Using Landsat Imagery to Model Increasing Habitat Fragmentation and Its Effects on Tree Migration

Abstract

Numerous models, such as that by Iverson and Prasad (1998), have been developed to investigate how climate change might alter species distributions. While these models all predict changes in species ranges, and thus alterations in community structure and the quality of ecosystem services they provide, they fail to address how increasing levels of habitat fragmentation (HF) might impede the migration potential of tree species. We will use Landsat imagery to develop a general model of increasing HF that we will use to create maps of future HF, as well as to improve Iverson and Prasad's atlas of 80 economically and ecologically valuable tree species of the eastern US. The maps generated will not only help guide decisions on improving landscape connectivity to facilitate tree migration in an increasingly fragmented landscape, but will also benefit research into how tree migration will affect productivity, carbon sequestration, and nutrient cycling in future ecosystems.

Introduction and Research Questions

An ecosystem is very much a large, spatially extended, natural machine whose parts are its various species, each performing some function contributing to overall ecosystem productivity and nutrient cycling. Trees are the backbone of forested ecosystems, providing spatially heterogeneous habitats for other plant and animal species. Depending on how robust an ecosystem is, any change to an area's tree species composition will have varying levels of negative impact on its carbon sequestration and nutrient cycling, as seen in reductions of tropical forest biomass (Iverson et al 1993). Thus, **our research falls under one of NASA's six Earth Science Enterprise focus areas: Carbon Cycle, Ecosystems, and Biogeochemistry.**

Species migration due to climate change is one mechanism that has and will continue to remove species from their original areas of distribution, resulting in a loss of some quantity of ecosystem function in those areas. For future research to investigate the impact on ecosystem function in an area due to species migration, we need to know how species will migrate. This has been investigated with many species migration models, but these models have left out an important factor serving as a barrier to species migration. This barrier is the expected increase in habitat fragmentation (HF) due to continued population growth and economic development.

Habitat fragmentation slows species migration by impeding propagule flow from one habitat patch to another (Malanson and Cairns 1997). Long-distance dispersal events are rare, so if a patch is fragmented into several smaller patches, then the greater the patch separation distance, the greater the likelihood these populations will not disperse (Cain et al 2001). Population declines and subsequent loss of ecosystem function will result if climate change causes habitat patches to become unfavorable, and trees have been unable to disperse to more favorable areas.

To pave the way for future research on how ecosystem functions will be impacted by species migration, our work will address the question of how species migration might be affected by increasing habitat fragmentation. We will answer this question by first creating a model of increasing HF. Then we will incorporate it into a widely-known plant migration-climate change model, that of Iverson and Prasad (1998), to predict how increasing HF will affect future tree species distributions. **Remote sensing will be highly important to our work since our HF measurements will be taken directly from Landsat imagery.**

Unlike previous cellular automata-based models of urban growth that are often specific to particular cities, our model will be a general spatial model of increasing HF that can be applied to any city. Such a model is possible because there are rules of urban growth that apply to all cities, such as when cities grow, HF within and beyond urban areas increases to make way for new growth. A model has already been developed to infer population distribution from land cover data for China with 3-5% mean error, and a linear relationship has already been shown for the developed/natural land ratio vs. population density (Tian 2005, August et al 2002). Thus, at least for China, population distribution is highly correlated with habitat fragmentation, which supports the idea that HF generally increases near cities and decreases with distance.

Since we are concerned only about reproducing the general pattern of habitat fragmentation over the landscape instead of trying to model exactly where and what kinds of habitat fragmentation occur at various locations around a city, our model will be very simple, with relatively few parameters. This will make it easy to incorporate it into a widely-known plant migration-climate change model, such as that of Iverson and Prasad (1998).

Methods

Overview of Model Development: Iverson and Prasad were able to model tree migration over the entire eastern US. To obtain HF measurements over that same scale would require numerous Landsat images. However, because our model of increasing HF will use rules that apply to most if not all cities, studying a small area should yield results applicable to other regions in the eastern US. Thus, we will only require the study of 10 small, 10 medium, and 10 large cities within the extent of just 2 Landsat images. We will measure HF within 100 km of these cities every 6 years within the 30-year period of 1973 and 2003.

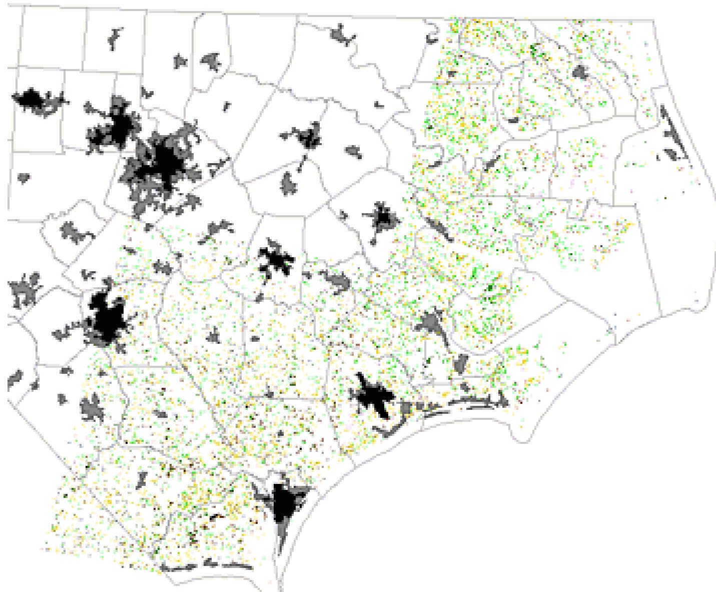

Fig. 1: Land cover change map, coastal NC. Small dots near coast (colored): areas where land cover changed between 1991 and 1997. Large areas are 1991 city extents (black) and 1997 city extents (gray).

Step 1 – Creating Land Cover Change Layers From Landsat TM Images: We will obtain Landsat TM images of 2 areas in the state of NC, each containing 10 small, medium, and large cities as defined by population, for each of the 6 time periods. Images from each pair of time periods (1973-1979, 1979-1985, 1985-1991, 1991-1997, and 1997-2003) will be used to create a new layer in ArcMap (ESRI) to show areas that had changed during the 6 year period in question, and to what type of land cover they had changed to. We have already obtained land cover maps of coastal NC for 1991 and 1997, which were generated by NOAA from Landsat TM images. The resulting ArcMap land cover change layer is shown in Fig. 1.

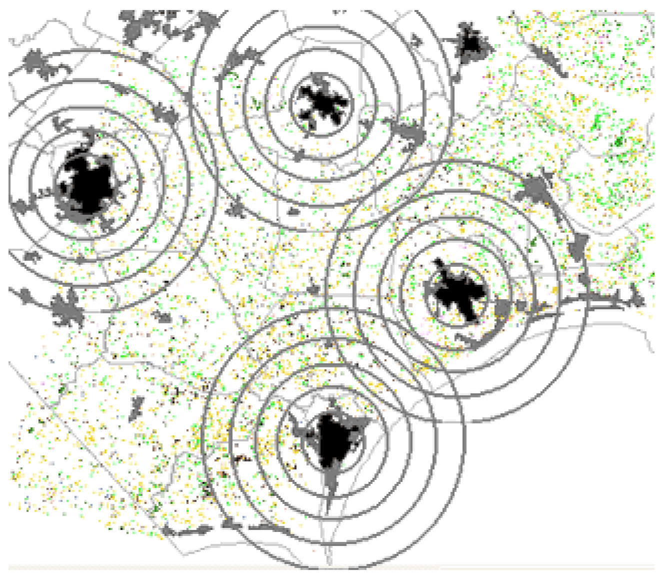

Fig. 2: Circles every 10 km around sample city centers show areas between circles where HF will be measured. Only the first 5 circles are drawn to avoid significant overlap; in actuality, the chosen cities will be far enough apart to avoid overlap.

Step 2 – Defining Boundaries For Measuring HF Around Cities: We will identify the centers of each of the 30 cities using urban area extent shapefiles obtained from Census 2000 TIGER/Line data. From the centers, we will create circles at every 10-km interval between 0-100 km that will form the boundaries inside which we will measure HF. We have already obtained shapefiles for coastal NC cities; Fig. 2 shows the four largest cities in southeastern NC that lie within the extent of the NOAA land cover data.

Step 3 – Find HF Values For Each Distance from City Center Over Time to Generate HF Rates For Each Distance: Once our measurement boundaries have been defined, we will start with the 1973-1979 land cover change layer, select a city, and determine HF values for each 10-km interval from 0-100 km. Habitat fragmentation will be defined as any change in land cover type to another type, or to developed land, as measured relative to 1973 land cover. We will normalize the HF values to area so more distant rings do not have higher HF values due to their greater area. We will then repeat this for each subsequent time period (1979-1985, 1985-1991, 1991-1997, and 1997-2003) so we can plot the normalized HF values vs. time for each distance from city center. Linear regressions will then be fitted to these graphs to obtain fragmentation rates for each distance from city center.

Step 4 – Find HF Rates Over Distance For All Cities: Now that we have HF rates for each distance from the center of one city, we will do the same for the other 29 cities. Together, the 30 cities may show differences in how HF rates vary with distance from city center. To investigate these differences, we will plot the HF rates vs. distance from city center. A curve will be fitted to each HF rate vs. distance plot to allow extrapolation of HF rates beyond 100 km so that later, a continuous map of HF can be formed for the state of NC. Finally, a three-axis graph will be generated of HF rates vs. distance vs. population size, to see how fragmentation rates might be dependent on increasing distance from urban areas of varying population size.

Step 5 – Modeling Habitat Fragmentation: The data obtained from these curves is expected to yield relationships between city population size, distance from city center, and increases in habitat fragmentation over the past 30 years. To predict what level of HF we can expect to see at a certain distance from urban areas at a later date, we will create a model of habitat fragmentation that will include the following parameters: population size, distance to city center, initial habitat fragmentation, driving time from residential and/or commercial areas, mean income of city residents, proximity to other urban areas, proximity to other fragmented areas, and proximity to farmlands, tree farms, or other natural resources that would encourage economic growth and subsequent development.

Initial HF and proximity to other fragmented areas will be taken from the Landsat imagery. Population size and mean income data will be obtained from Census 2000 TIGER/Line; driving time, proximity to other urban areas, and proximity to farmlands, tree farms, and other natural resources will be calculated from the Agriculture, Biology, and Transportation datasets from NationalAtlas.gov.

Step 6 - Incorporating The HF Model with a Species Distribution Model: We will write the necessary code to combine our model of increasing habitat fragmentation with a widely-known model of tree migration in response to climate change, that of Iverson and Prasad (1998). Their model, DISTRIB, is based on 33 environmental variables, and they have used it to predict the future distributions of 80 tree species in the eastern US for two climate change scenarios. They have since added a cell-based stochastic migration model, SHIFT, to explore the effect of HF on tree migration rate (Iverson et al 1999b, Schwartz et al 2001). Because our model will account for increasing HF based on actual trends between 1973 and 2003, it will be an improvement on the SHIFT model, and should enable more accurate predictions of future tree species distributions.

Anticipated Results

We anticipate the results will confirm our hypothesis that increasing levels of HF will slow the migration of tree species to more climatically favorable areas, to a greater extent than Iverson and Prasad originally predicted. This hypothesis is supported by an understanding of the mechanism by which species migrate—dispersal—and how it is affected by habitat fragmentation.

We already know that HF impedes the dispersal of species (Schwartz 1992). With increasing HF, more large patches will continue to be fragmented into smaller patches (inter-patch fragmentation), further slowing dispersal rates and thus the overall migration of the species. Examples of inter-patch fragmentation would be suburban development, and the encroachment of scattered homes into formerly pristine areas. Also, the original small patches may be divided into even smaller patches (intra-patch fragmentation), which increases the likelihood that the resulting small populations might go extinct without contributing to dispersal. As an example, trees whose seeds are dispersed by birds requiring deep forests for habitat will not be able to disperse in a suburban area where most of the original forest has been cleared.

Significant Products of Our Research

We will use our model to:

- Generate future habitat fragmentation maps for the state of NC,
- Provide an example that can be copied to generate HF maps for other states, and
- Create a new atlas of future distributions for the 80 economically and ecologically valuable tree species studied by Prasad and Iverson, to visualize how their distributions will change due to increasing levels of HF.

Together, these maps will be important guides for decision-making on how to best improve landscape connectivity for tree species affected by climate change. Connecting the landscape means bridging across areas strongly affected by habitat fragmentation, which will help facilitate climate change-driven tree migration in an increasingly fragmented landscape. **Enabling trees to migrate rapidly to more favorable locations will reduce losses in ecosystem productivity and carbon sequestration in affected areas due to changes in species composition during migration.**

Our work will also benefit ongoing research on how tree migration will affect future ecosystem functioning. By having a model that accurately predicts where 80 important tree species will migrate, we can overlay their maps to predict future species composition in various areas. The percent change in composition compared to the present will help identify areas where productivity, carbon sequestration, and nutrient cycling will likely be impacted. Iverson et al (1993) have already taken a similar approach of mapping losses of tropical forest biomass to estimate losses in carbon sequestration ability. However, we recognize that forests need not be lost to adversely affect carbon sequestration. Changes to tree species composition can also have an effect, since trees provide habitat for a host of species that contribute to forest productivity.

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Budget

Supplies: We request $5,400 in our first year to purchase 2 Landsat TM images at $450 each for the years 1973, 1979, 1985, 1991, 1997, and 2003. We also request $1,000/year for computing supplies and data storage/backup.
Publication Costs: We request $1,000/yr to cover publication costs for the three papers
Travel: We request $500/yr to cover travel costs for presenting our results at conferences and workshops.

	Year 1	**Year 2**	**Year 3**	**Total**
Landsat Imagery	$5,400	$0	$0	$5,400
Computer Services	$500	$500	$500	$3,000
Travel	$500	$500	$500	$1,500
Publication Costs	$1,000	$1,000	$1,000	$3,000
Health Insurance	$1,500	$1,600	$1,700	$4,800
Total	**$8,900**	**$3,600**	**$3,700**	**$16,200**

Timeline

Activity	**Year 1**		**Year 2**		**Year 3**	
	Fall	**Spr**	**Fall**	**Spr**	**Fall**	**Spr**
Gather Landsat imagery for 2 areas in NC for the 6 time periods, select 30 study cities within them, and create land cover change maps for each of the 6 time intervals.	O					
Complete measurements of habitat fragmentation for all 30 cities; prepare paper of results for publication.		O				
Gather demographic and transportation data for the 30 cities; decide which factors best correlate with the observed trends in HF around cities, in preparation for modeling HF.			O			
Develop the model of increasing HF; generate maps of predicted HF for NC for the next 25, 50, and 100 years.				O		
Prepare paper for publication describing model and maps.				O		
Incorporate the increasing HF model with Iverson and Prasad's tree migration model; use the combined model to map future ranges of their 80 eastern US tree species.					O	
Prepare paper for publication on results of combined model.						O