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Measuring and Modeling of Urban Growth and Its Impacts On Vegetation and Species Habitats in Greater Orlando, Florida

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Abstract

Urban growth is widely regarded as an important driver of environmental and social problems. It causes the loss of informal open space and 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. In this study, five distinct scenarios ("no constraints", "compact development", "transit-oriented development", "agriculture protection" and "environmental protection" scenarios) were tested on Greater Orlando, Florida, along with conservation objectives and projections for future land use/cover from development demands. The study examined the consequences of alternative scenarios of urban growth on potential habitat loss for a suite of species and vegetation habitats. As a result, the maximum impact is projected in "no constraints" scenario while minimum impact occurred in Scenario 5 ("environmental protection") across almost all vegetation and species habitats. The results indicated that the big challenge is how to manage compact growth to protect ecosystems. Florida has one of the biggest land acquisition programs in the US and a tradition in implementing sustainable development through growth management. The big challenge is how to allocate the fast-growing new population in the future along with these sustainable development objectives.

Keywords

Urban Growth, Species Habitats, Vegetation, Multi-Criteria Evaluation, Florida, Sustainable Development

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1. INTRODUCTION

Sustainable development is generally considered to be at the intersection of environmental services and biological diversity. From the ecological perspective, sustainable development would be one in which environmentally positive local land use plans conserve habitats of rare or endangered species through maintaining a connected critical mass of natural areas to support plant and animal populations. Timely and accurate assessments of future urban growth scenarios and associated ecological impacts are crucial for sustainable development in urban planning, policy decision, and natural resource management. Our study explores the consequences of alternative scenarios of urban growth change on potential habitats loss for a suite of species and vegetation in Greater Orlando, Florida, USA. The framework of impact analysis is presented in Figure 1. The study has two-fold objectives. The first objective is to describe multiple urban growth scenarios and investigate their relative significance in predicting changes in the environment. The second objective is to investigate the impacts of these changes on the vegetation and species habitats.
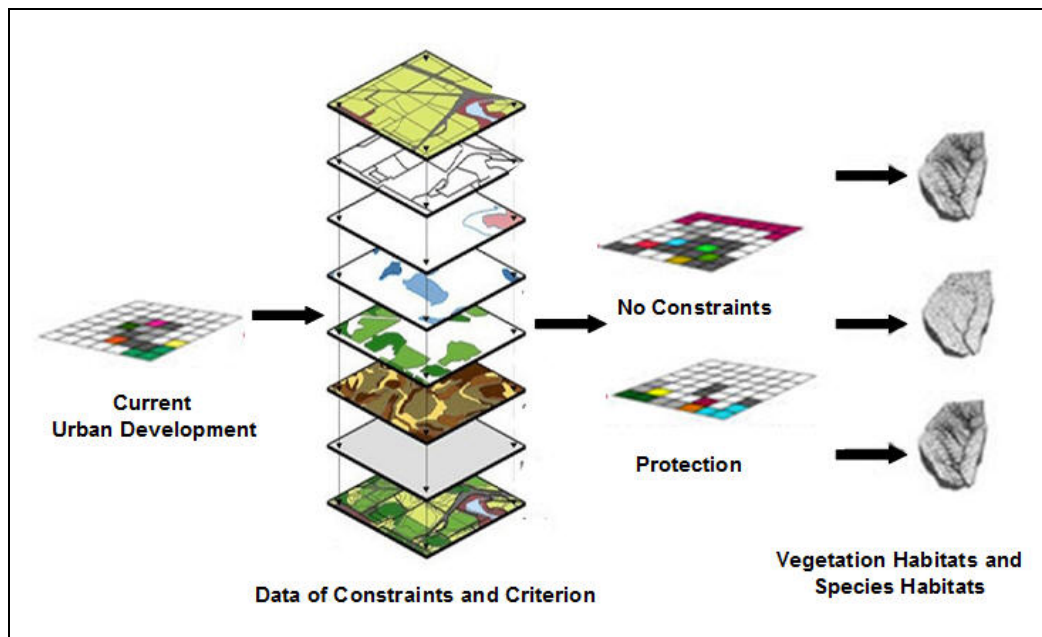

Figure 1. The framework of Impact Analysis

The state of Florida represents a transitional area between the tropical Caribbean and temperate North America, with examples of fauna and flora from both climates. Although fourth in the nation in human population, Florida still has many large forested tracts that support several wide-ranging vertebrates. Currently it has 127 vertebrate, 21 Invertebrate, and 256 plant species listed as endangered, threatened, or species of special concern according to Florida Natural Area Inventory (hereafter, FNAI) database (2010). Endangered species are in danger of becoming extinct throughout all or the majority of its

range while a "threatened" species is one that is likely to become endangered in the near future.

There is a need for new tools to applying sustainable approaches on future planning and management of sustainable development. Predicting future environmental outcomes (i.e., ecological impacts) requires being able to predict the spatial pattern of urban growth. Recently, spatially explicit simulation and time series models of urban growth have been used as a planning tool, including UrbanSim (Waddell 2002), a Markov chain model (Stewart 1994), LUCAS (Berry et al. 1996), CLUE (Verburg et al. 1999), the CA model (Dietzel et al. 2005; Clarke et al. 1998; Batty et al. 1994), and an agent-based model (Ligmann-Zielinska et al. 2010; Parker et al. 2003). In Florida, scenario tools (i.e., Box City, CommunityViz, INDEX, LUCIS and Smart Growth INDEX) are being used to understand alternative methods for new forms of developments and to understand how issues relating to urban land use and the environment are interrelated in planning processes. Some of these models have attempted to determine the environmental consequences of future urbanization by smart growth and sustainable development (Cogan 1997; Gude et al. 2007; Lee et al. 1999; Seto et al. 2012; Syphard et al 2011). However, those models did not address ecosystems and their relationships with human habitats, explicitly, and since natural resource management is one of the goals of growth management policies, landscape ecological perspective should be intrinsic for planning and policy making. In our study, we suggest and use a scenario approach to explore the future development and its consequences on ecosystems in Greater Orlando.

Given the regional scale of Greater Orlando and the relative ease of computation and implementation, we adopt the multi-criteria evaluation (hereafter, MCE) model which is applied to a set of discrete actions. Multiple criteria overlay was proposed by McHarg in 1969 and the main objective is "to assist the decision-maker in selecting the 'best' alternative from the number of feasible choice alternatives under the presence of multiple [decision] criteria and diverse criterion priorities". MCE has been applied successfully for decision making within GIS frameworks when combining the information from several criteria to form a single composite index of evaluation (Chen et al. 2010; Malczewski, 2006; Perpina et al. 2013; Phua et al. 2005; Store et al. 2001; Yu et al. 2011). Cartographic modeling and suitability mapping of land using MCE techniques have been broadly studied (Effat and Hegazy 2009), including one additive approach in a GIS environment where criterion scores are standardized and the total score for each alternative is calculated by multiplying each criterion score by its weight factor and then adding the results.

2. METHODS

2.1 STUDY REGION

The study was conducted in the Greater Orlando area, that includes four counties; Lake, Orange, Osceola and Seminole (Figure 2). The area is ranked as one of the top three regions for urban growth between 1973 and 1992 with a percentage change of 157% (Auch et al. 2004). 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.

Greater Orlando has a population of 2,134,411 according to the U.S. Census Bureau 2010 population. The size of the city of Orlando is very unusual for a metropolitan area of its size since most of the inhabitants of the area live in the suburbs and surrounding areas in the Orange and Seminole counties, whereas the total population of the city proper is only 238,300 people (2010 census). Orlando is only rivaled by the Twin Cities in the number of natural lakes in its metropolitan area. The Orlando area is home to more than 100 lakes, the largest of which are Lake Apopka, Eustis, Griffin, Harney, Harris, Jessup, Monroe, Saint Cloud, and Tohopakaliga. We consider Greater Orlando a good model and a reasonable representative of other fast-growing metropolitan regions in the US.
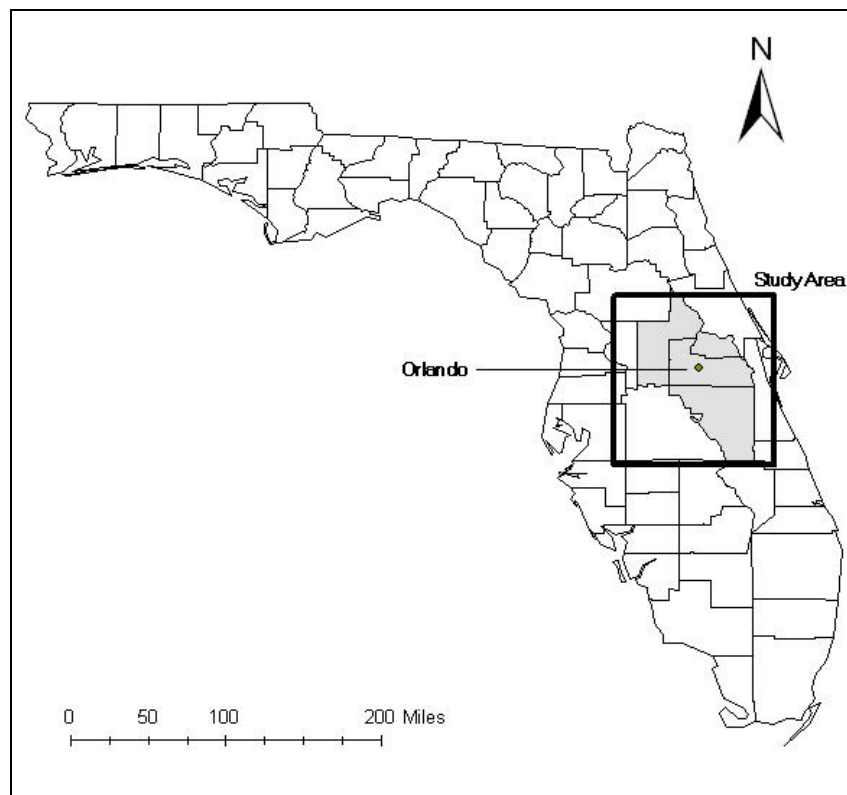

Figure 2. Map of Greater Orlando

2.2 SCENARIO DEVELOPMENT

We consulted with planners of the East Central Regional Planning Council (ECRPC) who identified visions for future growth in central Florida, and provided the regional growth vision statement for Greater Orlando:
- Conservation: protection of natural resource areas

- Countryside: preservation of agriculture and small villages
- Centers: development focused in close proximity to residential areas

Having this statement, we tested five distinct scenarios: no constraints, compact development, transit-oriented development, and agriculture protection and protection scenario (Table 1). These five scenarios are applied with appropriate factors and constraints. We determined the lands preferred for urban development in Greater Orlando along with conservation objectives and projecting future land use/cover with development demand.

Table 1. Future Policy Scenarios

Scenario Number	Scenario Name	Scenario Description
1	No Constraints	Urban development can occur just about anywhere in Orlando area and is permitted on all types of farmlands
2	Compact Development	Prohibits development outside the Sphere of Influence
3	Transit-oriented Development	Prohibits development outside the Sphere of Influence and encourage developments closer to transits
4	Agriculture Protection	Prohibits development outside the Sphere of Influence and on agriculture lands
5	Protection	Prohibits development outside the Sphere of Influence and on publicly owned and conserved lands

No constraints scenario simulates the random urbanization assuming new urban growth can take place anywhere in Greater Orlando, and it is not dependent on proximity to the existing urban core, proposed transit routes, agriculture lands and conserved lands. The overall high suitable non-urban areas will become urbanized randomly.

Compact development scenario simulates the random urbanization inside the "sphere of influence" (the urban growth boundary in the model). This scenario has one added constraint which prohibits development outside the sphere of influence.

Transit-oriented development scenario models the random urbanization inside the sphere of influence, where it is growth determined by transport. Areas with proximity of transits will experience high urbanization probability.

Agriculture protection scenario simulates the random urbanization inside the sphere of influence and outside agricultural lands. This scenario preserves countrysides as envisioned by the ECRPC.

Protection scenario models the random urbanization inside the sphere of influence and outside conserved lands. This scenario preserves public owned and protected lands.

It was assumed the existing gross urban density of developed lands in Greater Orlando will remain the same as in 2003. Gross urban density was calculated by taking 2003 population and dividing it by 2003 existing urban lands resulting in an expression of people per urban acre for Greater Orlando. The total acres required to accommodate the Greater Orlando's additional population was determined based on the calculated 2003 gross urban density. The Bureau of Economic and Business Research (BEBR) population

projection from 2003 to 2050 was used as the basis for determining a trend line extending to 2050.

The urban land use rate in this study represents the amount of land used for each person; and the amount of additional land converted to urban use for each projected year represents the urban land use rate multiplied by additional population.

Urban land use rate = Urban land / the base population

In Greater Orlando, the rate is 86 square meters per person. BEBR moderate population projection in 2003 was used as the basis for determining a trend line for the year of 2050. Additional population for 2050 is 2,480,345 and the demand land is 213,309,670 square meters.

2.3 DATA AND CRITERIA FOR URBAN GROWTH MODELING

We used the MCE modeling method to simulate and project urban growth in Greater Orlando. MCE operation was used with raster system in our study. MCE is most commonly achieved by three procedures (Eastman 1999). The first involves Boolean overlay whereby all criteria reduced to logical statements of suitability. Boolean variables are here used as constraints, since they serve to delineate areas that are not suitable for consideration. The second involves quantitative criteria evaluation where continuous criteria are standardized to a common numeric range. These numerical values express varying degrees of suitability for the decision (i.e. urban growth). Such criteria are typically called factors. The third step is known as weighted linear combination wherein continuous criteria (factors) are combined. Each factor is multiplied by a weight. In addition, the result may be multiplied by the product of any Boolean constraints. In the present study, the sphere of influence and flood hazard zone are used as Boolean constraints as well as factors.

Criteria as direct influence on the urban growth were identified and selected through an extensive bibliography (Batty et al. 1994; Berry et al. 1996; Clarke et al. 1998; Cogan 1997; Dietzel et al. 2005; de Koning et al. 1999; Gude et al 2007; Landis et al. 1998; Landis et al 2000; Lee et al 1999; Klosterman 1999; Pijanowski et al, 2000; Seto et al. 2012; Stewart 1994; Syphard et al. 2011; US EPA 2000; Verburg et al. 1999; Waddell 2002; Yang et al. 2003) and expert opinion. As can be expected, many different criteria can be taken into account in urban growth and those finally selected were in accordance with the required objectives, information available and planners' experience. Expert's opinion was consulted and the current standards were complied with planners from East Central Regional Planning Council and City of Orlando. The flood hazard zone, distance to existing urban, distance to major roads and distance to sewage treatment facilities are selected as major factors for future growth (Table 2).

Water bodies, wetland and public lands are considered as irreplaceable assets and constraints for all the scenarios. The sphere of influence is selected for controlling the growth inside urban growth boundary and used for Scenarios 2, 3, 4 and 5. Critical lands and waters are subject to protection and conservation measure and selected for Scenario 5 (Table 3).

Table 2. Factors considered in siting new urban growth for Greater Orland in 2050

Criteria	Description	Use
The sphere of influence	Based on urban footprint areas which are impervious surfaces and any open space with urbanness values over 10%. Urbanness was calculated as percent of neighborhood that is built-up within a 1 square km circle. Urban lands from FNAI	Scenario 2, 3, 4 and 5
Flood hazard zone	Identification of 100-year flood plain. Flood hazard zone from the Federal Emergency Management Agency (FEMA)	All scenarios
Distance to existing urban	Determination their proximity to existing urban core. Urban lands from FNAI	All scenarios
Distance to major roads	Determination their proximity to major roads. Roads data from Florida Geographic Data Library (hereafter, FGDL)	All scenarios
Distance to sewage treatment facilities	Determination their proximity to sewage treatment facilities. Sewage treatment facilities data from FGDL	All scenarios

Table 3. Constraints considered in siting new urban growth for Greater Orland in 2050

Criteria	Description	Use
Water bodies	Water from FGDL. Areas inside 100 meters buffer are excluded for modeling	All scenarios
Wetland	Wetland from FNAI which is based on National Wetland Inventory Data. Areas within 100 meters buffer are excluded for modeling	All scenarios
Public lands	Florida Managed Area from FNAI. The Inventory database includes boundaries for more than 1,600 federal, state, local, and private managed areas. National parks, state forests, wildlife management areas, local and private preserves are examples of the managed areas included. Areas within 100 meters were excluded for modeling	All scenarios
Existing urban lands	Urban lands from FNAI. Urban lands are defined as areas developed with buildings and other impermeable surfaces such as parking lots and roads. Urban lands are excluded for modeling	All scenarios
Agriculture lands	Agriculture extracted from land use and land cover data, Florida Geographic Data Library. Agriculture lands are excluded for modeling	Scenario 4
Critical Lands & Waters	This data layer represents a statewide network of ecological hubs and linkages designed to maintain large landscape-scale ecological functions throughout the state. Highly critical lands and water are excluded for modeling	Scenario 5

Each criterion is assigned an established value from each class in order to determine numerical values for urban growth probability. This involves using a scale of values between 1 and 3. After obtaining the values of the set of factors, they are then weighted based on their relative importance. Table 4 presents factors and their rating scores and weights.

Table 4. Example of Criteria and Rating for Scenario 5

Layer Name	Criteria and Rating				Weight
	Least Suitable	Low Suitable	Medium Suitable	High Suitable	Assigned Weight
	0	1	2	3	
The sphere of influence	Outside (excluded for the projection)			Inside	1
Flood hazard zone		inside		outside	1
Distance to existing urban		> 1mile	.5 - 1mile	< .5 mile	2
Distance to major roads		> 1mile	.5 - 1mile	< .5 mile	2
Distance to sewage treatment facilities		> 2 mile	1 - 2 mile	< 1 mile	1

Suitability for each criterion was created and summed into one final suitability map as a weighted liner summation. In this way, we can calculate the global value of each scenario. The final suitability maps were used to calculate the probability of a grid cell being urbanized. Future urbanization probabilities were assigned for all undeveloped cells. Figure 3 presents the results of the calculation of development probabilities in each grid cell in Greater Orlando for 2050 with the range between 33.3% and 99.9%. A probability over 90% was used to consider a grid cell as likely to become urbanized. This was derived through several trial and error attempts and comparison based on population demand.

2.4 IMPACT ANALYSIS ON VEGETATION HABITATS AND FOCUSED SPECIES HABITATS

The resulting urban growth allocations by five different scenarios were compared with the vegetation habitats maps developed by Florida Fish and Wildlife Conservation Commission (hereafter, FWC 2003) and the species habitats maps produced by FNAI (2008). The overlay function in ArcGIS was used to calculate quantitative estimates of the loss of vegetative land covers and species habitats.

Three main inputs: projected urban growth, vegetation habitats and species habitats were used for measuring impacts of urban growth on vegetation habitat and species habitats. Maps of vegetation habitats in 2003 produced by FWC were used for vegetation habitat analysis (Table 1). The current habitat maps for focused species were prepared by FNAI presented in Figure 3. We chose nine native vertebrate species based their conservation values according to FNAI field guide (2010). The habitat maps for each species were created by FNAI who delineated the actual habitat area that a species element occurrence represents. The method for creating species habitat maps is to generate spatial buffers to element occurrence points within land cover polygons based on the biology of each species. Figure 4 shows the species habitats.
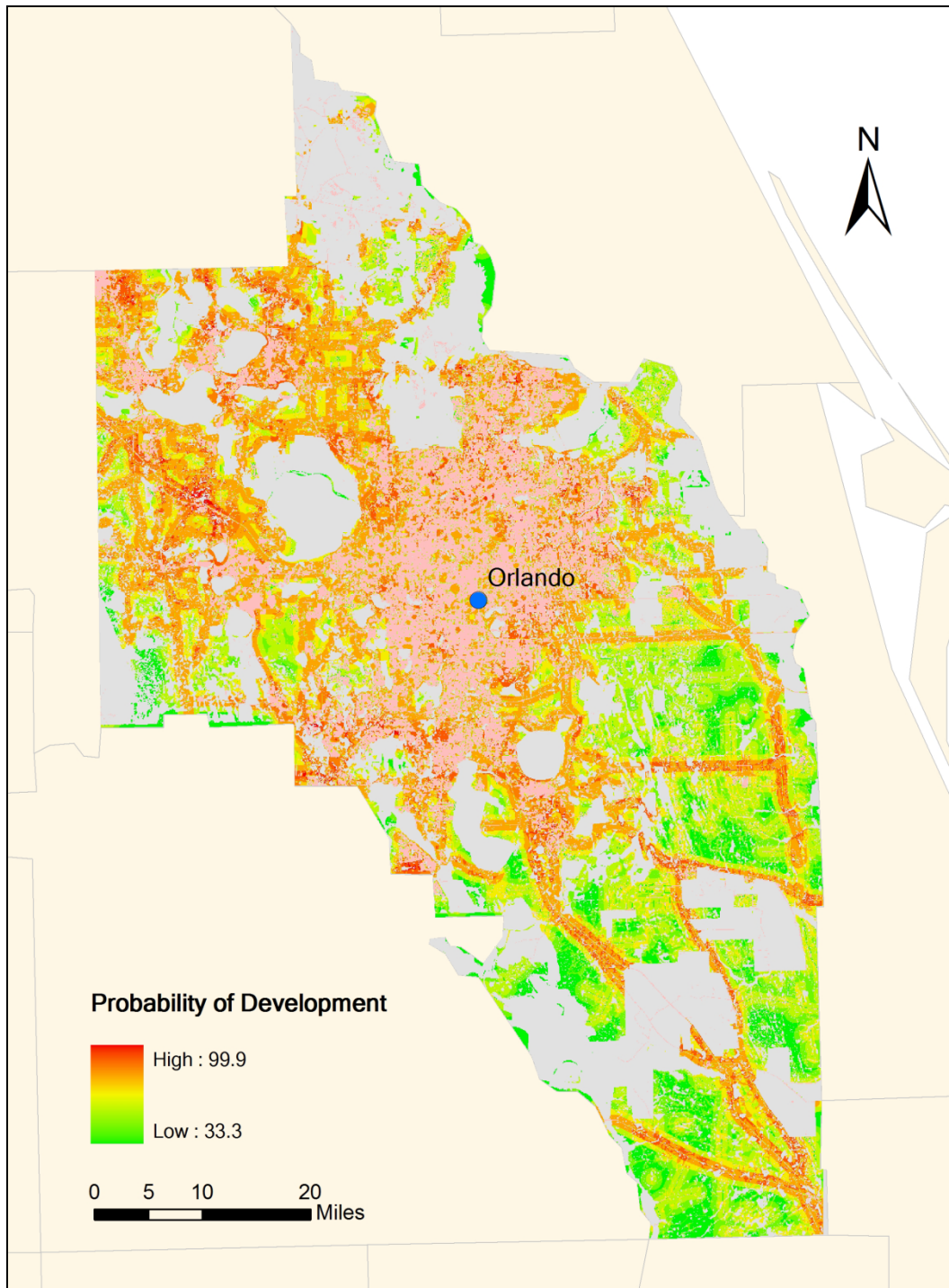
Figure 3. Probability of future development

Table 5: Area of Greater Orlando Vegetation Types
(Source: FWC 2003 vegetation maps)

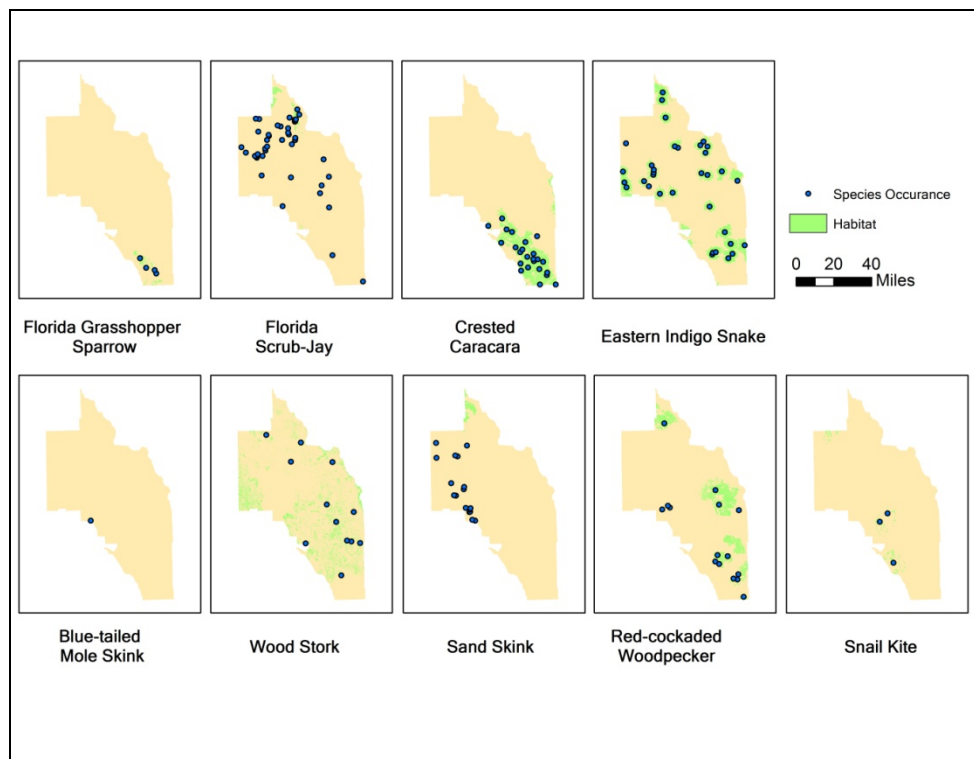| Class ID	Class-Description
1	Xeric Oak Scrub
2	Sand Pine Scrub
3	Sandhill
4	Dry Prairie
5	Mixed Pine-Hardwood Forest
6	Hardwood Hammocks and Forest
7	Pinelands
8	Freshwater Marsh and Wet Prairie
9	Shrub Swamp
10	Bay Swamp
11	Cypress Swamp
12	Cypress/Pine/Cabbage Palm
13	Mixed Wetland Forest
14	Hardwood Swamp

Figure 4. Maps of species and their habitats in Greater Orlando

3. RESULTS

3.1 RESULTS FROM URBAN GROWTH MODELING

The urban growth patterns projected with each of the scenarios are presented in Figure 5. Scenario 1 (no constraints) illustrates what may happen without the growth boundary. This scenario prohibits the development of publicly owned land and designated open space while ignoring both environmentally and agriculture constraints. The map for Scenario 1 predicts that development will occur around the existing urban lands of 2003. Scenario 2 (compact development) shows the future development patterns that are likely when development is prohibited outside existing urban growth boundaries. The comparison of the growth patterns projected with Scenario 1 indicates less "leapfrog" development. Scenario 3 (transit-oriented development) predicts future development with emphasized future transit routes and compact development. This particular scenario contained the different urban developments than the "compact growth" scenario although it has the same constraint within the urban growth boundary. The reason for this pattern is that transit routes crossed areas of state-managed lands and critical lands for conservation. Scenario 4 (Agriculture protection) and Scenario 5 (Environmental protection) combined the environmental and boundary constraints utilized in the compact development (Scenario 2) and showed the similar growth pattern of Scenario 2 and the addition of the environmentally sensitive lands constraints in Scenario 5 diminishes the opportunities for growth in natural areas far away from urban core.
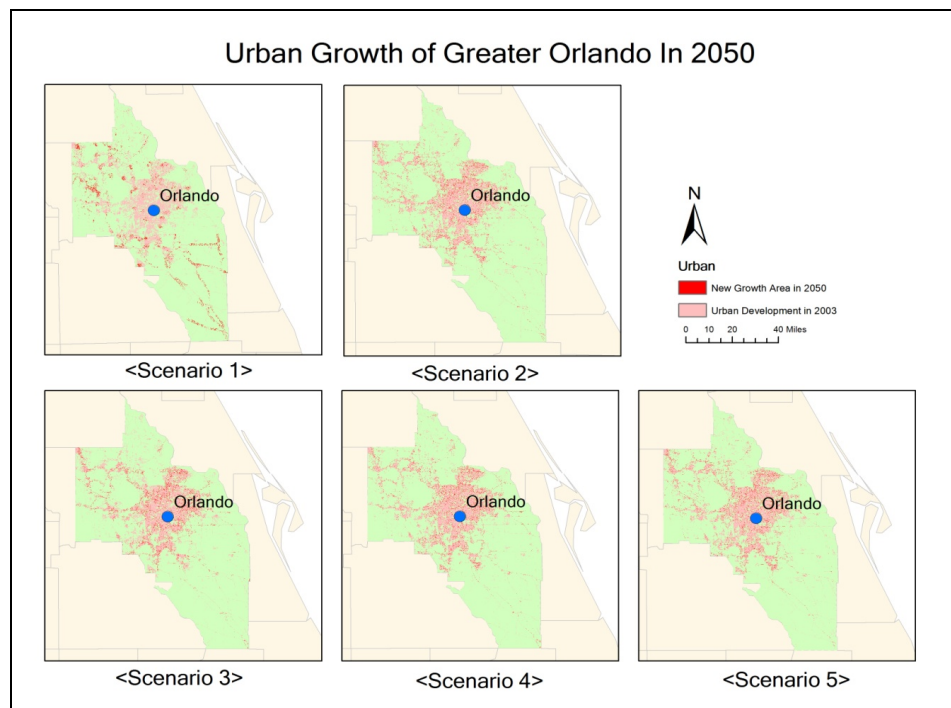

Figure 5. Results of growth scenarios

3.2 RESULTS FROM IMPACT ANALYSIS

The impact analysis on vegetation habitats in Greater Orlando was based on the land area lost to urbanization using five different growth models. They are compared and presented in Figure 6. For each of the 14 impacted vegetation habitats types, the sum of area lost is shown as a bar graph (Figure 8). Maximum impact is projected in Scenario 1 ("no constraints") resulting in over 2,000 ha of freshwater marsh and wet prairie converted to urban land cover except lands of mixed pine-hardwood forest and hardwood hammocks. Minimum impact occurred in Scenario 5 ("environmental protection") across almost all vegetation habitats. Secondly, our study demonstrates that Scenarios 2, 3, 4 and 5 show less habitat loss to urbanization than Scenario 1 in most vegetation habitats except areas of hardwood and pinelands. Hardwood and pinelands are located in the areas close to the existing urban area in 2003 which have high urbanization probability. Hardwood and pinelands do not have higher natural resource values according to the conservation objectives of Florida State.

Impact analysis on native animal species' habitats was assessed using the FNAI potential habitat maps. The habitats are compared in Figure 7. As with the habitat assessment, the maximum impact case is projected by Scenario 1 ("no constraints") resulting in ten percent habitat loss to urbanization in 2050 (Figure 7). All five growth models predict animal species impacts in similar rank order, with Scenario 1 most heavily impacted followed by Scenario 3 ("transit-oriented development"), Scenario 2 ("compact development"), Scenario 4 ("Agriculture Protection") and Scenario 5 ("Environmental Protection"). Crested Caracara has the largest variation between scenarios showing ten times more habit lost to urban development by Scenario 1 compared to the other scenarios. Preferred habits for this species are open areas of cabbage palms and live oaks. It is necessary to continue conservation programs as well as land acquisition to protect the Crested Caracara because it requires a large habitat area.
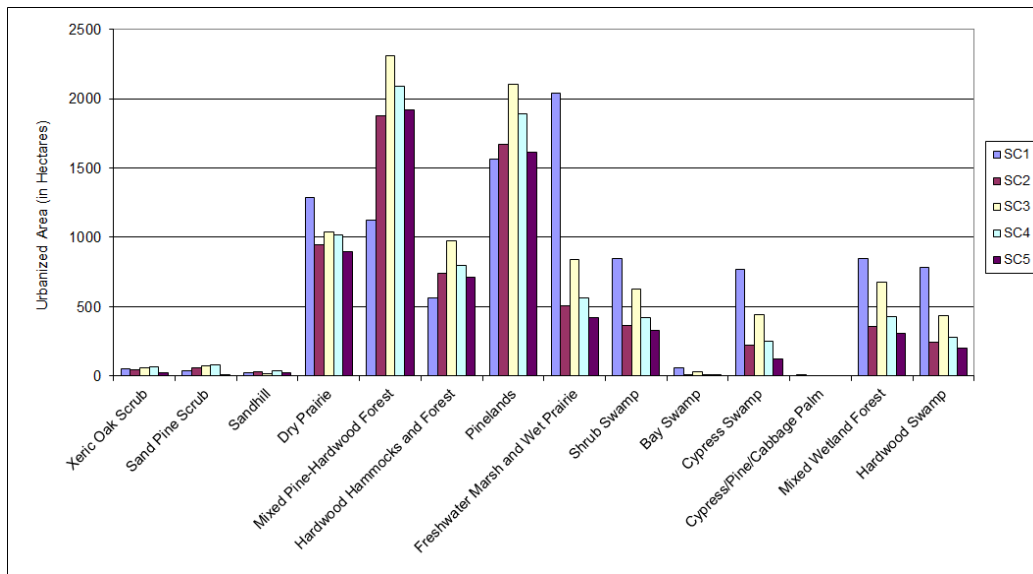
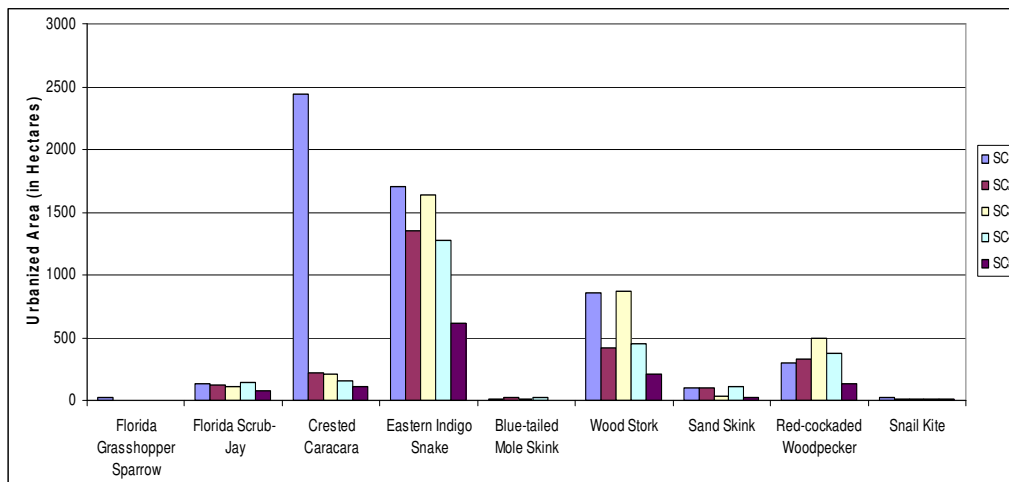Figure 6. Comparison of five growth scenarios on vegetation habitats

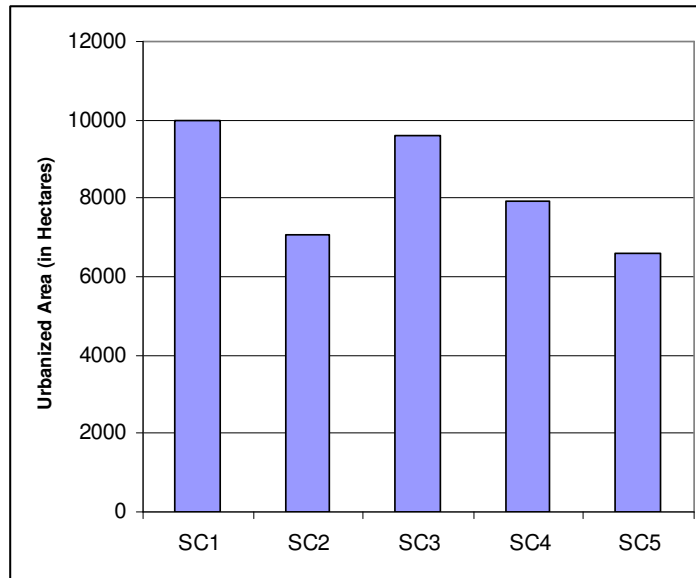Figure 7. Comparison of five growth scenarios on species habitats

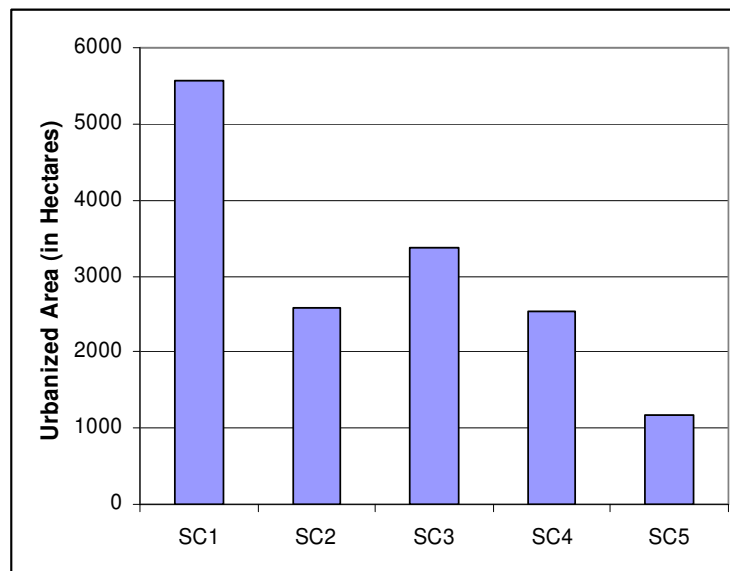Figure 8. Comparison of five growth scenarios on total vegetation areas

Figure 9. Comparison of five growth scenarios on species habitats

4. SUMMARY AND DISCUSSION

Our study explored the consequences of alternative scenarios of habitat change as a consequence of urban growth in Greater Orlando. The results demonstrated that the

maximum impact case is projected from Scenario 1 ("no constraints") while minimum impacts are projected in scenario 2 ("compact development"), and scenario 5 ("environmental protection") show the least habitat loss to urban.

The first issue raised here is how to manage compact growth. Policy on compact growth can play a big role in protecting vegetation and species habitats. Florida has one of the biggest land acquisition programs in the US and a tradition in sustainable development through growth management. The challenge is how to harmonize the fast-growing net in-population in the future with sustainable development objectives.

The second issue concerns predicted habitat losses for those species that occupy areas close to the existing urban core and major roads. These areas do not have high natural resource ranking for protection, so it is critical to continue positive incentives such as tax breaks, conservation easements as well as land acquisition.

Figures 8 and 9 show that the "transit-oriented development" scenario (SC3) would have the second highest habitat loss to urbanization (no constraints" scenario has the highest). This outcome coincides with one from previous studies which urge society to change from being auto-dependent to one with a balanced transportation system with compact development.

Environmental organizations and local policy makers should be reminded of the impacts that urban growth may have on environmental quality especially changes to ecological habitats. The results from our study on Greater Orlando may well be repeated on other regions with similar urban pressures.

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