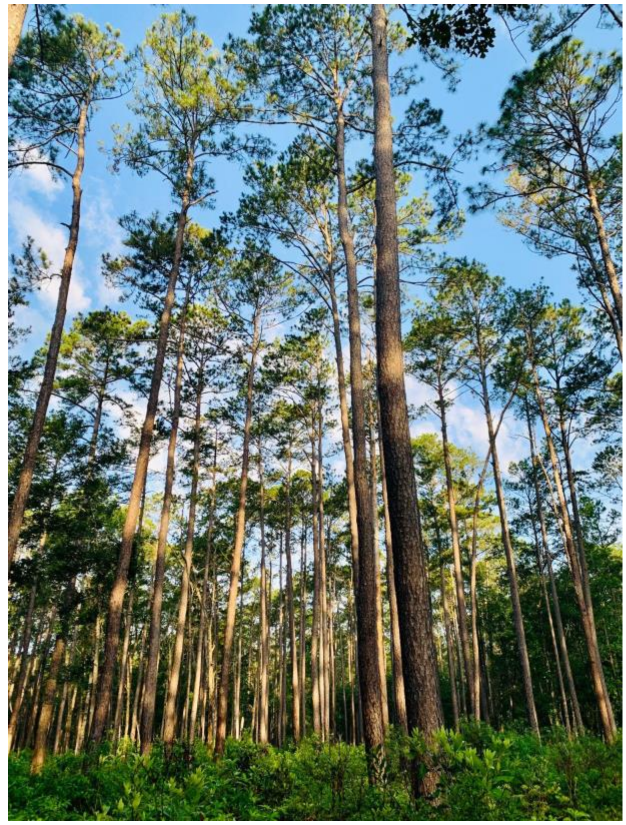
ACE Basin National Wildlife Refuge
Forest Inventory and Carbon Stock Analysis



Master's Project submitted in partial fulfillment of the requirements for
the Master of Forestry and Master of Environmental Management degrees in
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Executive Summary

The National Wildlife Refuge System (NWRS) was established in 1903 to conserve and protect the nation's wildlife and currently boasts 568 National Wildlife Refuges (NWR) across all 50 states. As multi-use lands, each NWR is distinct in its permitted recreational activities and resource management, but united in a central mission of wildlife conservation. The National Wildlife Refuge System Improvement Act of 1997 requires that all refuges supply a Comprehensive Conservation Plan (CCP) to provide guidelines for refuge management every 15 years. The CCP includes step-down management plans with specific guidance on objective areas such as forest management. Forest Habitat Management Plans (HMP), a component of the CCP, outline refuge forest conditions and suitable management activities, such as timber harvesting, that may enhance wildlife habitat.

The client for this project was the ACE Basin National Wildlife Refuge, which contains 11,815 acres of critical wildlife habitat in South Carolina's Lowcountry region. The Refuge consists of a variety of forest types, including upland pine and hardwood, bottomland hardwood, and cypress-tupelo swamps. Periodic forest inventories serve to update Refuge managers on current forest conditions and identify areas outside of desired forest conditions. Desired Forest Conditions (DFC) are defined forest composition and structure metrics representing critical wildlife habitat. These metrics are derived from the Refuge HMP and other U.S. Fish and Wildlife Service (FWS) recommendations. Active forest management, including thinning and prescribed fire, is often used on NWRs to meet DFC metrics, and thereby promote and enhance wildlife habitat.

The project sought to answer the following questions:

1. How do current Refuge forest habitat conditions compare to FWS Desired Forest Condition metrics?
2. What Refuge forest stands and cover types are in most critical need of active forest management?
3. How will active forest management activities affect Refuge carbon stocks?

A 10-week forest inventory field assessment of ACE Basin NWR was conducted from June - August 2021 to evaluate current forest conditions relative to DFC metrics. A total of 591 cruise points were established across two Refuge units (Grove and Bonny Hall) for a total 1,475 inventoried acres. Inventory results indicated that most forest types are outside of desired conditions and require a suite of management activities to achieve optimal wildlife habitat.

A subsequent analysis using the Forest Vegetation Simulator (FVS), a growth and yield modelling software, quantified how potential forest management activities to achieve DFC metrics would affect carbon stocks. The model contained two forest growth scenarios – a "Natural" run with no active management and a "Management" run where stands were thinned to desired basal area. Basal area, as the cross-sectional area occupied by tree stems (sq. ft./acre), is an indicator of many other forest metrics and was the primary DFC metric assessed for Refuge management. The FVS analysis showed that thinning to reduce basal area will also greatly reduce forest carbon stocks at the tradeoff of managing for suitable wildlife habitat.

Project findings revealed that active forest management is essential to improve Refuge forest conditions, but that carbon stocks will be greatly diminished as a result. Desired forest conditions

may be realized with repeated thinnings to reduce basal area, alongside a variety of silvicultural treatments that mimic the ACE Basin's historic landscape disturbance and habitat variation. Additional forest management practices were identified that may reduce carbon losses, such as delaying thinning cycles and maintaining inoperable sites in unmanaged conditions. This project ultimately recommends that the Refuge engage in active forest management to attain desired wildlife habitat while also incorporating forest carbon in management considerations and future HMPs.

Acknowledgements

This Master's Project was made possible by the U.S. Fish and Wildlife Service's Directorate Fellows Program (DFP), through which I spent Summer 2021 completing a forest inventory of the ACE Basin National Wildlife Refuge. I owe a massive thank you to Haven Barnhill of the U.S. Fish and Wildlife Service Southeast Region for his patient mentorship and guidance throughout this project. I am extremely grateful to Haven and Laura Dymond, whose field skills were instrumental in completing the field inventory. As a Forestry Intern, Laura's talent and dedication contributed immensely to the project and I'm indebted to her for braving ten weeks in the swamp with me. I'd also like to thank Mark Purcell and Jason (Brett) Craig of the ACE Basin National Wildlife Refuge for their incredible support and for graciously hosting me as a DFP intern.

Thank you to my advisor, Dr. Dean Urban of the Nicholas School of the Environment, for his counsel on this project and to Drs. Sari Palmroth and Jennifer Swenson, also of the Nicholas School, for their advisement. All have contributed their time and expertise to this project in addition to greatly influencing my time at Duke.

Finally, I'd like to thank my parents, Robin and Mary Claire, for their endless love and support.

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Introduction

The U.S. Fish and Wildlife Service (FWS) oversees 95 million acres of public land dedicated to conserving America's natural heritage.[1] The National Wildlife Refuge System (NWRS) was established by President Theodore Roosevelt in 1903 as part of the agency's mission "to conserve, protect and enhance fish, wildlife, and plants and their habitats".[2,3] There are currently 568 National Wildlife Refuges distributed across all 50 states, each differing in permitted recreational activities and resource management tools, but all with a leading goal to conserve wildlife and their habitats.

The National Wildlife Refuge System Improvement Act of 1997 was the first legislation to explicitly define the NWRS's mission of wildlife conservation.[4] The Act requires that all refuges supply a Comprehensive Conservation Plan (CCP) providing guidelines and long-term objectives for refuge management and prepared in consultation with federal, state, and private landowners. The CCP includes step-down management plans with specific guidance on objective areas such as forest management, cultural resources, hunting, and inventory and monitoring. Forest Habitat Management Plans (HMP) outline refuge forest conditions and suitable management activities, such as timber harvesting, that may enhance wildlife habitat. Refuges with a Forest HMP periodically implement forest inventory field assessments to evaluate current habitat conditions and assist in wildlife management. Forest inventories are an applicable tool for assessing CCP and HMP objectives as they provide a snapshot of refuge habitat conditions and reveal critical metrics, such as forest structure, species composition, and timber volume.

Forest inventories are particularly useful for identifying refuge forest stands outside of desired habitat standards and metrics. Forest stand structure is highly influenced by land use legacies, including agriculture, timber management, and land clearing or abandonment (Foster et al. 2003). These past disturbances often result in undesirable conditions such as overstocking and high prevalence of pathogens and invasive species (Pile et al. 2017). Undesirable stands may be manipulated with active forest management, including techniques such as thinning and prescribed burning. Active forest management can promote ideal wildlife habitat conditions by altering forest structure and composition to increase wildlife connectivity, nesting cover, and food supply (McIntyre et al. 2019).

In the wake of global climate change, forests are increasingly viewed as a 'natural climate solution' capable of sequestering and offsetting carbon emissions (Moomaw et al. 2020). As a result, there is a growing trend of forestry professionals including carbon in their management plans and selecting tactics that maintain, enhance, or reduce losses of carbon stocks (Ontl et al. 2020; Kaarakka et al. 2021). Active forest management holds differential effects on carbon stocks, with activities such as thinning and prescribed burning often resulting in carbon losses, and reforestation and afforestation in carbon gains (Ontl et al. 2020). Considering carbon effects in these plans allows managers to meet concurrent goals and contribute to both local adaptation and natural climate solutions.

[1] https://www.fws.gov/refuges/about/public-lands-waters/
[2] https://www.fws.gov/help/about_us.html
[3] https://www.fws.gov/refuges/
[4] Ernest F. Hollings Ace Basin National Wildlife Refuge: Comprehensive Conservation Plan

U.S. federal forests, including those under the jurisdiction of FWS, are a major carbon pool and serve a significant role in national greenhouse gas inventory (Smith, 2012). Carbon stocks on FWS forestlands average 163.7 metric tons of carbon per hectare, rivaling the National Forest System (167 metric tons C/hectare) and surpassing private forestlands (141 metric tons C/hectare) (Table 1). Federal lands are currently ineligible for offset projects without federal authorization, however, identifying ecosystem services such as carbon sequestration on FWS lands can support agency budget allocation and potential expansion of the NWRS (Patton et al. 2015; Smith, 2021). National Wildlife Refuges with HMPs tailored to forest management may seek to quantify carbon stocks on their forestlands for these reasons.

Table 1: Estimated carbon stocks on forested land by federal land ownership for the U.S. (excluding Alaska and Hawaii) (Smith, 2012).

State	Mean Forest Carbon (metric tons C/hectare)	Area (hectares)	Carbon (million metric tons)	Cumulative Percent of Forest Carbon
National Forest	166.95	58,820,322	9,820	80.2%
Bureau of Land Management	92.73	12,288,825	1,140	89.5%
National Park Service	195.45	3,392,385	663	94.9%
Department of Defense/Energy	150.02	1,740,859	261	97.1%
Fish and Wildlife Service	163.7	1,016,386	166	98.4%
Other federal	155.61	1,064,994	166	99.8%
National Grassland	97.69	114,324	11	99.9%
Other Forest Service	173.98	86,719	15	100.0%
All Federal		77,307,385	12,242	

Project Client

The client for this Master's Project was the U.S. Fish and Wildlife Service, specifically the Ernest F. Hollings ACE Basin National Wildlife Refuge. During Summer 2021, I served as a FWS Directorate Fellow and completed the ACE Basin Forest Inventory Project under the guidance and mentorship of Haven Barnhill, Deputy Regional Forester; Jason (Brett) Craig, Wildlife Refuge Specialist; and Mark Purcell, Refuge Manager; and with field assistance from Laura Dymond, Forestry Intern.

Statement of Purpose

This project used traditional forest inventory methods and further analyses to evaluate current Refuge habitat conditions and answer the following questions:

1. How do current Refuge forest habitat conditions compare to FWS Desired Forest Condition metrics?
2. What Refuge forest stands and cover types are in most critical need of active forest management?
3. How will active forest management activities affect Refuge carbon stocks?

Given limited active forest management activities on the Refuge for the past three decades, most stands were predicted to differ from Desired Forest Conditions. Management actions are critical to achieve Desired Forest Conditions and may also present tradeoffs if forest carbon stocks are reduced. Undesirable forest habitat conditions serve to highlight Refuge needs related to budget, staffing, and resource capacity while carbon sequestration potential presents a possible avenue for funding.

Study Area

The Ernest F. Hollings ACE Basin National Wildlife Refuge (ACE Basin NWR) was established in 1990 and is located along South Carolina's coastal plain, approximately 20 miles southwest of Charleston and 20-25 miles northwest of Beaufort. The Refuge is part of the 350,000-acre Ashepoo-Combahee-Edisto (ACE) Basin Project, one of the largest undeveloped wetland ecosystems on the Atlantic Coast. The Refuge is a partner of the ACE Basin Task Force, a collaborative effort among federal and state agencies, private conservation groups, and local landowners to protect the ACE Basin. The Refuge has a variety of management objectives as outlined in CCP and HMP planning documents.

The Refuge vision states:

> "Established in 1990, the Ernest F. Hollings ACE Basin National Wildlife Refuge provides resources for migratory birds, endangered species, and compatible public uses. Through motivated, experienced, and well-trained staff and volunteers and active partners, the refuge will strive to maintain the unique ecological landscape features and be an active partner to achieve the goals and objectives of the ACE Basin Project, a 350,000-acre estuary/ecosystem conservation partnership between state, federal, corporate, private landowners, and non-governmental organizations. Through team development, the refuge will strive to be a model of excellence in natural resource management and celebrate our achievements with the public and our partners. The management of wildlife and habitat on the refuge will be an adaptive, science-based, comprehensive endeavor that links biological needs with resource management. The refuge will actively seek to expand partnerships that advance conservation stewardship and protection of natural resources. We will actively pursue research supporting the informational needs of the refuge while being able to adapt and being responsive to change. We will seek and develop appropriate and compatible public use opportunities and enhance awareness and appreciation of the refuge and National Wildlife Refuge System. Through outreach and public participation, the neighboring communities within the ACE Basin area will share our values for the National Wildlife Refuge System and a fish and wildlife heritage for all Americans (Purcell M. and Ernest F. Hollings Ace Basin National Wildlife Refuge, 2009)."

Resources of concern include species, species groups, and communities that support Refuge purposes as well as FWS trust resource responsibilities including threatened and endangered species and migratory birds. The resources of concern outlined in the 2015 ACE Basin NWR Habitat Management Plan (HMP, 2014) include migratory landbirds and Threatened and Endangered species such as the Wood stork, Red-cockaded woodpecker, Flatwoods salamander, Canby's dropwort, Pondberry, American chaffseed, and Bachman's warbler. Refuge forest management actions are geared towards enhancing habitat for resources of concern and meeting other Refuge objectives.

Desired Forest Conditions

Desired forest conditions (DFC) are defined forest composition and structure metrics representing critical habitat for priority resources of concern. Tree species composition and density, canopy cover, midstory, understory, groundcover, cavities, and downed dead wood are a few examples of important variables influencing forest condition. The Refuge HMP and other FWS planning documents identify important variables for habitat.

Three major forest cover types were identified for the ACE Basin NWR inventory assessment – bottomland hardwood, open pine, and mixed pine-hardwood. DFC for bottomland hardwood forests were based on the guidelines set forth by the Lower Mississippi Valley (LMVJV) Forest Resource Conservation Working Group (2007) (Table 2). DFC for open pine forests were based on guidelines from a 2016 report jointly published by FWS and NatureServe titled "Rapid Assessment Metrics to Enhance Wildlife Habitat and Biodiversity within Southern Open Pine Ecosystems" (Table 3).

The Refuge currently lacks detailed DFC metrics for mixed pine-hardwood forests; however, the HMP notes that management action will be taken on all mixed pine-hardwood sites to treat and move them toward either an open pine or an altered mixed pine-hardwood condition. For the purposes of this inventory report, intermediate structural metrics – between open pine and bottomland hardwood – determined in consultation with the Deputy Regional Forester were used to assess desired conditions. DFC for mixed pine-hardwood included basal area between 40-70 sq. ft./acre and canopy cover between 30-70%. Mixed pine-hardwood sites will be assessed on a stand-by-stand basis to determine appropriate management action (as is generally the case with most Refuge stands).

Table 2: Desired forest conditions for bottomland hardwood based on the LMVJV Forest Resource Conservation Working Group (2007).

Forest Variables[1]	Desired Stand Structure	Conditions That May Warrant Management
Primary Management Factors		
Overstory Canopy Cover	60-70%	>80%
Midstory Cover	25-40%	<20% or >50%
Basal Area	60-70 ft^2/acre with ≥ 25% in older age classes[2]	90ft2/acre or ≥ 60% in older age classes
Tree Stocking	60-70%	< 50% or > 90%
Secondary Management Factors		
Dominant Trees[3]	>2/acre	<1/acre
Understory Cover	25-40%	<20%
Regeneration[4]	30-40% of area	<20% of area
Coarse Woody Debris (>10 inch diameter)	≥ 200 ft^3/acre	<100 ft^3/acre
Small Cavities (<10 inch diameter)	>4 visible holes/acre or >4 "snag" stems ≥4 inch dbh or ≥ 2 stems >20 inch dbh	<2 visible holes/acre or <2 snags ≥4 inch dbh or <1 stem ≥ 20 inch dbh
Den Trees/Large Cavities[5] (>10 inch diameter)	1 visible hole/10 acres or ≥ 2 stems ≥ 26 inch dbh (≥ 8ft^2 BA ≥ 26 inch dbh)	0 visible holes/10 acres or < 1 stem ≥ 26 inch dbh (< 4 ft2 BA ≥ 26 inch dbh)
Standing Den and/or Stressed Trees[5]	>6 stems/acre ≥ 10 inch dbh or ≥ 2 stems ≥ 20 inch dbh (> 4ft2 BA ≥ 10 inch dbh)	< 4 stems ≥ 10 inch dbh/acre or < 1 stem ≥ 20 inch dbh (< 2 ft^2 BA ≥ 10 inch dbh)

1 Promotion of species and structural diversity within stands is the underlying principle of management. Management should promote vines, cane, and Spanish moss within site limitations.

2 "Older age class" stems are those approaching biological maturity, (i.e., senescence). We do not advocate aging individual trees but use of species-site-size relationships as a practical surrogate to discern age.

3 Dominants (a.k.a. emergents) should have stronger consideration on more diverse sites, such as ridges and first bottoms.

4 Advanced regeneration of shade-intolerant trees in sufficient numbers (circa 400/acre) to ensure their succession to forest canopy. Areas lacking canopy (i.e., group cuts) should be restricted to <20% of stand area.

5 Utilizing BA parameters allows the forest manager to maintain this variable in size classes that re most suitable for the stand instead of using specific size classes noted.

Table 3: Desired forest conditions for open pine based on the report "Rapid Assessment Metrics to Enhance Wildlife Habitat and Biodiversity within Southern Open Pine Ecosystems" (Nordman et al. 2016).

Mesic Longleaf Pine Flatwoods				
Canopy Metrics				
	Excellent	**Good**	**Fair**	**Poor**
Canopy Southern Yellow Pine Basal Area	30-80 ft^2/acre basal area of longleaf or slash pine	20 to <30 or >80 to 90 ft^2/acre basal area of longleaf or slash pine	10 to <20 or >90 to 105 ft^2/acre basal area of longleaf or slash pine	<10 or >105 ft^2/acre basal area of longleaf or slash pine
Southern Yellow Pine Canopy Cover	30 to 65% canopy cover of longleaf or slash pine	20 to <30% canopy cover or >65 to75% canopy cover of longleaf or slash pine	10 to <20% canopy cover or >75 to 85% canopy cover of longleaf or slash pine	<10% cover or >85% cover of longleaf or slash pine
Southern Yellow Pine Stand Age Structure	BA ≥20 ft^2/acre of flat-top longleaf or slash pine of any diameter and/or longleaf or slash pine trees ≥14" DBH class	BA ≥10 ft^2/acre of longleaf or slash pine trees ≥ 4" DBH class	Longleaf or slash pine trees ≥14" DBH class are present, but at < 10 ft^2/acre BA	No longleaf or slash pine trees ≥14" DBH or flat-top slash or longleaf pine
Canopy Hardwood Basal Area	<20 ft^2/acre BA of hardwood trees	≥20 to 25 ft^2/acre BA of hardwood trees	>25 to 35 ft^2/acre BA of hardwood trees	>35 ft^2/acre BA of hardwood trees
Stand Density Index (applies to longleaf and slash pine)	SDI = 60 – 125 (15 - 31% of Maximum SDI of 400)	SDI = 40 – 60 or 125 - 160 (10-15% or 31-40% of Maximum SDI of 400)	SDI = 20 – 40 or 160 - 190 (5-10% or 40-48% of maximum SDI)	SDI <20 or >190 (<5% or >48%, 240 is 60% of Maximum SD of 400)
Midstory/Shrub Metrics				
	Excellent	**Good**	**Fair**	**Poor**
Midstory Fire Tolerant Hardwood Cover	<10% cover of midstory fire tolerant hardwoods	10 to <20% cover of midstory fire tolerant hardwoods	20 to 25% cover of midstory fire tolerant hardwoods	>25% cover of midstory fire tolerant hardwoods
Midstory Overall Cover	<20% cover of woody midstory	20 to <30% cover of woody midstory	30-40% cover of woody midstory	>40% cover of woody midstory
Short Shrub (<3 ft tall) Cover	Short shrubs average <30% cover	Short shrubs average 30 to <40% cover	Short shrubs average 40-45% cover	Short shrubs average >45% cover
Tall Shrub (3-10 ft tall) Cover	Tall shrubs average <20% cover.	Tall shrubs average 20 to <30% cover.	Tall shrubs average 30-35% cover.	Tall shrubs average >35% cover.
Ground Layer Metrics				
	Excellent	**Good**	**Fair**	**Poor**
Overall Native Herbaceous Ground Cover	40-98% herbaceous cover	30 to <40% or >98% herbaceous cover	20 to <30% herbaceous cover	<20% herbaceous cover
Longleaf Pine Regeneration	Longleaf pine regeneration cover is ≥1% of stand (Good and Excellent)	Longleaf pine regeneration cover is ≥1% of stand (Good and Excellent)	Longleaf pine regen cover is present but is <1% of stand, or no regen seen, but cone producing longleaf pine are present	Longleaf pine regen cover is apparently absent, and no cone producing longleaf pine are present in the stand
Native Warm Season Grass Cover	>25 to 97% foliar cover of all native warm season grasses	>15 to 25% or >97% foliar cover of native warm season grasses	10-15% foliar cover of all native warm season grasses	<10% foliar cover of all native warm season grasses
Invasive Plant Presence / Distribution	Invasive nonnative plant species absent or cover is very low (≤1% cover)	Invasive nonnative plant species in any stratum present but sporadic (1-5 % cover)	Invasive nonnative plant species in any stratum uncommon (5-10% cover)	Invasive nonnative plant species in any stratum common (>10% cover)

Management Units and Habitat Descriptions

ACE Basin NWR is comprised of two management units, the Edisto Unit and the Combahee Unit, which together encompass approximately 11,815 acres. The Edisto Unit consists of 7,203 acres in Charleston County (Figure 1). The Combahee Unit consists of 4,612 acres in Beaufort, Colleton, and Hampton Counties (Figure 2). These two units are further broken down into sub-units with the Edisto Unit containing the Barrelville, Grove and Jehossee sub-units, and the Combahee Unit containing the Bonny Hall, Combahee Fields and Yemassee sub-units. Given time and labor constraints, this inventory assessment was constrained to the Grove and Bonny Hall sub-units (Table 4). Future forest inventories will target the remaining four Refuge sub-units.

The Refuge sub-units are separated into nine management compartments by the ACE Basin NWR 2005 HMP. This organizational structure is utilized for forestry purposes as well as general cover type information. Compartment boundaries are established along geographic features that are easily identified on the ground (i.e. rivers, roads, trails, etc.). Refuge cover type maps are used to delineate individual sites for habitat management purposes (ACE Basin HMP, Appendix A, 2015). Current Refuge habitat cover types include: natural tidal marshes (mostly brackish and some freshwater), managed wetlands (impounded fresh water, brackish water, and greentree reservoir sites), forested wetlands, forested uplands, and early successional/grasslands. For this forest inventory, three primary habitat types were identified within the inventoried units and include bottomland hardwood, open pine, and mixed pine-hardwood (Table 5). Open pine areas include both natural pine and pine plantation areas identified in the HMP. Below are descriptions of forest habitat cover types surveyed in this inventory and derived from pages 26-28 of the Refuge HMP.

> **Bottomland Hardwood –** “While including a number of species found in the pine-hardwood type, bottomland hardwood forests occur on lower flats and are dominated by species tolerant of slightly longer periods of soil saturation and flooding (Wharton et al. 1982). Dominant tree species include overcup oak, swamp chestnut oak, water oak and red maple (*Acer rubrum*). Although loblolly pine is present, spruce pine (*Pinus glabra*) is the principal co-dominant pine species found on these wetter sites. Other co-dominants are: water hickory (*Carya aquatica*), pignut hickory, American hornbeam (*Carpinus carolinana*) and green ash (*Fraxinus pennsylvanica*). The Bald Cypress-Water Tupelo Swamp community occurs in the wettest parts of floodplains that have standing water for most of the year. As a result, few herbs occur. Along with bald cypress, water tupelo dominates the canopy. It is commonly found along the Combahee River.”
>
> **Natural Pine –** “This type occurs on somewhat poorly drained soils of broad, flat, low areas and knolls. Dominant canopy species are loblolly pine, longleaf pine and pond pine. Loblolly is the dominant pine species on all pine sites with the exception of Stand 3 in Compartment 3 (Grove North) where longleaf dominates. The understory is dominated by sweetgum with mockernut hickory, swamp red oak, laurel oak and switch cane also occurring. Shrub species include wax myrtle, sparkleberry and persimmon.”
>
> **Pine Plantation –** “The plantations are located on transition zones between forest wetlands and upland pine. Loblolly is the single tree species. Past logging and agricultural practices combined with present day forestry management have resulted in monotype loblolly pine

plantations being established on the [Bonny Hall Unit]. These plantations were established prior to refuge acquisition."

Mixed Pine-Hardwood – "This type, including Live Oak-Maritime, occurs on higher flats and is composed of tree species that tolerate limited periods of moderately high soil saturation and flooding (Wharton et.al. 1982). Dominant tree species include: loblolly pine (*Pinus taeda*), swamp chestnut oak (*Quercus michauxii*), cherrybark oak (*Quercus pagota*), laurel oak (*Quercus hemisphaerica*), and swamp red oak (*Quercus shumardii*). Co-dominant species are represented by live oak (*Quercus virginiana*), willow oak (*Quercus phellos*), water oak (*Quercus nigra*), white oak (*Quercus alba*), overcup oak (*Quercus lyrata*), sweetgum (*Liquidambar styraciflua*), blackgum (*Nyssa sylvatica*) and pignut hickory (*Carya glabra*). A diverse shrub layer is composed of horse sugar (*Symplocos tinctoria*), wax myrtle (*Myrica cerifera*), switch cane (*Arundineria tecta*), sweet pepperbush (*Clethra alnifolia*), American holly (Ilex opaca), fetterbush (*Lyonia lucida*), persimmon (*Diospyros virginiana*), dwarf palmetto (*Sabal minor*), gallberry (*Ilex glabra)* and blueberry (*Vaccinium* spp). Vines include greenbriar (*Smilax* spp), cross vine (*Bignonia capreolata*) and Virginia creeper (*Parthenocissus quinquefolia*). The ground layer is comprised of cinnamon fern (*Osmundastrum cinnamomeum*), royal fern (*Osmunda regalis*), marsh fern (*Thelypteris palustris*), nut rush sedge (*Scleria pauciflora*), partridge berry (*Mitchella repens*), panic grasses (*Panicum* spp.) and rushes (*Juncus* spp.) interspersed throughout the forest."

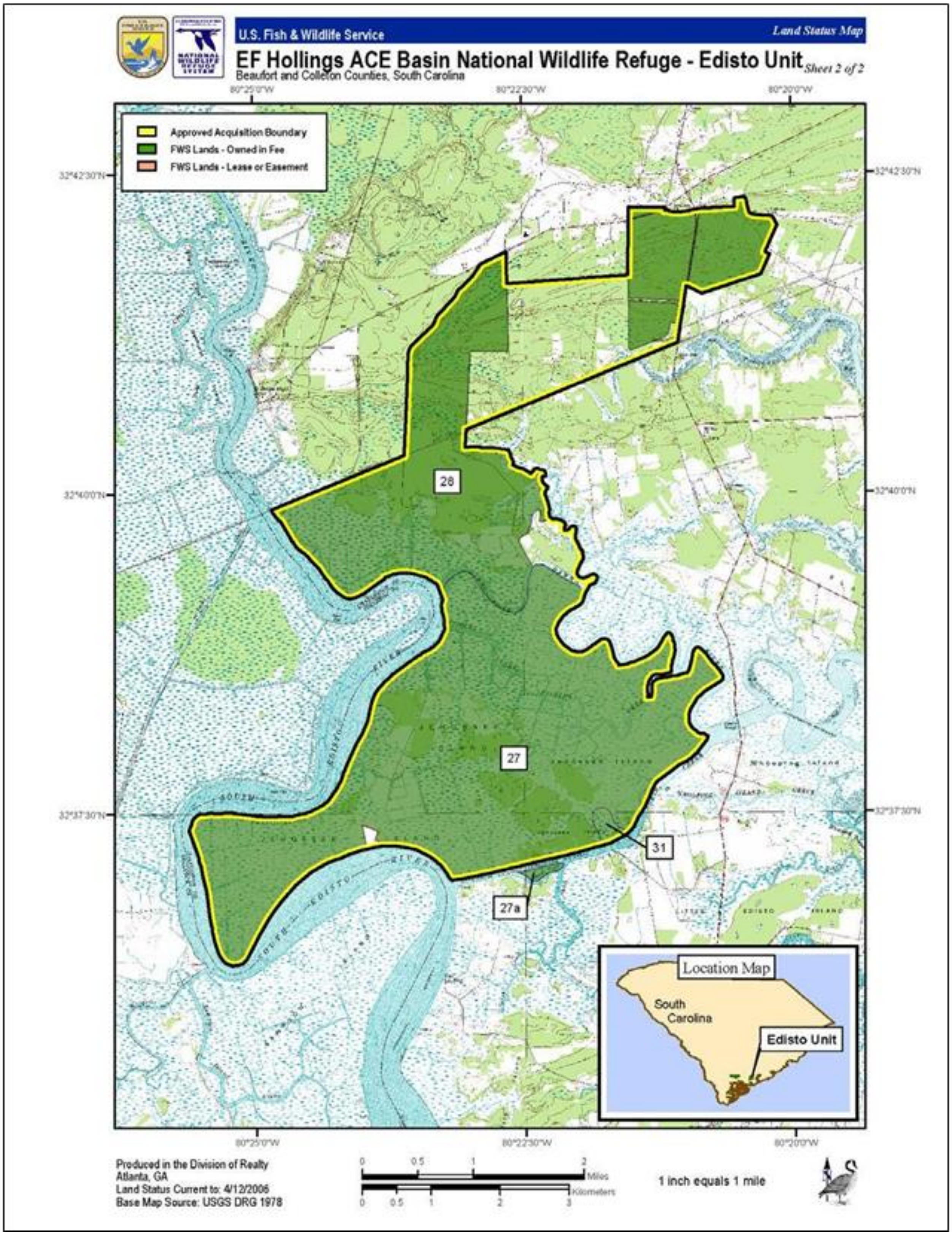


Figure 1: Edisto Unit Map

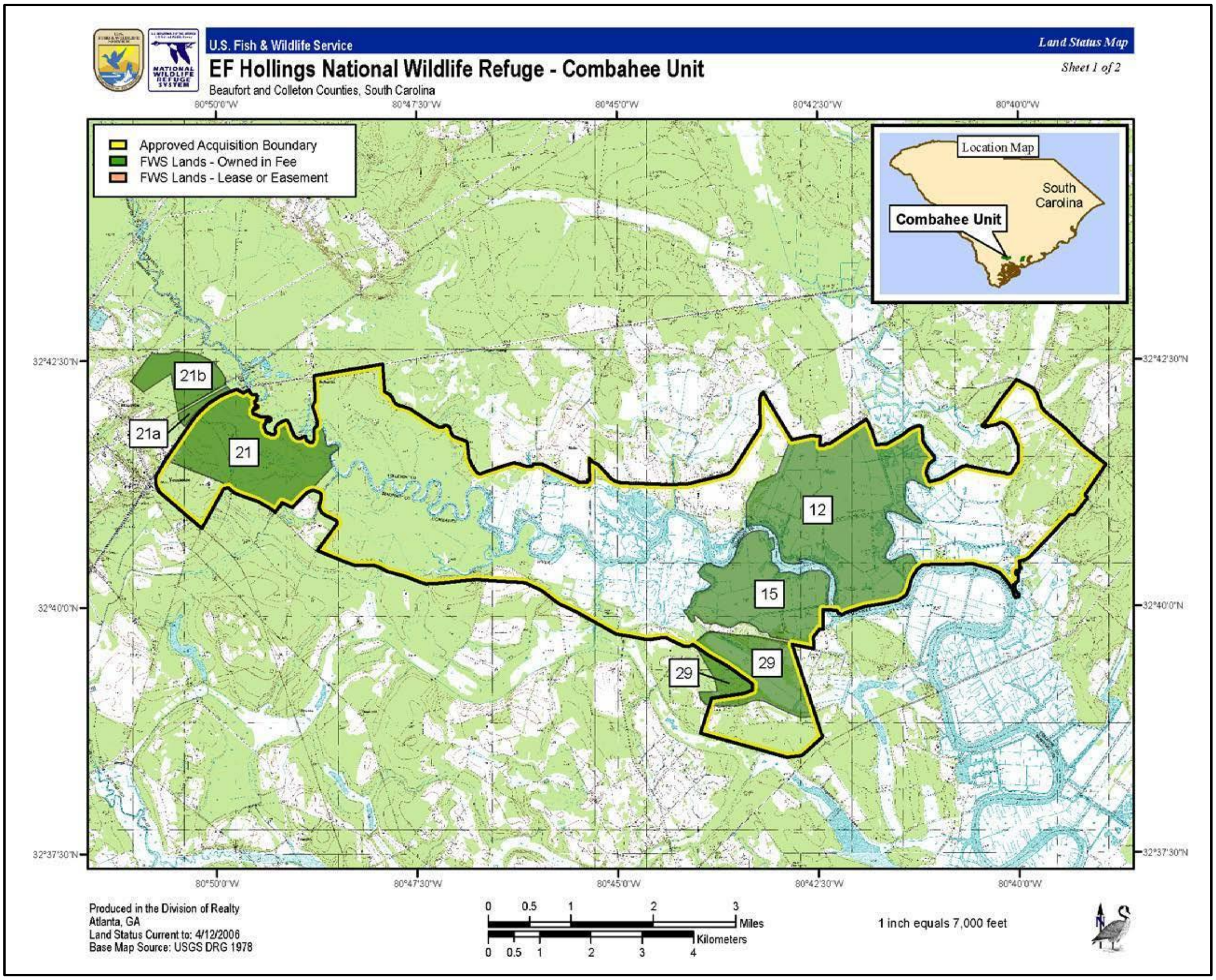


Figure 2: Combahee Unit Map

Table 4: Inventory Compartment Summary Table

Edisto Unit	**County**	**Acres**
Compartment 2 (Grove North)	Charleston County	589
Compartment 3 (Grove South)	Charleston County	1,508
Combahee Unit		
Compartment 7 (Bonny Hall)	Beaufort County	1,425
	Total Acreage	**3,522**

Table 5: Inventory Major Cover Types Acreage

Cover Type	**Grove Unit Acreage**	**Bonny Hall Acreage**	
Bottomland Hardwood	232	47	
Open Pine	141	38	
Mixed Pine-Hardwood	748	269	
Total Acreage	**1,121**	**354**	**1,475**

Methods

Methods consisted of a 10-week field inventory in Summer 2021 and model simulations of forest growth in Fall 2021. Inventory data were input into the U.S. Forest Service's Forest Vegetation Simulator (FVS), an individual tree growth and yield model, to analyze management effects on forest growth metrics and carbon stocks.[5]

Forest Inventory

Priority areas for the ACE Basin forest inventory were identified by Refuge staff and Haven Barnhill, Deputy Regional Forester for the FWS Southeast Region. Inventory focus areas included all forested habitat with long-term probability of silvicultural management. Areas known to be unforested, such as early successional fields, grasslands, managed wetlands, and natural marsh, were excluded from inventory as they will not be considered for active forest management in the near future.

[5] Forest Vegetation Simulator (Version 20210630) [Computer software]. (2021, June 30). Retrieved from https://www.fs.fed.us/fvs/software/complete.php

A total of 1,475 acres was identified for inventory assessment – 1,121 acres in the Grove Unit and 354 acres in the Bonny Hall Unit. A cruise grid was generated using the EZ Plot® Toolbar extension in ArcGIS at the rate of one cruise point per 2.5 acres, for an inventory of approximately 4% of Refuge forested habitat.[6] A total of 591 equidistant cruise points were established within the sample area, with 449 Grove Unit points and 142 Bonny Hall Unit points. Each point was separated by 4.18 chains (276 feet).

Two-person teams conducted the cruise using handheld data loggers.[7] SOLO Forest ®, a GPS program, provided spatial reference to navigate to each point using preloaded data templates and base maps.[8] TCruise forest inventory software was used to record data at each point.[9] Points that fell in inaccessible or non-operational areas, either due to dense regeneration or wet conditions, were not cruised.

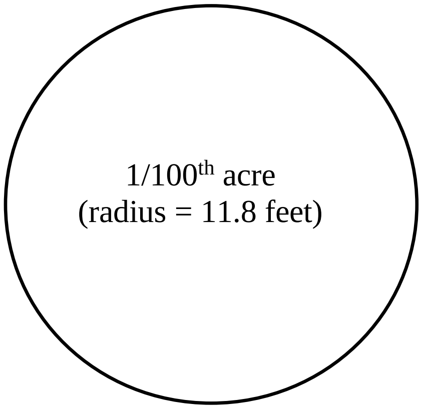
Both plot-level and tree-level data were recorded at each point. Plot-level data were ocular estimates taken from the cruise point. Plot-level variables were first recorded for a fixed radius of 1/100th acre (11.8-foot radius) and included advanced regeneration presence and groundcover type percentages (Figure 3).

Additional plot-level variables were recorded for a fixed radius of 1/10th acre (37.2-foot radius) and included understory/midstory height and percentage, percent canopy cover, presence of vines, downed woody debris, presence of large and small snags, fusiform rust count, cavity presence, and invasive species presence (Figure 3).

In addition to data gathered at the 1/100th and 1/10th-acre plot-levels, tree-level data for all trees determined to be "in" using a 10 Basal Area Factor (BAF) prism was recorded at each point. These variables included species, diameter at breast height (DBH), tree height (sawlog and merchantable), product, and canopy class. Basal area (BA) is a measure of stand density defined as the cross-sectional area of a tree at breast height (4.5 feet above the ground) in units of square feet. BA is determined on a per acre basis using a prism. A 10 BAF prism indicates that the number of trees counted as "in" are multiplied by 10 to get the basal area per acre.

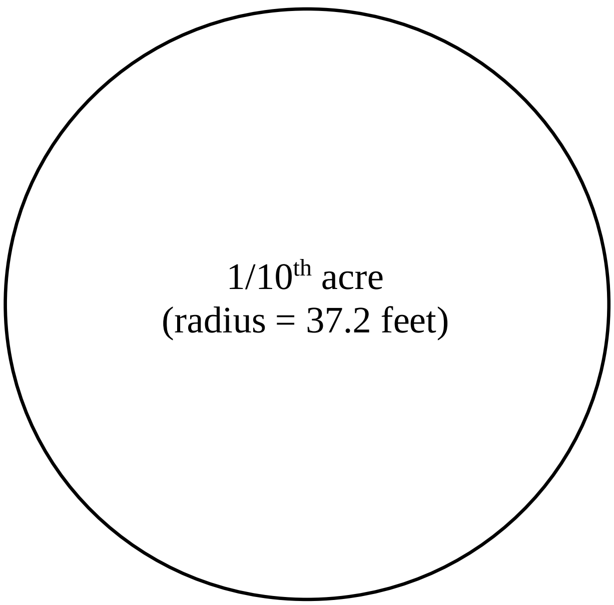
[6] Landmark Spatial Solutions LLC, Starkville, MS. EZ Plot® Toolbar [GIS/GPS software]. https://landmarkspatialsolutions.com/product/ez-plot-toolbar
[7] Trimble Nomad 1050® (2015) [Handheld computer]. https://www.trimble.com/Outdoor-Rugged-Computers/nomad.aspx
[8] Landmark Spatial Solutions LLC, Starkville, MS. SOLO Forest® [GIS/GPS software]. https://landmarkspatialsolutions.com/solo-forest
[9] Landmark Spatial Solutions LLC, Starkville, MS. TCruise® [Forest inventory software]. https://landmarkspatialsolutions.com/product/tcruise/

Figure 3: ACE Basin NWR Forest Inventory Protocol and Data Collection Variables. Variable definitions can be found in Appendix A.



Advanced Regen Presence
- Oak Regen Count
- Longleaf Regen Count

BaregroundPerc
LitterCoverPerc
VegCoverPerc
- Grass
- Forb
- Woody



UnderstoryPerc
UnderstoryHt
MidstoryPerc
MidstoryHt
% Canopy Cover
Vines
LrgWoodDown
LrgSnag
SmSnag
Fusiform Count
Cavities Present
- Small Cav
- Med. Cav
- Large Cav

Invasives
- Chinaberry
- Tallow
- Tree of Heaven
- Hog Rooting
- Jap Climbing Fern
- Chinese Privet

Forest Vegetation Simulator - Carbon Analysis

The US Forest Service's Forest Vegetation Simulator (FVS) software is an individual tree growth and yield model that produces estimates of forest stand metrics and allows for comparisons of management activities. FVS requires two primary input data types: tree data (species, DBH, tree height) and stand data (site index, slope, elevation, sampling design). The software employs localized equations, called 'Regional Variants', to predict growth, mortality, and volume based on site conditions and U.S. Forest Service Forest Inventory and Analysis (FIA) data. ACE Basin NWR falls within the Southern Variant, with Francis Marion National Forest serving as the nearest National Forest and input Location to further distinguish habitat characteristics (Keyser, C.E., 2008).

The Fire and Fuels Extension (FFE) to FVS models fuel dynamics and fire behavior within a stand's development (Rebain et al. 2010). Along with predicting fuel loading and fire hazard, the FFE model produces Stand Carbon Reports and Harvested Product Reports. The Stand Carbon Report shows forest biomass (dry tons C/acre where a ton is a short ton (2,000 lbs)) contained in live & dead trees and woody & live surface fuels. Estimates of live tree biomass are based on a combination of FVS variant-specific volume equations and allometric equations described by Jenkins and others (2003). The Harvested Products Report displays the fate of merchantable carbon removed from a stand, either as stored carbon (e.g. products, landfill) or emitted carbon (e.g. energy, emissions). The FFE is thus a useful tool for predicting the effects of management activities on stand carbon stocks.

Management scenarios in line with DFC basal area metrics were modelled in FVS for the 3 forest cover types in the Grove Unit. Inventory data for the Bonny Hall Unit were not included in this analysis section as the Unit has a much smaller forest area and will likely be managed similarly to the Grove Unit. Grove Unit bottomland hardwood, open pine, and mixed pine-hardwood plots were input as "Stands" into FVS (Table 6). Mixed pine-hardwood plots were divided into North, Southwest, and Southeast stands as these plots collectively exceeded FVS's 3,000 tree limit.

For each stand, the species and DBH from tree-level inventory data was included. Height was excluded from stand inputs as FVS requires total height and only merchantable and sawlog heights were collected during the inventory. FVS thus estimated total height based on regional estimates. Site index was calculated for each stand with USDA's Web Soil Survey using the majority soil type found within each cover type (Appendix B). Site index is a measure of site productivity based on the relationship between tree age and tree height.

Stand growth was first projected with a "Natural" run from 2021-2120, which included unchecked growth and no management activities. A "Management" run was then simulated with the following parameters (Table 7):

1) An initial 2021 thinning to a lower DFC BA threshold of 50 sq. ft./ac for bottomland hardwood and 40 sq. ft./ac for open pine and mixed pine-hardwood
2) Biomass removal and retention set to leave unmerchantable timber
3) Stands were thinned again once modelled growth exceeded an upper DFC BA threshold of 70 sq. ft.

Table 6: FVS Stand Inputs.

Stand Number	Forest Cover Type	# Plots	# Trees	Site Index Species	Site Index (ft) (Age = 50)	Acres
1	Bottomland Hardwood	86	1,251	Sweetgum	90	232
2	Open Pine	48	510	Loblolly pine	84	141
3	Mixed Pine-Hardwood (Grove North)	93	1,377	Loblolly pine	84	237
4	Mixed Pine-Hardwood (Grove SW)	38	583	Loblolly pine	108	98
5	Mixed Pine-Hardwood (Grove SE)	159	2,554	Loblolly pine	108	413
					Total:	**1,121**

Table 7: Management prescription input in FVS model

Order	Action	Condition	Result
1	Thinning	Thin from below	BA reduction • 50 sq. ft./ac for bottomland hw • 40 sq. ft./ac for open pine and mixed pine-hardwood
2	Biomass Removal and Retention	Manage logging slash	Only unmerchantable material left
3	Thinning	Thin from below once BA exceeds 70 sq. ft./ac for all cover types	BA reduction again to first thinning BA level

FVS projected stand growth to year 2120 and reported changes in inventory metrics such as basal area and trees per acre. The FFE model produced Stand Carbon Reports and Harvested Products Reports for each stand. Total stand carbon and basal area were compared for Natural and Management runs of each stand to determine management effects on carbon stocks. Harvested Products Reports were created for each stand Management run and were used alongside stand carbon and basal area comparisons to determine recommendations for Refuge forest management.

Results

In both inventoried units, the majority of cruise points exceeded DFC metrics. In the Grove Unit, 449 plots were established and 431 plots were actually sampled. In the Bonny Hall Unit, 142 plots were established and 134 were actually sampled. Omitted plots were inaccessible due to wet conditions or thick underbrush and were in areas where active forest management is not desired or feasible.

Forest Inventory - Volume Summaries

Forest inventory volume analyses were completed separately for the Grove and Bonny Hall units using TCruise software (Appendix C). Volume statistics per acre average at a 90% Confidence Interval were as follows:

Table 8: Per Acre Volume Estimates

	Grove Unit	**Bonny Hall Unit**
Trees Per Acre	121.5	139
Basal Area (sq. ft.)/Ac	142.9	140.7
Pulpwood Tons/ac	19.2	22.7
Sawtimber Tons/ac	103.6	99.6
Total Tons/ac	122.9	122.3
Sawtimber (Doyle) MBF	13.8	13.0

Grove Unit

In the Grove Unit, loblolly pine was the most abundant species, followed by sweetgum, spruce pine, and water oak. These species account for 56% of all trees inventoried in the Grove Unit. Pines comprised 52% of total inventoried trees while oaks comprised 26%. Total timber volume was 137,712.8 tons with pulpwood comprising 15.7% of the volume and sawtimber comprising 84.3% of the volume.

Bonny Hall Unit

Loblolly pine was again the most abundant species in Bonny Hall, followed by sweetgum, black oak, and willow oak. These species account for 81% of all trees inventoried in the Bonny Hall Unit. Pines comprised 44% of total inventoried trees while oaks comprised 31%.

Forest Inventory - Habitat Conditions Relative to DFCs

Primary Habitat Variables

Basal Area

Basal area averaged 142.9 sq. ft./acre in the Grove Unit with nearly 80% of sample points showing a BA greater than or equal to 90 sq. ft./acre. Among the plots, 12% had a BA below 60 sq. ft./acre. Bottomland hardwood areas showed 20.9% of plots within or near DFC, while Open Pine areas showed 29% (Table 8, Figure D.1). Mixed pine-hardwood areas deviated most from desired conditions, with only 7.9% of plots within or near DFC and 89.3% above DFC.

In the Bonny Hall Unit, basal area averaged 140.7 sq. ft./acre with 77% of sample points showing a BA greater than or equal to 90 sq. ft./acre. Of the plots, 5% had a BA below 60 sq. ft./acre (Table 8, Figure E.1). Bottomland hardwood areas showed 10.5% of plots within or near DFC, while Open Pine areas showed 25%. Mixed pine-hardwood areas also deviated most from desired conditions in this Unit, with 13.6% of plots within or near DFC and 85.4% above DFC.

Canopy Cover

All forest cover types showed canopy covers that were majority within desired conditions.
In the Grove Unit, mixed pine-hardwood areas were most within or near desired canopy metrics (92.4%) followed by bottomland hardwood (81.4%) and open pine (72.7%) (Table 9, Figure D.2). In the Bonny Hall Unit, bottomland hardwood was most within canopy desired conditions (89.5%) followed by open pine (83.3%) and mixed pine-hardwood (68%) (Table 9, Figure E.2).

Midstory Cover

In the Grove Unit, the majority of bottomland hardwood plots were above DFC for midstory cover (66.3%), with 24.4% within DFC (Table 16, Figure 12). Among the open pine plots, 52.7% were within DFC (Table 10, Figure D.3). In the Bonny Hall Unit, 52.6% of bottomland hardwood and 50% of open pine plots were within midstory cover DFC (Table 10, Figure E.3). Midstory cover was not used as a DFC for mixed pine-hardwood as management actions for these areas will vary greatly.

Secondary Habitat Variables

Although secondary habitat variables were not included as primary DFC, they remain important components of wildlife habitat. These variables offer a snapshot of stand conditions and assist in the Refuge's active management decisions. Positive indicators of suitable wildlife habitat, including cavities, canebrakes, snags, and down wood were well-represented in inventory results. Of the vegetative ground cover, 94% of plots contained woody cover, which may be managed to include more grass and forb components using prescribed fire management and silviculture tools to reduce woody cover. Invasive species were present in more than half of inventoried plots and are an issue the Refuge is presently aware of.

Understory Cover

Understory cover was ocularly estimated and categorized as 'low density' in areas with <25% shrubs, 'moderate density' in areas with 25-60% shrubs, and 'high density' in areas with >60% shrubs. In the Grove Unit, 17% (72 plots) of the area had low shrub density, 42% (182 plots) had moderate shrub density, and 41% (178 plots) had high shrub density (Figure D.4). In the Bonny Hall Unit, 20% of the area had low shrub density, 26% had moderate shrub density, and 54% had high shrub density (Figure E.4).

Groundcover

Although groundcover is not one of the primary DFC, it remains an important component of wildlife habitat, providing forage and cover for many species. Groundcover varies seasonally and is significantly impacted by flooding in bottomland hardwood forests. Vegetative groundcover was abundant in the Grove Unit, with 245 plots (57%) containing 50% or more vegetative cover and with 8 plots (2%) recorded with no vegetative cover (Figure D.5). In the Bonny Hall Unit, 64 plots (48%) contained 50% or more vegetive cover and 4 plots (3%) containing no vegetative cover (Figure E.5). Collectively among both Units, vegetative groundcover comprised 94% woody vegetation, 79% grass, 45% forbs, and 23% ferns.

Cavities

Cavities serve as a positive indicator of wildlife habitat for many cavity-nesting bird species and potential predators such as raccoons, opossums, and snakes (Sharpe, 2010). Cavities were recorded as the presence or absence of small (<4" opening), medium (4"-10" opening), and large (>10" opening) cavities within the plot. Cavities were recorded within 90% of all plots (90% within Grove and 89% within Bonny Hall).

Canebrakes

Canebrakes (*Arundinaria gigantia*) were once abundant across the Southeastern landscape and have declined due to agricultural land clearing, altered burn regimes, and changing floodplain hydrology (Brantley & Platt, 2001). We ranked cane presence as the following: none = 0%, sparce = <25%, moderate = 25-50%, and abundant >50%. Cane was recorded in 41% of all plots (39% within Grove and 50% within Bonny Hall).

Down Woody Debris

Down woody debris is an important component of wildlife habitat, providing cover, nesting sites, and nutrient recycling by way of decomposition. Woody debris was recorded as the presence or absence of large down wood (≥10" in diameter and 10' in length), or equivalent biomass. Down woody debris was observed in 78% of all plots (77% within Grove and 79% within Bonny Hall).

Snags

Snags, or standing dead trees, also serve as an important component of wildlife habitat and usually contain many cavities and den-sites for birds, mammals, and reptiles. These were recorded as the number of standing dead trees with a DBH of ≥12" for large snags and 4" - < 12" for small snags. Large snags tend to have greater longevity and provide abundant habitat while small snags are more ephemeral, lasting for a shorter duration. Snags were abundant across the sampled units and were present in 81% of all plots (77% within Grove and 96% within Bonny Hall). The Grove Unit had 893 large and 1,101 small snags and the Bonny Hall Unit had 179 large snags and 284 small snags.

Invasive Species

Chinese tallow (*Triadica sebifera*) was the most abundant invasive, found in 43% of Grove Unit plots and 80% of Bonny Hall Unit plots (Figures D.6 & E.6). Across both units, invasive species were found in 54% of all plots.

Table 8: ACE Basin Inventory Basal Area by Unit Forest Cover Type

Grove Unit							
Forest Cover Type	**Total Plots**	**# Plots with BA<50**	**% below DFC**	**# Plots with BA 50-80**	**% in (or near) DFC**	**# Plots with BA>80**	**% above DFC**
Bottomland Hardwood	86	1	1.2%	18	20.9%	67	77.9%
	Total Plots	**# Plots with BA<20**	**% below DFC**	**# Plots with BA 20-90**	**% in (or near) DFC**	**# Plots with BA>90**	**% above DFC**
Open Pine	55	11	20.0%	16	29%	28	50.9%
	Total Plots	**# Plots with BA<40**	**% below DFC**	**# Plots with BA 40-70**	**% in (or near) DFC**	**# Plots with BA>70**	**% above DFC**
Pine-Hardwood	290	8	2.8%	23	7.9%	259	89.3%
Bonny Hall Unit							
Forest Cover Type	**Total Plots**	**# Plots with BA<50**	**% below DFC**	**# Plots with BA 50-80**	**% in (or near) DFC**	**# Plots with BA>80**	**% above DFC**
Bottomland Hardwood	19	1	5.3%	2	10.5%	16	84.2%
	Total Plots	**# Plots with BA<20**	**% below DFC**	**# Plots with BA 20-90**	**% in (or near) DFC**	**# Plots with BA>90**	**% above DFC**
Open Pine	12	0	0%	3	25.0%	9	75.0%
	Total Plots	**# Plots with BA<40**	**% below DFC**	**# Plots with BA 40-70**	**% in (or near) DFC**	**# Plots with BA>70**	**% above DFC**
Pine-Hardwood	103	1	0.97%	14	13.6%	88	85.4%

Table 9: ACE Basin Inventory Canopy Cover by Forest Cover Type.

Grove Unit							
Forest Cover Type	**Total Plots**	**# Plots with <50% Canopy Cover**	**% below DFC**	**# Plots with 50-80% Canopy Cover**	**% in DFC**	**# Plots with >80% Canopy Cover**	**% above DFC**
Bottomland Hardwood	86	9	10.5%	70	81.4%	7	8.1%
	Total Plots	**# Plots with <20% Canopy Cover**	**% below DFC**	**# Plots with 20-75% Canopy Cover**	**% in DFC**	**# Plots with >75% Canopy Cover**	**% above DFC**
Open Pine	55	13	23.6%	40	72.7%	2	3.7%
	Total Plots	**# Plots with <30% Canopy Cover**	**% below DFC**	**# Plots with 30-70% Canopy Cover**	**% in DFC**	**# Plots with >70% Canopy Cover**	**% above DFC**
Pine-Hardwood	290	2	0.7%	268	92.4%	20	6.9%
Bonny Hall Unit							
Forest Cover Type	**Total Plots**	**# Plots with <50% Canopy Cover**	**% below DFC**	**# Plots with 50-80% Canopy Cover**	**% in DFC**	**# Plots with >80% Canopy Cover**	**% above DFC**
Bottomland Hardwood	19	2	10.5%	17	89.5%	0	0%
	Total Plots	**# Plots with <20% Canopy Cover**	**% below DFC**	**# Plots with 20-75% Canopy Cover**	**% in DFC**	**# Plots with >75% Canopy Cover**	**% above DFC**
Open Pine	12	0	0%	10	83.3%	2	16.7%
	Total Plots	**# Plots with <30% Canopy Cover**	**% below DFC**	**# Plots with 30-70% Canopy Cover**	**% in DFC**	**# Plots with >70% Canopy Cover**	**% above DFC**
Pine-Hardwood	103	0	0%	70	68.0%	33	32.0%

Table 10: ACE Basin Inventory Midstory Cover by Forest Cover Type. Midstory cover DFC metrics were not assessed for Mixed Pine-Hardwood cover types.

Grove Unit							
Forest Cover Type	**Total Plots**	**# Plots with <25% Midstory Cover**	**% below DFC**	**# Plots with 25-40% Midstory Cover**	**% in DFC**	**# Plots with >40% Midstory Cover**	**% above DFC**
Bottomland Hardwood	86	8	9.3%	21	24.4%	57	66.3%
	Total Plots			**# Plots with 0-30% Midstory Cover**	**% in DFC**	**# Plots with >30% Midstory Cover**	**% above DFC**
Open Pine	55	0	0%	29	52.7%	26	47.3%
Bonny Hall Unit							
Forest Cover Type	**Total Plots**	**# Plots with <25% Midstory Cover**	**% below DFC**	**# Plots with 25-40% Midstory Cover**	**% in DFC**	**# Plots with >40% Midstory Cover**	**% above DFC**
Bottomland Hardwood	19	2	10.5%	10	52.6%	7	36.8%
	Total Plots			**# Plots with 0-30% Midstory Cover**	**% in DFC**	**# Plots with >30% Midstory Cover**	**% above DFC**
Open Pine	12	0	0%	6	50%	6	50%

FVS-Carbon Analysis

Stand carbon stocks varied among management scenarios and forest cover types. All cover type stands were initially thinned in 2021 to the lower basal area range (50 sq. ft./ac for bottomland hardwood and 40 f sq. ft./ac for open pine and mixed pine-hardwood). The stands were thinned again once growth exceeded the upper basal area range (70 sq. ft./ac for all cover types). Resulting thinning cycles for each stand are summarized in Table 11.

Total stand carbon peaked at 119 tons per acre for the Natural run of mixed pine-hardwood, Grove SE stand in year 2066 (Figure 7). For the Management run, total stand carbon peaked at 45 tons per acre for mixed pine-hardwood, Grove SW in year 2021 following the initial thinning. In mixed-pine hardwood stands, total stand carbon tended to decline incrementally after the initial thinning and began to increase around 30 years later (Figure 7).

Average total stand carbon across all stands was 98.7 tons/acre for the Natural run and 34.5 ton/acre for the Management Run. When converted to metric tons C per hectare, this amounts to 221.3 and 77.3, respectively, compared to the FWS average of 163.7 metric tons per hectare (Table 1; Smith, 2012).

Table 11: FVS Management Run Thinning Cycle Results (with Cycle Length in Years)

Stand Number	Forest Cover Type	2nd Thinning (Cycle Length)	3rd Thinning (Cycle Length)	4th Thinning (Cycle Length)
1	Bottomland Hardwood	2046 (25)	2071(25)	2096 (25)
2	Open Pine	2056 (35)	2096 (40)	none
3	Mixed Pine-Hardwood (Grove North)	2076 (55)	none	none
4	Mixed Pine-Hardwood (Grove SW)	2066 (45)	2111(45)	none
5	Mixed Pine-Hardwood (Grove SE)	2061(40)	2101 (40)	none

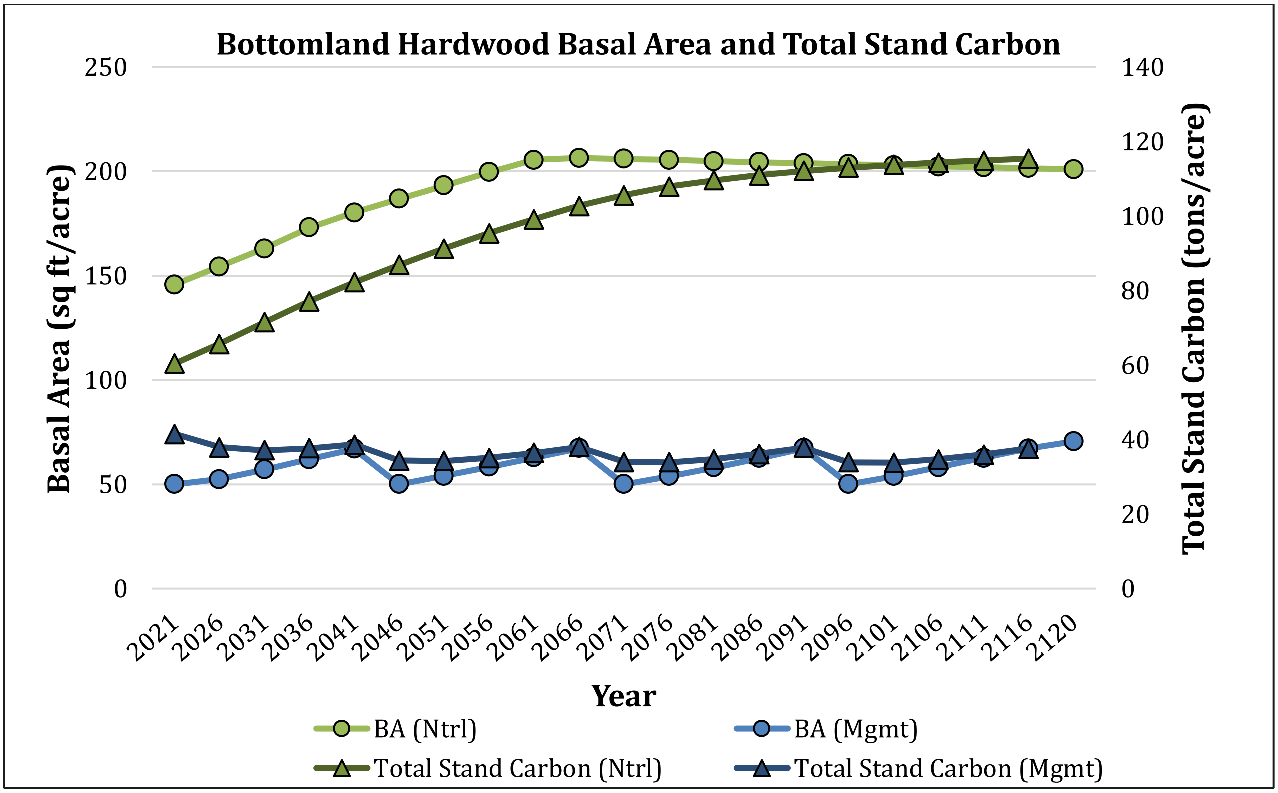


Figure 4: Bottomland hardwood basal area and total stand carbon. FVS projected total stand carbon for 95 years and basal area for 100 years.

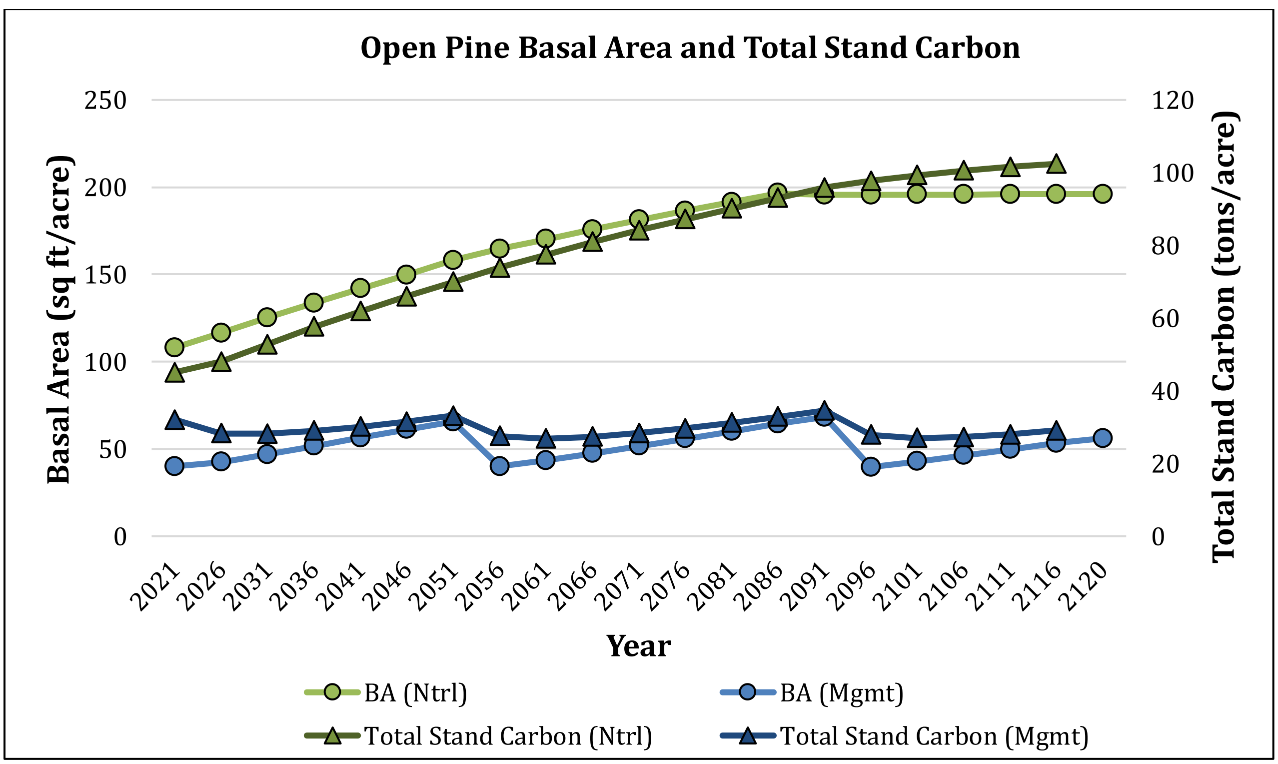


Figure 5: Open pine basal area and total stand carbon. FVS projects total stand carbon for 95 years and basal area for 100 years.

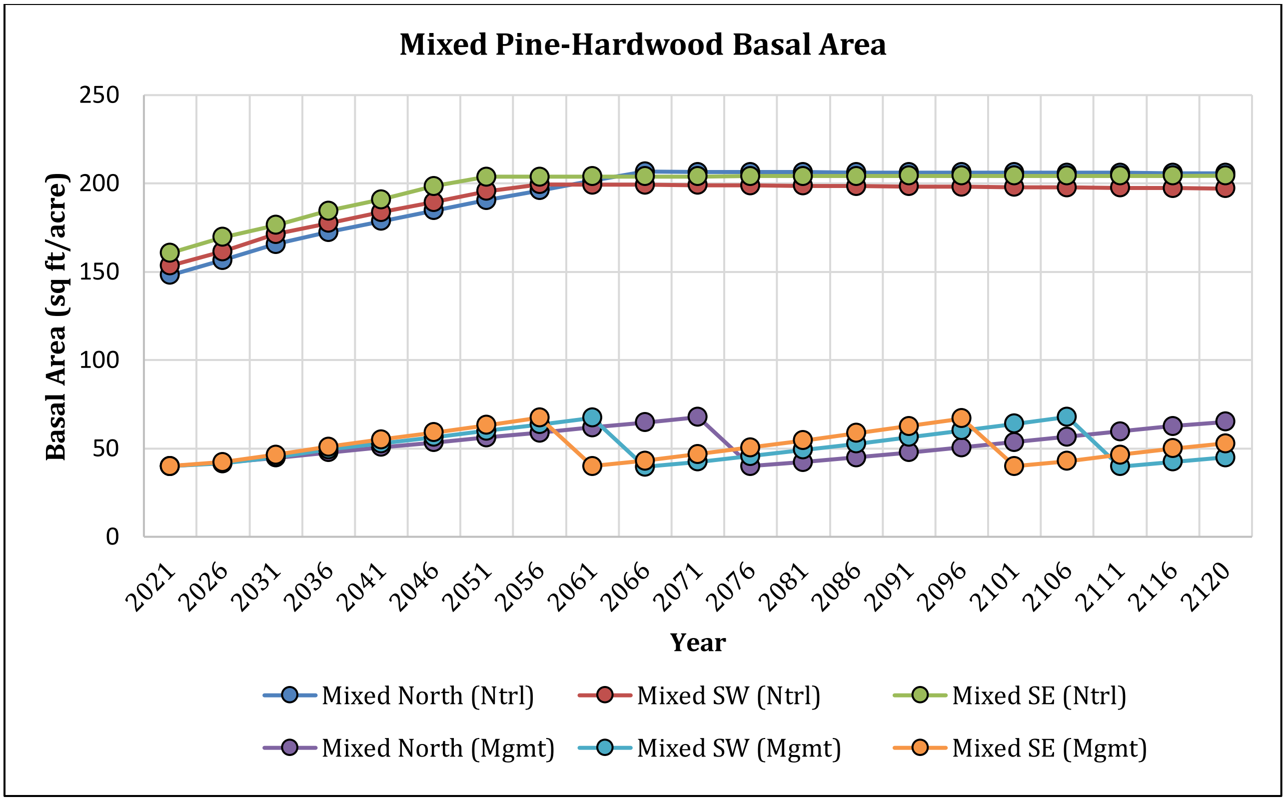


Figure 6: Mixed pine-hardwood basal area.

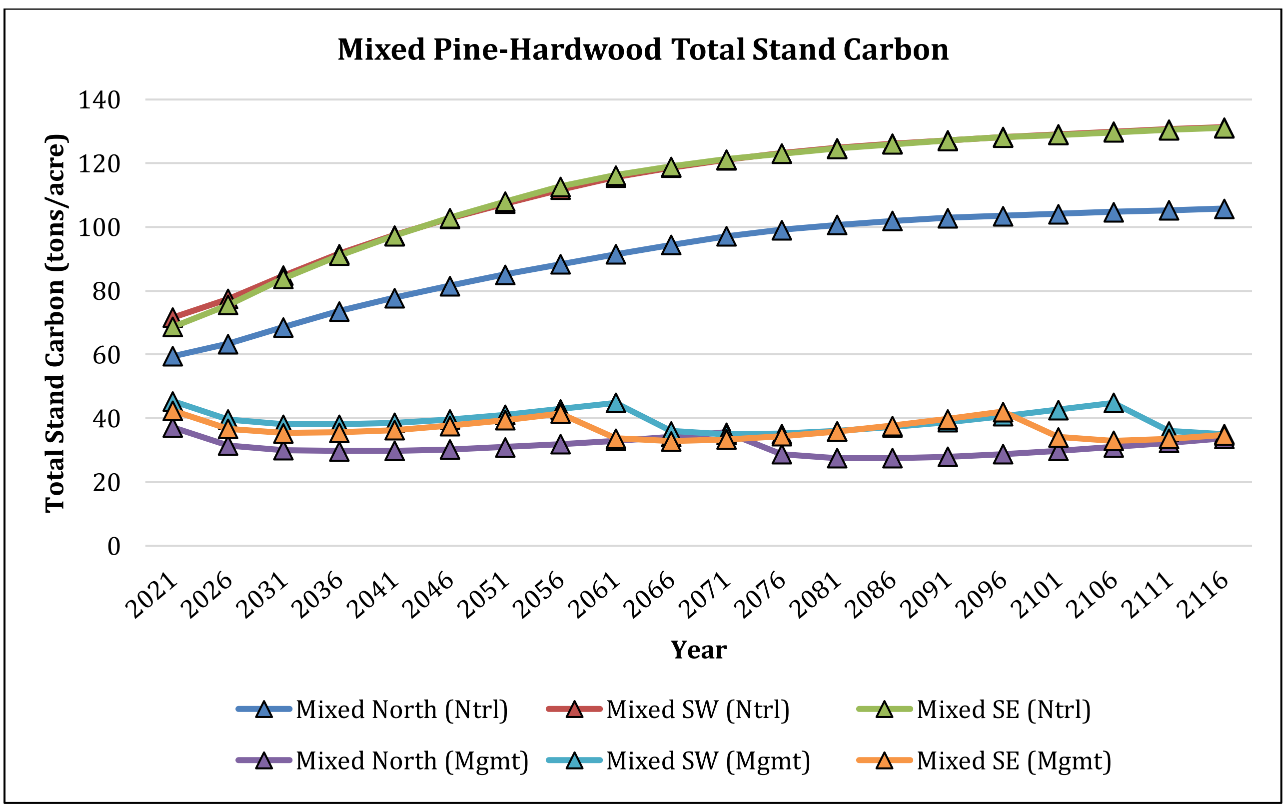


Figure 7: Mixed pine-hardwood total stand carbon.

Discussion

The findings of this forest inventory display that the majority of ACE Basin NWR forested habitat is well outside of desired forest conditions. A lack of active forest management, including silvicultural treatments and the use of prescribed fire, has allowed primary metrics including basal area, canopy cover, and midstory cover to exceed desired conditions. Multiple factors account for this lack of management, including understaffing on the Refuge and a lack of resources such as prescribed burns teams. Due to time constraints, inventory data was only collected for 2 of the 6 Refuge sub-units (Grove and Bonny Hall). However, based on these data and discussions with Refuge staff, the remaining units will likely display similar results outside of desired forest conditions.

Most plots require a basal area reduction upwards of 100 sq. ft./acre and may require multiple silvicultural treatments to approach DFCs. Despite high basal area metrics, most plots were within DFC for canopy cover. These ocular estimates, however, may be biased and inaccurate as high basal area measurements would imply corresponding high canopy coverage. Midstory cover DFC metrics were assessed for bottomland hardwood and open pine cover types and showed varying results, with some cover types within and others exceeding DFC. Like canopy cover, ocular estimates of midstory may be biased and better assessed with aerial imagery. If assumed to be consistent with basal area metrics canopy and midstory cover plot measurements are likely majority above DFC. Based on present midstory cover measurements, most plots may require reductions upwards of 50-60%.

Current forest conditions display the prevalence of hard edges among the three forest cover types described. Hard edges are not ideal for wildlife as they create abrupt transitions among habitat types (Sharpe, 2010). Refuge managers should seek to include edge feathering in their silvicultural techniques, which provides gradual transition zones between cover types and enable movement, shelter, and habitat diversity (American Forest Foundation et al. 2020). Thinning methods may include creating three zones with progressively decreased thinning from the edge area into the forest (American Forest Foundation et al. 2020).

Limited prescribed fire on the Refuge has allowed dense understory and midstory growth in many stands, inhibiting herbaceous groundcover development. This was evident based on observations of abundant woody groundcover vegetation and scarcity of more desirable grasses and forbs. The extremely high basal areas observed in bottomland hardwood and mixed pine-hardwood areas indicate that thinning and routine prescribed burning of these stands will help promote open understory conditions suitable for wildlife habitat. Active management may not be feasible in bottomland hardwood stands, however, as these areas are generally inaccessible for thinning and burning due to seasonal inundation and sloping terrain. Additionally, bottomland hardwood species produce little timber value and are not economically preferred for management activities (American Forest Foundation et al. 2020). Many areas identified as open pine are currently open fields with ongoing or planned longleaf pine regeneration. This accounts for the low values of basal area, canopy cover, and midstory observed in this cover type. Mixed pine-hardwood areas will likely be managed as open-woodland systems, similar in openness to upland pine systems but with mixed composition.

Refuge Carbon Stocks

The FVS carbon stock analysis highlighted that reducing basal area also greatly reduces stand carbon stocks at the tradeoff of managing for suitable wildlife habitat. As the Refuge embarks on achieving DFC metrics, certain carbon-friendly practices may be implemented in management decisions to mitigate or lessen these losses. The 2009 Refuge CCP outlines 18 goals and objectives for a 15-year timeframe, with the final Goal #18 specifically addressing carbon sequestration efforts. Objective 18B outlines a goal to "seek to make the refuge have a carbon-neutral footprint" with a strategy to "seek partnerships to restore forest communities (replant longleaf forests) on the refuge and within the ACE Basin Project Area" (Purcell 2009, p. 79). Reducing carbon losses thus holds co-benefits for meeting Refuge CCP priorities as well as contributing to climate change mitigation.

Lengthening thinning cycles is a primary method the Refuge may employ to delay carbon losses and increase sequestration. Thinning from below, which includes thinning small diameter trees first and was specified in the model's Management run, has been shown to produce greater volume and carbon sequestration rates (Hoover and Stout, 2007). Forest cover types varied in their cutting cycle length, with bottomland hardwood having the shortest at 25 years and mixed pine-hardwood (Grove North) with the longest at 55 years. Mixed pine-hardwood areas will likely see the greatest carbon stock losses as the dominant forest cover type with the most plots above basal area DFC. Based on FVS results, these areas also had the longest thinning cycles among Grove North, Southwest, and Southeast stands, which may positively benefit carbon stock maintenance in the long-term. Given that bottomland hardwood sites are likely to remain unmanaged, these areas will retain the high carbon stocks observed in the Natural Run. Open pine areas may see additive carbon benefits over the long-term due to longleaf pine regeneration and reforestation efforts.

When incorporating carbon objectives and strategies in CCP/HMP documents, the Refuge may consult practitioner guides such as the *Forest Carbon Menu of Adaptation and Mitigation Strategies and Approaches* (Ontl et al. 2020). This menu, created by the Climate Change Response Framework (CCRF), provides decision-support tools for managers to maintain or enhance their forest carbon. Five NWRs (Crab Orchard, Big Oaks, National Tallgrass Prairie, Patoka River, and Cypress Creek) have already partnered with CCRF to incorporate carbon and climate change considerations in their CCPs. ACE Basin NWR should recognize the co-benefits of climate adaptation and forest management strategies in future habitat management plans. These include current and planned aforementioned strategies such as reforestation, restoring fire in fire-adapted forests, and thinning to reduce risk of tree mortality, wildfire, and pest outbreaks.

Limitations

There were numerous limitations to this project's forest inventory and carbon stock analysis. Four Refuge sub-units were not inventoried due to time and labor constraints. Future forest inventories of these remaining units will provide a more comprehensive picture of Refuge conditions and management needs. Ocular estimates of multiple inventory variables, notably canopy and midstory cover, were likely underestimated as previously mentioned. Further analyses using remotely sensed imagery may provide more accurate canopy cover estimates.

The FVS-Carbon analysis revealed the baseline effects of managing for desired basal area, however, it did not account for changes in carbon stocks due to prescribed burning, natural regeneration, or site preparation. Mixed-pine hardwood and open pines areas will likely require prescribed burning to achieve DFC metrics and will thus see differing stand carbon stocks than those reported. Many inventory variables were also excluded from the FVS model, including snags, canopy, midstory cover, fusiform rust, and ground cover. The FVS input file either lacked parameters for these variables or the model automatically assumed the variables based on other inputs. Finally, tree growth estimates were not calibrated with local diameter and growth measurements, but instead represent regional averages for species growth rates. Cutting cycle lengths presented by the model should therefore be interpreted with these caveats and uncertainties in mind. Localized measurements and estimates of regeneration will further improve model accuracy in predicting carbon stocks.

Conclusion

The inventory results outlined in this project reveal that active forest management is needed on most ACE Basin NWR stands to improve forest conditions. Refuge managers should strive to incorporate a variety of silvicultural treatments to improve forest structure and composition and mimic historic landscape disturbances. These will include thinning and prescribed fire to reduce basal area and promote habitat variation, alongside continuing longleaf pine restoration efforts. Mixed pine-hardwood areas should be prioritized for management as these stands comprise the largest Refuge forest area and were majority outside of DFC metrics. Refuge managers should recognize the costs of inactive management as failure to improve forest conditions often result in lengthy and more costly restorations in the future.

Carbon stock analyses in FVS showed the degree to which carbon will be lost amidst thinning to reduce basal area. The FVS model predicted thinning cycles for each forest cover type; however, not all inventory variables were accounted for, and managers should adjust thinning cycles based upon on-the-ground conditions. Ultimately, Refuge managers should strike a balance between achieving DFCs and maintaining carbon stocks. Using an adaptive management approach and consistently reassessing stand responses to silvicultural treatments will serve to meet both goals.

The forest habitat conditions detailed here are not unique to ACE Basin NWR, but are indicative of broad-scale forest management deficiencies across the NWRS. These deficiencies are due to multiple factors including a lack of recruitment and retention of trained FWS foresters to advise on forest management and a lack of resources such as prescribed burn teams. Together, these factors contribute to the poor forest habitat conditions reflected in this inventory and presumably across many other refuges. NWRS should prioritize active forest management and allocate additional resources to achieve desired forest conditions and continue supporting resources of concern. Global climate change threatens to greatly alter forest ecosystems, affecting species composition and management windows. Adaptation and carbon sequestration strategies should be integrated into Refuge planning documents to prepare for these changing effects on forests.

References

American Forest Foundation, Southern Forestry Consultants, South Carolina State Commission of Forestry. (2020). Landscape Management Plan, State of South Carolina. https://dc.statelibrary.sc.gov/handle/10827/35308

Atchafalaya National Wildlife Refuge. (2013). Forest Habitat Inventory Assessment. US Fish and Wildlife Service.

Brantley, C., & Platt, S. (2001). Canebrake Conservation in the Southeastern United States. *Wildlife Society Bulletin* (1973-2006), 29(4), 1175-1181. Retrieved September 7, 2021, from http://www.jstor.org/stable/3784141

Dixon, G. E. (2002). *Essential FVS: A user's guide to the Forest Vegetation Simulator* (Tech.). Ft. Collins, CO: US Forest Service.

Foster, D., Swanson, F., Aber, J., Burke, I., Brokaw, N., Tilman, D. and Knapp, A. (2003). The importance of land-use legacies to ecology and conservation. BioScience, 53(1), pp.77-88.

Habitat Management Plan for Ernest F. Hollings ACE Basin National Wildlife Refuge. (2014). US Fish and Wildlife Service. https://www.fws.gov/uploadedFiles/ACE%20BASIN%20NWR%20HMP.pdf

Hoover, Coeli; Stout, Susan. (2007). The carbon consequences of thinning techniques: stand structure makes a difference. Journal of Forestry. July/August: 266-270.

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. (2003). National-scale biomass estimators for United States tree species. For Sci. 49:12-35.

Kaarakka, L., Cornett, M., Domke, G., Ontl, T. and Dee, L.E., 2021. Improved forest management as a natural climate solution: A review. Ecological Solutions and Evidence, 2(3), p.e12090.

Keyser, C.E. (2008). Southern (SN) variant overview—Forest Vegetation Simulator. USDA For. Serv., Internal Rep., Forest Management Service Center, Fort Collins, CO.

Landmark Spatial Solutions LLC, Starkville, MS. TCruise [Forest Inventory software]. https://landmarkspatialsolutions.com/product/tcruise/

LMVJV Forest Resource Conservation Working Group. (2007). "Restoration, management, and monitoring of forest resources in the Mississippi Alluvial Valley: recommendations for enhancing wildlife habitat." Edited by R. Wilson, K. Ribbeck, S. King, and D. Twedt.

McIntyre, R.K., Conner, L.M., Jack, S.B., Schlimm, E.M. and Smith, L.L. (2019). Wildlife habitat condition in open pine woodlands: field data to refine management targets. Forest Ecology and Management, 437, pp.282-294.

Moomaw, W.R., Law, B.E. and Goetz, S.J. (2020). Focus on the role of forests and soils in meeting climate change mitigation goals: Summary. Environmental Research Letters, 15(4), p.045009.

Nordman, C., White, R., Wilson, R., Ware, C., Rideout, C., Pyne, M., & Hunter, C. (2016). Rapid Assessment Metrics to Enhance Wildlife Habitat and Biodiversity within Southern Open Pine Ecosystems.

Ontl, T.A., Janowiak, M.K., Swanston, C.W., Daley, J., Handler, S., Cornett, M., Hagenbuch, S., Handrick, C., McCarthy, L. and Patch, N. (2020). Forest management for carbon sequestration and climate adaptation. *Journal of Forestry*, *118*(1), pp.86-101.

Patton, D., Bergstrom, J.C., Moore, R. and Covich, A.P. (2015). Economic value of carbon storage in US National Wildlife Refuge wetland ecosystems. *Ecosystem Services*, *16*, pp.94-104.

Pile, L.S., Wang, G.G., Knapp, B.O., Walker, J.L. and Stambaugh, M.C. (2017). Chinese tallow (*Triadica sebifera*) invasion in maritime forests: The role of anthropogenic disturbance and its management implication. Forest ecology and management, 398, pp.10-24.

Purcell, M and Ernest F. Hollings Ace Basin National Wildlife Refuge. (2009). Ernest F. Hollings Ace Basin National Wildlife Refuge: Comprehensive Conservation Plan. https://ecos.fws.gov/ServCat/DownloadFile/8234

Rebain, S. A., Reinhardt, E. D., Crookston, N. L., Beukema, S. J., Kurz, W. A., Greenough, J. A., ... & Lutes, D. C. (2010). The fire and fuels extension to the forest vegetation simulator: updated model documentation. Revised June 2021. *USDA For. Serv. Int. Rep, 408*.

Sharpe, T. (2010). Tarheel wildlife-A guide for managing wildlife on private lands in North Carolilna. Raleigh, North Carolina: North Carolina Wildlife Resources Commission. https://www.ncwildlife.org/Portals/0/Hunting/Documents/Tarheel_Wildlife.pdf

Smith, G. March 8, 2012. "Forest Offset Projects on Federal Lands". Climate Action Reserve. Retrieved September 30, 2021 from https://www.climateactionreserve.org/wp-content/uploads/2011/02/Forest_Offset_Projects_on_Federal_Lands.pdf

Smith, J.E., L.S. Heath, K.E. Skog and R.A. Birdsey. (2006). Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. USDA, Forest Service, Northeastern Research Station, Newtown Square, PA. 216 pp.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online. Accessed October 29, 2021.

APPENDICES
Appendix A – Inventory Methods

Table A.1: Inventory Species List

PINES		HICKORY	
Loblolly Pine	*Pinus taeda*	Bitternut Hickory	*Carya cordiformis*
Longleaf Pine	*Pinus palustris*	Mockernut Hickory	*Carya tomentosa*
Pond Pine	*Pinus serotina*	Pecan	*Carya illinoinensis*
Shortleaf Pine	*Pinus echinata*	Pignut Hickory	*Carya glabra*
Slash Pine	*Pinus elliottii*	Water Hickory	*Carya aquatica*
Spruce Pine	*Pinus glabra*		
RED OAKS		**WHITE OAKS**	
Bluejack Oak	*Quercus incana*	Live Oak	*Quercus virginiana*
Blackjack Oak	*Quercus marilandica*	Overcup Oak	*Quercus lyrata*
Cherrybark Oak	*Quercus pagoda*	Post Oak	*Quercus stellata*
Laurel Oak	*Quercus laurifolia*	Swamp Chestnut Oak	*Quercus michauxii*
Shumard Oak	*Quercus shumardii*	White oak	*Quecus alba*
Southern Red Oak	*Quercus falcata*		
Turkey Oak	*Quercus laevis*		
Water Oak	*Quercus nigra*		
Willow Oak	*Quecus phellos*		
CYPRESS		**ASH**	
Pond Cypress	*Taxodium ascendens*	Green Ash	*Fraxinus pennsylvanica*
Bald Cypress	*Taxodium distichum*	Pumpkin Ash	*Fraxinus profunda*
ALL OTHER HARDWOODS			
American Holly	*Ilex opaca*	Loblolly Bay	*Gordonia lasianthus*
American Sycamore	*Platanus occidenatalis*	Red Bay	*Persia barbonia*

Beech	*Fagus grandifolia*	Red Bud	*Cercis canadensis*
Black Cherry	*Prunus serotina*	Red Maple	*Acer rubra*
Black Gum	*Nyssa sylvatica*	Sassafras	*Sassafras albidum*
Black Locust	*Robinia psuedoacacia*	Southern Catalpa	*Catalpa bignonioides*
Black Walnut	*Juglans nigra*	Southern Magnolia	*Magnolia grandiflora*
Box Elder	*Acer negundo*	Sumac	*Rhus spp*
Cabbage Palm	*Sabal palmetto*	Swamp Titi	*Cyrilla racemiflora*
Chinese Tallow	*Triadica sebifera*	Sweet Bay	*Magnolia virginiana*
Eastern Red Cedar	*Juniperus virginiana*	Sweet Gum	*Liquidambar styraciflua*
Flowering Dogwood	*Cornus florida*	Tulip Poplar	*Liriodendron tulipifera*
Hackberry	*Celtis laevigata*	Water Tupelo	*Nyssa aquatica*
Hawthorn	*Crataegus*	Willow	*Salix*
Hophornbeam	*Ostrya virginiana*	American Elm	*Ulmus americana*
Mulberry	*Morus*	Winged Elm	*Ulmus alata*
Musclewood	*Carpinus caroliniana*	Miscellaneous Hardwood	
Persimmon	*Diospyros virginiana*		

1/100th Acre Plot-Level Variables Definitions

Advanced Regeneration: Recorded as the presence or absence of advanced tree regeneration (>3' tall up to 5.5"dbh). This variable was only recorded for oaks or longleaf pines, of which a count was also recorded.

Ground Cover: The following 3 fields were recorded to the nearest 25th percentile for a total of 100%

- **Bareground Percent:** The amount of the 1/100th acre plot where bare ground (sand, soil) is near fully visible.

- **Leaf Litter Percent:** The amount of the 1/100th acre plot, expressed in percent, that is completely or nearly completely covered by leaf litter. Leaf litter comprises pine straw, twigs, cones, unidentified decaying organic debris dead leaves and small fallen branches (<4").

- **Vegetation Cover Percent:** The amount of the plot where vegetation is present and is comprised of the four vegetation types noted below. For each category below, vegetation cover was recorded to the nearest 25th percentile for a total of 100%:
    1. **Grass:** Estimated as the percent of the vegetation that is grass.
    2. **Forb:** Estimated as the percent of the vegetation that is forbs (includes flowering plants such as legumes, asters, etc.).
    3. **Woody:** Estimated as the percent of the vegetation that is woody (defined as small trees, bushes, poison oak, and woody vines less than 3 feet).
    4. **Fern:** Estimated as the percent of vegetation that is ferns.

1/10th Acre Plot-Level Variable Definitions

Understory Percent: Estimated as the percent (in 10% increments) of the plot that contains understory - defined as trees, shrubs and woody plants that are 3 to 10 feet in height. Loblolly, wax myrtle, and gallberry are some examples.

Understory Height: Estimated as the average height of the understory (in 3, 6, and 10-foot increments).

Midstory Percent: Estimated as the percent of the plot that contains midstory - defined as trees, shrubs and woody plants that are >10' tall, but below the main tree canopy. Loblolly, sweetgum, persimmon, dogwood, redbay are examples.

Midstory Height: Estimated as the average height of the midstory (in 10-foot increments).

Canopy Cover: An ocular estimate of the percent canopy cover in the plot area, recorded in 10% increments.

Vines: Recorded as the presence or absence of vines (e.g. poison ivy, muscadine, etc.).

Cane: Recorded as the presence or absence of cane in the plot (none = 0, sparce = <25%, moderate = 25-50%, abundant >50).

Wood Down: Recorded as the presence or absence of large down wood (≥10" in diameter and 10' in length), or equivalent biomass.

Large and Small Snags: Recorded as the number of standing dead trees with a DBH of ≥12" for large snags and 4" - < 12" for small snags. Despite these diameter limits, some exceptions were made (for example, if a snag is seen within plot with a DBH <4" and contains multiple cavities or seems to be providing a home for wildlife, it may be counted as a small snag).

Fusiform Count: Recorded as the count of pine trees that display fusiform rust.

Small, medium, and large cavities: Recorded as the presence or absence of small (<4" opening), medium (4"-10" opening), and large (>10" opening) cavities in trees within the plot.

Invasive Species: Recorded as the presence or absence of any invasive species in the plot. The presence of the following species was also recorded:

Chinaberry
Tallow
Tree of Heaven
Hog Rooting
Japanese Climbing Fern (not known to occur on site)
Chinese Privet (not known to occur on site)
Other

Tree-Level Variables collected with 10 Basal Area Factor Prism

Species: A drop down list of 64 tree species was provided (Appendix Table A.1).

Diameter at breast height (DBH): Measured to the nearest tenth of an inch.

Tree Height: Collected on two trees per plot, on the second and fifth trees so to avoid bias (or last if fewer than 5 trees in plot).

- **Sawlog Height:** the upper height of saw timber (to an 8" diameter) on the tree. Collected on trees 10 inches DBH and up.
- **Merchantable Height:** the height of merchantable timber (to 3" top). Collected on all trees.

Product: Trees are automatically assigned a “product” of timber – sawlog, chip-n-saw (for pines), palletwood (for hardwoods), pulpwood, or cull. If necessary, a tree can be downgraded or upgraded to different “product” specifications based on its characteristics. Pulpwood has minimum 6” DBH and max 26”, Chip-n-saw and Palletwood is 10-14” DBH and Sawlogs >=14”. Non-merchantable timber >= 6” DBH was recorded as product class Cull.

Canopy Class for each tree:

- Super emergent – towers over all surrounding trees
- Dominant – full sun from above and some from sides
- Codominant – full sun from above
- Intermediate – partial sun from above
- Suppressed – crown below main canopy

Appendix B – Site Index Soils Data

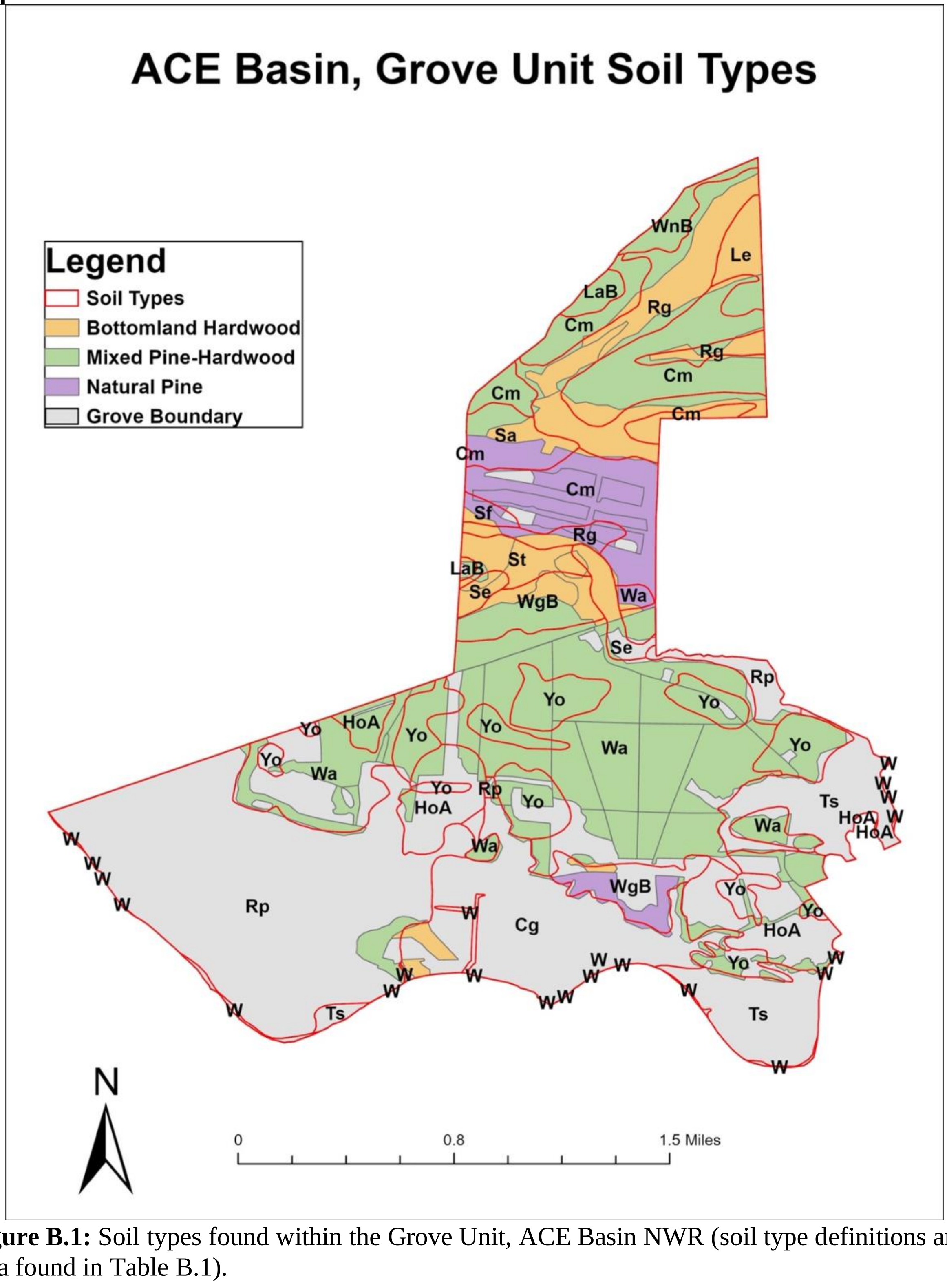


Figure B.1: Soil types found within the Grove Unit, ACE Basin NWR (soil type definitions and area found in Table B.1).

Table B.1: Soil type names and area corresponding with Figure B.1 and sourced from Web Soil Survey. Area of Interest (AOI) refers to Grove Unit, ACE Basin.

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
Cg	Capers silty clay loam	182.6	8.7%
Cm	Chipley loamy fine sand	235.8	11.2%
HoA	Hockley loamy fine sand, 0 to 2 percent slopes	128.0	6.1%
LaB	Lakeland sand, 0 to 6 percent slopes	11.9	0.6%
Le	Leon fine sand, 0 to 2 percent slopes	26.1	1.2%
Rg	Rutlege loamy fine sand	149.2	7.1%
Rp	Rutlege-Pamlico complex	434.2	20.7%
Sa	St. Johns fine sand	34.4	1.6%
Se	Santee loam	27.9	1.3%
Sf	Scranton loamy fine sand	7.8	0.4%
St	Stono fine sandy loam	26.7	1.3%
Ts	Tidal marsh, soft	146.6	7.0%
W	Water	9.8	0.5%
Wa	Wadmalaw fine sandy loam	415.8	19.8%
WgB	Wagram loamy fine sand, 0 to 6 percent slopes	80.9	3.9%
WnB	Wando loamy fine sand, 0 to 6 percent slopes	17.0	0.8%
Yo	Yonges loamy fine sand	165.6	7.9%
Totals for Area of Interest		**2,100.1**	**100.0%**

Appendix C – Inventory Volume Summaries

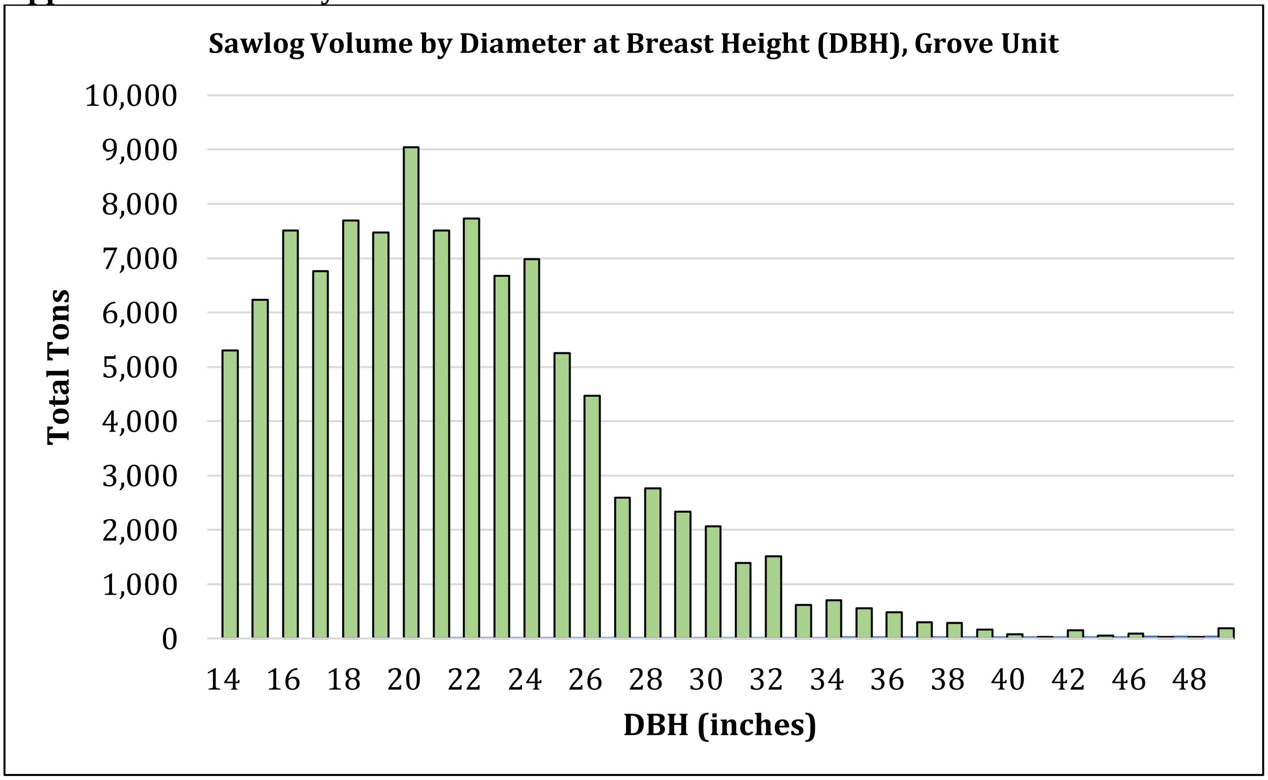


Figure C.1: Sawlog Volume by DBH, Grove Unit.

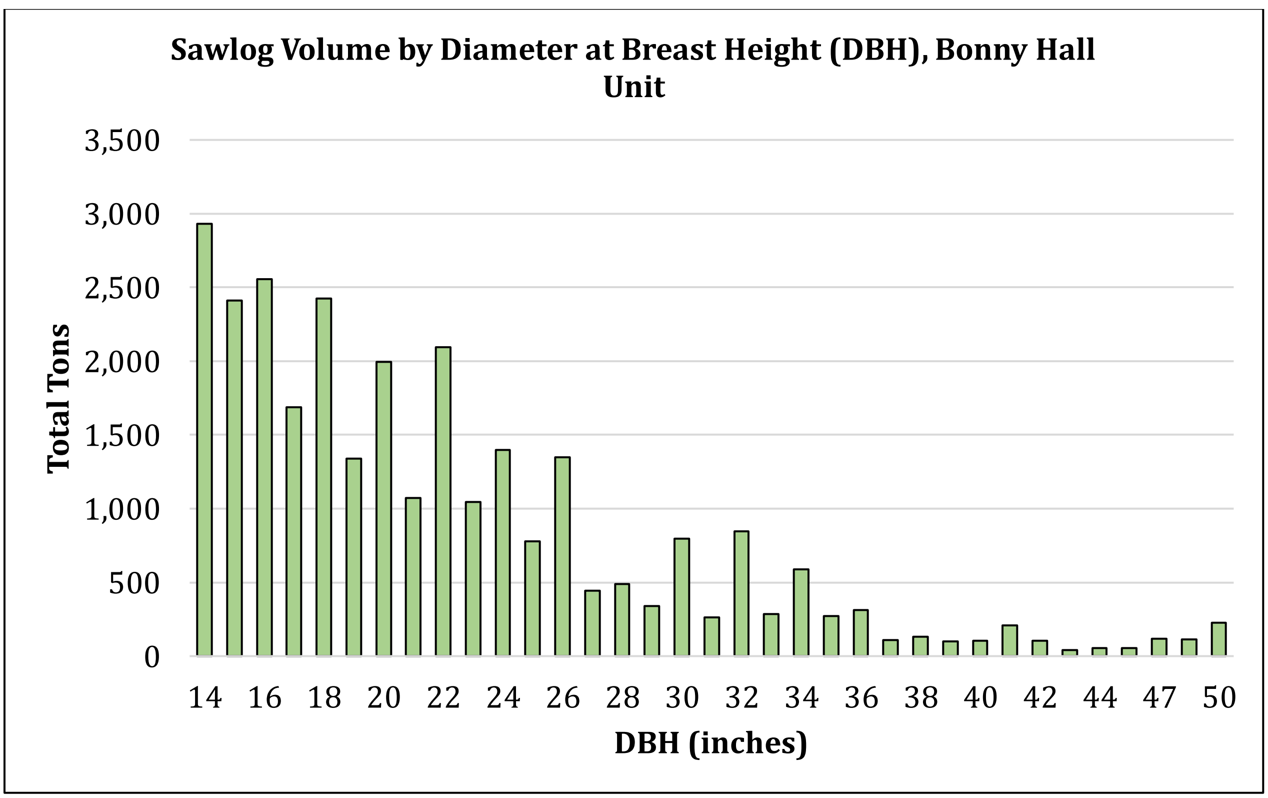


Figure C.2: Sawlog Volume by DBH, Bonny Hall Unit

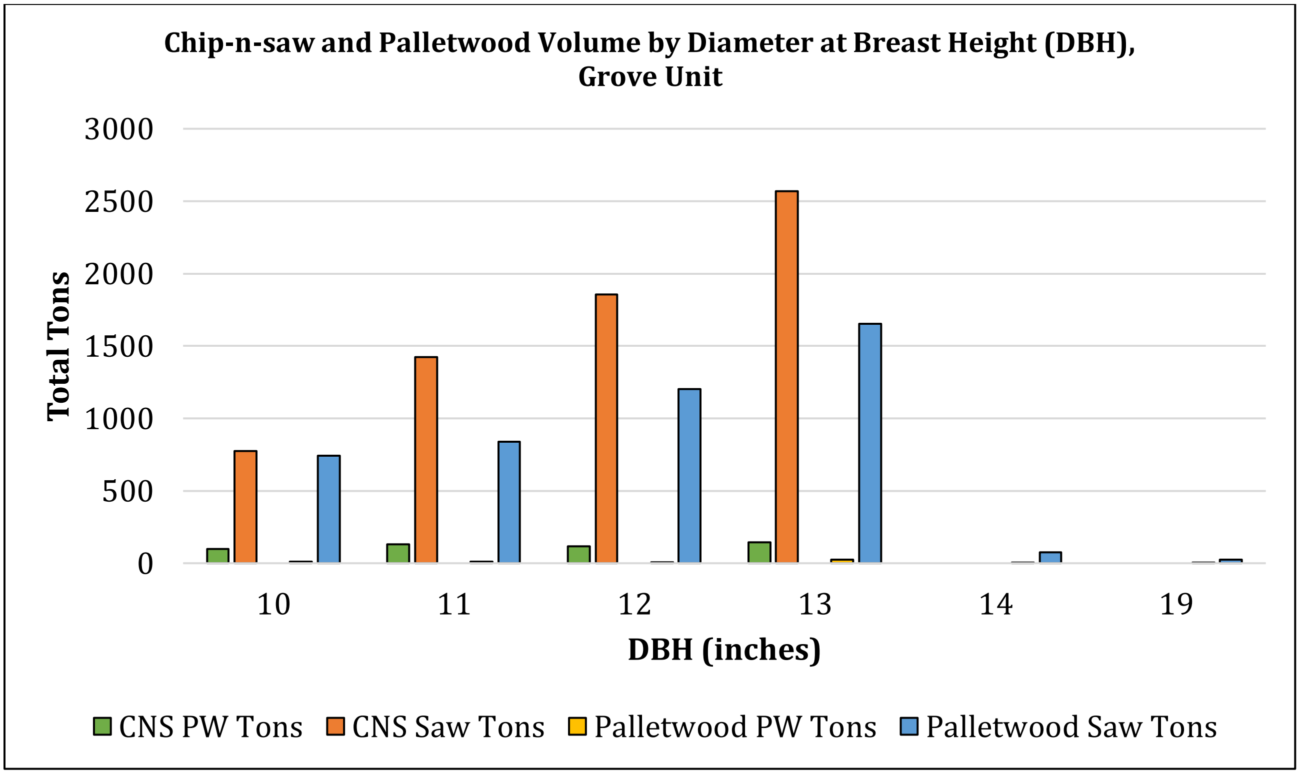


Figure C.3: Chip-n-saw and Palletwood Volume by DBH, Grove Unit.

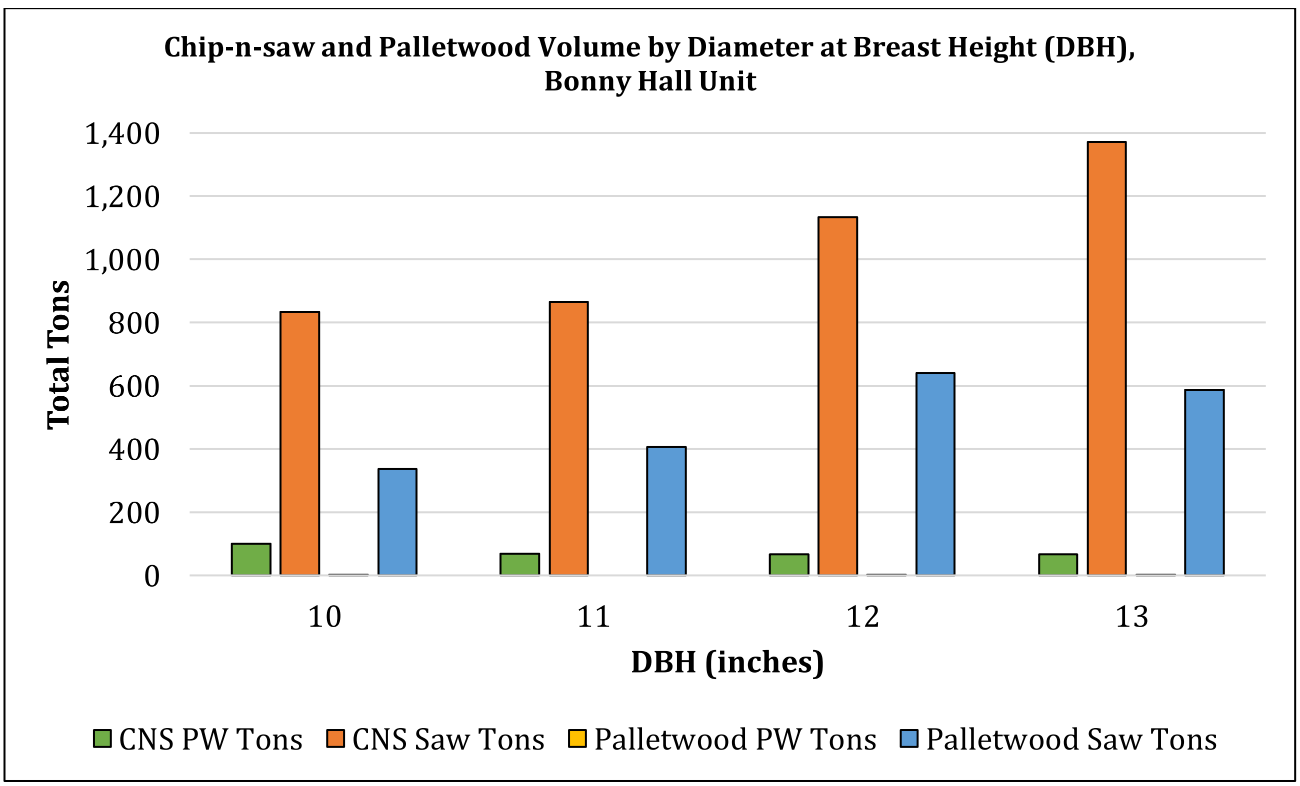


Figure C.4: Chip-n-saw and Palletwood Volume by DBH, Bonny Hall Unit.

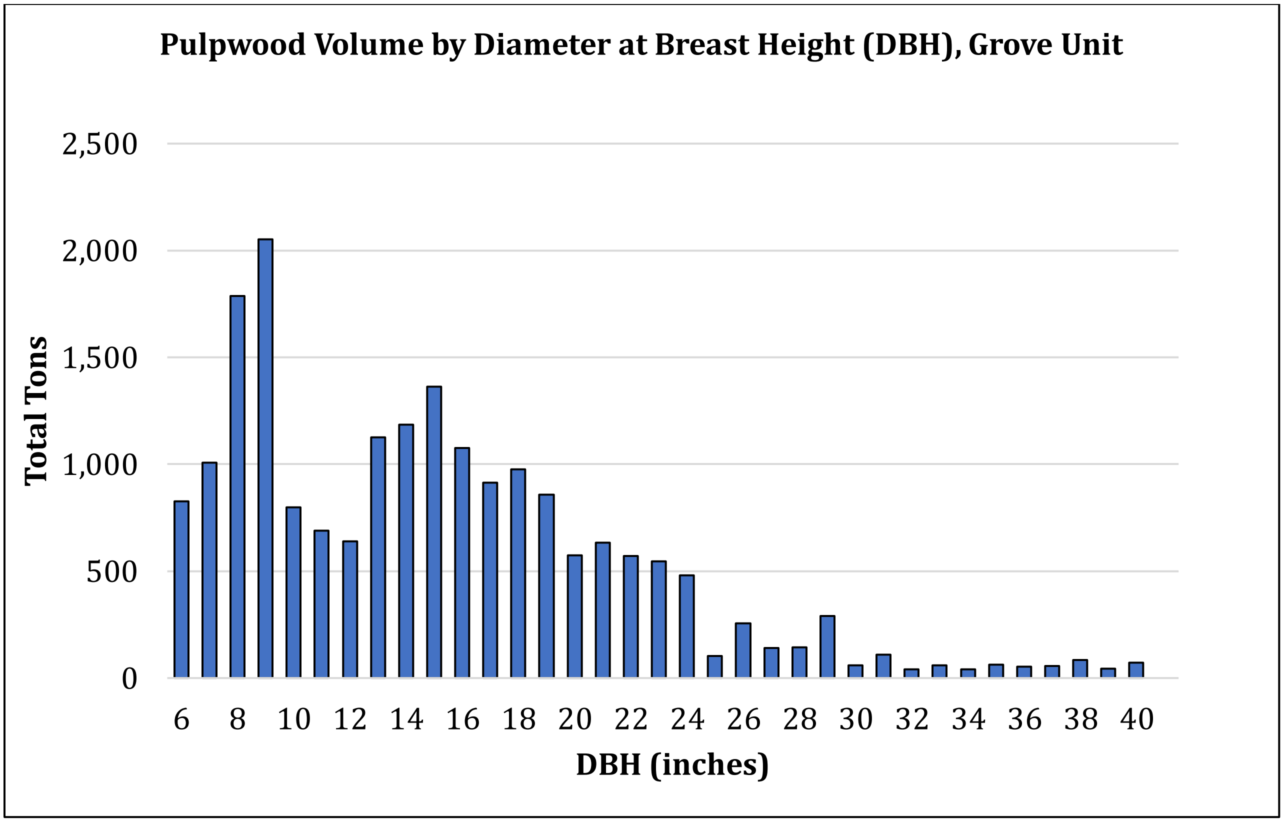


Figure C.5: Pulpwood Volume by DBH, Grove Unit.

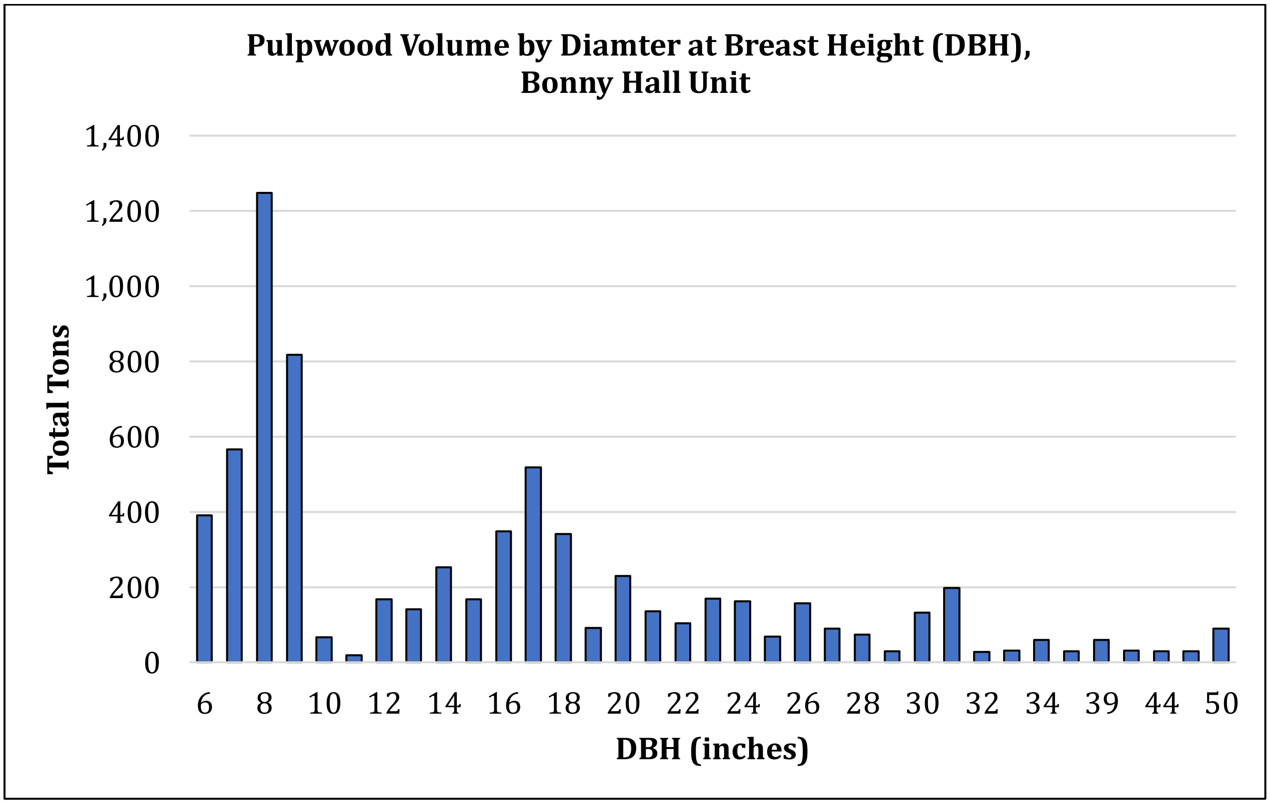


Figure C.6: Pulpwood Volume by DBH, Bonny Hall Unit.

Appendix D - Grove Unit Maps

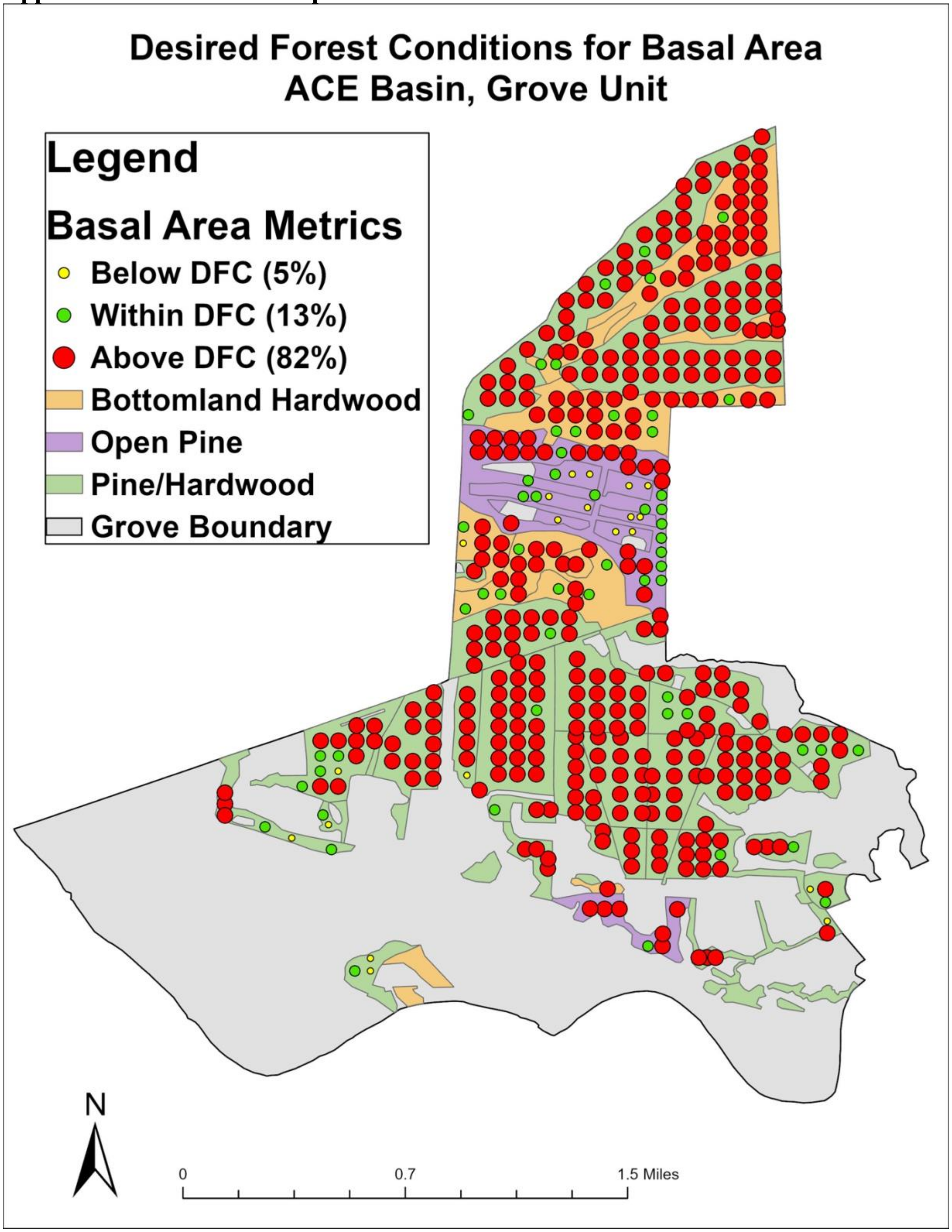


Figure D.1: Hotspot Map of Desired Forest Conditions for Basal Area, Grove Unit. Basal area units are sq. ft./acre.

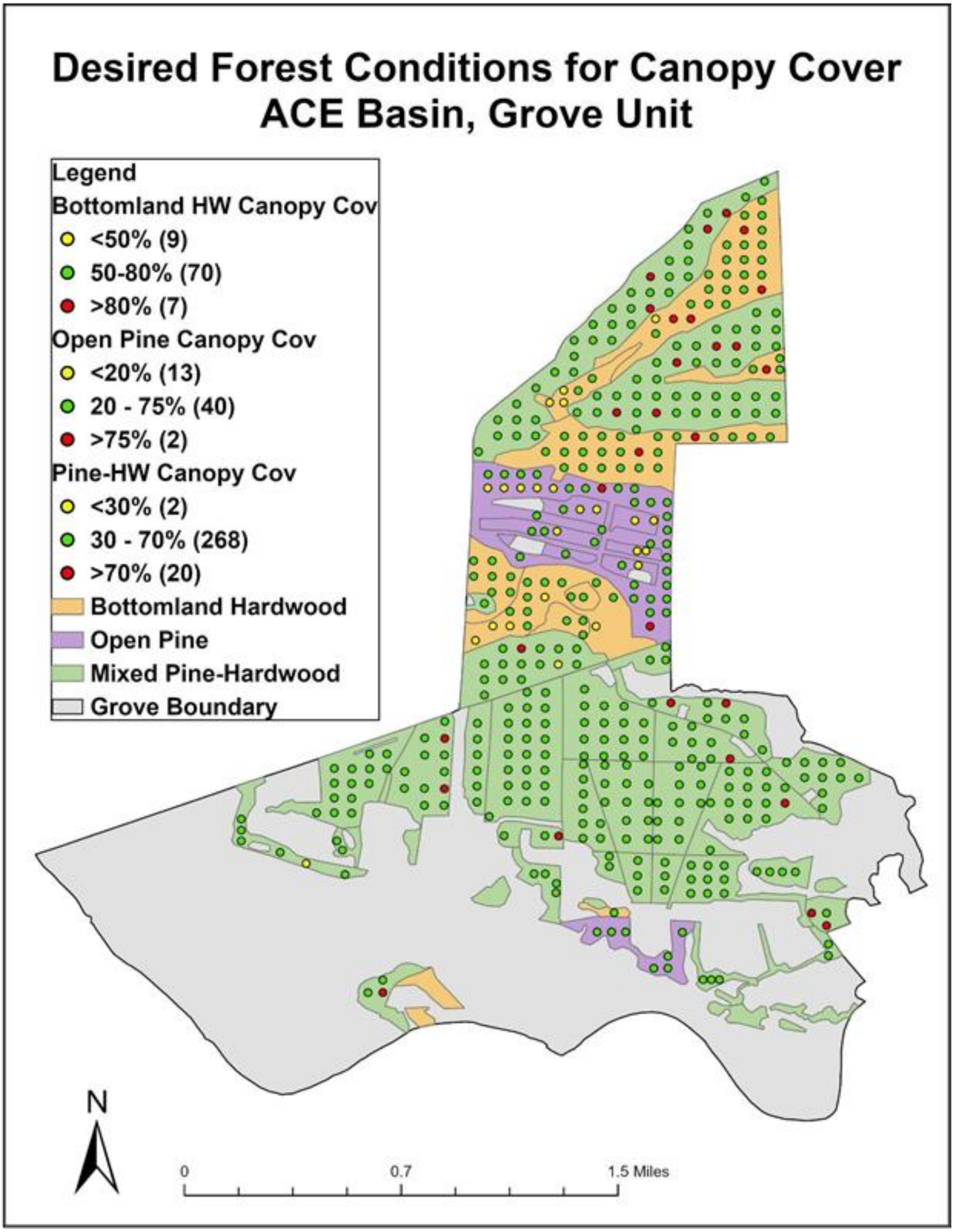


Figure D.2: Desired Forest Conditions for Canopy Cover, Grove Unit.

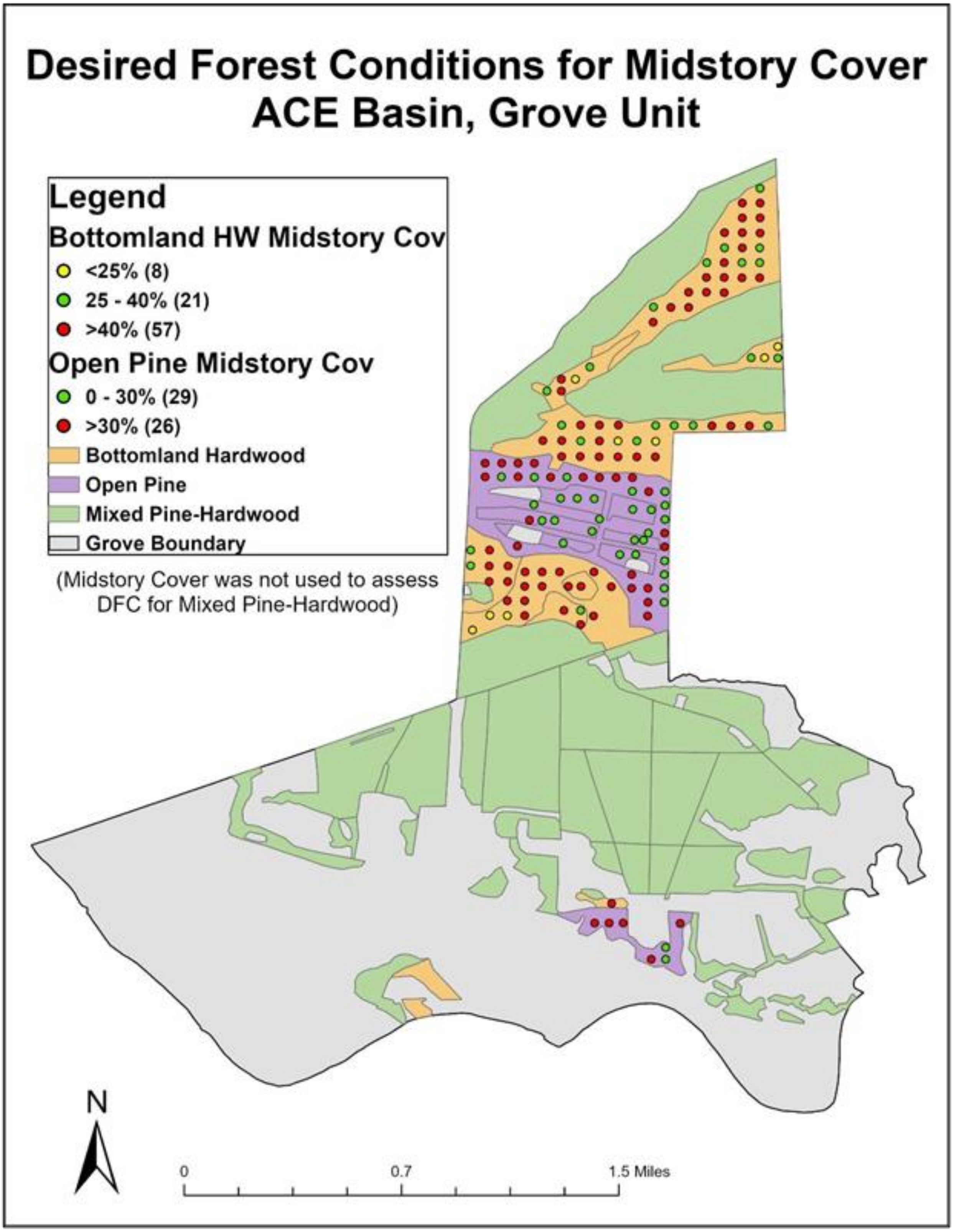


Figure D.3: Desired Forest Conditions for Midstory Cover, Grove Unit.

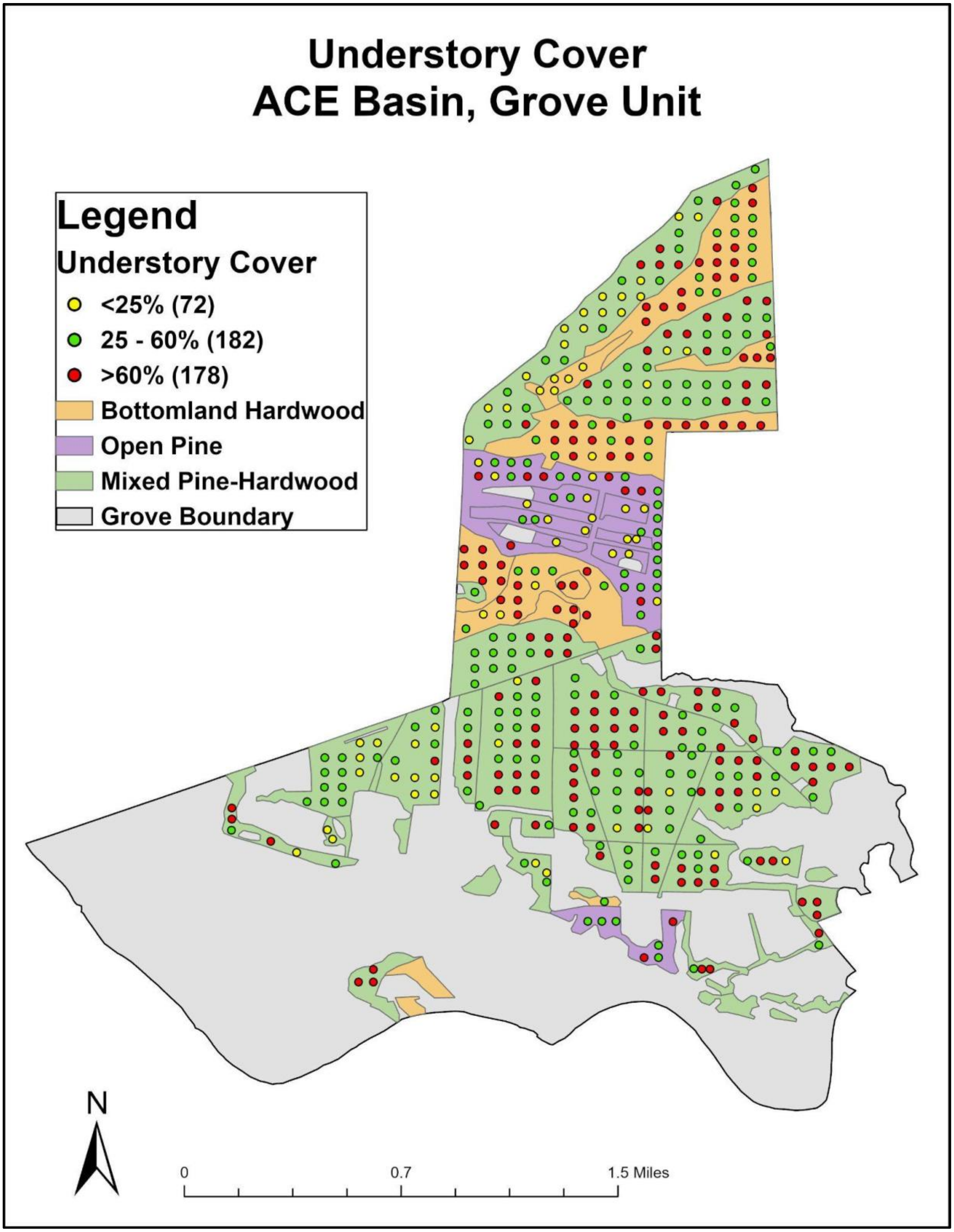


Figure D.4: Understory Cover, Grove Unit.

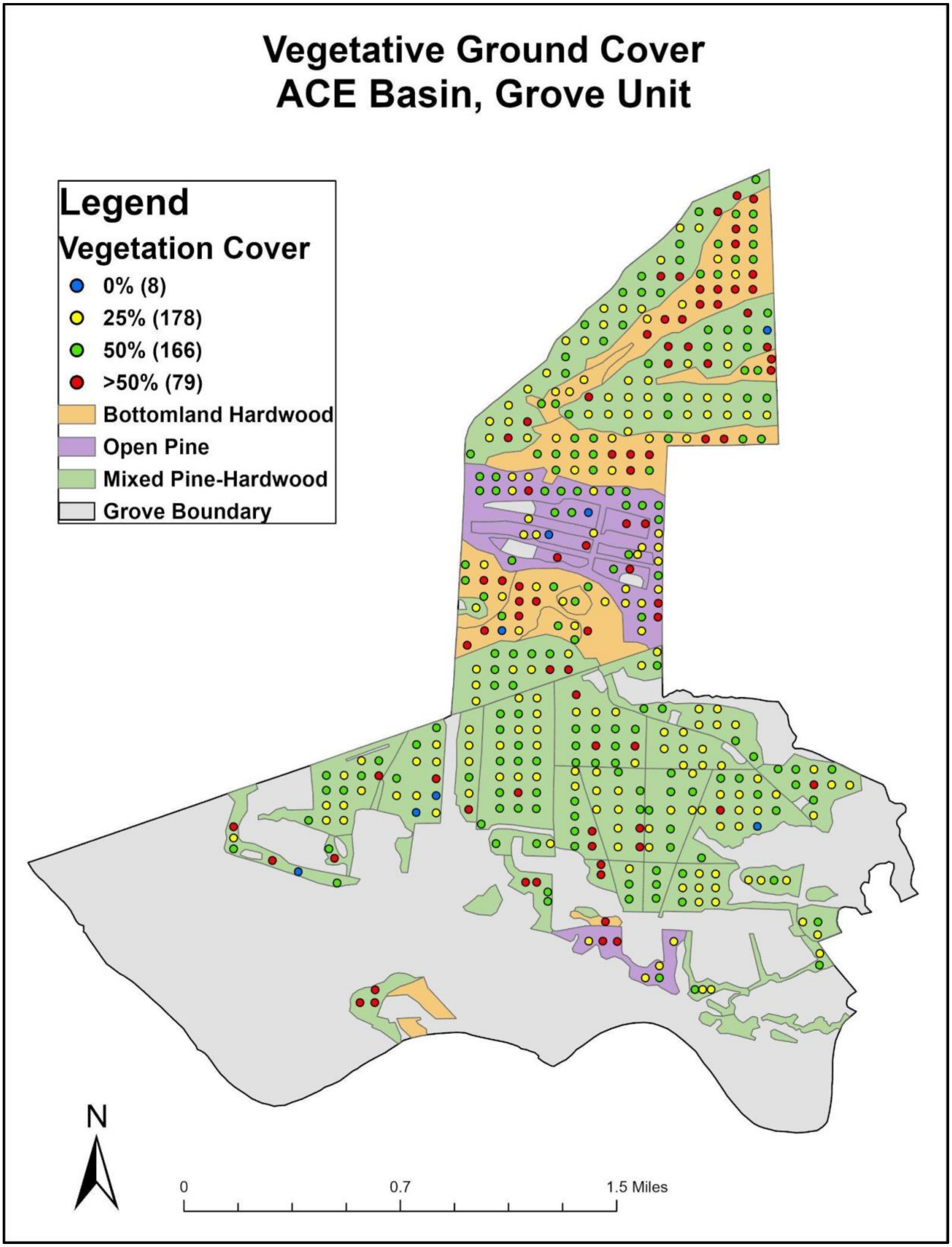


Figure D.5: Vegetative Ground Cover, Grove Unit.

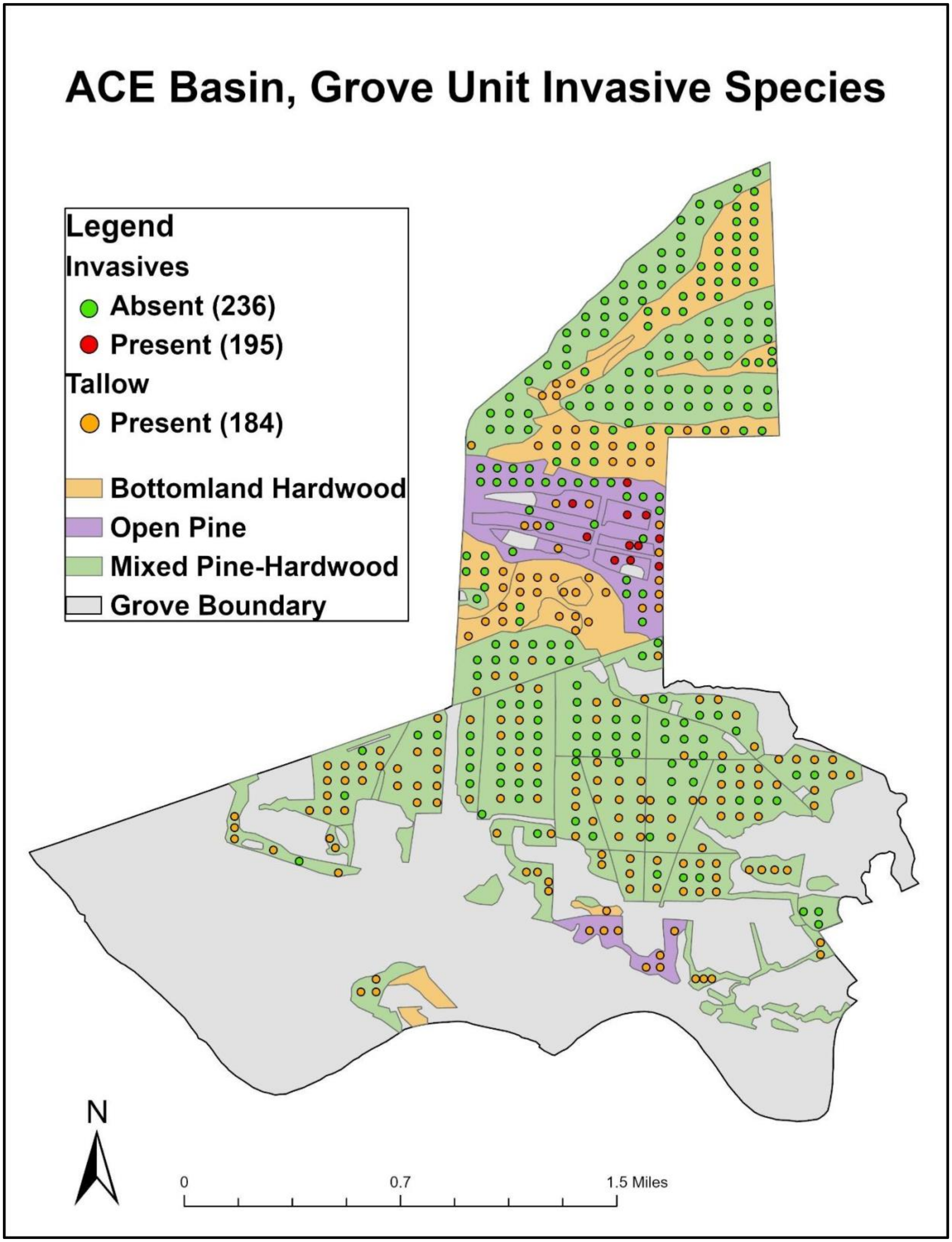


Figure D.6: Invasive Species Presence/Absence, Grove Unit.

Appendix E - Bonny Hall Unit Maps

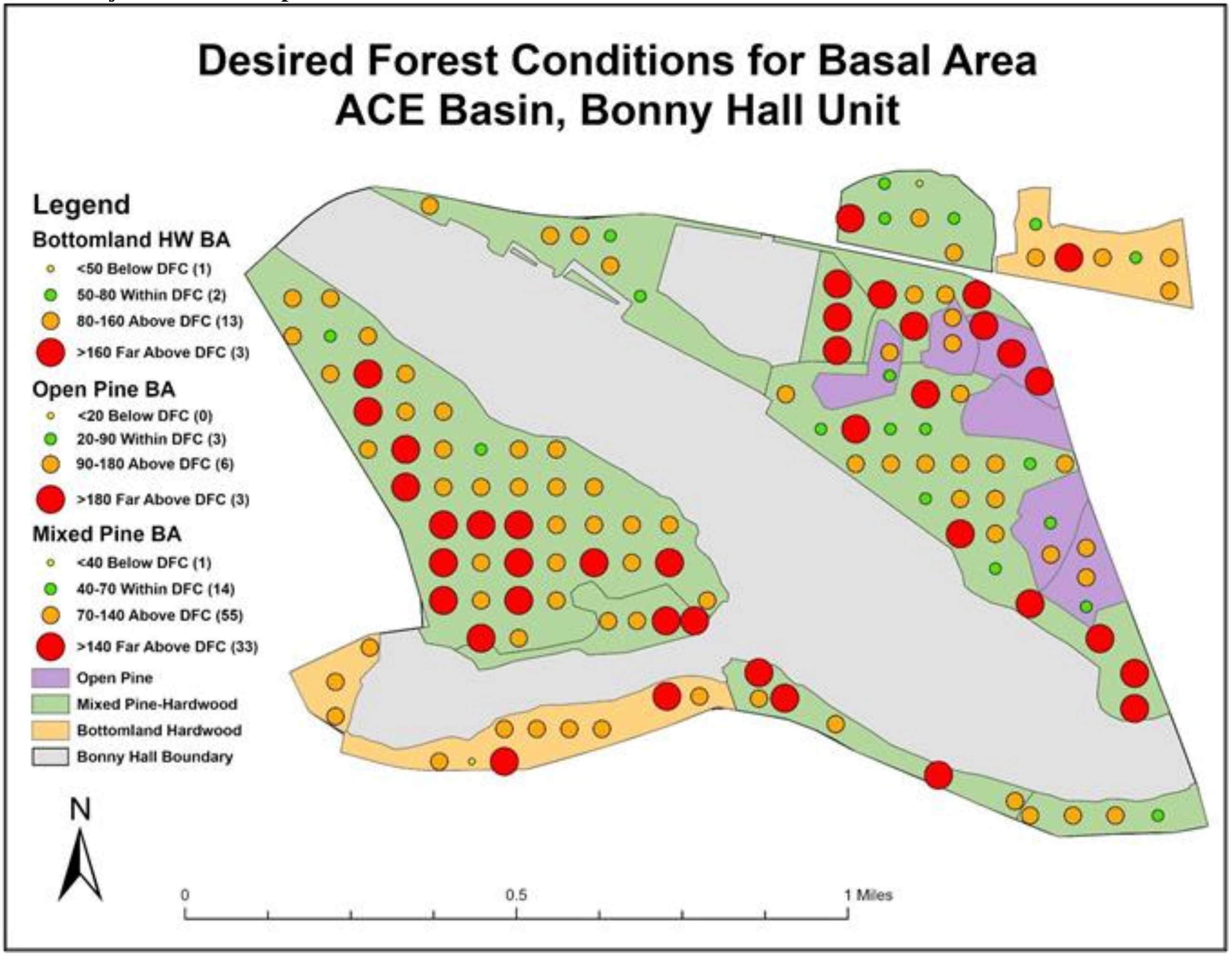


Figure E.1: Hotspot Map of Desired Forest Conditions for Basal Area, Bonny Hall Unit. Basal area units are sq. ft./acre.

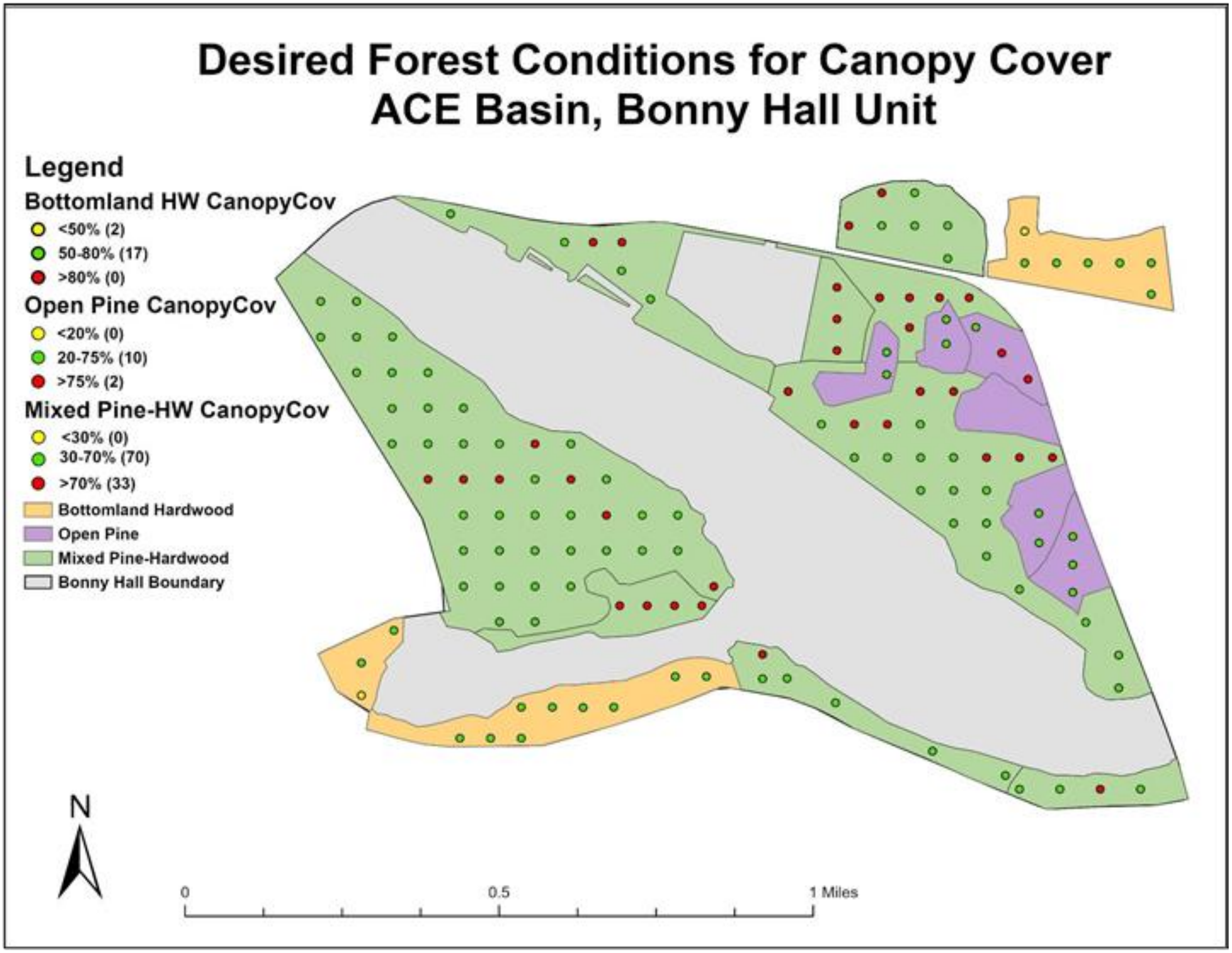


Figure E.2: Desired Forest Conditions for Canopy Cover, Bonny Hall Unit.

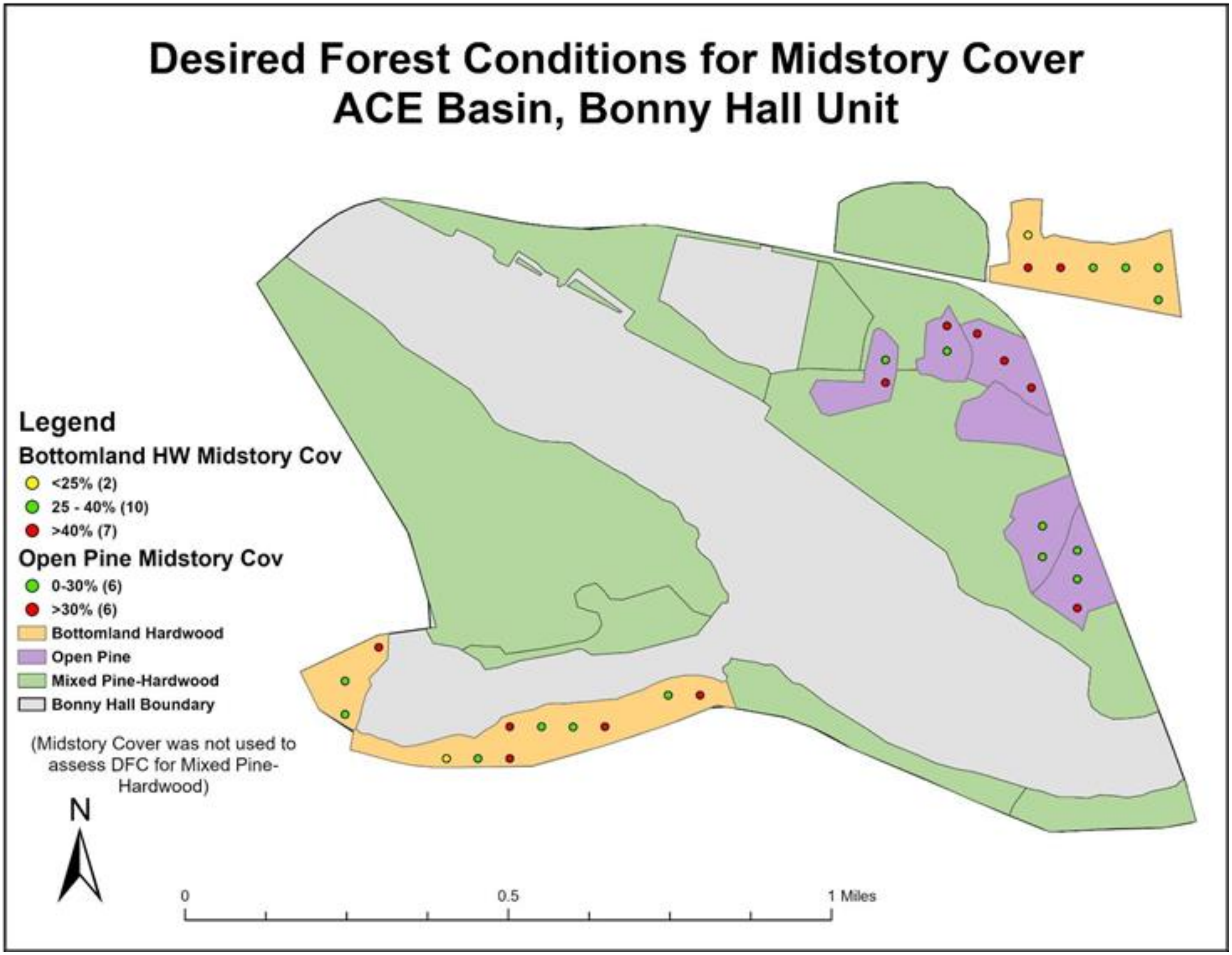


Figure E.3: Desired Forest Conditions for Midstory Cover, Bonny Hall Unit.

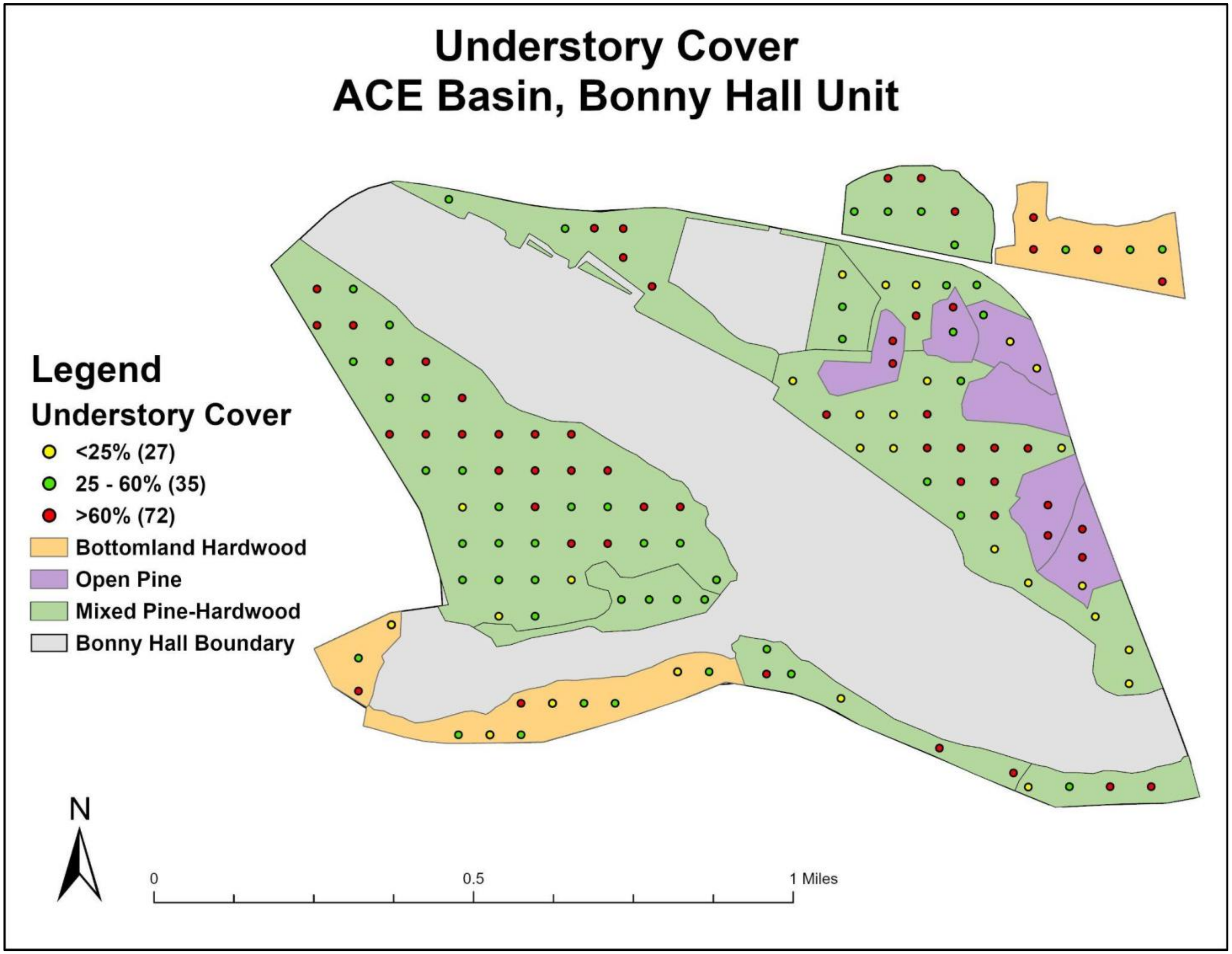


Figure E.4: Understory Cover, Bonny Hall Unit

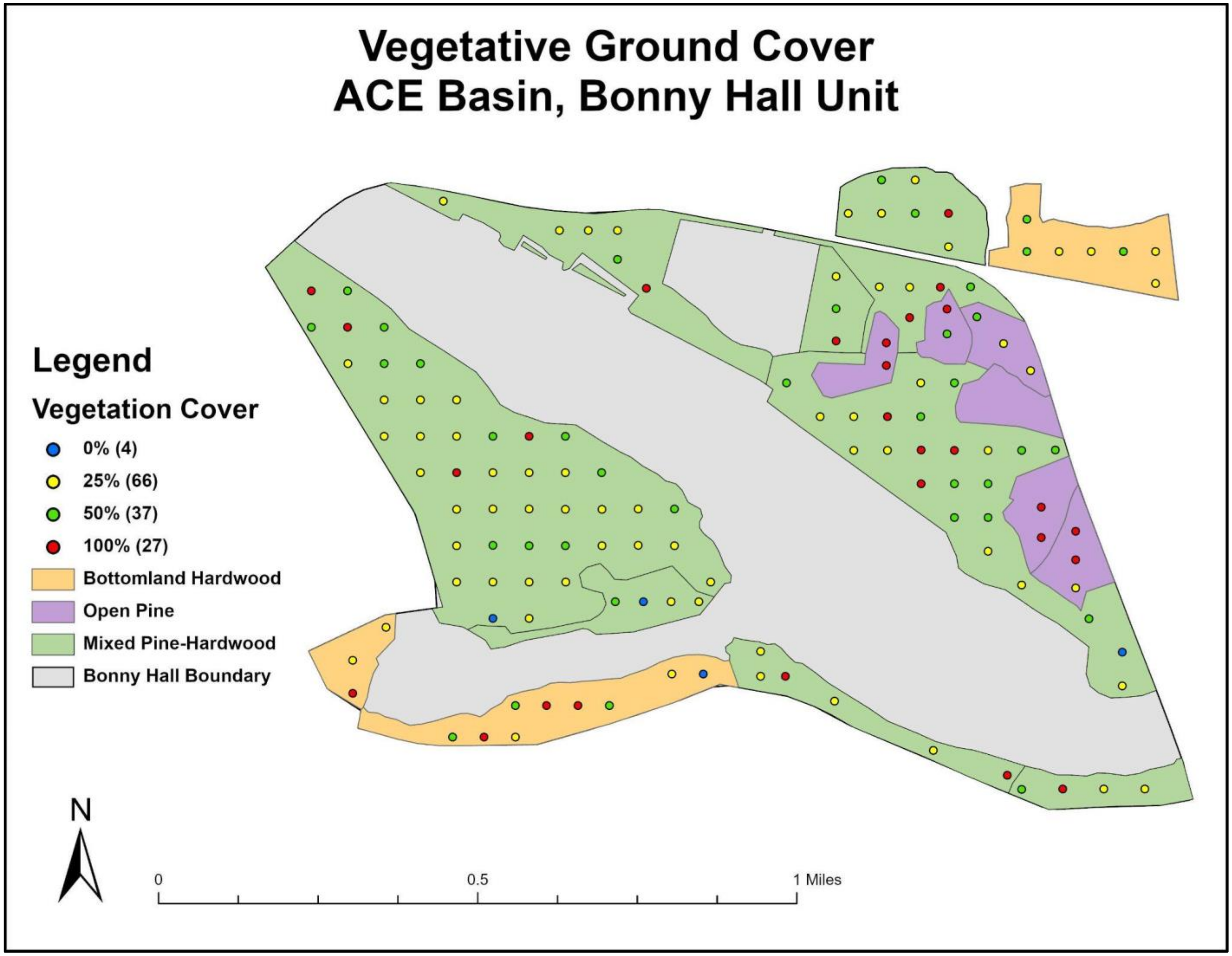


Figure E.5: Vegetative Ground Cover, Bonny Hall Unit.

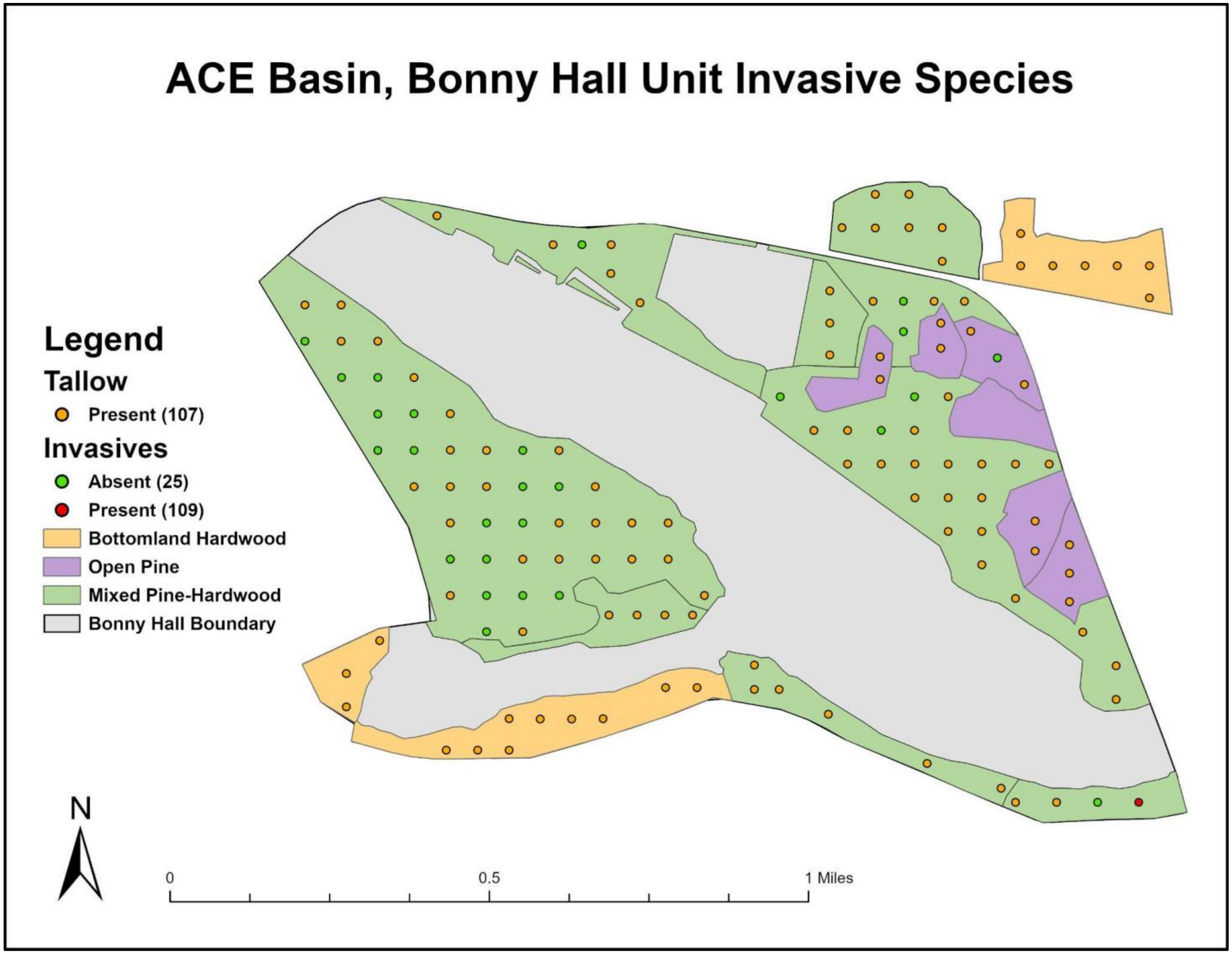


Figure E.6: Invasive Species Presence/Absence, Bonny Hall Unit.

Appendix F – FVS Stand and Carbon Reports

Table F.1: Bottomland Hardwood Carbon Report.

	Aboveground Live		Total Stand Carbon	Aboveground Live		Total Stand Carbon	Total Removed Carbon
Year	Total	Merch		Total	Merch		
2021	44.2	32.1	60.4	17.6	13.4	41.6	18.6
2026	47.9	34.8	65.6	18.7	14.3	37.9	0.0
2031	51.4	37.6	71.5	20.3	15.3	37.2	0.0
2036	55.3	40.6	77.2	21.9	16.4	37.7	0.0
2041	58.4	43.1	82.2	23.5	17.4	38.6	0.0
2046	61.3	45.4	86.9	17.6	12.9	34.4	5.6
2051	64.1	47.7	91.3	19.1	13.9	34.2	0.0
2056	66.9	49.9	95.4	20.6	15.0	35.1	0.0
2061	69.5	51.9	99.1	22.2	16.2	36.4	0.0
2066	70.5	52.8	102.7	23.9	17.5	38.0	0.0
2071	71.0	53.3	105.6	17.7	13.0	34.0	5.8
2076	71.5	53.7	107.9	19.0	14.0	33.9	0.0
2081	71.8	54.0	109.6	20.5	15.1	34.7	0.0
2086	72.2	54.4	111.0	22.2	16.4	36.2	0.0
2091	72.5	54.6	112.1	23.9	17.6	37.9	0.0
2096	72.8	54.9	113.0	17.7	13.0	33.9	5.8
2101	73.0	55.1	113.8	19.0	14.0	33.8	0.0
2106	73.3	55.3	114.3	20.5	15.1	34.7	0.0
2111	73.5	55.5	114.9	22.0	16.2	36.0	0.0
2116	73.7	55.6	115.4	23.6	17.4	37.6	0.0

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Table F.2: Open Pine Carbon Report.

	Aboveground Live		Total Stand Carbon	Aboveground Live		Total Stand Carbon	Total Removed Carbon
Year	**Total**	**Merch**		**Total**	**Merch**		
2021	32.2	24.0	45.6	13.4	10.7	32.0	13.4
2026	35.4	26.5	48.5	14.4	11.5	28.3	0.0
2031	38.7	28.9	53.3	15.8	12.4	28.2	0.0
2036	41.9	31.4	58.1	17.3	13.3	29.0	0.0
2041	45.0	33.7	62.4	18.8	14.2	30.1	0.0
2046	48.1	36.1	66.5	20.2	15.1	31.5	0.0
2051	51.3	38.7	70.5	21.8	16.0	33.2	0.0
2056	53.9	40.8	74.4	13.3	9.7	27.6	7.4
2061	56.2	42.7	78.0	14.4	10.5	26.8	0.0
2066	58.6	44.6	81.4	15.7	11.7	27.3	0.0
2071	60.8	46.4	84.6	17.1	12.9	28.4	0.0
2076	63.0	48.3	87.7	18.6	13.9	29.7	0.0
2081	65.3	50.1	90.6	20.0	15.0	31.2	0.0
2086	67.3	51.8	93.4	21.5	16.1	32.9	0.0
2091	67.6	52.1	96.2	22.9	17.1	34.6	0.0
2096	68.1	52.6	98.1	13.3	9.9	27.9	8.2
2101	68.6	53.0	99.7	14.4	10.7	27.0	0.0
2106	69.0	53.4	100.8	15.6	11.5	27.3	0.0
2111	69.4	53.7	101.8	16.8	12.4	28.0	0.0
2116	69.8	54.0	102.7	18.0	13.3	29.1	0.0

Natural	Management

Table F.3: Mixed Pine-Hardwood Carbon Report.

	Aboveground Live		Total Stand Carbon	Aboveground Live		Total Stand Carbon	Total Removed Carbon
Year	Total	Merch		Total	Merch		
2021	147.3	110.9	201.5	45.0	35.3	124.9	75.6
2026	161.0	121.9	218.1	48.1	37.7	107.9	0.0
2031	174.2	132.9	238.8	52.3	40.8	103.6	0.0
2036	185.6	142.6	257.8	56.7	43.7	103.5	0.0
2041	196.1	151.5	273.8	61.0	46.6	104.8	0.0
2046	206.7	160.4	288.3	65.4	49.8	107.6	0.0
2051	216.4	168.6	301.7	70.0	53.5	111.5	0.0
2056	223.0	174.3	314.0	74.8	57.4	116.3	0.0
2061	227.9	178.6	324.5	66.7	51.4	111.5	10.0
2066	232.3	182.4	333.2	57.2	44.1	103.1	10.7
2071	234.7	184.6	340.4	61.2	47.2	103.9	0.0
2076	237.0	186.7	346.3	54.7	42.2	98.4	8.1
2081	239.2	188.6	351.0	58.6	45.2	99.5	0.0
2086	241.1	190.2	354.8	62.7	48.3	102.5	0.0
2091	242.8	191.7	357.8	67.1	51.6	106.6	0.0
2096	244.4	193.0	360.6	71.8	55.2	111.5	0.0
2101	245.9	194.2	362.9	63.3	48.6	106.7	10.3
2106	247.2	195.3	365.0	67.1	51.6	108.9	0.0
2111	248.4	196.3	367.0	57.4	44.0	101.9	11.0
2116	249.6	197.2	368.8	61.3	47.0	103.5	0.0

Natural	Management

Table F.4: Categories for disposition of carbon in harvest wood (Smith et al. 2006)

Category	Label in Harvested Products Report	Description
Products in use	Products	End-use products that have not been discarded or otherwise destroyed, examples include residential and non-residential construction, wooden containers, and paper products.
Landfills	Lndfill	Discarded wood and paper placed in landfills where most carbon is stored long-term and only a small portion of the material is assumed to degrade, at a slow rate.
Emitted with energy capture	Energy	Combustion of wood products with concomitant energy capture as carbon is emitted to the atmosphere.
Emitted without energy capture	Emissions	Carbon in harvested wood emitted to the atmosphere through combustion or decay without concomitant energy recapture.

Table F.5: Bottomland Hardwood Harvested Products Report in units of tons C per acre.

					Merchantable Carbon	
Year	**Products**	**Landfill**	**Energy**	**Emissions**	**Stored**	**Removed**
2021	11.3	0.0	4.3	3.1	11.3	18.6
2026	7.8	1.7	5.2	3.9	9.6	18.6
2031	5.8	2.7	5.7	4.5	8.5	18.6
2036	4.5	3.2	6.0	4.8	7.8	18.6
2041	3.8	3.5	6.3	5.1	7.3	18.6
2046	6.7	3.7	7.7	6.1	10.4	24.2
2051	5.4	4.3	8.1	6.5	9.7	24.2
2056	4.5	4.7	8.3	6.7	9.2	24.2
2061	3.8	5.0	8.5	6.9	8.8	24.2
2066	3.4	5.1	8.6	7.1	8.5	24.2
2071	6.6	5.3	10.0	8.2	11.9	30.1
2076	5.3	5.9	10.4	8.5	11.2	30.1
2081	4.4	6.3	10.6	8.8	10.7	30.1
2086	3.8	6.5	10.7	9.0	10.3	30.1
2091	3.4	6.6	10.8	9.2	10.0	30.1
2096	6.6	6.8	12.2	10.3	13.4	35.9
2101	5.3	7.4	12.5	10.6	12.7	35.9
2106	4.4	7.8	12.8	10.9	12.2	35.9
2111	3.8	8.0	12.9	11.1	11.8	35.9
2116	3.4	8.2	13.0	11.3	11.6	35.9

Table F.6: Open Pine Harvested Products Report in units of tons C per acre.

					Merchantable Carbon	
Year	**Products**	**Landfill**	**Energy**	**Emissions**	**Stored**	**Removed**
2021	8.3	0.0	3.3	1.8	8.3	13.4
2026	6.0	1.1	3.9	2.4	7.0	13.4
2031	4.6	1.7	4.4	2.8	6.2	13.4
2036	3.8	2.0	4.6	3.0	5.8	13.4
2041	3.3	2.2	4.7	3.2	5.5	13.4
2046	2.9	2.3	4.8	3.3	5.2	13.4
2051	2.6	2.4	4.9	3.4	5.0	13.4
2056	7.0	2.5	6.8	4.4	9.5	20.7
2061	5.7	3.1	7.2	4.7	8.8	20.7
2066	4.9	3.5	7.4	5.0	8.3	20.7
2071	4.3	3.7	7.6	5.2	8.0	20.7
2076	3.9	3.9	7.7	5.3	7.7	20.7
2081	3.5	4.0	7.7	5.5	7.5	20.7
2086	3.2	4.1	7.8	5.6	7.3	20.7
2091	3.0	4.2	7.8	5.7	7.2	20.7
2096	7.9	4.3	9.9	6.9	12.2	28.9
2101	6.4	5.0	10.3	7.3	11.3	28.9
2106	5.4	5.4	10.5	7.6	10.8	28.9
2111	4.7	5.7	10.7	7.9	10.4	28.9
2116	4.3	5.8	10.8	8.0	10.1	28.9

Table F.7: Mixed Pine-Hardwood (all stands) Harvested Products Report in units of tons C per acre.

					Merchantable Carbon	
Year	**Products**	**Landfill**	**Energy**	**Emissions**	**Stored**	**Removed**
2021	46.8	0.0	18.3	10.6	46.8	75.6
2026	33.8	6.3	21.9	13.7	40.1	75.6
2031	26.0	9.9	24.1	15.7	35.8	75.6
2036	21.3	11.9	25.4	17.0	33.2	75.6
2041	18.3	13.1	26.2	18.0	31.4	75.6
2046	16.2	13.9	26.8	18.8	30.1	75.6
2051	14.5	14.5	27.2	19.4	29.0	75.6
2056	13.1	15.0	27.5	20.0	28.1	75.6
2061	18.2	15.4	30.2	21.9	33.5	85.6
2066	22.1	16.5	33.4	24.4	38.6	96.4
2071	18.3	18.2	34.3	25.6	36.5	96.4
2076	20.9	19.2	36.9	27.4	40.1	104.5
2081	17.8	20.5	37.7	28.4	38.4	104.5
2086	15.7	21.4	38.2	29.2	37.1	104.5
2091	14.2	22.0	38.5	29.8	36.2	104.5
2096	13.0	22.4	38.7	30.4	35.4	104.5
2101	18.3	22.8	41.3	32.3	41.1	114.8
2106	15.7	24.0	41.9	33.2	39.7	114.8
2111	20.6	24.8	44.8	35.6	45.4	125.8
2116	17.4	26.3	45.5	36.5	43.7	125.8