Forest Inventory and Grassland Restoration Planning of Redstone Arsenal in Huntsville, Alabama

By

John Perkins

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Approved by:

Becky Barlow, Chair, Associate Dean for Extension & Assistant Director for Agriculture, Forestry & Natural Resource Extension Program

Lana Narine, Assistant Professor, College of Forestry, Wildlife and Environment

Adam Maggard, Associate Professor, College of Forestry, Wildlife and Environment

John S. Kush, Research Fellow, College of Forestry, Wildlife and Environment

Abstract

Redstone Arsenal (RSA) is the largest landholding in the Tennessee River Valley of Alabama, encompassing 36,000 acres. This region was once dominated by expansive savannas, largely dominated by oak (*Quercus spp.)* and pines *(Pinus spp,)* with a highly diverse understory of herbaceous species. Following European colonization, much of these savanna ecosystems were lost to land use change and fire suppression. RSA, as a United States Department of Defense (DoD) installation, is responsible for protection of ecosystems found within its borders. Our goal was to determine the current composition of the installation's forests, create an Arc GIS database for its management, and develop a mapped product that may be used to aid in oak savanna restoration. The resulting map was developed using decision tree analysis and had an overall accuracy of 39.99% (kappa=0.22), outperforming support vector machine (25.41%, kappa=0.02) and maximum likelihood (14.40%, kappa=0.07).

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Chapter 1: Introduction

As a transitional region from the Appalachian Mountains to the east and the prairies of the western United states, the Cumberland plateau is a critically important region for fostering and protecting the native biodiversity of North America. This plateau extends from West Virginia to North Alabama. There, the plateau stretches about 217km south of the Tennessee border and makes up much of central to northeastern Alabama. The Cumberland Plateau's rich and varied topography arose during the Pennsylvanian subperiod, roughly 300 million years ago, when a continental collision forced a shallow sea in the middle of what is now North America upwards. The reefs in this sea were eventually compressed into limestone and its seafloor into shale. As the Cumberland Plateau rose from the sea, swamps in the area would eventually be compressed into coal deposits that would later be mined, and large domes formed, fractured, and eroded. The resulting peaks that still exist were once the bottom of the valleys that had formed from the continental collision (Duncan, 2013).

The combination of the Cumberland Plateau's topography, rich soils, and the climate differential that goes from the humid east to the dry west has resulted in one of the most biodiverse regions in North America, particularly in the cliff section found in north Alabama. This area is home to species native to the Cumberland Plateau that cannot be found elsewhere in Alabama and the cool, moist conditions of many of the cliffs in the area provide habitat for what many biologists believe are remnant populations from the last ice age (Duncan, 2013) .

Adjacent to the Cumberland Plateau in Alabama is the Eastern Highland Rim of the Interior Plateau. As tectonic forces pushed the Cumberland plateau upward, the shallow tropical ocean receded from it and the reef species that once thrived there receded with it. Eventually, this area arose and formed an area with flat terrain or gently rolling hills that now make up much of Tennessee and north Alabama. Here, forests were dominated primarily by shortleaf pine (*Pinus echinata* Mill.) and some oaks (*Quercus spp.*), with fire playing an active role in maintaining these forests and their open structure. Some areas were protected from fire by their topography and the dominant component of forests here were oak and hickory (*Carya spp.*) (Duncan, 2013). The resulting soils, generally flat or rolling terrain, and proximity to rivers such as the Tennessee River made much of this area ideal for agriculture and attracted European settlers (Duncan, 2013).

As agriculture became the dominant industry, forests were felled all over except on the occasional rocky outcropping or flood-prone bottomlands, and fire suppression became the norm. By the start of the 20th century, many farmers abandoned their lands due to soil depletion. At this time, Mohr described the region's forests as varied as its terrain, with mixed hardwood forests dominating moist bottomlands, shortleaf pine, and various oaks dominating drier areas. Along with shortleaf pine, eastern red cedar (*Juniperus virginiana* L.) was the region's dominant evergreen species. particularly along limestone ridges (Mohr, 1913). By mid-century, Braun noted that much of the forests in the region were dominated by pine and upland oak stands that transitioned to mixed mesophytic forests on the lower slopes with a dominant oak-hickory component (Braun, 1950).

These forests were what we would now call open forest ecosystems. The understory component is primarily composed of herbaceous species, and the understory is comprised of trees with varying diameters and stem densities. These ecosystems relied on fires to cycle nutrients, thin out regenerating stems, and create ideal seedbeds for new seeds by exposing bare mineral soil for oak and pine seeds (Hicks, 1998; Barefoot et al., 2018; Royse et al., 2010). These fires also provided for the maintenance of a rich herbaceous understory whose diversity rivaled that of the overstory component (Hanberry et al., 2020). However, the widespread practice of fire suppression throughout the twentieth century in the region resulted in a decrease in oak regeneration and an increasing shift towards fire intolerant species (Reid et al., 2007).

In particular, the loss of the understory component of these open forest ecosystems has been devastating as over 60% of all native plant species native to the southeastern United States require or prefer grasslands for their habitat. Loss of these grasslands has also resulted in the loss of vital ecosystem services such as water quality, carbon sequestration, and runoff control. More than ever, the study and restoration of southeastern grassland ecosystems are critical as these ecosystems are on the verge of being lost forever due to development and fire suppression (SGI, 2023).

With the abandonment of farmland in the region, the United States Army took the opportunity to establish a new installation south of Huntsville, Alabama, for the production, storage, and training in the use of chemical weapons known as Redstone Arsenal (RSA). By 1941, RSA had grown to include about 36,000 acres along the Tennessee River. As the largest landholding of the region, RSA presents a wide variety of topography resulting in numerous microclimates capable of supporting species found much further north and south of the area. Aside from the gently rolling hills and forested plains that have been allowed to regrow since the establishment of RSA in 1941, the area is home to a handful of mountains that remained as the nearby Cumberland plateau receded from the area. Because of the differences in underlying geology, differing topography, and variation in slopes, these mountains provide habitat for forest species not found elsewhere on RSA and provide unique management opportunities. Two mountains of interest, Weeden and Madkin Mountains, lie within the housing and recreation area on Redstone Arsenal and host numerous trails for hiking and mountain biking between their peaks and the connecting ridge. Weeden and Madkin mountains are also unique in that they are taller, vary greatly in their slopes compared to other mountains on RSA, and have several springs throughout that allow them to support a varied mixture of forest species (Hinkle and Magee, 1989).

Research on the species composition and structure of Cumberland plateau forests prior to 1980 is limited to only a handful of studies. While numerous ecological studies have been done on Redstone Arsenal, none have been found that have looked at the forest composition of Weeden and Madkin Mountains. Of the few studies done on the region prior to 1980, the most notable are Charles Mohr's Economic Botany of Alabama and Lucy Braun's Deciduous Forests of Eastern North America (Mohr, 1913; Braun, 1950). Mohr's book focused on observations he made throughout the state of Alabama that related forest species composition to topography, geology, and community associations. These observations by Mohr are now used as a foundation for ecological studies in much of the region. Braun's book was the result of 25 years of studying deciduous forests throughout the eastern United States where she tried to reconstruct the development of deciduous forests across the region based on forest remnants and Mohr's work. Her primary focus was on describing what she called mixed mesophytic forests, a forest composition dominated by several determinate species.

Hinkle and Magee (1989) called Braun's work into question regarding the Cumberland Plateau. He studied the forest composition of Cumberland Plateau communities and found significant differences between their observations and those of Braun. For example, where Braun claimed she had found pin oak (*Quercus palustris* Muenchh.) in poorly drained sites on the Cumberland plateau, Hinkle and Magee found that these sites were primarily dominated by red maple (*Acer rubrum* L.) with little to no pin oak present. Most importantly to this study, Hinkle and Magee described upland forests of the Cumberland Plateau as mixed oak forests rather than oak-hickory forests as described by Braun, since they found a much lower importance on hickory than Braun. Their conclusion was that the Cumberland Plateau should be classified as being dominated by mixed oak forests and that Braun's work was biased by focusing on protected sites where remnants of original forests of the region still grew (Hinkle and Magee, 1989).

Two natural disturbances are the primary drivers of forest succession in the Interior Plateau and the Cumberland Plateau: fire and wind. Fire was once the most important disturbance in this region. Repeated fires kill vegetation that may suppress the growth of oaks and other hardwoods in the region and quickly recycles nutrients back into the soil as potash. Oaks and other fire tolerant species such as pine rely on the bare mineral soil caused by fires for the germination of their seeds and the removal of competing woody vegetation (Hicks, 1998; Barefoot et al., 2018; Royse et al., 2010). Repeated fires are also critical to the maintenance of open forests such as savannas once found throughout the southeastern United States by limiting regeneration of some tree species through varied fire intensity. These fires also provided for the maintenance of a rich herbaceous understory whose diversity rivaled that of the overstory component (Hanberry et al., 2020). Despite all this evidence, fire suppression became a common practice in much of the region, particularly since the 1920s. The result has been a decrease in oak regeneration and an increasing shift towards fire intolerant species (Reid et al., 2007).

Where fire primarily affects the understory, wind related disturbances have little direct effect on the understory outside of providing them with more light (Hicks, 1998). Wind based disturbances can create small gaps by felling singular trees, allowing subcanopy trees an opportunity for increased growth; or they can result in the loss of entire stands in the case of events like tornadoes and hurricanes, favoring pioneer species. Response to gap formation varies by species. Hart et al., (2011) found that tulip-poplar (*Liriodendron tulipifera* L.), a shade intolerant species favored large canopy gaps, while intermediate and tolerant species such as red maple and sugar maple (*Acer saccharum* Marsh.) were able to outcompete tulip poplar in smaller canopy gaps. In stands once dominated by pines in the region, species composition has been shown to gradually shift towards a more dominant oak composition in response to gap formation (Weber et al., 2010).

Following the Civil War, America began construction of a massive rail network and needed timber for railroad ties and iron ore for steel. Many farmers abandoned their land and sold it to timber and mining companies who sought to extract what they could from the land. By 1920 much of the logging efforts in the central hardwood region, which includes RSA, were abandoned due to overcutting of forests (Hicks, 1998). This is the last known major disturbance throughout the region overall and particularly on RSA, resulting in the growth and development of a secondary forest at various stages of development (Hart et al., 2011).

Much of the land surrounding Weeden and Madkin Mountains lie on the eastern highland rim of the Interior plateau. In Alabama, this region is primarily defined by the Tennessee River, which cuts across North Alabama and borders the southern boundary of Redstone Arsenal. Much of the topography in the region consists of gently rolling hills with alkaline soils underlined with limestone. In some places, this limestone has dissolved and created sinkhole and depression ponds, creating wetland habitat for various reptiles and amphibians. Oaks and hickories were less common in this area than the western highland rim, and chinkapin oak and eastern red cedar dominated dry hilltops. As with the Cumberland plateau, fire was the most common disturbance prior to European settlement and encouraged the growth of oaks, hickories, and large areas of shortleaf pine (Duncan, 2013).

Openings formed throughout these forests and were quickly filled with herbaceous species, particularly big bluestem (*Andropogon gerardii* Vitman.) along with little bluestem (*Schizachyrium scoparium* Michx.) and Indian grass (*Sorghastrum nutans* L.). These savannas and barrens represent most of the floristic diversity within the region but have been threatened by the invasion of more competitive tree species, and human development. The loss of fire as a regulatory disturbance for this region has been particularly devastating for grassland species. Where fires may have returned on a 5-year interval, many areas have remained untouched many herbaceous species have become suppressed. Now, the diversity of these savannas and the associated open forest ecosystems has increasingly moved upward from an understory of shrubs and grasses to a less diverse, dense forest (NatureServe, 2023).

Due to its size and location in Huntsville, Alabama, RSA represents an ecotone between many ecosystems found on the Eastern Highland Rim and the Cumberland Plateau. Bhuta and Hart provide one of the most detailed accounts of the forests on RSA to date. The authors compiled forest inventory data from RSA and found that the most important species on the installation were loblolly pine (*Pinus taeda* L.), sweetgum (*Liquidambar styraciflua* L.), and willow oak (*Quercus phellos* L.). Regarding species diversity, loblolly pine was found to have a negative impact and the authors made recommendations to improve biodiversity in these stands (Bhuta et al., 2011). They also concluded that RSA's primary land use as a military installation may have a negative impact on its species diversity by fragmenting habitats. These fragments are more likely to be invaded by nonnative species that inhibit the regeneration of native plant species and destroy habitat for native wildlife species (Bhuta et al., 2011). However, no mention was made of Weeden or Madkin mountains, despite being one of the largest areas of unfragmented habitat.

Hart et al., (2011) researched the effects of gap canopy disturbances on RSA and found no major disturbance events had occurred on the installation since its establishment in 1941, after the period of heavy logging in the central hardwood region. They concluded that little subcanopy growth had occurred on base and that trees largely responded with lateral canopy growth in response to gap formation. Even though three tornadoes and the remains of Hurricane Opal had all caused damage to the area, only 2 of the 42 release events the authors had found in their study could be tied to these storms. The authors speculated that the lack of large-scale disturbances may be a common phenomenon throughout the region, and that gap-formation because of windthrow only becomes common in stands over 40 years old. Prior to this, self-thinning appeared to be the primary driver in gap formation. The authors propose that as stand age increases, the frequency of gap formation will decrease, but the size and duration of each release event will increase (Hart, 2011).

As these habitats at RSA continue to fracture, the intentional management of forests as a buffer between civilian and DoD activities, and the protection of species on RSA will become difficult (Reid et al., 2007). Coupled with the findings that that canopy gap formation will continue to decrease over time, open forest ecosystems that were once common on RSA and the surrounding region face increasing threats. By utilizing planning level survey data to locate potential areas of restoration for these open forest ecosystems, RSA may provide a site for research into restoration. Thankfully, the largest area of forest that has remained relatively untouched at RSA is a recreational mountain biking and hiking area consisting of two large mountains connected by a ridge – Madkin and Weeden Mountains.

Weeden and Madkin Mountains are the two largest mountains on RSA and are outcroppings of the nearby Cumberland Plateau. According to aerial imagery taken in 1942, these mountains were heavily forested, unlike much of the surrounding landscape (Alabama Maps, 1942). As a result, it is likely that they were reminiscent of the forests that Braun and Mohr found in the Eastern highland rim of the Interior Plateau and of the Cumberland Plateau. However, in the years following the acquisition of RSA by DoD and the widespread practice of fire suppression the forests have likely become much denser since 1942, and the species composition has likely begun to favor fire intolerant species such as maples.

A consequence of this change was the loss of open forest ecosystems such as oak savannas which were once common along Cumberland Plateau escarpment and similar places such as Madkin and Weeden Mountain. As these forests grew in their stem density and light was interrupted by the overstory, herbaceous plants began to dwindle – taking much of the biodiversity here with them as they died. Restoration of these ecosystems would provide habitat for many declining species in the region, as well as providing an opportunity for incorporating restoration activities such as prescribed fire, alongside military activities, and recreational activities on federally protected land (Dey et al., 2017) To that end, the establishment of a baseline for recreation of these areas would be useful for planning a coordinated restoration effort and illustrating the changes within an ecosystem (Camaretta et al., 2020).

As a military installation under the control of the United States Department of Defense (DoD), RSA is subject to following the Sikes Act of 1960, which requires DoD installations to actively monitor and protect ecosystems found on these installations in accordance with federal, state, and local laws (USDoD, 2013). Under the Sikes Act, these installations must regularly collect data on species and ecosystems found within their borders and create integrated natural resource management plans (INRMPs) to properly balance the sustainable use of natural resources, DoD missions, recreational activities, and species and ecosystem conservation such as the restoration of oak savannas at RSA.

The purpose of this thesis is to show the current state of forests at RSA by conducting a preliminary forest inventory and creating a subsequent geodatabase of forest inventory stands and plots, as well as using some of these data to create a baseline remotely sensed product for grassland restoration on Weeden and Madkin mountains at RSA.

Chapter 2: Forest Inventory Summary of Redstone Army Arsenal, Alabama

2.1 Introduction

Redstone Arsenal (RSA) is in Madison County, Alabama, and is in the Tennessee Valley Proper, also referred to as the Eastern Highland Rim of the Interior Plateau of north-central Alabama. Historically, this area was used for intensive agriculture following European colonization but was abandoned and then acquired by DoD. At the time, most remaining forests were in areas unsuitable for agriculture, such as oak-dominated wetlands and mountains dominated by oaks, pines, and cedars (Harper, 1913; Bhuta et al 2011). Of the 38,100 acres RSA occupies, approximately 16,000 acres are forested, with about 10,000 acres suited for commercial forestry, recreational activities, mission support, and ecosystem services. In addition, there are multiple conservation opportunities for endangered species management. These opportunities vary from maintaining habitat for Indiana bats (*Myotis sodalist* Mill.) and the gray bat (*Myotis grisescens* Howell.) to hosting one of three federally protected sites for the endangered Price's potato bean (*Apios priceana* B.L. Robins.).

As a result of the Sikes Act of 1960, all Department of Defense installations are required to protect their natural resources according to federal, state, and local environmental regulations by creating and implementing an integrated natural resource management plan (INRMP). The objective of this project was to support Redstone Arsenal's INRMP by conducting a preliminary forest inventory of RSA and creating an updated forest inventory database for use by RSA personnel. The field inventory portion of this project was completed in the summer/fall of 2020 by inventorying 97 forested stands across RSA, covering a total of 6,781 acres. These stands ranged from 5 acres to

375 acres in size. Of the surveyed area, approximately 4,670 acres were mixed pine-hardwood stands, 1,442 acres were hardwood stands, and 669 acres were pine stands. In 2021, forest inventory summary tables were created for each stand and merged into an ArcGIS geodatabase for RSA personnel. This document outlines inventory methods and results of this field inventory.

2.2 Methods

Site Description

Due to its varying topography consisting of swampy bottomlands and limestone mountains, as well as a mild, humid climate, RSA can support a wide variety of species. Soils here are well-drained, loamy, and derived from limestone erosion or alluvial deposits. Much of the area at RSA is secondary forests, where commercially valuable species such as southern yellow pines were planted in abandoned farmland by DoD to act as a barrier between military civilian activities and to generate revenue. Other areas where intensive agriculture was not possible, such as bottomlands, were dominated by hardwood forests, while mountains scattered around the base were dominated by a mixture of hardwood and coniferous forests (Hart et al 2011).

Forest inventory

A geodatabase representing forest stand boundaries and inventory plot locations across RSA was created to prepare for the field inventory. Using 0.15 m aerial imagery supplied by RSA and previous forest inventory data, stand boundaries were manually delineated by species composition, natural boundaries, and manmade boundaries (Figure

2.1). Forested areas that fell within the jurisdiction of Wheeler Wildlife Refuge and the US Fish and Wildlife National Wetlands Inventory were excluded from the inventory area as they fall outside of the jurisdiction of base personnel relevant to this project (Hicks, 2019). Larger scale maps of the various stands and their locations on RSA are presented in Figures 2.2-2.4.

Plot locations were determined using Landmark Spatial Solutions EZ-Plot Toolbar, a program designed to generate plot locations within defined stand boundaries and export them to a GPS (Jenness, 2016). Plot size was determined based on stand composition as determined by visually assessing aerial imagery. Stands dominated by hardwood or mixed pine-hardwood stands were inventoried with 1/10th acre (radius of 37.24 feet) plots with the intent to better document the diversity within them. Pine-dominated stands were inventoried with 1/20th acre (radius of 26.34 feet) plots because of higher homogeneity in tree species and distribution.

The percent inventory established for each stand varied depending on tree species type and plot size. Pine-dominated stands were inventoried so that the area surveyed was at least 0.5% of the total stand acreage, with a minimum of three plots sampled in each stand. Hardwood and mixed pine-hardwood stands were cruised so that the area surveyed was at least 0.75% of the total area, with at least three plots sampled per stand. In total, 576 plots were surveyed across 97 stands with a total combined area of 6781 acres.

The field inventory was conducted during the summer and fall of 2020. In the field, GPS coordinates for each plot from the geodatabase were used to direct field crews to stand and plot locations on RSA. At each plot, the following was collected: tree diameter at breast height (DBH) in inches (in), tree species, merchantable tree height in feet (ft), and total tree height (ft). Diameters were measured using loggers' tape, while heights were taken with a digital hypsometer. Where pines were present, the age of at least one pine tree per plot was estimated using an increment borer to establish site index (base age 25). The presence of invasive plant species and understory species were recorded as comments. Invasive species with stem diameters greater than 4 inches DBH were recorded for DBH, total height, and species. Regeneration for hardwoods, pines, and eastern red cedar was recorded as the number of stems for each group below 4 inches DBH on a 1/100th acre subplot at the plot center of the original inventory plot locations.

Tree species were grouped based on their value to RSA. For example, pine, yellow poplar, and sweetgum can be sold commercially to local timber markets for revenue generation. While other tree species like oaks and hickories are primarily managed for the wildlife habitat value. Based off these criteria, eight tree species groups were established 1) Pines, 2) Sweetgum, 3) Yellow-Poplar, 4) White Oak species, 5) Red Oak species, 6) Hickory species, 7) Eastern Red Cedar, and 8) Other Hardwood species. The forest inventory program, T-Cruise Forest was used to calculate stand volumes/weights for each species group . T-Cruise was also used to estimate form class for each species group to determine its volume in board feet (Doyle log rule) and tons within a group in each stand. Age values for pine trees were also input into T-Cruise to assess the site index for each stand (Landmark Spatial Solutions, 2019). Other stand data calculated for each using these data were square feet (ft^2) of basal area per acre (BA), trees per acre (TPA), minimum height (ft), mean height (ft), maximum height (ft), minimum DBH (inches), mean arithmetic DBH (inches), maximum DBH (inches), quadratic mean diameter (QMD) (inches), and number of regeneration stems per acre.

Summary inventory tables for each stand were generated using collected field inventory data and processed using the Pandas library; a data analysis library created for the Python programming language (The Pandas Development Team, 2020; McKinney, 2010). Using Pandas, square feet of basal area per acre, TPA, QMD, aggregate statistics for DBH, and total height, were calculated on each plot regardless of tree species and for the pine species group. Square feet of basal area per acre and TPA were calculated for each species group, including invasive species. If the age of a pine tree was estimated on a plot, it was also recorded in this table. Stand level data were averaged from across all the plots for each stand. The sample size required for a 15% allowable error was calculated from the average square feet of basal area per acre and TPA for all other tree species and for the pine species group.

Importance values (IV) and diameter distributions for each species group were calculated within each stand type on RSA using Pandas. IV is a useful ecological index for measuring the dominance of a species within an area and comparing it to other species within the same area. IV can also be used to compare changes in an ecosystem over time, as was the case of one study 2011, where they used IV to compare changes in eastern US forests between 1980 to 2008 (Fei et al., 2011). For this study, IV was calculated by taking an average of three measurements: relative proportion, relative frequency, and relative basal area. Relative proportion is defined as the number of times that a species group was found in a stand, over all instances that the species group was found. Relative density the number of stems per acre for the species group, over the stems per acre for all species groups. Finally, relative basal area is calculated as the basal area in square feet per acre for each species group over the basal area for all species groups. The average of these three values was then taken to create one cohesive importance value for each species. Diameter distribution charts for each forest type were generated showing the forest composition of all stands within a specific forest type using the eight species groups that were defined. Diameter distributions were calculated based on all measured stands of the same forest type. As such, it was expected that these distributions would present as a reverse j-shaped curve, indicative of an uneven-aged forest – particularly the pine stands planted at different times throughout RSA's history, creating multiple age classes within the same distribution. These charts were meant to visualize the changes in RSA's forests and illuminate the potential changes that may happen in the future.

ArcGIS geodatabase

Within the geodatabase is a mosaicked image of 2018, 0.5-foot resolution imagery provided by RSA, a polygon feature class representing stand boundaries, and a point feature class representing plot locations for the 2020 forest inventory at Redstone Arsenal. Excel tables representing summarized data on the stand and plot levels were joined to their respective feature classes. Plot-level attributes include the square feet of basal area per acre and TPA for all species groups, aggregate data (minimum, mean, and maximum) of DBH and total height, age of one pine tree on the plot (if any), number of stems for regeneration on a per-acre basis, and comments for the plot. Stand level data include the averaged data and aggregate data from all plots across a stand, as well as quadratic mean diameter and the number of plots needed for an inventory with a 15% allowable error for the square feet of basal area and TPA attributes across all species groups and the pine species group.

2.3 Results

In total, 97 stands were cruised across RSA, covering 6,781 acres, ranging from 5 acres to 375 acres in size. Of the surveyed area, approximately 4,670 acres were in mixed pine-hardwood stands with an estimated total volume of 495,000 tons , 1,442 acres were in hardwood stands with an estimated total volume of 100,000 tons, and 669 acres were in pine stands with an estimated total volume of 185,000 tons. Table 1 below shows the basal area per acre and trees per acre for all species groups within each forest type.

Species composition by forest type as determined by the average importance value of relative proportion, density, and basal area found that the pine species group was the most important in two of the three categories. Within the pine forest types as determined by visual assessment, the pine species group was found to be most important with an importance value of 69.6%, followed by the other hardwoods species group (13.7%), eastern red cedar group (8.0%), and sweetgum group (4.9%). All other species groups had importance values less than 2%. The mixed species stands were also largely dominated by the pine species group (26.8%), but to a much lesser extent than the pine stand type. Again, other hardwoods were the next most common group (18.5%), followed by sweetgum (15.2%), and red oak (13.0%). All other species groups in the mixed forest type were at or below 7%. The hardwood forest type is dominated by the other hardwoods species group (27.2%), followed by hickory (19.3%), white oak (17.9%), eastern red cedar (16.6%), and red oak (14.2%). All other species groups in the hardwood forest type were found to be below 2.5%.

Mixed forest types on RSA followed a reverse j-shaped curve with a sudden uptick in the 25+ inch diameter class(Figure 2.6). , This highlights the a large number of trees greater than or equal to 25 inches DBH in this forest type. Pine was most prevalent in all diameter classes but was closely matched by sweetgum and other hardwoods in all diameter classes 10 inches DBH or lower. In general, this diameter distribution shows that sweetgum and other hardwood species are replacing pines in these stands, likely because these stands have not been managed for timber for some reason.

The diameter distribution for pine forests on RSA shows a reverse j-shaped curve indicative of the multiple age classes planted on RSA throughout its history (Figure 2.7). In all diameter classes below 17 inches DBH, the primary competition is from easter red cedar and other hardwoods, a pattern that we also found when calculating importance values for this forest type.

2.4 Discussion

The data summarized in the diameter distributions show that the general structure of RSA allows us to infer potential changes over time, particularly as species in smaller diameter classes grow into the larger classes. For hardwood stands on RSA, the data presented indicate that the forests are gradually being replaced by other hardwoods such as maple and ash, as well as eastern red cedar. Mixed hardwood stands would appear to be former pine dominated stands that have gradually been replaced by sweetgums and other hardwood species. Finally, pine stands appear to have been invaded by other species but are ultimately still dominated by pines – particularly in the larger diameter classes.

Hardwood dominated stands are largely dominated by other hardwood species (27.2%), with most of these species in the smaller diameter classes as indicated by the diameter distribution, Hickory and white oak were the next most important species group by IV in these stands (19.3% and 17.9%). These secondary groups comprise a larger proportion of trees in the larger diameter classes than do the other hardwood species groups. With few members of the other hardwoods species group in the larger diameter classes in the diameter distribution and a greater importance value, this would indicate that other hardwoods are generally more numerous, but smaller than all the other species groups. Along with the seemingly more normal distribution that indicates a more even-aged structure, this would suggest that the other hardwood species are gradually replacing the other species groups, particularly white oaks, and hickories.

IVs for the mixed hardwood stands also show a significant importance of pines (26.8%), but other hardwoods and sweetgums (18.5% and 15.2%) have a significantly higher importance in these stand types. The presence of larger diameter sweetgums in the diameter distribution for mixed pine-hardwood stands would suggest that sweetgum's importance in these stand types is derived from relatively few larger members seeding these stands, while other hardwood species are being introduced via other means. Regardless, the presence of smaller diameter species outside of the pine species group would suggest little is being done to limit their spread in these stands and that while these stands may have at one point been planted for timber production, their main purpose has changed to some other goal for DoD.

Importance values for the pine stands correspond with the data from the pine stand diameter distribution in that pines are the overwhelmingly dominant species group (IV=69.6%), while the other hardwoods group and eastern red cedar groups (13.7% and 8.0%) are less dominant in terms of their IV, they are the next most important groups, suggesting that they occur frequently in these stands. The high importance value and the consistently larger proportion of pines in all diameter classes would indicate that other species are being excluded from these stands thanks to some form of management aimed at production of timber.

A recent study looking at the forest conditions of this region by reporting on the importance values of species at RSA found that pines, sweetgums, and red oaks were the most dominant species at the site (Bhuta et al., 2011). The researchers did this by calculating and comparing the IV of species found on RSA based on relative basal area and relative density. Similarly, our data indicates that pines, other hardwoods, and red oaks are the most important species groups on RSA. Regardless, the authors' suggestion that mass planting of loblolly pine, as well as fragmentation of habitats for DoD operations have a negative impact on forest biodiversity. A seemingly hands-off strategy for mixed pine-hardwood stands may have led to an increase in other hardwood species invading these sites, but a similar management strategy for hardwood stands is gradually leading to the loss of ecologically significant species such as oaks and hickories. (Bhuta et al., 2011).

Our data indicate that other hardwoods, while not widely present in larger diameter classes, are the most ecologically important species group found in hardwood stand types at RSA, suggesting that their relative frequency and density are significantly greater than other larger diameter species and that this group will eventually replace the species found in the larger diameter classes. This coincides with another study looking at the types of disturbance at RSA where researchers concluded that larger windthrown trees were creating large gaps that would be filled by smaller diameter faster growing trees. These trees would then further suppress seedling growth in the subcanopy. Furthermore, this change would indicate that forests that were once relatively open with a diverse understory are now considerably dense and suppressing the growth of herbaceous species in the understory.

Redstone Arsenal's forests are constantly changing and as steward of the land, DoD is responsible for protecting the natural resources found within its boundaries. Part of that responsibility allows for the harvesting of valuable timber to fund land management, but DoD's current management strategy is leading to the replacement of certain species groups such as oaks and hickories for other species such as maples. While this change is not necessarily negative, the change in forest ecosystems suggests a forest ecosystem that suppresses an incredibly biodiverse herbaceous understory capable of supporting a wide variety of wildlife. If DoD is committed to protecting its natural resources at RSA, including biodiversity on site, then it must seriously consider changing its current management strategy to allow for restoration of open forest ecosystems such as oak savannas that once dominated the area.

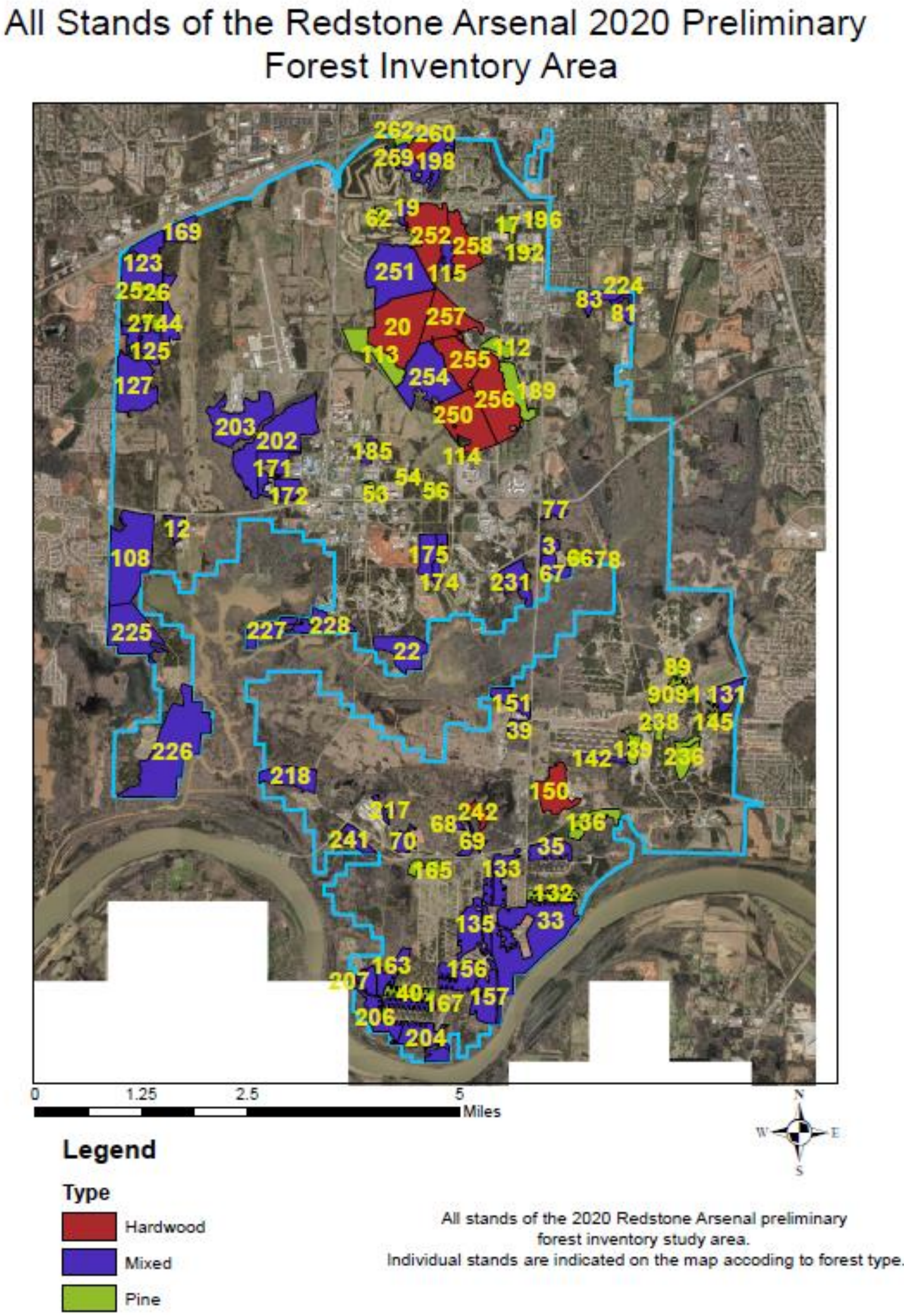

Figure 2.6: Map of Redstone Arsenal, Alabama showing stands surveyed from March 2020 to December 2021 and their forest types.

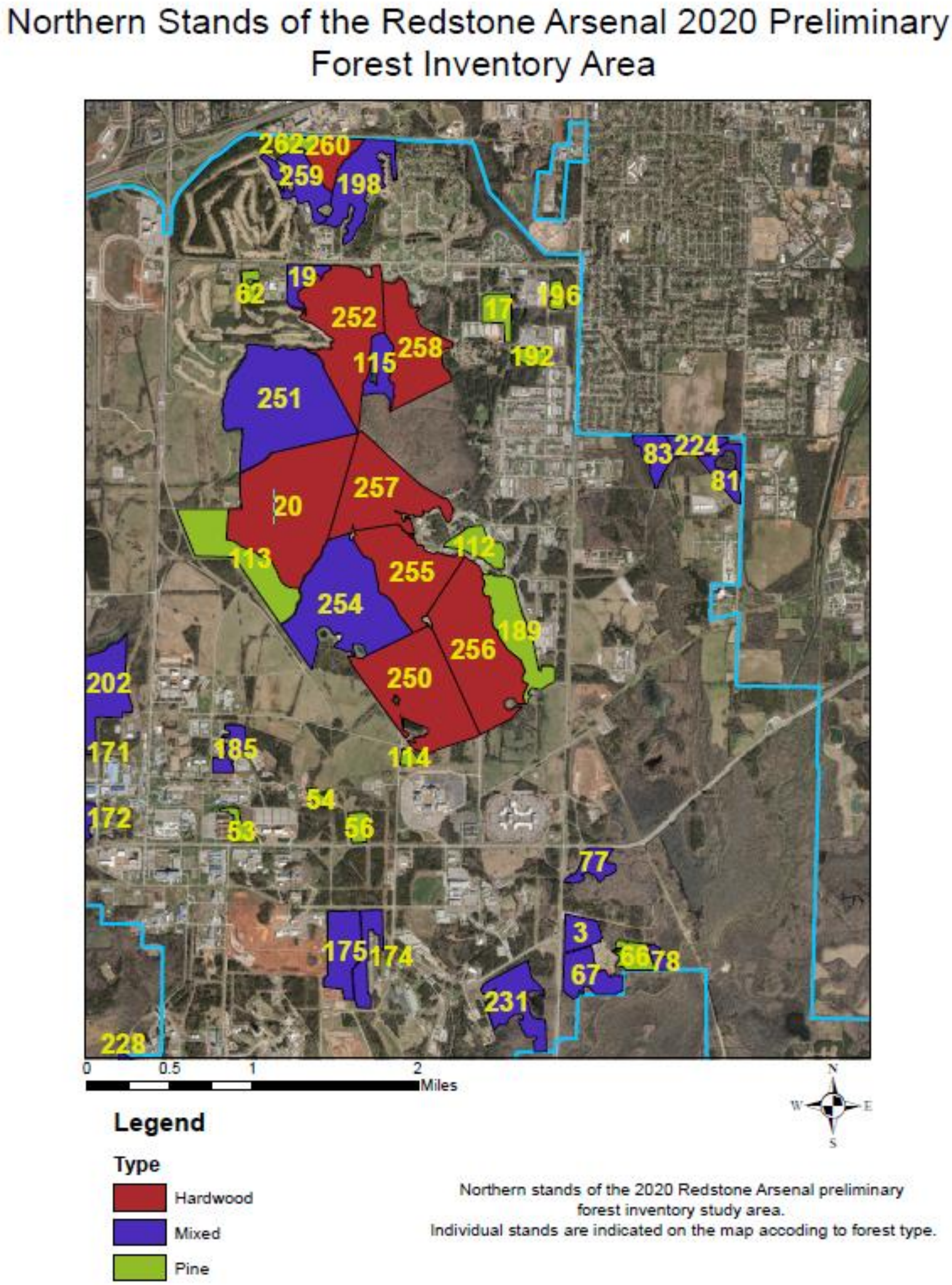

Figure 2.7: Map of Northern Redstone Arsenal, Alabama showing stands surveyed from March 2020 to December 2021 and their forest types.

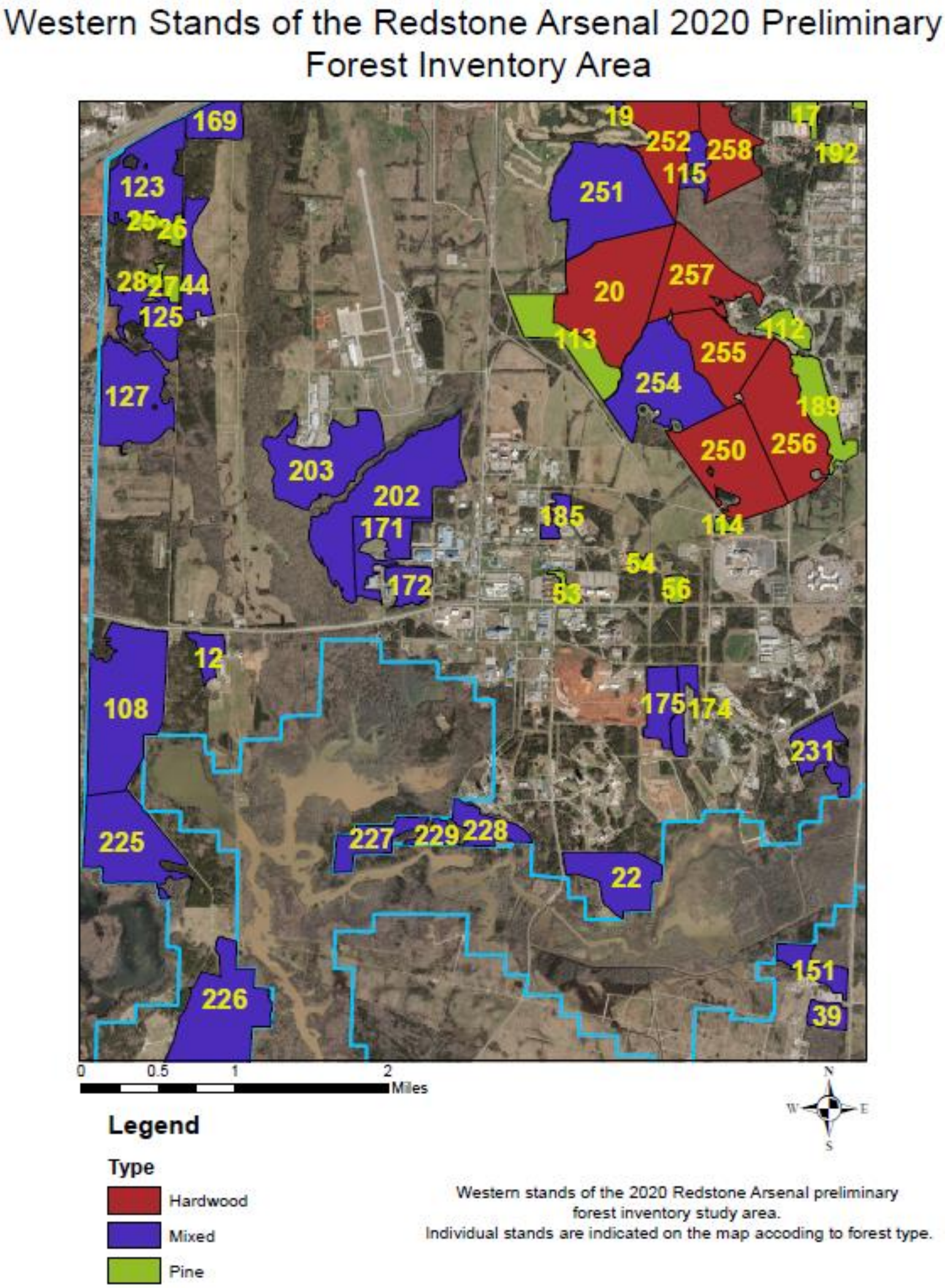

Figure 2.8: Map of western stands at Redstone Arsenal, Alabama, showing stands surveyed from March 2020 to December 2021 and their forest types.

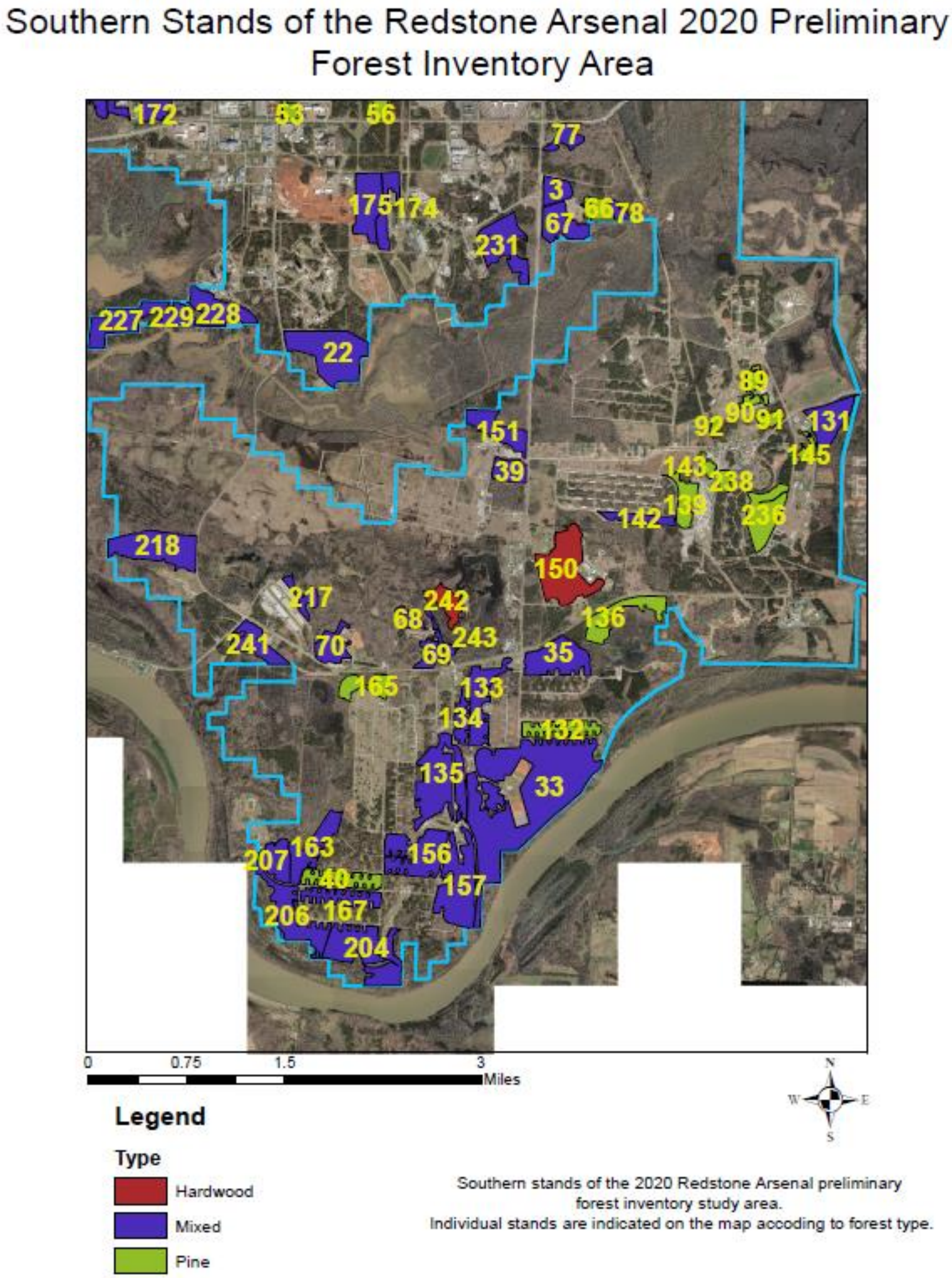

Figure 2.9: Map of southern stands at Redstone Arsenal, Alabama, showing surveyed from March 2020 to December 2021 and their forest types.

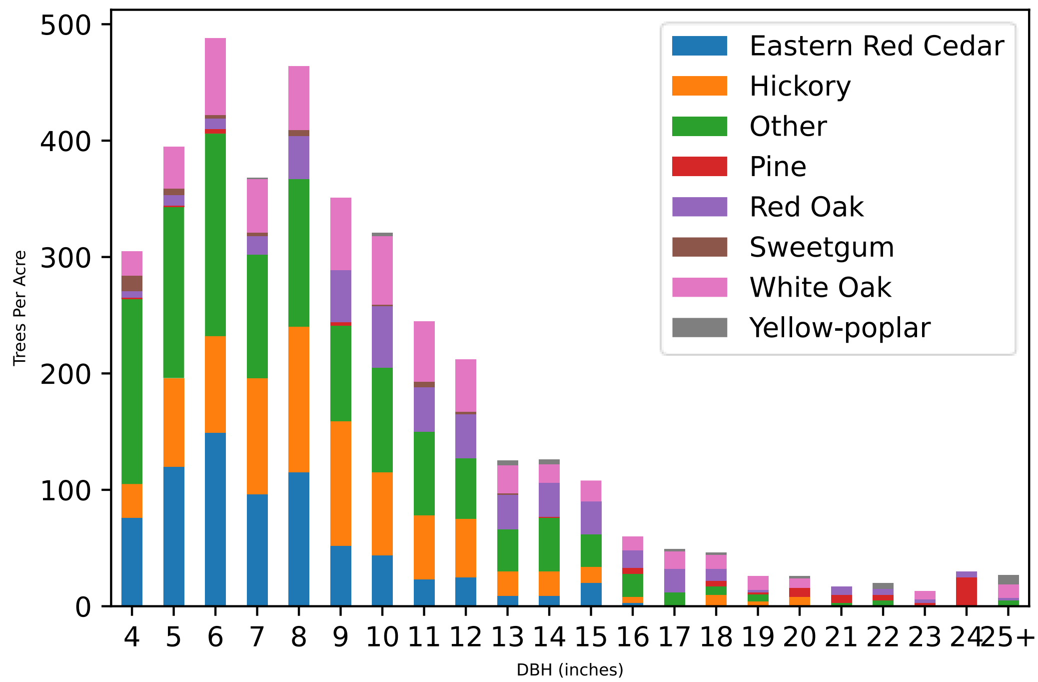

Figure 2.10: Diameter distributions for all hardwood forest stands at Redstone Arsenal, surveyed March 2020 to December 2021.

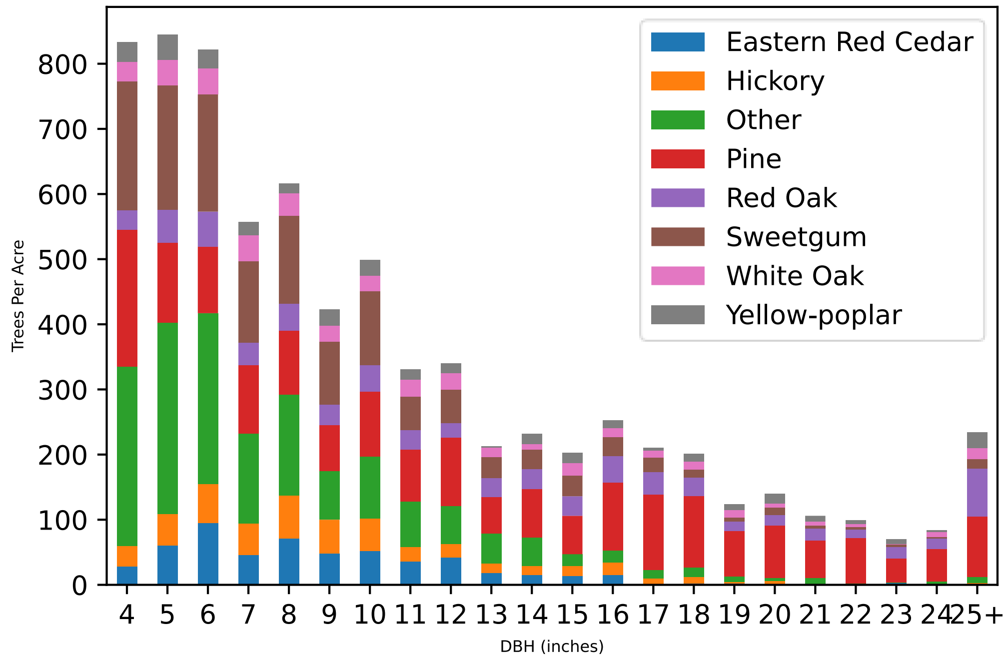

Figure 2.6: Diameter Distribution for all mixed hardwood-pine forest stands at Redstone Arsenal, surveyed March 2020 to December 2021.

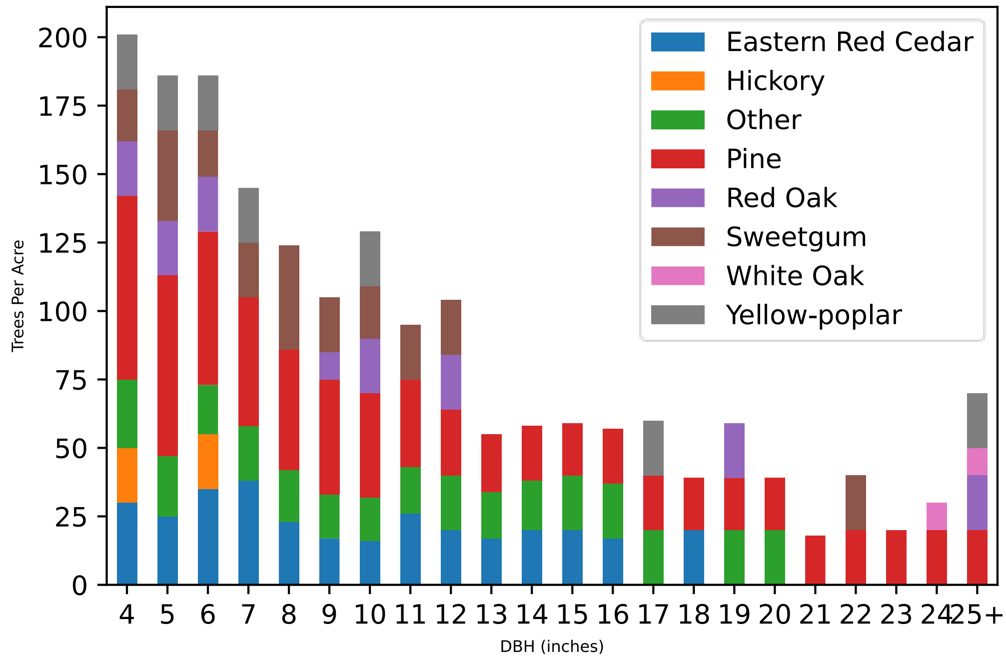

Figure 2.7: Diameter Distribution for all pine forest stands at Redstone Arsenal, surveyed March 2020 to December 2021.

Table 2.2. Basal area per acre and trees per acre for each species group and stand type surveyed at Redstone Arsenal from March 2020 to December 2021.

Stand Type	Species Group	Average Basal Area (ft2/Acre)	Average Trees Per Acre
Hardwood	Eastern Red Cedar	3.5	11
	Hickory	5.2	12
	Other Hardwoods	4.6	11
	Pine	18.5	10
	Sweetgum	2.9	10
	Red Oak	8.6	11
	White Oak	6.8	11
	Yellow-poplar	17.7	10
Mixed	Eastern Red Cedar	5.0	10
	Hickory	6.0	10
	Other Hardwoods	4.3	10
	Pine	16.3	14
	Sweetgum	5.5	11
	Red Oak	13.7	10
	White Oak	8.6	10
	Yellow-poplar	12.1	11
Pine	Eastern Red Cedar	9.6	24
	Hickory	2.5	20
	Other Hardwoods	7.1	20
	Pine	21.4	34
	Sweetgum	28.0	19
	Red Oak	7.3	24
	White Oak	67.3	10
	Yellow-poplar	10.4	20

Chapter 3: Integrating Imagery, Airborne LIDAR, and Field Inventory Data to Create a Spatially Complete Grassland Restoration Plan- A study of Madkin and Weeden Mountains in Redstone Arsenal, Alabama, USA

Abstract:

Redstone Arsenal (RSA) is the largest forested landholding in North Alabama, USA. However, much of the grassland ecosystems that once contributed to the region's ecosystem services such as biodiversity and erosion control, has been lost. The primary objective of this work was to determine prescribed treatment areas for grassland restoration for Madkin and Weeden Mountains in RSA, which comprise 780 hectares of forest. Image classification techniques were applied to generate maps of coniferous forest cover, understory brush, and potential grassland restoration sites, using aerial imagery, light detection and ranging (LIDAR) and field inventory data. Three image classification algorithms were implemented, and accuracies were compared: (1) maximum likelihood, (2) support vector machine, and (3) decision tree (DT). Using the most accurate product, recommendations were developed. Of the three methods used for classification, output from the DT classifier was the most effective, although modest (Overall accuracy = 39.9%). Nevertheless, this study demonstrates the possibility of creating a mapped product for grassland restoration. Specifically, application of this product enabled spatially explicit plans for where a combination of prescribed fire and herbicide for brush control may be used as the first step for grassland restoration. Overall, this work created a baseline for future research and the development of a more accurate product to support grassland restoration.

3.1 Introduction

Before Europeans' arrival to North America, the Southeastern United States was home to numerous prairies, meadows, and savannas. In the centuries before European settlement, American Indians used fire as a tool to clear land for agriculture, create and maintain hunting grounds, and protect their territories from fire. In conjunction with lightning-ignited fires, these anthropogenic fires created the various grassland ecosystems that act as habitat for roughly 60% of all plant species endemic to the Southeastern United States. Following European settlement, these fires were continued in some areas to clear land for row crops such as corn and cotton or grazed by cattle. Over time, the productivity of these lands decreased, farms were abandoned, and forest remnants could invade the once open land in the absence of fire. As a result, over 90% of all southeastern grasslands have become infested by tree species or converted into other land uses. One of the biggest challenges in protecting and restoring these ecosystems is merely identifying them among the fractured landscape (SGI, 2023).

Redstone Arsenal (RSA) was established near Huntsville by the U.S. Army in 1941 for weapons development and storage. It is the largest landholding in the Tennessee Valley of Alabama. It is located on the Eastern Highland Rim of the Interior Plateau, near the Cumberland Plateau in north-central Alabama. RSA is characterized by broad, gentle ridges with short but moderately steep slopes ranging from 170-206 meters in elevation. Of the 15,400 hectares on RSA, roughly 485 hectares make up various ponds, streams, and other water features on base, with another 5,900 hectares are prone to seasonal flooding. Upland areas on base are characterized by karst topography, such as sinkholes and caves.

RSA's red-brown soils are typically clayey or loamy and originated from alluvium, limestone, shale, or silt deposits. Soils in other parts of the base that are more dissected can be classified as cherty, clayey, silty, or silty. There are also three mountains on RSA, Madkin, Weeden, and Ward, which are outcroppings from the Cumberland Plateau and illustrate RSA's position as an ecotone between the Cumberland Plateau and the Eastern Highland Rim (Hart et al 2011).

Today, the Department of Defense requires all military bases, including RSA, to manage their lands for recreational purposes, natural resource extraction, and ecosystem health. Redstone Arsenal's unique place along the Eastern Highland Rim near the Cumberland Plateau makes it an incredibly diverse area home to 10 plant and nine animal species that are threatened, endangered, or of concern. This diversity is partly due to the varying topography, which creates microclimates for species that are typically found further north and south of RSA. The installation and other DoD lands can protect these species in the buffers between civilian and military activities. These areas have been used to practice troop maneuvers or, in the past, dump chemical waste from military exercises. However, these buffers are now used for natural resource management activities that may include conservation or related commercial activities to secure funding for conservation such as forestry, hunting leases, and agricultural activities (Hart et al 2011).

By that time, much of the Eastern Highland Rim was dominated by the prairie, oak savannas, shortleaf pine forests, and oak-pine forests. In seasonally wet savannas, a combination of oak and loblolly pine dominated the canopy, while oak and shortleaf were the main components of drier uplands savannas and forests (Schmidt, 2022). Prehistorically, these forests and grasslands were regularly burned by various indigenous groups to drive wildlife species, maintain farmland, and create hunting grounds for large game (DeSelm, 1990).

Since the early 20th century, the forest composition has begun to shift away from oak savannas and oak-pine forests to forests increasingly dominated by maple species (*Acer spp.*) and eastern red cedar (*Juniperus virginiana* L.). This invasion is the direct result of fire suppression, which allowed fire-sensitive species to grow unimpeded across the landscape and suppress the growth of oaks, pines, and grassland species. This change in composition has led to a loss of ecosystem services like biodiversity, hydrology, and nutrient cycling (Hart and Buchanan, 2012).

Former grasslands across the Cumberland Plateau and the eastern Highland Rim succumbed to fire intolerant tree species like eastern red cedar that indicate former farms, barrens, savannas, and meadows. Before fire suppression on the landscape, species like eastern red cedar and maple would have been confined to areas protected by fire, but land use and fire management policy changes have since allowed these species to spread from their refugia and invade grassland ecosystems. Fire suppression of these ecosystems has also contributed to the decline of economically important species, such as white oak (*Quercus alba* L.) (Abrams, 2003). Redstone Arsenal's position as a protected ecotone between the Cumberland Plateau and the eastern Highland Rim provides a unique opportunity to protect endangered species that were once common across both physiographic regions.

Of the five mountains on Redstone Arsenal, Madkin and Weeden mountains are one of the best sites for the installation's grasslands restoration. Redstone Arsenal is federally protected land and is managed according to the DoD, federal guidelines, and state and municipal laws. It is already one of three publicly owned areas that are home to the endangered Price's potato-bean (*Apios priceana* B.L. Robins.), a species that only grows on forest edges and suffers from forest closure (USFWS, 2019). The mountain is also the site of numerous bike trails that allow for engagement between ecosystems found on Madkin and Weeden mountains and the surrounding military and civilian communities. This community engagement allows land managers to connect the surrounding community to the restoration process and improve grassland restoration efforts on Madkin and Weeden mountains. RSA is also responsible for developing a broad scientific community in the region by providing highly specialized jobs in the engineering and aerospace fields. As a result, five universities, numerous technical schools, and over 40 primary and secondary schools have been created in Madison County, Alabama, and allow for more technical and educational opportunities that may help with the success of restoration projects in the region (Schmidt, 2022).

Oak-hickory-ash savannas like those historically found on Madkin and Weeden mountain are characterized by relatively low average basal areas of 8m^2/hectare and 82 trees per hectare. By removing or thinning stands of fire intolerant species, thinning other stands of fire-tolerant species, reintroducing fire-dependent species such as shortleaf pine and oaks, as well as creating a fire regime that is like that of the precolonial period, we may see the return of oak and pine savannas on RSA (Dey et al., 2017). A restoration project like this would face many hurdles, particularly in the form of public scrutiny over the use of prescribed fire that would be necessary for the re-establishment and maintenance of grasslands. However, RSA's location and the policies placed on it by the DoD protect it from land-use changes that affect the surrounding landscape, making land management easier so long as it furthers RSA's and the DoD's missions. Restoration of the fire regime on base would help improve recreational activities for hunters, hikers, and mountain bikers by increasing the biodiversity present on base and creating more aesthetically pleasing environments for such activities. However, the first task for restoring any ecosystem must be inventory and mapping of the area.

While RSA sits primarily on the Eastern Highland Rim of the Interior Plateau ecoregion, numerous mountains on the base are outcroppings of the Cumberland Plateau (Hart et al 2011). Thanks to the rough terrain and rocky soils, one such mountain, Madkin and Weeden mountains, was left untouched by agriculture. This terrain also creates microclimates that provide habitat for species found much further and south of the other areas on the eastern Highland Rim. Because of fire exclusion, grassland remnants across the mountain have since been invaded by fast-growing, fire intolerant species such as eastern red cedar (*Juniperus virginiana* L.) and maples (*Acer spp.*) that put grassland ecosystems at risk of extinction (Camaretta et al., 2020). Restoration of grasslands on Madkin and Weeden mountains would provide the avid mountain-biking community, numerous colleges, universities, and primary schools, as well as hunters and other outdoor enthusiasts that live in and around RSA every day an opportunity to engage with the restoration process. Restoration would also improve critical habitat for game species such as turkey and deer, as well as endangered plant species, like Price's potato bean (*Apios priceana* B.L. Robins.), of which the RSA population is one of only three communities on federal land (USFWS, 2019).

Every ten years, each military base in the United States is required to submit a complete forest inventory to the Department of Defense (DoD) to determine if the base follows federal, state, and local environmental regulations. This forest inventory data is typically used to plan future harvests of timber, wildlife management plans, and environmental remediation and mitigation programs put on by the base. The primary goal of this study was to create grassland restoration recommendations for Madkin and Weeden mountains for RSA. By collecting field data typically used for updating the base's field inventory, along with observations on plot understory condition, this study served to investigate an approach to inform grassland restoration of an ecologically significant site (Hart et al 2011). To develop a product showing the locations and recommended restoration activities for understory invasive species, coniferous species, and remnant grasslands (less than 0.2 hectares in size), image classification methods using ground observations, airborne light detection and ranging (LIDAR) data and aerial imagery were utilized. The motivation for such an approach was to create a spatially complete product so that land managers can plan restoration activities and more efficiently allocate resources. With such a product, restoration practitioners may discern where to focus resources for restoration activities such as prescribed fire, thinning, and herbicide applications, as well as monitor the progress of restoration activities (Dey et al., 2017). Without establishing such a baseline, monitoring of ecological restoration projects may remain challenging (Camaretta et al 2020).

3.2 Materials and Methods

Study Area

The study area (Figure 1) is located on the Eastern Highland Rim of the Interior Plateau, near the Cumberland Plateau in north-central Alabama in the Southeastern United States (34°40'N,86°38'W). RSA is characterized by broad, gentle ridges with short but moderately steep slopes ranging from 170-206 meters in elevation. Of the 15,400 hectares on RSA, roughly 480 hectares make up various ponds, streams, and other water features on base, with 5,900 hectares are prone to seasonal flooding. Upland areas on base are characterized by karst topography, such as sinkholes and caves. RSA's red-brown soils are typically clayey or loamy and originated from alluvium, limestone, shale, or silt deposits. Soils in other parts of the base that are more dissected can be classified as cherty, clayey, or silty. There are also three mountains on RSA, Madkin, Weeden, and Ward, that are outcroppings from the Cumberland Plateau and illustrate RSA's position as an ecotone between the Cumberland Plateau and the Eastern Highland Rim (Hart et al 2011).

Data

For this project, we collected field inventory data on the number of trees per hectare, diameter at breast height, and total height at ninety-eight 0.04-hectare plots placed along a grid using Landmark Spatial Solutions' EZ plot toolbar for ArcGIS The EZ plot toolbar is a powerful tool that establishes a grid of plots for field inventory data based off a polygon for the area and user defined inputs. In the field, plots for data acquisition were randomly selected and found using a Nautiz X8 GPS with 1-3m accuracy (Landmark Spatial Solutions, 2023). One-meter subplots were established at 5.7 meters north of the plot center and used to observe and estimate understory species composition. Data collected on these one-meter subplots consisted of qualitative descriptions of the forest understory but were primarily used to determine if native herbaceous species or woody understory species such as Bush Honeysuckle (*Lonicera Maackii* Rupr.) or Chinese privet (*Ligustrum sinensis* Lour.) were present in the area. These data were used for image classification to generate maps of forest and grassland ecosystems. Understory data were used to classify each plot as grass, brush, hardwood forest, or coniferous forest. Finally, unvegetated areas totaling 0.4625 hectares in size such as exposed soil, road surfaces, buildings, and rocky outcroppings were visually assessed and marked for classification since these areas may potentially cause class confusion but were removed from the final mapped product.

Imagery used in this project were derived from DoD and US Geological Survey (USGS) sources. RSA personnel provided true color, leaf off, aerial imagery of the installation with 0.5-meter spatial resolution taken in 2018.While more recent LIDAR data were available as recently as 2020, these data only included classified ground points and no vegetation data and were excluded as a result. LIDAR data used had a point density of 7.0 points per m^2 and were collected in 2011, nearly a decade prior to the start of field data collection. Interactions with RSA personnel indicated that current control methods for nonnative invasive species within the study area had been met with limited success. Therefore, it was assumed that few changes to the populations of bush honeysuckle and Chinese privet had occurred in the intervening years (Hicks, 2020).

USGS data were collected as part of the National Agricultural Imagery Program (NAIP) in the summer of 2017 which was the latest available at the time of the study. The 1-meter resolution NAIP imagery bands used were bands 1 (red) and 4 (near-infrared) to create a Normalized difference Vegetation Index (NDVI), calculated using the red and near-infrared bands from the NAIP imagery. Only the NDVI derived band was used for classification and is expressed in the following equation (Huang et al., 2021).

$$(1)\ NDVI = \frac{NIR - Red}{NIR + Red}$$

Where NDVI is the normalized vegetation index and NIR and Red are the brightness values for the near infrared and red bands respectively. NDVI has been used in the past to estimate various attributes in remote sensing such as leaf area index (LAI), biomass, and plant stress (Huang et al., 2021). However, the most important application of NDVI for this study was its ability to assist in differentiating between dense evergreen forest, seasonal forest, savanna, grassland, and other land types.

Data processing

Field data were input into an ArcGIS database where each plot was classified based on species composition, presence of woody understory species, and presence of herbaceous understory species for image classification. Plots with greater than 50% coniferous species (*Pinus spp. or Juniperus virginiana* L.) by basal area were classified as coniferous or otherwise classified as hardwood overstory. Plots with woody understory species were classified as understory brush. Plots with herbaceous understory species and not classified as coniferous, were classified as remnant grassland. Plots, roads, and other areas with no vegetation were classified as unvegetated areas. Thus, information classes used for image classification were grass, coniferous forest, hardwood forest, brush, and unvegetated areas.

Discrete return LIDAR point clouds were processed using LAStools (Isenberg, 2022). First, the LASheight function was used to compute the height of points above all the classified ground points. The normalized point clouds were then used to generate a 0.15-m^2 canopy gap grid, which shows the gap fractions of the overstory, and a 0.15-m^2 gridded brush layer, which shows the relative density of points at 1.4 meters above the ground. Both products were generated using LAScanopy, which can compute the density of points within an area.

Imagery was processed using ENVI (L3 Harris Geospatial, 2022). NAIP imagery was first used to create a Normalized Digital Vegetation Index band using its near infra-red (NIR) band and ENVI's NDVI tool. Image mosaicking was used to combine multiple scenes for images from DoD, NDVI, and LIDAR-derived rasters prior to clipping images to the study area. All bands were resampled to 0.5-meter spatial resolution and stacked for image classification in ENVI.

Image classification

To establish a baseline for remote sensing analyses in the region, three popular classification techniques were implemented, and their accuracies were compared: maximum likelihood, support vector machine, and decision tree analysis. These techniques were selected for their popularity in land cover classifications with the expectation that one of them would be best suited for establishing a baseline product for the region with the data available. Decision tree was found to be popular for its ability to easily work with nonparametric data and with data sources of varying spatial resolutions (Holloway et al., 2019). Maximum likelihood's popularity stems from its ability to produce higher overall accuracy for normally distributed data (Otukei and Blaschke, 2010). Finally, support vector machine is often used for its ability to produce higher accuracy than other methods when there are very few data for training and validation data (Mountrakis et al., 2011). One study, Otukei and Blaschke (2010), compared these three techniques and found that while all techniques produced similar results, decision trees were the most accurate. However, their research focused on the classification of crop types over time rather than the classification of forest cover or grassland identification.

Part of the popularity for decision trees is their ability to handle data measured on different scales, lack of assumptions, and the ability to handle non-linear relationships (Otukei and Blaschke, 2010). Training of decision trees is also relatively easy to understand compared to what one would find in the case of support vector machines and other black box methods as the model for decision tree is user-defined and designed to be easily interpreted (Berhane et al., 2018). Decision tree classification works by creating a recursive separation of data based on a series of binary decisions to determine the end-user class for each pixel and has proven useful for many remote sensing applications in the past. For instance, Holloway et al., (2019) used decision trees to classify areas of grassland and forest in satellite images. Hansen et al., (2016) utilized decision trees to map land cover at a continental scale. Al-Obeidat et al., (2015) compared a modified decision tree algorithm with other conventional decision trees for classifying large datasets of spectral data. Sharma et al., (2013) also developed a decision tree for satellite image classification using open-sourced tools.

Rules for the decision tree involved classification of bare earth, grassland, brush, coniferous forest, and hardwood forest. In the first node of the decision tree, vegetation and bare earth were separated based on NDVI, where values less than or equal to 0.3 were classified as bare earth. Anything greater than 0.3 was classified as vegetated. Pixels with an NDVI value less than or equal to 0.5 were classified as grassland. In the third node, the LIDAR-derived brush grid was used, since that shows the density of returns within 0 and 1.4 meters in and is used to identify areas with a large amount of brush. Pixels within the brush grid where the proportion of returns was greater than or equal to 0.4 were classified as having a large amount of brush that would need removal with herbicide and prescribed fire. Values from the green image band (band 2) of the RSA imagery where values of green coloration were less than 100 were classified as coniferous forests while all other values were classified as hardwoods.

Maximum likelihood, one of the more commonly used supervised classification tools, assigns pixels to a class based on the probability that they belong to that class. For normally distributed data, this allows for the algorithm to take variance and covariance of data into account and more correctly assign data to the correct class. The result is that maximum likelihood typically outperforms other classification techniques when used to classify normally distributed data (Otukei and Blaschke, 2010). Non-parametric data, such as those acquired from multi-sensor or multi-temporal sources may have a negative impact on accuracy with maximum likelihood classifiers (Nitze et al., 2012).

Support vector machine (SVM), a set of non-parametric training algorithms for regression and classification, was also applied. Machine learning algorithms used in SVM can model complex relationships often better than other parametric techniques, especially when using data with high dimensionality (Otukei and Blaschke, 2010). The SVM classification method does this by focusing on the edges between two classes and define that boundary (Maxwell et al., 2018). One of the key advantages to SVM is its ability to classify areas with relatively little training data compared to other methods. However, it is more prone to errors derived from user input parameters and from noisy or highly dimensional data such as mountainous terrain or with multi-temporal data (Mountrakis et al., 2011).

Sixty-five plots were used as training data for image classification. Plots were stratified based on understory species recorded in the field survey and dominant overstory species. Plots with herbaceous species were labelled as grassland, while plots with brushy understory species such as bush honeysuckle were labelled as brush. Plots with no species recorded in the understory were labelled based on the dominant overstory species composition on the assumption that they were too dense to support herbaceous species and had not yet been invaded by nonnative invasive species. Another 33 randomly selected plots from each class and roughly 0.46 additional hectares of pixels consisting of visually assessed unvegetated areas such as roads, buildings, and bare earth were used for conducting accuracy assessments using confusion matrices. Overall accuracy and kappa coefficient values were also computed for each classification, where overall accuracy is the percentage of correctly identified pixels (Chuvieco, 2020). Overall accuracy is calculated as the percentage of correctly classified pixels of the total number of validation pixels.

Kappa coefficient, which is a value of agreement between classified values and ground truth values, is calculated as overall accuracy minus chance agreement divided by 100 percent minus the chance agreement. Values closer to one indicate a strong agreement between the classification and the ground truth pixels while values closer to 0 indicate that any agreement between values was up to chance (L3 Harris Geospatial, 2022). Kappa is calculated according to the equation below:

$$(2)\ K = \frac{N\sum_{i=1}^{n}(m_{i,i}) - \sum_{i=1}^{n}(G_i C_i)}{N^2 - \sum_{i=1}^{n}(G_i C_i)}$$

Where i is the number of classes, N is the total number of classified values compared to the truth values, $m_{i,I}$ is the number of values found along the diagonal of the confusion matrix, C_i is the total number of predicted values in class i, and G_i is the total number of truth values belonging in class i (Congalton et al., 1983).

Errors of commission are another component of confusion matrices and represent the fraction of false positives within a classification. These values were predicted to be in a class but do not belong to that class. The following equation was used to calculate errors of commission for each class:

$$(3)\ Com = \frac{bA+cA}{\sum A}$$

Where Com represents the errors of commission for a class, $\sum A$ represents the sum of all pixels for class A, where bA and cA are the number of pixels that were incorrectly attributed to class A (Congalton et al., 1983).

Errors of omission are the measure of false negatives in a confusion matrix and represent the fraction of values that belong to a class but were predicted to be in a different class. The following equation was used to calculate errors of omission:

$$(4)\ Om = \frac{(aB+aC)}{\sum a}$$

Where Om is the number of pixels for errors of omission, $\sum a$ is the sum of all pixels predicted to be in class A, aB and aC are the number of pixels that belonged in class A but were predicted to be in classes B and C respectively (Congalton et al., 1983).

Producer's accuracy is the probability that a given class was correctly classified and is a measure of a given method's ability to correctly classify imagery. This can be calculated as:

$$(5)\ PrAC = \frac{aA}{\sum A}$$

Where aA is the number of correctly identified pixels for class A and $\sum A$ is the sum of all ground truth pixels for class A(Congalton et al., 1983).

User accuracy is the probability that that a predicted pixel is really in that class and is a measure of how useful the resulting product would be to a user in the field.

$$(6)\ UsAC = \frac{aA}{\sum a}$$

Where aA is the number of correctly identified pixels in a class and $\sum a$ is the number of pixels for class A in the classified image (Congalton et al., 1983).

Prescriptions

Oak-savanna restoration would require the prescribed use of three methods to increase light in the understory and to reduce or eradicate woody stems that may outcompete herbaceous species. These prescriptions include thinning of the overstory, herbicide application, and prescribed fire. Thinning is the simplest of these methods, where removal of overstory species creates an almost immediate – although ephemeral – flourishing of understory herbaceous species. The removal of overstory species also benefits woody species that, without intervention, will soon outcompete herbaceous species (Dey et al., 2017). By mapping these areas out, mechanical thinning operations may be conducted more efficiently and possibly even generate some income to fund further restoration activities. Thinning of coniferous forests would also have to be more intensive to encourage hardwood species such as oaks to grow on site alongside the herbaceous understory (Dey et al., 2017).

Herbicide applications have been proven to reduce the competition from woody stems in grassland ecosystems, whether by applying it after mechanically damaging the stem such as injections, or by applying a foliar spray – particularly following prescribed fire. Herbicide applications have the added benefit of controlling nonnative invasive species such as bush honeysuckle or Chinese privet that outcompete many native herbaceous and woody species. By mapping out areas that are already heavily affected by brush, herbicides may be more efficiently applied to combat midstory and understory woody species (Dey et al., 2017).

Finally, prescribed fire is perhaps the most critical prescription for oak savanna restoration. Regular application of prescribed fire exposes bare mineral soils that aid in the establishment of many herbaceous species found in grasslands as well as fire-tolerant woody species, eliminates fire-intolerant species such as maples, and has been found to severely reduce the presence of invasive species on a site when used in conjunction with herbicides. When done properly, prescribed fire can encourage the growth of native herbaceous species and improve oak germination, further supporting the development of oak-savanna ecosystems. However, prescribed fire applications can be dangerous and require proper weather conditions and proper timing to be safe and effective. Therefore, proper planning is critical to the application of prescribed fire (Dey et al., 2017). With this in mind, we focused mapping areas of coniferous forests largely dominated by eastern red cedar for thinning and prescribed fire, as well as areas with a large amount of brush in the understory with the purpose of applying prescribed fire followed by herbicide applications.

3.3 Results

Of the three classification techniques, maximum likelihood provided least accurate results, with an overall accuracy of 14.40% and a kappa of 0.07 (Table 1). User's accuracy for the maximum likelihood classification was highest for the unvegetated area class with a 99.98% accuracy. The class with the next highest accuracy using maximum likelihood was grass with a 36.25% accuracy. Brush, coniferous forest, and hardwood forest all had similar accuracies of 22.21%, 26.46%, and 25.46% respectively. Producer's Accuracy was also highest for the unvegetated area class (99.19%) followed by the coniferous class (49.58%). Hardwood and brush had producer’s accuracies of 32.63% and 20.90% while grasses had the lowest producer’s accuracy of 2.21%.

The image produced from SVM classification had an overall accuracy of 25.41% and a kappa of -0.02 (Table 2). The results for each of these are below, along with an image of the associated classification. User’s accuracy was highest for the unvegetated area class (100%), the grassland class (30.61%) followed by brush (24.27%). Coniferous forest and hardwood forests had similar user accuracies of 7.88% and 7.85% respectively. Producer’s accuracy was highest for the unvegetated area class (100%), followed by the hardwood class (16.83%), the coniferous forest class (11.84%), the brush class (3.45%), and the grassland class (0.57%).

The Decision tree was most accurate with an overall accuracy of 39.99% and a kappa of 0.22 (Table 3). User’s accuracy using the decision tree classification was highest for the unvegetated area (99.16%) and the grassland classification (99.16%). Coniferous forest, hardwood forest, and brush had user’s accuracies of 33.58%, 24.44%, and 23.83% respectively. Hardwood forest had the lowest user’s accuracy of 19.20%. Producer’s accuracy was highest for unvegetated area at 100%. Brush, coniferous forest, and hardwood forest had producer’s accuracies of 55.02%, 17.41%, and 14.10% respectively. Grass had the lowest producer’s accuracy of 8.53%.

Given accuracy achieved with the Decision tree algorithm, this output was used for developing grassland restoration prescriptions. Figure 2 shows the decision tree classification with the unvegetated area and hardwood forests classes removed and overlaid onto NAIP 2017 imagery. Each remaining class was given a prescription for restoration of oak savanna based on Dey et al., (2017). Areas of dense brush were given the prescription of herbicide treatment followed by burning. Coniferous forests were marked for thinning and burning. Grasslands were marked so that the species currently listed could be inventoried and these areas could be maintained. In particular, the reintroduction of fire to grassland ecosystems such as oak savannas are critical in their restoration. When used in combination with selective herbicide use and thinning of overstory species, prescribed fire has a significant impact on the restoration of grassland species.

3.5 Discussion

Grasslands once covered much of North America and greatly contributed to the biodiversity that was found in this region. In the southeastern United States, these ecosystems contribute to over 60% of all plant species that are endemic to the region (SGI, 2013). Following colonization by European settlers, much of the land-use practices in the region favored intensive agriculture, fire suppression, and urban development that have led to the decline of grasslands across the continent (Hart et al., 2012). As a result, biodiversity across the region has begun to decline and many plant and animal populations found in early successional habitats like grasslands have been declining, including economically important species such as oaks and shortleaf pine (*Pinus echinata* Mill.) (SGI, 2023; Dey et al 2017).

Restoration of these grassland ecosystems in the southeastern United States would provide an opportunity to save some of these species. Areas such as national parks and military bases like Redstone Arsenal (RSA), would provide added protections and connect the public to restoration projects. In particular, the Weeden and Madkin mountain recreation area on RSA would provide an opportunity to connect the public to the importance of grassland ecosystems while also providing long term protection of the site through the US Department of Defense (DoD). This area, while lying in the Eastern highland rim of the interior plateau, is an outcropping of the nearby Cumberland plateau and was like the Cumberland escarpment, an area that was likely covered by oak-savannas (Hart et al 2011). However, the area is rather large (780-hectares), and a restoration project of this scale would require careful planning and support. One way to achieve more effective prescriptions for restoration would be using remote sensing to identify areas within an area that need different methods for ecological restoration – particularly use of herbicides to remove invasive brush species, reintroduction of fire, thinning of overstory species, and surveying grassland remnants. These methods have been found to reduce competing understory vegetation such as invasive brush species and improve seed germination in grassland species.

Using mapped products like those produced here helps restoration practitioners to plan and more precisely apply their methods for restoration to a site, potentially leading to reduced costs and increased effectiveness of those methods (McKenna et al., 2021). Prescribed fire, herbicide application, and thinning of the overstory are all necessary methods for the re-establishment of grassland ecosystems on sites like Weeden and Madkin Mountains on RSA. With the output in Figure 2 as a baseline, herbicide application and prescribed fire may be used to control invasive understory brush species such as bush honeysuckle and Chinese privet, while overstory thinning would allow for the natural regeneration of oak species. Areas of potential refugia for grassland species shown in

Figure 2 may be inventoried to determine what herbaceous species are currently present and potentially serve as a seed source for their re-establishment.

Similarly, these mapped products provide a baseline to measure the progress of restoration projects that future mapped products may be compared to. Monitoring of restoration activities via remote sensing or any other means has been relatively rare in many situations. Martin et al. (2021), found that only three out of 174 organizations focusing on tropical and subtropical forest restoration had some kind of monitoring program in place to effectively measure their impact . Improved access to and use of remote sensing tools may provide restoration practitioners with an easier and more cost-effective method of monitoring projects (McKenna et al., 2021). Regardless of the low accuracy, the product here may be used to measure the impact of restoration activities at Weeden and Madkin mountains.

Of the three techniques used to create the mapped product, the DT technique created the most accurate mapped product with an overall accuracy of 39.99% while SVM and maximum likelihood produced worse results (25.41% and 14.42% respectively). These findings are consistent with what Otukei and Blaschke (2010) found in their study comparing these three techniques However, in that study, all of their techniques achieved an overall accuracy of more than 85% and focused on crop-type identification rather than strictly grassland and forest cover classification. The researchers also found that removing unnecessary data, such as certain bands in images, either had no effect or in the case of SVM, improved classification.

Maximum likelihood classification created the worst results in this study, likely due to the use of multi-source data. In a comparison of nonparametric methods such as SVM, artificial neural networks (ANN), and random forest (RF) classification (Nitze et al., 2012) found that maximum likelihood performed worse than the other methods studied. Their findings indicated that the use of a parametric method such as maximum likelihood would yield lower accuracies for multi-sensor and multi-temporal data relative to nonparametric methods.

Support Vector Machines (SVMs) have generally been considered popular within remote sensing, particularly for their ability to get a high accuracy with limited training samples. However, there are several pitfalls to this method, namely the fact that parameter selection may have a large influence on classification outcome, and there are no clear heuristic approaches to the selection of these parameters (Mountrakis et al., 2011). The result is either classifications with low accuracies or a timely trial and error approach to classification. SVMs are also sensitive to noisy or highly dimensional data, such as imagery of mountainous areas or multi-sensor data. While SVM had the second highest overall accuracy in this study, it is likely that the mountainous terrain and multiple sensors used had a major impact on the overall accuracy and kappa value of the resulting product.

Overall, the limited sample size might have contributed to the modest accuracies found in this study; of 98 plots spread out across the study area (780-hectares), 65 of them were used for training and the remaining 33 were used for accuracy assessments. Other potential sources of error include the point density of the LIDAR data and the subsequent gridded products created, and the temporal mismatch between field data (2020) and the available LIDAR data (2011). While this is a significant difference in time between acquisition of LIDAR and field data, the 2011 data were the most recently acquired data with point clouds that included vegetation data. It is certainly possible for changes to have occurred in understory vegetation within the intervening years, but base personnel indicated that the populations of nonnative understory vegetation within the study area are steady. Therefore, it was assumed that very little change in these populations had occurred. In a study by Berhane et al., (2018), authors found that the use of ancillary data in their classification of wetlands decreased overall accuracy regardless of the method used. Their reasoning was that use of low-resolution digital elevation model (DEM) and hydrogeomorphic layers with high-resolution imagery, provided noise rather than discernible data for classification.

In general, use of LIDAR-derived and other ancillary data has been found to improve accuracy of remote sensing classification, particularly in grassland remote sensing. There are, however, limitations that need to be addressed when using these data. In particular, the use of nonparametric deep learning models such as random forest, SVM, or ANN are needed to better handle the high dimensionality of multi-source products such as satellite imagery combined with LIDAR derived products like DEMs and canopy gap models. Vegetation indices, like the NDVI used in this project, are also more likely to improve accuracy of land cover classifications, particularly for grasslands. While this project provides a baseline for establishing a restoration plan of Weeden and Madkin mountains, to potentially achieve more accurate outputs, future studies may investigate use of deep learning models, higher-resolution ancillary data and other mapped products, such soil maps (Martin et al., 2021).

This study served to determine where certain grassland restoration practices would need to occur within the study area and to establish a baseline for future research. In doing so, a methodology for assigning these practices with remotely sensed data was established, and limitations to the current study were acknowledged. Future research in the area may rely on a larger sample size than what was used here. More up-to-date LIDAR data or other ancillary data may also be examined for creating a more accurate mapped product for future restoration efforts. Regardless, repeated sampling of an area undergoing ecological restoration is needed to determine project success. As a result, any project involving the restoration of ecosystems should involve the regular acquisition of field data that may be used to generate accurate and updated mapped products.

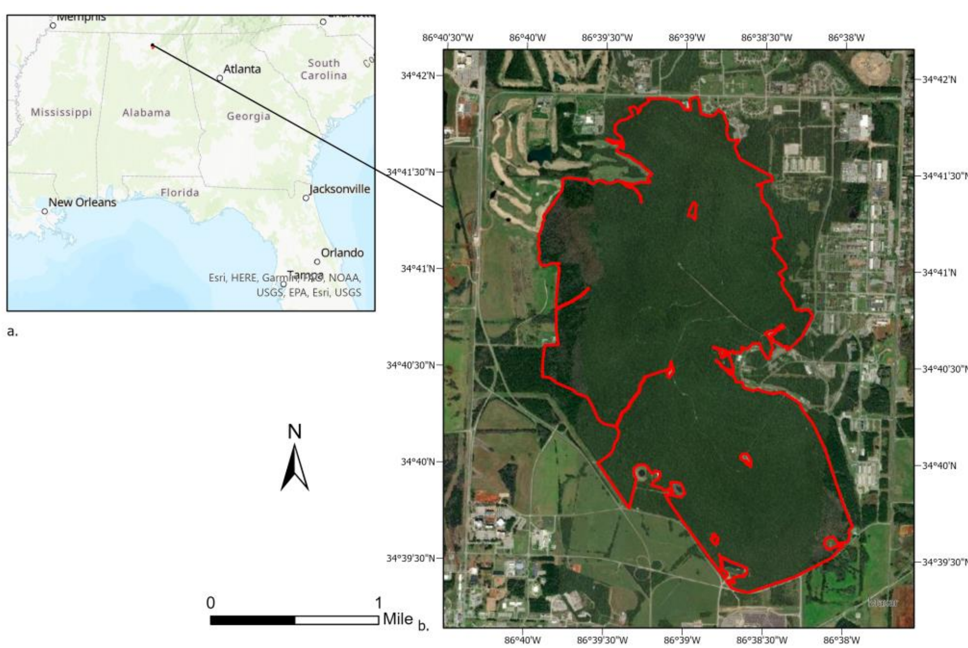

Figure 3.1. Location of the study site in (a) Alabama, USA on Esri's Topographic basemap and specifically, (b) Madkin and Weeden mountains within Redstone Arsenal over Esri's Imagery basemap (Esri, 2022).

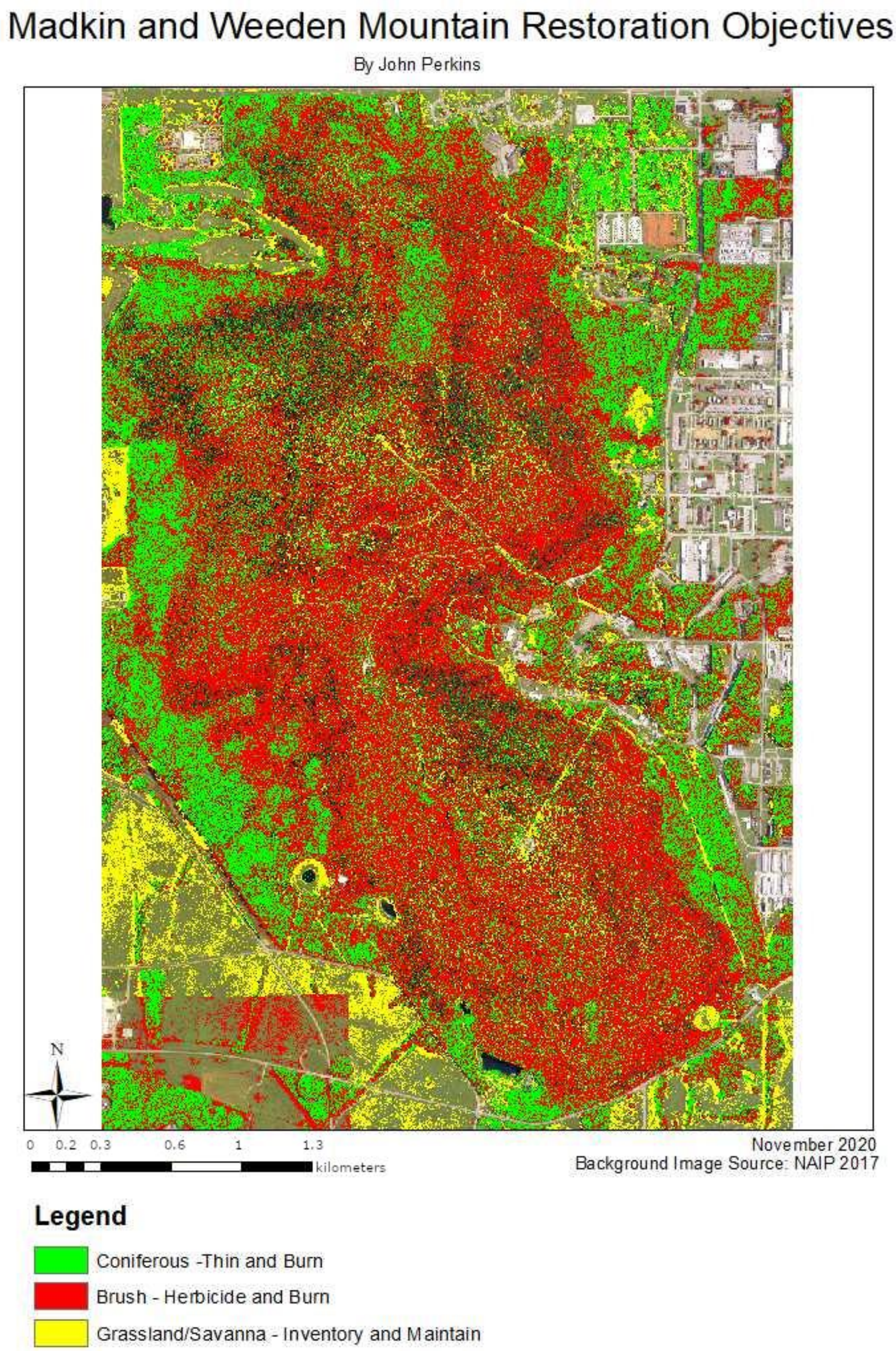

Figure 3.2. Map generated from decision tree classification showing prescribed treatment areas for grassland restoration.

Table 3.1. Confusion Matrix Results for Maximum Likelihood Classification.

	Ground Truth (Percent)						User's Accuracy (Percent)	Commission Error (Percent)
Class:	Unvegetated Area	Grass	Brush	Coniferous	Hardwood	Total		
Unvegetated Area	99	0	0	0	0	45	100	0
Grass	0	3	1	1	1	1	36	64
Brush	0	21	21	17	14	10	22	73
Coniferous	0	34	42	50	52	24	26	74
Hardwood	0	42	37	32	33	19	25	75
Total	100	100	100	100	100	100		
Producer's Accuracy (Percent)	99	2	21	50	33			
Omission Error (Percent)	1	98	79	50	67			

Table 3.2. Confusion Matrix results for Support Vector Machine.

	Ground Truth (Percent)						User's Accuracy (Percent)	Commission Error (Percent)
Class:	Unvegetated Area	Grass	Brush	Coniferous	Hardwood	Total		
Unvegetated Area	100	0	0	0	0	46	100	0
Grass	0	1	0	1	0	0	31	69
Brush	0	1	3	3	6	2	24	76
Coniferous	0	24	24	12	77	20	8	92
Hardwood	0	74	72	84	17	33	8	92
Total	100	100	100	100	100	100		
Producer's Accuracy (Percent)	100	1	4	12	12			
Omission Error (Percent)	0	99	96	88	88			

Table 3.3. Confusion Matrix results for Decision tree.

	Ground Truth (Percent)						User's Accuracy (Percent)	Commission Error (Percent)
Class:	Unvegetated Area	Grass	Brush	Coniferous	Hardwood	Total		
Unvegetated Area	100	0	0	1	0	46	99	1
Grass	0	8	4	5	7	3	34	66
Brush	0	47	55	60	59	30	24	76
Coniferous	0	19	12	17	19	9	24	76
Hardwood	0	25	28	16	14	1	19	81
Total	100	100	100	100	100	100		
Producer's Accuracy (Percent)	100	9	55	17	14			
Omission Error (Percent)	0	91	45	83	86			

Chapter 4: Conclusions

Since its establishment in 1942, RSAs landscape has gone from mostly barren, abandoned farmland, to a largely forested area. As a result, much of the biodiversity that was once here has been restored, due in part to DoD's use of the land and its commitment to protecting natural resources through the Sikes Act of 1960 (Bhuta et al., 2011). To that end, DoD has had to submit planning level surveys on a regular basis to inform management plans that keep DoD installations within federal, state, and local environmental regulations, known as integrated natural resource management plans (INRMP). The primary goal of this study was to conduct a preliminary forest inventory as a planning level survey for RSA to create up to date INRMPs (USDoD, 2013).

A secondary objective was to create a remotely sensed product for the restoration of grassland ecosystems, particularly oak savannas, on Weeden and Madkin mountains. These ecosystems were once commonplace throughout the eastern United States and relied heavily on fire to maintain their composition and structure (Estes, 2016). Since the arrival of Europeans, fire has been heavily suppressed across the landscape and much of the forests have been denuded. Today, fire is still not as commonplace, and forests have been allowed to regrow, resulting in dense forest ecosystems that are increasingly favoring fire intolerant species (Barefoot et al., 2018; Dey, 2017).

The findings of the forest inventory indicate that much of RSA is dominated by planted pines, as well as less marketable hardwood species in the area such as maple and ash. Of the three forest types on RSA, as determined by visual assessment of aerial imagery, there are 4,670 acres are in mixed pine-hardwood stands with an estimated 495,000 total tons of harvestable timber, 1,442 acres were in hardwood stands with an estimated 100,000 total tons of harvestable timber, and 669 acres were in pine stands with an estimated 185,000 total tons of harvestable timber. Species composition of each forest type found other hardwood species such as maple and ash were increasingly present, particularly in the smaller diameter classes. This is likely due to these species filling in large gaps created by the loss of large overstory oaks and pines (Bhuta et al., 2011).

Data from the forest inventory of RSA and the subsequent ArcGIS database will be used for the next decade to plan and monitor changes in forest ecosystems across the installation. These findings will assist base personnel with timber management, wildlife management, endangered species conservation, and water quality management, as well as maintaining a barrier between DoD operations and the public (Guertin, 2013). In general, the only limitations to these data were that in many of the stands that were surveyed, data were based on 0.5-0.75% of each stand surveyed. However, limiting ourselves to such a small area of each stand allowed us to cover a wider geographic area of the installation in a shorter amount of time.

Importance values and diameter distributions of all forest types showed that pines were the most important species group on RSA, followed by mixed hardwoods of lesser economic importance. Hardwood dominated stands are particularly interesting as the findings indicate that the diameter distribution within these stands is gradually changing towards a more normalized distribution with most of their trees around the average diameter. Pines, red oaks, and white oaks are also being replaced by other hardwoods and eastern red cedar in the smaller diameter classes, indicating that these species in the larger diameter class may one day be replaced entirely. These findings follow the same conclusions of Hart et al., (2011), where the authors determined that the fragmentation of forests by DoD operations and the widespread planting of loblolly pine negatively impacted the biodiversity of forests on the installation, and the active restoration of different forest ecosystems, as well as the reintroduction of disturbances such as fire, would benefit forest biodiversity and structure.

The remote sensing analysis of Madkin and Weeden mountains using data for the planning level surveys created a product that, while it had a low accuracy, provided information that could easily be used to plan and monitor restoration activities at the study site. Of the three methods used, decision tree was found to be the most effective with an overall accuracy of 39.99% and a kappa of 0.22. Support vector machine (SVM) and Maximum likelihood (ML) techniques did not yield products that were as favorable (25.41% and 14.4% overall accuracy respectively). These accuracies were generally low as there were 98 1/10th acre plots to use as training and validation data across the study area of 1938 acres, as well as a mixture of data collected at various times.

In particular, the LIDAR data that was used was collected nearly a decade prior to the assessment but was assumed to be useful as it was the most recent LIDAR data with vegetation point clouds that was available and very little change had occurred within the study area since that time (Hicks, 2020). It is likely that the rasters derived from these data may have been of low resolution and generated noise rather than data, interfering with the ability of SVM and ML to generate accurate classifications (Berhane et al., 2018). In the future, a similar study could be done with more ground-points to generate an even more accurate map for oak savanna restoration planning and monitoring.

In summary, the forest inventory, its resulting geodatabase, and the restoration plan generated by this project provide RSA with a valuable starting point for planning the management of its natural resources for the next decade. The stand and plot level data collected here may be used to plan future timber harvests, monitor the progress of various conservation goals on RSA, or guide the development of RSA’s military operations in the future. Hopefully, these data will highlight the need to improve forest biodiversity at RSA and encourage active restoration of forest ecosystems. The mapped product for restoration also shows promise in that it may be used for future restoration planning at RSA. Overall, this project demonstrates the value of combining forest inventory with remote sensing to inform conservation planning and management decisions, as well as showing a need for improved biodiversity on RSA. The data and products generated by this project can be used to guide the sustainable use and management of RSA's natural resources, while also contributing to broader restoration efforts in the region.

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