

Ecological and Financial Suitability of Sites for Long-Term Oak Management in Western North Carolina

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Executive Summary

The oak forest ecosystem has been identified as a forest system with high ecological value including its ability to adapt to a warming climate. Due to its broad suite of ecosystem services, it is a haven for species migration and reproduction as climate changes. Oak species also provide important economic value to the local communities. However, due to both environmental and anthropogenic forces oak forests have declined in density since the mid-20th century. This reduction has spurred local and national organizations to work to conserve them.

The Nature Conservancy (TNC) seeks to conserve and expand the range of oak forests in support of their Resilient and Connected Landscapes project. Specifically, TNC seeks to engage in active oak forest management in western North Carolina (WNC) using mechanical thinning and prescribed fire. This project assists TNC in identifying sites that are both ecologically and financially feasible for oak forest management. To meet this objective, the following questions were considered:

1. Where is oak management or restoration ecologically viable in western North Carolina?
2. Where is logging most accessible in the mountains of western North Carolina?
3. What is the financial potential of oak management based on a silviculture prescription?

Geographic Information Systems (GIS) were used to analyze ecological viability and logger accessibility as criteria to identify individual tax parcels in WNC that might meet TNC's objectives. Ecological viability was defined as specific fire adapted ecozones based on the work of Simon et al. (2005). For logger accessibility, a survey was created and distributed to loggers and timber buyers in WNC to assess logging access and operational needs and constraints in the area. Using the results of this survey, a weighted sum map was created and then combined with the identified ecozones, which was then averaged across each land parcel. The final map identified high priority sites for TNC to engage in oak management. A tool was built in ESRI ArcGIS Pro (v2.7.3) that allows the user to manipulate inputs to select parcels that meet minimum criteria on a county level. A tiered list of land parcels was created for TNC to begin initiating oak management.

To determine financial potential, oak management harvest yields were modeled using the Forest Vegetation Simulator (FVS), a growth and yield modeling software hosted by the USDA Forest Service, based on a common oak silviculture prescription (FVS_Install_20210331, USDA Forest Service). Harvest yields were valued using Timber Mart South pricing data for the North Carolina mountain region. Net present value (NPV) was derived using the per acre harvest values, prescribed fire pricing, and land management cost assumptions. The approach and associated results may be used by TNC to help understand the movement of value of oak management over time. This approach to valuing financial tradeoffs may be applied to other silviculture prescriptions and management scenarios based on the particular management prescription TNC selects.

This project provides a framework for organizations seeking to identify areas to conserve oak forests. The combination of ecological viability and logger constraints incorporates two critically important variables to consider in active oak management. The results provided to TNC transfers knowledge and approach needed to identify areas to implement intentional and forward-thinking land stewardship of oak forests in the eastern United States.

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Introduction

It is commonly understood that oak has been an integral component of eastern United States forests for 6,000 years, replacing much of the boreal spruce pine forest from the end of the last glacial episode (Craig 1969, Lorimer 1993, Moser 2006). The Southern Blue Ridge (SBR) ecoregion, in the southern Appalachian mountain range, has undergone complex changes over the past few centuries since European settlers arrived. Geospatial analysis of fire scar data and fire regime change indicates that eastern United States vegetation classes have changed dramatically since European settlers arrived (Nowacki and Abrams 2008). Research over the past few decades has shown that regional oak abundance has been declining in the eastern United States (McWilliams 2002, Moser 2006, Fei et al. 2011). Moser et al. (2006) demonstrated that oak overstory abundance was decreasing as a function of the total basal area of a forest. Fei et al. (2011) built on these results and found that in 60% of all eastern forests oak density declined. However, they found that in those same forests more than 82% gained oak volume. Specifically, the southern Appalachians oak density change ranged from -0.4 to 0.0 trees/ha/yr and volume change ranged from 0.6 to 2.7 m³/ha/yr from 1980 to 2008 (Fei et al. 2011). In summary, these studies support the idea/hypothesis that the Oak component of eastern forests is declining and is being replaced by other species as they die or are removed from the forest.

These studies illuminate reproduction as a critical issue for oak management. Oaks are a long-lived species that are moderately shade tolerant, and often spend a significant amount of time in the understory before reaching the canopy – if they reach the canopy at all. Most oak species prefer open canopy, park-like woodlands with frequent low-intensity fire and disturbance (Nowaki and Abrams 2008, Hanberry and Nowaki 2016). Loss of density but increase in volume

indicates oaks may be surviving but not reproducing. Oaks are being out-competed by other species. These new species are often fast growing or shade intolerant like yellow poplar (*Liriodendron tulipifera*) and red maple (*Acer rubrum*) (Moser et al. 2006, Fei et al. 2011). Issues around oak regeneration were not recognized until after 1930, but little research was being conducted regarding the issue (Van Lear and Harlow 2002). Oak silviculture is now a highly researched topic to promote the regeneration and management of this important genus, however expected changes in environmental conditions as the climate changes seem likely to present new challenges.

Changing environmental conditions of the SBR ecoregion have become a recent concern as more research indicates increasingly cooler and wetter understory environments (Nowaki and Adams 2008). These conditions favor species like red maple and sweet birch (*Betula lenta*). This shift is thought to be driven by the lack of open canopy structure reducing light to the forest floor and the fire-retardant litter structure that yellow poplar, red maple, and birch trees produce (Nowaki and Adams 2008). Historically, Native Americans of the SBR, especially the Cherokee in western North Carolina, managed the oak-pine forests using low-intensity, frequent fire, which reduced competition of fast-growing hardwood species (e.g. yellow poplar, red maple) (Nowaki and Abrams 2008, Hanberry and Nowaki 2016). Oaks' physiological structure and root system allow many of them to withstand frequent, low-intensity fires, better than their competition. Early European settlers continued to support fire regimes and maintain fire adaptive communities, but over time fire suppression management reduced the fire incidence by a magnitude of 3 (Nowacki and Abrams 2008). These variable fires kept the midstory open and allowed more light to forest floor to keep it dry and warm.

Fire suppression as a forest management technique became prominent in the early 20th century due to changes in land use, wildfire scares in the West, and federal mandates around fire safety (Van Lear and Harlow 2002). US Forest Service publicity campaigns negatively influenced public perception of fire as a tool for forest management, despite centuries of use (Van Lear and Harlow 2002, Arthur et al. 2012). The reduced fire regime favored fire-sensitive, fast growing competitors, leading to incremental shifts away from open forest systems towards more closed canopy, thick understory, mesic environmental conditions (Van Lear and Harlow 2002, Nowacki and Abrams 2008, Dey 2014). The escalation of mesic microenvironments accompanied by reduced prospects for fire dependent species has been termed “mesophication” by Nowacki and Abrams (2008). The mesophication of many areas of the Southern Blue Ridge ecoregion presents a threat to the oak and pine fire-tolerant species that have thrived here for millennia.

Importance of Oaks

Management of oak ecosystems is of local and international importance due to the ecological and economic importance of oaks (McShea and Healy 2002). Oaks are critically important to wildlife during dormant seasons (fall/winter) due to the high caloric capacity of acorns (McShea and Healy 2002). Oak timber is prized for its strength, machinability, acceptance of different varnish, and durability (Kirkman et al. 2007). Oaks have consistently been some one of the highest value hardwood timber species in the southeastern United States over the last century, especially after the loss of the American chestnut (*Castenae dentata*).

The fire adapted oak woodland plays host to many important ecological species of both fauna and flora. Mast, produced by oaks and other seed producing trees are the most important food source for wildlife in dormant seasons (McShea and Healy 2002). Over 90 species of birds and mammals have been documented eating acorns (Martin et al. 1961) and the loss of a foundational tree genus like oaks may present an impending crisis for wildlife (McShea and Healy 2002). Fire adapted ecosystems, like oak woodlands, also promote necessary light requirements for understory species like turkeybeard (*Xerophyllum asphodeloides*) (Bourg et al. 2014). The importance of fire in montane forests has been linked to increased mass flowering events, increasing light levels for understory vegetation, and understory regeneration success (Bourg et al. 2014). Oak management with prescribed fire and mechanical thinning would promote flora and fauna native to fire adapted oak-pine ecosystems.

Hardwood timber logging was the backbone of western NC economics at the turn of the 20th century (Mastran and Lowerre 1983). The completion of a new section of the Southern Railroad between Asheville and Murphy, NC and the establishment of pulp mills in Canton, NC by Champion Paper and Fibre company around 1900 were the beginning of the true era of logging in western North Carolina (Lambert 1963, Mastran and Lowerre 1983). The early harvesting method was selective cutting of the highest value trees due to the lack of technology to transport the logs. As steam power became more accessible for logging equipment and train engines began climbing steeper grades the era of clearcutting began (Lambert 1963, Mastran and Lowerre 1983). In 1885 loggers were not felling trees under 30in. in diameter, but by 1910 few trees were cut that were greater than 15in. in diameter as the logging boom culled the Southern Appalachian forests (Pearsall 1959). The peak of the logging boom was 1909, with over 2,500 logging camps

in the Southern Appalachians (Pearsall 1959). Selective harvest or diameter limiting harvest is still used in hardwood timber harvesting. This type of selection harvest tends to remove the largest timber (i.e. highest value) but leave behind poor quality trees, thus creating a degraded forest in a dimly-viewed practice colloquially called “high grading”. This type of harvest method supports red maple and other midstory species that overtop oak saplings and reduce their reproductive vigor (Marquis and Ernst 1991, Lorimer et al. 1994, Fajvan 2005). The impact of these harvesting methods are still being felt today as loggers are harvesting second and third generation forests from early 20th century operations.

Hardwood Timber Value

The economic importance of oak and hardwood logging is a driving force for oak management into the future, as oak is the highest grossing timber product for the region. The value of these species helps pay for the management costs associated with regenerating this ecosystem.

According to Timber Mart South (TMS) price index, white oak (*Quercus alba*) (\$49.16) and red oak (*Quercus rubra*) (\$38.47) are currently the first and third highest valued timber in western NC with black walnut (*Juglans nigra*) (\$43.16) being second. It must be understood that these values are averages and only a very general view of the market. Timber markets are extremely localized around the mill and prices can vary dramatically over short distances. The current state of the North Carolina hardwood sawtimber market (4Q2020) is level where it was a year ago (\$23.04/ton) and still up from the lowest stumpage price (~\$18/ton) in the last five years in 2Q2016 (Figure 1). Over the past 10 years the hardwood and oak markets have gradually gained value in the mountain region of NC. As a national export, data from the USDA Global Agriculture Trade System database shows a 50% drop in forest product export revenue to China

from 2017 Q1 to 2019 Q4 (\$3.2 billion to \$1.6 billion). This is the largest drop for this product since 2008, largely driven by tariff increases between the two countries. Of these forest products, hardwood lumber and log products are more than half of the top 20 export products, with red oak lumber being the highest component by volume. These local products of western North Carolina contribute to a larger global market.

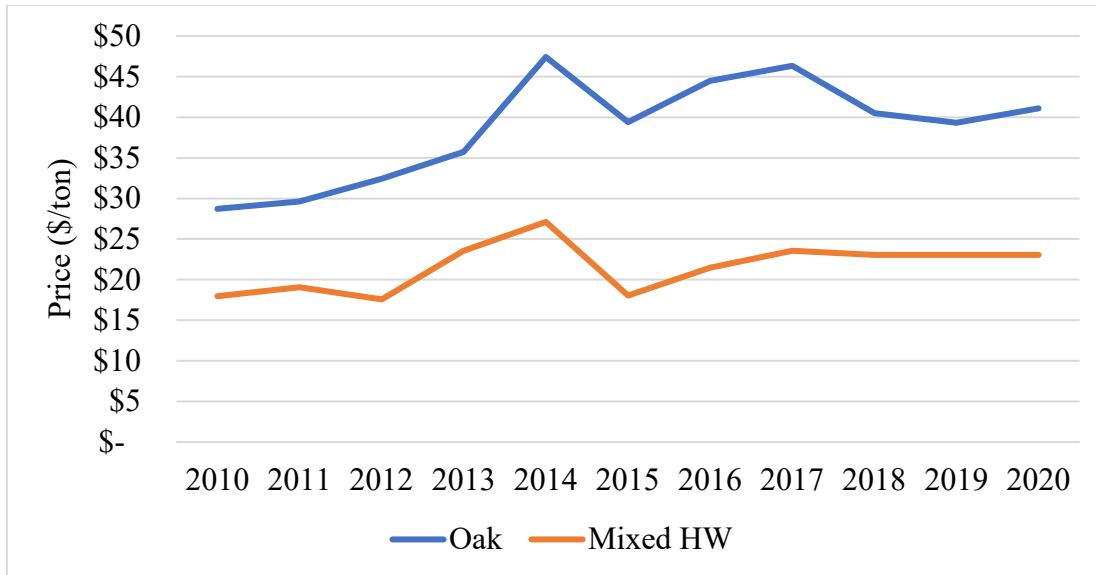


Figure 1: Oak and mixed hardwood sawtimber price over the past ten years (Timber Mart South annual reports).

Over the past 25 years there have been large fluctuations in the amount of hardwood timber harvested by North Carolina mountain counties, with the 2008 financial crisis driving the largest fluctuation. Using the *Timber Products Output (TPO)*¹ survey conducted by the USFS and Timber Mart South historical price record, timber harvests have accounted for \$37 million - \$110 million for the region (Figure 2). The four largest hardwood timber producing counties in the mountain region exemplifies this trend (Figure 3). Wilkes County is the largest producer of

¹ <https://www.fia.fs.fed.us/program-features/tpo/>

hardwood volume according to the TPO survey. Hardwood logging represents 2 – 4% of these four counties' Private Goods-Producing Industries GDP².

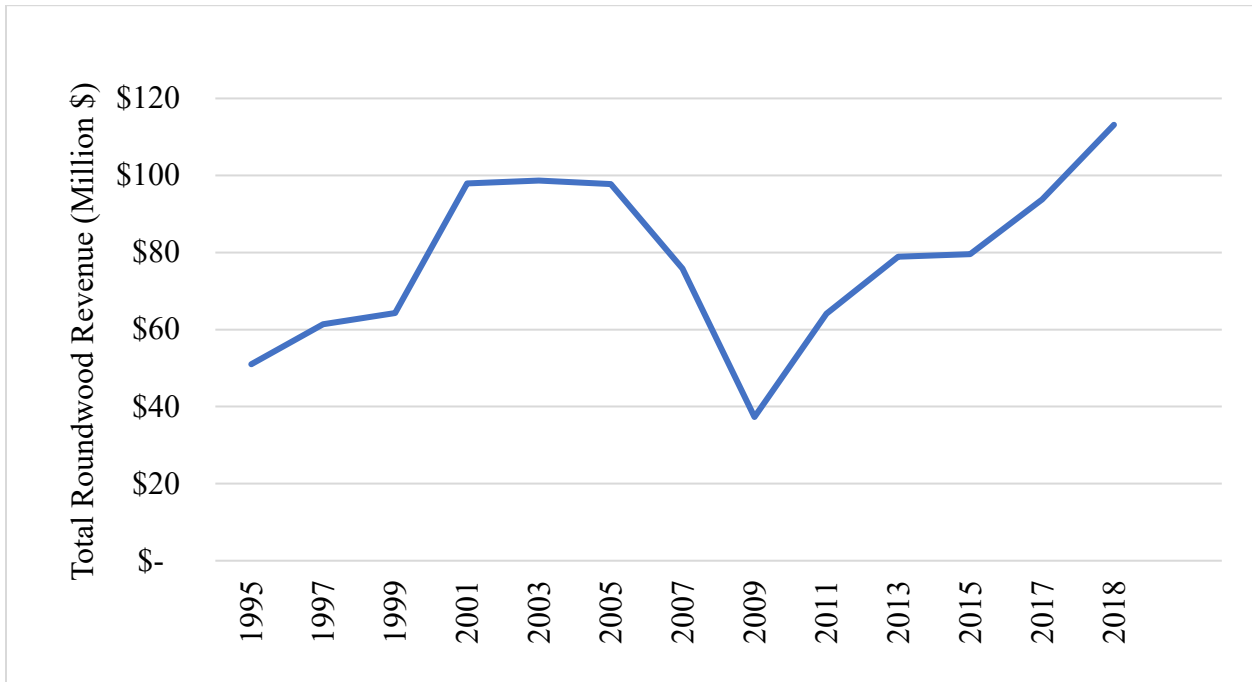


Figure 2: Total value of all hardwood products harvested in the 24 mountain counties of North Carolina.

² <https://fred.stlouisfed.org/release/tables?rid=397&cid=1079693#snid=1080178>

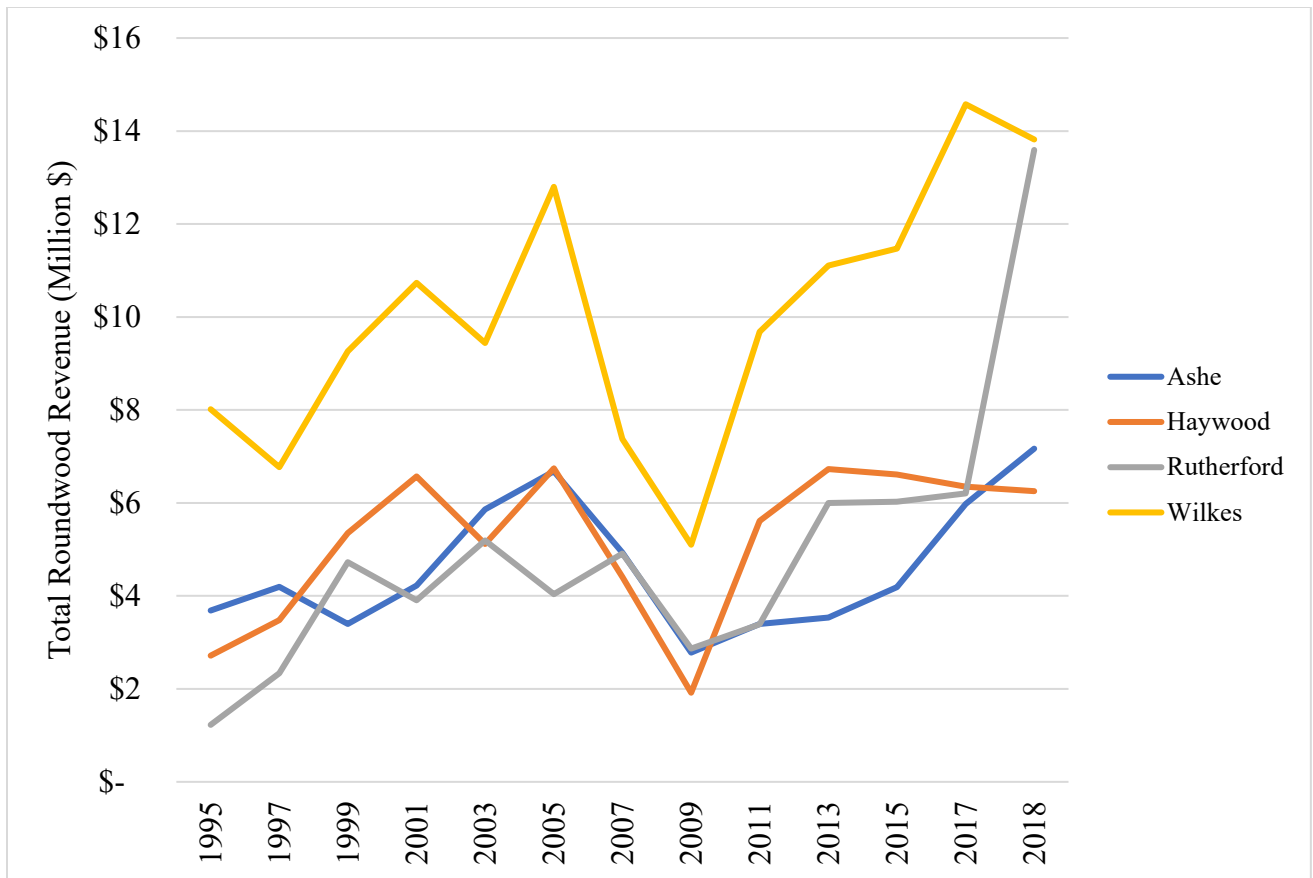


Figure 3: The four mountain counties with the highest grossing timber roundwood values of the mountain region.

Future of Oak Forests

Climate change models predict increasing temperatures and consecutive dry days throughout the southeastern United States, thus suggesting a warmer and drier climate for southern forest ecosystems (IPCC 2014, Vose and Elliot 2016). A warmer and drier climate may give oaks an advantage over mesic soil species (red maple, yellow poplar), due to oaks physiology (ring-porous xylem anatomy). Ring-porous species can regulate water use better than diffuse-porous species and are less susceptible to fluctuations in precipitation (Vose and Elliot 2016). The precipitation fluctuations are predicted to increase severe droughts in the southeast. The future climate is also predicted to increase wildfire frequency and intensity, thus reducing soil nutrients and carbon storage (Vose and Elliot 2016). These changes in precipitation and wildfire frequency

lead the authors to conclude that oaks will be favored over mesophytic species in the long run (Vose and Elliot 2016). They posit, however, that without management to guide the system, the current mixed oak stands could potentially become classified as “degraded” oak stands, characterized by: reduced tree vigor, accelerated decomposition and reduced soil nutrients, and decreased net primary production and carbon accumulation (Vose and Elliot 2016). A degraded oak system is a serious concern to the economic markets that rely on oak wood products.

It has been known to American foresters since the early 1900s that disturbance regimes were important to oak regeneration. Such regimes were implemented in various harvesting methods to regenerate oak (Leffelman and Hawley 1925, Clark 1993, Loftis 1990). Due to research into the historic importance of fire regimes in the eastern United States, re-introducing fire in forest management is now being championed by forest researchers. The use of prescribed fire as a silviculture tool has been shown to help increase oak regeneration and to temper the positive trend towards mesophytic systems (Arthur et al. 2012, Vose and Elliott 2016). Brose et al. (2013) found that prescribed burning after a canopy disturbance (e.g. thinning, selection harvest) provided the most benefit to oak regeneration, but burning alone in a closed canopy system did little to promote oak regeneration (Arthur et al. 2012). Thus, alternative and adaptive silviculture prescriptions (e.g. expanding gap or irregular shelterwood systems with prescribed burning) should be considered to manage for oak-pine open canopy forest systems in the Southern Blue Ridge ecoregion (Dey 2014).

Project Client

The client for this Masters Project is The Nature Conservancy (TNC), specifically the Southern Blue Ridge office in Asheville, NC. The mission of The Nature Conservancy is to “conserve the lands and waters on which all life depends”³. Following the ethos of this mission statement, TNC launched their Resiliency and Connected Landscapes project in 2010 (Anderson et al. 2016). The project mapped 20 ecoregions identifying where factors that permit natural climate resiliency lie based off topography, bedrock, and soil (Anderson et al. 2016). Using the findings of the climate resiliency project, TNC is now engaged in identifying and protecting areas that provide corridors for biodiversity migration, known biodiverse areas, and places with suitable microclimates for reproduction and movement (Anderson et al. 2016). Their findings show that the SBR ecoregion, specifically western North Carolina, is an area of high diffuse flow (highly natural areas where species movement is easily facilitated), high concentrated flow (areas where species will accumulate or be forced through), and high species diversity (Anderson et al. 2006). Western North Carolina is an important region for species movement and climate resiliency, and therefore warrants habitat conservation projects.

Due to the diverse resiliency benefits and abundance of oak forests or areas for oak expansion in western North Carolina, TNC is interested in focusing conservation projects here. Oak forests provide important food, structure, and protection for myriad wildlife species, as well as being tolerant of a warmer, drier climate. Using fire and mechanical harvesting techniques, TNC would like to restore areas to fire adapted, open canopy woodlands. However, not all areas in western

³ <https://www.nature.org/en-us/about-us/who-we-are/>

North Carolina are suitable or even warrant this type of management, so analyzing and prioritizing the land is important for viable and scalable projects.

This Masters Project seeks to identify land parcels that are financially and ecologically feasible for oak management. To accomplish this, the following factors will be considered: areas that support fire-adapted ecosystems, logger accessibility, and financial potential of oak silviculture prescriptions. Ecologically viable areas for fire adapted oak management will be based off of Simon et al. (2005) modeled ecozones of the SBR ecoregion. Logger accessibility is a supply chain issue that must be considered due to the integral need for harvest operations in oak management. For active oak forest management to be successful, open canopy systems must be created by harvest operations. Logging in the mountains is complex in nature and there is a small population of logging contractors available to do such work. Their constraints and success factors are important to know in order to not only derive economic value from the resource but to also accomplish silvicultural objectives. Understanding the potential financial gains from oak management will help TNC tailor projects to economic scale. Potential financial gains from large management projects can then possibly be used to fund smaller land parcel projects to expand oak management both spatially and into the future. Addressing these three areas will provide TNC with a foundation to prioritize and implement their management plans.

Statement of Purpose

This project draws on traditional methods of geospatial analysis to identify land that meets explicit criteria. GIS analysis was used to identify land that meets TNC's needs for long term oak

management. To identify areas of highest prioritization for TNC the following questions were asked:

4. Where is oak management or restoration ecologically viable in western North Carolina?
5. Where is logging most accessible in the mountains of western North Carolina?
6. What is the financial potential of oak management based on silviculture prescription?

Combining logging accessibility with areas of ecological viability will lay the foundation for prioritizing land parcels for TNC to focus on. A financial analysis of oak management prescription will provide TNC with an understanding of the financial potential of oak silviculture. Being able to scale this project up with larger projects paying for smaller projects is an important priority for TNC.

Due to the large project area (24 counties), The Nature Conservancy expressed the need for prioritized maps and a tiered recommendation of where to invest resources for fire-adapted oak management in western North Carolina. Therefore, the deliverables of this project are three-fold: First, an assessment of loggers and timber buyers in the SBR ecoregion by survey, specifically focusing on western NC, to determine logging and timber buying needs and constraints that will provide TNC with more nuanced information about logging in the area. This will be statistically analyzed and compiled into a report. Secondly, a GIS tool that can be used to identify land parcels based off specified criteria by TNC and analysis from the logging survey. The tool will come with detailed instructions on how to run and manipulate the inputs for tailored analysis. Lastly, a report of land parcels based on tiered priority levels that will be provided to TNC.

Methods

Study Area

The study area for this project was western North Carolina in the Southern Blue Ridge ecoregion (Figure 4). Data were collected for land tax parcels that fell within the mountain region of North Carolina. This region is the smallest of the three regions in North Carolina (19% of total NC land area), containing 24 of 100 counties (Figure 4) (Appendix A) (10,261 mi²). This area is home to some of the tallest mountains east of the Mississippi river, reaching over 6,000 ft., and the variable terrain allows for a diverse array of flora and fauna. The geologic landforms, structures, processes, and materials of the SBR were used as an ecological component to predict vegetation composition and distribution by Simon et al. (2005). The parent material rock units are a major driving force of the ecological diversity of this region (Simon et al. 2005).

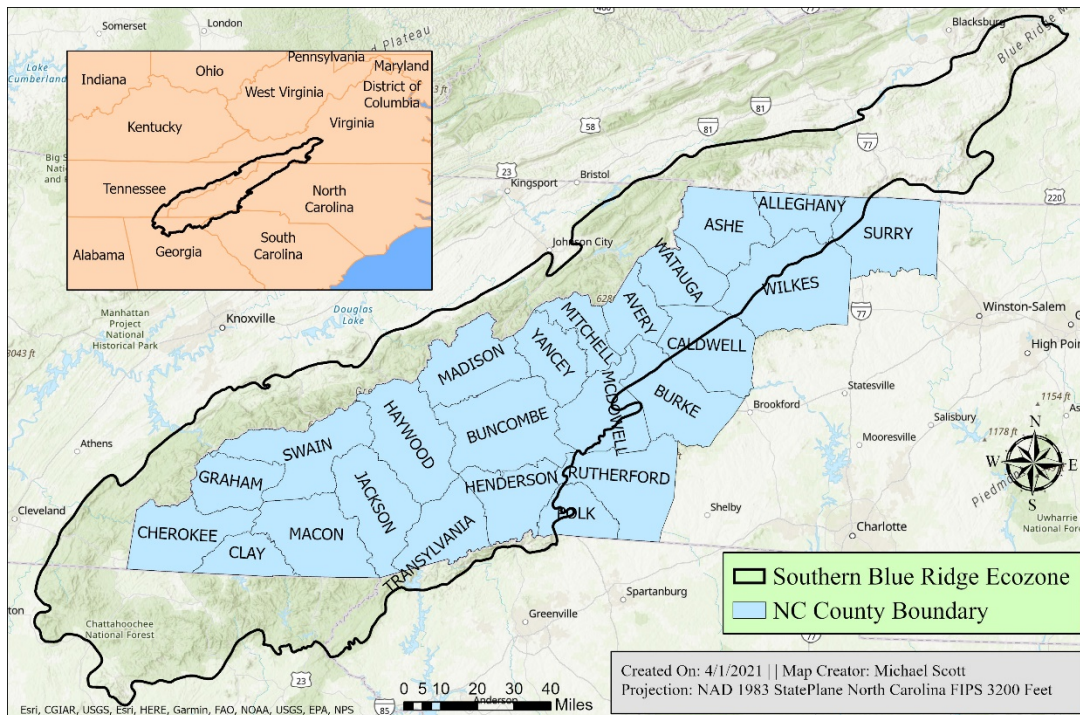


Figure 4: Study area of this project.

Logging/Timber Buyer Survey

Survey Design

Understanding the topographic and environmental considerations loggers and timber buyers evaluate when purchasing timber was one of the bases for identifying manageable land for TNC. The population identified as the subject of this analysis was anyone engaged in purchasing or harvesting timber in the mountains of the Southern Blue Ridge, with high priority placed on reaching the western North Carolina population. A survey was determined to be the best way to obtain local knowledge of timber harvest practices. Approval was received from the Internal Review Board of Duke University to work with human subjects. A literature review was performed to determine previous survey approaches for this population and if timber harvest surveys have been conducted. Semi-formal interviews were conducted with experts including state foresters, consulting foresters, forest operations managers, and forestry researchers to determine important logging variables that can be analyzed spatially and would provide the foundation of the survey questions. Areas of focus for the survey were: slope, access to timber, haul distance to mills, species harvested, site complexity (stream crossings), tract size, and land ownership. The survey was administered using Qualtrics online survey collection and distribution software, and phone interview format (Appendix B). Two options for participants to respond were used to minimize response barriers (e.g. time, lack of computer resources, lack of computer knowledge) and to increase overall participation. The survey contained open-ended questions to gather qualitative detail, ranking lists, yes/no questions, and Likert-scale questions.

Survey Distribution

Participants were found using NC Forest Service timber buyer database and mill database, NC Forestry Association logger database, VA Department of Forestry, and online search engines. Timber buyers were emailed and/or called to inquire about participation in late 2020 and early 2021. Every non-answer or voicemail left was followed up at least two more times. Due to low initial response numbers, the search area for participants was extended to the mountains of Virginia, Tennessee, and West Virginia.

Survey Analysis

Survey results were analyzed for population saturation, for significance, and used to create a pairwise comparison matrix. Survey saturation was determined by randomly choosing half of the respondents and analyzing the responses to determine if there were differences between the two groups using t-tests. Comparing mean responses for ranking questions and Likert scale response questions were used to determine saturation. Kendall's W statistical test was applied to determine if the ranking data were statistically significant. Kendall's W is a normalized statistical method of the Friedman test, meaning the results are between 0 and 1 (Willerman 1955). Results closer to 1 indicate that the participants ranked the data in the same order. Results closer to 0 indicate that there is no overall trend of agreement. Kendall's W was chosen over Friedman because Kendall's W does better with 15 or more respondents than Friedman. T-tests were performed on mean ranked order per variable to determine the most important to least important variable for timber buyers. Qualitative data was aggregated into general trends for reporting to TNC.

Geospatial Data

Geospatial analysis was used to determine ecological viability for oak management as well as logger accessibility. This component required data from myriad sources. Ecological data of oak habitat was used as a proxy for identifying where oak management could be viable. Topographic and ecological variables from the survey analysis were incorporated into the GIS analysis to identify areas of high accessibility for loggers. Refer to Table 1 for data, source, and variables derived from them.

Table 1: Data source for analyzing site suitability and the variables derived from each source.

Data	Source	Variables	Short Name
Elevation	NED	slope - minimum	slope_MIN
		slope – average	slope_AVG
		slope – maximum	slope_MAX
Sawmill location	NC Forest Service	Distance to sawmill	dist_mill
Landcover class	CDL	Major landcover class	land_MAJ
		Total forest cover	first_cover
Ecozone	Simon et al. (2005)	Ecozone majority	eco_MAJ
Streams	NCDEQ	# of streams crossing	streams
Roads	NCDOT	Distance to roads	rds_dist

NC Onemap Tax Parcels

North Carolina tax parcels are identified by tax number, parcel size, ownership, parcel use, and location. These tax parcels are the base boundary layer for site prioritization. Python scripts were written to organize and remove excess tax data not pertinent to this analysis but kept necessary information to look up ownership. The information remaining for each tax parcel was a parcel identification number (ALTPARNO), an owner name, the county name, and size (acres). This data was obtained from the NC OneMap website run by the NC Geographic Information Coordinating Council.

Mill Location

Mill access was an important factor for determining financial feasibility and accessibility when harvesting timber. Shorter routes to mills will increase financial viability. This data was obtained from the North Carolina Forest Service. Euclidean distance was calculated out from each mill throughout the study area.

Cropland Data Layer (CDL) (2020)

This dataset was downloaded from the USDA National Agriculture Statistics Service to assign landcover data to each tax parcel. CDL was chosen over the National Land Cover Dataset due to it being more current than the NLCD 2016 data. The majority landcover was analyzed for each parcel.

Total forested area for each parcel was evaluated. Forested area included deciduous forest, evergreen forest, mixed forest, and woody wetlands. Area was calculated in total acres.

National Elevation Data (NED)

Digital elevation data was used to determine slope for forest parcels. Slope was evaluated for minimum, maximum, and mean. Data was obtained from the USGS National Elevation Dataset.

Ecozone

Ecozone data was obtained from TNC from “Ecological Zones of the Southern Blue Ridge Ecoregion: A First Approximation” paper by Simon et al. (2005). Simon et al. (2005) used the geological substrate along with various environmental parameters to estimate the composition

and distribution of vegetation in the Southern Blue Ridge. They define an ecozone as “relatively large area of generally similar environmental conditions of temperature, moisture, fertility, and disturbance.” TNC uses these areas as classification for project areas and were used as coarse approximation of ecological viability for oak management. Ecozones were used as a mask to focus site suitability prioritization.

NC Streams

Stream spatial data from NCDEQ were used as a proxy for logging site complexity. The Clean Water Act requires that all US States with forest operations have a water quality protection program based on Best Management Practices (BMP) (Shaffer et al. 1998). Stream crossings are a crucial part of timber harvest planning as different crossing techniques have different associated costs and materials (Aust et al. 2003). North Carolina requires all silviculture activities to comply with Forest Practice Guidelines related to water quality or risk citation, fines, or legal action (Sedimentation Pollution Control Act, 1973). This requires that loggers must provide a streamside management zone that reduces sedimentation from entering streams, does not block the flow of streams, and returns the stream to its original flow conditions. Common stream crossing apparatus in western NC are wooden and steel bridgemats, culverts, or fording. Each of these have a cost and time factor associated with them.

NC Roads

NC road data were used to determine accessibility to forest stands. The further away a parcel is from a road the more money the logger must spend building an access road. Distance to route class 2, 3, 4, 5, 6, and 7 roads were calculated using the Euclidean distance tool. Interstate roads

were excluded because logging trucks cannot directly enter an interstate road from the forest. This data was downloaded from the Connect NCDOT GIS data layers website.

Geospatial Site Suitability Analysis

Geospatial site suitability was based off ecological viability and site access for loggers. This required assigning each land parcel an ecozone value, a weighted raster of accessibility, and finally creating a site prioritization map. All geospatial data, except tax parcels, were converted to raster images with pixel size 20ft x 20ft and used the NAD 1983 StatePlane North Carolina FIPS 3200 (Feet) spatial projection.

Ecological Viability

Ecological viability was assigned based on ecozone classification. The Nature Conservancy uses ecozones as a proxy for forest type or potential forest type and direct their efforts based on those classifications. The ecozone data were determined based on geologic soil productivity, elevation, precipitation, slope, temperature, and other environmental data (Simon et al. 2005). Models were corroborated with sample plots for accuracy (Simon et al. 2005). This project focused on specific fire-adapted ecozones: dry oak, dry mesic oak, pine-oak heath (Table 2). These ecozones met TNC's requirement of fire tolerance, dryness, and oak dominated or a large oak component for this project. The ecozone data were aggregated using the Zonal Statistics as Table tool based on the majority of pixels that were contained within a tax parcel boundary.

Table 2: Ecological zones of the SBR ecoregion.

Ecological Zone	Acres	% Total
Montane Oak	1142727	24%
Acidic Cove	984627	20%
Rich Cove	834428	17%
Dry Mesic Oak	736155	15%
Pine-Oak Heath	555105	11%
Dry Oak	258456	5%
Northern Hardwood	175313	4%
High Elevation Red Oak	105279	2%
Spruce-Fir	49315	1%

Reclassification of Accessibility Variables

All geospatial variables were reclassified based on a discrete continuum of 1-10 with 10 being the best, and 1 being the worst. Variables reclassified were from Table 1.

Forest cover from CDL (2020) was reclassified based on presence or absence. Any pixel not associated with a forest cover type was ranked lowest, while forest cover was ranked highest (Table 3).

Table 3: Reclassification of forest cover to generate total forest cover for a tax parcel.

Landcover Type	Value
Forest	10
Non-forest	1

Landcover from CDL (2020) was reclassified based on the type of forest available. This allowed for nuanced changes in site preference based on overall forest type (Table 4).

Table 4: Reclassification of landcover class to evaluate different forest types.

Landcover Type	Value
Deciduous Forest	10
Mixed Forest	8
Evergreen Forest	5
Other	1

Slope mean was obtained on a degree scale (0 – 90). The degrees were categorized in 10 bins for reclassification. The lower the slope the better the accessibility for loggers (Table 5).

Table 5: Reclassification of mean slope values.

Mean Slope (degrees)	Value
0 – 9	10
10 – 18	9
19 – 27	8
28 – 36	7
37 – 45	6
46 – 54	5
55 – 63	4
64 – 72	3
73 – 81	2
82 – 90	1

Distance from a mill (haul distance) was calculated in miles using the Euclidean distance tool in ArcGIS. This created continuous data radiating out from each mill location. The data were converted from continuous to integer before reclassification. Closer distances to a mill reduce time on a site and reduce fuel costs associated with hauling lumber (Table 6).

Table 6: Reclassification of haul distance.

Haul Distance (miles)	Value
0 – 10	10
11 – 20	9
21 – 30	8
31 – 40	7
41 – 50	6
51 – 60	5
61 – 70	4
71 – 80	3
81 – 90	2
> 91	1

Streams were reclassified as present or absent in a pixel. Stream pixels provide no benefit in increasing site prioritization, so parcels with more streams will be less accessible to loggers due to the higher complexity (Table 7).

Table 7: Reclassification of streams.

Stream Pixels	Value
Non-stream	10
Stream	1

Access distance to a road is crucial for loggers. The longer the access road the more money and planning is required. Some crews must outsource road building, while others can build and maintain it themselves. Road distance was calculated using Euclidean distance tool from all road classifications except interstate and ramps. The continuous data were converted to integer data before reclassification. The minimum distance from any road to any portion of the tax parcel was considered the access road distance (Table 8).

Table 8: Reclassification of road distance to any portion of a tax parcel.

Access Road Distance (miles)	Value
0 – 0.1	10
0.1 – 0.2	9
0.2 – 0.3	8
0.3 – 0.4	7
0.4 – 0.5	6
0.5 – 0.6	5
0.6 – 0.7	4
0.7 – 0.8	3
0.8 – 0.9	2
> 0.9	1

Weighted Accessibility Map

Using the reclassified variables, a base map of accessibility was created. Each variable was weighted based on survey response data using a pairwise decision matrix. Survey participants were asked to rank the following variables in order of importance from greatest to least: slope,

tract size, haul distance, stream crossings, distance from access road, and forest type. They were also asked to categorize each individual variable as “not at all important”, “not very important”, “somewhat important”, “very important”, or “extremely important.” These two questions guided the creation of a pairwise decision matrix.

Pairwise comparison has been proven as a successful method for weighting important themes for environmental analysis (Thorne et al. 2005, Kaya and Kahraman 2011, Ahmad and Goparaju 2017). Using the survey responses, a pairwise decision matrix based on Analytical Hierarchy Process (Saaty 1980) was created to weight each variable. The ranking variables were compared against each other using Saaty’s (1990) 1 – 9 values with 1 indicating equal importance and 9 representing extreme importance (Table 9). The decision matrix was normalized, and weighted values were determined by averaging the row data for each variable (Table 10). Consistency ratio maximum was set at 10% to assume metrics selected are reasonably consistent.

Table 9: Description of values used to create pairwise decision matrix. Table reformatted from Saaty (1990).

Intensity of Importance on Absolute Scale	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent judgments

Table 10: Pairwise comparison matrix of thematic variables. Consistency ratio = 3.5%.

Pairwise Comparison							
	Road Access	Forest Type	Slope	Haul Distance	Stream Crossings	Tract Size	Criteria Weights
Road Access	1	3	5	9	9	9	48%
Forest Type	0.33	1	3	5	8	7	26%
Slope	0.2	0.33	1	2	5	6	14%
Haul Distance	0.11	0.2	0.5	1	2	2	6%
Stream Crossings	0.11	0.125	0.2	0.5	1	1	4%
Tract Size	0.11	0.14	0.17	0.5	1	1	4%
Sum	1.87	4.80	9.87	18	26	26	

The six reclassified variables were multiplied by their respected weight value. The layers were then stacked and added together for a total value at each pixel of 1020. Pixels were then aggregated for each tax parcel by mean value. The weighted access map shows the land parcel's accessibility value for logging. The higher the value, the more easily operated on by loggers.

$$\text{Overall Access Weight} = (\text{Road Access} * 48) + (\text{Forest Type} * 26) + (\text{Slope} * 14) + (\text{Haul Dist.} * 6) + (\text{Streams} * 4) + (\text{Tract Size} * 4)$$

Site Identification Tool

The Nature Conservancy requested an analysis of where to conduct oak management projects based on the ecological viability, and profitability. Site suitability was determined by combining the weighted accessibility raster and the ecological viability ecozone mask to identify high priority project areas. The ecozone mask removed any tax parcels not within the specified fire adapted ecozones identified for this project. This generated a site suitability map for the entire western North Carolina study area. However, The Nature Conservancy needed the ability to identify sites on a finer scale.

A GIS tool was created to select tax parcels based on specific user inputs to select parcels on a county basis and increase the utility of the map. This is a multistep GIS model with two major inputs to select land for oak management. Python scripts were written to clean the tax parcel data, removing excess information that would slow down analysis. Using the Zonal Statistics as Table tool, topographic data was calculated per parcel and then added to each parcel as a new

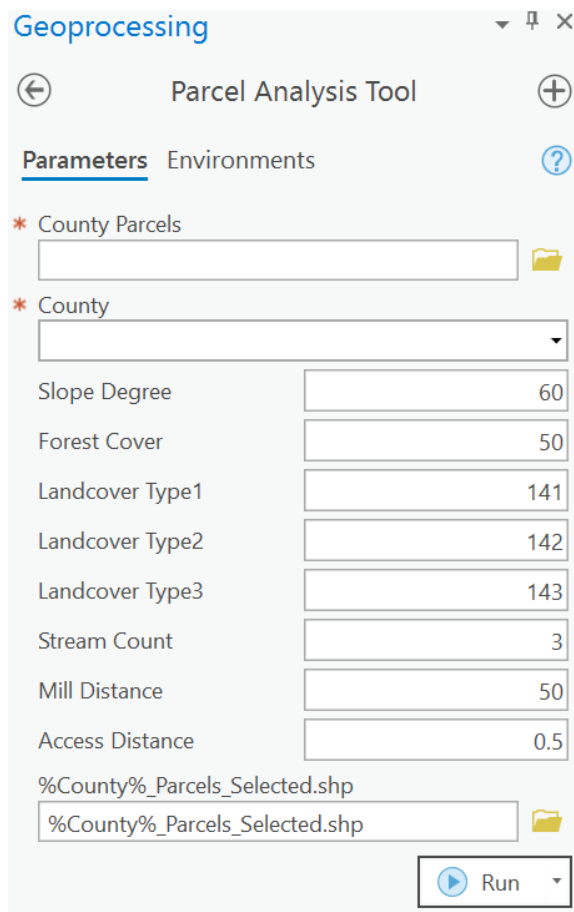


Figure 5: The default values in the GIS toolbox created to identify feasible land parcels for oak management.

column using the short name (Table 1). The user can assign the values necessary for selection. The default values built into the model reflect the analysis from the timber buyer survey (Figure 5). These defaults can be adjusted based on user priorities. TNC indicated that they want to focus on larger parcels. For this analysis, the default values were used, with a minimum size of 50 acres of forest. Suitable sites were analyzed on a county basis and provided to TNC in a ranked priority format. The parcel information can be used to initiate conversations with landowners, evaluate nearby parcels for larger project adaptation, or purchasing forest land for management.

Oak Management and Harvest Yields

It was important to TNC for oak management projects to be scalable so that larger projects can help pay for smaller projects. A financial accounting analysis of current oak management silviculture techniques provided a general understanding of the revenue that can be generated from this type of management. A representative silviculture prescription for oak regeneration was first researched, then run through Forest Vegetation Simulator⁴ using western North Carolina mountain hardwood data, and harvest outputs were valued using Timber Mart South 2021 1st quarter price values.

Oak Silviculture Prescription

Oak silviculture research, in particular regeneration, has been ongoing since the 1960s (Loftis 1990). One of the main concerns with regenerating oak stands is the need for established oak propagules termed “advanced oak regeneration” (Carvell and Tryon 1961, Loftis 1990, Loftis and McGee 1993). Advanced oak regeneration is considered anything from oak seedlings to saplings greater than 4.5ft tall with a diameter less than 2in at the base (Sander 1972). Oak can also sprout from stumps after harvesting and this has shown promising results for regenerating oak, as long as the parent oak is not too large (Sander 1972, Loftis 1990). Regenerating oak is complicated by oak’s conservative physiological traits like focusing on strong root foundation before upward growth, low photosynthetic capacity, and high respiration. These traits make it difficult to compete with species like yellow poplar that have higher photosynthetic capacity and allocate resources to growing upwards when light is available (Hodges and Gardiner 1993).

⁴ <https://www.fs.fed.us/fvs/index.shtml>

Due to its competitive disadvantage, research has shown the need for competition control for oaks to make it out of the understory to the canopy. Arthur et al. (2012) and Brose et al. (2013) published meta-analysis on the relationship between oak and fire and the ability for fire to reduce competition and prepare a site for oak regeneration. Their studies report oak's ability to persist in the understory during variable low intensity prescribed burns, while other species are significantly hampered by fire (e.g. yellow poplar, red maple). After harvest, oaks need 10-30 years without fire to establish themselves in the mid/upper canopy. This project used results from Arthur et al. (2012) to develop a fire regime for the silviculture prescription. Prescribed fire was used in the model two years before harvest to prepare the site, 2 years after harvest to reduce competition, and then every 15 years to continually reduce competition and open up midstory canopy.

Foresters and researchers have employed several silvicultural methods to regenerate oak: clearcutting, shelterwood, irregular shelterwood, and expanding gap/femelschlag (Nyland 1996, Raymond 2009, McNab and Oprean 2020). Shelterwood harvest is the most common harvest technique to regenerate oak forests. For this study, a traditional shelterwood with removal harvest was modeled with prescribed fire (Table 11). Regardless of harvest technique, careful planning and site layout by a forester is necessary to accurately and carefully remove trees (Dey 2014). Timber inventory data was obtained from NC Wildlife Resource Commission from a mountain game land. Stands were selected based on ecozone and low to moderate site quality (<70 site index) (Table 12). Low to moderate site indexes were used because oak can regenerate more effectively in these areas compared to other species (Loftis 1990, Dey 2014).

Table 11: Oak management prescription input in FVS model.

Order	Action	Condition	Result
1	Rx Fire	2yrs before harvest	Competition reduction
2	Harvest	BA = 130ft ² /ac or Age = 90	BA = 40ft ² /ac
3	Regeneration	400 Chestnut oak and Scarlet oak/acre	Advanced regen.
4	Rx Fire	2yrs after 1 st harvest	Competition reduction
		2yrs before 2 nd harvest	
5	Harvest	15 yrs after 1st harvest	Young trees remain
		Remove all overstory trees (> 12in dbh)	
6	Rx Fire	Every 15 years	Competition and midstory reduction

Table 12: Stand characteristics for timber inventory data used in FVS.

Stand Demographics	Value
Number of stands	18
Age range (years)	48 – 84
Site index range	27 – 69
Size range (acres)	12 – 83
Total Acres	844

Harvest Financial Analysis

Harvest volumes were generated using Forest Vegetation Simulator (FVS). The data were run using the Southern Variant (SN) and reference forest 81107 (Pisgah National Forest). Harvest volumes were exported as species and 4in DBH classes for each stand. FVS volume output was in cubic ft. per acre, which was converted to tons per acre (common harvest metric used in Southeast US). Only sawtimber sized harvest value was used in the financial analysis (> 12in DBH) due to the variability and localization of the hardwood pulp market. Timber Mart South species values were used to calculate per acre value of each stand (Table 13). The stand per acre values were averaged to create a mean per acre value for the first and second harvest. These values were used in a net present value (NPV) analysis to determine how the value per acre would change over time. NPV is an important tool in assessing the favorability of future cash flows in the present. The assumptions used in this NPV were a discount rate of 7%, \$30/ac for

prescribed fire⁵, \$10/ac maintenance cost, and \$100/ac in taxes. NPV can be used to visualize the time value of money as profit is pushed further out into the future. Model outputs were internal rate of return (IRR) and net present value (NPV)

Table 13: Timber inventory species and associated prices from Timber Mart South.

Species	Price	Species	Price
Red Maple	27.77	Table Mountain pine	21.35
Birch spp.	23.04	Pitch pine	21.35
Musclewood	23.04	White pine	8.75
Hickory spp.	29.34	Virginia pine	13.05
Dogwood	23.04	White oak	49.16
Silverbell	23.04	Scarlet oak	38.47
American Holly	23.04	Chestnut oak	38.47
Yellow Poplar	31.69	Red oak	38.47
Magnolia spp.	14.96	Black oak	38.47
Black gum	23.04	Live oak	38.47
Ironwood	14.96	Black locust	23.04
Sourwood	14.96	Basswood spp.	23.04
Shortleaf pine	21.35	Hemlock spp.	23.04

Results

Logging Survey

There were 18 respondents in total out of 85 recipients (21% response rate). Respondents represented 38% (9) of mountain counties and three respondents from Virginia. 44% (8) of respondents identified as logger, 11% (2) as mill operator, 39% (7) as company procurement forester, and 5% (1) as other. When splitting the responses randomly into two groups, the null hypothesis that the mean results were not different could not be rejected ($p > 0.2$). Therefore, adding more responses would not significantly alter the response data.

⁵ https://www.ncforestservice.gov/Managing_your_forest/pdf/Burning%20rates.pdf

Variable Ranking Results

Respondents ranked six variables in order of importance from most important (1) to least important (6). The Kendall's W statistical test found that participants significantly ranked the variables in a similar order ($w = 0.355$, $p < 0.001$). Post hoc test found that only forest type and access to roads were significantly different than other variables (Figure 6). Due to the lack of statistical significance, these results were used to create a pairwise comparison matrix, which does not require statistical significance, only general trends.

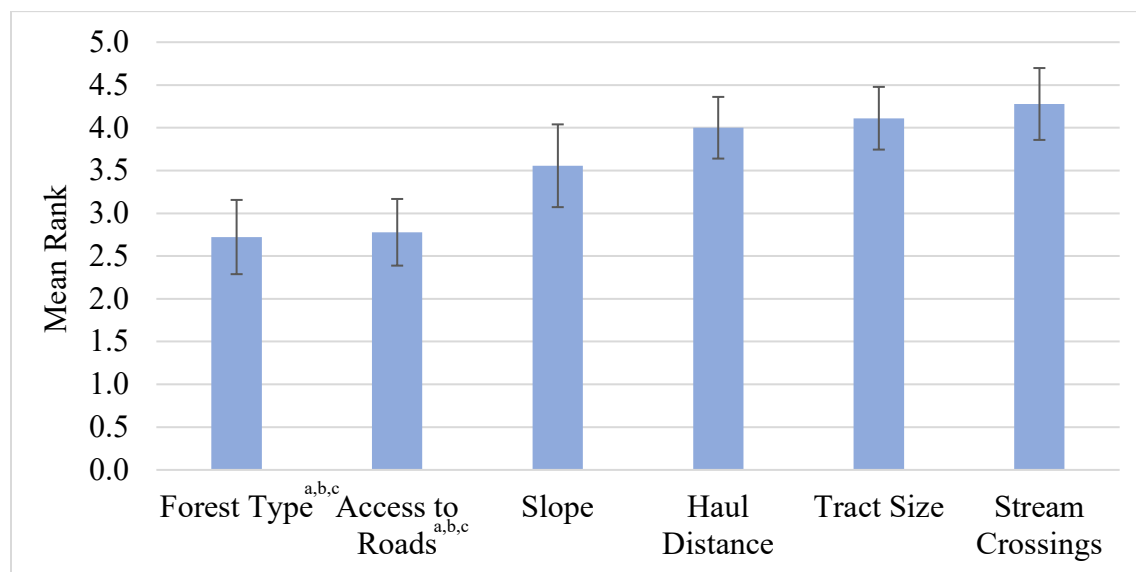


Figure 6: Mean rank for each variable by respondents. Error bars represent standard error.
a = significantly different from haul distance ($p < 0.05$)
b = significantly different from tract size ($p < 0.05$)
c = significantly different from stream crossings ($p < 0.05$)

Variable Importance Results

Participants responses to the importance of each variable were aggregated from 5 responses to 3 due to the low sample size. Responses that were “Not at all important” and “Not very important” were binned together as “Not important”. Responses that were “Very important” and “Extremely important” were binned together as “Very important.” The response “Somewhat important” was left as a neutral point of reference. The responses in Figure 7 show consistency with the ranked results. 100% of participants responded that access distance was very important. 61% of

respondents considered forest type very important and 89% considered it at least somewhat important. Slope was considered at least somewhat important by all participants (100%) with 33% considering it very important. One stream crossing was the least important variable, with 50% of respondents considering it not important.

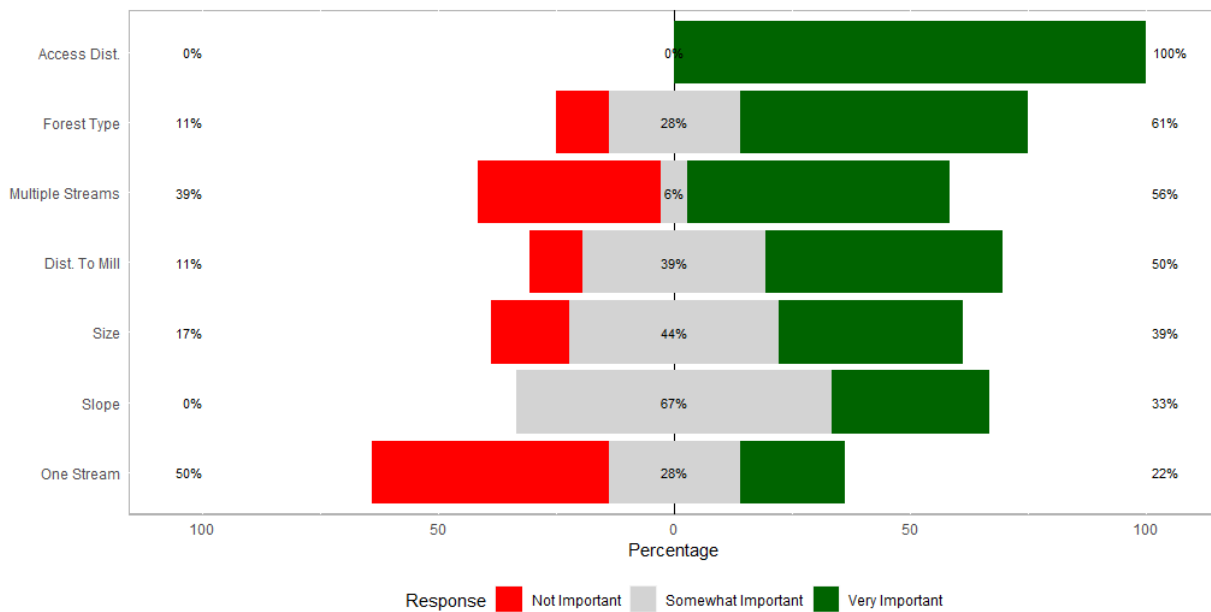


Figure 7: Participants response to reporting the importance level of each variable individually.

Qualitative results from the survey were compiled into a report for TNC to provide perspective on logging in western North Carolina.

Harvesting Equipment

For skidding equipment, the majority of respondents use rubber-tired skidder (88%) and 12% indicated using a tracked skidder (Figure 8). 47% reported using a cable skidder, 12% used a forwarder, and 6% used a cable yarding system. These specific types of skidding systems overlap with the rubber-tired versus tracked responses. Equal amounts of participants reported using a rubber-tired feller-buncher (59%) and a tracked feller buncher (59%). 77% of participants

reported using a chainsaw to cut timber as well. Only 12% reported using a cut-to-length processor.

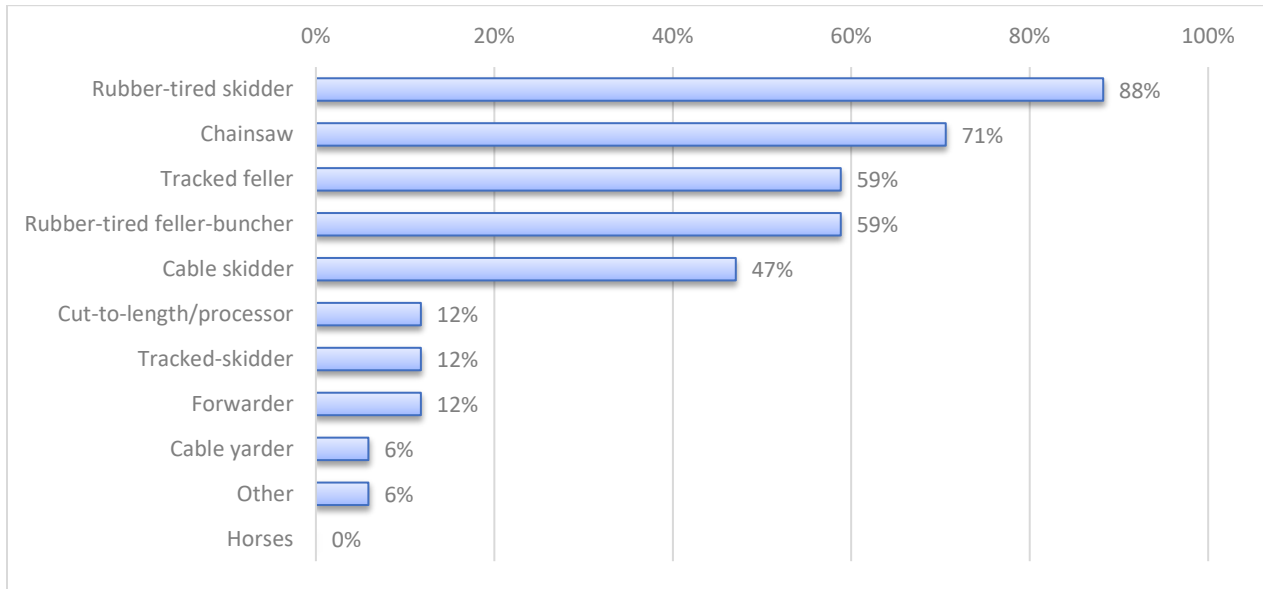


Figure 8: Participants responses to the types of equipment used in timber harvesting operations.

Geospatial Results

Site Identification

Site prioritization combined the ecological viability map and the logger accessibility map.

214,247 tax parcels contain a majority of fire adapted ecozone land (Figure 9). High densities of these parcels occur in the south west and south east counties of western North Carolina (Cherokee, Clay, Henderson, Transylvania). No tax parcels are found in the higher elevation Black Mountains. Most of the parcels lie in the low foothills between the larger mountain ranges. Dry mesic oak (53%) and shortleaf pine-oak (25%) were the most common ecozone types found within the tax parcels.

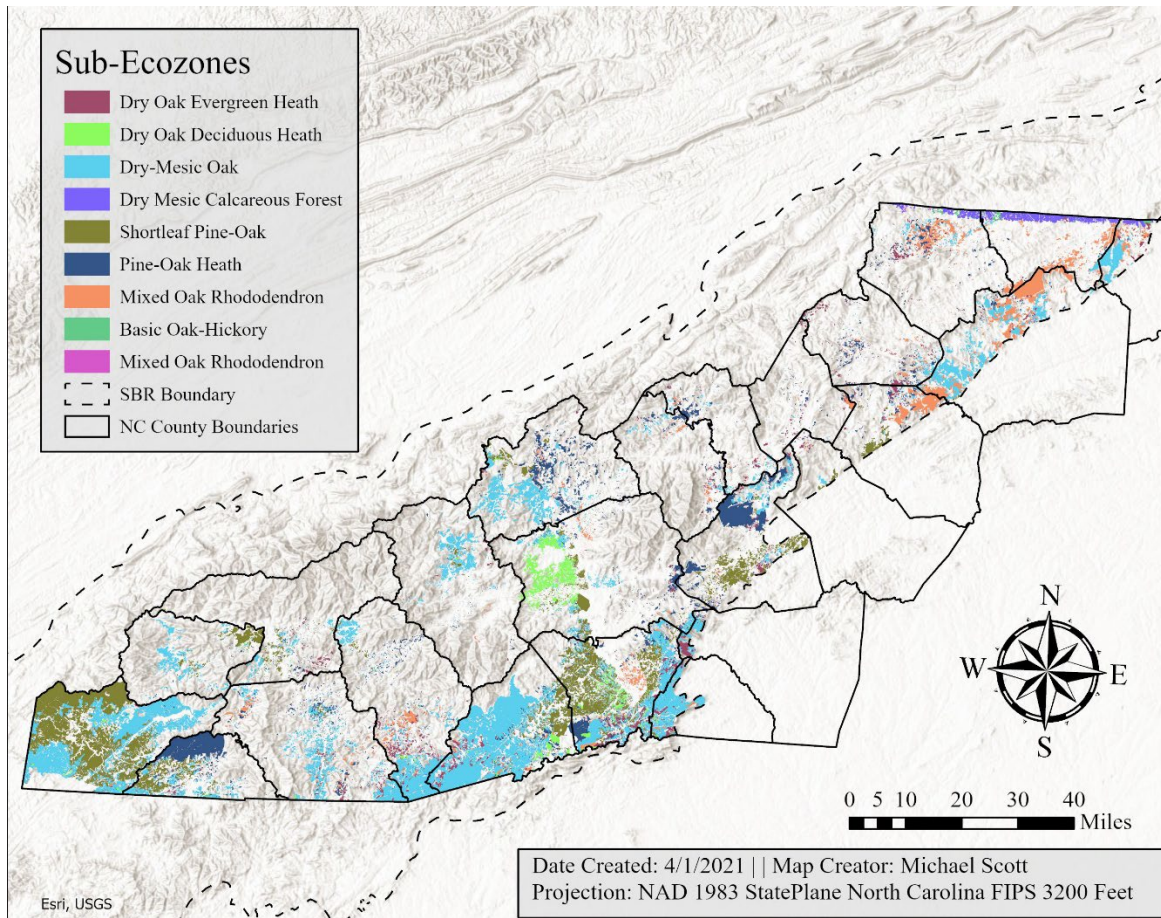


Figure 9: This map illustrates the ecozones that support fire adapted oak management.

The accessibility raster was made up of six thematic maps stacked and aggregated by tax parcel (Figure 10). The values ranged from 416 – 946 per tax parcel. Urban areas have a lower accessibility value due to the lack of forested area and land cover type. The larger national and state forests received low values due to the high variability of slope.

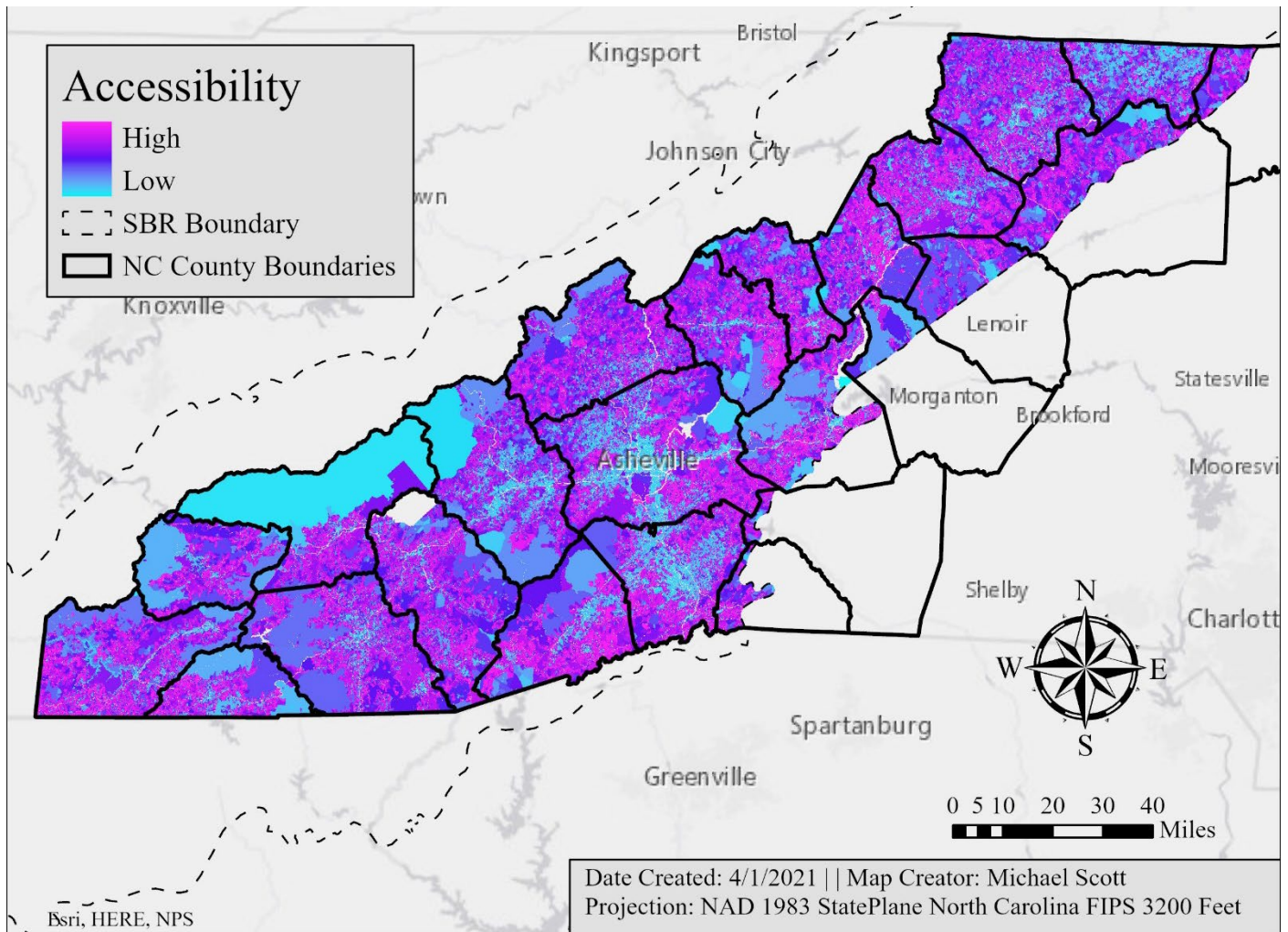


Figure 10: This map illustrates the weighted average accessibility for each tax parcel in western NC SBR ecoregion. The values are derived from the pairwise decision matrix variables.

The site prioritization map was created by masking the accessibility map with the ecological viability ecozone map (Figure 11). A high density of high priority sites were located in the southern portion of western North Carolina, where the highest density of dry mesic oak and shortleaf-pine oak is located.

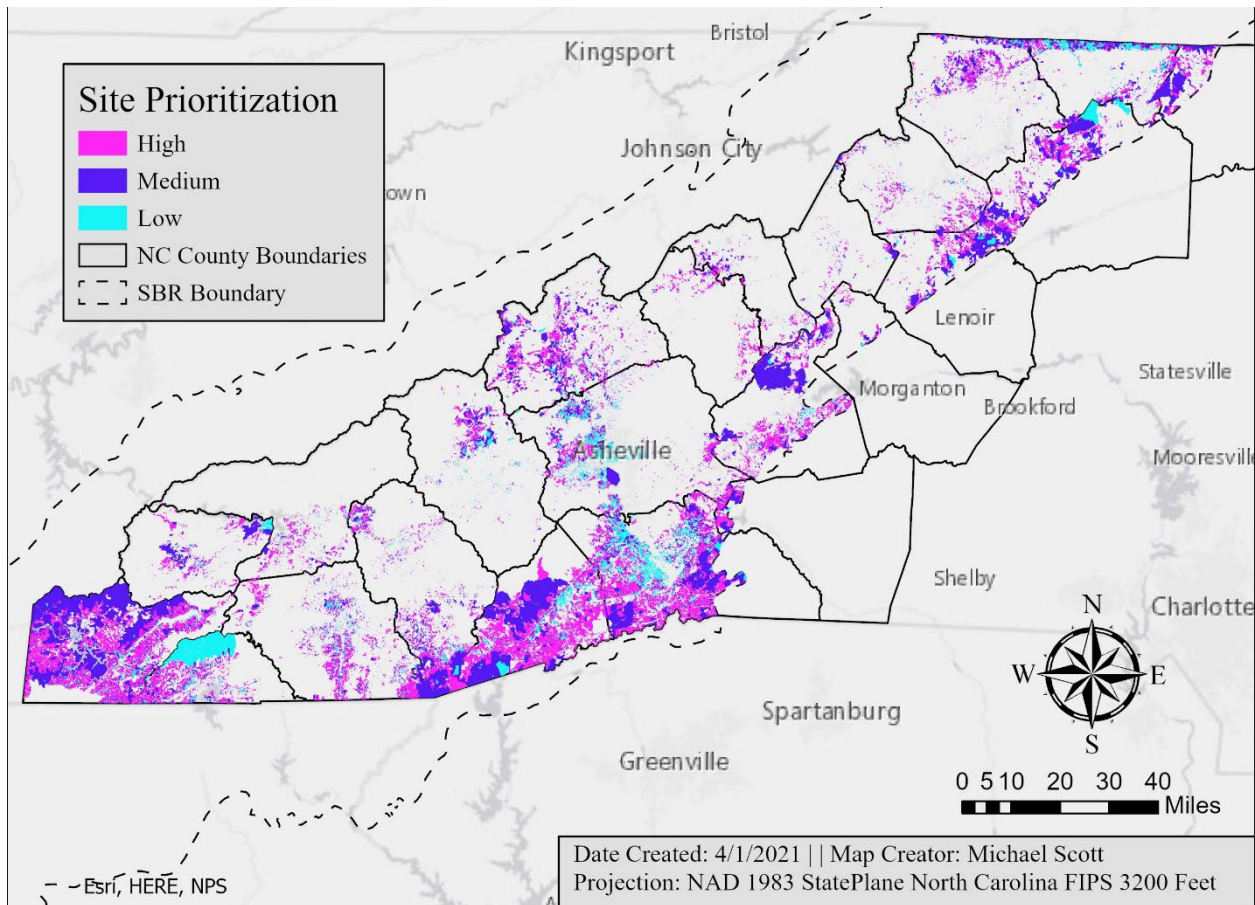


Figure 11: This map illustrates the priority levels of tax parcels based on accessibility and ecological viability.

The GIS tool built for this project used the site prioritization map to identify tax parcels on a fine scale. Over 215,000 tax parcels were found to have a major concentration of the specified fire adapted ecozones for this project. The range of priority values were 566 – 917 with a mean of 670 and a standard deviation of 84. High priority values were assigned as parcels with a value greater than 800.

The Parcel Analysis Tool created for this project then identified parcels that are greater than 50 acres and have a mean slope less than 60 degrees (including default values from Figure 5). These results allow TNC to have a fine scale plan of where to engage oak management projects first.

Combining this tool with the overall site prioritization map, TNC can identify nearby parcels or high priority parcels near public land or group private landowners together. The tool returned 149 total parcels containing 11,653 total acres in 13 counties (Table 14). 86% of the parcels are privately owned land and 14% are publicly owned land.

Table 14: Breakdown of percent total acres for each county with parcels greater than 50 forested acres and less than 60 degree mean slope.

County	% of Total Acres
Henderson	24
Cherokee	15
McDowell	14
Transylvania	14
Burke	14
Buncombe	6
Clay	3
Alleghany	3
Surry	3
Jackson	1
Polk	1
Madison	1
Caldwell	1

Financial Analysis

The shelterwood harvest model successfully regenerated oak in FVS. The total volumes resulted in approximately 3 truckloads for the first harvest and 2 truckloads for the second harvest (1 truck load is approximately 25 tons) (Table 15). Using the TMS species pricing list for the mountain region of North Carolina an average value of \$2,475 was calculated for the first harvest and \$2,186 for the second harvest (Table 16). This evaluation was confirmed as a reasonable estimate with local experts in western North Carolina. These evaluations should be used as an approximation as to the potential of oak management. FVS tends to overestimate hardwood growth and this should be used as a guide to potential financial gain. Other software programs

could aid TNC in determining recruitment post-harvest like REGEN3⁶ (USFS regeneration software program). This software was designed for hardwood forests that are inherently difficult to model regeneration. REGEN3 provides the user with information on the tree species that survive from the new cohort of seedlings/stump sprouts/root suckers post-harvest and grow into the canopy before canopy closure (10 years) (Upland Hardwood Ecology and Management). The use of REGEN3 could help TNC and landowners fine tune the regeneration of a site based on a regeneration inventory.

Table 15: Mean sawtimber volume per acre for the modeled hardwood stands.

	1st Harvest	2nd Harvest
Mean Volume(tons/ac)	80.4	63.3
Std. Dev.	30.2	36.5

Table 16: Mean sawtimber value per acre for the modeled hardwood stands.

	1st Harvest	2nd Harvest
Mean Value (\$/ac)	\$ 2,475	\$ 2,186
Std. Dev.	\$ 1,056	\$ 1,419

The net present value analysis reported that under the assumptions utilized in this project, a harvest ready project at the beginning of the project lifetime results in a NPV of \$1,851/ac (Figure 11). The NPV decreases on an average of 16% each year for the first five years as the harvest is delayed. The NPV analysis runs for 25 years total (2021 – 2046). NPV can be manipulated based on the length of the project. These results provide context to The Nature Conservancy as they look for and plan oak management projects.

6

<https://www.srs.fs.usda.gov/uplandhardwood/tools/regen3/#:~:text=Forest%20managers%20require%20the%20ability,designed%20to%20secure%20natural%20regeneration.>

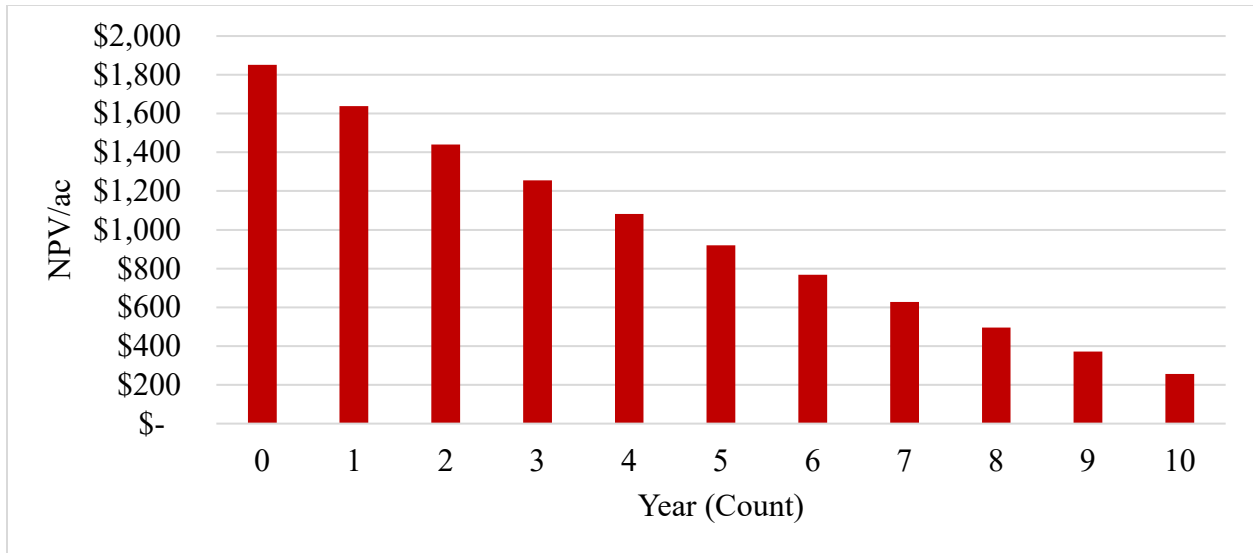


Figure 11: This figure shows the decreasing trend of net present value of a project that pushes the initial harvest back by one year. Year 0 represents the starting year of the project.

Discussion

Survey

As forest harvesting becomes more mechanized, the evolution has resulted in many operating efficiency studies. Common among these studies are investigations into the time it takes operators to move around a site and production per hour per employee. While these studies are important for understanding how production can be maximized, no study has examined the collection of constraints used here to determine harvest optimization requirements. Research often focuses on skidding distance, time, and tree size to determine operating efficiency. Diniz et al. (2019) reported that operating on slopes greater than 22 degrees significantly decreased productivity of a harvest operation of loblolly pine (*Pinus taeda*) in central Brazil. Ghaffaryian (2014) reported that tracked equipment has a downslope maximum of 75% slope (37 degrees) with an uphill maximum of 55% (29 degrees) (global metadata analysis). These constraints point to the issue with harvesting timber on steep slopes in the mountains and the importance of the accessibility survey in this project.

Access to existing roads was reported as the most important aspect to site accessibility. It was statistically significant compared to haul distance, stream crossings, and tract size. It was not statistically significant to forest type or slope. Road construction reduces the value of the tract as crews build and maintain the road. Participants reported a range of 0.5 – 2 miles as the furthest distance they would build an access road. It depended on the value of the timber available. This study prioritized land parcels with nearby access roads to reduce the amount of road needed. This distance would vary based on where the logging deck was constructed. Careful consideration must be given to this aspect of planning to increase the ability of loggers to maximize the value of the timber available.

It was expected that slope would have a larger impact on logger's evaluation of a tract of timber than was found in the survey. While all respondents indicated that it was at least somewhat important, it was ranked lower than access distance and timber species. The ranking results were not statistically significant when comparing slope to any of the other factors. Slope was a difficult variable to quantify for many participants. Slope provides complexity to a harvest site based on length of slope, landform shape, and ability to cut in an access road. Many respondents reported anecdotally that slope was also influenced by soil type and presence of rock outcrops when cutting in access roads or skid trails. Future studies should consider visiting sites that respondents are operating on and collect slope data. Creating standardized complexity values to evaluate sites would provide more insight when comparing sites across different geographical areas. It also could be helpful to get the specifics of the equipment used to determine the

manufactures slope rating. The ability to identify specific slope values would allow TNC to target specific areas more effectively with the GIS tool created.

Responses indicated that many participants used a chainsaw as part of their harvesting equipment while also reporting a mechanized harvester as well (Figure 8). The lack of cable yarding systems indicates that the crews using chainsaws were using mechanized skidding operations, which requires a network of skid roads throughout the tract. The chainsaws were probably used for de-limbing and bucking logs. Increasing skid roads increases the amount of time an operator can deliver roundwood to the logging deck (Egan and Baumgras 2003). When working on steep slopes, as in the mountains, a dozer is required to cut in roads for skidders to operate on. This was anecdotally reported by many participants, that the ability to cut in a road network was vital for a tract to be profitable. This question was too vague to have a complete understanding of what type of equipment was used. The results provide a picture of the types of equipment in use in the mountain region but is not specific enough to understand which equipment are used together. These results will give The Nature Conservancy an idea of the abilities of logging crews in western North Carolina when planning an oak management project.

There were specific limitations to this survey. First, the overall population of loggers and timber buyers in the SBR ecoregion is small. These organizations are not well documented and are difficult to find on a large scale. North Carolina Forest Service updates their timber buyer database yearly, but even then some numbers were disconnected or some businesses had shutdown. Outside of North Carolina, statewide databases were not available for loggers or timber buyers. Often, it required calling specific county offices to request information, and this

was not always successful. Using Google Maps to search for logging and lumber companies was the most efficient way to find information for companies outside of North Carolina. Another limitation is the imprecise and qualitative nature of the logging industry. Many participants responded to questions as “it depends on the value of the timber” as they reported answers. Slope was a very difficult variable to quantify as many loggers do not carry slope measuring tools like traditional foresters. They rely on generational knowledge and personal experience when evaluating the complexity of a tract. Finally, the last important limitation is the variable schedule that loggers and timber buyers keep. Many of the responses occurred when the weather was bad in western North Carolina. The lack of computer availability affected the ability of participants to respond at their convenience and required setting up time in their busy schedule to have a phone interview. Mailing out surveys may be more effective in the future.

Site Prioritization

Areas that fall within the prioritized ecozones for this project span the entire length and width of western North Carolina. It is nearly impossible to identify suitable parcels without the use of an adaptable tool. The accessibility weighted map (Figure 10) created from the survey results provides added specification to each parcel for prioritization. Many of the high priority parcels are located in the southern counties of western North Carolina and TNC should focus their efforts in that region. That region has a higher potential for combining parcels or finding high priority parcels that are adjacent to public land. This may make conducting prescribed burns more accessible. The Parcel Analysis Tool (Figure 5) gives TNC the added benefit of focusing on one county or conducting a broad search of the entire region based on their project needs. The

parcel information found in this study using the 50-acre minimum and 60 degree slope maximum will be broken down and provided to TNC in a tiered prioritization proposal.

The lack of timber inventory data for western North Carolina was a limitation for this project. This model is based on past empirical modeling of ecozones and the logger survey assessment. If there were timber data available on a parcel level, or provided by TNC, more specific recommendations could be made. As satellite imagery and remote sensing continue advancing, the use of hyperspectral imagery to distinguish tree species or species groups will allow for a better understanding of where oak management can be beneficial and successful.

Financial Potential

The financial results show that an oak management project has potential to be financially stable if the proper resources are in place. As the value of a tract in financial terms declines significantly with any delay, a timber harvest of sawtimber sized trees must be ready to be harvested in the first few years. Hardwood pulp volume was not considered in this analysis due to the extremely localized markets of pulpwood in the mountains and the uncertainty of being able to sell it. The average pulpwood removed in this management scenario was almost 23 tons per acre. This could equate to \$148/ac using TMS hardwood pulpwood value. If TNC were to buy land, it would need to be at or around \$1800/ac to break even, based on the average value NPV. There is flexibility due to the variability of the value of timber, which will need to be assessed by a registered forester for actual value. If the land is received as a donation, there is higher potential for financial success due to not having to spend project capital up-front at the beginning of the management cycle. These numbers can also be used to teach landowners about

the financial potential of their forests. If TNC implements a project similar to the Working Woodlands⁷ program where they provide professional forestry advice and forest management planning, landowners could successfully manage for oak ecologically and financially. Using federal and state resources to combine prescribed burning projects near public land could also increase the feasibility of a project. Prescribed burning can often be difficult for landowners, but using state resources, applying for cost share help, and combining parcels together can make it more accessible.

The limitation of this analysis was again the lack of timber inventory data. Due to the value of these assets, organizations were not keen on sharing inventory data. Also, some of the data I was given was in PDF form and the time constraints were too great to convert that to a FVS ready database. Including inventory data from multiple places in the study area would make this analysis more robust. The lack of local timber pricing is another factor that hurts this analysis. The prices from TMS are a broad indicator of value for the region. Timber markets are very localized around mills and can change based on weather, the economy, mill needs, etc. Local knowledge will be required when determining the financial potential of an oak management project after a timber inventory has been conducted.

Conclusion

This project identified areas in western North Carolina that can be ecologically and financially viable for oak management by The Nature Conservancy. The goal of this project was to create a site prioritization map and tired recommendation for TNC to implement oak management

⁷ <https://www.nature.org/en-us/about-us/where-we-work/united-states/working-woodlands/>

projects. This was accomplished by determining ecological viability based on ecozones, logger accessibility based on a survey, and a financial analysis of oak silviculture techniques. This project found that many high priority properties are in the southern counties of the study area. This high clustering could potentially allow TNC to combine properties with private and public land that might help to facilitate large scale oak regeneration projects. The GIS tool created for TNC will allow selection of parcels at the county level based on local knowledge or project needs. The default setting is based on survey results and is a starting point for TNC to focus their efforts. Finally, if oak management is going to be financially successful, the project needs sawtimber sized trees and advanced oak regeneration present on the landscape at the beginning of the project. The sooner an initial harvest can occur, the higher the profitability of the project because the value starts to diminish as cash flow is pushed further into the future. Oak management is an important undertaking to steward healthy forests into the future under impending climate change and this can be successful in the Southern Blue Ridge ecoregion for The Nature Conservancy.

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Appendices

Appendix A. Western North Carolina Counties

- | | |
|---------------|------------------|
| 1. Alleghany | 13. Macon |
| 2. Ashe | 14. Madison |
| 3. Avery | 15. McDowell |
| 4. Burke | 16. Mitchell |
| 5. Buncombe | 17. Polk |
| 6. Caldwell | 18. Rutherford |
| 7. Cherokee | 19. Surry |
| 8. Clay | 20. Swain |
| 9. Graham | 21. Transylvania |
| 10. Haywood | 22. Watauga |
| 11. Henderson | 23. Wilkes |
| 12. Jackson | 24. Yancey |

Appendix B. Logger and Timber Buyer Survey

1. The purpose of this survey is to gather information about how timber is harvested in the mountains and what important factors influence how loggers and timber buyers evaluate and harvest a site. Your information will be used in a larger project by the Nature Conservancy to evaluate forest land for restoration/management of oak dominated forests. The data from this interview/survey will be used to create a map that identifies land parcels in western NC that are good candidates for forest restoration. The goal is to create more resilient forests in the face of a warmer/drier climate and provide valuable timber species to the local economy. No personally identifiable or company identifiable information will be collected. If you consent to answering questions regarding logging and timber procurement in the mountains, please select “Yes”. If you select “No” the survey will be over.
 - a. Yes
 - b. No
2. Please select the item that best describes your job:
 - a. Logger
 - b. Mill operator
 - c. Company procurement forester
 - d. Consulting forester
3. Please rank, from most important (1) to least important (7) in terms of timber harvest operability, the following site characteristics when harvesting timber in western North Carolina:
 - Slope
 - Forest type (tree species)
 - Stream crossings
 - Acreage
 - Distance to mill
 - Access to established road

- Land ownership type (State, Federal, industrial, non-industrial, NGO/Land trust)

4. Please evaluate the following variables based on their importance for selecting timber sites to operate on in western North Carolina: **Write an “X” in the appropriate box**

	not at all important	not very important	somewhat important	very important	extremely important
Slope					
Forest type (tree species)					
1 stream crossing					
Multiple stream crossings					
Acreage					
Distance to mill					
Access to established road					
Land ownership type					

5. How do you purchase standing timber on average?
 - a. Lump sum
 - b. “pay-as-cut”
6. How is the purchase usually financed?

7. What type of equipment do you primarily use to cut and skid timber? (Select all that apply)
 - a. Cut-to-length/processor
 - b. Chainsaw
 - c. Tracked feller-buncher
 - d. Rubber-tired feller-buncher
 - e. Rubber-tired skidder
 - f. Tracked skidder
 - g. Forwarder
 - h. Cable yarder
 - i. Cable skidder
 - j. Horses
 - k. Other
8. How do you determine if an area is too steep? (Equipment rating, land shape, etc. Any information is helpful)

- a. Do you have a specific slope/grade that you cannot work above? (example >40% slope)
9. Streams
- a. Do you use bridge mats? (steel/wood bridge mats)
Yes, No
 - b. If No, how do you cross streams?
10. Besides slope and stream crossings, are there other terrain features that are important considerations when logging in western North Carolina?

11. Forest type/Species

- a. What species do you harvest? (Select all that apply)
 - i. White pine
 - ii. Southern Yellow pine
 - iii. Red oak
 - iv. White oak
 - v. Hickory
 - vi. Tulip/Yellow Poplar
 - vii. Red Maple
 - viii. Sugar Maple
 - ix. Birch
 - x. Ash
 - xi. Hemlock
 - xii. Fir
 - xiii. Cherry
 - xiv. Walnut
 - xv. Other – (please write species types)

- b. In the past 5 years what is the dominant tree species you harvest by volume?
 - i. White pine
 - ii. Yellow pine
 - iii. Red oak
 - iv. White oak
 - v. Hickory
 - vi. Tulip/Yellow Poplar
 - vii. Red Maple
 - viii. Sugar Maple
 - ix. Birch
 - x. Ash
 - xi. Hemlock

- xii. Fir
- xiii. Cherry
- xiv. Walnut
- xv. Other – (please write species types)

c. Currently what is the most valuable species you harvest?

d. What species do you look for when cruising a timber sale?

White pine if it's mature, and big poplar

e. What species would you like to see more of?

f. Do you purchase timber with a large white pine component? (Greater than 50% white pine)

g. Is there a maximum amount of white pine that would stop you from buying a tract of timber? (All values are percentage)

- i. 0-25%
- ii. 25-50%
- iii. 50-75%
- iv. 75-100%

h. Are there any other tree species considerations when buying timber?

12. Distance to mill

a. What is the furthest distance you are willing to haul timber to a mill? (All values in miles)

- i. 0-25
- ii. 25-50
- iii. 50-75
- iv. 75-100
- v. 100+

13. Tract size acreage

a. What is the smallest tract size (acres) you would be willing to purchase/harvest if the timber value on the tract was average?

- i. 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100, 100+

b. Would you consider bidding on a sale or buying timber that contained multiple small adjacent tracts from different landowners that met your minimum acreage?

- i. Yes, No

- c. What considerations need to be met for you to bid on multiple small tracts together?

14. Ownership type (public, private, industrial)

- a. Please select all the landownership types you have harvested on:
 - i. Non-industrial private landowner
 - ii. Timber company-owned land
 - iii. State land, Federal land
 - iv. Private conservation group land

- b. What is the most common landownership type you have harvested on in the past 5 years?
 - i. Non-industrial private landowner
 - ii. Timber company-owned land
 - iii. State land, Federal land
 - iv. Private conservation group land
- c. Do you prefer harvesting on one landownership type?
 - i. Yes
 - ii. No
- d. If yes, what landownership type do you most prefer harvesting on?
 - i. Non-industrial private landowner, timber company-owned land, State land, Federal land, private conservation group land
 - ii. Why?

15. Road access

- a. How far are you willing to build a haul road to access average value timber?
Needs to be good value for long road

- b. Do you have a set limit or percentage of the timber value you are willing to spend on building or upgrading a haul road?

16. Silvicultural Systems

- a. What types of harvest have you done in the past?
 - i. clear-cut
 - ii. select cuts
 - iii. thinning
 - iv. shelterwood
 - v. irregular shelterwood/expanding gap
- n ot much of hardwood pulp market
- b. What type of harvest do you do most often?
 - i. clear-cut

- ii. select cuts
- iii. thinning
- iv. shelterwood
- v. irregular shelterwood/expanding gap

c. Are you willing to do different types of harvests to meet the landowner's needs?

Thank you for your time and thoughtful responses. If you have any follow up questions, or want to know how the project is going, please feel free to email me at Michael.K.Scott@duke.edu.