

MEASURING URBAN SPRAWL AND COMPACTNESS: CASE STUDY ORLANDO, USA

SIM S.(1), MESEV V.(2)

(1) University of North Alabama, FLORENCE, UNITED STATES ; (2) Florida State University, TALLAHASSEE, UNITED STATES

ABSTRACT

Urban growth is widely regarded as an important driver of environmental and social problems. It causes the loss of informal open space and the fragmentation of wildlife habitats. Timely and accurate assessments of future urban growth scenarios and associated environmental impacts are crucial for urban planning, policy decision, and natural resource management. Orlando, and the central Florida region has been experiencing explosive growth recently and continuous urban development. Our study explores a set of quantitative variables to characterize urban forms at the metropolitan level and, in particular, to distinguish compactness from sprawl using a GIS and remote sensing methodology. Six dimensions of sprawl indicators (size, density, continuity, scattering, shape and loss of green space) are selected and evaluated for the Orlando metropolitan region. Results show that spatial characteristics of sprawl can be routinely and quantified using appropriate tools and technologies for monitoring macro-scale long-term changes to urban environments.

INTRODUCTION

Urban growth takes places either in a radial direction around a city core or linearly along the highways. The latter is dispersed urban development and is often referred to as sprawl. Urban sprawl has increased in the U.S. over the last few decades and has unintentional consequences, including city center decline, increased reliance on the use of the private car, and the loss of open space. A growing trend of smart growth in the suburbs hails ideas for a new type of urbanism for fighting sprawl such as mixed-use zoning, pedestrian-friendly streets, efficient transit, and town center redevelopments. The term smart growth can also be defined as a way for more compact urban development, combined with heavy investments in mass transit as an alternative to driving that is often held up as the antithesis of sprawling development. The question is how we decide whether a tract of development is in fact sprawl and not compact development (Hasse, 2004). Recent literature tends to support the notion of sprawl, coupled with a series of measurable indicators such as density gradients and sprawl indices which have been used in previous studies (Peiser 1989; Ewing 1994; Batty and Longley 1997; Alberti and Botsford, 2000; Torrens and Alberti, 2000; Sudhira, 2004; and Jager, 2008). Moreover, the strive for standardization in the means for quantifying the characteristics of urban sprawl and compact development facilitates more consistent comparisons. Our study explores a set of quantitative variables to characterize urban forms at the metropolitan level and, in particular, to distinguish compactness from sprawl using GIS and remote sensing methodologies.

BACKGROUND**1. Urban Pattern Analysis**

Abstracting urban change across cities and scales has a long tradition in the field of geography. Historically, geographers have examined how and why areas or spaces are the same or different. And urban geographers have sought to understand and to identify regular patterns of urban development based on demographic or socio-economic or political trends. These originally were expressed in the concentric zone theory by Ernest Burgess (1925), the sector theory by Hoyt (1939), the multiple nuclei theory describe by Harris and Ullman (1945), in addition to von Thuen's bid-rent theory (1826). Geographers now test hypotheses derived loosely from the legacy of those models, analyzing census tract data with multivariate statistical methods (Johnston, Gregory, Pratt and Watts, 2000). Recent studies have conducted detailed spatio-temporal analysis on dynamic urban growth (Batty, 2002; Clarke et al, 2002; Herold et al, 2001; White et al, 2001) with the concept of urban growth that characterize inconstant urban growth over time and a-uniform spatial configuration of these areas.

The advent of high spatial resolution satellite imagery and more advanced image processing and GIS technologies, has resulted in a switch to more routine and consistent monitoring and modeling of urban growth patterns. Recently, landscape metrics have been used for urban applications in conjunction with remote sensed imagery. Significant progress has been made in quantifying spatio-temporal urban patterns using spatial metrics (Torrens et al., 2000; Herold et al, 2001; Hasse, 2003). Landscape metrics are excellent vehicles for representing fractal measures in urban geography, and can be traced back to original work of the mathematician B. Mandelbrot (1977). Fractal geometry is different from Euclidean geometry

which proposes only the integer dimensions of 0, 1, 2, 3 etc. Fractals are useful for describing spatial forms which are not regular in the sense of Euclidean geometry but are characterized by alternate patterns of continuity and fragmentation (Tannier, 2005). Urban geographers have applied this concept to similar structures at different scales of analysis in urban settings. In our research, fractal dimensions are used to analyze the changes in spatial configuration in Greater Orlando between 1974, 1985, 1993 and 2003. One of the hot topics in urban application is how to measure sprawling development by means of geo-spatial techniques.

2. Characterizing and Measuring Urban Sprawl

The literature characterizing sprawl is extensive including “the scattering of urban settlements” (Harvey and Clark, 1971). Altshuler and Gomez-Ibanez (1993) describes sprawl as “continuous low density residential development on the metropolitan fringe, ribbon low density development along major suburban highways, and development that leapfrogs past undeveloped land to leave a patchwork of developed and undeveloped tracts.” The term sprawl refers to a range from low-density urban development all the way to discontinuous and dispersed or even decentralized forms of urban expansion. At this point, it is important to review the most widely debated concerns and efforts to characterize sprawl as an urban form.

First, many definitions describe sprawl as a development pattern that consumes more open space and produces more impervious area causing a less environmentally sustainable form compared to a compact development. A growing trend of smart growth suburb depicts new urbanism ideas for handling sprawl such as mixed-use zoning, pedestrian-friendly streets, transit, and town centers. The concern here is how to decide whether a tract of development is actually sprawl compared to compact development. Secondly, sprawl represents a stage in the development process. The EPA (2001) report notes, “at a metropolitan scale, sprawl may be said to occur when the rate at which land is converted to non-agricultural uses exceeds the rate of population growth.” Therefore, sprawl should be considered in a space-time context, and not as a simple increase of urban lands (EPA, 2001). This suggests that sprawl should be measured on a development pattern continuum over time. Thirdly, many characteristics associated with sprawl relate to density either using population or housing data. Some studies (Barnes, 2001; Galster et al, 2001 and Harvey et al, 1971) suggested the expanded dimensions of sprawl such as continuity, concentration, clustering, centrality, nuclearity, mixed use and proximity. Finally, urban sprawl causes the loss of informal open space and wildlife habitats. Some of the fastest rates of loss have been occurring at the interface of urban core and rural areas at the metropolitan region. Hasse (2003) blamed the loss of farmland and forest to urban development and high degrees of sprawl.

APPROACH AND METHODS

1. Study area

The study was conducted in Greater Orlando, USA, covering four counties (Lake County, Orange County, Osceola County and Seminole County). According to the new book "Urban Growth in American Cities," (USGS, 2004) the Orlando metropolitan region ranked in one of the top three regions for additional urban land cover areas between 1973 and 1992; a percentage increase of 157%. Furthermore, two studies released by 1000 Friends of Florida (2005) showed that “the central Florida region will experience explosive growth, with continuous urban development across Orange County (where Orlando city is located) and leading to the fragmentation of the natural systems and wildlife corridors.”

The Orlando Metropolitan Region is now the third most populated in the state of Florida. It has a population of 2,032,496 according to the U.S. Census Bureau based on 2007 population estimates. The size of the city of Orlando is very unusual for a metropolitan area because most of the inhabitants live in the suburbs and surrounding areas in the Orange and Seminole counties; whereas the total population of the city proper is only 220,186 people (2006 estimates). Orlando is only rivaled by the Twin Cities in the number of natural lakes in its metropolitan area and is home to more than 100 lakes. We consider the Orlando Metropolitan Region a good model and a reasonable representative of other fast-growing metropolitan regions in the US.

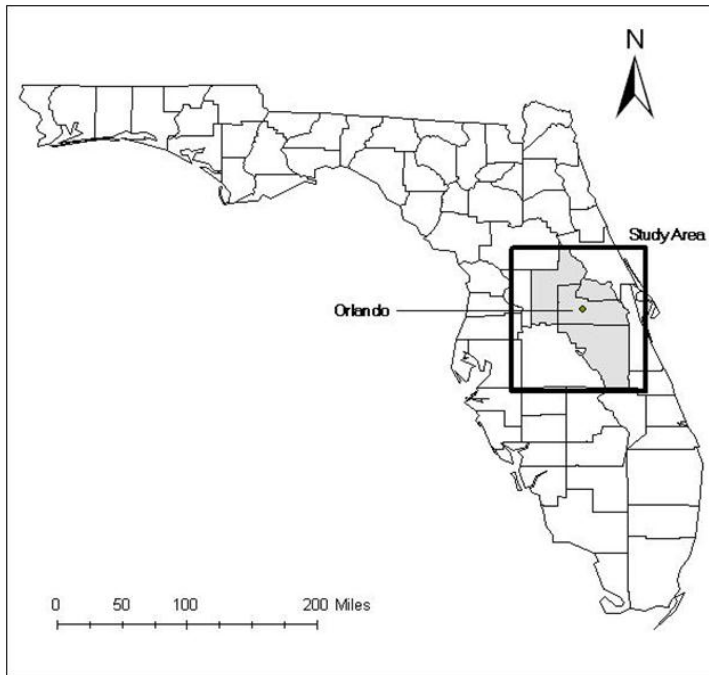


Figure 1: Map of the Orlando Metropolitan Region

2. Developing a Measurable Definition of Compactness and Sprawl

Despite a lack of rigorously defined idea of sprawl, the term is often defined by four land use characteristics: low density; scattered development (i.e. decentralized pattern); commercial strip development; and leapfrog development (Tsai et al, 2009). The last three characteristics are related to the spatial arrangement of the urban area. These phenomena often occur at a metropolitan area. In contrast to sprawl, compactness can be defined as more energy efficient and less polluting. Advocates claim that a compact development is more sustainable for economic, environmental and social dimensions. Ewing (1997) defined compactness as some concentration of employment and housing as well as a mixture of land uses. Galster et al (2001) defined compactness as the certain degree of clustered developments and measured it by the amount of land developed in each square mile. Tsai (2009) described compactness as often involving the concentration of development as apposed to sprawling development. There are similarity and differences of sprawl and compactness in terms of measurement of urban development at a metropolitan level. Hanson et al (2001) employ metrics to describe land development along six geographical dimensions: density; continuity; concentration; centrality; nuclearity; and diversity. Tsai (2009) used a set of four dimensions of metropolitan form - metropolitan size, density, degree of equal distribution and degree of clustering and utilized Moran, Geary, Gini, and Entropy indicators to measure those four dimensions for both population and employment distribution. With these issues in mind, six dimensions of sprawl indicators were selected.

| Dimension | Indicator |
|---------------------|---|
| Size | The spatial extent of urban area |
| Density | The amount of newly developed land per capita |
| Continuity | The size and the distance of newly developed lands from the main developed |
| Scattering | The Euclidean nearest neighbor (ENN) distance |
| Shape | Perimeter-area fractal dimension (PAFRAC) |
| Loss of green space | The amount of wetland and forest areas lost to urban development per capita |

Table 1: Sprawl indicators used for the analysis

Size: the urban land area which has often been used as a simple index of sprawl. The idea of using the urban land size for sprawl causes more land consumption than compact development. Because sprawl is characterized by an increase in the built-up area along the urban and rural fringe, this attribute gives considerable information for understanding the behavior of such sprawl. Larger urban size values indicate a greater degree of sprawl.

Density: this can be measured by the population per unit of developed land. There are numerous density-based measurements that use population and employment data. Hasse (2004) suggested that density of new urbanization should be used as a measure of land consumption for new urban growth, Schneider et al (2009) used density of built-up land by measuring ratio of amount of urban land to all land by percentage. This index provided information on whether new land development is low or high density. Higher ratio of low-density development to total development indicates sprawl whereas lower ratios indicate more compact or smarter growth patterns. In our study, the density indicator provides a measure of land consumption for new urban growth per capita. Population increment was calculated by comparing the difference between years from the following, 1974, 1985, 1993 and 2003. The amount of new urban growth in 1985, 1993 and 2003 was extracted from FWC land use and land cover maps and was then generated by intersecting urban areas in the earlier year. The new urban density indicator was calculated by normalizing the amount of new growth by the concurrent increase in population. Larger per capita new growth density values indicate a greater degree of sprawl.

Continuity: The index of continuity is a measure of the size or the distance of newly developed areas from the main developed part of a metropolitan area (Tsai, 2005). Typically a more sprawled landscape experiences decreasing continuity of built-up land. We adopted and used the definition and the model from the Urban Landscape Analysis Tool (ULAT) developed by Parent et al (2009). New development is any built-up land added between two time periods (T1 and T2). The classification of new development in T2 is based on location relative to the urban footprint in T1 (Figure 2). The urban footprint in T1 is defined as impervious surfaces and any open space likely to impact the city. The classification of new development is divided into infilling, edge-expansion or spontaneous growth. Infilling development is defined as "newly developed pixels that are in the urbanized area of the previous time period." Extension development is defined as "newly developed pixels that are in the fringe area of the previous time period." And leapfrog development is defined as "newly developed pixels that are outside of the rural area of the previous time period." Any built-up areas in T2 where there is no contiguity with the previous developed areas (T1) are considered to be leapfrog development areas. Smaller infilling percentage values indicate a greater degree of sprawl.

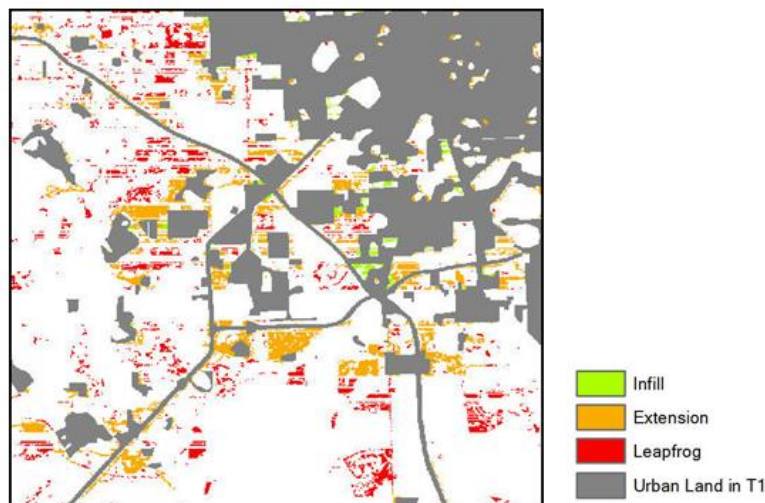


Figure 2: New urban growth type (Continuity Measure)

Scattering: this is a measure for characterizing how developed land parcels are isolated from each other. Concentration is the extent to which development is confined to a relatively small portion of a jurisdiction's total land area. A wide variety of techniques are employed in measuring concentration including, Shannon's entropy (Yeh and Li, 2001) and the global Moran's I coefficient (Tsai, 2004). Some techniques are based on distance measures. Examples include the Euclidean nearest neighbor (ENN) distance, proximity (PLADJ) and Clumpy. These are landscape fragmentation measures available by open source GIS software, such as FRAGSTATS. For this study, we used mean Euclidean nearest-neighbor

distance (ENN_MN) to measure the degree of scattering. Euclidean nearest neighbor distance (ENN) has been used extensively to quantify patch isolation and is defined as the shortest straight-line distance between urban patches (McGarigal et al, 2002). Larger ENN values indicate a greater degree of sprawl.

Shape/Fractal dimension: shape complexity is another important attribute of sprawl. Since we are interested in compactness, shape indicators can be used to describe compact shapes with low values. Fragstats (McGarigal and Marks, 1995) provides diverse measures based on perimeter-area relationships. The simplest shape index is a straightforward perimeter-area ratio (PARA). This shape index (SHAPE) measures the complexity of patch shape compared to a standard shape (square or almost square) of the same size, and therefore alleviates the size dependency problem of PARA. Another other basic type of shape index based on perimeter-area relationships is the fractal dimension index. Perimeter-area fractal dimension (PAFRAC) is appealing because it reflects shape complexity across a range of spatial scales (patch sizes). Larger PAFRAC values indicate a greater degree of sprawl. For example, small and large patches alike have simple geometric shapes, then PAFRAC will be relatively low, indicating that patch perimeter increases relatively slowly as patch area increases.

Loss of open space under urban development: loss of open space is a measure of a decrease in important land resources such as wetlands and critical wildlife habitats; both lost to urban growth. Sprawling development consumes open space across the landscape. The indicator was developed by first creating maps of wetland and forest from FWC land use and land cover maps in 1974, 1985 and 1993. The wetland and forest maps then intersected with the new urban growth maps in 1985, 1993 and 2003 extracted from FWC land use and land cover maps. The open space loss indicator was generated by tabulating area of all open land (wetland and forest) categories in the earlier year that became urbanized by the later year for the metropolitan level. The per capita open space loss indicator was generated by normalizing the amount of open space loss by the concurrent increase in population. Larger per capita open space loss values indicate a greater degree of sprawl.

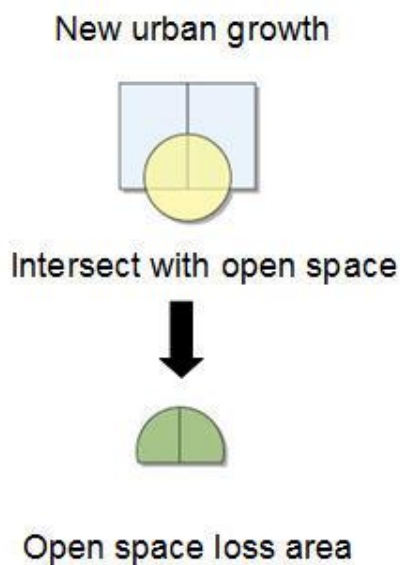


Figure 3: The conceptual measure of open space loss indicator

3. Application of Sprawl indicators to the Orlando metropolitan region

Six sprawl indicators are applied to the land use and land cover maps for the Greater Orlando Metropolitan Region described in the previous section. The original land use and land cover maps in 1974, 1985, 1993 and 2003 were classified using multi-time series Landsat TM and ETM imagery by different research agencies in Florida (FWC and FGDL). The original classification of land-use of more than 20 categories was aggregated to urban, agriculture, forest, water bodies and wetland based on the Florida Land Use, Land Cover Classification System (FLUCCS) and regrouped into urban and non-urban for landscape metrics calculation (table 2).

Table 2: Initial input values from the 2003 FWC Land Use and Land Cover Data and their reclassification into seven land use classes

| FWC class value | FWC land use classification | Reclassified land use class |
|-----------------|----------------------------------|-----------------------------|
| 3 | Xeric Oak Scrub | Shrub land |
| 4 | Sand Pine Scrub | |
| 5 | Sandhill | Forest |
| 6 | Dry Prairie | Grassland |
| 7 | Mixed Pine-Hardwood Forest | Forest |
| 8 | Hardwood Hammocks and Forest | |
| 9 | Pinelands | |
| 12 | Freshwater Marsh and Wet Prairie | Wetland |
| 15 | Shrub Swamp | |
| 16 | Bay Swamp | |
| 17 | Cypress Swamp | |
| 18 | Cypress/pine/Cabbage palm | Forest |
| 19 | Mixed Wetland Forest | Wetland |
| 20 | Hardwood Swamp | |
| 27 | Open Water | Water |
| 28 | Shrub and Brush land | Shrub land |
| 29 | Grassland | Grassland |
| 30 | Bare Soil/ Clearcut | Bare land |
| 31 | Improved Pasture | Agriculture |
| 32 | Unimproved Pasture | |
| 34 | Citrus | |
| 35 | Row/Field Crops | |
| 36 | Other Agriculture | |
| 41 | High Impact Urban | Urban |
| 42 | Low Impact Urban | |
| 43 | Extractive | Bare land |

The landscape metrics were generated using functions in FRAGSTATS. A detailed description on landscape metrics can be found in McGarigal et al. (2002). Measuring and mapping urban size and loss of open space were performed in ArcGIS v. 9.3 (ESRI, Inc.). Maps of new urban growth (figure 4) were used to calculate urban size, new urban density and open space loss per capita.

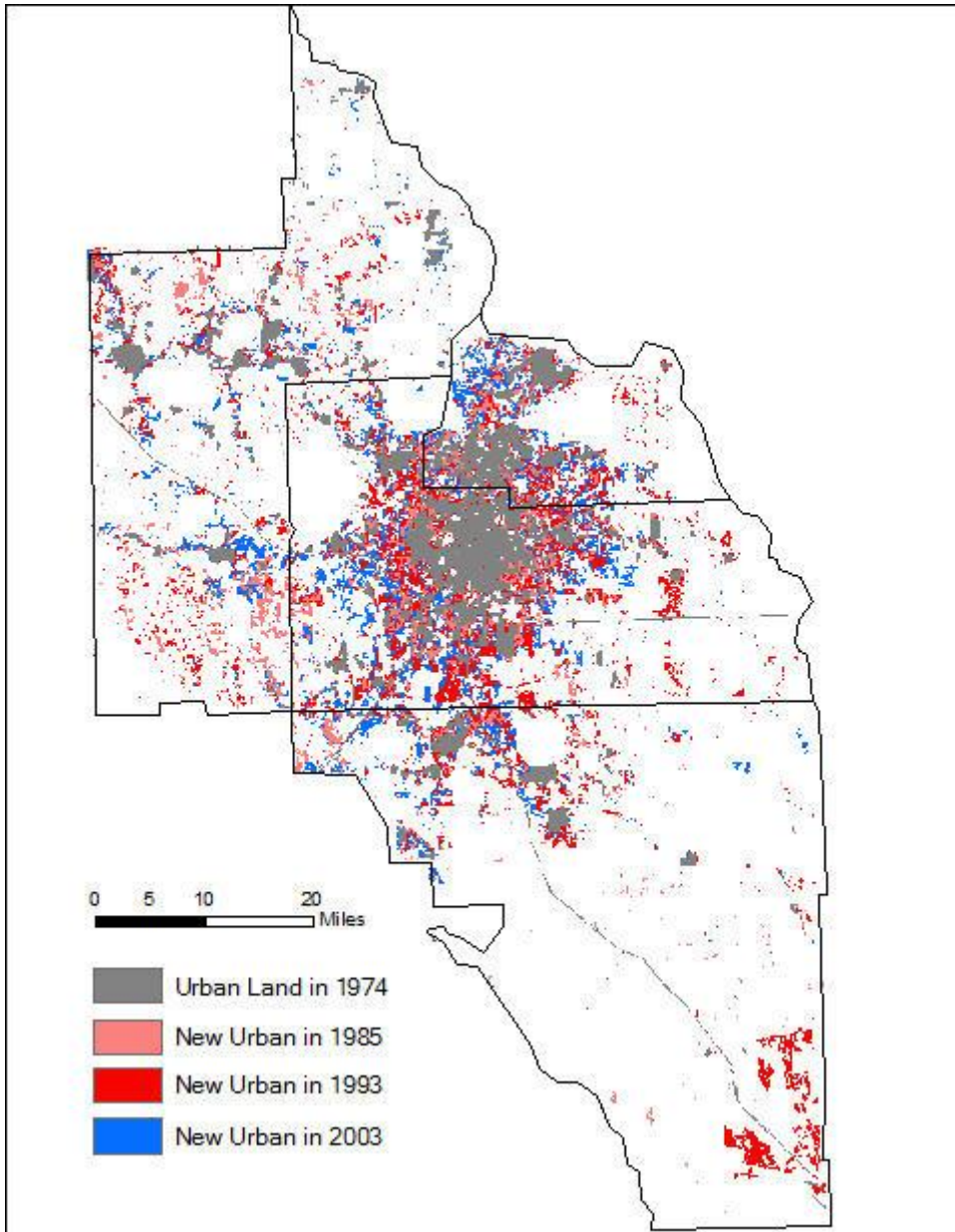


Figure 4: Urban growth changes in Orlando in 1974, 1985, 1993 and 2003

RESULTS

The six sprawl indicators were calculated for each of the years across all three decades. Table 3a and Table 3b summarize the results. They show an overall reduction in the level of sprawling for Greater Orlando. This suggests that the Orlando metropolitan area expanded rapidly to fill its available space successively and indicates an overall regional compact development in its spatial structure. Urban size in the past 30 years has constantly increased especially between 1985 and 1993. Shape complexity has increased over time except between 1985 and 1993. In Table 3-3a the scattering measures indicate that Greater Orlando area had experienced less scattering development over time since 1974. The highest scattering level is found for the year 1974 when the landscape was the most heterogeneous. The time period represents the initial phase of diffuse allocation of new development units which are separated by large distances. With further expansion of the urban core, it shows that scattering indicators decrease as the landscape becomes more homogeneous.

Table 3a: Urban Sprawl Measure for Greater Orlando

| Dimension | 1974 | 1985 | 1993 | 2003 |
|------------------|----------|----------|-----------|-----------|
| Size | 77550.48 | 92122.92 | 151241.76 | 156903.12 |
| Shape | 1.31 | 1.51 | 1.48 | 1.56 |
| Scattering (ENN) | 972.83 | 188.58 | 204.23 | 175.17 |

Table 3-3b: Urban Sprawl Measure for Greater Orlando

| Dimension | 1974-1985 | 1985-1993 | 1993-2003 |
|-------------------------------|-----------|-------------|------------|
| New Growth Density | 1.36 | 5.68 | 0.56 |
| Infill | 1037.97 | 6430.77 | 7601.4 |
| Extension | 9039.06 | 44589.78 | 28741.14 |
| Leapfrog | 28686.51 | 11997.45 | 6633.27 |
| Loss of Open Space Per Capita | 0.0393385 | 0.206698305 | 0.10808683 |

Leapfrog development during the period between 1974 and 2003 had decreased while infilling development had increased. With the major spread of the extension type new growth in the period 1985 and 1993, new growth density has however, peaked during the time between 1985 and 1993 as well as the loss of open space per capita. This development results in larger amounts of natural areas.

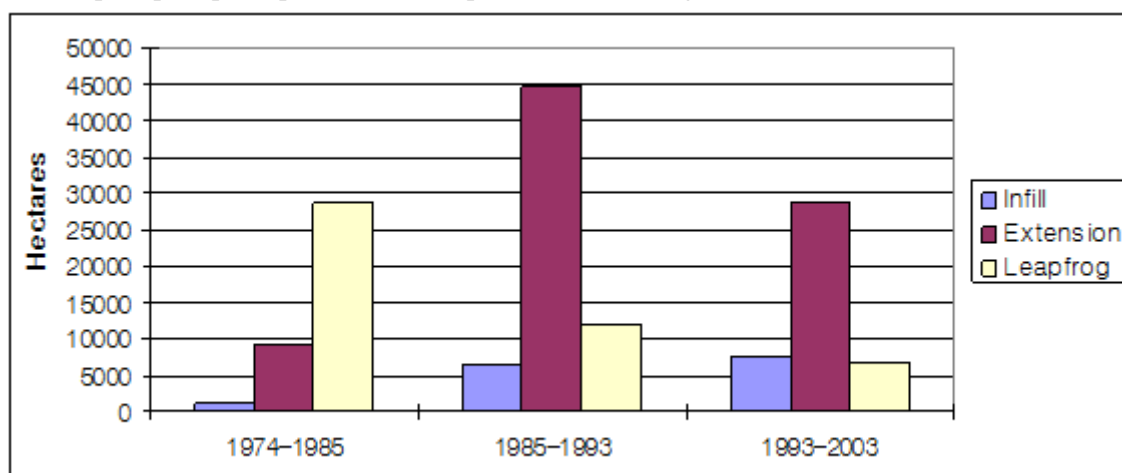


Figure 4: Continuity Measure (New growth type) for Greater Orlando

Table 3a and 3b shows the performance of urban development for each year in Greater Orlando. The time between 1993 and 2003 reported the lowest scattering levels and new density; and the highest value in the infilling development, suggesting that it is the least sprawling (that is smartest growing of the three time periods in Orlando). The time between 1985 and 1993 revealed the highest new growth density, the extension growth and the loss of open space per capita, suggesting the relatively high sprawling development pattern even with the decreasing shape complexity. Between 1974 and 1985 the scattering and leapfrog development measures were at their highest, suggesting the most dispersed and fragmented urban patterns. However the period also represented the least amount of the loss of open space per capita. Land consumption per capita was not high as the other time periods if standardized with the population increase.

DISCUSSION AND CONCLUSION

Understanding the forms of urban sprawl is important. Urban development is realized on the ground over time beyond form. Unlike compact development, sprawl represents a stage in the development process where development activities encroach onto open space causing discontinuous patterns in a regional context compared to compact development. The study explored a set of quantitative variables used to characterize urban form by distinguishing compactness from sprawl using a GIS and remote sensing framework. Six dimensions of sprawl (size, density, continuity, scattering, shape and loss of green space) were selected and evaluated for the Orlando Metropolitan Region. These indicators provided insight into

urban dynamics, a deeper understanding of the patterns and processes associated with urban growth. The results from the study show that spatial characteristics of sprawl can be objectively analyzed and meaningfully quantified. Size, shape, scattering and leapfrog development measures indicate that Orlando experienced the extreme sprawling development between 1974 and 1985. However, “the extension category type” of new growth and the loss of open space per capital showed the peak in the period 1985 and 1993 suggesting the urban pattern during this period was not only moderate sprawling but also the least sustainable of the three time periods in Orlando. Continuity and loss of green space measures provide the more detailed information in spatial and temporal pattern of the underlying ecological processes at play. These six measures hold potential for evaluating land use planning and urban management strategies across different scales and regions. Even though not a major drawback, it becomes apparent that there is the need for a standardized methodology for diagnosing sprawl across measures so that spatial characteristics of sprawl can be objectively analyzed and meaningfully quantified.

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