SIMULATING LANDSCAPES AND USING METRICS TO ASSESS WILDLIFE HABITAT AND ECOSYSTEM HEALTH FOR AGENT-BASED MODELS

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TABLE OF CONTENTS

I. Introduction

III. Methodology

IV. Research Plan

INTRODUCTION

Background and Rationale

The field of landscape ecology has in recent years emerged as an important component in both theoretical ecology and in applied fields such as biodiversity conservation planning. Sanderson *et al.* define a landscape as two or more ecosystems in close proximity (2000). Turner *et al.* (2001) give a more general definition: a landscape as any area that is spatially heterogeneous in at least one factor of interest. In landscape ecology, the objects of study are generally on the scale of geographic regions. However, neither of these definitions is scale dependent and landscape ecology can be applied to landscapes on the scale of tens of meters as well as those on the scale of hundreds of kilometers. The scale used depends on the phenomenon of interest. Understanding the reciprocal effects that spatial configurations and patterns of landscape elements have on ecological processes is at the heart of landscape ecology. For example, understanding how factors such as the total area, shape and fragmentation of a particular ecosystem or land cover type affect the survival and success of the species inhabiting that ecosystem is a key goal in applied landscape ecology. For conservation management, understanding these relationships would allow for better decisions on the size, shape and connectivity requirements for an effective nature preserve. Techniques on how to measure such landscape attributes through various metrics are abundant. However, applied landscape ecology is still relatively new, and the application and interpretation of landscape metrics remains difficult as there is not enough data to truly understand the relationships between these metrics and ecological processes (Turner *et* al. 2001). Another limitation in the application of landscape ecology is that much of our knowledge base is small-area

(Urban *et al*. 1999). For example, plant physiologists have considerable knowledge on how individual trees grow and respond to environmental factors. As a result, there are many forest models where stand dynamics is modeled through the behavior of individual trees. For these kinds of models, the dynamics are a result of deterministic equations based on the understood physiological processes of the tree species present. At larger, landscape-level scales, vegetation is often simulated through abstractions such as plant functional types and land cover types. The dynamics of these kinds of models is often based on transition probabilities from one land cover type to another. However, models from these different scales often do not share a common empirical basis.

The thesis proposed here will touch on both of these issues. Accomplishing this will require the use of two existing ecological models: FACET and MOSAIC. FACET is an individual-based forest growth model that incorporates growth parameters and environmental factors to simulate tree stands, using a plot-level scale (Urban *et al*. 1999). FACET is one of several versions of ZELIG. Individual-based forest growth models such as FACET and the other versions of ZELIG are also referred to as gap models since they simulate forest growth at a scale where the gap created from the death of an individual large tree is an important dynamic factor. In fact, the plot size used in a gap model simulation is defined by the size of the crown of an individual canopy-dominate tree. MOSAIC is a semi-Markov patch transition model that uses transition probabilities between different land cover types to simulate a dynamic landscape (Acevedo *et al*. 1995). The small-area forest model FACET will be used to generate transition probabilities for successional forest growth that will be used in a large-area MOSAIC-modeled landscape. Using FACET to generate these transition probabilities allows to empirically link the large-area scaled landscape model with the individual-based forest growth model (Acevedo *et al*. 2001,a,b, Urban *et al*. 1999).

There are two primary objectives of the thesis. The first is to parameterize and use MOSAIC to simulate dynamic landscape changes of forested areas in the modeled study area. Multiple runs of FACET will be used to generate parameter values for this MOSAIC model. The second objective will be to determine how landscape metrics can be applied to the modeled study area to get a measurement or interpretation of ecological health. Selected metrics will be calculated on the output maps from MOSAIC, and the results of these metrics will be used to interpret the success of selected wildlife species and the general environmental quality of the modeled landscape. The modeled study area is based on a landscape in North Central Texas surrounding the Greenbelt Corridor of the Elm Fork of the Trinity River.

The results of the thesis will be used in the NSF supported project *Biocomplexity: Integrating Models of Natural and Human Dynamics in Forest Landscapes across Scales and Cultures* that is being conducted by the University of North Texas and other collaborating institutions. The objective of this Biocomplexity project is to study the complex interrelationships between human and natural systems on a landscape-level scale. This is done using an agent-based model (ABM), where the agents act on a modeled landscape, with feedback going in both directions between the two. The MOSAIC model will provide the landscape for the Biocomplexity model. The transition probabilities calculated as part of this thesis will be specific to the forest cover types found in the modeled study area, and will thus make up only a subset of all the transition probabilities needed in the Biocomplexity landscape model. Metrics calculated on the landscape will be used to provide feedback on ecological health to the modeled human agents. The agents then use this feedback in the decision making on how to act on the landscape. This thesis will provide the basis for determining what metrics to use and how to interpret them to achieve this end.

Literature Review

The importance of empirically linking small-area (tree stand) models to large-area (landscape) models has been recognized in the literature. There are various approaches on how to accomplish this (Urban *et al*. 1999). One approach consists of using FACET to generate transition probabilities for MOSAIC, which has the advantage of providing a consistent method to bridge the gap between the two scales (Acevedo *et al*. 1995, 2001*a*, *b*, Urban *et al*. 1999). Holcomb's (2001) research on bottomland forests in North Central Texas examines much of the parameterization needed to develop a FACET model in the study area. Geographic Information Systems (GIS) will be used as a tool throughout this project. Using GIS in linking gap models with patch transition models is discussed by Acevedo *et al*. (1996).

Although there has been considerable work done in the theory of landscape ecology, far less has been accomplished in applying these theories to practice (Bissonette and Storch 2003). Bissonette (1997) presents some conceptual frameworks for applying landscape ecology theory to the practice of wildlife management. Bissonette and Storch (2003) further this effort to link landscape ecology theory with applications useful to wildlife and natural resource managers. Turner *et al.* (2001) present many of the methods and techniques of landscape ecology and their practical applications to fields such as forest management. Forman (1995) discusses many basic concepts of landscape ecology and their applications to resource management. General information on the use of landscape metrics, as well as details on the calculation of various metrics is discussed extensively by McGarigal and Marks (1994), McGarigal (2002), and Baker (1997). Parker and Meretsky (forthcoming) discuss the use of specific landscape metrics to measure model outcomes in an agent-based landscape model similar to the University of North Texas Biocomplexity model. However, very little data or research exists relating specific landscape metrics to generic ecosystem health or to the ability for any particular species to be successful. Johnson and Gage (1997) discuss the use of landscape metrics to quantify aquatic ecosystem health. Andrén (1994) discusses in general the effects of habitat fragmentation on mammals and birds. Hoffman (2001) discusses the relationships between some species richness indices and forest width and distance-to-edge metrics for avian communities in the Greenbelt Corridor. Barry (2000) presents a more thorough study relating biological indices and landscape metrics in the Greenbelt Corridor.

OBJECTIVES

The objectives of the study can be stated hierarchically. At the top-level, the goals of the study are to provide a basis for modeling forest growth at the landscape level in the Greenbelt study area, and to provide a method for modeled agents to obtain feedback on environmental health from the modeled landscape. These research goals will be addressed through a set of more specific research objectives. An empirical basis for forest succession in the MOSAIC landscape model will be provided by calibrating the FACET model to the Greenbelt study area and using FACET to determine transition probabilities from the various land cover types to the various forest cover types.

Feedback on environmental health will come in the form of metrics calculated on the output landscape. To accomplish this, the study will have to determine which metrics will be relevant to the study area, and how those metrics are interpreted. These research objectives can be divided into two distinct sets of tasks. The following tasks will be performed in order to use FACET to determine the MOSAIC transition probabilities for forest growth:

1. Use GIS data layers to generate FACET input parameter maps for the study area.
2. Classify terrain types from input parameter maps.
3. Classify various forest cover types and stages for the study area.
4. Perform multiple FACET runs using various terrain and cover types.
5. Use established statistical techniques to determine transition probabilities to be used in the MOSAIC model.
6. Test and analyze results from simulation.

Another set of tasks will be undertaken to address the use of landscape metrics to measure environmental health:

1. Determine which species in the Greenbelt study area are representative of general ecosystem health.
2. Determine which species in the Greenbelt study area have a substantial impact on human perception.
3. Select a subset of these species based on existing information on their landscape requirements.
4. Determine landscape metrics that are relevant to these requirements.

5. Determine landscape metrics to be used in general characterization of landscape structure and pattern.

6. Calculate metrics on MOSAIC simulated landscapes produced as a result of the first set of tasks.

7. Integrate metric measurements into the model in order to provide agent-based models with environmental feedback.

METHODOLOGY

Study Area

The study area, found in Denton County, Texas, includes a portion of the watershed that contains the Greenbelt Corridor of the Elm Fork of the Trinity River that runs between Lake Ray Roberts and Lake Lewisville. The map below shows the study area and its location within Denton County. As can be seen on the map, the study area is a largely rural area ringed by mostly small municipalities and two lakes. With its proximity to Dallas and its surrounding suburbs, it is an area that is subject to rapid urbanization. The Greenbelt Corridor, an area with a considerable amount of native bottomland and upland forest cover, can be seen as the thin extension of the Denton city limits that runs up from the northeast corner of Denton to Lake Ray Roberts, going up approximately a third of the way from the eastern edge of the study area.

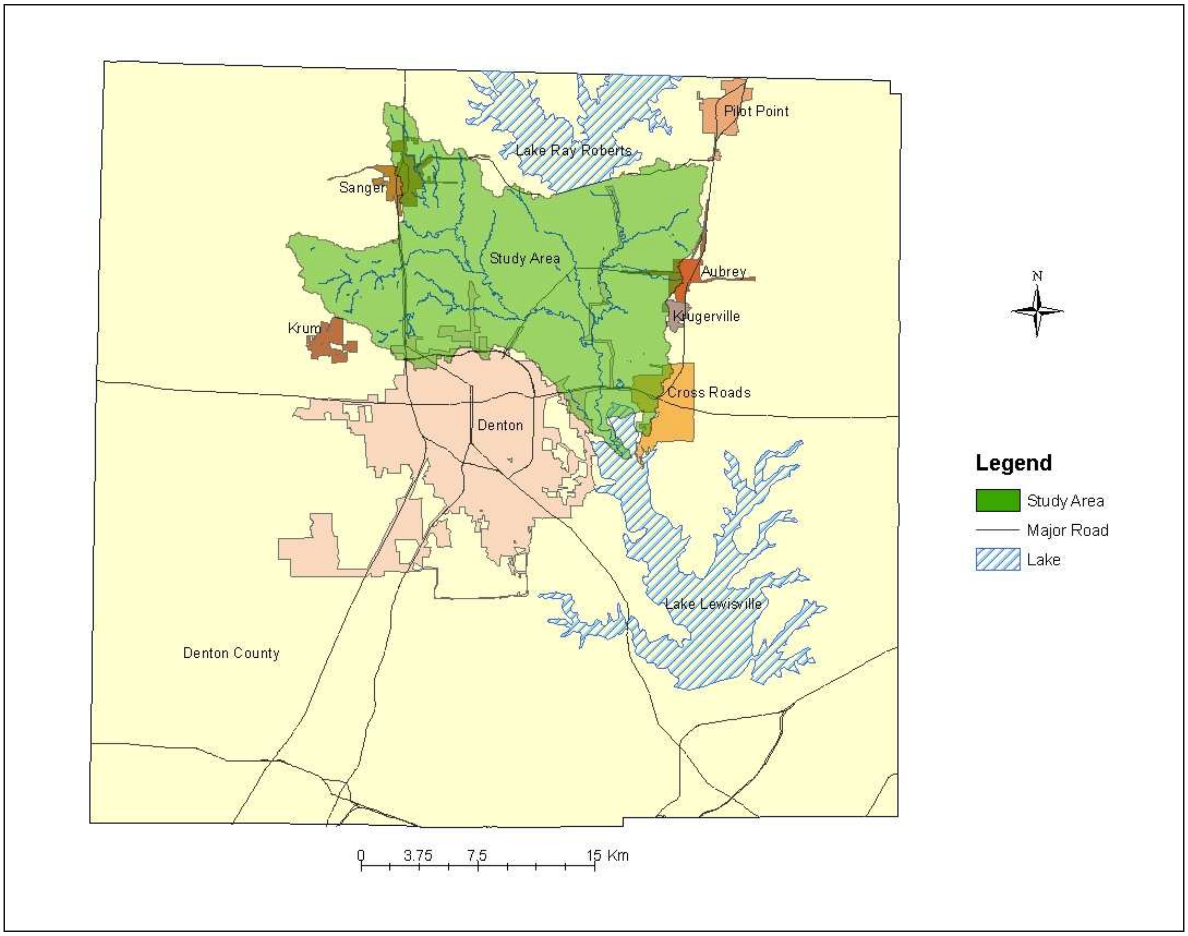

Figure 1: Greenbelt study area within Denton County. Only those streams within the study area boundary and only those municipalities that border or intersect the study area are depicted.

Although mostly rural, the study area contains a mixture of urban, suburban, agricultural, and natural vegetation land covers. Input for the FACET forest model will include parameters for the entire study area. However, it should be noted that the transition probabilities from developed areas to any vegetated land cover type will be zero, thus not allowing forest growth to occur on areas that are developed. The MOSAIC transition probabilities determined with FACET will only include transitions between vegetated land cover types.

FACET and MOSAIC

The steps required to use FACET for generating the MOSAIC transition probabilities include obtaining and manipulating GIS data layers for the study area, defining the terrain and forest cover types, and using multiple FACET simulations to generate the probabilities. One limitation of the current version of FACET for modeling bottomland forests is that it does not simulate the run-on flow or the possible surface pooling of water. A parameter called a run-on coefficient will be added as an input to FACET in order to represent the rain water that runs onto a low-lying plot from surrounding areas. A prototype of this input parameter was implemented in ZELIG (Holcomb 2001) and will be used as a starting point to develop this FACET modification. Another parameter called a storage coefficient will be added as an input to FACET to simulate the pooling of surface water. Currently FACET handles rainfall by initially removing a certain portion of it to represent surface run-off and allowing the rest of it to percolate into the soil at a rate that depends on soil type and percent of saturation. Once the soil is saturated, the remaining water runs off and is no longer accounted for. The intent of the run-on coefficient is to account for the movement of this run-off water. The run-on water will be added to the rainfall amount, and will be subjected to the same initial diversion of a certain portion due to run-off. The remaining sum of rainfall and run-on water will be allowed to percolate into the soil until saturation. The storage coefficient, calculated from the slope of the plot, will be used to prevent all of the remaining water from running off once the soil has reached saturation. If the plot has a non-zero storage coefficient, then some portion of that water will remain on the plot, keeping the soil saturated.

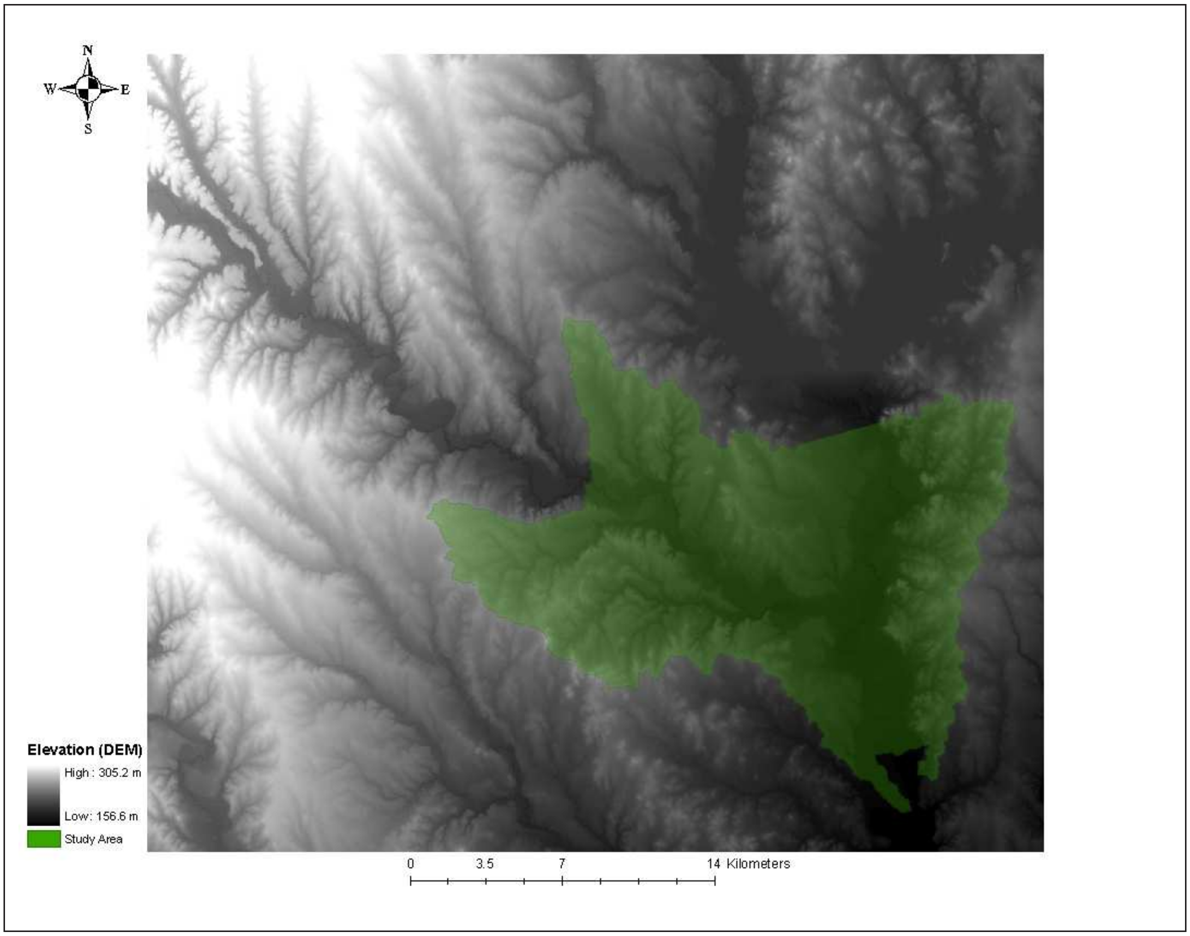

Figure 2: Digital elevation model with the Greenbelt study area. The study area boundary and all the hydrological maps of the study area are determined from the DEM.

The run-on coefficient will be determined through a series of GIS hydrological calculations that start with the digital elevation model (DEM) layer. The run-on coefficient will be based on a secondary topographic attribute known as the compound topographic index (CTI), also referred to as the steady state wetness index (Gessler *et al*. 1996, Chamran *et al*. 2002). The CTI is a measure that combines the tendency of water to accumulate in any cell from the surrounding catchment area with the tendency for the force of gravity to move that water out of that cell. The first steps in generating the CTI map are to obtain the flow accumulation and slope layers from the DEM. The slope is calculated directly from the DEM, while flow accumulation is derived from slope and aspect. The flow accumulation map indicates for each cell the number of cells in the DEM layer that contribute run-on to that cell. The specific catchment area is calculated from the flow accumulation. The CTI is then defined for each cell based on the specific catchment area and slope of that cell. The formula is $CTI = \ln(\frac{A}{\tan\beta})$, where A is the specific catchment area and β is the slope of the cell. The CTI can be seen to increase with larger catchment areas and with smaller slopes. The run-on coefficient map will be determined from the CTI.

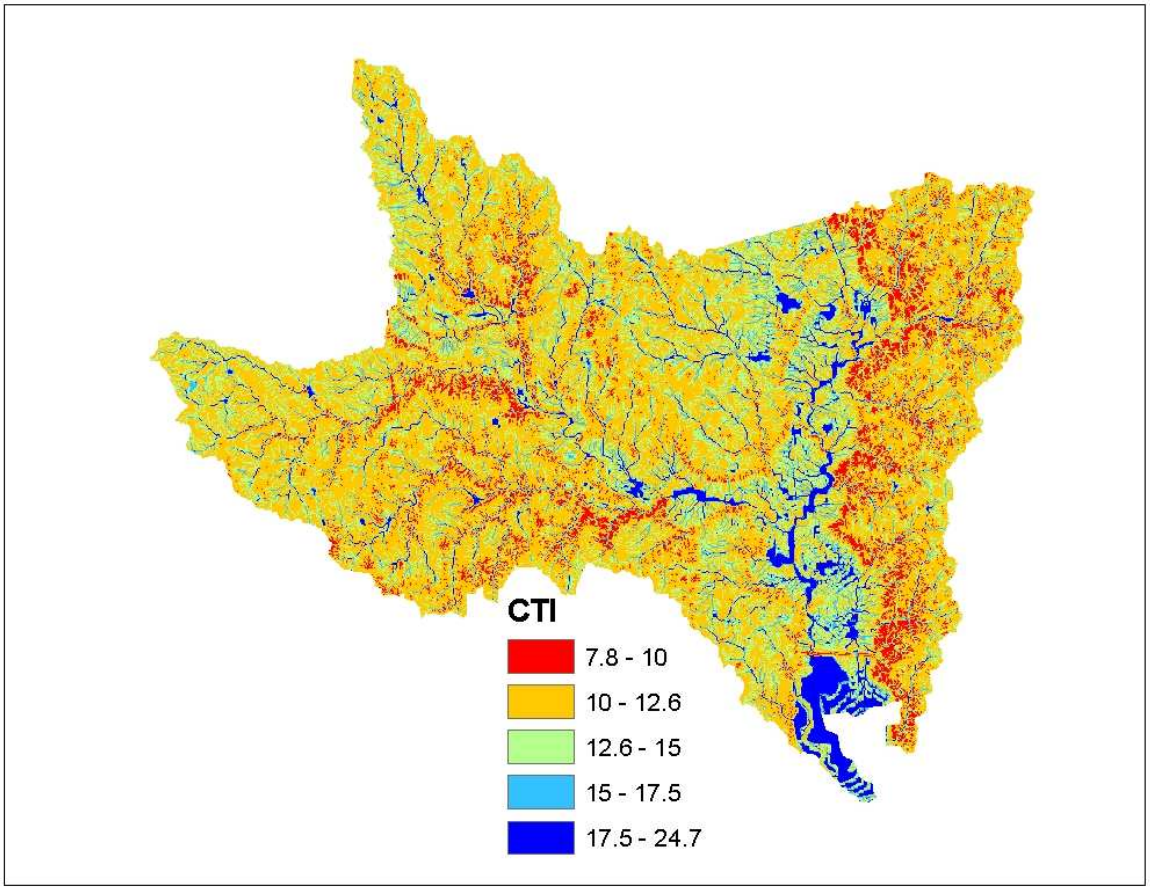

Figure 3: This image shows the compound topographic index (CTI) for the study area. The classification used here was chosen arbitrarily as an example.

In addition to the run-on coefficient, FACET requires input of several soil parameters, parameters for tree species and forest cover types, site-specific data including longitude and latitude, slope, aspect, elevation, and statistical weather data. The soil parameters will be determined from the soil type as defined in the National Resources Conservation Service soils map. Each combination of run-on coefficient and set of soil parameters will determine a unique terrain type of input parameters for the study area. Determining the terrain types will be accomplished by overlaying the run-on coefficient and soil type maps.

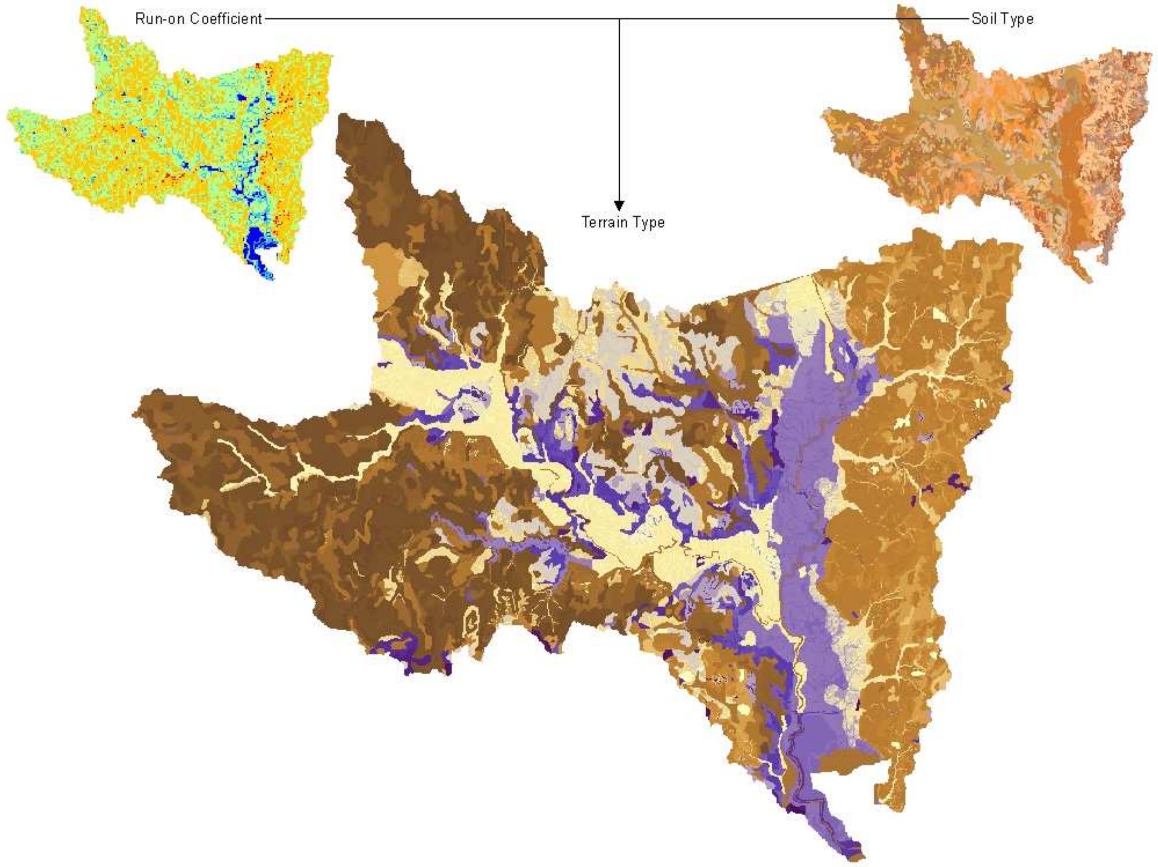

Figure 4: Combinations of sets of soil parameters and run-on coefficients will define the different terrain types. Terrain types will be determined by overlaying the run-on coefficient and soil type maps.

Forest cover types are defined by species composition and tree maturity. Determining the forest cover types will be done using a review of literature on vegetation in the study area, beginning with Holcomb's (2001) work on bottomland forests in the study area. After FACET has been modified with all the site-specific and vegetation parameters, multiple simulations will be performed for each terrain type. Results from the FACET runs will be analyzed using a developed semi-Markov model parameter estimation program, SEMAPAR (Acevedo *et al.* 2001*a*, *b*). These steps are summarized in the flow chart below.

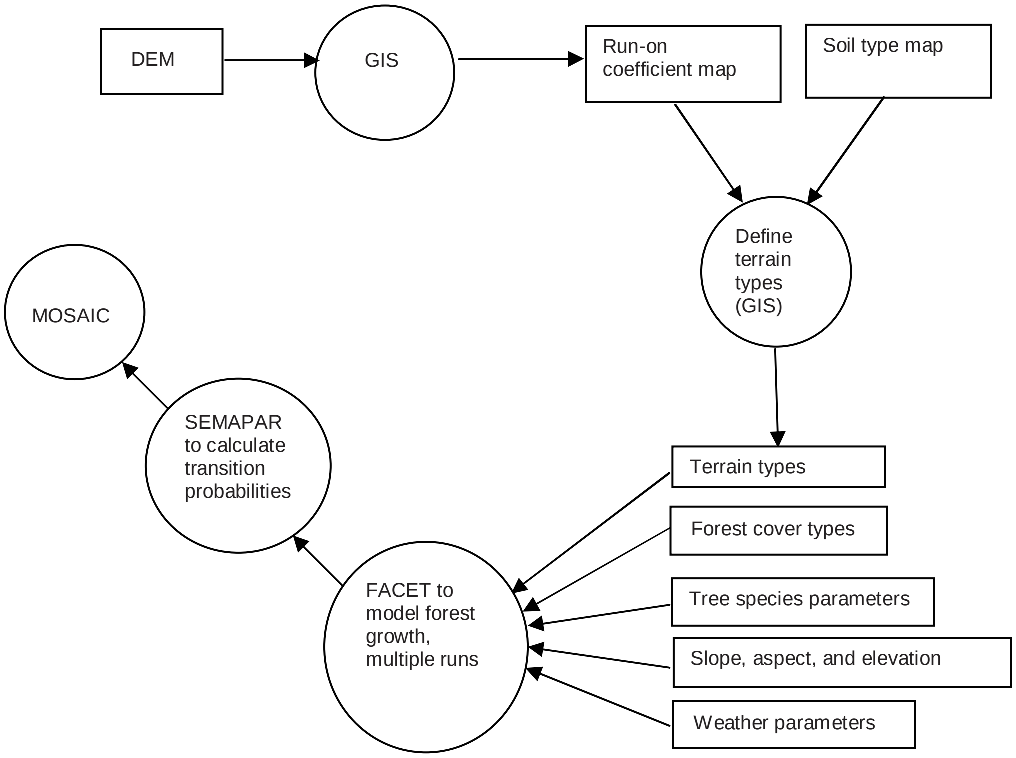

Figure 5: Diagram showing steps for generating transition probabilities with FACET.

Landscape Metrics

Implementing landscape metrics to provide information on environmental health to the modeled agents will include steps to determine a relevant set of wildlife species and metrics, calculate metrics on output maps, and integrate the metrics into the Biocomplexity model as feedback to agents. The first step in this process will be to use existing literature, research data, and expertise available from the University of North Texas' Institute of Applied Science to determine a set of species. Factors involved in this decision include the ecological importance of the species to the study area, human perception of the species, and knowledge of the species' landscape requirements. Data on local wildlife and the studies by Barry (2000) and Hoffman (2001) that investigate the relationship between certain landscape metrics and avian health in the Greenbelt area will be used as a starting point for this determination. Once the species list is known, metrics that measure the landscape requirements for those species will be determined. Those metrics will then be used to determine the viability of specific wildlife species. The selection and interpretation of metrics relevant to local wildlife viability will present a challenge as there is little empirical data on their quantitative relationships (Turner *et* al. 2001). That habitat fragmentation, *i.e.* loss of habitat, reduction in habitat patch size, or increasing patch isolation, has an effect on wildlife viability is broadly accepted. The problem is in understanding which metrics are relevant for any given situation. Andrén (1994) found that the class of metrics relevant for some birds and mammals, *i.e.* total area or spatial arrangement, changes with the percentage of the landscape that the habitat occupies.

Metrics will also be selected in order to give a general characterization of landscape structure and pattern. This characterization will include patch size, number and density for the various patch types, landscape composition, and landscape configuration. Information on generic landscape characterization through metrics is abundant (McGarigal 2002, Turner *et al.* 2001). As with application to wildlife species, the problem is a lack of empirical data relating the landscape characterization with ecological processes. This study will seek to find ways of using this landscape characterization to more generally quantify environmental quality, or the human perception thereof, of the landscape. Metric calculations will first be done on static output maps using the FRAGSTATS program. The metric calculations will then be integrated into the dynamic landscape model as feedback to the modeled agents. The two diagrams below summarize the process of species selection and the steps required for metric selection and implementation.

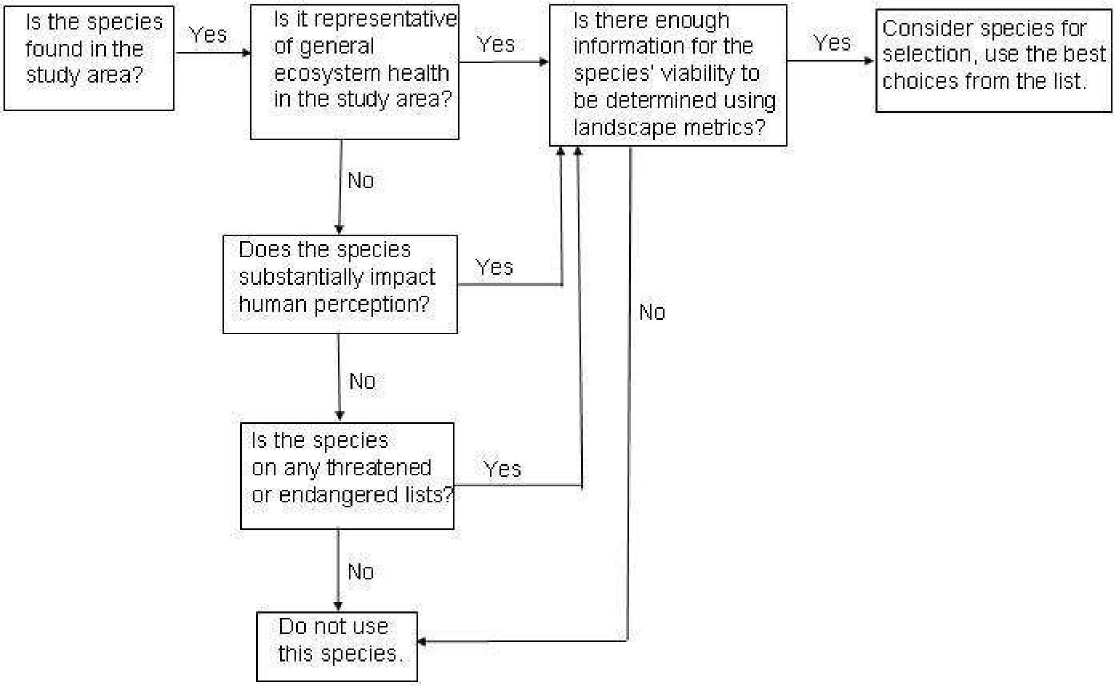

Figure 6: Diagram of the species selection process.

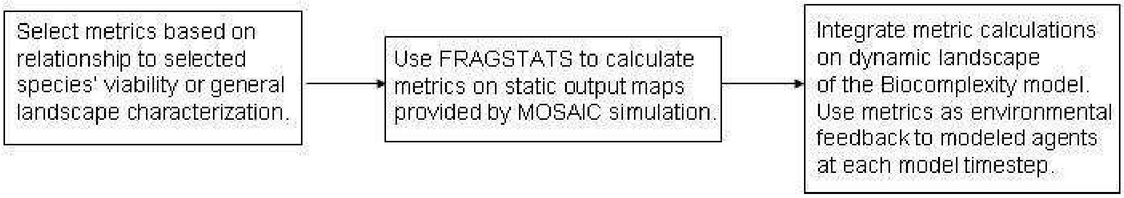

Figure 7: Steps for metric calculation and implementation.

RESEARCH PLAN

Data Sources

The data required for the thesis includes GIS data layers of the study area and data regarding local wildlife. Sources for the GIS data layers are summarized in the table below.

Data Layer	**Source**
Greenbelt study area boundary	Derived from DEM.
Digital Elevation Model (DEM)	United States Geological Survey (seamless.usgs.gov) Download: 6/28/2004, Published: 1999
Lakes	Texas Water Development Board (twdb.state.tx.us/mapping.gisdata.asp) Download: 6/28/2004, Published: 1997
Soil type	Soil Survey Geographic Database, Natural Resources Conservation Services, USDA (ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/) Download: 5/21/2004, Published: 8/27/2002
Land cover/Land use	Institute of Applied Sciences, University of North Texas
Streams	Denton County GIS data disc, 2004

Table 1: GIS data sources

Timeline

The timeline for the required research activities is summarized below.

Task	**Target completion date**
Obtain necessary data layers	June 2004
Proposal presentation	August 2004
Generate necessary data layers for model input	September 2004
Determine tree and terrain categories	September 2004
Determine species and metrics to use	September 2004
Run FACET model to generate transition probabilities	October 2004
Calculate metrics on static MOSAIC output map	October 2004
Integrate metrics into dynamic Biocomplexity model	October 2004
Thesis write up	November 2004
Thesis defense	December 2004

Table 2: Research activity timeline

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