Evaluating Conservation Assessments in the Sandhills of North Carolina

Matthew Copeland Simon

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in the Department of Geography.

Chapel Hill
2009

Approved by:

Aaron Moody, Ph.D.

Martin Doyle, Ph.D

Allen Hurlbert, Ph.D.

ABSTRACT

Mathew Copeland Simon: Evaluating Conservation Assessments
in the Sandhills of North Carolina
(Under the direction of Aaron Moody)

Conservation assessments are spatially explicit techniques that assign value to areas based on their ability to protect natural resources such as species, habitat and environmental processes. These may be spatially congruent thereby providing value-added conservation opportunities, or incongruent, representing trade-offs that should be considered with full knowledge in the conservation planning process. However, little attention has been given to the congruency of multiple conservation assessment criteria, or to how a multi-criteria framework might be used to improve the conservation planning process. My thesis presents a comparison of commonly employed conservation assessment techniques in the Sandhills surrounding Fort Bragg, North Carolina; biodiversity hotspots, habitat connectivity for the red-cockaded woodpecker (*Picoides borealis*), and ecosystem services (carbon storage). My research shows that priority areas can be identified even when overall congruence among assessment criteria is low. I also discuss the difficulty of comparing assessments and present a novel approach to comparing conservation assessments criteria.

ACKNOWLEDGEMENTS

This thesis could not have been completed without the guidance and support of my advisor, Aaron Moody. He allowed me the freedom to develop my own ideas and provided me with thoughtful advice. For his support over the past few years I am deeply indebted.

I am also grateful for the advice and guidance provided by my other two committee members, Martin Doyle and Allen Hurlbert. They encouraged me to think more critically about my analysis while also keeping the scope of my project in check and achievable.

I am also eternally grateful for the patience and support that the Moody Lab provided me reading drafts, critiquing analysis and helping me struggle through an often arduous process. I would especially like to thank Anne Trainor, the Moody lab marm. My success is due in large part to her mentoring, support and ability to keep me on track. Thanks also to Jen Costanza, Todd Jobe, and Ian Breckheimer. I know that I could not have done this without all of your support, so thanks!

Finally, I would like to thank my wife, Carrie Elizabeth Banks, for her support through this process. I could not have done it without her editorial eye, shoulder to lean, love and support. Of course I have to acknowledge my other best friend, Wasatch Andy Banks Simon, best dog ever. I also want to thank my sister, Margaux Simon, for providing me with support in times of crisis, my father Steven Simon for being there to bounce ideas off of and my mother Janet Copeland for her constant encouragement and goodies. Thanks also to the Carrboro Family for keeping my spirits high through this process, especially when times were rough. I love you all!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ArcGIS	ESRI's GIS software platform
CCX	Chicago Climate Exchange
DEM	Digital Elevation Model
LiDAR	**Li**ght **D**etection **a**nd **R**anging
ESB	Endangered Species Branch (Ft. Bragg)
ESRI	Environmental Systems Research Institute
ETR	Endangered, Threatened and Rare Species
EETR	Endemic, Endangered, Threatened and Rare Species
FunConn	Functional Connectivity Model (ArcGIS toolbox)
GAP	Gap Analysis Program
GIS	Geographic Information Services
InVEST	**In**tegrated **V**aluation of **E**cosystem **S**ervices and **T**radeoffs
IPCC	Intergovernmental Panel on Climate Change
MA	Millennium Ecosystem Assessment
MRLC	Interagency **M**ulti-**R**esolution **L**and Cover **C**haracterization
NAD	North American Datum
NCCGIA	North Carolina Center for Geographic Information and Analysis
NCP	Natural Capital Project
NHEO	Natural Heritage Element Occurrences
NHP	Natural Heritage Program
NLCD	National Land Cover Database
NRCS	Natural Resource Conservation Service
NWI	National Wetland Inventory
RCW	Red-cockaded Woodpecker (*Picodies borealis)*
SLI	Strategic Lands Inventory
SSURGO	Soil Survey Geographic Database (NRCS soils)
USGS	United States Geological Survey
USFW	United States Fish and Wildlife Service

Chapter 1: Introduction

1.1 Problem statement and purpose

Natural resource conservation is implemented at various levels by public and private land managers. It is often a struggle for managers to determine which properties should be purchased, protected and managed. Conservation assessments are spatially explicit techniques that assign value to areas based on their ability to protect natural resources such as species, habitat and environmental processes (Knight et al. 2008, Noss 2002). Assessments reflect organization-specific goals, objectives and mission statements, and have become an integral part of the conservation planning process to help inform the placement of new reserves. Although goals vary from case to case, conservation assessments often assign value to those elements in the landscape that if preserved will protect or restore biodiversity (Brooks et al. 2006, Clark and Slusher 2000, Egoh et al. 2007).

For regional scale conservation planning, different assessment criteria will result in the prioritization of different parcels for land conservation. Yet it is difficult to gain consensus among land-management practitioners, funding organizations, NGOs and other stakeholders on which assessment criteria to use for conservation planning (Mace 2000). Assessments based on different criteria may be spatially congruent, providing value-added conservation opportunities, or incongruent, presenting trade-offs among different conservation criteria that may need to be considered simultaneously. Little attention has been given, however, to the geographic congruency of different conservation assessment criteria, or to how a multi-criteria framework might be used to improve the conservation planning process. Explicitly examining the tradeoffs and value-added opportunities in a multi-assessment framework may lead to better conservation assessment models and facilitate consensus-building among stakeholders, while increasing the efficiency and efficacy of conservation management.

According to Pimm *et al.* (1995) species extinction rates are as much as 1000 times higher than background, pre-human levels. In response to this unprecedented species loss, conservation assessments often prioritize land with high biodiversity value in the form of endangered species habitat or biodiversity hotspots (McNeely et al. 1990, Myers 1988). More recently, other conservation criteria such as maintenance of habitat connectivity or provision of ecosystem services are increasingly used for conservation priority setting. These different criteria may compete for the scarce resources available for land conservation.

Conservation planning can benefit from information regarding the trade-offs and value-added opportunities related to different conservation assessment criteria. For example, areas of congruence, where high priority status coincides across multiple conservation criteria, are locations where multiple conservation goals can be accomplished simultaneously and arguably should be given highest conservation priority. In a multi-criteria framework we can locate the congruencies and tradeoffs between different assessment criteria. My thesis presents a comparison of multiple conservation assessments based on biodiversity hotspots, habitat corridors, and ecosystem services in the Sandhills surrounding Fort Bragg, North Carolina and shows that win-win areas can be identified even when overall congruence among assessment criteria is low.

1.2 Past research attempts

Recent research on conservation assessments often emphasize the integration of ecosystem-service values into conservation planning (Chan et al. 2006, Egoh et al. 2007), incorporating socio-ecological models (Tallis and Kareiva 2006), and translating the recommendation of conservation research into action (Knight et al. 2008, Opdam et al. 2008). Efforts have also been focused on development of software tools to assist land managers through Geographic Information System (GIS) driven decision-support tools (Appendix A). However, to date only a few studies have compared the prescribed outcomes of different assessment criteria in a spatially explicit manner (Chan et al. 2006, Naidoo et al. 2008) despite recognition of the value in understanding the degree of concordance amongst assessments (Balvanera et al. 2001). Unlike previous work analyzing biodiversity and ecosystem service congruence at global scales (Naidoo et al. 2008), this study integrates habitat connectivity, biodiversity hotspots and carbon storage in a finer scale-analysis of congruence in an 8 county area containing the Sandhills ecoregion and surrounding Fort Bragg, North Carolina. This work results in specific recommendations for conservation within the study region.

1.3 Research Objectives

My research goals were 1) to implement a multi-assessment framework for conservation land prioritization in the North Carolina Sandhills, 2) to quantify and map conservation value, trade-offs and priority hotspots, and 3) to compare the multi-assessment framework to other conservation assessment models. To do this I modeled conservation priority according to multiple conservation assessment criteria, and analyzed the spatial congruence (priority hotspots) and tradeoffs among them. The different assessment models included 1) biodiversity hotspots, 2) habitat connectivity for *Picoides borealis* (red-cockaded woodpecker) and 3) carbon storage as an ecosystem service (Figure 1). In my research I attempted to answer the following questions:

1. Where is the top 10% of the landscape based on each assessment?
2. Where are the priority hotspots throughout the Sandhills region?
3. What are the rates of congruence among the different assessment models?
4. How effective is a priority hotspot approach relative to individual models and the current conservation landscape?
5. Where are the tradeoffs among assessment criteria? For example, how much of one criterion, like biodiversity, do you give up if you prioritize another criterion, such as ecosystem services?

Chapter 2: Background

2.1 Overview

Conservation assessments are spatially explicit techniques that assign value to areas based on their ability to protect natural resources such as species, habitat and environmental processes (Knight et al. 2008, Noss 2002). Typically, conservation assessments assign value to those elements in the landscape that if preserved will protect or restore biodiversity (Brooks et al. 2006, Clark and Slusher 2000, Egoh et al. 2007) but conservation objectives are expanding to include many other possible assessment criteria, including ecosystem services, ecosystem representation, habitat connectivity, and others. The basic conservation assessment approach can be used to assign value to any landscape on the basis of any of the above criteria. The resulting information can be used to help identify priority areas for conservation. In this way, conservation assessments supply support and information to the conservation planning process.

Conservation planning and conservation assessments are often confused with one another, though they are two distinct areas of conservation science (Knight et al. 2006). The process of conservation planning has been described as involving six distinct stages: 1) measure and map biodiversity, 2) identify conservation goals for the planning region, 3) review existing reserves, 4) select additional reserves, 5) implement conservation actions, and 6) management and monitoring of reserves (Margules and Pressey 2000). Note that in their scheme, Margules and Pressey (2000) assumed that biodiversity would be the primary prioritization criteria. Conservation assessments occur in stages 1-4 of this scheme, and involve mapping the value of the landscape according to the prioritization criteria. The key distinction is that conservation assessments are a subset of the planning process and do not include an implementation and management/monitoring strategy.

2.2 History of conservation's theoretical debate

Conservation sentiment first expressed during the late 1800's reflected a desire to preserve nature's intrinsic value; that we have an ethical obligation to preserve nature and wilderness for its own sake as described in the writings of such naturalists as Henry Thoreau, John Muir, and Aldo Leopold (Kareiva and Marvier 2007). However, Leopold also advocated for management in a manner beneficial to both humans and nature (Callicott 1990). In the early 1990's, conservation practices shifted to sustainable landscape management which eventually coalesced into ecosystem management (Christensen et al. 1996b). Some have argued that the push for sustainable management devalued wilderness in its attempt to integrate humans into the ecology of conservation (Noss 1991). Today attention is still largely focused on the global biodiversity crisis and the creation of protective nature reserves (McNeely et al. 1990), although momentum is shifting to conservation of ecosystem function and ecosystem services, the benefits to humans provided by natural systems (McCauley 2006).

What has historically been an ad-hoc, opportunistic approach to nature reserve design has grown in the direction of systematic conservation plans that are science-based, objective driven, and where geospatial modeling is often used to prioritize areas for conservation (Knight and Cowling 2007). However, Knight and Cowling (2007) claim that systematic conservation assessments are flawed, because they do not account for the complex social, economic and political factors that stakeholders must negotiate in order to develop an actionable conservation strategy. The current paradigm in conservation has also been criticized as operating under a binary logic that has created protected areas that are "islands of nature surrounded by an inimical matrix with little conservation value (Wiens 2007)."

2.3 Conservation assessments in the context of land management

The preservation of biodiversity is often accomplished through a single-species approach using an umbrella, flagship, keystone or indicator species as a shortcut (Simberloff 1998). By contrast, ecosystem management blends social, physical, economic and biological needs to sustain ecosystem composition, structure, and function (Christensen et al. 1996a). Empirical evidence in support of corridors includes positive relationships with plant species richness (Damschen 2006), preferential dispersal for many plants and animals (Haddad et al. 2003) and enhanced movement for some habitat specialists (Gillies and St. Clair 2008). These studies reinforce the notion that land management decisions should also consider ecosystem and habitat connectivity. However further empirical support for positive corridor effects on populations and communities remains ambiguous (Haddad and Tewksbury 2006).

Currently there is significant momentum in land management planning to integrate ecosystem services that will provide for human natural resource needs under increasing population demands (Mooney et al. 2004). The Millennium Ecosystem Assessment, a five-year study involving nearly 1,400 experts worldwide, assessed the effects of ecosystem change on human well-being and identified opportunities to enhance the conservation and sustainable capacity of ecosystems critical for human well-being (MA 2005). However, skeptics worry that valuing the landscape in terms of its ecological services will only perpetuate a conservation dichotomy of defining nature as being either economically valuable or valueless and only worth conserving if it can be made profitable (McCauley 2006, Wiens 2007).

Reflecting conservation's varied objectives, multiple conservation assessment models are in use. Three main criteria for assessing conservation value include biodiversity hotspots, habitat connectivity, and ecosystem services.

Biodiversity Hotspots

A 2007 review of conservation assessments published between 1998 and 2005 found that 99% of studies used some measure of biodiversity (Egoh et al. 2007). One popular and widespread assessment of biodiversity is the "biodiversity hotspots" approach (Myers 1988). This method targets areas that harbor the greatest variety of endemic (geographically restricted) species that are under threat. Since most species depend directly or indirectly on plants for habitat or resources, endemic plants were chosen as a surrogate for total taxonomic diversity (Myers 1988). The idea of a biodiversity hotspot combines two distinct concepts. The first is biodiversity, which is distributed unevenly across the globe. According to Myers et al. (2000) 1.4% of the Earth's land surface contains 44% of all plant species and 35% of all vertebrates worldwide. The second concept is the degree of threat faced by a landscape: certain areas are under more intense or imminent threat than others. Based on these two principles, areas with the highest level of plant endemism and highest degree of threat are ranked highest and targeted for conservation.

The hotspots approach is used conservation practitioners to invest scarce funds efficiently (Mittermeier et al. 1999) and is employed in regional analysis to prioritize areas particularly high in species richness and at risk of development (Reid 1998). For example, the National GAP analysis program has been implemented state by state across the entire

United States aiming to identify 'gaps' in protected areas using biodiversity hotspots (Scott et al. 1993). Because it promotes efficient conservation of biodiversity, the hotspots approach is the principal conservation assessment strategy of several large transnational conservation organizations including Conservation International and the World Wildlife Fund (Mittermeier et al. 1999, Myers 1988).

The hotspots approach is criticized by many and is not universally accepted as appropriate (Kareiva and Marvier 2003, Lombard 1995, Reid 1998). The most prominent criticism is that hotspots based on different measures of rarity or different taxa may not overlap. According to Lombard's (1995) study of six different vertebrate taxa in South Africa, hotspots among the different species were not spatially congruent. Studies have also found that hotspots of endemism, species richness and rare species occurrences are not congruent (Lombard 1995, Orme et al. 2005). These studies indicate that multiple hotspot indices need to be used when setting hotspot priorities, not just endemic flora and brings attention to the fact that there are many ecological, evolutionary and anthropogenic mechanisms responsible for biogeographic patterns (Orme et al. 2005). Based on all these critiques, assigning value based on a single index will exclude much of the world's biodiversity.

Another critique of hotspots is they are difficult to apply at the scale at which conservation and management decisions are made thus making regional hotspot assessments limited in value (Reid 1998). A final critique, is that public support for biodiversity conservation can be hard to garner (Abbot and Thomas 2001), partially explaining why conservation campaigns are often anchored by flagship species capable of capturing the public's interest or sympathy (Simberloff 1998).

Habitat connectivity

Habitat connectivity and movement ecology are fast-growing areas in conservation biology (Holden 2006). These research areas have their foundation in theories developed from island biogeography, metapopulation biology, and graph theory. The current prominence of connectivity studies is due, in large part, to increases in human-induced landscape fragmentation (Saunders et al. 1991), leading to the wide-spread recognition that the degree to which the habitats are linked or connected by dispersal needs to be quantified (Calabrese and Fagan 2004). The development of freely available software to quantify habitat fragmentation, resistance to dispersal, and landscape structure has facilitated the increased use of connectivity measures in resource management and conservation assessments (McGarigal and Marks 1995).

Techniques for assessing connectivity vary because connectivity can be defined in terms of its structure or function, both of which can be measured at the habitat patch scale or at the landscape scale (Minor and Urban 2008). Connectivity can also be defined and measured differently depending on the data available and the scale of analysis (Calabrese and Fagan 2004). Structural connectivity is a landscape measure that refers to the spatial arrangement (size, shape, location) of habitat while functional connectivity is a measure of the behavioral response (in the case of animals) to the physical structure of the landscape (Theobald 2006).

In the most general sense, landscape connectivity has been defined by Taylor (1993) as "the degree to which the landscape facilitates or impedes movement among resource patches." Some measures of landscape connectivity are extremely simple, and include those physical features in the landscape that influence the degree of connectedness such as the amount and spatial distribution of suitable habitat (Hutchinson and Vankat 1998). Just as habitat is species-specific (Hall et al. 1997), habitat connectivity should be used when referring to the connectivity for a single species at either the landscape or patch-scale.

Perhaps the clearest conceptual representation of connectivity is presented by Calabrese and Fagan (2004). In this paper, connectivity is conceptualized in terms of: 1) structural connectivity, 2) potential connectivity and 3) actual connectivity. Structural connectivity commonly describes the size, shape, or location of habitat patches, like the example given above. Potential connectivity combines structural with limited dispersal information or movement behavior. Actual connectivity relates measured individual movements to the landscape. From a cost-benefit perspective actual connectivity is the most difficult or costly to measure while structural connectivity is readily quantified in a GIS. However the relationship between structural and actual connectivity remains ill-defined and requires further empirical support (Calabrese and Fagan 2004). Potential connectivity is commonly analyzed using graph analysis, discussed below in further detail.

Increasingly, conservation biology and planning research is relying on graph theory to better understand the effects of fragmentation on the landscape (Urban et al. 2009). Graph theory presents conservation planners with a concise spatial data structure that represents habitat patches as nodes (points) connected by edges (lines) (Urban and Keitt 2001). In this framework it is relatively easy to analyze the connectivity of a landscape under different development scenarios or conservation plans. For example, nodes can be removed or added, or edges can be thinned, and the effects on the overall connectivity of the graph can be assessed. Graphs are commonly recognized as having the best benefit-to-effort ratio for characterizing connectivity at large scales (Calabrese and Fagan 2004) and providing a concise, unifying solution to evaluating multiple aspects of connectivity at various scales (Minor and Urban 2008).

Likely the most common application of connectivity research is in the design and implementation of corridors. While studies have found positive corridor effects on species movement (Haddad et al. 2003, Gillies and St. Clair 2008) and richness (Damschen 2006), empirical support for positive corridor effects on populations and communities remains ambiguous (Haddad and Tewksbury 2006). Enhancing connectivity alone is not a panacea for conservation as there must be "movement with consequences" (Wiens 2006). That is, species movement is only important as it relates to population dynamics, gene flow and genetic diversification of populations and predator prey-dynamics (Crooks and Sanjayan 2006). It has also been shown that there are costs to increasing connectivity. For example, corridors could facilitate the spread of invasive species (Hutchinson and Vankat 1998) and disease (Jules et al. 2002) and promote disturbance (With 2004).

Ecosystem services

In many cases throughout the world, conservation reserves have forced people from their land. In the process, local inhabitants have been deprived of their sources of food, shelter and income resulting in resentment and backlash against the notion of preserving 'biodiversity' and 'habitat' (Kareiva and Marvier 2007). Partly in response to this backlash, the need to reframe the motivations and goals of conservation were recognized, and the concepts of community-based conservation and conservation of ecosystem services have emerged. It is recognized that many of the traditional mechanisms employed to curb species-loss, ensure functioning ecosystems, and protect natural resources remain inadequate (Balmford et al. 2005, MA 2005, Sec. CBD 2006). By assigning a monetary value on the services that healthy ecosystems provide to human populations, conservationists are now turning to market forces to safeguard ecosystems (Aldhous and Holmes 2007).

Ecosystem services are defined as the human benefits obtained from ecological systems (Costanza et al. 1998). An early conception of ecosystem services describes indirect and direct services from nature (McNeely et al. 1990). Indirect services include watershed protection, photosynthesis, regulation of climate, and production of soil. Direct ecosystem services can be broken down into non-commercial (firewood, fodder, game meat) and commercially harvested (timber, fish, ivory, medicinal plants). The Millennium Ecosystem Assessment (2005) identified four categories of ecosystem services: 1) supporting (e.g., nutrient cycling, soil formation, primary production, crop pollination, pest and disease control), 2) provisioning (e.g., food, fresh water, wood and fiber, fuel), 3) regulating (e.g., climate, flood, disease, water purification, carbon sequestration), and 4) cultural (e.g., aesthetic, spiritual, educational, recreation, ecotourism, inspirational). A fifth ecosystem service category is preservation, or the conservation of options that ensures genetic diversity for future use (Daily et al. 2000). This fifth ecosystem service is also referred to as biodiversity.

Being a relatively new area of inquiry, ecosystem service research has largely focused on efforts to quantify and map ecosystem values. The Natural Capital Project (NCP) is a joint venture launched in October 2006 between The Woods Institute for the Environment at Stanford University, The Nature Conservancy and the World Wildlife Fund. The NCP aims to "align economic forces with conservation by developing tools that make incorporating natural capital into decisions easy (NCP 2006)." Part of this project has involved the development of a set of GIS tools called Integrated Valuation of Ecosystem Services and

Tradeoffs (InVEST). This toolset helps stakeholders model and map the economic and biological implications of various land-use decisions including carbon storage and sequestration, water resources (drinking, irrigation, power), flood mitigation, native pollination, commodity production, biodiversity, recreation and tourism, and cultural and aesthetic-use.

The strength of an ecosystem service approach is its broad public appeal and holistic landscape and ecosystem approach to conservation, which is similar to ecosystem management. Ecosystem management has essentially laid the groundwork for linking ecosystem health with human health (Christensen et al. 1996a). Ecosystem services also have the benefit of valuing the function of the entire ecosystem and not just the requirements of a single-species such as an umbrella species that requires large tracts of land (Simberloff 1998).

Much progress has been made in estimating the economic value of a particular landscape, however the valuation is far from perfect. These efforts represent a 'second-best' strategy of attempting to assign value to ecosystem services greater than their current market value of zero (Troy and Wilson 2006). Ecosystems are complex, both dynamic and adaptive systems which are subject to internal changes such as natural succession and external forces such as climate variability (Arrow et al. 2000). As a result, the amount and quality of service that a particular ecosystem provides can vary widely. It has therefore proven difficult to assign accurate service-values in these complex systems.

With these uncertainties it is not surprising that, although ecosystem services are often mentioned in conservation planning, they are rarely explicitly included (Egoh et al. 2007). A significant challenge of integrating ecosystem services into conservation assessments is the lack of available empirical economic valuation studies (Troy and Wilson 2006). There is also resistance to the notion of trading aspects of an ecosystem as a commodity (Robertson 2006) and potentially devaluing wilderness preservation in the pursuit of sustainable ecosystem management (Noss 1991). However, there is some market momentum in the regulating services of water quality in the form of wetland mitigation banking, and in carbon sequestration and storage in the form of carbon-trading.

Currently there are only two established carbon offset markets that allow for trading credits from sequestration: the Chicago Climate Exchange (CCX) and the European Climate Exchange (ECX). Financial incentives to dissuade the release of carbon through deforestation practices are being integrated into a follow-up agreement on the Kyoto Protocol, but are currently not established (Angelsen 2008, Miles 2008). However, the volatility of the markets represents a potential pitfall in applying market principles to conservation. Currently sequestered carbon is trading at around $USD 20 per metric ton of CO_2 off from its peak of $USD 74 in June 2008 (CCX 2009).

2.4 Thesis Aim

The three conservation assessment approaches described above are potentially divergent and in a field where funds are scarce it is important to avoid duplicate efforts. To determine if there are synergies or gaps, this study will evaluate the most commonly employed conservation assessment techniques. This study compares assessments based on biodiversity hotspots, habitat connectivity for the red-cockaded woodpecker (*Picoides borealis*), and carbon storage as an ecosystem service. This is followed by a comparative analysis of each assessment and comparison with several commonly used statewide assessments. Habitat loss and fragmentation in the ecologically rich Sandhills ecoregion of

North Carolina provides an interesting and timely system for this case study. My research provides an analysis of this landscape and identifies areas of highest conservation value.

Chapter 3: Protecting the hotspots of hotspots: A study of congruency in conservation

3.1 Introduction

There are different criteria on which to assess the conservation value of landscape parcels. These may be spatially congruent thereby providing value-added conservation opportunities, or incongruent, representing trade-offs that should be considered with full knowledge in the conservation planning process. However, little attention has been given to the congruence of multiple conservation assessment criteria, or to how a multi-criteria framework might be used to improve the conservation planning process.

The conservation of biodiversity hotspots has been one of the dominant paradigms of conservation planning for the past decade. However, the paradigm is shifting to protection of lands that enhance or promote habitat connectivity. Conservation trends are also increasingly relying on market-forces and the human-derived benefits ecosystems provide. In this thesis I present a comparison of multiple conservation assessments for the sandhills surrounding Fort Bragg, North Carolina. This work was conducted in four stages: 1) assemble a spatial database with the capacity to support multiple conservation assessment models; 2) implement the conservation assessment models to construct multiple land protection scenarios for the eight county sandhills area; 3) analyze the congruencies and trade-offs among these assessments and some of the more commonly implemented assessments in the region; and 4) assess the value of the current conservation network within the study area.

3.2 Study Area

Physical landscape and context

The Sandhills Region lies between the Piedmont and Coastal Plain of North Carolina and Georgia and ranges in elevation from below sea level to 946 feet above sea level (Figure 2). The characteristic deep and porous sandy soils are thought to be remnants of the advance and retreat of ancient seas and eroded Piedmont clays washed downstream and deposited over time (U.S. Fish and Wildlife Service 2007). This heterogeneous landscape of rolling, sandy hills and valleys formed by wind and water erosion hosts a diverse group of plant communities (U.S. Fish and Wildlife Service 2007). The unusually high species richness is attributed to the spatial and temporal variation in site conditions coupled with a fire regime of frequent low-intensity burns that creates an open park-like understory (Landers 1995, Mitchell et al. 2006). This region is often referred to as the center of southeastern biodiversity (Gilliam et al. 2006). A comprehensive inventory of vascular flora in 2006 identified over 1,200 species representing 143 families and 490 genera on Fort Bragg and Weymoth Woods alone, an area covering approximately 74,000 hectares (Sorrie 2006). Remarkably the plant species diversity per square meter in the longleaf pine (*Pinus palustris)* ecosystems is one of the highest outside of the tropics (Peet and Allard 1993).

Longleaf pine forests once occupied over 90 million acres from Virginia to Florida and westward to Texas (Ft. Bragg ESB 2007). It is estimated that the current range of this ecosystem still spans the same geographic extent but is highly fragmented with only 2.7 million acres or approximately 2.4% to 4% remaining (Jose et al. 2007, The Nature Conservancy 2007). Old-growth longleaf is now considered to be completely extirpated from its historic range (Gilliam et al. 2006).

Sandhills delineation; stakeholders and interested parties

The Sandhills region is defined differently by the numerous land management and conservation organizations who work in the area. The Environmental Protection Agency delineates ecoregions which represent similar ecosystems based on type, quality and quantity of environmental resources (EPA Western Ecology Division 2007). The level IV ecoregion, “Sand Hills,” covers just over one million acres (405,000 hectares) in nine North Carolina counties (Figure 2). The Nature Conservancy (TNC) has historically used this to define the Sandhills Region, but also has partnered with numerous organizations in the area to help form The North Carolina Conservation Partnership (NCSCP), whose mission is to preserve the longleaf pine ecosystem and its dependent species in the N.C. Sandhills. This partnership includes most of the key stakeholders in natural resource management in the area including the N.C. Division of Forest Resources, N.C. Wildlife Resources Commission, TNC, Sandhills Area Land Trust, Sandhills Ecological Institution, U.S. Army Environmental Command (Ft. Bragg), and the U.S. Fish and Wildlife Service. The NCSCP defines the Sandhills as an eight-county area including Cumberland, Harnett, Hoke, Lee, Montgomery, Moore, Richmond, and Scotland counties (Figure 2). This definition of the Sandhills was adopted as the study area for this project.

Military Stewardship; Ft. Bragg

However contradictory “conservation” and “military” may seem, the United States Department of Defense has an important role to play as the third largest land holder in a federal government (Goodman 1996) which manages over 670 million acres of land or roughly 1/3 of the land area of the United States (National Atlas 2007). Perhaps the most prominent feature of the Sandhills is Fort Bragg, a military installation occupying around

63,000 hectares, approximately 15% of the Sandhills and home to the largest expanse of intact healthy longleaf pine as well as the U.S. Army's 82nd Airborne and Special Operations Force. Ecosystem and wildlife management are central to land-stewardship activities on many military installations. However, development pressures and land fragmentation around military installations undermine efforts to manage on-base ecosystems and the wildlife that they support. On Fort Bragg, land management has focused primarily on the recovery of the red-cockaded woodpecker (*Picoides borealis*, here after referred to as RCW), a federally endangered species whose historical range covered the Piedmont and Coastal plain from New Jersey to Texas and inland to Tennessee, Kentucky, Oklahoma and Missouri (AOU 1983). This species now occupies only a fraction of its range and is restricted to small patches of longleaf pine forest in coastal states (Walters 1991).

Habitat management of RCW is one of the most extensive management programs for a fragmented population in the world (Crooks and Sanjayan 2006). Ft. Bragg met the U.S. Fish and Wildlife recovery goals for RCW on base in June 2006. However there remains a need to assess the effectiveness of ecosystem management as well as the value of RCW as an umbrella species. Ft. Bragg hosts multiple federally endangered species and each has different habitat requirements (Appendix B). Moreover, Ft. Bragg is interested in expanding their land holdings to enhance the habitat connectivity of the endangered species on base. However the region surrounding the base is quickly becoming fragmented by residential and commercial development further isolating the remaining longleaf pine forest in the area (Figure 3). It is precisely this threat which motivated this study of trade-offs and congruency in conservation assessment models and to identify high priority lands for conservation in the Sandhills.

3.3 Methods

Conducting the conservation assessments involved four steps. The first step was to compile the necessary data to carry out the assessments (sec. 3.3.1). This also included preparation of the data layers and evaluating the available software packages capable of this type of analysis. The next step involved three distinct methods to assess the conservation value of the landscape; biodiversity hotspots, connectivity and carbon storage (sec. 3.3.2). The three assessments were compared to each other and the One NC Naturally Conservation Planning Tool's Biodiversity and Wildlife Habitat Assessment (BWHA), and GAP modeled vertebrate diversity (sec. 3.3.3, (McKerrow et al. 2006)). Finally the existing conservation network of protected lands was described in terms of species richness, connectivity, carbon storage, GAP vertebrate diversity, and the BWHA (sec. 3.3.4).

3.3.1 Data Description and Software

When considering the data needs for the conservation assessments one goal was to use data that was readily available, free, and that had statewide coverage (Appendix C). In some cases data was excluded from use if it wasn't available for the entire project study area. National Wetlands Inventory (NWI) was considered for use as these data are commonly used in conservation assessments. In my previous work, NWI boundaries were found to be very inaccurate when compared to actual on-the-ground delineation and was therefore excluded from modeling efforts. However, NWI is part of the Conservation Planning Tool's Wildlife and Biodiversity Assessment which is used for comparison.

The first step in data preparation was to decide on a minimum mapping unit (mmu) and projection. To meet the goal of using readily available data that could be obtained free of cost, I chose the 30 meter mmu standard. The Multi-Resolution Land Characteristics

Consortium (MRLC) has developed the 2001 National Land Cover Database (NLCD) at a spatial resolution of 30 meters for the entire United States. This categorical data is projected in Albers NAD 83 (m) and it was determined that projecting this dataset would result in the greatest amount of information loss. Since another goal of the project was to expand the study area extent beyond the state, Albers NAD 83 was adopted for the projection of all data. After all necessary data was projected to Albers it was clipped to the project extent area.

A second preparatory step involved exploring the software available to land managers and researchers to conduct conservation assessments and planning. There are many GIS tools available for conservation planning and the list is growing (Appendix A). To choose appropriate software for this analysis I had two criteria; functionality and compatibility. Future analysis would require a reassessment of available software. Software packages that were in beta release (e.g. CircuitScape) were avoided unless they were the only option (InVEST). Since the analysis was spatially explicit, a raster approach was taken. A visualization component was also a criterion, which excluded Portfolio. Tools that worked in ESRI's ArcGIS environment were also preferred as it is the industry standard for GIS analysis.

To model species richness I used a statistical distribution model based on maximum entropy (Maxent) for its simplicity, interpretability, processing efficiency and open-source access. Maxent has been shown to perform well in comparison with alternative approaches to prediction of species' distributions (Elith et al. 2006). To map connectivity, I used FunConn since it models functional connectivity and maps multiple pathways between all patches, not just adjacent patches. This is an improvement upon traditional least-cost approaches and produces a graph that can be analyzed through a variety of landscape metrics.

Another software package, CorridorDesigner, is primarily used to connect blocks of wildlife habitat, not to model the connectivity of the entire landscape. Since the Natural Assets Information System is a proprietary piece of software, InVEST was used to map carbon storage (Nelson et al. 2009).

3.3.2 Analytical Methods

Biodiversity Hotspots

A modification of the classic biodiversity hotspots approach was implemented to identify regional Sandhills hotspots. This approach identified areas with the highest concentration of endemic, endangered, threatened or rare (EETR) vascular plant species habitat under the greatest threat of development. This was achieved in two phases; modeling EETR habitat and creating a development threat proxy.

Modeling EETR habitat

There were three distinct process steps to modeling rare species habitat; 1) preparation of sample data, 2) collection and creation of environmental variables, and 3) Maxent ecological niche modeling. To identify EETR species present in the Sandhills I supplemented the International Union for Conservation of Nature (IUCN) Red List of Threatened Species with the Natural Heritage Program (NHP) Natural Heritage Element Occurrence (NHEO) coverages. Environmental variables were either used as provided or developed from a digital elevation model (Appendix C). Detailed process steps and descriptions of each variable can be found in Appendix D. These data were supplied as predictive surfaces to Maxent, a maximum entropy model for predictive mapping of species potential geographic distributions using species occurrence data and environmental variables (Phillips 2006, 2008).

Preparation of sample data

The NHEO data contain polygons delineating known populations of plants, animals, exemplary or unique natural communities and important animal assemblages for all of North Carolina and range in size from 38 m^2 to over 30,000 ha. For the purpose of this analysis only vascular plant species were used. The NHEO coverage includes endangered, threatened, special concern, significantly rare and endemic species. The species occurrence data was obtained from the NHP on November 20th 2008 with Misty Buchanan's assistance, a Natural Heritage Program botanist.

A systematic filtering process was undertaken first to ensure accurate representation of species occurrences. All records with an estimated accuracy of very low or low and with uncertainty distances greater than 100 meters were deleted. Element occurrence records classified as destroyed or historic were excluded from this analysis and spatially redundant records were omitted. The final outcome from the above filtering was a single polygon coverage with 1686 records for 131 vascular plant species.

Maxent requires species presence localities to be geolocated. Since the NHEO polygons represent patches of habitat where a species has been found, a strategy to populate the polygons with sample points was developed. I used a stratified random sampling scheme within each polygon based on area, accuracy and polygon shape, and enforced a minimum distance of 30 meters between samples points (Table 1, Appendix E, (Beyer 2004)). I referred to the NHP Guidelines for Determining Representation Accuracy to determine the density of sample points for features.

Environmental variable collection and creation

The next step was to gather appropriate environmental variables for modeling potential rare vascular plant species distribution (Table 2). Detailed descriptions and process steps for the creation of the environmental grids can be found in Appendix C and D. Aspect, elevation, slope, relative slope position (rsp, (Wilds 1996)), solar radiation, topographic relative moisture index (trmi, (Parker 1982)), and wetness index (Beven and Kirkby 1979) were all derived from the digital elevation model (DEM). This DEM was created by the NCDOT GIS department from LiDAR data collected by the North Carolina Floodplain Mapping Program. The NCDOT compiled the data to a 20 foot cell size and is distributed by county. Using ArcInfo Workstation all 100 counties were merged together. The resulting grid was resampled using cubic convolution and reprojected from North Carolina State Plane NAD 83 ft to Albers NAD 83 m, at a 30 meter spatial resolution. ArcInfo Workstation was then used to derive aspect, rsp and trmi. ArcToolbox was used to create the solar radiation index. The Wetness Index was created using the Terrain Analysis System (TAS) (Lindsay 2005). Precipitation and temperature were obtained from an 18-year annual average produced by Daymet (Thornton et al. 1997). The National Land Cover Database 2001 provided both land use/land cover and canopy cover data produced by the Multi-Resolution Land Characteristics Consortium.

Maxent Ecological Niche Modeling and Richness Maps

Potential EETR plant species distribution was modeled based on the principle of maximum entropy (Maxent) using species presences only (Phillips et al. 2004, Phillips 2006). Phillips et al. (2006) provides a concise mathematical definition of Maxent and its application to species distribution modeling in their paper introducing the model. Maxent is a machine learning, presence only species distribution model and has been shown to be effective with sample sizes as low as five (Pearson et al. 2007). It also performs well in comparison with alternative models such as GARP, BIOCLIM and commonly used generalized additive models (Elith et al. 2006). For my analysis only species with at least 10 occurrence records were used.

Unlike typical approaches to habitat modeling that are discriminative and distinguish habitat from non-habitat, Maxent characterizes habitat samples in themselves, without reference to other absence samples (Urban 2008). The optimal probability distribution based on a set of environmental constraints is sought. This approach attempts to map the probability distribution of maximum entropy, that which is closest to uniform, subject to the constraint that the expected value of each environmental variable under this estimated distribution matches its empirical range (Phillips et al. 2004, Phillips 2006).

In order to use the Maxent model all that is needed are species occurrence records along with a set of environmental variables that are thought to influence the suitability of the environment for the species in question. Maxent was run with the environmental variables in Table 2 and the presence locations derived from the NHP data described above. The model was implemented using version 3.2.19 of the software developed by S. Phillips and colleagues (for free download at: http://www.cs.princeton.edu/~schapire/maxent/). Recommended default values were used for the convergence threshold (0.001%) and maximum number of iterations (500). The maximum number of background points was 10 000 and 25% of occurrence samples were withheld randomly for testing the output model. See Appendix F and G for the screen shot of the GUI and the Maxent log.

Species range maps were created for each species based on the balanced logistic threshold. This threshold is simply the logistic cutoff value that distinguishes habitat from non-habitat. Richness maps were created by running a script (see Appendix H) that took the output ascii grids from Maxent and converted them to binary range maps. The ascii grids were converted to ArcGIS grids and summed up to get a total number of potential species per pixel.

Development Threat Proxy – SLI

Areas are defined as hotspots based on both degree of threat and richness. For areas of high richness, the degree of threat is analyzed. In Myers et al. (2000), if less than 70% of the "primary vegetation" remains in an area then it qualifies as a biodiversity hotspot on the risk dimension. I assessed the degree of threat using the Strategic Lands Inventory (SLI). The second release of the SLI was carried out by The Conservation Fund and North Carolina Center for Geographical Information and Analysis based on work initially conducted by the Sustainable Sandhills Partnership and the BRAC Regional Taskforce. This release was completed in November 2008 (TCF and NCCGIA 2008).

The SLI ranks the suitability of each 30 m pixel for each of six types of land use using a scale from 1-9 based on landscape attributes relating to infrastructure, site location preference, and known land constraints. Three of the six land uses are relevant for development; *commercial, industrial* and *residential*. These three SLI land use models were used to develop a proxy for development threat.

From these data I determined, for each pixel, the suitability for residential, commercial, or industrial development. I then created a composite development risk index (CDRI) for each pixel based on its priority level in the three development categories

(Appendix I & J). For example, a grid value of 60 indicates those pixels which were classified as highly suitable (7-9) for industrial, residential and commercial development. A value of 20 indicates areas which are highly suitable (7-9) for industrial development only. The three CDRI maps represent highest risk, high risk and moderate risk for development. The SLI model was then re-classified in a number of ways in order to create binary maps that depict areas of highest risk (value = 60), high-moderate risk (values = 40-70), and moderate risk (values = 20, 30, 80). Summing the three models together also created a continuous development model.

Producing Hotspot Maps

Biodiversity hotspots are typically defined as ecoregions containing at least 0.5% of the world's 300,000 plant species as endemics which translates as 1500 total (Myers et al. 2000). The most recent statewide inventory for North Carolina recorded 18 endemics and 4242 vascular plant species (Buchanan and Finnegan 2008). There were 1715 total plant species in the eight county area according to the USDA plants inventory, only one of which is endemic (USDA and NRCS 2009). However, in a study compiling vascular flora data surveys from 1965 to 2003 of Fort Bragg and Weymouth Woods Sandhills Nature Preserve five endemics were recorded (Sorrie 2006). By using the traditional mechanism of defining a hotspot, 0.5% of the total number of vascular plant species in an area, a statewide hotspot (4242 plant species) would have to contain 21 endemics and a regional Sandhills hotspot (1715 plant species) would have to contain 9 endemics. Since these thresholds exceed the total number of endemics in the state and likely the region, the traditional definition of a hotspot was amended to include endangered, threatened and rare (ETR) species. The inclusion of ETR species also addresses one of the common criticisms of incongruence of hotspots among rare and endemic species (Lombard 1995, Orme et al. 2005). Species cutoffs of 21 (statewide), 15 (halfway in between scales), and 9 (regional) were used as three degrees of hotspot priorities.

Hotspot maps were produced in two ways. Three binary hotspot maps were created by multiplying the binary richness map (n >= 21, 15 and 9) by the three CDRI maps described above (highest, high, moderate). Another way to conceptualize these three binary maps is as inclusive, moderate, and stringent. A continuous hotspot index was also created by constraining (normalizing) the value of the richness and development models between 0-100. Assuming equal weight, the two models were multiplied together to obtain a continuous hotspot index. The final step for both binary and continuous models was to mask out land not at risk of being developed that is already in the conservation network; lands managed for conservation, open space, state parks, conservation easements, and other managed areas.

Habitat connectivity for the RCW

The first step in modeling habitat connectivity was preparation of a land use/land change map. The next step was to model habitat connectivity using the FunConn toolset for ArcGIS. (Theobald 2006, Theobald et al. 2006). I used FunConn to produce a landscape network that was analyzed using minimum spanning trees to describe the most efficient path of connecting all patches in a network.

Land Use/Land Cover reclassification

The landscape characterization (Appendix K) was devised based on review of the USFW RCW Recovery Plan (U.S. Fish and Wildlife Service 2003), relevant literature describing the habitat affinities for RCW (Walters 1991), and similar studies which defined relevant RCW land classes (Bruggeman and Jones 2008). The land classes that were deemed important for RCW movement and habitat selection are longleaf pine, other pines, hardwood, open and urban. Longleaf pine is the preferred habitat for RCWs, offering the least resistance to movement. Sub-optimal habitat is assumed to offer more resistance. As described in the recovery plan RCWs avoid moving through open areas or areas with a dense hardwood understory.

Once the land use types were determined, NLCD and GAP land cover data were combined and reclassified (Appendix K). In order to map longleaf pine the land cover data created by the Southeast GAP Analysis Program was used. Those NLCD cells classified as evergreen or mixed forest were grouped and then classified as longleaf pine if they were mapped as any form of longleaf in the GAP data. The remaining classes were mapped by collapsing similar classes together (Appendix K).

Functional connectivity and FunConn

In order to map functional connectivity for the RCW, a landscape network was created and analyzed using FunConn tools for ArcGIS (Theobald et al. 2006). A landscape network is similar to the traditional graph analyzed in graph theory (Urban and Keitt 2001) which stores both the topology of the graph and the topology of the nodes and edges (Theobald 2006). The landscape network represents habitat patch connectivity and contains nodes, patches, edges, linkages, corridors and relationship tables (Figure 4).

Connectivity was modeled and then analyzed with FunConn in two stages. The first stage built the landscape network by creating a habitat quality raster and then defining functional patches. Functional patches are based on the species' minimum foraging requirements and its minimum home range. The second stage involved analysis of the landscape network by calculating the minimum spanning tree and thinning edges.

Implementing FunConn required estimation of the following parameters; 1) minimum patch size, 2) patch/foraging radius, 3) habitat quality values per land class, 4) habitat quality threshold and 5) the resistance to movement through each land class.

Estimating Parameters

The first step in estimating parameters was a literature review (Appendix L). Many methods have been used to estimate RCW home-range (patch) size with results that range from 40.5 to 161.9 ha (U.S. Fish and Wildlife Service 2003). This study used the recommendations from the U.S. Fish and Wildlife Recovery Plan that stipulates a minimum of 49 ha of good quality habitat (U.S. Fish and Wildlife Service 2003). The foraging radius is also given in the recovery plan as 800 meters.

Habitat quality values are often determined through expert opinion. To take a more objective approach, I implemented a maximum entropy approach to species modeling with binary land classes (longleaf pine, other pine, hardwood, urban, and open) as the environmental variables (Phillips et al. 2004). The lambda values are used in the logistic output and their relative magnitudes describe the weight or importance of each variable in creating the potential distribution. These values were re-scaled from 0-100 to get habitat quality values for each land class (Appendix M).

The resource quality threshold typically lies near 75-80 (Theobald et al. 2006) but for the RCW a lower threshold was used. According to research conducted by Walters et al. (2002) defining quality of red-cockaded woodpecker foraging habitat in the Sandhills of North Carolina, of the 30 groups studied 13 contained no habitat that met their definition of high quality habitat . However, this does lend support to the idea that the red-cockaded woodpecker has the capacity to occupy patches of forest that are sub-optimal or medium quality. Therefore a habitat quality threshold of 60 was used, meaning that there has to be at least one pixel classified as longleaf pine (100) per nine-cell neighborhood (Appendix M).

To assign resistance values, the dispersal behavior preferences of RCW modeled by Bruggeman and Jones (2008) were adopted. In this research old-growth longleaf pine was twice as attractive (permeable) for dispersal movement as restored second-growth longleaf pine, second growth longleaf pine was 2.5 times as attractive as pine-hardwood, and pine-hardwood was 4 times as attractive as the non-forested cells. In my study longleaf pine (old-growth above) is twice as attractive as other pine (second-growth). Other pines are 2.5 times as attractive as hardwood and hardwood is 4 times more permeable than open areas (Appendix M).

Graph Analysis

Graph theory presents conservation planners with a concise spatial data structure that represents habitat patches as nodes (points) connected by edges between nodes (Urban and Keitt 2001). A landscape network is analyzed using traditional graph theory and has four prominent characteristics (Theobald 2006). First, landscape networks store both the topology of the graph and the topology of the nodes and edges (Figure 4). Second, nodes represent functionally defined habitat patches. Third, edges are weighted by the relative representation of land cover types using cost-weighted distance. Finally, landscape networks employ planar graph algorithms (2-D space, edges do not cross one another) and recognize stepping stone movement (Theobald 2006).

Three landscape networks were created and analyzed. All parameters were held constant except the cost threshold (q_n = 5, 10, 25) which resulted in different edges, linkages and corridors. Next the minimum spanning tree was calculated based on linkage resistance.

The minimum spanning tree represents the least resistant set of linkages that connects all nodes. Since FunConn produces multiple corridors between patches only those corridors that made up the minimum spanning tree were used. Three binary grids were then produced which contained the patches and corridors for the different least-cost path thresholds. Finally, edges were thinned to the median dispersal distance to measure how connected populations were.

Ecosystem Services; carbon storage

The InVEST carbon tool quantifies carbon storage based on the sizes of four pools: aboveground biomass, belowground biomass, soil and dead organic matter. The first step to mapping carbon stores was to determine which land cover classes the average carbon storage would be summarized for. Next, a literature search was conducted to determine the amount of carbon stored in each pool for each cover class. Finally, the InVEST model was run and the results were analyzed.

Land cover classification

Local field estimates for detailed land cover classes are the ideal data source, however these were not available. Therefore, land cover classes were reclassified into six broad land-use categories set forth by the Intergovernmental Panel on Climate Change (IPCC) for consistent representation of lands; forestland, grassland, cropland, wetland, settlement and other (Appendix K).

Estimating carbon pools

Since local field estimates were not available, estimates were drawn from a literature review of the available economic valuation studies. Where appropriate estimates could not be found the IPCC default values were used or the InVEST defaults (IPCC 2006). The most accurate source of data was The Carbon Online Estimator (COLE) which provided carbon characteristics of forested land in the aboveground, belowground, soil and dead carbon pools. COLE draws upon the available Forest Inventory Analysis (FIA) data and can be summarized for individual counties. COLE was used to generate report 1605(b) for North Carolina for the 8-county project study area on October 28, 2008. The estimates and their sources are summarized in Table 3.

InVEST carbon modeling

Inputs to the InVEST carbon model included the reclassified land cover discussed above and the carbon pool estimates in Table 3. The model output for carbon storage is a single raster surface totaling the amount of carbon from all four pools combined. Mapping carbon sequestration requires a future land cover map and was not available for this study. Refer to Appendix G for an image of the model.

3.3.3 *Comparative* Analysis

Two analyses were conducted to compare the conservation assessments; pixel based and parcel/area based. First the three binary assessments were compared in a congruence table (Table 4). This was created by combining the grids and analyzing the area of overlap between assessments. The congruence table answers the question; If you preserve the entire area of one binary assessment how much of the other two assessments are you also preserving? Next a parcel analysis was conducted whereby different measures of the conservation value were calculated for each tax parcel. Parcels that were smaller than two acres were excluded from this analysis (8100 m^2, a nine-cell neighborhood). The mean, median, standard deviation and sum was calculated for the rare plant habitat, hotspots index, and total carbon within each parcel. The total area of patch and corridor ($q_n = 10$) were also calculated per parcel. Conservation value was summarized for private and protected/managed land separately. Parcels were then ranked based on different conservation values to determine the top 10% of the landscape for each assessment.

Parcels were ranked based on two different priorities; per-unit area and area-weighted. In this scenario, those parcels with the highest density of rare species habitat and total carbon per hectare were ranked highest. The area-weighted ranking was implemented by multiplying the mean habitat score, mean carbon, and mean hotspot index by the area of each parcel. This technique favored larger parcels. To rank parcels based on connectivity those parcels with the highest proportion of patch and corridor were ranked highest.

After parcels were ranked the conservation value of each assessment was accumulated to get a running sum of total habitat score, carbon, hectares of corridor and patch and accumulated mean index. To compare the assessments the accumulated conservation value was scaled from 0-1 and plotted against accumulated area to simulate building the reserve by adding parcels.

The assessments were then compared to the Southeast GAP Analysis Project vertebrate predicted distribution maps, hereafter referred to as GAP richness (McKerrow et al. 2006). The GAP richness data is a compilation of habitat models for 606 species. Comparisons were also made to the Biodiversity and Wildlife Habitat Assessment (BWHA). The BWHA is part of the Conservation Planning Tool created by ONE North Carolina Naturally and ranks pixels from 0-10 based on ecosystem function; aquatic and terrestrial habitat, landscape function and connectivity. Values of -1 are assigned to pixels of impervious surface. The final comparative analysis examined the intersection of all parcels that made up the top 10% of the landscape for each assessment.

3.4 Results

Rare Plant Species Habitat

Of the 66 plant species distributions modeled in Maxent, 10 were discarded as the model predictions were no better than a random model. This resulted in 56 range maps being overlaid. Since Maxent predicts the probability of suitable habitat and not the actual species occurrence this overlay resulted in an index of rare plant species habitat. This habit index showed a clear concentration of rare habitat in the Sandhills ecoregion especially within Ft. Bragg, Camp Mackall and the Sandhills Gamelands (Figure 5). The average habitat score per pixel was 15.1 on protected areas, 12.8 on private lands (Table 5).

To validate the richness model a comparison was made to the Carolina Vegetation Survey (CVS) database. There were 389 plot locations in the project study area and 341 with a location accuracy of 100 meters or less. The CVS database tracks ALL plant species in 10 by 10 meter plots. The correlation coefficient for CVS total richness and rare habitat was 0.137 and -0.066 for rare habitat and the 56 EETR species modeled. By limiting the CVS plots to only those with the highest spatial accuracy (<= 100m), plots that were 100 m^2, and only occurred in the Sandhills the correlation coefficient was 0.430. These results indicate that there is very little correlation between the rare plant species habitat model and the CVS data. However, as stated before, Maxent maps the probability of suitable environmental conditions for the species in question and does not predict the actual occurrence of a species being present.

Biodiversity Hotspots

The three different richness (rare habitat) and development thresholds created three very different hotspots maps (Figure 6). The statewide hotspots were sparse, occupying only 1.7% of the landscape with the highest concentration occurring northeast of Ft. Bragg. On the other hand, the regional hotspot definition classified 28% of the landscape as a hotspot (Figure 6). Land surrounding Ft. Bragg, Camp Mackall and the Gamelands would all be a high priority to protect if preserving for biodiversity hotspots (Figure 7).

Habitat Connectivity for RCW

The three landscape networks created depicting habitat connectivity for RCW appear similar (Figure 8-A). However, the three different corridor scenarios prioritize different portions of the landscape. When the cost threshold is low (q_n= 5), linkages between patches are only made in the least-costly manner. Movement is therefore tightly constricted as evident by the narrow corridors (Figure 8-B). When the cost threshold is high (q_n = 25) the linkages can be made across more of the landscape. Corridors are thus wider and connections are made through areas that are likely not permeable for the RCW, such as through Fayetteville in the southern part of the study area.

There were a total of 131 unique patches with an average size of 764.7 ha, and median patch size of 217.8 ha. The largest five patches make up over half of the entire patch network. The largest patch is over 19,000 ha, 95% of which is contained within the boundaries of Ft. Bragg. The second largest patch is 10,400 ha, 60% within Ft. Bragg boundaries. In fact, 50% of all patches are contained within protected lands and lands managed for conservation. However, only 4.5% of the total corridor (q_n = 10) land area that makes up the minimum-spanning tree is currently under protection. When the median dispersal distance for RCW is used to thin the edges it is shown that the landscape is largely connected (Figure 9).

Carbon Storage

According to InVEST, the total standing stock of carbon stored in the study area is 166,015,119 metric tons. If this service had the same value as a ton of sequestered carbon it would be worth $3.3 million. The highest concentration of carbon is found in wetland soils and aboveground forest biomass (Table 3). The carbon storage mapping highlights forestlands and wetlands in dark green concentrated within the Ft. Bragg boundaries, to the Uwharrie National Forest Area and the Cumberland County Carolina Bay area in the southeast (Figure 10). The average carbon storage per pixel on private and protected lands is roughly the same though the vast majority of carbon is stored on private land (Table 5), which makes up over 87% of the landscape and hold 80% of the standing stock of carbon.

Comparative Analysis

Overall there was very low congruence amongst the highest value assessments (Table 4). The lowest congruence occurred between high value carbon storage (wetlands) and the other two assessments. The cutoffs for the binary assessments showed a large influence on the congruence as the more inclusive assessments prioritized a greater portion of the landscape and increased overall congruence amongst assessments. If conservation priorities are set to protect the highest risk hotpots, then 2.6% of the land valued for connectivity and 0.6% of the most carbon rich areas are also conserved. This illustrates a very low congruence. However, if land is conserved based on the highest value land for connectivity, 16.5% of the hotspots and 6.9% of the Carbon are also conserved, a modest improvement. Conserving a comparable amount of land based on carbon rich areas only preserves 3.8% and 6.1% of the hotspots and connectivity respectively.

The existing conservation network makes up 12.7% of the entire landscape (129,007 ha). Parcels in this network are on average 100 times larger than privately owned parcels. Protected parcels also have higher plant species richness and a higher Biodiversity and Wildlife Habitat Assessment value per pixel (Table 5). The mean sum of these two assessments per parcel is also more than 100 times greater as the area difference would suggest. However the average carbon storage value and GAP vertebrate richness were roughly the same on protected vs. private land. This relationship can also be seen when looking at the frequency distribution of conservation values on protected and private land (Figure 11). However, these distributions also show that protected lands are carbon rich or carbon poor, a pattern not discernable from the table alone.

Though the congruence amongst assessments was low, parcels which were in the top 10% of all six assessments were still identified on the landscape when using an area-weighted selection algorithm (Figure 12). These parcels can be considered win-win opportunities for conservation since they are important for all six conservation assessments. Ranking parcels by their per unit area conservation value favors smaller more homogenous parcels. However, there are no shared parcels between all six assessments when using this prioritization scheme (Figure 13).

Conservation value was accumulated most quickly by ranking and protecting parcels based on their proportion of corridor area (Figure 14). If parcels are ranked and then protected according to the area-weighted hotspot index or BWHA score, conservation value accumulates the slowest. Accumulating carbon and rare plant habitat appears to be a linear relationship with area.

3.5 Discussion

Land conservation remains under-funded, with inadequate resources to curtail the currently high rates of habitat loss and species extinction (Balmford et al. 2005). In North Carolina, the population is expected to increase by 50% to over 12 million by the year 2030 (U.S. Census Bureau 2005). This population growth and subsequent land-use change will cause further land degradation and habitat fragmentation. With the increased pressure placed on natural lands due to anthropogenic change, as well as limited funding for conservation, conservation practitioners need to be efficient and effective in choosing which land to conserve.

There are numerous ways to value the landscape; biodiversity, ecosystem services, habitat connectivity, and others. This research has shown that there is strength in diversifying conservation efforts as each technique prioritizes different parts of the landscape. However, if the three assessment criteria considered here are assumed to be of equal importance, and if only one criterion can be used in the Sandhills, corridor protection would be prioritized because it picks up the highest percentage of land from the other assessments and at the highest rate. Based on the rate of conservation value accumulation, those assessments with higher rates were spatially clumped whereas the other assessments were more evenly disbursed spatially. Even with low congruence, win-win parcels can be identified on the landscape that are important for all six assessments implemented in this study. Though limited in geographical scope, the same framework can be applied in any setting or at any scale.

The geographic scope of this study could be expanded to include an assessment of the entire state of North Carolina to determine whether the same congruence patterns hold. It would also be wise to examine if the resolution of modeling affects patterns of conservation value by re-sampling the input data to 100 m, 250 m, and 1 km since research has shown that there is dependence between species range maps and the scale of input data (Hurlbert and Jetz 2007). Conducting the assessments at this scale would also allow for the inclusion of other remote sensing data such as those available from MODIS.

To improve upon the hotspots modeling several additional environmental variables could be included. One valuable source of data that was not used but would likely enhance the results of the species niche models is the Soil Survey Geographic (SSURGO) Database soils dataset. The Natural Resource Conservation Service (NRCS) is in the process of digitizing the county soil surveys and will likely be available for all 100 North Carolina counties by the end of the 2009. Additionally, all of the elevation-derived variables could be produced at a finer resolution (20 ft.) that could possibly result in a more robust species model. An additional source for plant species locations that should be used in future analysis is the Carolina Vegetation Survey (CVS) database. Finally, both InVEST and NatureServe's conservation planning tool VISTA map and model biodiversity and should be considered for future analysis. Field validation of the species richness model would also make this study more robust. To validate the species richness model, vegetation plots could be randomly sampled to record the total number of rare species occurrences.

Past work has shown that high quality RCW habitat consists of intermediate pine density, abundant herbaceous ground cover, scattered midstory low in density and height and abundant old-growth pines (James et al. 2001, Walters et al. 2002) and that the structure and quality of foraging habitat is directly related to fitness and habitat selection. However, such detailed data on forest structure for the entire 8-county project study area were not readily available. Therefore this study assumed equal quality within a longleaf pine pixel. Future analysis should attempt to incorporate forest structure into habitat quality estimates for the RCW as well as differentiate forest types and quality of longleaf pine.

By definition, habitat connectivity is species-specific. This study examined the connectivity for a species that could be considered both the flagship and umbrella species for the Sandhills region. However, future analysis should examine multiple species in a multiple scale framework. For example, a landscape network for the endangered amphibians (ETS, CGF) on Ft. Bragg and Camp Mackall using known breeding sites could be created and analyzed relatively easily. However, very little is known on the movement preferences of these species and additional data is needed to parameterize accurate movement models.

The first step to more accurately mapping the standing stock of carbon is to further distinguish between land-use types and to differentiate age class within forest types. To improve upon the carbon storage estimates obtained from the literature, local field estimates of the fundamental carbon pools should be incorporated. Sample plots could be established in each of the broad land-use categories or a more detailed classification could be used.

There are also many assumptions in the InVEST carbon storage model that simplify the carbon cycle and dilute the precision and utility of the results. Therefore future analysis should focus on sequestration and implementation of the second tier of InVEST models that incorporate more complexity in the carbon modeling. More empirical research is also needed to quantify ecosystem services, especially wetland carbon pools and sequestrations rates. This could be collected in the field and would be especially useful if part of a LTR.

However, the actual value that the ecosystem service of storing and sequestering carbon is still debated. In a 2007 congressional testimony to the Committee on Natural Resources, Dr. William Schlesinger concluded that growing forests to store carbon will not contribute significantly to reducing concentrations of carbon dioxide in the atmosphere. Furthermore, administrative costs including audits to measure the carbon uptake of a forest and costly fire insurance would reduce the modest financial gains expected from this form of carbon trading. In the Longleaf Pine Ecosystem, which is adapted to frequent low-intensity burns, fire could potentially reduce the amount of carbon stored in the understory. However, fires in this landscape would likely not affect storage and sequestration rates in the largest pool, wetland soils. In the 8-county Sandhills area, carbon storage will likely not be a realistic conservation goal but carbon storage does become a publicly traded commodity, the large amounts of carbon currently stored in private land will likely play a big part.

InVEST also models other ecosystem services such as pollination, timber, water quality (sedimentation and pollution control), and biodiversity. Future work should examine the relationship between multiple ecosystem services, biodiversity and connectivity. Finally, as Hartig (2009) argues, the spatial relationship amongst different assessments deserves further examination as ecological values based solely on quality and size ignores the fundamental rule of geography that spatial context matters.

Much of the current focus in conservation planning research is on bridging the research-implementation gap by translating conservation plans into action through effective land management (Knight et al. 2008, Opdam et al. 2008). Further research is needed to determine the degree to which this gap can be closed and to identify the key components of a successful plan (Ferraro and Pattanayak 2006). However, it is clear that if conservation actions are to be effectively implemented they should: 1) follow an "informed opportunism" when possible (Knight and Cowling 2007, Noss 2002), 2) practice systematic conservation planning that embraces social science research and integrates it with economic and political imperatives (Groves 2003, Margules and Pressey 2000) and 3) manage the matrix between reserves (Wiens 2007).

No matter which assessment criteria are implemented, our land use decisions leave an almost indelible imprint on the landscape. This research has shown that even with low congruence amongst criteria, parcels can be identified which represent win-win opportunities for multiple conservation values. These parcels would likely be a good place to start when looking to expand the existing conservation network and when building consensus amongst stakeholders.

3.6 References

Abbot, J. I. O., & Thomas, D. H. L. (2001). Understanding links between conservation and development in the bamenda highlands, cameroon. *World Development, 29*(7), 1115.

Aldhous, P., & Holmes, B. (2007). Innovate or watch rare species disappear. *New Scientist, 2621*

American Ornithologists' Union (AOU). (1983). *Check-list of north american birds* (6th ed.). Lawrence, Kansas: Allen Press, Inc.

Angelsen, A. (2008). REDD models and baselines. *The International Forestry Review, , 10*(3) 465-475.

Arrow, K., Daily, G. C., Dasgupta, P., Levin, S. A., Maler, K., Maskin, E., et al. (2000). Managing ecosystem resources. *Environmental Science & Technology, 34*(8), 1401-1406.

Balmford, A., Crane, P., Dobson, A., Green, R. E., & Mace, G. M. (2005). The 2010 challenge: Data availability, information needs and extraterrestrial insights. *Philosophical Transactions.Biological Sciences, 360*(1454), 221-228.

Balvanera, P., Daily, G. C., Ehrlich, P. R., Ricketts, T. H., Bailey, S., Kark, S., et al. (2001). Editorial: Conserving biodiversity and ecosystem services. *Science, 291*(5511), 2047.

Beven, K. J., & Kirkby, M. J. (1979). A physically based variable contributing area model of catchment hydrology. *Hydrologic Science Bulletin, 24*, 43-69.

Beyer, H. L. (2004). *Hawth's analysis tools for ArcGIS*

Bridgham, S. D., Megonigal, J. P., Keller, J. K., Bliss, N. B., & Trettin, C. (2006). The carbon balance of north american wetlands. *Wetlands (Wilmington, N.C.), 26*(4), 889-916.

Brooks, T. M., Mittermeier, R. A., da Fonseca, G. A. B., Gerlach, J., Hoffmann, M., Lamoreux, J. F., et al. (2006). Global biodiversity conservation priorities. *Science (New York, N.Y.), 313*(5783), 58-61.

Bruggeman, D. D., & Jones, M. L. (2008). Should habitat trading be based on mitigation ratios derived from landscape indices? A model-based analysis of compensatory restoration options for the red-cockaded woodpecker. *Environmental Management (New York), 42*(4), 591-602.

Buchanan, M. F., & Finnegan, J. (2008). *Natural heritage program list of the rare plants of north carolina, 2008 edition*. 1601 MSC, Raleigh, NC 27699-1601: North Carolina Natural Heritage Program, Department of Environmental and Natural Resources.

Calabrese, J. M., & Fagan, W. F. (2004). A comparison-shopper's guide to connectivity metrics. *Frontiers in Ecology and the Environment, 2*(10), 529-536.

Callicott, J. B. (1990). Whither conservation ethics? *Conservation Biology, 4*(1), 15-20.

CCX. (2009). *Chicago climate exchange; CFI historical closing prices.* Retrieved 03/09, 20090311, from http://www.chicagoclimatex.com/index.jsf

Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation planning for ecosystem services*. PLoS Biology,* 4(11), 2138-2152.

Christensen, N., Bartuska, A. M., Brown, J. H., Carpenter, S., DAntonio, C., Francis, R., et al. (1996a). The report of the ecological society of america committee on the scientific basis for ecosystem management*. Ecological Applications,* 6(3), 665-691.

Christensen, N. L., Bartuska, A. M., Brown, J. H., Carpenter, S., DAntonio, C., Francis, R., et al. (1996b). The report of the ecological society of america committee on the scientific basis for ecosystem management*. Ecological Applications,* 6(3), 665-691.

Clark, F. S., & Slusher, R. B. (2000). Using spatial analysis to drive reserve design: A case study of a national wildlife refuge in indiana and illinois (USA). *Landscape Ecology, 15*(1), 75-84.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1998). The value of the world's ecosystem services and natural capital*. Ecological Economics, 25*(1), 3.

Crooks, K. R., & Sanjayan, M. (2006). *Connectivity conservation (conservation biology*) (1st ed.) Cambridge University Press.

Daily, G. C., Soderqvist, T., Aniyar, S., Arrow, K., & Dasgupta, P. (2000). The value of nature and the nature of value*. Science, 28*9, 395-396.

Damschen, E. I. (2006). Corridors increase plant species richness at large scales*. Science (New York, N.Y.), 31*3(5791), 1284-1286.

Egoh, B., Rouget, M., Reyers, B., Knight, A. T., Cowling, R. M., van Jaarsveld, A. S., et al. (2007). Integrating ecosystem services into conservation assessments: A review. *Ecological Economics, 6*3(4), 714-721.

Elith, J., Graham, C., & the NCEAS Species Distribution Modelling Group. (2006). Novel methods improve prediction of species' distributions from occurrence data*. Ecography*

(Copenhagen), 29(2), 129-151.

EPA Western Ecology Division. (2007). *Ecoregion maps and GIS resources*. Retrieved 2/21, 2008, from http://www.epa.gov/wed/pages/ecoregions.htm

Ferraro, P. J., & Pattanayak, S. K. (2006). Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *PLoS Biology,* 4(4), e105; E105-488.

Ft. Bragg ESB. (2007). *Longleaf ecosystem*. Retrieved 09/25, 2007, from http://www.bragg.army.mil/esb/longleaf_ecosystem1.htm

Gilliam, F. S., Platt, W. J., & Peet, R. K. (2006). Natural disturbances and the physiognomy of pine savannas: A phenomenological model. *Applied Vegetation Science,* 9(1), 83-96.

Gillies, C. S., & St Clair, C. C. (2008). From the cover: Riparian corridors enhance movement of a forest specialist bird in fragmented tropical forest. *Proceedings of the National Academy of Sciences of the United States of America, 10*5(50), 19774-19779.

Goodman, S. W. (1996). Ecosystem management at the department of defense. *Ecological Applications,* 6(3), 706-707.

Groves, C. (2003). *Drafting a conservation blueprint :A practitioner's guide to planning for biodiversit*y. Washington, DC: Island Press.

Haddad, N. M., Bowne, D. R., Cunningham, A., Danielson, B. J., Levey, D. J., Sargent, S., et al. (2003). Corridor use by diverse taxa. *Ecology, 8*4(3), 609-615.

Haddad, N. M., & Tewksbury, J. J. (2006). Impacts of corridors on populations and communities. In K. R. Crooks, & M. Sanjayan (Eds.), *Connectivity conservatio*n (pp. 391-415). University Press, Cambridge: United Kingdom.

Hall, L. S., Krausman, P. R., & Morrison, M. L. (1997). The habitat concept and a plea for standard terminology. *Wildlife Society Bulletin, 2*5(1), 173-182.

Hartig, F., & Drechsler, M. (2009). Smart spatial incentives for market-based conservation. *Biological Conservation, 14*2(4), 779-788.

Holden, C. (2006). Inching toward movement ecology. *Science, 31*3(5788), 779-782.

Hurlbert, A. H., & Jetz, W. (2007). Species richness, hotspots, and the scale dependence of range maps in ecology and conservation. *Proceedings of the National Academy of Sciences of the United States of America, 10*4(33), 13384-13389.

Hutchinson, T. F., & Vankat, J. L. (1998). Landscape structure and spread of the exotic shrub lonicera maackii (amur honeysuckle) in southwestern ohio forests. *The American*

*Midland Naturalist, 13*9(2), 383-390.

James, F., Hess, C. A., Kicklighter, B. C., & Thum, R. A. (2001). Ecosystem management and the niche gestalt of the red-cockaded woodpecker in longleaf pine forests. *Ecological Applications, 1*1(3), 854-870.

Jose, S., Jokela, E. J., & Miller, D. L. (2007). *The longleaf pine ecosystem: Ecology, silviculture, and restoration (springer series on environmental management*) (1st ed. 2006. Corr. 2nd printing ed.) Springer.

Jules, E. S., Kauffman, M. J., Ritts, W. D., & Carroll, A. L. (2002). Spread of an invasive pathogen over a variable landscape: A nonnative root rot on port orford cedar. *Ecology, 8*3(11), 3167.

Kareiva, P., & Marvier, M. (2003). *Conserving biodiversity coldspots: Recent calls to direct conservation funding to the world's biodiversity hotspots may be bad investment advic*e

Kareiva, P., & Marvier, M. (2007). Conservation for the people. *Scientific American, 29*7(4; 4), 50-57.

Knight, A. T., Cowling, R. M., Rouget, M., Balmford, A., Lombard, A. T., & Campbell, B. M. n. (2008). Knowing but not doing: Selecting priority conservation areas and the Research–Implementation gap. *Conservation Biology, 2*2(3), 610-617.

Knight, A. T., & Cowling, R. M. (2007). Embracing opportunism in the selection of priority conservation areas. *Conservation Biology, 2*1(4), 1124-1126.

Knight, A. T., Driver, A., Cowling, R. M., Maze, K., Desmet, P. G., Lombard, A. T., et al. (2006). Designing systematic conservation assessments that promote effective implementation: Best practice from south africa. *Conservation Biology, 2*0(3), 739-750.

Landers, J. L. (1995). The longleaf pine forests of the southeast - requiem or renaissance. *Journal of Forestry, 9*3(11), 39-44.

Lindsay, J. B. (2005). The terrain analysis system: A tool for hydro-geomorphic applications. *Hydrological Processes, 1*9(5), 1123-1130.

Lombard, A. T. (1995). The problems with multi-species conservation: Do hotspots, ideal reserves and existing reserves coincide*? South African Journal of Zoology, 3*0(3), 145-163.

MA. (2005). *About: Overview*. Retrieved 10/15, 2007, from http://www.millenniumassessment.org

Mace, G. (2000). It's time to work together and stop duplicating conservation efforts ... *Nature (London), 405*(6785), 393-393.

Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. *Nature (London), 405*(6783), 243-253.

McCauley, D. D. (2006). Selling out on nature. *Nature (London), 443*(7107), 27-28.

McGarigal, K., & Marks, B. (1995). *Fragstats: Spatial pattern analysis developed for quantifying landscape structure. general technical report 351*. Pacific Northwest Research Station, Corvalis, OR: USDA Forest Service.

McKerrow, A. J., Williams, S. G., & Collazo, J. A. (2006). *The north carolina gap analysis project: Final report*. Raleigh, North Carolina: North Carolina Cooperative Fish and Wildlife Research Unit, North Carolina State University.

McNeely, J. A., International Union for Conservation of Nature and Natural Resources, World Resources Institute, Conservation International, World Wildlife Fund, & World Bank. (1990). *Conserving the world's biological diversit*y. Gland, Switzerland: Iucn.

Miles, L. L. (2008). Reducing greenhouse gas emissions from deforestation and forest degradation: Global land-use implications. *Science (New York, N.Y.), 320*(5882), 1454-1455.

Millennium Ecosystem Assessment (MA). (2005). *Ecosystems and human well-being: Synthesis.* Washington, D.C.: Island Press.

Minor, E. S., & Urban, D. L. (2008). A graph-theory framework for evaluating landscape connectivity and conservation planning. *Conservation Biology, 22*(2), 297-307.

Mitchell, R. J., Hiers, J. K., O'Brien, J. J., Jack, S. B., & Engstrom, R. T. (2006). *Silviculture that sustains: The nexus between silviculture, frequent prescribed fire, and conservation of biodiversity in longleaf pine forests of the southeastern united states (1)*

Mittermeier, R. A., Goettsch Mittermeier, C., Myers, N., Robles Gil, P., Conservation International, Cemex, S. A. d. C. V., et al. (1999). *Hotspots :Earth's biologically richest and most endangered terrestrial ecoregions* (1st English ed.). Mexico City: Cemex.

Mooney, H. A., Cropper, A., & Reid, W. (2004). The millennium ecosystem assessment: What is it all about? *Trends in Ecology & Evolution, 19*(5), 221-224.

Myers, N. (1988). Threatened biotas: "hot spots" in tropical forests. *The Environmentalist, 8*(3), 187-208.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature (London), 403*(6772), 853-858.

Naidoo, R. R., Balmford, A., Costanza, R., Fisher, B., Green, R. E., Lehner, B., et al. (2008). Ecosystem services special feature: Global mapping of ecosystem services and conservation priorities. *Proceedings of the National Academy of Sciences of the United States of America, 105*(28), 9495-9500.

National Atlas. (2007). *Federal lands and indian reservations.* Retrieved 02/27, 2008, from http://nationalatlas.gov/printable/fedlands.html

NCP. (2006). *About the natural capital project*. Retrieved 11/26, 2007, from http://www.naturalcapitalproject.org

Nelson, E. E., Mendoza, G., Regetz, J. P., S., Tallis, H., Cameron, D. R., Chan, K. M. A., et al. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment,* 7(1), 4-11.

Noss, R. F. (1991). Sustainability and wilderness. *Conservation Biology,* 5(1), 120-122.

Noss, R. (2002). A multicriteria assessment of the irreplaceability and vulnerability of sites in the greater yellowstone ecosystem. *Conservation Biology, 1*6(4), 895-908.

Noss, R. F. (1991). Sustainability and wilderness. *Conservation Biology,* 5(1), 120-122.

Opdam, P., Pouwels, R., van Rooij, S., Steingrover, E., & Vos, C. C. (2008). Setting biodiversity targets in participatory regional planning: Introducing ecoprofiles. *Ecology and Society, 1*3(1), 20.

Orme, C. D., Davies, R. G., Burgess, M., Eigenbrod, F., Pickup, N., Olson, V. A., et al. (2005). Global hotspots of species richness are not congruent with endemism or threat. *Nature (London), 43*6(7053), 1016-1019.

Parker, A. J. (1982). The topographic relative moisture index: An approach to soil-moisture assessment in mountain terrain. *Physical Geography,* 3(2), 160-168.

Pearson, R. R., Raxworthy, C. J., Nakamura, M., & Peterson, A. T. (2007). Predicting species distributions from small numbers of occurrence records: A test case using cryptic geckos in madagascar. *Journal of Biogeography, 3*4(1), 102-117.

Peet, R. K., & Allard, D. J. (1993). *Longleaf pine-dominated vegetation of the southern atlantic and gulf-coast region, US*A. Tallahassee, Florida: Tall Timbers: Proceedings, Tall Timbers Fire Ecology Conference, 18.

Phillips, S. J., Dudik, M., & Schapire, R. E. (2004). A maximum entropy approach to species distribution modeling. *ACM International Conference Proceeding Series, Proceedings of the Twenty-First International Conference on Machine Learning, 6*9, 83.

Phillips, S. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling, 19*0(3-4), 231-259.

Phillips, S. (2008). Modeling of species distributions with maxent: New extensions and a comprehensive evaluation. *Ecography (Copenhagen), 3*1(2), 161-175.

Pimm, S. L., Russell, G. J., Gittleman, J. L., & Brooks, T. M. (1995). The future of biodiversity. *Science, 26*9(5222), 347-350.

Reid, W. V. (1998). Biodiversity hotspots. *Trends in Ecology & Evolution, 1*3(7), 275-280.

Robertson, M. M. (2006). The nature that capital can see: Science, state, and market in the commodification of ecosystem services. *Environment and Planning.D, Society & Space, 2*4(3), 367-387.

Saunders, D. A., Hobbs, R. J., & Margules, C. R. (1991). Biological consequences of ecosystem fragmentation - A review. *Conservation Biology,* 5(1), 18-32.

Scott, J. M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., et al. (1993). Gap analysis: A geographic approach to protection of biological diversity. *Wildlife Monographs,* (123, Gap Analysis: A Geographic Approach to Protection of Biological Diversity), 3-41.

Secretariat of the Convention on Biological Diversity (Sec. CBD). (2006). *Global biodiversity outlook* 2. Montreal:

Simberloff, D. (1998). Flagships, umbrellas, and keystones: Is single-species management passé in the landscape era*? Biological Conservation, 8*3(3), 247-257.

Sorrie, B. A. (2006). The vascular flora of the longleaf pine ecosystem of fort bragg and weymouth woods, north carolina. *Castanea, 7*1(2), 129-161.

Tallis, H. M., & Kareiva, P. (2006). Shaping global environmental decisions using socio-ecological models. *Trends in Ecology & Evolution, 2*1(10), 562-568.

Taylor, P. D., Fahrig, L., & Henein, K. (1993). Connectivity is a vital element of landscape structure. *Oikos, 6*8(3), 571-573.

TCF, & NCCGIA. (2008). *Strategic lands inventory: Planning and decision support tools for achieving sustainability for north carolin*a No. Phase 2)The Conservation Fund, North Carolina Center for Geographic Information Analysis.

The Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC guidelines for national greenhouse gas inventorie*s No. Volume 4: Agriculture, Forestry and Other Land Use). Hyama, Japan: Institute for Global Environmental Strategies (IGES).

The Nature Conservancy. (2007). *Coastal plain: Sandhills*. Retrieved 11/15, 2007, from http://www.nature.org/wherewework/northamerica/states/northcarolina/preserves/art17451.html

Theobald, D. M. (2006). Exploring the functional connectivity of landscapes using landscape networks. In K. R. Crooks, & M. Sanjayan (Eds.), *Connectivity conservatio*n (pp. 416-443). University Press, Cambridge: United Kingdom.

Theobald, D. M., Norman, J. B., & Sherbune, M. R. (2006). *FunConn v1: Functional connectivity tools for ArcGIS v*9. Fort Collins, CO: Natural Resource Ecology Laboratory, Colorado State University:

Thornton, P. E., Running, S. W., & White, M. A. (1997). Generating surfaces of daily meteorological variables over large regions of complex terrain. *Journal of Hydrology (Amsterdam), 19*0(3-4), 214-251.

Troy, A., & Wilson, M. A. (2006). Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. *Ecological Economics, 6*0(2), 435-449.

U.S. Census Bureau. (2005). *Table A1: Interim projections of the total population for the united states and states: April 1, 2000 to july 1, 203*0

U.S. Fish and Wildlife Service. (2003). *Recovery plan for the red-cockaded woodpecker (picoides borealis): Second revision*. Atlanta, GA: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. (2007). *The longleaf Pine/Wiregrass ecosystem*. Retrieved 11/20, 2007, from http://www.fws.gov/carolinasandhills/longleaf.html

Urban, D. L., Minor, E. S., Treml, E. A., & Schick, R. S. (2009). Graph models of habitat mosaics. *Ecology Letters, 1*2(3), 1-14.

Urban, D., & Keitt, T. (2001). Landscape connectivity: A graph-theoretic perspective. *Ecology, 8*2(5), 1205-1218.

USDA, & NRCS. (2009). *The PLANTS database*. Retrieved 09/15, 2008, from http://plants.usda.gov

Walters, J. (1991). Application of ecological principles to the management of endangered species - the case of the red-cockaded woodpecker. *Annual Review of Ecology and Systematics, 2*2, 505-523.

Walters, J. R., Daniels, S. J., Carter, J. H., & Doerr, P. D. (2002). Defining quality of red-cockaded woodpecker foraging habitat based on habitat use and fitness. *The Journal of Wildlife Management, 6*6(4), 1064-1082.

Wiens, J. A. (2007). The dangers of black-and-white conservation. *Conservation Biology, 2*1(5), 1371-1372.

Wiens, J. A. (2006). Introduction: Connectivity research - what are the issues? In K. R. Crooks, & M. Sanjayan (Eds.), *Connectivity conservatio*n (pp. 23-27). New York: Cambridge University Press.

Wilds, S. (1996). Gradient analysis of the distribution of flowering dogwood (cornus florida L.) and dogwood anthracnose (discula destructiva redlin.) in western great smoky mountains national park. (MA Thesis (Ecology), University of North Carolina at Chapel Hill, NC).

With, K. A. (2004). Assessing the risk of invasive spread in fragmented landscapes. *Risk Analysis, 2*4(4), 803-815.

3.7 Tables

Table 1. Natural Heritage Program Element Occurrence sampling strategy based on estimated accuracy and feature area.

Accuracy	*Uncertainty Radius (m)*	*One sample per; (m^2)*
Round Polygons		
Medium	100	31,146
High	50	9,864
Very High	--	900
Irregular Polygons		
Medium	50	9,864
High	25	1,968
Very High	--	900

Table 2. Environmental Grids used for species modeling.

Data	Grid Name	Date	Description
Digital Elevation Model Derived			
Aspect	asp_cos	2000-2003	Direction of maximum rate of change in z value from each cell. Cosine was taken so that variable was not circular
Elevation	dem	2000-2003	Elevation above sea level at center of cell – LiDAR derived from NC Floodplain Mapping
Slope	slp	2000-2003	Rate of maximum change in z value from each cell – percent rise.
Relative Slope Position	rsp	2000-2003	A measure of the cell position along a slope in relationship to the nearest ridge and drainage
Topographic Relative Moisture Index	trmi	2000-2003	Combines aspect, slope, slope configuration (curvature) and relative slope position
Solar Radiation Index	sol	2000-2003	Derived incoming solar radiation (insolation) in watt hours per square meter (WH/m^2)
Wetness Index	wi	2000-2003	Topographic index calculated as ln A/B where A is the catchment area and B is the slope.
Environmental Data			
Land Use/Land Cover	nlcd	2001(2006)	MRLC – National Land Cover Database
Canopy cover	ccov	2001(2006)	MRLC, NLCD percent canopy cover
Precipitation	prec	1980-1997	Daymet - 18 year annual average
Temperature	temp	1980-1997	Daymet - 18 year annual average

Table 3. Final Carbon Pools for InVEST model. Units are metric tons of carbon per hectare. Aboveground, belowground, soil and dead carbon pools estimates were derived from numerous sources. References to tables were found in IPCC report on greenhouse gas inventories (2006).

Class	C_above	Source	C_below	Source	C_soil	Source	C_dead	Source
Forestland	103.4	COLE[1]	24.8	COLE[1]	70.6	COLE[1]	18.7	COLE[1]
Cropland	63.0	Table 5.1	40.0	Table 6.4	48.7	Table 2.3 & 5.5	6.0	InVEST
Grassland	2.7	Table 6.4	5.1	Table 6.4	67.1	Table 2.3 & 6.3	4.0	InVEST
Wetland	54.9	Birdgham 2006	45.0	Birdgham 2006	162.0	Birdgham 2006, table 2.3	1.0	InVEST
Settlement	15.0	InVEST	5.0	InVEST	15.0	InVEST	2.0	InVEST
Other[2]	27.3	InVEST	25.6	InVEST	27.3	InVEST	11.1	InVEST

[1] Carbon Online Estimator (COLE) was used to generate report 1605(b) for North Carolina for the 8-county project study area on October 28, 2008.
[2] The Other class is 82% shrub/scrub and 18% barren land (rock/sand/clay). A weighted average of the InVEST default values for shrub/undergrowth and open/urban was used

Table 4. Binary Congruence Table. Stringent – highest value and risk assessment were as follows; richness >=21, development suitability high for all three models, Carbon > 25, Connectivity q = 5. The table is read as follows; For the first row, Hotspots – If you conserve the landscape for the highest risk hotpots, you are also conserving 2.6% of the land valued for connectivity and 0.6% of the most carbon rich areas, a very low congruence.

	Hotspots	Connectivity	Carbon	Total Area (ha)
		Stringent - Highest Value and Risk		
Hotspots	---	2.6	0.6	17,261
Connectivity	16.5	---	6.9	126,339
Carbon	3.8	6.1	---	111,360
		Moderate		
Hotspots	---	5.3	4.5	64,519
Connectivity	10.4	---	17.5	127,358
Carbon	40.0	79.0	---	574,490
		Inclusive		
Hotspots	---	19.7	24.3	279,465
Connectivity	10.3	---	16.8	146,102
Carbon	59.2	78.2	---	680,520

Table 5 Conservation Assessment values for protected land and private land. Parcels under protection are on average 100 larger than private land parcels. Notably, only 4.5% of modeled corridor is already under protection highlighting the need to preserve and/or restore suitable lands for RCW connectivity. The mean value refers to the mean pixel value per parcel.

Assessment Model	**Private**		**Protected**	
Average Parcel Size (ha)	9.05		926.74	
Total Area (ha)	796,611		129,008	
	ha	*% of total*	*ha*	*% of total*
RCW Connectivity				
Patch	47,104.4	47.0%	50,095.1	50.0%
Corridor	23,592.6	86.7%	1,236.0	4.5%
TOTAL	70,697.0	55.5%	51,331.1	40.3%
	Mean	*SD*	*Mean*	*SD*
Plant Species Niche Model Score (0 to 41)	12.8	3.41	15.1	3.83
Total Carbon Storage (Tons C per pixel, 3-24)	13.7	4.68	13.8	4.74
GAP Vertebrate Richness Model (4 to 176)	84.0	16.32	83.9	19.52
Biodiversity Wildlife Habitat Assessment (-1 to 10)	0.7	0.78	2.9	1.78

3.8 Figures

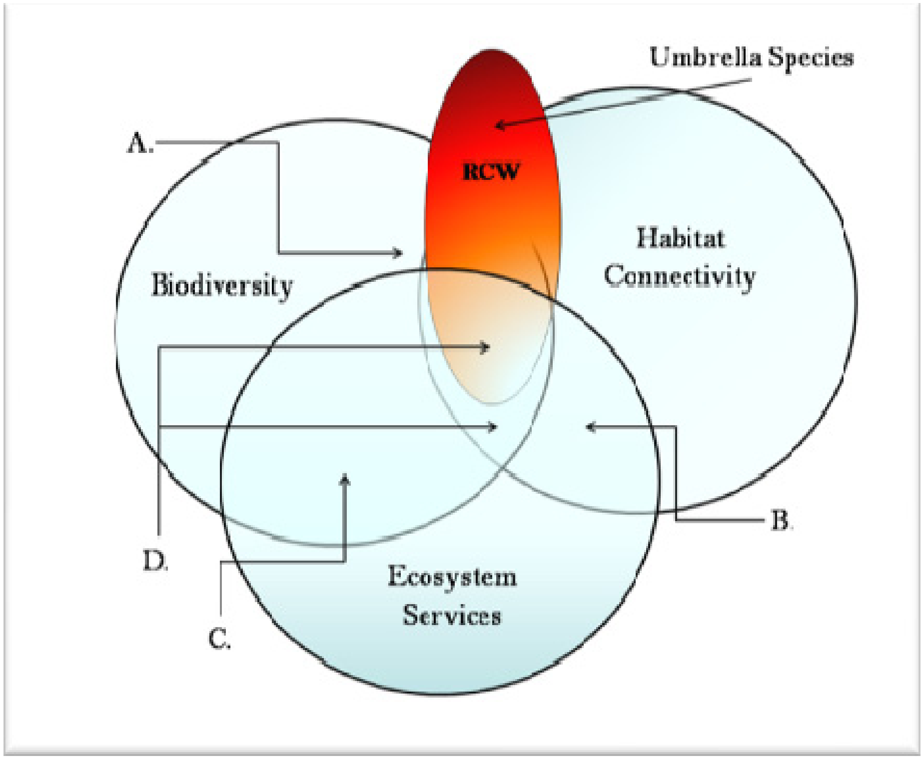


Figure 1: This concept map illustrates the spatial relationship of different methods of quantifying the ecological value of the landscape. A.) The umbrella species concept presumably protects multiple aspects of the ecosystem B.) For hydrologic services and connectivity there is likely high concordance but what about other water services and RCW connectivity? C.) Could show the highest concordance and one to one mapping for some species rich areas BUT certain low-diversity sites will also provide ecosystem services. D.) Where does this occur on the landscape? Why? What is characteristic of these areas?

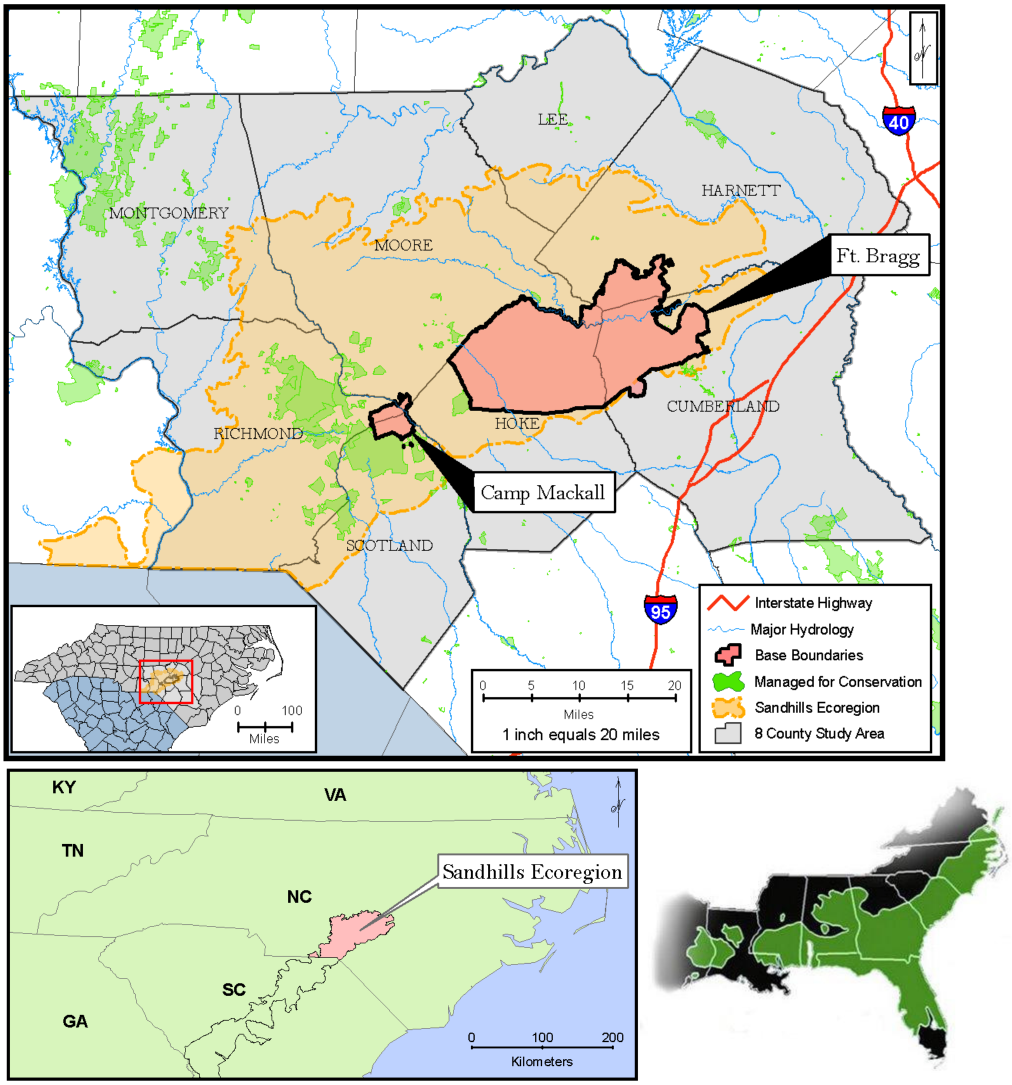
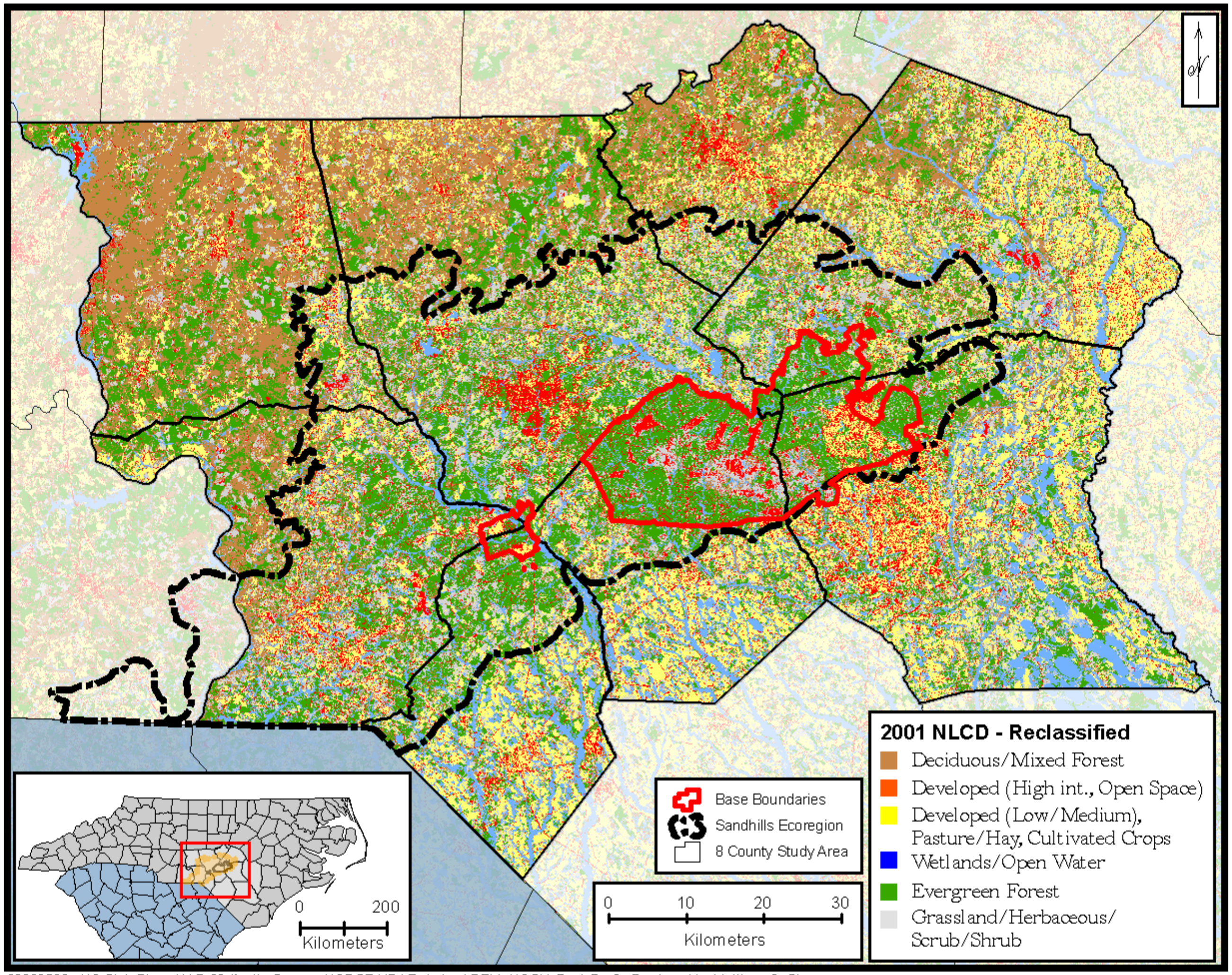
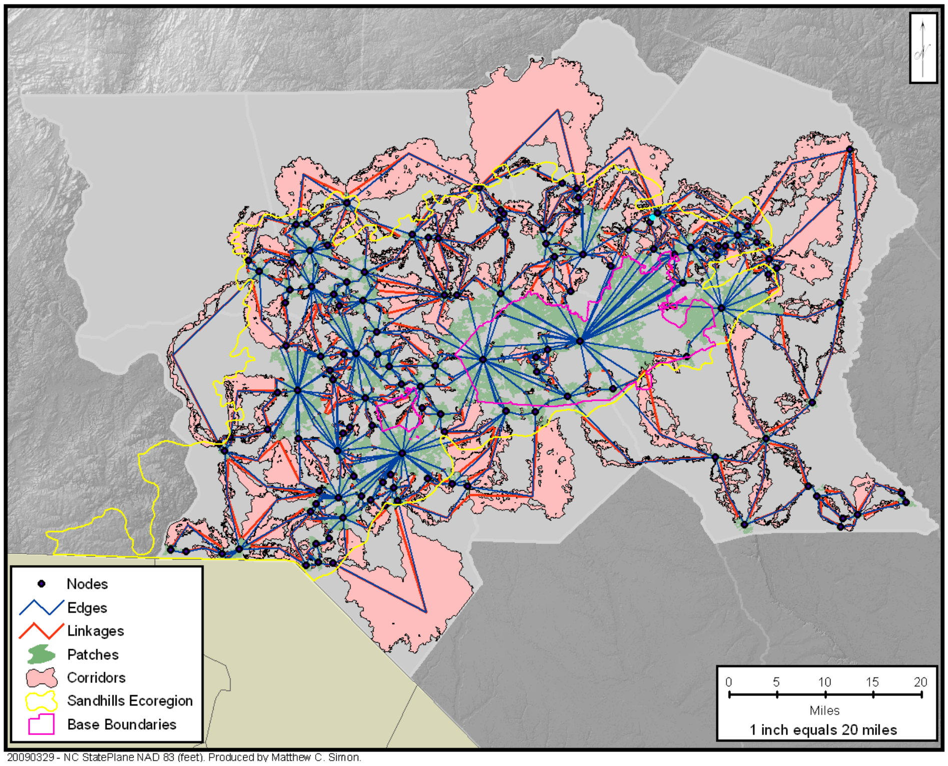


Figure 2: Sandhills 8-County Project Study Area. The Uwharrie National Forest and Sandhills Game Lands are the largest areas managed for conservation. Counties are labeled in white and major municipalities are labeled in black. The historic range of the longleaf pine ecosystem is shown in the lower right map.



20080508 - NC StatePlane NAD 83 (feet). Source; NCDOT LiDAR derived DEM, NCGIA BasinPro8. Produced by Matthew C. Simon

Figure 3. 2001 Land use and land cover (NLCD). The fragmentation and loss of longleaf pine forest (Evergreen) is clearly evident as the largest contiguous tracts remain on base. Development in the form of industry, residential, commercial and agriculture dominate south of Ft. Bragg.



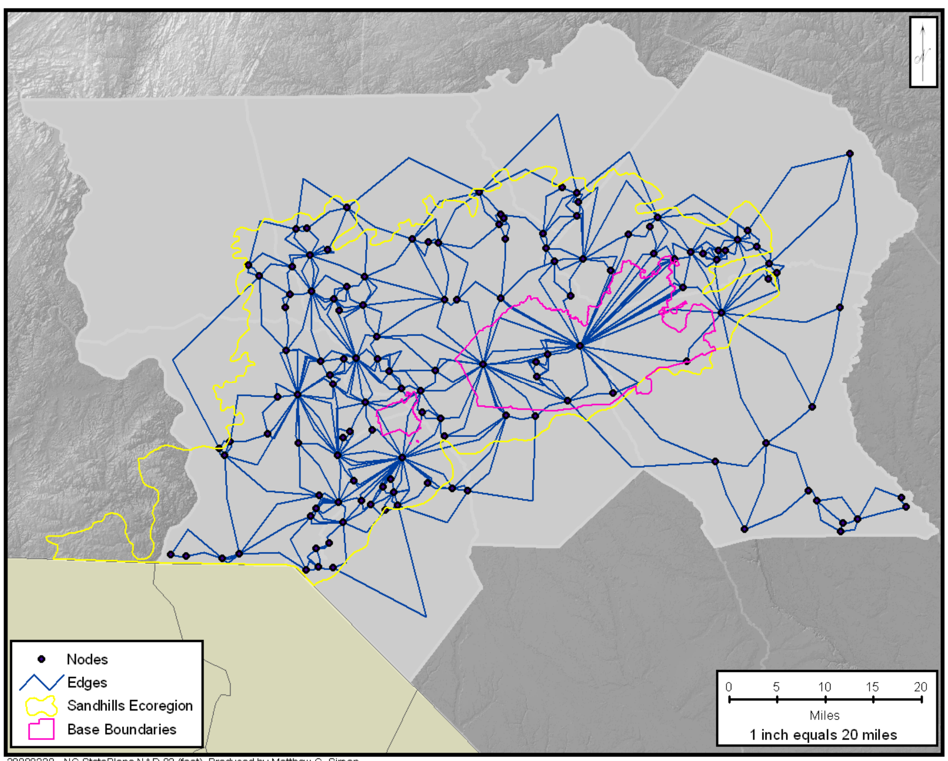
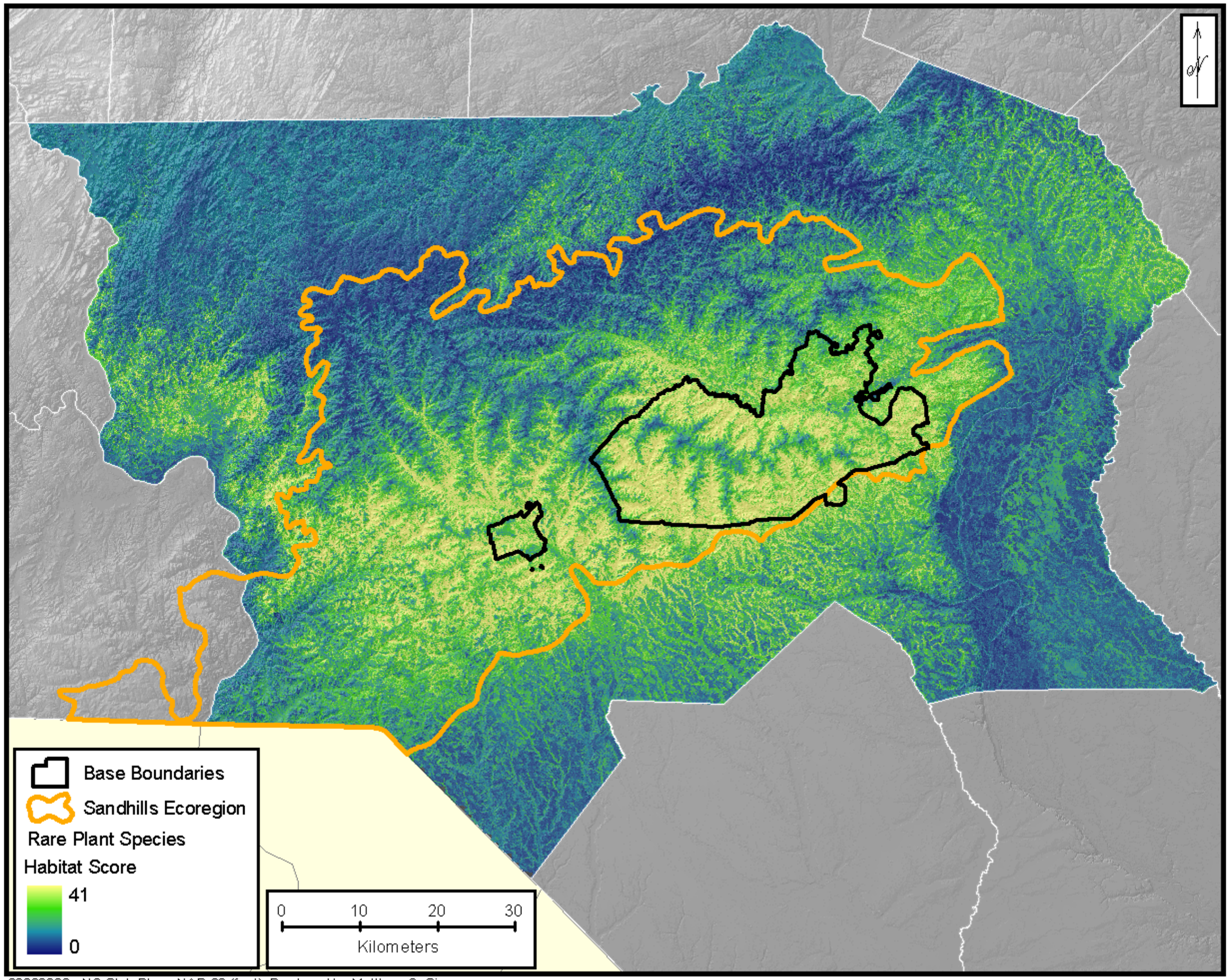
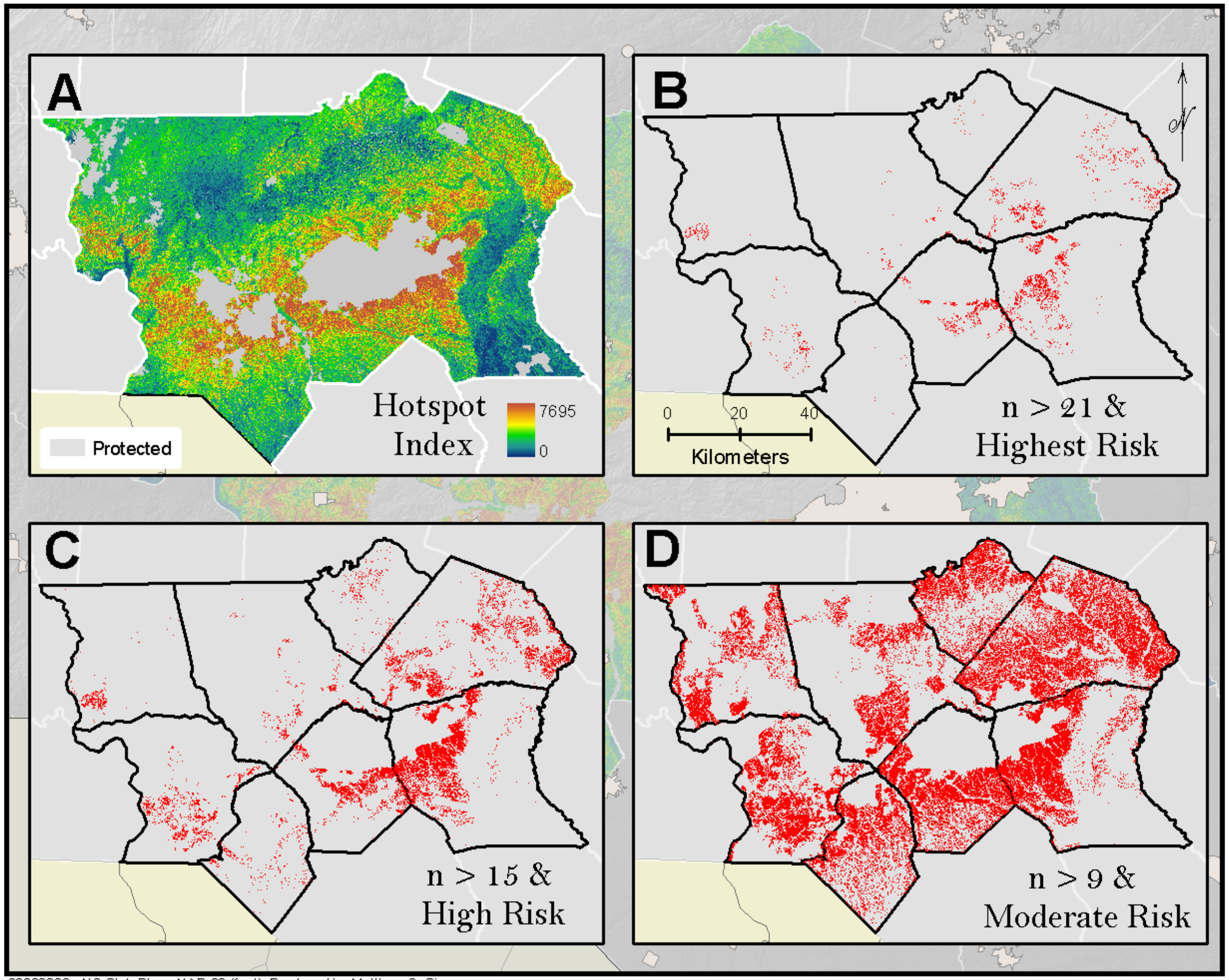


Figure 4. The landscape network depicts the habitat connectivity for the RCW. The top image shows the entire network including patches, corridors and links. The image on the bottom only includes the nodes and edges. Both images illustrate the concept of multiple pathways in analyzing landscape connectivity.



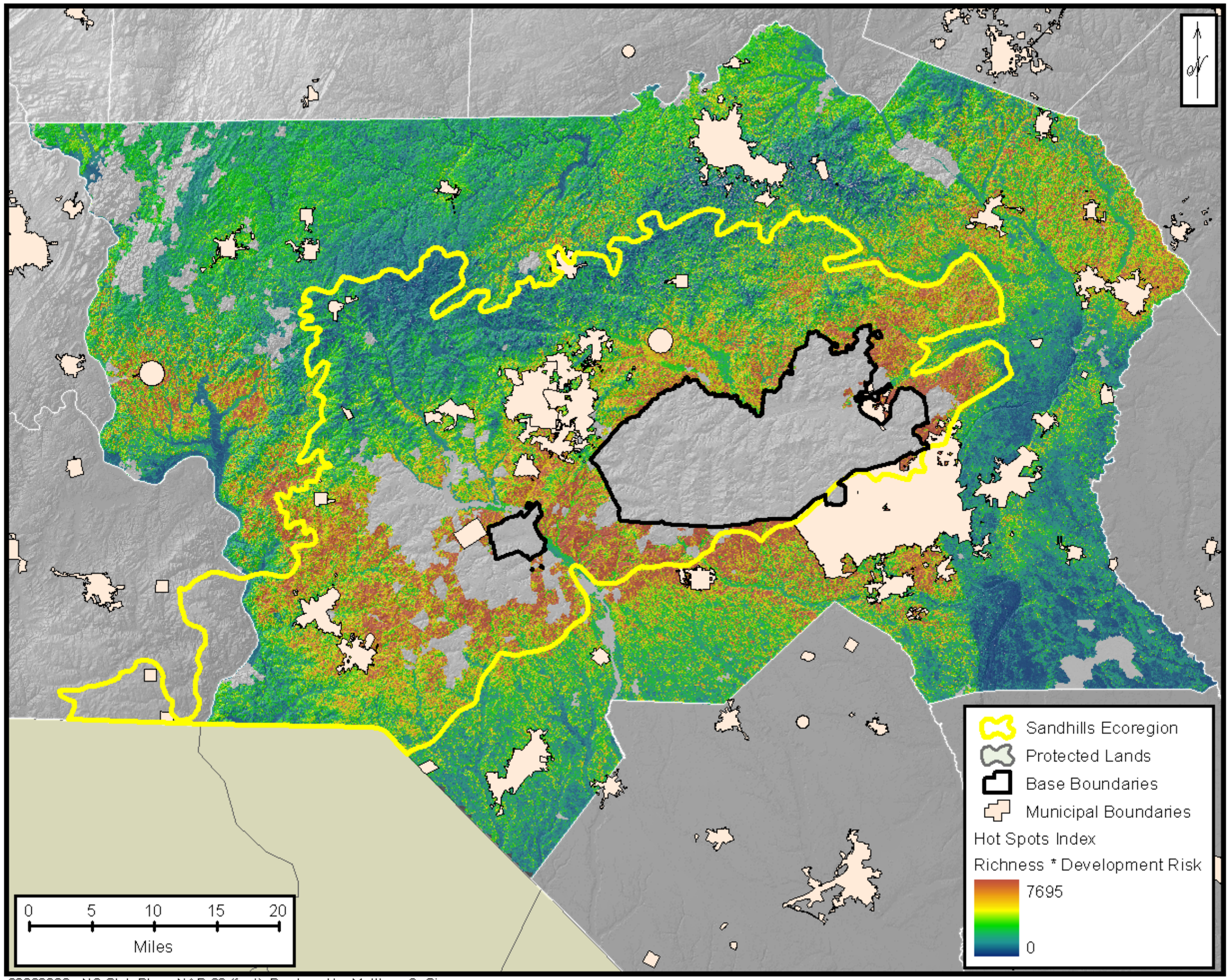
20090329 - NC StatePlane NAD 83 (feet). Produced by Matthew C. Simon.

Figure 5. The rare plant species habitat score was modeled using Maxent. The results of 56 species models were converted to binary range maps and then combined.



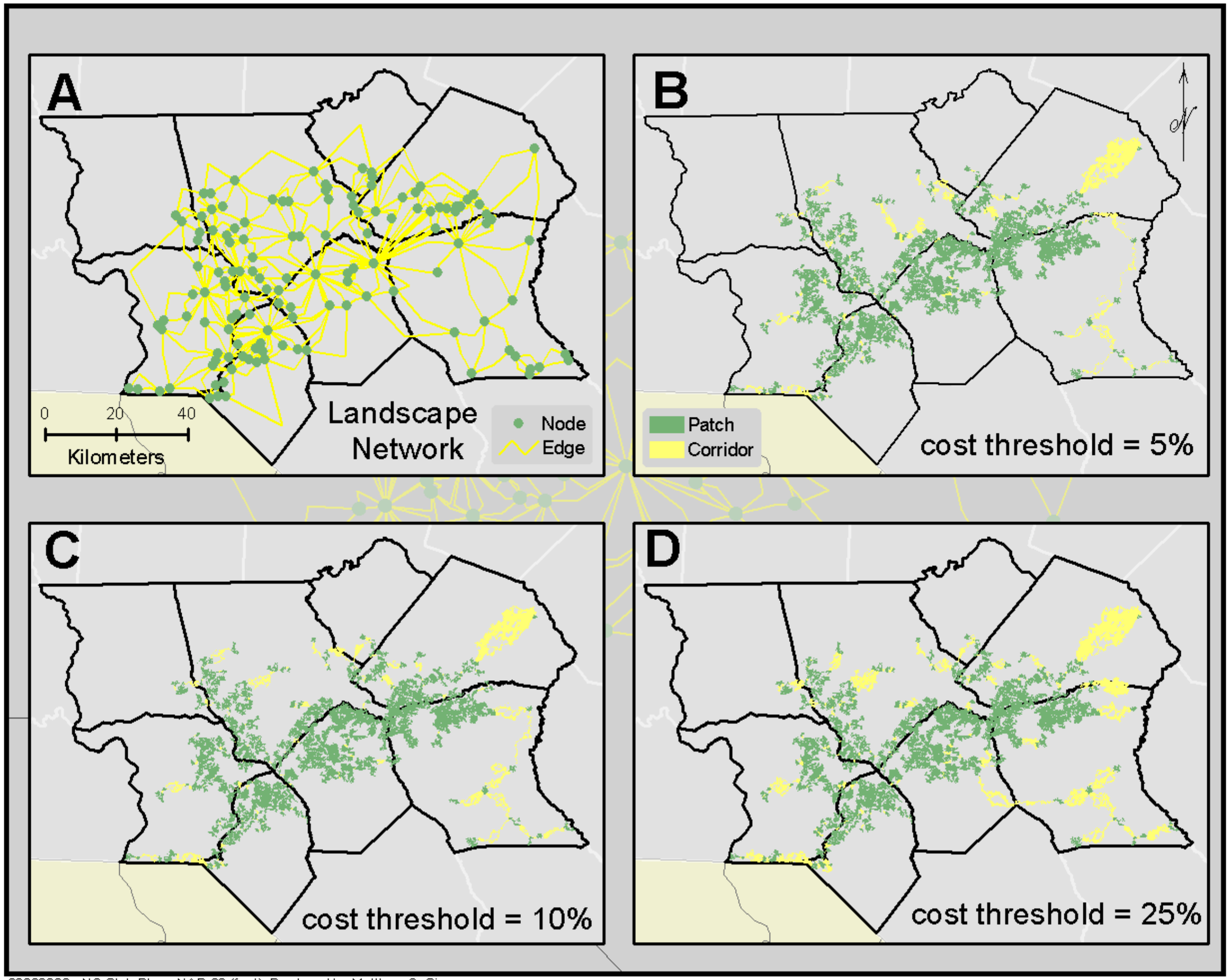
20090329 - NC StatePlane NAD 83 (feet). Produced by Matthew C. Simon.

Figure 6. Three classes of hotspots were classified based on species richness and development thresholds. Map A is the continuous hotspots index. Map B identifies those pixels with a potential species richness >= 21 and where three of the development suitability models classify a pixel as highly suitable. Map C species richness >= 15 and two development models are high. Map D richness >= 9 and one development model is highly suitable. .



20090329 - NC StatePlane NAD 83 (feet). Produced by Matthew C. Simon.

Figure 7. Continuous Hotspots index with municipal boundaries and protected lands masked out. A concentration of hotspots surrounds both base boundaries.



20090329 - NC StatePlane NAD 83 (feet). Produced by Matthew C. Simon.

Figure 8. The landscape network was analyzed by extracting the minimum spanning tree which represents the most efficient way to move through the landscape, connecting all patches at different cost thresholds (q_n).

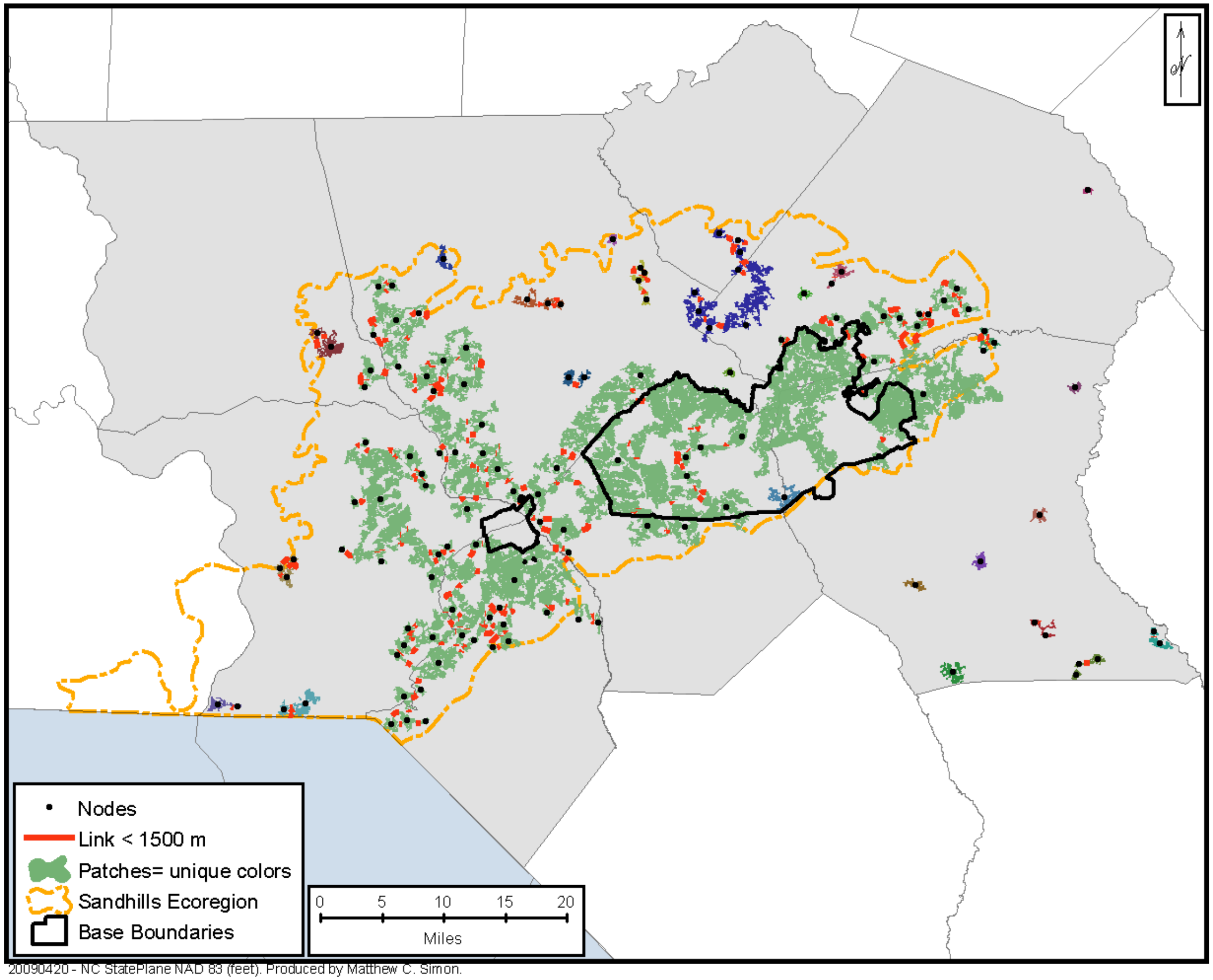
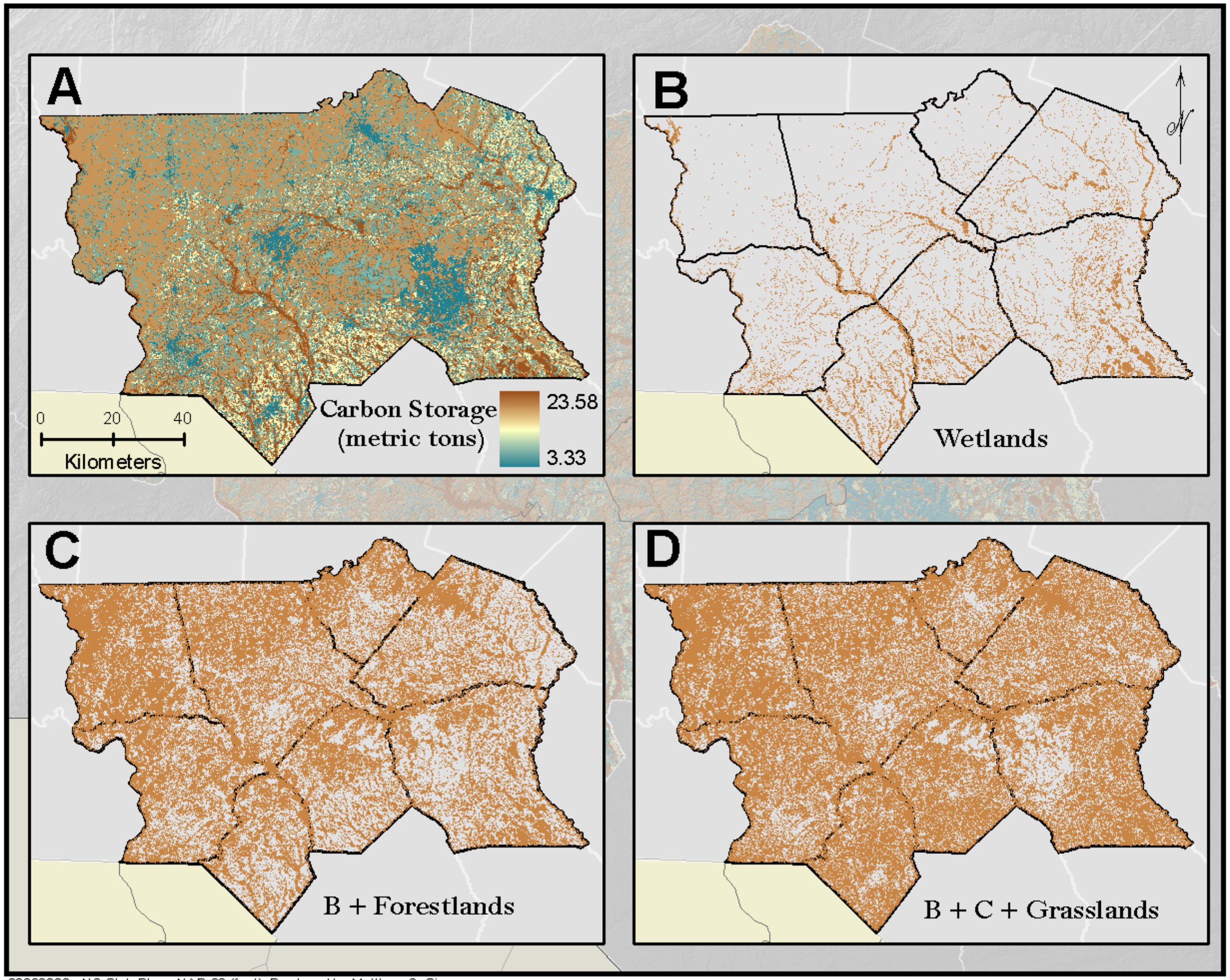


Figure 9. The above network(q_n = 10) represents the potential connectivity of the network. All patches which less than 1500 meters apart (median RCW home range estimate) are grouped together and displayed in the same color. The green patch in the middle represents the potential connectivity if all corridors linking patches less than 1500 meters apart were preserved. There are 25 different groups of patches in this scenario.



20090329 - NC StatePlane NAD 83 (feet). Produced by Matthew C. Simon.

Figure 10. Carbon storage mapping. (A) A continuous estimate of the carbon pool, from 3.33 to 23.58 metric tons of carbon per pixel. (B)-(D) The largest 3 carbon pools in the study area.

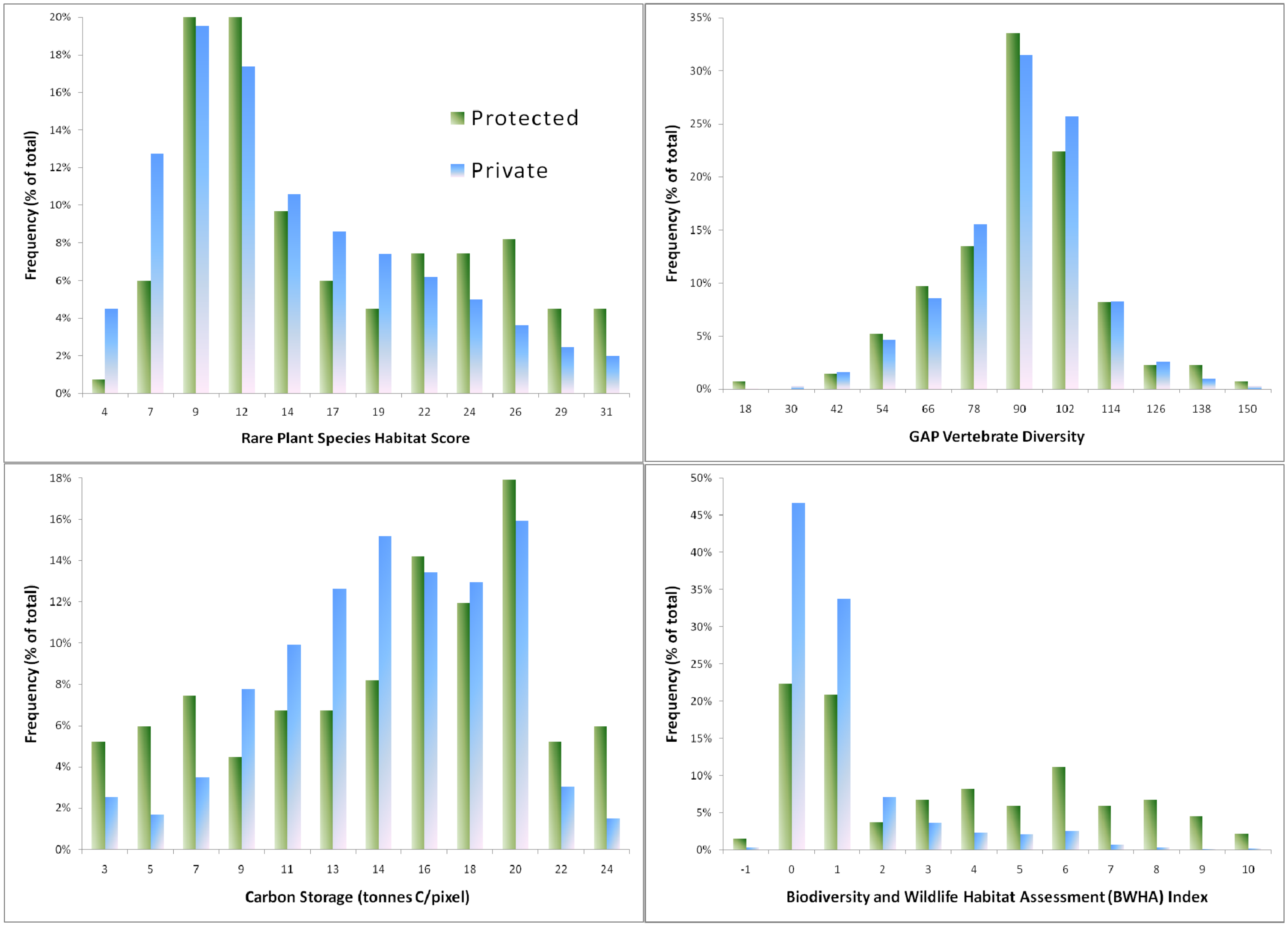
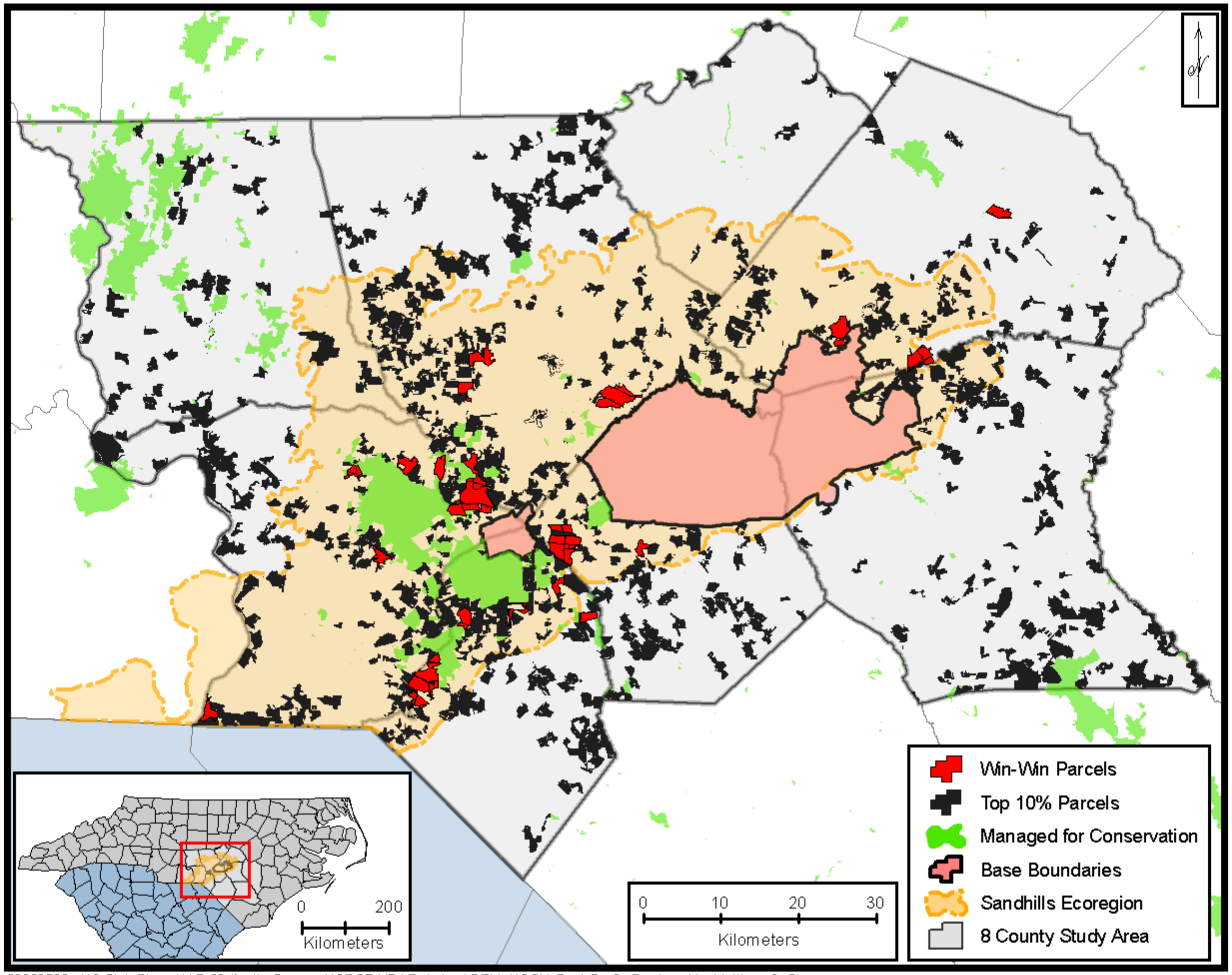
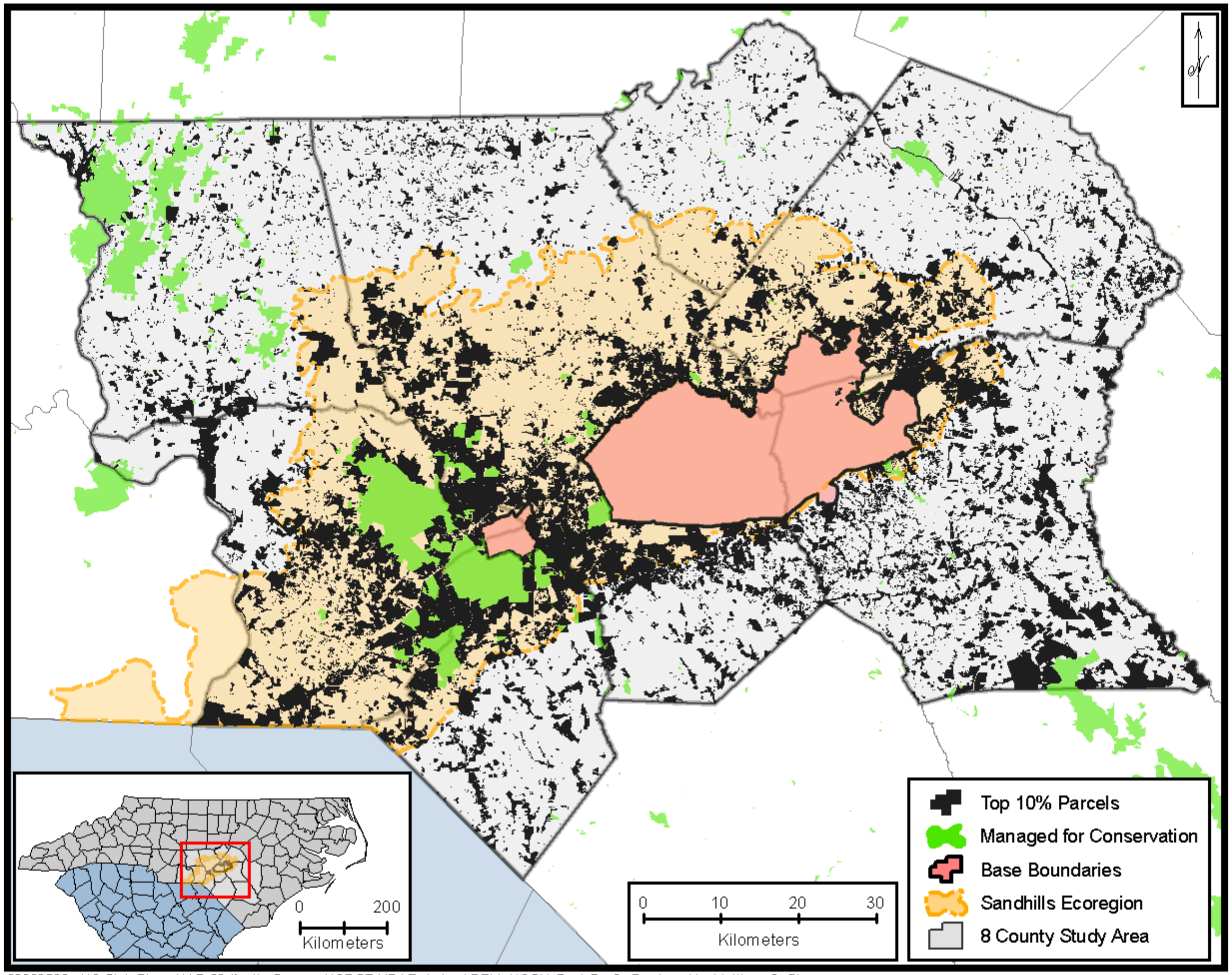


Figure 11. The frequency distribution of conservation values for Private (blue bars) and Protected (green bars) per parcel. Note that the y-axis depicts the percent of total (frequency/total parcels) and is not consistent across graphs.



20080508 - NC StatePlane NAD 83 (feet). Source; NCDOT LiDAR derived DEM, NCGIA BasinPro8. Produced by Matthew C. Simon

Figure 12. Win-Win parcels (area-weighted) held in common amongst all conservation assessments (biodiversity hotspots, rare plant habitat, RCW connectivity, carbon storage, vertebrate diversity, and BWHA.



20080508 - NC StatePlane NAD 83 (feet). Source; NCDOT LiDAR derived DEM, NCGIA BasinPro8. Produced by Matthew C. Simon

Figure 13. Top 10% of the landscape for all six assessments. Note there are no parcels held in common amongst all assessments.

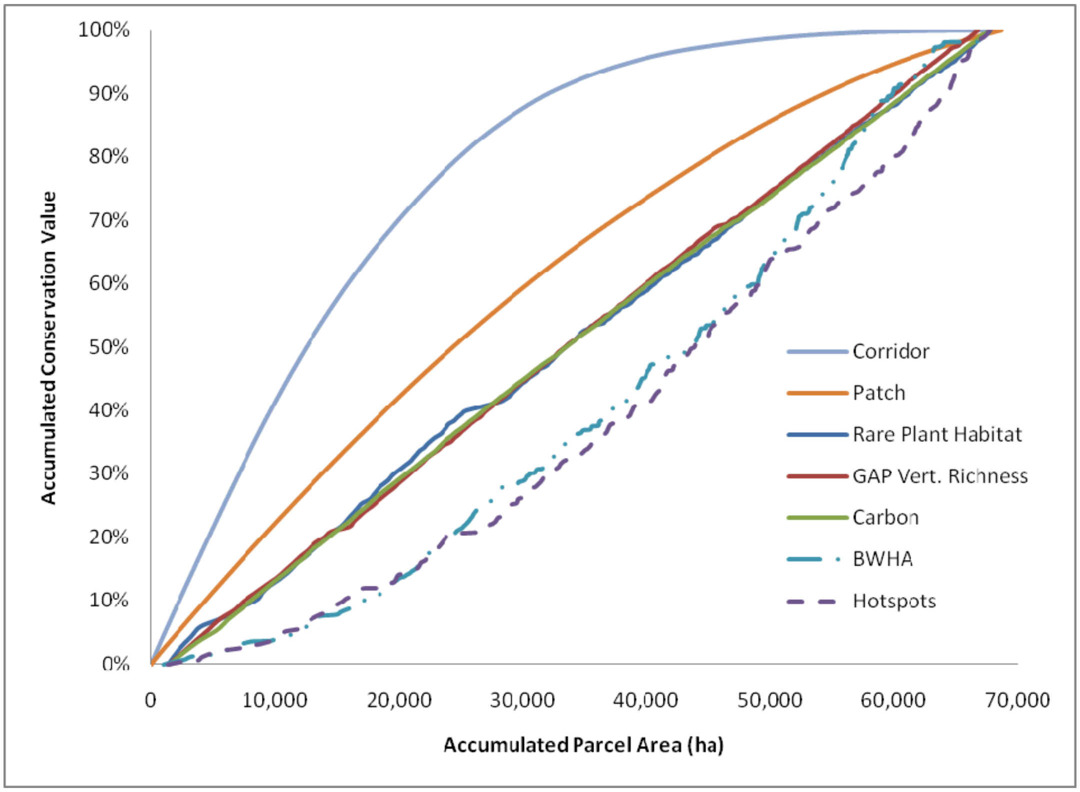


Figure 14. Accumulated relative conservation value as a total area increases. Parcels were ranked after multiplying the mean conservation value by the area of the parcel. Conserving parcels with the highest proportion of corridor results in the quickest accumulation of corridor value (ha). Conserving parcels based on Biodiversity Hotspots or the Biodiversity Wildlife Habitat Assessment (BWHA) results in the slowest rate of accumulation. Accumulated value is in total number of species, habitat score, carbon, hectares of corridor and patch, and accumulated mean index for hotspots and the BWHA.

3.9 Appendices

Appendix A
GIS driven decision support systems

Geographic Information System (GIS) driven conservation assessment and planning tools. Bold tools indicate the software implemented in this study and those in italic were used to compare against.

TOOL NAME	DESCRIPTION OF APPLICATION
Decision Support Systems for Planning and Species Distribution	
FragStats	spatial pattern analysis for categorical maps
GreenGrowthToolbox	NC DSS to guide 'nature friendly growth'
LINK	analyze habitat patterns across a landscape
Marxan	decision support for reserve system design
Maxent	**potential species distribution modeling**
NatureServe VISTA	DSS integrates conservation information with land use patterns
One NC Naturally Conservation Planning Tool	*DSS to assess biodiversity and wildlife habitat, open space and conservation lands, water services, agricultural lands, forestry lands and marine and estuarine resources*
Portfolio	Nature reserve design – ranks sites to create a Portfolio
Landscape and Habitat Connectivity	
CircuitScape	predict patterns of movement, gene flow, and genetic differentiation using circuit theory
CorridorDesigner	wildlife corridor design
FunConn	**habitat modeling and landscape network connectivity**
Ecosystem Services	
InVEST	**models and maps natural capital: the delivery, distribution, and economic value of ecosystem services**
Natural Assets Information System	Spatially explicit - quantifies environmental assets

Appendix B

Federally endangered species of concern and threatened species habitat requirements on Fort Bragg Military Installation in North Carolina.

Common Name	Scientific	Preferred Habitat[a]	Status[b]
E. Tiger Salamander	*Ambystoma tigrinum tigrinum*	NOT YET ASSESSED	G5T5, NNR?.
Roughleaf Loosestrife	*Lysimachia asperulaefolia*	Ecotones between longleaf pine uplands and pond pine pocosins	G3, N3, S3
St. Francis Satyr	*Neonympha mitchellii francisci*	Sedge wetlands	G1T1, N1, S1
Red-cockaded woodpecker	*Picoides borealis*	Open, mature pine woodlands	G3, N3,S2
Carolina Gopher Frog	*Rana capito*	Primary xeric upland habitats, breeding occurs in ephemeral wetlands	G3,N3,S2
Michaux's Sumac	*Rhus michauxii*	Sandy or rocky open woods	G2, N2, S2
Chaffseed	*Schwalbea americana*	Open pine flatwoods	G2, N2, S2

a As determined by NatureServe {{187 NatureServe 2007; }}. **b**-Status refers to the species' conservation status as designated by NatureServe, the U.S. Endangered Species Act (ESA) and the International Union for the Conservation of Nature (IUCN) ranging from critically imperiled (G1) to demonstrably secure (G5). Status is assessed and documented at three distinct geographic scales-global (G), national (N), and state/province (S) {{187 NatureServe; }}. State status above is only for North Carolina.

Appendix C

Geographic Information Systems (GIS) data available for conservation assessments.

Data	*Geographic Extent*	*Date*	*Source*
ETR Species			
NHP occurrences	**Statewide**	**Current**	**N.C. Natural Heritage Program (NHP)**
CVS database	**NC, SC**	**Various**	**N.C. Vegetation Survey Database**
ESB rare species	*Ft. Bragg*	*Current*	*Ft. Bragg ESB*
Environmental			
SSURGO Soils	*County-wide*	*Varies*	*Natural Resource Conservation Service (NRCS)*
Hydrology	Statewide	1998	NCGIA BasinPro 8
Wetlands	*Nationwide*	*1980's*	*NWI – National Wetlands Inventory*
Elevation Data	*Ft. Bragg*	*July 2006*	*Airborne 1, 1m LiDAR derived*
Elevation Data	**Statewide**	**2006**	**NC Floodplain Mapping - 20' LiDAR derived**
Land Use/Land Cover	**Nationwide**	**2001(2006)**	**MRLC – National Land Cover Database**
Land Use/Land Cover	*Statewide*	*2001 (2007)*	*NC GAP Analysis, and SE GAP*
Forest Stands	*Ft. Bragg*	*2005*	*Ft. Bragg ESB*
Biodiversity/Wildlife	**Statewide**	**2008**	**NCDENR – Conservation Planning Tool**
Socioeconomic			
Tax parcels	**County**	**Varies**	**County tax assessors**
Census	*County*	*2000*	*US Census Bureau*
Zoning	*County*	*Varies*	*Individual counties*

Appendix D

Environmental Variables for Maxent Model

1. Elevation (dem_30m_cc); elevation above sea level at cell center in feet. 30 meter DEM compiled from NC Floodplain Mapping Program LiDAR data (2000-2003). Original data set is in NC Stateplane NAD 83, Survey Feet with a 20 foot cell size. Data was resampled using ArcGIS and a cubic convolution interpolation and reprojected to Albers NAD 83 meters. Z values are in feet.

2. Aspect (asp, asp_cos); GRID function *aspect* and GRID function *cos*.

3. Slope (slp_pr); GRID function *slope* with *percentrise*.

4. Relative Slope Position (rsp); a measure of the cell position along a slope in relationship to the nearest ridge and drainage. RSP (Wilds 1996) uses (1) a threshold level of flow accumulation to represent slope bottom, (2) the difference between mean elevation and highest elevation in a moving window to represent ridges, and (3) flowlength to calculate distance.

   XX add Script XX

5. Landform Classification (Pennock et al. 1987); Calculated in TAS, the classification scheme is based on Pennock, Zebarth and deJong. The scheme classifies individual cells based on local (3 x 3 roving window) measures of slope and curvature coding each cell as one of the following;
   1. Convergent Footslope
   2. Divergent Footslope
   3. Convergent Shoulder
   4. Divergent Shoulder
   5. Convergent Backslope
   6. Divergent Backslope
   7. Level

6. Wetness Index or topographic index (Beven and Kirkby 1979) Notice that the normal range for wetness index is approximately 0-20; however, if your DEM contains flat areas (even if they are corrected for flow) the wetness index image will contain very large values because of the very small values slopes. The numerical values for these gently sloped areas are not meaningful, but they can be thought of as being extremely likely to be saturated because of their gentle slopes. Topographic wetness index (TWI) can quantify the control of local topography on hydrological processes and indicate the spatial distribution of soil moisture and surface saturation.

7. Topographic Relative Moisture Index (TRMI) based on the weighted scalar developed by Parker (1982). TRMI combines aspect, slope, slope configuration

(curvature) and relative slope position.

8. Solar Radiation Index (sol); derived incoming solar radation (insolation) in watt hours per square meter (WH/m2). creates a viewshed for every 200 by 200 cell window for each cell and calculates both direct and diffuse radiation

9. Percent Canopy Cover (NLCD 2001)

10. Precipitation - 18 year annual average (Daymet - resampled to 30 meters using cubic convolution from 1000)

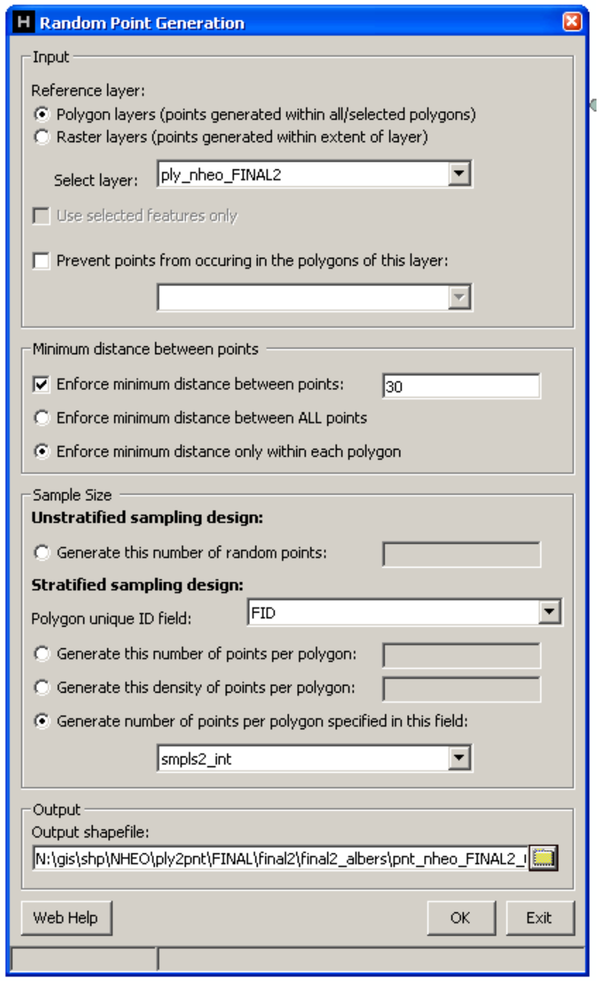
11. Temperature - 18 year annual average (Daymet - resampled to 30 meters from 1000)

Mask Creation:
mask = [asp_cl] | [c_lf_cl] | [ccov_cl] | [dem_cl] | [pa_cl5] | [rsp_cl] | [slp_cl] | [sol_cl] | [taa_cl2] | [trmi_cl] | [wi_clf]

mask2 = [asp] | [c_lf] | [ccov] | [dem] | [ncgap_9cnty] | [nlcd_9cnty] | [prec] | [rsp] | [slp] | [sol] | [tmpr] | [trmi] | [wi]

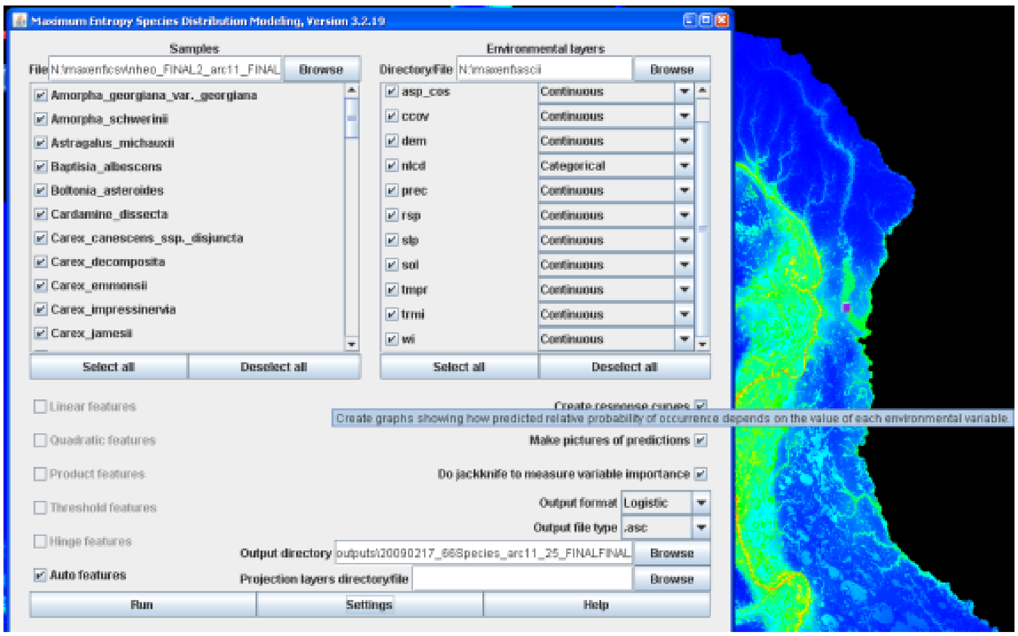
Appendix E

Screen Shot of Hawth's Tool, Generate Random Points



Appendix F

Final Maxent Run



Appendix G

Maxent log

Tue Feb 17 11:38:46 EST 2009
MaxEnt version 3.2.19
Checking header of N:\maxent\ascii\asp_cos.asc
Checking header of N:\maxent\ascii\ccov.asc
Checking header of N:\maxent\ascii\dem.asc
Checking header of N:\maxent\ascii\nlcd.asc
Checking header of N:\maxent\ascii\prec.asc
Checking header of N:\maxent\ascii\rsp.asc
Checking header of N:\maxent\ascii\slp.asc
Checking header of N:\maxent\ascii\sol.asc
Checking header of N:\maxent\ascii\tmpr.asc
Checking header of N:\maxent\ascii\trmi.asc
Checking header of N:\maxent\ascii\wi.asc
Reading samples from nheo_FINAL2_arc11_FINAL.csv
Read samples: max memory 1352663040, total allocated 71135232, free 28932016, used 42203216, increment -2323728
Extractor: max memory 1352663040, total allocated 71135232, free 6450496, used 64684736, increment 22481520
Extracting random background and sample data
Time since start: 24.438
12805937 points with values for all grids
Adding samples to background in feature space
Command line: -X 25 -t c_ -J -K -P
Species: Amorpha_georgiana_var._georgiana Amorpha_schwerinii Astragalus_michauxii Baptisia_albescens Boltonia_asteroides Cardamine_dissecta Carex_canescens_ssp._disjuncta Carex_decomposita Carex_emmonsii Carex_impressinervia Carex_jamesii Carex_sp._4 Cirsium_carolinianum Cladium_mariscoides Crocanthemum_rosmarinifolium Danthonia_epilis Desmodium_fernaldii Dichanthelium_sp._9 Dionaea_muscipula Eleocharis_robbinsii Enemion_biternatum Eupatorium_resinosum Euphorbia_mercurialina Eurybia_mirabilis Fothergilla_major Gaillardia_aestivalis_var._aestivalis Galactia_mollis Helianthus_laevigatus Helianthus_schweinitzii Ilex_amelanchier Iris_prismatica Liatris_squarrulosa Lilium_pyrophilum Lindera_melissifolia Lindera_subcoriacea Luziola_fluitans Lysimachia_asperulifolia Matelea_decipiens Oldenlandia_boscii Parnassia_caroliniana Phacelia_covillei Polygala_grandiflora Potamogeton_confervoides Pseudognaphalium_helleri Pyxidanthera_brevifolia Rhexia_aristosa Rhus_michauxii Rhynchospora_crinipes Rhynchospora_macra Ruellia_ciliosa Salvia_azurea Schoenoplectus_etuberculatus Schoenoplectus_subterminalis Schwalbea_americana Scleria_reticularis Sedum_pusillum Solidago_plumosa Solidago_verna Stylisma_pickeringii_var._pickeringii Symphyotrichum_georgianum Tridens_chapmanii Trifolium_reflexum Vaccinium_virgatum Viola_walteri Xyris_chapmanii Xyris_scabrifolia
Layers: asp_cos ccov dem nlcd prec rsp slp sol tmpr trmi wi
Layertypes: Continuous Continuous Continuous Categorical Continuous Continuous Continuous Continuous Continuous Continuous Continuous
Linear: true, Quadratic: true, Product: true, Threshold: true, Hinge: true, Auto: true
Species file: N:\maxent\csv\nheo_FINAL2_arc11_FINAL.csv
Environmental variables directory: N:\maxent\ascii
Output directory: N:\maxent\outputs\20090217_66Species_arc11_25_FINALFINAL
Projection layers directory:
Output format: Logistic
Output file type: .asc
Maximum iterations: 500
Convergence threshold: 1.0E-5
Remove duplicates: false
Number of background points: 10000, Bias file: Random test percentage: 25

Appendix H

Script for converting .asc text files to binary

```
#!/usr/bin/perl
# toBinary.plx
#Written by Dr. Todd Jobe
# Converts an ASCII grid of continuous values to a binary grid using a cutoff.
# We're going to assume that you're running the program from the location of the ASCII
grids.
# Usage: toBinary.plx [spfile] [outpath] [inpath]
# speciesfile: A comma separated file with "species,cutoff".  No header.
#           Defaults to "Cutoffs.csv"
# outpath: Path to the output folder.  Defaults to

use warnings;
use strict;
my $spfile = shift @ARGV || "Cutoffs.csv";
my $outpath = shift @ARGV || "../binary";
$outpath =~ s|/$||;

$| = 1;
#turns off the cmd line buffer, so that the processing can be viewed, lines totalled

# Get the cutoff and species lists
open SP, $spfile or die "Can't read on file $spfile:$!\n";
my %sp;
while (<SP>) {
  my @sp = split(',',$_);
  chomp($sp[1]);
  $sp{$sp[0]} = $sp[1];
}
# Compute the new ascii grids
for my $key (keys %sp) {
  open IN, "$key.asc" or die "Can't read on file $key.asc:$!\n";
  open OUT, ">$outpath/$key.asc" or die "Can't write on file $outpath/$key.asc:$!\n";
  my $counter = 0;
  while(<IN>){
    if($_ =~ /^\s*[\d\-]/) {
      my @rec = split /\s/;
      for my $i (@rec){
          $i = ($i > $sp{$key}) ? 1 : 0 unless $i == -9999;
      }
      print OUT "@rec\n";
    }else{
      print OUT;
```

```
    }
    print "\r$counter lines of $key calculated." if (not ++$counter % 100);
  }
  print "\r$counter lines of $key calculated.\n";
  close IN;
  close OUT;
}
close SP;
```

Appendix I

Strategic Lands Inventory (SLI) development suitability model.

Value	*Description*
10	none (0-6)
20	industrial only (7-9)
30	commercial only (7-9)
40	industrial and commercial (14-18)
50	residential and industrial (14-18)
60	residential, commercial, industrial (21-27)
70	residential and commercial (14-18)
80	residential only (7-9)

Appendix J
Conditional Statement used on LEAM model

to create Development Suitability Model

```
##Conditional loop to combine the three development suitability models
##com – commercial development model
## ind – industrial development model
##res – residential development model
#10 - none (0-6)
#20 - industrial only (7-9)
#30 - commercial only (7-9)
#40 - industrial and commercial (14-18)
#50 - residential and industrial (14-18)
#60 - residential, commercial, industrial (21-27)
#70 - residential and commercial (14-18)
#80 - residential only (7-9)

if (com < 7 && res < 7 && ind < 7) then dev_mdl = 10
else if (ind >= 7 && com < 7 && res < 7) then dev_mdl = 20
else if (ind < 7 && com >= 7 && res < 7) then dev_mdl = 30
else if (ind < 7 && com < 7 && res >= 7) then dev_mdl = 80
else if (ind >= 7 && com >= 7 && res < 7) then dev_mdl = 40
else if (ind < 7 && com >= 7 && res >= 7) then dev_mdl = 70
else if (ind >= 7 && com < 7 && res >= 7) then dev_mdl = 50
else if (ind >= 7 && com >= 7 && res >= 7) then dev_mdl = 60
else dev_mdl = 2000
endif
```

Appendix K

National Land Cover Data 2001 (NLCD) reclassification for the Red-cockaded woodpecker (RCW) habitat mapping and reclassification for carbon storage in compliance with the six broad land-use categories set forth by the Intergovernmental Panel on Climate Change (IPCC) for consistent representation of lands.

NLCD		*RCW land classes*		*IPCC land classes*	
Value	*Description*	*Value*	*Description*	*Value*	*Description*
11	Open Water	205	Open	4	Wetland
21	Developed, Open Space	204	Urban	5	Settlement
22	Developed, Low Intensity	204	Urban	5	Settlement
23	Developed, Medium Intensity	204	Urban	5	Settlement
24	Developed, High Intensity	204	Urban	5	Settlement
31	Barren Land (Rock/Sand/Clay)	205	Open	6	Other
41	Deciduous Forest	203	Hardwood	1	Forestland
42	Evergreen Forest	212	Forest	1	Forestland
43	Mixed Forest	212	Forest	1	Forestland
52	Shrub/Scrub	205	Open	6	Other
71	Grassland/Herbaceous	205	Open	3	Grasslands
81	Pasture/Hay	205	Open	3	Grasslands
82	Cultivated Crops	205	Open	2	Cropland
90	Woody Wetlands	203	Hardwood	4	Wetland
95	Emergent Herbaceous Wetlands	205	Open	4	Wetland

Appendix L

RCW literature review for connectivity parameters.

Parameter	Estimate	Sources	Method	Population
Minimum Patch Size	103 (60.7-168.8)	Convery and Walters 2004	minimum convex polygon	Camp Lejeune, NC - 23 groups
	49 ha	**USFS 2003**	**Federal Guidelines of Recovery Plan**	**various - Walters et al. 2000, 2002a, James et al. 2001, Engstrom and Sanders 1997**
	80.2 (39-145.4)	Convery and Walters 2004	fixed kernel esimtator	Camp Lejeune, NC - 23 groups
	83.6 avg (56.3-128.7) ha	**Walters et al 2002**	fixed kernel esimtator	North Carolina Sandhills - 30 groups
	91.9 avg	Franzreb 2006	fixed kernel esimtator	Savanah River Site, SC - 7 groups
	70.3 (30-195) ha	Hooper et al. 1982	modified minimum convex polygon	Francis Marion NF, Coastal SC - 24 groups
Patch/Foraging Radius	300-500 m	Schiegg et al. 2005	territorial radius	
	1500 m	SERDP annual report year 2008	based on two years of telemetry survey medians	SERDP annual report year 2008
	800 m	**James et al. 2001, USFW 2003**	**Federal Guidelines of Recovery Plan**	
Resource Quality Threshold	**site index >= 60**	**USFS 2003**	**Federal Guidelines of Recovery Plan**	**site idex is a measures quality of site (for growing trees using tree height at given ages as indicators)**
	75-80	FUNCONN default		

Patch Size: the smallest biologically significant patch size - may be based on known home range sizes.
Patch/Foraging Radius; The distance than an animal moves on the landscape seeking out forage - influenced by the organism's perceptual ability.
Resource Quality Threshold; the minimum habitat quality value acceptable to the target organism to define patches - typically near 75-80.

Appendix M

RCW parameters used in the FunCONN model and permeability values

Parameter	***Value***	
Resource Quality Threshold	60	
Minimum Patch Size	49 ha	
Patch/Foraging Radius	800 m	
Land Class	***Habitat Quality (0-100)***	***Permeability (0-1)***
Longleaf Pine	100.00	1.00
Other Pine	55.86	0.50
Hardwood	0.00	0.20
Urban	53.03	0.05
Open	16.81	0.05