfront settings largely accounts for this result and suggests that this metric may have low utility for applications in barrier island or narrow oceanfront settings. There was little difference between the *transitional* and *least coastal* regions (Table 7), although period specific differences (not shown) were present.

Table 8
Multiple comparisons of sprawl metrics over time for township groups

| Period | Most coastal:least coastal | | | | Most coastal:transitional | | | | Transitional:least coastal | | | |
|-----------|----------------------------|----|----|-----|---------------------------|----|----|-----|----------------------------|----|----|-----|
| | LC | LF | SL | DIV | LC | LF | SL | DIV | LC | LF | SL | DIV |
| 1971–2000 | – | – | – | – | – | – | – | – | + | + | + | + |
| 1971–1975 | – | – | – | – | – | – | – | – | – | + | + | + |
| 1976–1980 | – | – | – | – | – | – | – | – | – | + | o | + |
| 1981–1985 | – | – | o | – | – | – | – | – | + | + | + | + |
| 1986–1990 | – | – | – | – | – | – | – | – | + | o | + | + |
| 1991–1995 | – | – | – | – | – | – | – | – | + | + | – | + |
| 1996–2000 | – | – | – | – | – | – | – | – | + | + | + | + |

The Wilcoxon Rank Test was used. “+” indicates that the region listed before the “:” had a higher sprawl value at $p \leq 0.01$. “–” indicates that the region listed before the “:” had a lower sprawl value at $p \leq 0.01$. “o” indicates no significant difference. LC: land consumption; LF: leapfrog; SL: segregated land use; DIV: land use diversity.

5. Discussion

The sprawl metrics revealed clear differences in spatial patterns of residential development during the study period. New residential development in the *most coastal* region was consistently denser, had shorter distances to existing residences, and was surrounded by a greater mix of land uses—all indicators of lower levels of sprawl. *Transitional* regions that bordered the estuaries and with locations between the Wilmington urban core and the barrier islands exhibited the highest levels of sprawl. This coupled with the fact that this region had a large number of newly developed parcels, only slightly trailing the *least coastal*, accentuates sprawl as a phenomenon within the *transitional* region. With the exception of Figure Eight Island—a special case gated community, the fact that barrier island communities were the least sprawling for all metrics except highway strip is particularly interesting due to commonalities with principles of Smart Growth. Land scarcity, cultural preferences for beach locations causing high demand for land, and the desire for walkable landscapes to promote accessibility to amenities may predispose many barrier island to exhibit lower sprawl as measured by these metrics. Nonetheless, other barrier islands may have different results thereby warranting comparative research across a wider sample of barrier island communities. Results for Figure Eight Island demonstrated that this particular gated beachfront community exhibited the most sprawling pattern. Future research is warranted that examines impacts of gated communities requiring even finer scale analyses for specific neighborhoods.

Correlation analysis revealed that segregated land use and land use diversity were essentially identical despite the richer amount of information inherent to the diversity metric. Due to their redundancy, this study reported results for segregated land use; however, such redundancy may not be present for other regions. While the segregation metric is simpler to compute and understand compared to the entropy-based diversity metric, by capturing differing land use amounts the diversity metric may be preferred for future sprawl research. Land consumption was strongly positively correlated with both of these measures indicating that higher consumption was associated with greater homogeneity of surrounding land use. Both segregated land use and diversity were positively associated with leapfrog distance but only weakly. Leapfrog distance was negatively related to highway strip. Thus, new residences established along highway strips tended, though weakly, to be located closer to previously established residential parcels. Leapfrog distance had a weak positive correlation with land consumption. This makes intuitive sense because center points for parcels with larger land areas would have greater distances to center points of previously established parcels due to their more expansive pattern of land use. Land consumption was redundant with segregated land use and diversity which in turn were redundant with each other. To summarize dimensions of sprawl effectively represented by these metrics: land consumption captures density, leapfrog distance primarily captures spatial clustering and secondarily captures density, segregate land use and land use diversity capture land use heterogeneity (or mix), and highway strip captures clustering in proximity to major transportation arteries. While positive

correlations were present among several of the metrics, results suggest that there is no “magic bullet” measure to singularly represent sprawl—a finding that agrees with results from Hasse and Lathrop (2003a).

A key finding was that many of the metrics had fluctuating up and down behavior over time. For some of the townships, the ending values for some metrics were lower than initial values. This suggests that sprawl may be a regularly occurring yet temporary phenomenon as the region undergoes development. A likely explanation for this result is increasing land scarcity and infill. As developable land becomes increasingly scarce due to infill of areas previously located on the fringe, land consumption and leapfrog distance per parcel should logically decrease. However, this process may be accompanied by simultaneous new development that leaps out beyond the developed fringe where land is not as scarce so that these areas may exhibit higher sprawl metrics that during subsequent periods would be expected decrease over time as development continues to expand outward.

Within New Hanover County, one expectation for post-2000 patterns is that least coastal settings, particularly upper portions of Cape Fear Township which are lightly developed and proximal to Interstate 40, will experience intense development and perhaps overtake transitional settings in terms of highest sprawl values. Additionally, transitional settings in neighboring counties (Pender and Brunswick) are likely targets for development. Resulting sprawl patterns for this post-2000 development is dependent on multiple factors. In a status quo scenario, an expectation is that new development will exhibit fairly high sprawl. Alternatively, critiques of sprawl that are increasingly commonplace in local media coverage may sway developers to design less sprawling neighborhoods. A potentially contested scenario is for local governments to enforce designs that conform to principles of Smart Growth. If such principles are commonly implemented, resulting sprawl values may show mixed results. For example, one would expect to find lower land consumption (higher density) and greater land use mix. However, leapfrog distances may still be high, and acceptably so, if value is placed on preserving greenspaces located in between newly developed neighborhoods. In practical terms, the GIS-based methods demonstrated here could be used by local planning boards to evaluate proposed development as part of their regular protocol. This would require user-friendly GIS software designed to produce simple reports and to make the intense spatial data geoprocessing transparent to end users.

A fuller understanding and explanation of these results requires a richer analysis than is pursued here of land development histories in the region. For example, substantial tourism-related and residential development of oceanfront communities within this region date back to at least the late 19th and early 20th centuries. By 1970, many of these desirable sites were already developed so that the *transitional* region was largely and effectively the development frontier during the study period. This is a highly desirable location because it is close to estuaries, large tracts of undeveloped land, and urban Wilmington. Throughout transitional, estuarine regions of coastal North Carolina and the southeast U.S., sprawl associated with suburban or ex-urban development is a likely scenario that may become

accentuated with retirement migration and ageing of the baby boom generation. When analyzing sprawl for a specified time period, the issues of prior historical development and the period's current availability of potentially developable land point to a fundamental challenge of careful specification of which land should be considered in quantitative sprawl analyses (Wolman et al., 2005). For example, development in some coastal settings may be prevented by the presence of wetlands. Thus, the spatial pattern of wetland or other undevelopable land tracts may influence resulting sprawl metrics. Future research should endeavor to separate such effects.

The complex linear sprawl trajectories are most likely related to an interplay of spatially oriented political economic processes that may vary through time. In addition to accounting for contextual land use histories, locally varying real estate markets, local-to-national economic cycles, and demographic change (especially in-migration) are all implicated in coastal land use dynamics. Also, important are the effects of planning policies that either enable or constrain potentials for coastal sprawl. One can envision historical analysis of policy prescriptions that assesses their relationships and effects with respect to identified sprawl trajectories (see Helm, 2001). Additionally, land speculators and developers play important roles as economic agents who in turn may either respond to or help drive cultural attitudes towards appropriate landscape configurations.

The issue of scale is another important consideration. Within broader regional and national contexts, the entirety of New Hanover County would have to be considered "coastal". Regional classification such as the one presented here is required to differentiate patterns among the most or least coastal of coastal settings. Temporal scale is equally important. Prior studies have commonly engaged in cross-sectional analyses for a single date or for two dates to assess change. Use of just two dates prevents examination of trajectories present during the intervening years. Here, a richer treatment of temporal scale was implemented by using a 30-year duration and multiple 5-year periods. The value of this temporal approach is demonstrated by the fact that several metrics had close to identical or lower values at the terminal periods but widely different values for intermediate periods.

Perhaps the most notable example of temporal scale effects is found in results for the leapfrog metric. Its fluctuating trajectories for many of the townships can be interpreted as waves of dispersed development alternating with infill that would be invisible using only the terminal periods. Hasse and Lathrop (2003a) examined this same metric using a single 10-year time extent (1986–1995) with no intermediate, shorter time periods. Leapfrog distances for all new units during this period were calculated as nearest distances to residential units existing prior to 1986. Compared to the present use of multiple, 5-year intervals, Lathrop and Hasse's (2003a) use of a single 10-year period will have the effect of inflating the leapfrog metric value. For example, new units built in 1990–1995 may be near to units built during 1986–1989 but far from units existing prior to 1986. The units built during 1986–1989 would be excluded from consideration when calculating leapfrog distances using Lathrop and Hasse's (2003a) temporal scheme. Using a finer temporal grain of 5 years, as done in the present analysis, reduces this

inflation effect but not entirely because new units built in the preceding 4 years of a 5-year time increment are also excluded from nearest distance calculations. This underscores the potential scale-dependent nature, in this case temporal scale, of this as well as other metrics. Future research employing multiple temporal and spatial scales is needed to better understand scale dependencies of sprawl patterns.

With the use of spatially explicit parcel data, this research has demonstrated a micro-level approach towards characterizing coastal sprawl. The approach is enabled by the database management and analytical functions of GIS technologies and expertise. One can envision similar analyses spanning multiple counties—for example, the entire collection of coastal North Carolina counties or similarly defined regions. One challenge for this vision is the effort required in assembling hundreds of thousands parcels that span multiple jurisdictions with different database formats and reporting protocols. Few studies have attempted such an effort, although research by Hart and Vargas (2000) demonstrated its feasibility for an 11 county region of coastal Wisconsin.

To conclude, in New Hanover County transitional regions between the ocean and interior mainland sprawled the most and experienced the highest amounts of new residential development since 1980. Micro-level metrics measuring land consumption, leapfrog distance, land use segregation, and highway strip required the use of GIS and were found in most cases to be weakly correlated with each other. While results are specific to this case study, the approach can be extended to other regions, both coastal and non-coastal, to determine if there are differences in sprawl patterns that are unique to coastal or other environments.

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