Multi-Objective GIS Analysis for Avoided Conversion Carbon Credits and Biodiversity Conservation

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Abstract

This project develops a unique methodology in identifying individual tax parcels in North Carolina as possible locations for generating avoided conversion carbon offset credits, as well as including co-benefits such as ecological conservation and corridor viability. We used LiDAR canopy height data to estimate current and future carbon storage on each parcel, which were discounted based on their respective probability of conversion as determined by the randomForest statistical model. Conservation value was added to the carbon value in order to accommodate the multi-objective interests of our client, Duke Carbon Offset Initiative. The result of this project is a flexible GIS model that uses the three major inputs (carbon, conversion risk, conservation) to rank parcels for suitability based on the interests of the user. This unique method will help DCOI obtain their 2024 carbon-neutral goals for Duke University, protect key biodiversity areas, and set a framework for other academic institutions.
Executive Summary

This project introduces a unique methodology for identifying possible locations to acquire avoided conversion carbon credits from the viewpoint of a purchaser interested in multiple objectives. Our client, Duke Carbon Offset Initiative (DCOI), is interested in meeting carbon footprint goals set for 2024 and is incorporating avoided conversion carbon credit acquisition into their portfolio. They have a unique opportunity to lead higher education institutions in this effort through initiating projects with multiple objectives, of which include offsetting the carbon footprint of the University as well as protecting significant biodiversity areas in the state of North Carolina. This project incorporates both of these objectives and produces a GIS model that will identify individual tax parcels in North Carolina that have potential for an avoided conversion carbon offset project and contain a specified level of conservation value.

This is a multi-step model with three major inputs that account for the potential carbon credits and conservation value. To execute this model, we started with tax parcel data and filtered for parcels that are viable for such a project. We then assigned a carbon value to each parcel based on the current and future carbon stocks derived from LiDAR data. The carbon value was then discounted based on the parcel's probability of conversion. We derived the probability of conversion using an advanced statistical method known as the randomForest model in R. This discounted carbon value is in essence the estimate of potential carbon credits that each parcel would hypothetically yield. Finally we added the conservation value onto each carbon value that is now in relative terms. The conservation value includes inputs like proximity to protected/biologically significant areas, corridor viability, and species richness. The user of the model can manipulate the importance of each input variable to accommodate a variety of interests ranging from exclusively carbon credit generation to simple biodiversity/conservation planning, and everywhere in between.

The final output of our model is a ranked list of parcels that contains their tax information, carbon estimates, and overall project score based on the importance of each input defined by the user. This model is designed specifically for the needs of DCOI, but could accommodate other similar users in North Carolina. However, the process and model schema could be applied in other states with the appropriate inputs for canopy height, probability of conversion, and conservation in the given area.

This is a unique project and methodology for valuing a project that combines avoided conversion carbon credits and conservation. A multi-objective GIS model is an attempt to incorporate a variety of uses and interests from users, while utilizing an assortment of key datasets. Our hope is that this model can be used for its intended purpose at DCOI: to conserve properties that will help offset Duke University’s carbon emissions, but also be used as a template for other academic institutions, conservation groups, and businesses interested in entering the voluntary carbon market with a co-benefit of ecological conservation.
Introduction

As the global population increases and our nation's cities continue to expand and convert forests into urban areas, land conservation for multiple objectives has become vitally important. Conserved lands protect biologically significant areas, provide green space for wildlife and humans, and promote carbon sequestration in the forest biomass to reduce the amount of greenhouse gases being released into the atmosphere. Duke Carbon Offset Initiative is excited to explore possible locations for an avoided conversion forest carbon project in North Carolina. They are interested in protecting a piece of land which would otherwise be deforested, to generate the actual credits, but also fulfills traditional conservation goals such as protecting biodiversity. Our Masters Project constructs a GIS model that identifies potential areas and parcels in the state for such a project.

DCOI seeks to offset Duke University’s carbon emissions. To do this, DCOI is looking to generate carbon credits through avoided conversion in North Carolina, using protocols established in the California carbon market. By locating parcels that are at high risk of conversion, and either providing financial assistance to a local partner to place a conservation easement on the property or purchasing the property fee-simple, DCOI will generate avoided conversion carbon credits to offset Duke’s carbon footprint. These conserved properties (or easements) will generate credits based on their current and projected carbon stores. DCOI is also interested in conserving properties that are biologically significant, so our project also considers areas of high biodiversity, sensitive/listed species, and wildlife corridors across North Carolina. A parcel that has high potential for carbon credit generation and has positive biodiversity implications will rate highest.

As the global carbon market develops, it is important for Duke to become an institutional leader in efforts to reduce carbon emissions and protecting lands to offset their carbon emissions. This project showcases a model to identify specific high-risk areas and properties in North Carolina, and initiate a focused and efficient pursuit of avoided conversion carbon offset credits for Duke University.

Background on Carbon Offset Credits and Protocols

Carbon markets are a rapidly developing opportunity for domestic and international forestland owners, and an emerging marketplace in the natural resources sector. Carbon banking can be a profitable prospect for timberland owners, and also an opportunity for private entities to invest in offsetting their own, or others’, carbon emissions.

Carbon accounting is similar to traditional forestry in the sense that timberland owners are often interested in maximizing timber volumes for harvesting, but are now becoming more interested in maximizing volumes in order to generate carbon offset credits. Trees are carbon sinks, meaning they sequester carbon through photosynthesis, and pack it away in their biomass, both above and below ground. This natural carbon sequestration is a key tool in combating climate change at a global level, and this is why carbon markets are such a hot topic in current climate change mitigation techniques.¹

Generally, forestland carbon credits are generated through carbon sequestration in trees and wood products through standardized verification processes, and the captured carbon effectively offsets carbon that is being emitted elsewhere. Because greenhouse gas (GHG) emissions being emitted in

¹ Newell et al. 2013
one place have the same implications as if they were released somewhere else, climate change and GHG reductions are a global challenge, and have led to regionally/globally accepted methods for carbon accounting and offset credit generation. Emitting companies or individuals can buy into the carbon market (compliance or volunteer market) and purchase these credits to offset their carbon emissions. By buying credits, their emissions are considered negated for the amount of credits purchased. Currently this is an accepted practice for climate change mitigation efforts, but is controversial among some groups.

Creating a carbon bank can be a lucrative option for many different types of forest landowners, especially those interested in conservation. Larger land parcels with significant amounts of carbon are great opportunities for private and public entities to offset carbon emissions, as well as take a positive step towards combating climate change on a local scale.

Carbon Offset Programs Around the World

Carbon offset markets are a specific type of GHG reduction strategy being used around the world. These market structures vary regionally, but can generally be split into compliance markets and voluntary markets. In 1997, 37 industrialized countries and the European community committed to reduce GHG emissions as part of the Kyoto Protocol. The Kyoto Protocol was essentially a global debate that included some of the most powerful countries in the world in order to determine the best ways to fight against climate change, and determined that the most effective vehicle for this would be carbon credits. Several different trading schemes have stemmed from the Kyoto Protocol and are now being implemented around the world. Some of the most notable marketplaces being in the European Union, California, northeastern United States and New Zealand.

European Union Emissions Trading System
The European Union’s Emissions Trading System was initiated in 2005, and is now one of the most robust carbon markets in the world. This is designed as a cap-and-trade program where the cap on carbon emissions was originally set at 2.1 billion metric tons in 2011, and captured many of the major GHG producers in their economy. The program has since expanded to more sectors of the economy and has also evolved to more of a sector regulated system rather than a national plan for allowable emissions.

California Cap-and-Trade System
The California Cap-and-Trade system was designed in the early 2000’s and had its first auction in 2012 as this strict GHG reduction compliance market commenced in 2013. This program sets caps on the largest sources of GHG emission (initially targeting the energy sector) and allows up to eight percent of their emissions to be offset by carbon credits. In this program, companies can buy offset credits from third party forestland owners that are a part of the program as “sellers” through several different types of approved offset projects, including forestry projects that will be discussed in more detail later. This program is the current standard for carbon offsets in the United States market, as it is the most developed, stable, and robust program.

Regional Greenhouse Gas Initiative

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2 California Air Resources Board
3 American Carbon Registry website
4 CARB website: [https://ww2.arb.ca.gov/homepage](https://ww2.arb.ca.gov/homepage)
The Regional Greenhouse Gas Initiative began in the northeastern region of the United States in 2005, and was the first GHG reduction program of its kind to gain traction in the U.S. This program is designed more as an allowance system where companies (mainly in the electricity sector) can purchase emission allowances, and sought to reduce emissions by 10 percent below 2009 levels by 2018. This program was wildly successful due to the transition away from coal-powered energy systems in the region, but is still active today due to an established floor price of allowances and additional, more ambitious, GHG reduction goals.

**New Zealand Emissions Trading System**

The New Zealand Emissions Trading System is a somewhat modified cap-and-trade system due to the size of their economy. This program is set up to buy and sell credits under a cap, but is also designed to interact with the European Union’s Emissions Trading System. The program includes the Clean Development Mechanism which is a “vehicle for translating emissions reduction efforts in developing countries into credits that can be used to offset emissions elsewhere,” an ideal scenario for smaller economies that can’t support a robust GHG offset market.

**Domestic Carbon Market Overview**

In the United States there are several different GHG markets with various goals and structures; the California Cap-and-Trade system being the benchmark of the compliance GHG reduction markets. Compliance and voluntary markets have proven to be successful in the United States and are continuously growing as more government agencies and regulators are seeking answers to the climate change problem. Different regional markets around the country have various standards, protocols, and expectations, most notably between the compliance and voluntary markets.

**Compliance and Voluntary Markets**

Compliance markets, like the ones listed above, often target a specific industry or sector to reduce the emissions from some of the biggest producers. Historically this has been seen in the energy sector, which has led to some transition away from burning fossil fuels and incorporating more renewable energy sources. The standard compliance market in the U.S. is the California Cap-and-Trade program. Outside of the compliance markets, there are voluntary markets developing around the country to accommodate interested parties outside of the regulatory environment. They enable businesses, governments, NGO’s, and individuals to offset their carbon emissions through the Verified Emissions Reduction (VER) market. This marketspace allows these groups to invest in offsetting their carbon emissions to combat climate change, for moral obligations, and for corporate social responsibility.

While sharing similar goals of reducing GHG emissions, compliance and voluntary markets differ in many respects. A big difference is the size of projects and the market price for offset credits. Sizes of carbon projects in the voluntary market are typically much smaller than in a compliance market because the buyers are voluntary, and therefore the demand is not being facilitated by a regulatory instrument. Lower market prices for the offset credits result from the lower demand compounded with the fact that VER’s cannot be used in the compliance markets, severely restricting access to a strong market. Lastly, it has been found that VER standards are generally less stringent than Compliance Emission Reduction (CER) credits, which can lead to lower project costs, but also lower quality projects. Because voluntary markets have less regulation and established rules, it is a great

5 CORE website: [http://www.co2offsetresearch.org/index.html](http://www.co2offsetresearch.org/index.html)
opportunity for innovation from foresters and investors, and can also serve as a testing site for new methodologies, technologies, and procedures.\(^5\)

The California carbon market is the current standard for U.S. GHG market programs and has been successful since its inception in 2013. California Air Resources Board (CARB) is the regulating agency for this program and has published dozens of documents outlining the program, as well as the procedures, methodologies, and descriptions of projects that are eligible to enter the program.\(^4\) Their publication, "Compliance Offset Protocol – U.S. Forest Projects" is particularly important. This document outlines the purpose of the program, types of recognized quantification methodologies, project eligibility, project boundaries quantification, how to determine the GHG reductions/removals, monitoring and reporting guidelines, and verification requirements.\(^6\)

**CARB Overview and U.S. Standards**

The cap-and-trade system implemented by CARB is part of the state’s plan to reduce GHG emissions that contribute to climate change and global warming. This system is set in place to help California reduce GHG emissions to 80% of 1990 levels by 2050.\(^4\) By setting caps on GHG producers by sector, CARB will limit the total amount of emissions from the state, and with their plan to reduce that cap by 3% each year the total climate change contributing gases will be reduced significantly.\(^4\) Carbon offset credits can only apply to a portion of the allowable carbon emissions however; meaning that yes, the credits purchased by an organization will essentially negate those emissions, but this can only be applied to a portion of the total emissions. Without having a limit on the number of allowable credits for each GHG producer, companies would be able to still produce the same amount emissions as before and just pay for additional credit. This is a big point of debate in the program because it is unclear to some people that the offset credits generated from reforestation/active management/etc. are actually reducing the concentration of GHG in the atmosphere in perpetuity.\(^7\) The “in perpetuity” piece of that argument is extremely important because of the amount of time it takes for GHG compounds to breakdown in the atmosphere. Also, some climate change activists and scientists are still skeptical of the true validity of this mitigation strategy because of the short time frame these programs have been active.\(^8\)

The American Carbon Registry is the first voluntary greenhouse gas registry of its kind in the world, and was approved in 2012 from CARB as an Early Action Offset Program (EAOP) as well as an Offset Project Registry (OPR).\(^4\) Because of American Carbon Registry’s EAOP and OPR status, they have the ability to administer VER credits that have the potential to roll over into the compliance market when applicable; and they also have the opportunity to be at the cutting edge of new methodologies and quantification methods because of the more lax regulations.\(^4\) ACR brands the premium verified emission reductions issued against their standards as Emission Reduction Tons (ERTs).\(^4\) A single ERT represents the reduction or removal of one metric ton of carbon dioxide from the atmosphere.\(^4\) ACR also manages the database of carbon offset projects across the country, and is the supervisor of project verification in the California compliance market and national voluntary market.

The GHG emission reduction markets are extremely complex with many different layers of provisions, regulations, and hundreds of pages of documentation. Many landowners have the ability to enter these markets, but are in need of the professional services that can make a project on their

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\(^{6}\) CARB Forest Protocol 2015  
\(^{7}\) World Bank Carbon Finance Report 2012
lands worthwhile. The U.S. voluntary carbon market is one that is gaining traction for smaller landowners around the country and is seeing increasing interest from not just smaller private landowners, but large corporations, conservation groups, and even government agencies. The following sections will describe in more detail the process for implementing a carbon offset project, the types of approved methodologies and quantification techniques, eligible projects, and some of the cutting-edge technology that can now be used to identify and monitor potential project areas, focused in the United States.

**Carbon Estimation and Project Conception**

CARB and ACR have established standard protocols for the process of entering the carbon market that include the accepted methods of quantifying carbon on site, accounting for reversal risk, additionality, verification, and reporting. Generally, for a project to enter the carbon market, the site must go through an initial vetting process to determine first if the project is viable, and if it is, how many credits will be generated. This is where carbon banks are a little more efficient, and why they are typically used in the compliance market setting. A carbon bank is essentially a large holding of forestland carbon that can accommodate multiple carbon projects. These are normally large tracts of forestland with a good distribution of age classes in the timber across the property. They are particularly convenient for a high demand market because they allow projects to be more readily accessible to accommodate the high demand for carbon offset credits as seen in California. These are less common in voluntary markets because of the lower relative demand for credits and the types of projects that are usually implemented.

*Types of GHG Offset Projects*

There are several types of projects that can be used to generate carbon credits in both the compliance and voluntary markets, but this project is focusing only on the forestry sector. Eligible projects in the CARB Forest Protocol include reforestation, improved forest management, and avoided conversion. Reforestation projects generate carbon credits by planting trees in an area that hasn’t been forested in at least 10 years; by adding trees to the property, there will be more sequestered carbon than if the tract was left in non-forest use. Improved Forest Management projects generate credits from increasing the productivity of the forest, implementing sound silvicultural techniques that will improve the stands age class distribution, stocking, and rotation ages. Avoided Conversion projects are essentially conserving private forestland from being converted into agriculture or urban development. Credits are generated in this project type by keeping land forested and sequestering carbon rather than being cleared for alternative use.

*Getting a Carbon Offset Project off the Ground*

To start on any of the carbon projects listed above, there will always be an initial carbon accounting exercise to estimate the amount of stored carbon on the property. With reforestation projects there must be proven evidence that the site was in non-forest use at least 10 years prior, and for avoided conversion projects there must be solid evidence that the site would have been converted if not for implementing the project. The accepted carbon accounting techniques are described in the CARB Forest Protocol documentation, and there are specific instructions on the allowable cruising and biometric methods. Once there is a baseline for the current carbon pool, that amount must be discounted to account for all the different risks to the longevity of the offsets.

Carbon deductions are implemented on an individual project basis to account for potential losses to the carbon asset through leakage or reversal. Leakage is mainly in consideration with avoided
conversion projects because it is essentially accounting for the fact that although the conversion was stopped in a particular area where there is now a carbon project, that development or agriculture may just go down the road and deforest the neighbor’s property. So, to account for this, it is standard practice to deduct a certain percentage of the generated carbon credits, discounting the offsets of the project. There are also several different common practices to deal with the risk of carbon reversals.

The risk of carbon reversal refers to the likelihood that the carbon sequestered as part of a carbon offset project will be lost. This is a minor detail in the grand scheme of the program, but can have major implications on the market supply as it can greatly reduce the number of carbon credits generated in more “risky” sites. CARB recognizes specific risks to their projects that include financial failure of the landowner, illegal harvesting, conversion to non-forest use, over harvesting, social risks, wildfire, disease/insects, and other natural disasters. These risks are given a percentage value for their likelihood of happening on the specific project site, and the aggregated percentage is the amount of credits that must be contributed to a forest buffer account, an insurance holding account for offset credits. There are many different ways to account for carbon reversal, but the California market uses the buffer account methodology.

It is required for the California Forest Protocol, and most other programs, to have some sort of risk reversal assessment for each individual project. The United Nations Framework Convention on Climate Change (UNFCCC) provides a list of possible mechanisms to account for carbon reversal. Credit reserves or buffer accounts are a common risk mitigation mechanism, and the buffer account is used in the CARB Forest Protocol for the California carbon market. A buffer account is a credit holding vehicle that reserves a certain percentage of carbon credits generated from each project based on the risk that the carbon will be reversed. An extension to the buffer account is the idea of aggregation and pooling. This allows project reversal to be covered by a broader pool of projects in the program, region, or country. Other mechanisms include discounting, host country guarantees, insurance, and credit holding exceptions for low-risk projects. Each of these methods has unique benefits and shortcomings, so it is often most successful to have a combinations of multiple risk reversal mechanisms in an offset program.

Another important detail for starting carbon projects is the idea of additionality. Additionality refers to the requirement of proving that the specific carbon project will provide additional carbon sequestration than if it were not implemented. This is very important for avoided conversion projects because credits are distributed based on the likelihood that the property would’ve been converted to non-forest-use if it were not placed into the program. The verification process will determine compliance with this requirement and all others before the project is declared eligible for a program and credits can be distributed and sold. There is also an expectation and often a requirement for annual, or regular, project reporting that tracks carbon sequestration over time, changes to the property, alterations to the risk assessment, and other updates that may have an effect on the project’s validity.

The most important aspect of getting a carbon offset project off the ground is the initial carbon accounting and cruising at the onset of the project. For the California market, there are specific guidelines and recommendations on how to estimate the carbon on a property, but other programs allow for different methodologies as long as the estimate is reliable. The most common carbon accounting on a property will often only be in the standing trees and above-ground biomass (AGB). Estimating the volume of wood on a tract is a proven baseline method for estimating AGB carbon
because carbon is typically about 50% of the wood mass. This can vary by species, density, specific gravity of the wood, and a number of other factors, but this 50% rule is very common in AGB carbon estimation. Historically this volume estimate is conducted with a thorough cruise, with higher plot densities and more intense measurements. Increasingly however, there has been more interest in using remote sensing methods for initial carbon estimations.

Carbon estimations can vary significantly on a property depending on the type of carbon that is included or excluded. AGB is often the type of carbon thought of when talking about carbon offsets, and that is what will be used in any sort of wood product if that aspect is included in the offset protocol. However, there are many other carbon sources that should be considered in a carbon project including AGB, but also belowground biomass (e.g. roots), standing dead trees/stumps, and downed woody material. Although these carbon sources other than AGB and belowground biomass will not be sequestering carbon as time goes on (the dead biomass will actually be releasing carbon) it is important to account for it in the initial estimation. The carbon cycle is very complicated and complex, so it is important to intimately understand the initial carbon pool so that it can be tracked accurately over the life of the project.

**LiDAR and Remote Sensing — The Future of Carbon Estimation**

Light detection and ranging (LiDAR) and other remote sensing applications are becoming more common for estimating timber volumes, vegetation density, cover types, and now carbon stocks. Although this methodology is currently not accepted by CARB, ACR is allowing pilot projects to test the validity of using LiDAR to estimate carbon stocks. In the voluntary market, individuals could implement a LiDAR regime for carbon estimations to accommodate clients interested in entering the carbon market. Although LiDAR can be highly accurate, there is still a lot of quality control and model honing to be done to make LiDAR more consistent in estimating AGB. One main issue with LiDAR is the generality associated with individual tree estimates. It is common to be able to identify forest types with these datasets, but being able to identify individual trees with height and species data will significantly increase the accuracy of this carbon estimate method. Once there is a basis for the current carbon stocks, if information on species composition, site index, and growing conditions are known, the future carbon can be estimated through growth and yield modeling; so properties can be evaluated for investment with knowledge of the current carbon as well as the projected carbon sequestration. If this methodology can develop in the voluntary market and gain a reputation for being a more reliable carbon estimation technique, it could be a huge advancement in the carbon offset markets around the world. The challenge is to create models robust enough to include all of the quantitative data collected in the field. Ground-truthing is necessary for LiDAR carbon estimates at this point, and is required to generate carbon credits in the United States.

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8 Perry et al. 2008  
9 Miles 2009  
10 Wilson et al. 2013  
11 Lu et al. 2012  
12 Drake et al. 2003  
13 Kwak et al. 2007  
14 Smith et al. 2004  
15 Keyser 2008
Risk of Conversion

Risk of conversion is critical to site suitability for avoided conversion projects. It is how additionality is addressed in this breed of carbon credit project. Carbon credits are generated only if the land that is protected was demonstrably at risk of being deforested, and credits are awarded proportionally to that risk.\(^{16}\) Existing protocols use the land’s appraised value as a proxy for risk of deforestation, with a land value substantially higher than the land’s value in forestry use indicating a high risk of conversion. At least a 40% higher land value in an alternate land use is generally the benchmark to be eligible for avoided conversion. The higher the land’s value above the forestry value, the more likely the land is thought to be destined for conversion, and the more carbon credits can be generated by its protection.\(^{19}\) In this study we chose to directly model probability of deforestation. If appraised value is an unbiased proxy for probability of deforestation, then our results should be useful even if the eventual project will use appraised value to prove a risk of conversion.

Land use change modelling has a rich literature which contains many different statistical methods. The FUTURES model\(^{17}\) has been applied in North Carolina. FUTURES outputs a map of a predicted land use scenario, but the model contains a submodel which predicts probability of development using a mixed effects logit regression. Parametric models such as that have advantages, but for this study, the random forest regression algorithm was chosen because parameter estimation was not a goal and random forest models require no assumptions about the data and are known to perform very well without the need for extensive model tuning.

Conservation Value Evaluation

Trying to tackle global environmental problems with finite resources and budget leads to difficult decisions. To help make decisions, more and more conservation-prioritization schemes and methods have been developed over the past years. Prioritization schemes provide guidance on decisions to protect locations serving as habitats to rare species.\(^{18}\) Conservation value is a commonly used metric to rank candidates sites based on their importance and contribution to species and ecosystem integrity for decision-makers.

Definition of Conservation Value

Broadly, conservation value represents a more generic concept of prioritizing conservation efforts. The principle applied in assessing conservation value is to represent the intrinsic features of sites, and these features can be used to compare sites in terms of their quality and quantity, such as size, naturalness, diversity, etc.\(^{19}\) There are several quantitative approaches to measure conservation value in previous studies and each of them could lead to different outcomes (Table 1). In our project, we identified conservation value as the quality of habitats to sustain species population and connectivity, and the resilience of a site to future climate change.

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\(^{16}\) Carbon Action Reserve 2017
\(^{17}\) Meentemeyer, et al 2013
\(^{18}\) Capmourteres & Anand 2016
Table 1. Definition of conservation value (CV). Values in the occurrences represent the percentage of the occurrences of meanings of CV and inside the parentheses are the numbers.

<table>
<thead>
<tr>
<th>Ranking Position</th>
<th>Meaning of CV</th>
<th>Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Provision of habitat and food to sustain wildlife populations</td>
<td>31.58 (78)</td>
</tr>
<tr>
<td>2</td>
<td>Complement conservation in anthropic ecosystems and contribution to management goals</td>
<td>21.86 (54)</td>
</tr>
<tr>
<td>3</td>
<td>Tool to prioritize conservation efforts</td>
<td>18.22 (45)</td>
</tr>
<tr>
<td>4</td>
<td>Indicator of endangerment, species at risk, uniqueness, or conservation priorities</td>
<td>12.15 (30)</td>
</tr>
<tr>
<td>5</td>
<td>Potential of species or areas to provide ecosystem services</td>
<td>8.50 (21)</td>
</tr>
<tr>
<td>6</td>
<td>Importance to enhance landscape connectivity and function as corridors</td>
<td>3.24 (8)</td>
</tr>
<tr>
<td>7</td>
<td>Measure of ecosystem integrity, health, and resilience</td>
<td>2.43 (6)</td>
</tr>
<tr>
<td>8</td>
<td>Value of genetic resources, wild breeds, hybrids, or remnant populations</td>
<td>2.02 (5)</td>
</tr>
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**Evaluation Metrics of Conservation Value**

There are various metrics to quantify conservation value. Capmourteres and Anand’s (2016) tabulated the metrics that were introduced in previous studies to evaluate conservation value (Table 2). In our analysis, we chose the following metrics: species richness (representing richness), Natural Area Natural Heirate score (as a proxy of rarity or uniqueness of species or ecosystems), corridor (representing degree of naturalness and habitat quality), and landscape diversity as the biophysical attribute.

Table 2. Evaluation metrics of conservation value (CV). Values in the occurrences represent the percentage of the occurrences of metrics to assess CV and inside the parentheses are the numbers.

<table>
<thead>
<tr>
<th>Ranking position</th>
<th>Metrics</th>
<th>Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Richness, hotspot</td>
<td>22.30 (93)</td>
</tr>
<tr>
<td>2</td>
<td>Spatial distribution, habitat use</td>
<td>18.71 (78)</td>
</tr>
<tr>
<td>3</td>
<td>Abundance, density</td>
<td>12.71 (53)</td>
</tr>
<tr>
<td>4</td>
<td>Rarity or uniqueness of species or ecosystems</td>
<td>11.27 (47)</td>
</tr>
<tr>
<td>5</td>
<td>Diversity, evenness, dominance</td>
<td>7.67 (32)</td>
</tr>
<tr>
<td>6</td>
<td>Endangered species</td>
<td>7.43 (31)</td>
</tr>
<tr>
<td>7</td>
<td>Degree of naturalness and habitat quality</td>
<td>7.19 (30)</td>
</tr>
<tr>
<td>7</td>
<td>Others</td>
<td>7.19 (30)</td>
</tr>
</tbody>
</table>
Protected areas and the importance of corridors
Previous studies have proven the significance of connected networks of protected areas to maintaining the connectivity between ecosystems and populations, reducing the risk of extinction, and sustaining biodiversity. Protected areas are established to reduce and minimize human impacts and they serve as the foundation of conservation to maintain biological diversity. However, if protected areas are isolated, they could not support species’ migration, dispersal and other essential activities to sustain species’ population. Unconnected to a habitat network, they are more vulnerable and fragile to environmental change, which is more likely to experience local species distinction.

Natural areas
A site is designated as a natural area if it is of biodiversity significance because of the presence of rare species, unique natural communities or other special ecological features. Natural areas are estimated to be the best locations to support natural diversity. These areas are evaluated and classified into different ranks as a representation of their importance for conservation. This information can provide guidance for different stakeholders to make conservation decisions that influence the state’s biodiversity.

Landscape diversity
Landscape diversity, defined as the variety of landforms which was created by an area’s topography and terrain, along with the alteration of elevations, improves a site’s resilience to changes in the regional climate. A site with high landscape diversity can serve as a buffer to slow down the rate of change for species by providing diverse micro-topographic thermal climate options, and therefore, areas like this are also important for sustaining the population of plants, invertebrates and other species.

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19 Belote et al. 2016
20 NC Natural Area website: https://www.ncnhp.org/activities/conservation/natural-areas
21 Anderson et al. 2016
**Statement of Purpose**

This project initiates a unique methodology for launching a carbon project in the voluntary market, specifically for academic institutions that have multiple objectives. Specifically, our analysis is based on avoided conversion carbon credits, and tailored towards a voluntary, peer-reviewed system among academic institutions looking to reduce their campus' carbon footprint. Duke Carbon Offset Initiative (DCOI), a subsidiary of the Duke Sustainability Office, expressed interest in three main areas: 1) identifying parcels that have potential to generate carbon credits to offset Duke University’s carbon footprint, 2) analyzing areas of biological importance or biodiversity significance as an additional benefit to land conservation, and 3) producing a model that can be manipulated and distributed to other academic institutions for their use.

The deliverables of this project are three-fold. First we produced the GIS model mentioned above with a description of how to manipulate the weights, the necessary inputs, and the processes involved in the calculations. Secondly, we produced multiple maps for DCOI illustrating areas of interest for carbon credits, biodiversity corridors and hot spots, areas most at risk for land conversion, and our final parcel recommendations. Finally, we produced a list of prioritized parcels from our model accompanied by greater description of the potential project at that location, economic analysis, and potential partners in the respective area for DCOI to work with on launching a project. These deliverables are a compilation of our own research, professional input, and multi-criteria decision analysis from our client and advised by the group.
Data

Carbon Analysis

National Land Cover Dataset (2011)
This dataset was acquired online from the NLCD database to assign land cover types to each parcel. Parcels that had multiple land cover designations within it were still considered, but only to the extent of the forested area. Forested areas in this analysis included the following NLCD classifications: Deciduous Forest (41); Evergreen Forest (42); Mixed Forest (43); Woody Wetlands (90).

LiDAR-Derived Canopy Heights (2005; 2011)
The canopy height raster used in this analysis was a modified digital surface model derived from the 2005 (western 40 counties) and 2011 (eastern 60 counties) LiDAR data collection representing the maximum canopy height within each 60 ft. cell and 20 ft. cell, respectively. The 2005 data is based on LiDAR data averaging two points per square meter, and the 2011 data averaging eight points per square meter (NCSDD). This dataset was provided to us by Doug Newcomb of the US Fish and Wildlife Service. Newcomb derived these canopy heights using a proven derivation method in GRASS and QGIS. By performing a pseudo-landscape analysis, or geornorphs, the GRASS GIS software can be trained to identify tree tops, and ultimately one can estimate the aboveground biomass from a single data point derived from the LiDAR. This would be similar to identifying a summit of a mountain on a larger scale, or a ridgetop and determining the elevation. See the citations above for more detailed information on this method.

Forest Inventory and Analysis Tree Height and Biomass Data
We used the most recent FIA tree height data to confirm the viability of our canopy height layer before determining the biomass. This step was necessary in order to ensure that our tree heights were within a reasonable range and had a similar distribution as the ground-truthed FIA across each North Carolina ecoregion. By assuring our initial tree data were reliable, the resulting biomass estimates would also be reasonable given the location of the parcel in consideration.

Tree heights were analyzed between LiDAR and FIA data to determine there was no statistical difference between the datasets (<0.05). However, biomass/carbon was not given in the same form from FIA as tree heights, so the biomass data from FIA was used more as bounding figures for our biomass/carbon estimates derived from the LiDAR heights. Specifically, the FIA biomass data provided gave a mean value based on stocking levels for each ecoregion. The biomass estimates from our LiDAR-derived canopy height calculations were compared to these figures for each ecoregion. Because we did not determine the stocking level of each parcel, the maximum and minimum FIA biomass values were used as upper and lower bounds. All of our estimates fell close within this range. Average derived values were within the 95% confidence interval for the total mean.

Current Managed Areas
We considered all lands owned and/or managed by a public agency or conservation group to be under no risk of conversion, and were therefore not included in our analysis. These parcels, acquired from

22 Newcomb 2016
23 Newcomb & Petras 2018
NC Natural Heritage Program, included areas that are currently being managed by a public agency at any level, parcels encumbered by conservation easements of any kind, and areas with any other use restrictions that would otherwise prevent them from being converted from their current natural state.

**NC OneMap Tax Parcels**
We preselected tax parcels for our analysis based on attributes found in the listings. The main attributes used in our filtering process and throughout the analysis included total tax parcel data, land value, location, parcel use, and ownership relative to any deed/development restrictions. Parcels with irregular parcel listings, which were very few, were not considered due to unreliable data.

**Risk of Conversion Analysis**
A suite of variables was selected for conversion risk modelling that were expected to influence site suitability for development and agriculture. In some cases multiple predictor variables were derived from one original data source. Refer to table 3 for data, source, and variables derived therefrom.

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
<th>Variables Derived</th>
<th>Short name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>NED</td>
<td>Elevation</td>
<td>elevation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slope</td>
<td>slope</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ratio of slope to mean slope within 1 mile radius</td>
<td>relative slope r = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ratio of slope to mean slope within a 5 mile radius</td>
<td>relative slope r = 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean slope within a 1 mile radius</td>
<td>mean slope r = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean slope within a 5 mile radius</td>
<td>mean slope r = 5</td>
</tr>
<tr>
<td>Land cover</td>
<td>NLCD</td>
<td>Land cover class*</td>
<td>NLCD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent developed with a 1 miles radius*</td>
<td>dev pressure r = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent developed within a 5 miles radius*</td>
<td>dev pressure r = 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forest cover conversion 2011 - 2016</td>
<td>converted</td>
</tr>
<tr>
<td>Population</td>
<td>NC Office of State and Budget Management²⁴</td>
<td>County population*</td>
<td>county pop</td>
</tr>
<tr>
<td>Sawmill locations</td>
<td>Primary Forest Products Network²⁵</td>
<td>Distance to sawmill</td>
<td>dist sawmill</td>
</tr>
</tbody>
</table>

²⁴ [https://www.osbm.nc.gov/demog/county-projections](https://www.osbm.nc.gov/demog/county-projections)
²⁵ [https://primary.forestproductslocator.org/mill-map](https://primary.forestproductslocator.org/mill-map)
Conservation Value Analysis

National Land Cover Dataset (2016)
This dataset was acquired online from the NLCD database in its most recent form to evaluate the naturalness of each land cover type. The naturalness layer was utilized to produce cost surfaces in the corridor generation.

National Wilderness Preservation System Map
This dataset was acquired online from the Wilderness Institute website to identify the large protected areas in North Carolina as a subset of the core areas in the corridor generation.

Protected Areas in the U.S.
This dataset was acquired online from the Protected Area Database to identify lands that are under the legislative or management direction to maintain biodiversity and forbid any land cover conversion, and we combined these areas with the large protected areas identified from the above step as the complete core areas in the corridor generation.

NC Roads
We downloaded the NC Route data and selected the roads that have a class of 1, 2 or 3. These roads were used to generate remoteness layer which was utilized to produce cost surfaces in the corridor generation.

NC Census Block
We acquired the municipal population data across North Carolina from the U.S. Census Bureau database. The population density was used to develop the solitude layer which was utilized to produce cost surfaces in the corridor generation.

Natural Heritage Natural Areas
This layer was downloaded from the North Carolina Natural Heritage Program. This shapefile includes terrestrial sites that have special biodiversity significance due to the presence of rare species, unique natural communities or assemblage, etc. We used this layer to examine selected parcels’ relative contribution to maintaining high-quality habitats as one of the two biodiversity indices.
NCGAP Vertebrate Predicted Distribution Mapping

This layer was downloaded from NC GAP analysis project’s website to demonstrate the species richness across the state. We used this dataset to assess the parcel’s species richness score as one of the two biodiversity indices.

TNC Landform

Landform data was acquired from The Nature Conservancy’s database and combined with the soil type data as a proxy of landscape diversity.

NC Soils

Soil type data across North Carolina was downloaded from NRCS’s database and combined with The Nature Conservancy’s landform dataset as a proxy of landscape diversity.
Methods
This is a multi-step model with three major inputs that account for the potential carbon credits and conservation value. To execute this model, we started with tax parcel data and filtered for parcels that are viable for such a project. We then assigned a carbon value to each parcel based on the current and future carbon stocks derived from LiDAR data. The carbon value was then discounted based on the parcel’s probability of conversion. We derived the probability of conversion using an advanced statistical method known as the randomForest model in R. This discounted carbon value is in essence the estimate of potential carbon credits that each parcel would hypothetically yield. Finally we added the conservation value onto each carbon value that is now in relative terms. The conservation value includes inputs like proximity to protected/biologically significant areas, corridor viability, and species richness. The user of the model can manipulate the importance of each input variable to accommodate a variety of interests ranging from exclusively carbon credit generation to simple biodiversity/conservation planning, and everywhere in between.

Tax Parcel Selection
To make this analysis realistic for both conservation groups and carbon project logistics, we selected parcels in a specific manner to accommodate the size and specifications of a carbon project that also had realistic acquisition probability. We started by restricting our analysis to parcels with 100 or more acres of wooded area (see Data -- National Land Cover Dataset above). We concluded that 100 acres was a realistic area of wooded area to construct a carbon offset project in a voluntary, peer-reviewed style market described above.

Because our project was focused specifically on ‘Avoided Conversion’ carbon offsets, we used parcel zoning restrictions and the Current Management Areas shapefile (see above) to remove all parcels that currently do not have any risk of being converted from forestland.

This filtering process resulted in a list and map of around 13,000 parcels across the state that contain 100 acres or more of forestland, and are not encumbered by any sort of use restrictions. These parcels were the base of our model, and continued through our analysis to the LiDAR-based canopy heights portion of the project.

Carbon Analysis
Using LiDAR-Derived Canopy Heights to Estimate Carbon Stores
We extracted maximum canopy heights from each cell in each parcel. As mentioned above, the canopy height rasters used in this analysis were provided from a previous study, LiDAR data from 2005 for the western 40 counties and data from 2011 for the eastern 60 counties (Figure 1).
Using tree height data from each ecoregion of North Carolina from Forest Inventory Analysis, we were able to compare our average maximum canopy height distribution with the most recent ground-truthed FIA tree height distribution. This step was performed to confirm our canopy height estimates were reasonable across the entire state as well as the two different LiDAR datasets used to derive our canopy height estimates. As expected, our canopy height values had a somewhat normal distribution with a long tail at higher values and a higher quantity of low to mid range heights as shown below (Figures 2, 3).
Figure 2. Distribution of tree heights in each ecoregion. Tree height is on the X-axis and frequency of heights is on the Y-axis. As expected heights are a normal distribution, skewed to having higher volumes of shorter tree, and having very few trees on the high end nearing the saturation point.

By plotting tree heights based on their ranking we are able to further demonstrate the saturation point of tree heights for our LiDAR derived heights and FIA-recorded tree heights (Figures 2, 3). Notice the difference in saturation points (where the slope of the line is nearing 0) between the three ecoregions, but also within each region, how similar the lines are to the FIA data. This tells us that our LiDAR tree heights are reliable, assuming the FIA dataset is correct, and has a representative sample across North Carolina. We confirmed that the datasets from each ecoregion were not statistically different from the FIA data.
Figure 3. Distributions of tree heights between the LiDAR-derived canopy height data (right) and the most recent FIA data collected (left) to ensure validity of data layer. There was no statistical difference between the two datasets for each region. Note the similarities in saturation points between each of the two datasets. As tree heights approach the regional maximum, the quantity of data points decreases. The saturation point deemed the maximum tree height for each region is where the slope approaches 0.

From this point forward, our analysis was conducted separately on the two different height datasets from 2005 and 2011 due to the nature of precision in the data available. Because the two LiDAR datasets were collected in different years and at different resolutions, we did not believe we could responsibly compare parcels to one another across the two datasets. After creating the canopy height estimates for each cell and aggregated to the parcel, we followed a previous method of estimating biomass by applying a simple quadratic equation from Lefsky et al. (2005). This equation was derived from a range of forest types as well as several different geographic regions that were similar to the landscape diversity seen across the state of North Carolina. Lefsky et al. (2005) derived this height to above ground biomass from temperate forests in Tennessee and Oregon as well as tropical forests of Brazil. By using these diverse forest types, this method provides an approximate biomass estimate.
over large areas of land with a range of forest types. We estimated biomass for each cell with a maximum canopy height value, then aggregated the cells to compare carbon estimates between parcels.

\[ AGBM = 20.7 + 0.098 \times H_{\text{est}}^2 \]  

Where

- \( AGBM \) is aboveground biomass (MgHa\(^{-1}\))
- \( H_{\text{est}} \) is maximum canopy height (m) estimated from ICESat waveforms and SRTM elevation, as in section 3.3

Because there are no other known studies that have done a similar analysis, we decided to use this method despite the different height data collection method. However, because this method collected height data on a per unit area basis, we were able to manipulate this method to accommodate our needs. After converting each parcel area to a biomass estimate, we assumed carbon was 50% of the biomass in any given area.

Once again after each parcel had a carbon estimate value assigned to it, we further compared our results to FIA biomass and carbon estimates from each North Carolina ecoregion to confirm that our carbon estimates, on a per acre basis, were in a reasonable range (Figure 4).

![Figure 4](image)

**Figure 4.** This is the average carbon estimate for each N.C. eco-subregion given four different stand stocking levels. This FIA data provides validity in our carbon estimates across each ecoregion in N.C. as they are not statistically different from our estimates. 231=Piedmont region, 232=Coastal Plain region, M221=Mountains region.

Finally, to properly analyze these current carbon store estimates, we aggregated each raster cell on a per acre basis to relatively compare parcels. Additionally, we aggregated cells for the individual parcel and ranked each parcel based on its total and average per acre carbon stores.

*Estimating Future Carbon Accumulation*
As carbon credits after the initial action are distributed on an annual accumulation basis, we needed to estimate the potential future carbon accumulation for each parcel. To do this without utilizing any growth and yield modeling, we simply used the largest per acre value in each ecoregion as a pseudo-maximum carbon value and subtracted each parcel’s current carbon from that declared maximum value. The difference was our estimate for potential carbon accumulation in the future for each parcel.

**Risk of Conversion Analysis**

*Development of Predictor and Response Variables*

Predictor variables were collected from various publicly available sources. A mix of environmental and socioeconomic variables were sought. In some cases multiple variables were developed from one initial layer, such as with elevation and land cover class, and in some cases multiple raw data layers were converted into a single predictor layer, such as with the soils data. NRCS’s site index data includes values for multiple species for each soil type. The highest site index for each soil type was extracted for use here. Development limitation also comes in multiple classes; Each soil has a score for each property that can be limiting for development. Here the limitation value of the most limiting property was extracted for each soil type. Distances are simple Euclidean distance. All predictor layers were developed in ArcGIS Pro.

The response variable for model training is a binary (0/1) layer covering all NLCD cells that were forested in 2011 but not inside managed areas according to NCNHTF’s data. Managed areas are generally under some variety of protection, are extremely unlikely to be deforested, and therefore could have skewed the regression model. Zero represents cells that remained forested in 2016 and one represents cells that were no longer forested in 2016, or cells that were “converted” or “deforested” over the 2011-2016 interval. 20,000 points were placed randomly within the coverage of this layer.

*Model Training*

The predictor and response variables were read into an R session using the “raster” package. They were resampled to a uniform grid and aggregated into a raster stack. The random points were also read in. The values from the predictor and response variables at the locations of those points were extracted. The data was very unbalanced. Only roughly five percent of the points fell in cells that had been deforested over that interval. The deforested class was oversampled using ADASYN. A random forest regression (package “randomForest”) was trained on that data.

*Conversion Risk Forecasting*

The random forest model was then used to predict the response variable across the entire state. The time-varying predictors (population and land cover class) were updated to 2016 levels for the prediction. Occasional “NoData” cells in the output caused by incomplete coverage of explanatory variables were interpolated using a focal mean of each cell’s 50x50 cell rectangular neighborhood.

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26 He et al 2008
27 Brieman 2001
**Conservation Value Analysis**

In this section we evaluated conservation value per parcel from four aspects: corridor, natural areas (as a proxy of rare species), species richness, and landscape diversity. We conducted four separate analyses and reclassified each output into 20 evenly distributed classes to prepare it to be combined in relative terms. Similar to the carbon weighting above, the final rasters of each input: corridor score, NHNA score, species richness and landscape diversity were weighted according to the client’s preferences.

**Corridor - Identifying protected areas**

For our analysis we decided to focus on protected areas with conservation mandates that demand maintenance of biodiversity and prevention of land conversion, commercial resource extraction, etc. Only “large” protected areas are the targets in our analysis because these areas are likely to serve as important conservation lands that support a higher number of species and populations. These areas have a higher probability of maintaining intact ecological processes in a relatively undisturbed regime. To define and identify our target protected core areas, we used a simple ruleset. First, we selected all polygons in North Carolina from the National Wilderness Preservation System (NWPS) database. Then we selected areas within the state boundary of North Carolina from the Protected Area Database (PAD) with the GAP Status of 1 and 2. These lands are under the legislative or management direction to maintain biodiversity, limit commercial resource extraction and forbid any land cover conversion. We set the acreage limit to 5000 acres to limit our analysis to connections between “large” protected areas.

**Corridor - Human Modification Index Generation**

**Solitude**

We acquired the municipal population data across North Carolina, and then calculated the population density (population/km²) for each municipality by dividing the 2016 population by its municipal size. To generate a continuous population density layer across North Carolina, we first converted the feature layer to point layer and then used IDW tool to extrapolate the population density of the areas that are outside of the municipal boundaries. In IDW, we used a power of 2 with search radius set to Variable and we set the number of points to 12. Then we reclassified the generated population layer into 5 classes using the following classification:

<table>
<thead>
<tr>
<th>Population density range (pop/km²^2)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;800</td>
<td>5</td>
</tr>
<tr>
<td>400-800</td>
<td>4</td>
</tr>
<tr>
<td>200-400</td>
<td>3</td>
</tr>
<tr>
<td>100-200</td>
<td>2</td>
</tr>
<tr>
<td>0-100</td>
<td>1</td>
</tr>
</tbody>
</table>

---

28 Gaston et al. 2008  
29 Aplet et al. 2000
Areas with a higher population density were assigned a higher value indicating a higher human modification level. This layer represented solitude.

*Remoteness*

We used a “major roads” (essentially paved intercity routes) dataset compiled by the North Carolina Department of Transportation. To assign a remoteness value to each cell, we calculated the euclidean distance to major roads and reclassified them into five classes. Cells within 1 km of a road were assigned a value of 5; between 1 and 2 km a value of 4; 2-5 km a value of 3; 5-10 km a value of 2; and greater than 10 km a value of 5 (Table 5).³⁰

<table>
<thead>
<tr>
<th>Distance range</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;=1km</td>
<td>5</td>
</tr>
<tr>
<td>1-2km</td>
<td>4</td>
</tr>
<tr>
<td>2-5km</td>
<td>3</td>
</tr>
<tr>
<td>5-10km</td>
<td>2</td>
</tr>
<tr>
<td>10-25km</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 5. Reclassification of distance range to generate remoteness.**

*Naturalness*

To access the naturalness, we downloaded the National Land Cover Dataset 2016 collected by USGS and reclassified different land cover types into five classes.³¹³²³³

<table>
<thead>
<tr>
<th>Land Cover Code in 2016 NLCD</th>
<th>Land Cover Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Open Water</td>
<td>4</td>
</tr>
<tr>
<td>21</td>
<td>Developed, Open Space</td>
<td>5</td>
</tr>
<tr>
<td>22</td>
<td>Developed, Low intensity</td>
<td>5</td>
</tr>
<tr>
<td>23</td>
<td>Developed, Medium Intensity</td>
<td>5</td>
</tr>
<tr>
<td>24</td>
<td>Developed, High Intensity</td>
<td>5</td>
</tr>
<tr>
<td>31</td>
<td>Barren Land</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 6. Reclassification of land cover to generate naturalness.**

³⁰ Aplet et al. 2000
³¹ Ferrari et al. 2008
³² Anderson et al. 2016
³³ Szilassi et al. 2017
Weighted sum
We combined the three layers by summing their values to generate a human modification index layer which was later utilized to generate the cost surface and corridors among protected areas.

We adopted the methods in the paper Identifying Corridors among Large Protected Areas in the United States\textsuperscript{34} and created two resistance surfaces. The Human Modification Index was rescaled using linear and non-linear methods, which allowed us to create a composite corridor map. For the linear scaled resistance surface, we transformed the original value range from 4 to 15 to the scaled range 1 to 25. We used two points (1,4) and (15, 25) to solve the linear equation coefficient and got our transformation equation:

\[
\text{Linear cost score} = \frac{24}{11} \times \text{Human Modification Index} - \frac{85}{11}
\]

For the non-linear scaled resistance surface, we transformed the original value range from 4 to 15 to the scaled range 1 to 625. We fit an exponential line through the two points in Excel and got our non-linear transformation function:

\[
\text{Non-linear cost score} = 0.0962e^{0.5853 \times \text{Human Modification Index}}
\]

Table 7. Reclassification of human modification index into linear and non-linear scaled cost surface score.

<table>
<thead>
<tr>
<th>Human Modification Index</th>
<th>Linear scaled</th>
<th>Non-linear scaled</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>19</td>
</tr>
</tbody>
</table>

\textsuperscript{34} Belote et al. 2016
Corridor generation
We utilized Linkage Mapper: build network and linkage tool\textsuperscript{35} and generated two corridor layers based on linear-scaled and non-linear-scaled resistance surface. Then we reclassified them into 10 classes using the quantile method and assigned 10 to the least-cost corridor class and 1 to the most costly ones. Then we made a composite map simply by adding them up.\textsuperscript{36} This layer has a value that ranges from 2-20 with 20 being the best corridors. Then we extracted values to selected parcels to determine the contribution of the parcels to connectivity, which helped identify potential land units important for maintaining a national network of large, connected, and protected areas.\textsuperscript{23}

Biodiversity Estimation

Natural areas
We downloaded the Natural Area shapefile from North Carolina Natural Heritage Program website and created a 2-km buffer around all natural areas to set the area of interest for this analysis. In this way, we eliminated some of the land parcels that are way too far away from any natural areas. We used the inverse-distance weighting method\textsuperscript{37} to evaluate the contribution of parcels to the integrity of different levels of natural areas due to their adjacency relationship. We generated a scoring system and reclassified the score into 20 classes with 20 indicating the highest contribution to maintaining the functions of natural areas and 1 indicating the lowest.

Species richness
The analysis of natural areas focuses mainly on rare species and endangered species, so we also incorporated a layer of species richness/distribution model developed by NC GAP. The distribution model represents the species richness of terrestrial vertebrates (birds, mammals, reptiles, and amphibians) that are known to have bred for five of the last ten years that occur regularly in NC.\textsuperscript{38} Among the parcels that have been selected from the NHNA step, we extracted the mean of the species richness to each parcel. Lastly, we reclassified the values into 20 classes with 20 being the highest species richness and 1 being the lowest.

Landscape Diversity

\textsuperscript{35} McRae & Kavanagh 2011
\textsuperscript{36} Belote et al. 2016
\textsuperscript{37} Hanski & Ovaskainen 2000
\textsuperscript{38} NC GAP Analysis Project: \url{http://www.basic.ncsu.edu/ncgap/}
We downloaded the soil type data from USDA Natural Resources Conservation Service Soils website and the landform layer from The Nature Conservancy. We adopted the zipcode method\textsuperscript{39, 40} which combines different biophysical indicators into one number to generate unique combinations of landform and soil type as a proxy of landscape diversity. We extracted the value to selected parcels.

Our final step in this section was to use the weighted sum to combine all four layers to generate a final conservation value layer which was combined with carbon and risk of conversion layer in the following paragraphs. The weighting system was provided by our client DCOI as follows:

Table 8. Ranking survey provided by DCOI to help determine the importance of different conservation value layers, which determined the weighting system in the GIS model.

<table>
<thead>
<tr>
<th>Conservation Value</th>
<th>Biodiversity (Rare species + Species richness)</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landscape diversity</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Corridor/connectivity</td>
<td>9</td>
</tr>
</tbody>
</table>

**Combining Areas of Interest and Weighting System**

To accommodate all the interests of our client, we combined the three major analyses of this project in a weighting system so that parcels could be compared to each other on relative terms. To determine the weights assigned to each input, we used a survey from DCOI that conveys their interests (Table 9). DCOI gave us the following “rankings of importance” to them for each input and subcategory which we used in our original weighting system.

Table 9. Ranking survey provided by DCOI to help determine the importance of each area to them, which ultimately determined the weighting system in the GIS model.

<table>
<thead>
<tr>
<th>Main Category</th>
<th>Sub Category</th>
<th>Importance (1-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>Current carbon</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Future carbon</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Parcel Size</td>
<td>3</td>
</tr>
</tbody>
</table>

\textsuperscript{39} Yeh 2012 (Master’s Thesis)  
\textsuperscript{40} Kintsch & Urban 2002
<table>
<thead>
<tr>
<th>Conservation Value</th>
<th>Biodiversity</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landscape diversity</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Corridor/connectivity</td>
<td>9</td>
</tr>
</tbody>
</table>

However, because baselines are constantly shifting and needs change over time, our final model allows the user to manipulate the weights of inputs to reflect numerous combinations and parcel prioritization. This will be discussed in greater detail later. See Appendix for ArcGIS Pro model illustration.

As mentioned before, the initial weighting was applied within each main category. The initial subcategory weights for carbon inputs were applied as listed above: parcel size = 3, current carbon estimate = 9, potential carbon accrual = 8. Each raster input was multiplied by the weight and then added together for an overall weighted carbon raster.

**Overall Carbon Weight = (Parcel size * 3) + (Current Carbon * 9) + (Potential Future Carbon * 8)**

This weighted carbon raster was then ultimately combined with the overall probability of development of each parcel. The probability of conversion model was performed in conjunction with other more environmentally-focused data to produce two separate rasters, one for conversion to urban development and one for agricultural development. The higher value of the two was used as the “risk of conversion” within the weighting system. The overall weighted carbon raster was then multiplied by the probability of conversion (on a 0–100% scale) to produce a final carbon value that takes into account the potential size of the project, current and future carbon estimates, and is discounted appropriately based on the probability of that parcel being converted from its forested state. Finally, this carbon value raster, and conservation value input were reclassified into 20 evenly distributed classes to prepare each input to be combined in relative terms.

Similar to the carbon weighting above, the final rasters of each input: carbon value and conservation value were weighted according to the client’s preferences. The total carbon raster was given a weight of 7 and the conservation value raster, 6.

**Final Parcel Weights = (Total Carbon Value * 7) + (Total Conservation Value * 6)**

Final summary statistics from this process were then analyzed based on the prioritized list of parcels produced in the model, as a product of the user's preferences.
Results and Discussion

Carbon Analysis

Overview
Carbon estimation for the current stock and the potential future carbon accumulation is one input into our analysis, and a main driver of what will result in any carbon offset credits released from an avoided conversion project. The current carbon estimates include only above ground carbon for the 2005 and 2011 LiDAR datasets. This section illustrates the results of our carbon analysis exclusively, with no influence from the risk of conversion or biodiversity analyses.

Carbon Estimation
In the carbon analysis in this project, we estimated the total aggregated carbon of each parcel, carbon per acre, and potential future carbon accumulation (Figures 5-8).

Total Tons of Carbon by Parcel for Avoided Conversion Offset Project

Figure 5. Total Carbon. Values range from 250 to 112,000 tons of carbon per parcel. Carbon values for each pixel were aggregated to the parcel scale. Red parcels are higher in the range while yellow values are lower.

The total carbon stock includes estimates based on the 2011 LiDAR in the eastern 60 counties, and 2005 LiDAR for the western 40 counties. These estimates also only include aboveground biomass within the area of designated forest types from the 2011 National Land Cover Dataset. Values range from 250 to 112,200 tons of aggregated carbon per tax parcel. In general, larger parcels have higher
carbon stocks simply due to the positive correlation between parcel size and forested area. Thus, a decision on the validity of a parcel cannot solely be determined from this metric. Many of the higher ranked parcels can be found in the Coastal Plains (Figure 5). Generally, parcel size is larger in this part of the state and it is more rural with relatively smaller cities and towns compared to the Piedmont and Mountains regions. Thus there is potential for a higher density of parcels in the upper rankings of this metric. Also, the soils in many areas of the Coastal Plains have a much higher organic component than the western regions resulting in better growing conditions. Specifically, loblolly pine and longleaf pine of the sandhills area are driving these high carbon values.

Comparing total carbon stocks to the carbon per acre values for each parcel can help explain the distribution and concentration of carbon on a single parcel (Figure 6). Because this analysis is looking at potential carbon projects for a university in partnership with a land trust, carbon per acre will help determine which parcels have larger carbon quantities on smaller tracts, which may yield carbon offset credits more efficiently.

![Carbon Stock per Parcel Acres for Avoided Conversion Offset Project](image)

**Figure 6.** Carbon per Acre. Values range from 2 to 51 tons carbon per acre. Red parcels are higher in the range while yellow values are lower.

Very few parcels have a high volume of carbon in high concentrations on any single property (Figure 6). Properties that have the most total carbon combined with the highest carbon per acre will be the parcels yielding the most efficient carbon offset credits upon acquisition. Values range from 2 to 51
tons per acre of carbon accumulated in above ground biomass. Higher carbon per acre values can be found in both the Mountains and Coastal Plains region of the state. This result is likely being influenced by the operational limitations of managed forests, or managed lands in general. As parcels get larger, it becomes more likely that there will be multiple age classes of tree stands on the property, more diverse species composition, and multiple land uses. This metric is attempting to value carbon is distributed across a single parcel in order to better understand the efficiency of a carbon project. In other words if the property has a relatively high amount of carbon compared to the total size of the parcel.

We also determined the potential future carbon accumulation based on the difference between the current carbon stocks and the maximum carbon stocks in each respective ecoregion, on tons per acre basis (Figure 7). The inverted scale for carbon per acre and future potential carbon accumulation is a result of the methods described above. Because the potential future carbon is derived from the difference between the current carbon on a parcel and the highest carbon estimate in the respective region, there is a correlation between these two metrics. This is just another way to visualize this metric to see where there is potential for additional carbon sequestration. Parcels that have a large amount of carbon relative to their region will have lower potential future carbon accumulation values, and vice versa.
Values for potential future carbon accumulation range from 0 to 50 tons of carbon per acre across the state. Here again, the Coastal Plains of North Carolina seem to have higher carbon stocks than the rest of the state while the Piedmont and Mountains regions have more potential to increase carbon stocks. Unlike the total carbon volume, relative values of carbon are not being influenced by the size of the parcels. This metric is on a per acre basis, so the carbon from our rasterized dataset is aggregated to an acre instead of to each parcel in order to make a relative metric to compare parcels. This result is driven solely by the amount of carbon in a given area.

Finally, the result of the carbon analysis yields a weighted sum value for each parcel under consideration across the state (Figure 8). This weighted value takes into account the size of the parcel, the total current carbon tonnage held on a parcel, and the potential future carbon accumulation.

The weights of each input were determined by our client in combination with our research (see Methods). Approximately a dozen parcels shown in red that have a “High” score in the weighting system, based on these three inputs (Figure 8). These parcels will have the highest overall carbon
ranking using the specific weighted sum model described above. If the weights are manipulated based on preferences or a change in carbon credit policy, the ranking of parcels will likely change relative to the severity of the change in weights. Additionally, the user of this model can readily update these weights to align with different interests.

Our canopy heights are derived from 2006 and 2011 LiDAR, thus it is important to note that these carbon values have likely changed since the data was collected. In many cases, this will not have changed a significant amount, especially for the 2011 data in the eastern half of the state. However, if a parcel has been subdivided or the trees were harvested, this will cause a major loss of carbon from what is estimated in this project. It is imperative for users of this model to look at recent aerial imagery or visit a parcel of interest before pursuing it in any way. Local land management organizations or agencies should be able to help with this process when needed.

A major limitation of this analysis is the scale at which the carbon is calculated. Because this project is focusing on the entire state of North Carolina, we were unable to analyze carbon for each individual tree for each parcel due to time, storage and computing power constraints. To efficiently estimate carbon we used the canopy height metric described above. Therefore, areas with extremely dense tree cover/high stocking could be underestimated. Moreover, this model is based on averages of carbon stocks given a maximum canopy height. Thus, the pixel size necessary for this scale will cause underestimates of denser areas of tree cover, and over estimates of sparser areas. This is particularly important where there is a significant understory component under a fully closed canopy. Analyzing each individual tree with the most recent NC LiDAR would be the most accurate way to estimate carbon, however this is not realistic at this scale. This method would be more applicable at a county or smaller scale.

If exclusively looking at the carbon value on a parcel of interest, it is our recommendation to have a sample carbon cruise conducted on the property by a third-party organization. This will allow for a much more accurate estimate of carbon stock currently on the property, as well as the amount of initial credits that it will yield from the acquisition. However, this project was not designed to be used in this way because there are multiple inputs that include carbon value, the risk of conversion (which will also factor into the number of carbon credits), and the biodiversity value. This multi-objective approach allows for the integration of multiple interests for a party not solely interested in carbon credits alone. This model is more ideal for an entity looking to enter the voluntary carbon market, minimizing initial costs, and accommodating a more holistic interest in the property.

**Risk of Conversion Analysis**

*Random Forest Model Results*

The random forest model had a pseudo $R^2$ of .81. A few of the predictor variables were highly correlated. Six pairs of variables had a Pearson’s correlation coefficient greater than .80. Highly correlated predictor variables do not affect the validity of random forest predictions, but they do affect the model’s reported variable importance. Two highly correlated variables may each appear to be only moderately important, when either one alone would be highly important if the other was not included in the model. For each pair of predictors that was highly correlated, one of them was dropped (focal mean slope 1 mi, focal mean slope 5 mi, and focal percentile slope 5mi) and a random forest was

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41 Calculated as one minus the ratio of the mean squared error to variance in the response variable. The original dataset (before oversampling) was used to calculate error.
trained on the resulting variables solely to assess variable importance with reduced bias against variables that are highly correlated with other predictor variables.

Referencing the variable importance of the model using fewer variables, a soil attribute ended up being the most important predictor. The limitations of the soil properties for development included the most mean square error, which is the measure used to assess variable importance. The second most important was 2011 land cover class. Distance to class 1 roads was the third most important, and distance to class 2 roads was the fifth. The fourth was distance to sawmill. Since the main purpose of this study was to model deforestation risk as accurately as possible and not to quantify the effect of any specific variable on that risk, very little analysis in that direction was performed.

Spatial Patterns of Conversion Risk

The raster layer of the risk of conversion displays mostly unsurprising patterns with a few unexpected trends. Areas near cities and major roads are relatively at-risk of conversion. High slope areas are at relatively low risk. There are some county line artifacts, especially noticeable in Caswell and Polk counties. This reflects the influence of the variable County Population as this was the only predictor variable that follows county lines. It should be noted that although a conversion risk was predicted for all forested cells, including those within protected areas, the training data did not include any points
from protected areas, as that could have skewed the model’s predictions. The protected areas are also not considered eligible for an avoided conversion project in this study.

Figure 10. Variable importance in terms of percent increase in Mean Square Error. Note that high correlation between predictor variables suppresses the importance between each one. For instance, slope is contained within “slope,” the “mean slope” layers, the “relative slope” layers, and it is also baked into “dev limit,” so one can assume slope would appear as very important variable if the other correlated variables were not included in the model.
Figure 11. Histogram of predicted probability of conversion values. The vast majority of pixels have less than a 10% chance of being deforested. Although the bars in this figure disappear at 0.3 because the density values become so low, the actual values range from zero to 0.53.
Figure 12. Spatial distribution of predicted conversion risk.

To accurately estimate the possible carbon credit yield for each parcel, we used the risk of conversion factor as a multiplier for the current carbon estimate (Figure 13).
Figure 13. This map illustrates the value of each parcel to yield avoided conversion carbon offset credits. The values are derived from the current carbon estimate on the parcel multiplied by the probability of conversion.

It is likely that the probability of land converting to agriculture is contributing to the high values in the coastal plains region due to the flat terrain and rural communities. Additionally, many of these parcels have high carbon estimates, making them very good candidates for avoided conversion carbon offset credits.

Conservation Value Analysis

Conservation Value Estimation
In the conservation value analysis, we examined corridor value, Natural Heritage Natural Area value, species richness, and landscape diversity by parcel across the state (Figures 14-19).

**Composite Corridor Value between Large Protected Areas in North Carolina**

*Figure 14.* Composite corridor value. This figure is a map of composite corridors between large protected areas, which was calculated by summing least-cost corridors under both linear and non-linear cost surfaces.
Figure 15. Corridor score. This figure demonstrates a composite map of corridors generated from non-linear and linear cost surface. Corridor value for each pixel were extracted to the parcel scale using the mean method. Red parcels are higher in the range while yellow values are lower.

The composite corridor map was included to demonstrate the corridor generation results (Figure 14). This layer examined the corridor score of each land parcel (Figure 15). Conserving parcels with a higher corridor score are likely to contribute more to maintaining the connectivity among different protected areas in North Carolina. Parcels located in the eastern part near the coast and southeastern part of the state in general have a higher value. These parcels tend to distribute along more natural areas with less development disturbances such as low population density, less dense road network, and more vegetated.
The NHNA score computed in this analysis was a proxy of the importance of a land parcel to rare plant and animal species, rare or high quality natural communities. From the map we can tell that the parcels with a high NHNA score tend to concentrate on the eastern side of the state and one of the reasons is because there are more higher-rating and larger natural areas designated on the eastern side of the state. To conclude, this layer assessed the importance of each land parcel to its surrounding designated Natural Heritage Natural Areas. Conserving parcels with a high NHNA score is beneficial to maintaining the integrity of different levels of natural areas due to their adjacency relationship. One thing to note here is that there are fewer parcels included in this analysis because we set a maximum distance to natural areas limitation and filtered out the ones that are outside that range.
Figure 17. Species Richness score. This figure demonstrates the species richness score of each parcel. Species richness value for each pixel were extracted to the parcel scale using the mean method. Red parcels are higher in the range while yellow values are lower.

Parcels on the eastern side of the state tend to have a higher biodiversity in general (Figure 17). One of the reasons for the coastal plain region appearing as the biodiversity hotspot is its ecosystem’s geology which provides a wide array of soil types that support plants species, and ultimately vertebrate species. Also Coastal Plain area has different ecoregions from Beach Dune to Tidal Swamp Forest and Wetlands which provide habitats for a diverse range of species.  

42 North Carolina Wildlife Resources Commission website: [https://www.ncwildlife.org/Conserving/Habitats/Coast](https://www.ncwildlife.org/Conserving/Habitats/Coast)
Parcels with a high landscape diversity have a high resilience (Figure 18) because these sites can offer a more sophisticated micro-topographic thermal climate options to species who inhabit these areas, meanwhile sites with a high landscape diversity can serve as buffers when regional climate changes. This demonstrates that parcels on the western side of the state have a landscape diversity score in comparison to the ones located on the eastern side. This is partly because of the topography and mountain ranges on the eastern part, whereas in the Piedmont and coastal plain the terrain is flatter with less obvious elevation changes.
Finally, we produced a weighted sum score conservation value for each parcel combining all four aspects mentioned above (Figure 19). The assessment of conservation values is less volatile and it is less susceptible to policy changes compared to the carbon analysis, since the variables being examined in this section were based on objective natural attributes such as the ecosystem and species condition.

As mentioned above in the methods section, we only included large protected areas within the boundary of North Carolina and therefore some of the least-cost paths that connect the protected areas within the state and the ones located outside of the state were not included in our analysis. And therefore it's possible that we undervalued the parcels that contribute to the connectivity across different states.

**Final results**

**Spatial Patterns**

The process by which the risk of conversion, carbon content, and conservation values are combined results in spatial patterns that are not determined by any one of the input layers alone. Hot spots of high suitability for avoided conversion projects are scattered around the state (Figure 20). One can make out some of the state's major rivers on the map. Highly suitable areas follow the Cape Fear River.
from south of Jordan Lake down to the coast. A similar pattern can be seen along the Dan, Roanoke, and Chowan in the Northern part of the state. Areas on the banks of the Yadkin light up on the Rowan/Davidson county line and again down south of the Uwharries until the state line. Interestingly, the Tar and Neuse Rivers are not as apparent in the final output map.

The urban crescent, a band of urbanization that extends from the Charlotte Metropolitan area up Interstate 85 to the Triad area, across to Durham, and then down into Raleigh and its suburbs, is mostly empty of qualifying parcels, probably due to small parcel sizes, but some of the parcels that do qualify are good candidates for an avoided conversion project nonetheless, probably due to high conversion risk. The southwestern mountain region is home to promising parcels as well despite the prevalence of already-conserved land and steep slopes, which make conversion relatively unlikely in much of the region. This is likely due to high conservation values and carbon content. One area in southern McDowell County stands out in particular. The northwestern mountains have few promising parcels. The difference between this area and the southwestern mountains seems to be coming from conservation value. There are also fewer qualifying parcels based on acreage of woody vegetation in the Northwestern region.

**Final Tax Parcel Suitability for Avoided Conversion Offset Project**

![Figure 20](image)

*Figure 20.* This map illustrates the suitability of all parcels across the state that will satisfy all of the initial criteria from our client. Parcels that are red have a higher suitability ranking, while yellow indicates a lower ranking. These values are all in relative terms and are a product of the final overall weighting system (Table 9).
**Limitations**

This study relies strongly on the accuracy of our input data layers, especially the National Land Cover Dataset, which despite being the authoritative land cover map on its scale, is subject to some degree of error. Our model of “risk of conversion” is a straightforward approach to predict deforestation risk, but comes at the question from an entirely different direction than avoided conversion protocols do. There are many unobserved factors that determine where development or agricultural expansion happens. There are many reasons why parcels which our model predicts to be safe from conversion may actually be at high risk and vice versa. This is illustrative of the complexity of the issue of additionality and should also serve to emphasize that our results are just a starting point; they simply point to regions and parcels that may be worth looking into for a possible avoided conversion project that generates certain ancillary conservation benefits.

This study also looks at each parcel separately. In reality an avoided conversion project could include multiple parcels, especially if they are contiguous or owned by the same entity. This study ignores that possibility due to the time and computing power necessary to flesh out this complexity.

**Directions for Future Study**

Possible directions for future study include finer scale carbon modelling and incorporating demand into the risk of conversion model. The accuracy of the corridor generation can be improved by incorporating more layers or refining the reclassification to produce a more granular cost surface. From the composite map (Figure 14) we can tell that some of the protected areas were disconnected even if they were relatively proximate to each other. Future studies can examine the possible reasons why the disconnection exists. To improve the analysis, future studies should also include more protected areas to better represent the contribution of parcels to the connectivity within North Carolina and other neighboring states. The species richness layer acquired from NC GAP only included a subset of species due to the data and resource availability. Terrestrial vertebrate species that are known to breed (5 of the last 10 years)\(^{38}\) and that are regularly occurring non-accidentals in the state of North Carolina were the species of interest in the analysis even if there are many more species that should be added to the analysis and assessment. To improve the accuracy of the species richness assessment, future studies can look into invertebrate and aquatic species if resources allowed. Future studies should include more biophysical attributes such as elevation range changes, slope, aspect, topographic relative moisture index, etc when it comes to assessing landscape diversity. Lastly, some post hoc adjustments of the weighting system should be considered to refine the output visualization. The raster value distribution of different operation layers might not be on the same order of magnitude hence might exaggerate or reduce certain layer’s contribution to the final output.
Acknowledgements

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References


Newcomb, D. & Petras, V. (2018). Construction of Landscape Level QL2 LiDAR Datasets for Species Habitat Assessment in Eastern NC.


Appendix

Appendix 1. User guide for GIS tool.

This guide is intended to help users adapt our GIS model to their own study area and instruct users on how to manipulate weights and substitute input layers. The model was created using Model Builder in ArcGIS Pro version 2.4.1. The model takes six input layers:

Table 1.

<table>
<thead>
<tr>
<th>Input</th>
<th>Format</th>
<th>Potential source</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1: Tax parcels</td>
<td>Polygon shapefile</td>
<td>State or local government GIS portal</td>
</tr>
<tr>
<td>I2: Conservation value</td>
<td>Raster layer</td>
<td>Prior analysis or preexisting layer</td>
</tr>
<tr>
<td>I3: Risk of conversion</td>
<td>Raster layer</td>
<td>Prior analysis</td>
</tr>
<tr>
<td>I4: Current carbon content</td>
<td>Raster layer</td>
<td>Prior analysis or preexisting layer</td>
</tr>
<tr>
<td>I5: Potential future carbon accumulation</td>
<td>Raster layer</td>
<td>Prior analysis</td>
</tr>
<tr>
<td>I6: Parcel Size (acres)</td>
<td>Raster</td>
<td>Prior analysis</td>
</tr>
</tbody>
</table>

five numerical parameters:

Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1: Weight: parcel size</td>
<td>Weight given to size of tax parcel</td>
<td>1-10</td>
</tr>
<tr>
<td>P2: Weight: current carbon</td>
<td>Weight given to current carbon</td>
<td>1-10</td>
</tr>
<tr>
<td>P3: Weight: future carbon</td>
<td>Weight given to potential carbon accumulation</td>
<td>1-10</td>
</tr>
<tr>
<td>P4: Weight: Carbon value</td>
<td>Weight given to carbon value</td>
<td>1-10</td>
</tr>
<tr>
<td>P5: Weight: conservation value</td>
<td>Weight given to conservation value</td>
<td>1-10</td>
</tr>
</tbody>
</table>

and includes three main operations:

Table 3.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Inputs</th>
<th>Result</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Carbon weighting</th>
<th>( P_1 \times I_6 + P_2 \times I_4 + P_3 \times I_5 ) = Total carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion risk times carbon</td>
<td>Total carbon ( \times I_3 ) = Carbon value</td>
</tr>
<tr>
<td>Carbon plus conservation</td>
<td>( P_4 \times \text{Carbon value} + P_5 \times I_2 ) = Final weights</td>
</tr>
</tbody>
</table>

Please see the text of our masters project for details on the creation of the input data layers. The model does not require that the input layers be created in a certain way, only that all are provided and are in the correct format. We used the model for North Carolina in 2019. To be used in other geographic areas or time periods, the inputs must be changed. To adjust the input layers, open the model in Model Builder in an ESRI product and simply replace the data layers with another set. The parameters can be adjusted either in Model Builder or in the run time interface in ESRI software. Parameters setting (weighting of inputs) is entirely dependent on the end user’s priorities. A higher weight for an input should reflect that input being a relatively higher priority for the end user. The user should examine the raster value distribution of operation layers before creating a weighting scheme. In order to detect ranking changes when weighing layers differently, the multiplication results (e.g. \( P_4 \times \text{Carbon value} \) and \( P_5 \times I_2 \)) should be at least on the same order of magnitude. Otherwise the contribution of some layers to the final outputs might not be observed. A more detailed discussion of weighting / multicriteria decision analysis is beyond the scope of these instructions. The user will likely want to run the model under a few different weighting schemes to understand how different weightings affect that final output in their study area. Please refer to Appendix 2-4 for different scenario examples.

In the runtime window, the user can select the weights for each parameter listed above. They can also name the output shapefile and save it to a specific location. For advanced users, the model is not locked, so it can be manipulated to include different variables, inputs, and operations to accommodate the needs of the user. This is not recommended for beginners as changing aspects of the model can break links and cause the model to no longer run consistently.
Appendix 2. Final output map considering only carbon.

Final Tax Parcel Suitability for Avoided Conversion Offset Project - Only Considering Carbon

Legend
- Major Rivers
- Parcel Suitability
  - High
  - Medium
  - Low
- County Boundaries

Data Sources: Esri, HERE, Garmin, i-cy, OpenStreetMap contributors, and the GIS user community. Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. | Date Created: September 18th, 2019 | Map Creator: Sunny Qiao
Projected Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet
Appendix 3. Final output map considering only conservation value.

Final Tax Parcel Suitability for Avoided Conversion Offset Project - Only Considering Conservation value
Appendix 4. Final output map with carbon and conservation value having equal weights.

Final Tax Parcel Suitability for Avoided Conversion Offset Project - Equal weights

Legend
- Major Rivers
- Parcel Suitability
  - High
  - Low
- County Boundaries