A Decision Support Tool: Integrating Wildlife Occupancy Models with Stand Projections

by

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Abstract

With the increase in consumptive trends of wood products there is greater push for ecosystem management. Ecosystem management is a process that aims to conserve major ecological services and restore natural resources while meeting the socioeconomic, political and cultural needs of current and future generations, and more efficient natural resource management. Forests provide natural resources for consumption; however, they also support wildlife and provide many other ecosystem services. Therefore, it is increasingly common that natural resource managers are asked to balance multiple objectives on a single property.

The main objective of this study was to show how the theoretical outcomes from growth and yield models and wildlife occupancy models could be combined to give land managers an idea of what to expect before management is executed. A growth and yield model, the Forest Vegetation Simulator (FVS), is used for stand projection. The resulting stand structures are input into species-specific wildlife occupancy models to estimate probability of occurrence. A simplified example from the Barbour Wildlife Management Area in Alabama is used to illustrate this approach. Area managers wish to convert existing mixed loblolly pine-hardwood stands into an open-canopy, fire maintained, longleaf pine ecosystem. Though species specific occupancy models are used here for simplification, other species or objectives can be used for other properties.

Three management scenarios were projected 100-years into the future: no treatment; immediate conversion through clearcutting, site preparation, and planting at three different densities; and long-term conversion through single-tree selection. Regression models were developed to predict reproductive and ground cover, variables not projected by FVS which are important parameters for occupancy of species. At five-year intervals, projected stand structure was input into occupancy models developed for four species of migratory songbirds; wood thrush, pine warbler, yellow-breasted chat, and prairie warbler.

Stand structure varied through time for each of the scenarios, but there was little difference between reproductive cover and ground cover between scenarios. The pine warbler was predicted to occupy stands under both the no management and single-tree selection scenarios throughout the entire projection period. Under the even-aged management scenarios, the pine warbler has a probability of use between 80 and 100% throughout the projection cycle. The yellow-breasted chat's probability of use varies between management scenarios. The wood thrush has less than a 30% probability of use under any management scenario. The prairie warbler has the highest probability of use in the even-aged scenarios over time, but will still use the other management scenarios between 20 to 30% of the time.

While there seems to be little difference in the probability of use between management scenarios for each species, there is still predictive power for this decision support tool. Only three management alternatives were simulated in this example. There are an infinite number of other possible alternatives that were not reviewed here. By integrating these two models (stand projection and habitat occupancy) a unique tool is available for land managers to gauge the efficacy of their management plans while also developing a timeline of predicted forest structure that can be compared with future inventory for use in adaptive management.

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List of Abbreviations

ALDCNR- Alabama Department of Conservation and Natural Resources

AOS-Alabama Ornithological Society

BA- Basal area

CWCS- Comprehensive Wildlife Conservation Strategy

DBH- Diameter at breast height (1.3m)

FVS- Forest Vegetation Simulator

GCN- Greatest Conservation Need

ICP- Inventory and Conservation Planning

LDT- Largest diameter tree

SI_{50}- Site index at a base age of 50

CHAPTER 1

INTRODUCTION

Essentially, all models are wrong, but some are useful.
(George Box, 1979)

With consumptive trends of wood products on the rise (Bowyer 2007), the need for more comprehensive management grows (Bowyer et al. 2007). The Multiple-Use Sustained-Yield Act of 1960 required by law that national forests broaden their focus to include the production of other commodities such as recreation, wildlife and water. However, some argue that the practice has fallen short of the ideal set up by the act (McQuillian 1990, Shepard 1990). Shands (1988) argued that "multiple use has become a pejorative term that many people believe is synonymous with management that emphasizes timber production to the detriment of other forest resources". In recent years there has been a push for more "Ecosystem Management" (Bengston 1994), a process that aims to conserve major ecological services and restore natural resources while meeting the socioeconomic, political and cultural needs of current and future generations (Bengston 1994, Grumbine 1994, Brussard et al. 1998, Szaro et al. 1998).

Natural resource management is frequently used when dealing with a particular resource for human use rather than managing the whole ecosystem (Kellert et al. 2000). One of the main objectives in natural resource management is sustainability, which natural resource managers apply to balance natural resource utilization over a long time frame (Ascher 2001). Therefore, one of the many goals of natural resource management is to fulfill the demand for a resource without injuring the ecosystem or jeopardizing the future of the resource.

With the greater push for ecosystem management and more efficient natural resource management, the forests that provide timber also need to incorporate other uses, such as wildlife habitats, aesthetics, recreation, soil conservation, and clean water. Therefore, it is increasingly common that natural resource managers are asked to balance multiple objectives on a single property. Management of these multiuse areas can be exceedingly complex, but extremely important for all the parties involved (Keeney and Raiffa 1993). However, bringing multiple fields together, with either real or perceived competition among objectives, is never easy.

The fields of wildlife biology and forest management are often perceived to have mutually exclusive objectives for the use and management of forests. Wildlife biologists tend to focus on the organism of interest, while forest managers tend to look at the growth and utilization of the trees from the forest. The common area is in forests where both wood products and wildlife habitat are provided. It may be suggested that disagreements on the best way to manage the forests often occur because of differences in the way management is implemented. Wildlife biologists tend to implement management based on a particular species of interest, while forest managers implement management that mostly focuses on the vegetation. Although the management perspectives from each field vary, the results are not necessarily mutually exclusive.

Tools exist in each discipline to model forest growth and response of wildlife to changes in habitat respectively. However, they are seldom used together. Forest growth and yield models use current forest inventory to predict future stand structure by using a set of tree based measures that include tree species, sizes, and densities. Wildlife occupancy models provide an estimate of species occurrence based on a variety of factors, including habitat characteristics like tree species and size, density, and available cover. Because habitat characteristics, (structure) are a big predictor of a species occurrence, and growth and yield models project future structure it should be possible to integrate these tools to determine the effects of forest management on species before implementation.

Objectives

The main objective of this study was to show how the theoretical outcomes from growth and yield models and wildlife occupancy models could be combined to give land managers an idea of what to expect before management is executed. Essentially, the models provide a baseline for the biological response of forest structure and wildlife species to management over time, which can be interpreted to make better science-based decisions. By doing this, an adaptive, situationally specific tool to assist in decision making for land management under multiple objectives was created.

Barbour Wildlife Management Area is used as a case study to showcase the utility of the tool. There are an infinite number of management scenarios that could be projected; however three were developed based on Barbour's current objectives to restore longleaf pine (*Pinus palustris*):

(1) No active management, excludes prescribed burning.
(2) Immediate conversion to longleaf pine through clearcutting, site preparation and planting, and reintroduction of fire on a 5-year interval. Three planting densities are used (741, 1112, and 1483 trees per hectare) to compare the different outcomes.

(3) Single tree selection based on the Proportional-B system (allocation of growing space among 3 broad diameter classes and maintaining a sustainable diameter structure) (Loewenstein 2005) with the reintroduction of fire at a 3 year return interval.

Four bird species were chosen to show how management would influence their probability of use:

(1) Pine Warbler
(2) Yellow-breasted Chat
(3) Wood Thrush
(4) Prairie Warbler

These species all have different habitat requirements; therefore management and different management scenarios should change the species' probability of use.

I hypothesized that the structure created by the proportional-B method would have the most utility for pine warbler based upon its known habitat characteristics. Pine warbler is associated with a dense canopy layer and a sparse understory or a low density shrub layer (Rodewald et al. 1999). The proportional-B method should create a tall dense canopy that would be ideal for pine warbler. Wood thrush, prairie warbler, and yellow-breasted chat would be more likely to use structures created by other scenarios based upon what is known about their habitat characteristics. Both prairie warbler and yellow-breasted chat inhabits early successional habitats. They would be better suited to the even-aged projections because early in development early successional habitat is created. Wood thrush likes mixed deciduous forests, especially well developed mesic uplands (Bertin 1977, Roth et al. 1996) with a dense understory.

Most of the implemented management focuses on restoring longleaf pine, and wood thrush is not associated with that habitat.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

Inventory and Conservation Planning Project

The inventory and conservation planning (ICP) project was initiated by the state of Alabama in order to coordinate the development of multi-species Inventory and Conservation Plans for selected lands managed by the Alabama Department of Conservation and Natural Resources (ALDCNR). The initiation of the ICP project was based upon the comprehensive four volume publication *Alabama Wildlife* (Mirarchi et al. 2004) and the Comprehensive Wildlife Conservation Strategy (CWCS) (ALDCNR 2006).

Mirarchi et al.'s (2004) publication of *Alabama Wildlife* illustrated the serious danger of wildlife in the state and outline recommendations for conservation and management. The subsequent publication of the CWCS filled in precisely what Alabama needed to do to help the at risk wildlife populations (ALDCNR 2006). Specifically, the CWCS outlines five major reasons why wildlife is threatened in Alabama, included in their list of threats is lack of adequate protection and knowledge to make decisions about wildlife and their habitats (ALDCNR 2006).

The ICP project was set up to be a five year project managed by the Alabama Cooperative Fish and Wildlife Research Unit (ALCFWRU). The overall goal was to provide a science-based plan for the conservation of species of greatest conservation need (GCN) and the habitats they depend on as they occur or could occur on ALDCNR managed lands. The outcome of the ICP project will lead to a management plan that will help protect GCN species and their habitats throughout the state. It will also lead to decision support based tools that allow for land mangers to evaluate their progress over time.

Alabama Physiography

Alabama is separated into six physiographic provinces; Interior Plateau, Southwestern Appalachians, Ridge and Valley, Piedmont, Southeastern Plains and Southern Coastal Plain. These level III ecoregions are areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources (Figure 1). They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components (Omernik 1987, Griffith et al. 2001). In Alabama the six level III ecoregions are divided into 29 separate level IV ecoregions (Griffith et al. 2001). The smaller level IV ecoregions are identified through the analysis of the spatial patterns and the composition of biotic and abiotic occurrences (Omernik 1987). Omernik (1987) developed the system of ecoregions on the basis of similarity in land use, land form, soils and potential vegetation. Therefore, similar habitats are potentially found in each region.

Since there are 29 unique ecoregions with the potential to support an array of plants and animals that might not be found elsewhere, there is a diversity of habitat that drives extraordinary biodiversity in Alabama. Alabama's species diversity exceeds all eastern states for numbers of plant and animal species and ranks fifth in the nation after California, Texas, Arizona, and New Mexico for all animal species (Alabama Natural Heritage Program 2003). There are over 4,000 species of plants, 850 species of vertebrate animals, and nearly 250 species of fresh water mussels in Alabama (Nature Conservancy of Alabama 2009). In particular there are 93 native reptiles, 73 native amphibians, 62 native mammals, and 420 bird species that comprise the official Alabama Ornithological Society (AOS) state list (Mirarchi et al. 2004).

Alabama has the most imperiled species of any state east of the Colorado River. Only Hawaii has lost more species to extinction than Alabama (Stein 2002). One hundred thirty-four species found in the state have been listed as either threatened or endangered. This list includes 116 animals and 18 plants (USFWS 2006). Twenty-one additional species have been identified as candidates for future listing. The 116 listed animals include 6 birds, 7 mammals, 12 reptiles and amphibians, 15 fishes, and 76 mussels and snails. Several of these populations have reached critical levels and are the main focus of several recovery plans and protective measures. With limited resources available for conservation, it is essential that state conservation plans be developed to protect species of greatest conservation need.

According to the Alabama Forestry Commission 70% of the states land area is forested (Alabama Forestry Commission 2009). As of the 2005 forest inventory of Alabama approximately a quarter of the forested lands were in plantations, most of them being Loblolly pine (*Pinus tadea*) (Hartsell and Johnson 2009). The majority of the forested land is held by private landowners with less than 5% held by state and federal government agencies (Hartsell and Johnson 2009). Alabama owns and manages 109,668 hectares of protected land, 89% of which is managed by the Alabama Department of Conservation and Natural Resources (Silvano et al. 2008).

The majority of terrestrial GCN species occur in forested habitats and most (≈

95%) of Alabama's 9.3 million hectares of forest are in private ownership (Hartsell and Johnson 2009). However, low timber values, increasing recreational use, and pressure for development are resulting in conversion of forest land to other uses often in conflict with natural resource conservation. Consequently, land management and natural resource management is essential to ensure the continuation of many species of conservation need in Alabama. Through education and outreach, the tool presented here could then be used by land owners to minimize jeopardy to GCN species on private lands.

The Forest Vegetation Simulator

History

The Forest Vegetation Simulator (FVS) is a computer software modeling system developed by the USDA Forest Service to assist in the prediction of forest growth and yield. FVS can also simulate a variety of silvicultural treatments for the dominant forest species and types found in the United States. It is used by a variety of other public and private entities to report current stand conditions and project future stand conditions and statistics, as well as predict disease and fire potential (Dixon 2002, Teck et al. 1996, Keyser 2008).

The FVS framework was adapted from the *Prognosis* (Stage 1973) single tree model, developed for forest stands within the Inland Empire region of the western United States. It was a set of computer programs used to make predictions about the course of stand structure and produce expectations under alternative management prescriptions (Stage 1973). Stage visualized the *Prognosis* model to use tree growth interactions to direct the course of forest stand development under different silvicultural treatments. He wanted the model to be applicable to mixed stands of various age structures and sufficiently flexible so that it could be applied to new management techniques (Stage 1973).

The *Prognosis* model took significant of effort led by the US Forest Service with the cooperation of private and university entities to evolve into FVS. Stage (1975) developed the original large tree growth model within *Prognosis*, while Hamilton and Edwards (1976) developed the mortality model. Eventually, *Prognosis* was released to the public in 1982 (Wykoff et al. 1982).

Since its development and release, *Prognosis* has had many additions and updates. The growth model has been extensively modified (Hamilton 1986,1990, Wykoff 1990, Stage and Wykoff 1998) to include the addition of small and large tree diameter increment models (Wykoff 1983). Regeneration and establishment models were developed and added to the model (Ferguson et al. 1986), and then revised (Ferguson and Crookston 1991, Ferguson and Carlson 1993). Crookston (1985) developed the “Event Monitor” Extension; this allowed for the management activities to be scheduled during the projection cycle. The “Event Monitor” was expanded (Crookston 1990) and eventually led to the development of a “Parallel Processing” Extension (Crookston and Stage 1991) which allowed for the concurrent projection of many stands. With the creation and incorporation of extensions, *Prognosis* developed into a system capable of modeling most aspects of natural resource management. The *Prognosis* model name was changed to FVS in the mid-1990’s to convey the idea that the Forest Service has adopted a national forest growth and yield modeling system.

The FVS framework has been expanded to other regions and forests types outside of the original Intermountain region. A uniform model framework was developed to support many different forest types throughout the United States. Since the early 1980’s twenty different variants have been developed that follow the *Prognosis*-FVS framework and cover every forest type within the United States. Each variant corresponds to a specific geographic region of the nation. The Forest Service’s Forest Management Service Center (FMSC) in Fort Collins, Colorado (http://www.fs.fed.us/fmsc/) serves as the primary agency that maintains, develops, and distributes all components of FVS and its variants.

FVS Utility

Scientists and land managers use FVS as a planning tool or in conjunction with other programs as part of a decision-making process. Ceder and Marzluff (2002) used an extension of FVS, known as the Landscape Management System, to evaluate habitat across an entire management area. They used different silvicultural systems to manage the area and coupled the projections with habitat suitability models.

Some studies utilize FVS for decision support in mind to help plan management before implementation. This allows the user to predict the outcome of management decisions. Marzluff et al. (2002) showed how timber revenues would differ among scenarios; they wanted to find a management alternative that would maximize revenue while maintaining suitable wildlife habitat. Hummel et al. (2002) used FVS to optimally plan management on a land reserve. Other studies have used FVS projections to compare observed with projected events such as oak decline (Vandendriesche and Haugen 2008). Such studies allow the user to test the predictive capacity of FVS, and where it is shown to be robust, allows its use in planning as a tool to aid in the decision-making process.

FVS: the Southern Variant

For the purpose of this project the Southern (Sn) Variant of FVS was used. FVS-Sn was developed with the cooperation of the Southern Research Station of the Forest Service and the FMSC by Donnelly and Lilly (2001) for use in the southeastern United States. The variant is based on age and distance independent individual-tree model equations that specify the recruitment, growth, and mortality of each tree (Donnelly and Lilly 2001). Although stand-level predictions are the main concern to most users of FVS-Sn, the sub-models that lead to these predictions were developed from tree-level considerations and fitted to individual tree data to give greater flexibility and consistency to operate within the FVS framework. Unlike other variants FVS-Sn simulates management in five-year cycles.

The framework provided by all FVS variants allows equations or sub-models to operate together to get to a stand-level projection, which includes stem density per unit area, basal area, diameter distributions, and species composition.

Longleaf Pine

Longleaf Pine was once found on more than 37 million hectares of the southern landscape (Van Lear et al. 2005). It was estimated to be the dominant species on at least 23 million hectares (Frost 1993). Longleaf pine could be found at elevations ranging from sea level to over 60 meters (Harper 1905, Stowe et al. 2002). This once wide ranging species is now only found on a fraction of its range; about 1.3 million hectares remain today (Landers et al. 1995).

Frequent low intensity fires set both by Native American populations and lightning strikes are hypothesized to have maintained the longleaf communities (Denevan 1992, Van Lear et al. 2005). Being extremely fire dependent longleaf thrived under the management of the Native American people. However, this forest type started to decline as European colonization swept over the southeast in the 15^{th} century (Denevan 1992, Van Lear et al. 2005). Although, fire was still used to manage areas of land, it occurred on a much smaller scale (Van Lear et al. 2005). The forest structure in many places also was changed. Longleaf systems were dominated by extremely tall trees, with little midstory or understory. The suppression of fire allowed dense thickets of hardwood to invade (Van Lear et al. 2005), effectively changing the vertical structure of the forest.

Longleaf pine has been described as a very intolerant pioneer species (Baker 1949, Boyer 1993, Hardin et al. 2001), but it is also known to be an irregular seed producer, and the seeds do not remain viable for long periods of time (Landers et al. 1995, Boyer 1998). Good seed crops are only estimated to occur once every 5 to 7 years (Hardin et al. 2001). Because seeds are large they are not likely to disperse over long distances, rarely dispersing more than 30 meters from the parent tree (Boyer 1958, 1963). Few of the dispersed seeds become established as seedlings, mainly due to predation by small mammals (Boyer 1964).

Once seeds become established and are able to germinate they enter what is known as the "grass stage" (Pessin 1939, Wahlenberg 1946, Haywood, 2000). During the grass stage longleaf pine seedlings concentrate most of their growth on their root system. The grass stage can last from 1 to more than 20 years, but 3 to 6 years is typical (Hardin et al. 2001), after which they begin height growth, a process referred to as "bolting." The seedling is considered established once it reaches 1 meter in height (Wahlenberg 1946).

The decline in the longleaf pine resource can be attributed to several additional factors. Widespread harvesting, particularly between 1900 and 1930, greatly reduced the area occupied by mature longleaf pine (Croker 1979). Therefore, natural regeneration was limited by the lack of mature trees available to produce seed. Biology of the tree was also poorly understood. Longleaf pine is an irregular seed producer (Landers et al. 1995, Boyer 1998). Bumper crops are not common (Boyer 1987). Furthermore, seedlings were depredated by feral hogs (Wahlenberg 1946), which led to the failure of many regeneration efforts. Finally, many sites were converted to other commercially valuable species, mainly loblolly pine and slash pine (*Pinus elliottii var.*

elliottii Engelm), or to other land uses such as agriculture (Wahlenberg 1946, Landers et al. 1995).

Because of the historical presence and life history of longleaf pine, it has become the focus of many restoration projects in the southeast. However, it is not just the tree that is sought after. The longleaf pine ecosystem is considered highly diverse (Brockway et al. 2005a). There are 191 taxa of vascular plants that largely exist only in longleaf pine communities (Brockway et al. 2005a), and more than 40 species per square meter have been recorded in some longleaf pine communities (Brockway et al. 2005b). Longleaf ecosystems are associated with a variety of bunch grasses. These associated bunchgrasses facilitate fire that helps maintain the system (Brockway et al. 2005a, 2005b).

Continually, several terrestrial vertebrate species are also tied to longleaf pine communities (Brockway et al. 2005a). Two well know endangered species are largely associated with longleaf pine habitat; the gopher tortoise (*Gopherus polyphemus)* and the red-cockaded woodpecker *(Picoides borealis)*. Both of these species are known to be great excavators (Brockway et al. 2005a, 2005b). The gopher tortoise digs large burrows and the red-cockaded wood pecker excavates trees cavities, which provide homes for a number of other associated insects, birds, snakes, amphibians, and mammals (Brockway et al. 2005a, 2005b).

Moreover, longleaf pine is the most critically endangered ecosystem in the United States, occupying less than 3% of its historical range (Ware et al. 1993, Noss et al. 1995). Many longleaf pine stands have been converted to other land uses, such as agriculture or urban development (Brockway et al. 2005b). This extreme habitat loss has also impacted the 191 taxa of vascular plants and several animals that are associated with the longleaf pine ecosystem.

Many of the associated animals are considered threatened or endangered because of loss of this critical habitat.

Restoration of the longleaf pine forest ecosystem would not only benefit the associated species, it also provides considerable economic values (Brockway et al. 2005b). These forests provide more poles than either loblolly or slash pine stands (Brockway et al. 2005b). Pine straw also increases the value of these stands. When maintained in a “park like” condition stands of longleaf provide higher quality habitat for deer, turkey and quail (Brockway et al. 2005a, 2005b), which may bring in more money from hunting leases. There are also a number of other unquantifiable services that a healthy longleaf ecosystem can perform including (but not limited to) carbon sequestration, water purification, soil stabilization, wildlife habitat, and nutrient cycling (Brockway et al. 2005b).

Occupancy Models

Occupancy (Ψ), which is the probability of species use, is a measure used to quantify the status of a population or community. The occupancy model’s outputs provide estimates of the probability that a species will inhabit a site. Therefore, applying occupancy models outputs over time to different management treatments has the potential to serve as the basis of management decisions for conservation (Nichols et al. 1998, Peterson and Dunham 2003, Gu and Swihart 2004, MacKenzie et al. 2006).

However, surveys for organisms are not always able to detect their presence. Therefore, a detection probability (p) is included when creating an occupancy model (Mackenzie et al. 2002). A detection probability is defined as the probability of detecting at least one individual of the species during sampling of an occupied site (MacKenzie et al. 2006). It is important to recognize that non-detections do not always mean that a species is absent. Detection is often both species and survey specific. Therefore, detection may vary spatially and temporally depending on various factors such as sampling method, habitat, observer, underlying population size or density, and seasonal behaviors (Mackenzie et al. 2002, Bailey et al. 2004).

Focal Species

To show the effects of management focal species needed to be used. A variety of species were chosen that are known to key on different habitat structures. Therefore, different management would have a different affects on each species. However, the amount of data limited the species that could be chosen from. Thus, four different species of birds were chosen to show the effects of management. These species have been detected on the study site in sufficient quantities for occupancy models to be constructed.

Wood Thrush

Wood thrush (*Hylocichla mustelina*) is a large spotted thrush known for its enchanting song. As a neo-tropical migrant, this bird spends its summers breeding in the interior and edges of mixed deciduous forests, especially well developed mesic uplands (Bertin 1977, Roth et al. 1996). Breeding requirements include a mature forest with an understory of deciduous shrubs (Mirarchi et al. 2004). Recent findings indicate that they have higher nesting success in forests with higher densities of trees and shrubs and higher canopies (Hoover and Brittingham 1998, Newell and Kostalos 2007). One study indicated that nest success of the wood thrush is dependent on nest placement; lower nests in dense understory are more vulnerable to predation (Newell and Kostalos 2007). Like other neo-tropical migrants the wood thrush is experiencing population declines. Habitat fragmentation is the biggest threat to the wood thrush because it is typically an interior forest species (Mirarchi et al. 2004, Newell and Kostalos 2007). In Alabama the wood thrush is experiencing habitat degradation and fragmentation, which is leading to more nest parasitism (Mirarchi et al. 2004).

Pine Warbler

Pine warbler (*Dendroica pinus*) is a large wood warbler that is most associated with the North American pine forests. As its name implies it is mainly found in and breeds in upland pine or mixed pine-hardwood stands (Rodewald et al. 1999). In most of its range it is associated with a dense canopy layer and a sparse understory or a low density shrub layer (Rodewald et al. 1999). In Alabama it is not consider a species of concern, but like other neo-tropical migrants it may be vulnerable to population declines because of habitat loss and fragmentation.

Yellow-breasted Chat

Yellow-breasted Chat (*Icteria virens*) is considered the largest wood-warbler. Over its range it is found in low dense vegetation, like power-line corridors, fence rows, and forest edges (Eckerle and Thompson 2001). It is considered a generalist with regard to habitat. When selecting nesting sites; its only preference seems to be toward edges and openings (Eckerle and Thompson 2001). In Alabama it is not consider a species of concern, but like other neo-tropical migrants it may be vulnerable to population declines because of habitat loss and fragmentation.

Prairie Warbler

Prairie Warbler (*Dendroica discolor*) is a small warbler that inhabits early successional habitats. These birds are typically found in is southern pine forests that lack a closed canopy, dunes along the coast, abandoned fields, and pastures with shrubby growth (Nolan et al. 1999). Contrary to what its name implies, these birds are not found on prairies. The Prairie Warbler experienced a population increase as deciduous forest was cleared in the United States during colonial times (Nolan et al. 1999). However, the breeding bird survey has show population decline in recent times (Audubon Watch List). In Alabama it is on the birds watch list because of population declines and having a limited distribution (Mirarchi et al. 2004).

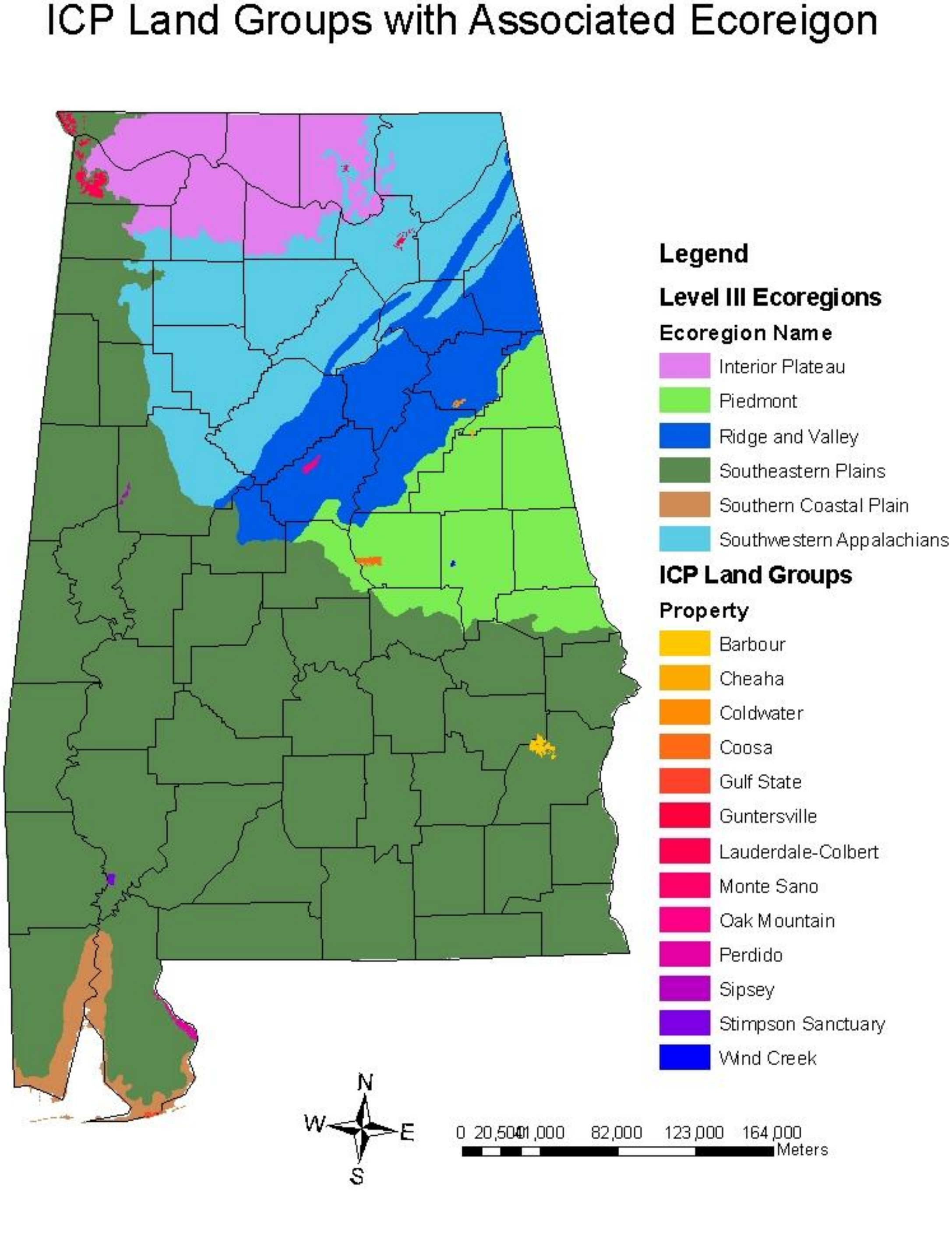

Figure 1: The level III ecoregions of Alabama based upon Griffith et al. 2001 with the inventoried land groups by the ICP project.

CHAPTER 3

RESEARCH METHODS

Study Site

This project was conducted on Barbour County Wildlife Management Area (31.99°N 85.46°W), (Barbour WMA, Figure 2) located on 8,000 hectares of Barbour and Bullock counties in southeast Alabama. Barbour WMA is located in the Southeastern Plains (Griffith et al. 2001). The natural vegetation of this region is characterized by longleaf pine with smaller areas of hardwoods. It includes areas of oak-pine and other mixed forests (Griffith et al. 2001). The physiography of the ecoregion is characterized by dissected irregular plains and gently rolling low hills with east-west bands of sand and clay formations (Griffith et al. 2001). Rock formations or cuestas have formed, with gentle south-facing slopes and steep north-facing slopes; this area of the Southeastern Plains there tends to exhibit higher relief than the rest of the ecoregion, mixed in with the rolling hills and irregular plains (Griffith et al. 2001). Landcover is generally mostly forested with some agricultural uses mixed into the overall matrix (Griffith et al. 2001).

The site is in Bailey’s (1995) Humid Temperate Domain, Subtropical Division, Southeastern Mixed Forest Province; such sites are characterized by hot humid summers and mild winters. Rainfall is well distributed throughout the year, but can sharply increase in between spring and summer because of thunderstorms (Bailey 1995). Average rainfall is around 122cm per year (Ware et al. 1993). Soils are principally ultisols (Ware et al. 1993), with inceptisols on floodplains of the major streams (Bailey 1995). Vertisols, clayey soils that form wide, deep cracks when dry, can also be found on locally formed limestone (Bailey 1995).

Before settlement by Europeans the vegetation of this area was characterized by old longleaf pine stands that were maintained mainly by fire (Ware et al. 1993). However, now more than half of the vegetation is composed of yellow pine species like loblolly pine and shortleaf pine (Bailey 1995, Ware et al. 1993). Fire no longer maintains the system; while patches of hardwoods would have existed, these areas are now denser (Ware et al 1993).

The inventory performed showed that most stands are mixed pine-oak and oak-pine stands; the main pine component is loblolly pine, while the oaks encompass a collection of species including water oak (*Quercus nigra*), white oak (*Quercus alba*), post oak (*Quercus stellata*), black oak (*Quercus velutina*), and Northern red oak (*Quercus rubra*). These stands are mixed with a variety of hickories and other hardwoods, as well as a variety of woody shrubs and vines in the understory. There are also several stands of loblolly pine plantations with understories composed mainly of blackberry (*Rhus* spp.). On Barbour WMA there are also stands, smaller in area, which are considered bottomland hardwoods. These are composed of oaks, red maple (*Acer rubrum*), elms, and hickories. Openings are maintained to attract wildlife species during hunting seasons.

There are several different fauna in the region. Generally, White-tailed deer, cottontail rabbits, foxes and raccoons are commonly found. Also, fox squirrels, gray squirrels and nine-banded armadillos can be regularly encountered (Bailey 1995, Ware et al. 1993). White-tailed deer, squirrels, and rabbits are hunted on this property. The eastern wild turkey and mourning dove are commonly hunted, while a variety of neo-tropical migrants inhabit this area during migration (Bailey 1995, Ware et al. 1993). During point counts over 65 different bird species were encountered. Among the most common were the Northern cardinal (*Cardinalis cardinalis*, 323 encounters) and the Northern parula (*Parula americana*, 235 encounters). There are several common forest snake, lizard, and salamander species that inhabit this area (Bailey 1995). During the forest inventory we encountered several Eastern box turtles (*Terrapene carolina carolina*) and a few Eastern king snakes (*Lampropeltis getula getula*).

Study Design

Points were placed using a stratified random sampling method. Existing landcover information was used to stratify the area into 12 distinct landcover types based upon the Alabama Gap Analysis Project landcover maps (Kleiner et al. 2007). A 250 meter grid was placed over the landcover map in ArcGis (version 9.1 ESRI, Inc.). Points were then randomly chosen to cover approximately 10% of the points from the grid in each of the 12 landcover types. In total 100 points were chosen to survey from the 1071 points that were placed with the grid across the property. All survey points were at least 250m apart in order to minimize double counting for fauna surveys. Handheld GPS units were used to navigate to each predefined point. Because multiple surveys were performed at each point a pin flag was positioned at the GPS location in order to keep a consistent center point.

Field Methods

A forest inventory was designed to quantify vegetative structure, focusing on characteristics that are most important for wildlife habitat suitability (Van Horne and Weins 1991). Fixed area circular plots, 0.20 hectares (25m radius) were established during July and August 2008. Starting at plot center, a grid of 49 points spread 6.25m apart, was established along the cardinal directions (Figure 3). At each point on the grid the presence or absence of cover was recorded for the canopy, mid-story, reproductive/shrub, and herbaceous/ground cover layers using a “moose horn” densitometer. In order to sample the layers below the scope of the “moose horn” densitometer, because it generally points up, it was flipped over to point down. The canopy layer was defined as the dominant tree cover above the point on the grid. The mid-story layer was defined as trees that were 2/3 the height of the dominant canopy, but not extending into the dominant canopy. The reproductive/shrub layer was defined as vegetation not exceeding 3.5 meters in height. The herbaceous/ground layer was defined as any herbaceous ground cover.

Within the plot the presence of snags and their DBH was recorded. The heights of three trees among the dominant canopy were recorded to establish canopy height. Two of these three trees were aged at breast height using an increment borer. To obtain total age five-years was added to the measured age. However, sweetgum (*Liquidambar styraciflua)* and yellow poplar (*Liriodendron tulipifera*) were never cored because they are diffuse porous trees, which make counting tree rings difficult. Duff layer was recorded at the center of the grid and at 25m in each cardinal direction.

A variable radius plot using a 10-factor angle gauge was established using the center of the grid to determine the basal area of the stand. These trees were tallied by species and DBH.

Age and height were measured to predict site index based upon *Site Index Curves for Forest Tree Species in the Eastern U.S* (Carmean et al. 1989). Curves used included loblolly pine, water oak, and white oak. Site index is a relative measure of forest site quality based on the height of the dominant trees at a specific age. However, measurements were inconsistent when compared to Carmean et al. (1989). Technicians were new to determining which trees to core, therefore, the tree age measurements were not of sufficient quality to be used. Therefore, soil series information at the plot level was pulled from the Soil Survey Geographic (SSURGO) database in ArcGis (version 9.1 ESRI, Inc.). The SSURGO database gives site index at the base age of 50 (SI_{50}) for common tree species. However, this data is often unreliable because it is taken from soil surveys that are often preformed in agricultural fields. At each plot SI_{50} was recorded for a common tree species, if longleaf pine was available it was recorded for longleaf pine. Longleaf was chosen as the site index tree when available because of Barbour WMA's desire to restore longleaf to the property. Where longleaf pine was unavailable loblolly pine was used as the site index tree.

Point count surveys for birds were conducted at each plot center during the breeding season (May-July) no later than four hours after sunrise. Each survey consisted of three, four minute counts during which each bird that was seen or heard was tallied along with the estimated direction and distance (0-25m, 25-50m, greater than 50m) (Hamel et al. 1996). At the beginning of each survey, the temperature was recorded (°C) along with the date and time.

Stand Projections

The Southern variant of FVS was used for stand projection. Three different management scenarios were produced for each stand; (a) No Management, (b) even-aged, and (c) single-tree selection using the Proportional-B Method. Even-aged simulations were repeated at three different planting densities (741, 1112, and 1483 trees per hectare). All projections with FVS started in 2008 and were for run 100 years at five-year intervals. For the purposes of this project the hardwood sprouting module (SPROUTING) was turned off in the FVS program and all regeneration was simulated manually. The hardwood sprouting module tends to overestimate the amount of reproduction when simulating management.

For the No Management simulations no management treatments were simulated in FVS. The stands were projected for 100 years with neither anthropogenic nor natural disturbance.

In the three even-aged simulations run for each stand, the current existing trees were clearcut in 2008 and replanted in 2009 with 741, 1112, and 1483 trees per hectare, respectively, assuming 90% survival. Alternating summer and winter burns were simulated every 5 years starting in 2013. Winter burn parameters were: wind speed of 8mph, dry, 21C, 70% of the area burned, Fire and Fuels extension (FFE) mortality off, and season 2 (before green up, winter). Summer burn parameters were: wind speed of 8mph, dry, 21C, 70% of the area burned, FFE mortality off, and season 3(before fall, summer). The FFE mortality is turned off because it over estimates the mortality of trees in the stand. In running a number of simulations it was found that if the FFE mortality is turned on during a simulated burn all the trees are killed, no matter the species. However, fire is an important factor for both tree mortality and understory cover, and should have a greater influence on understory development.

Each stand was grown for a 60-year period, during which time a thin from below was applied when BA exceeded $18.3 m^2 ha^{-1}$ or when growth was being impeded, on average 2 times during the rotation for 741 and1112 trees per hectare, and 3 times for 1483 trees per hectare. A final harvest took place in 2068. In 2069, the stand was replanted at the same initial planting density. The same management parameters were applied throughout the second rotation until the end of the projection in 2108.

For the single-tree selection simulation using the Proportional-B Method, each stand was prescribed a unique treatment based on the initial stand structure in 2008. In the Pro-B method three broad size classes are used to proportionally distribute basal area. A total amount of residual basal area is set (i.e. $13.8\ m^2 ha^{-1}$). Then, an approximate proportion of 3:2:1 is used to distribute basal area among the size classes, with the largest size class having the most basal area. For this project size classes were always set to 5 to 20cm DBH, 20 to 35 cm DBH, and greater than or equal to 35cm DBH[1]. If the stand was missing either the 20 to 35cm or greater than or equal to 35cm size class, the initial stand structure was deemed inappropriate to apply Pro-B. In this case, the stand was converted to an uneven-aged structure as per Loewenstein (2005) before Pro-B was implemented. The conversion process took between 15 and 40 years depending on the initial stand structure. The largest diameter tree (LDT) was set to equal the largest tree existing in the stand. Typically LDT is set to the largest DBH a nearby mill could handle. However, that restriction was not taken into account. Also, Barbour WMA's management plans include long term restoration of longleaf pine into old growth stands. Therefore, the LDT was allowed to continually change based on the growth of the trees present. Residual basal area (RBA) was set to 13.8m^2ha^{-1}, and Q=1.3 (for 5cm classes).

If the current structure fit the parameters for an uneven-aged stand Pro-B was implemented immediately. The LDT was set to equal the largest tree existing in the stand. Residual basal area (RBA) was set to 13.8 m^2ha^{-1}, and Q=1.3. Harvest of trees was applied using Table 1 to cut each size class to the appropriate BA for each cutting cycle. Subsequent harvests were applied when the stand accrued 3.6 m^2ha^{-1} to 6.9 m^2ha^{-1} of BA or roughly 10 or 15 year cutting cycles. Because FVS-sn projects growth at 5-year intervals, cutting cycles for the Pro-B method were simplified to fall on an existing cycle boundary; in practice, cutting cycles tend to fall between 7 to 15 years.

One of Barbour WMA management objectives is to restore the Longleaf pine ecosystem (open pine woodland); however it is not currently present on the property. Loblolly pine can

[1] These are approximated from English units. Size classes equal 2-6in, 8-12in and greater than 14in for the equivalent English units.

also form an open pine woodland. Therefore, if loblolly pine was present it was kept as a main component of the stand to surrogate for longleaf until it can be established.

All cuts were made by using the “thin throughout a diameter range” option. The “thin throughout a diameter range” option allows for the user to define diameter classes and cut those classes to a defined amount of BA. As seen in Table 1, defining diameter classes and cutting those classes to defined amounts of BA is the easiest way to apply Pro-B in FVS.

All reproduction was simulated manually to adequate levels for structure to be maintained, meaning enough regeneration was simulated to maintain levels of BA needed in the smallest diameter class. Composition of the simulated regeneration was decided by the dominate species within the initial stand structure, and were attempted to be kept proportional to the dominate canopy.

Using the “Compute Stand Variables with SpMcDBH” function canopy cover was calculated for every cycle in the simulation. Midstory cover was calculated with “Compute Stand Variables in Editor”. A code that defined our definition of midstory cover was written (pers. comm. With C. Keyser[2]) and calculated for each cycle. All other structural characteristics needed for calculation of probability of use (BA, TPA, and Canopy height) through the occupancy models were pulled from the main FVS output and compiled into an Excel worksheet.

Of the 100 points sampled on Barbour WMA only 84 were considered to be forested stands and were used for simulation. Of the 100 points sampled 16 were considered to be openings. These were not projected because it is presumed that most of them will perpetually remain as openings or food plots. However, a higher amount of canopy cover than would be

[2] Chad Keyser, Forester, USFS Forest Management Service Center - FVS Staff, October 4-13, 2010.

expected was present in some openings. Plots were placed randomly. Depending upon how big the opening was and where in the opening the plot was located, it could be located closer to a forested edge.

Only 69 of the forested stands were used for the even-aged simulations; the 15 bottomland stands were excluded because it is assumed that they would not be converted to longleaf. The Pro-B method was applied to 82 stands; Pro-B was applied to 23 immediately, 38 stands went through conversion from an even-aged structure, 21 stands had to grow before Pro-B was implemented, and 2 never developed the proper structure to implement Pro-B during the simulations.

Vegetative Cover Projections

FVS does not provide an estimate for the reproductive or ground cover layers; both of which are known to influence occupancy by certain wildlife species. Linear regression models (R ver. 2.12.0) were created to project the amount of reproductive cover and ground cover at each time step. Multi-model inference was used to estimate model coefficients. Multi-model inference is a statistical technique based upon the concept of multiple working hypotheses where alternative plausible models are assessed and ranked based on relative likelihoods according to Akaike's information criterion (AIC) given the data presented (Anderson et al. 2000, Burnham and Anderson 2002). Although AIC does not use a significance level, it ranks the models based on fit to the data and the principle of parsimony (Anderson et al. 2000). The weight given for each model can be interpreted as the approximate probability that that model is the best model in the set of models considered (Anderson et al. 2000). Using multi-model inference allows the model parameters to be averaged overall the models in the *a priori* set, weighted by their performance, rather than picking the best model in the set (Anderson et al. 2000). According to Anderson et al. (2000) the averaged model parameters often have better predictive ability and reduced bias than the best model.

A global model was created to include all potentially influential variables for each layer of cover (pers. comm. E. Loewenstein[3]). The global model parameters for reproductive cover consisted of the variables canopy cover, midstory cover, basal area (m^2 ha^{-1}), and trees per hectare. The global model parameters for ground cover consisted of canopy cover, midstory cover, reproductive cover, percent basal area hardwood, basal area (m^2 ha^{-1}), and trees per hectare. The model parameters from all the *a priori* models were averaged to perform the multi-model inference. Relative importance of each variable was calculated, and only variables with an importance value of greater than 0.5 were included in the finished model. Variance inflation factors and comparisons of r^2 values were used to test for collinearity after the models were created.

Occupancy Models

Occupancy models were created by the Alabama Corporative Fish and Wildlife Research Unit using vegetation structure variables combined with bird point count data. Rather than using an averaged model, as was developed to predict cover variables, top or best model was used (Table 2). The best model was used because averaged models were not available at the time of the study. The best model is the most applicable or has the highest likelihood of being correct from the list of generated models.

[3] Dr. Edward F. Loewenstein, Associate Professor of Silviculture, Auburn University School of Forestry and Wildlife Science, October 22, 2010

Probability of use was calculated at each time step interval using stand projections from FVS, cover models, and the occupancy models for each focal species. The Yellow-breasted Chat model included a landscape component, edge density, which could not be simulated in FVS. Edge is defined as a border of one area to another, like forest to field or forest to road. The amount of edge is given as a continuous variable with a value between -1 and 1. One represents forest interior with no edge (0%), while -1 represents a completely open field with no edge (0%). Zero represents the maximum amount of edge present (100%). So, positive numbers less than one are forested with edge and negative numbers greater than -1 are open with edge. Edge was held constant at three levels (0, 0.5, and 1) to represent various forested situations with edge that would be present throughout Barbour WMA.

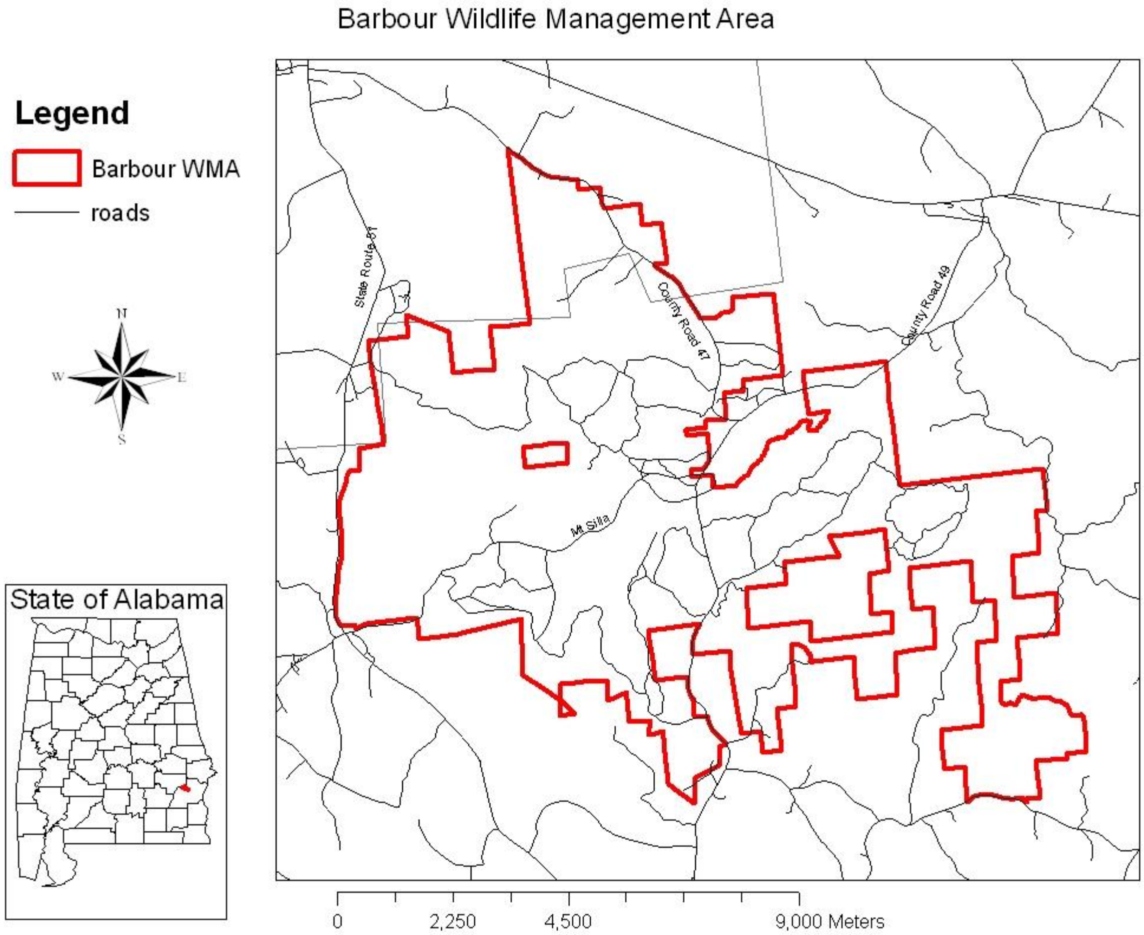

Figure 2: Map of Barbour Wildlife Management Area.

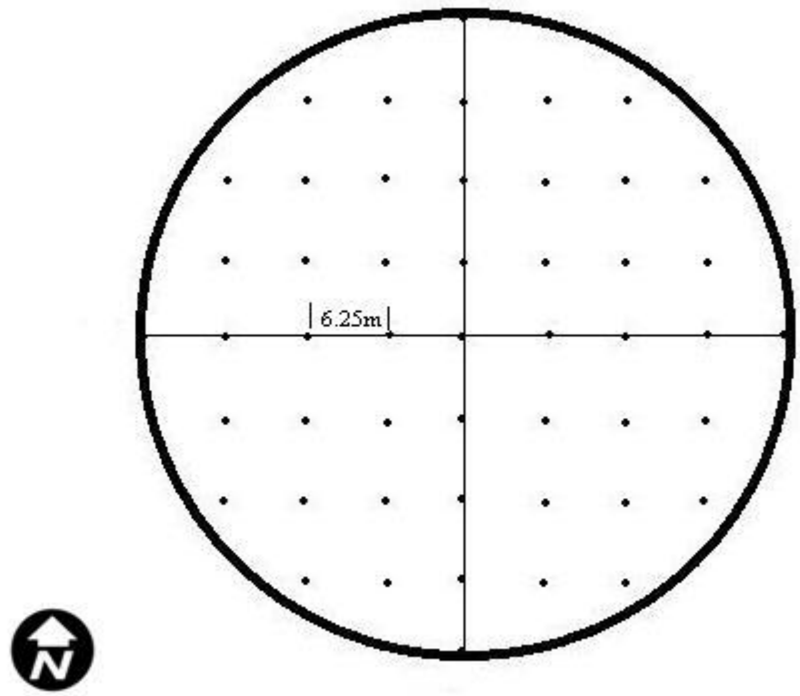

Figure 3: Grid layout used for measuring cover at each of the four layers. At each point on the grid the presence or absence of cover was recorded for the canopy, mid-story, reproductive/shrub, and herbaceous/ground cover layers using a “moose horn” densitometer. In order to sample the layers below the scope of the “moose horn” densitometer, because it generally points up, it was flipped over to point down. The radius is 25m and the distance between points is 6.25m.

Table 1. Amount of basal area (m^2ha^{-1}) remaining in each size class based on the largest diameter tree, residual basal area of $13.8m^2ha^{-1}$, and Q of 1.3. This table was used to determine how much basal area should remain in each size class for the Proportional-B Method cuts being made in the single-tree selection projections.

	Size Class		
LDT (cm)	5-20 cm (m^2ha^{-1})	20-35cm (m^2ha^{-1})	35+ cm (m^2ha^{-1})
50.8	1.73	4.74	7.31
55.9	1.56	4.22	7.98
61.0	1.41	3.85	8.50
66.0	1.31	3.58	8.87
71.1	1.24	3.36	9.19
76.2	1.16	3.19	9.41
81.3	1.11	3.06	9.61
86.4	1.06	2.94	9.76
91.4	1.04	2.84	9.88
96.5	1.01	2.79	9.98
101.6	0.99	2.72	10.1

Table 2. The best (most likely) occupancy model for each focal species on Barbour Wildlife Management Area in the East Gulf Coastal Plain of Alabama. Psi (Ψ) represents the probability of use, where P (p) represents the detection probability for each species. While AICc, -2*ln(Lik), and Delta are presented for informative purposes, they should not be used for inter-specific comparisons.

	Model	AICc	-2*ln(Lik)	Delta	Model Likelihood	Model Probability	K
Pine Warbler	$\Psi_{\text{Canopy height + Canopy Cover + Midstory Cover+ Reproductive Cover +Ground Cover}}\ p_{\text{date}}$	132.274	114.709	0	1	.762	8
Wood Thrush	$\Psi_{\text{Reproductive Cover}}\ p_{\text{wind}}$	229.418	221.001	0	1	.101	4
Yellow-breasted Chat	$\Psi_{\text{Edge Density + Canopy Cover + Reproductive Cover + Midstory Cover + Ground Cover}}\ p_{\text{wind}}$	323.318	305.753	0	1	.390	8
Prairie Warbler	$\Psi_{\text{Canopy Cover + Reproductive Cover}}\ P_{\text{wind}}$	186.334	175.702	0	1	.114	5

CHAPTER 4

RESULTS

Stand Demographics

Of the 100 stands inventoried on Barbour WMA, 84 stands were forested, and 16 stands were classified as openings. The average canopy cover for the openings was 12.1% (±14.5), average midstory cover 15.1% (± 15.7), average reproductive cover 25.9% (± 22.8), and average ground cover 63.9% (± 27.6). The average canopy cover in forested stands was 59.2% (± 22.3), average midstory cover 58.9% (± 23.9), average reproductive cover 49.8% (± 22.0) and average ground cover 58.4% (± 21.8).

In forested stands, an average of 15.4 (± 6.1) snags were tallied per hectare. The average DBH for all snags measured in forested areas was 21.2cm ± 12.5cm (n=258). Species of snags measured in forested stands included *Ulmus* spp., *Fagus granifolia, Betula* spp., *Quercus* spp., *Prunus* spp., *Cornus* spp., *Pinus* spp., *Acer rubrum, Salix* spp., *Liquidambar styraciflua*, and *Liriodendron tulipifera*. Pine snags (*Pinus* spp.) had an average DBH 22.6cm ± 11.0cm (n=145) in the forested stands, and oak snags (*Quercus* spp.) had an average DBH 27.1cm ± 18.4cm (n=20). All hardwood snags (includes oaks) had an average DBH of 19.6cm ± 14.0cm (n=113). Openings had an average of 6.8 (± 17.9) snags per hectare. The average DBH was 11.7cm (n=22, ± 8.6cm). The species of snags measured in the opening included *Quercus* spp., *Prunus* spp., *Cornus* spp., *Pyrus* spp., *Pinus* spp., *Liriodendron tulipifera* and *Liquidambar styraciflua*.

A variety of tree species were measured for canopy height, including *Ulmus* spp., *Nyssa sylvatica, Quercus* spp., *Pinus* spp., *Acer rubrum, Carya* spp., *Liquidambar styraciflua*, and *Liriodendron tulipifera*. The average height of the tallest trees measured was 21.8m ± 7.9m (n=250). For species specific information see Table 3.

The SI_{50} had a range of values from of longleaf pine was 21 to 24m. The range SI_{50} of loblolly pine was 26 to 32m.

In forested plots an average of 3.1cm ± 1.2cm of duff was measured. In open stands the average of duff was 0.4cm ± 0.5cm. The average amount of basal area in forested stands was 16.8m^2ha^{-1} ± 8.2m^2 ha^{-1}. In openings the average amount of basal area was 2.5m^2 ha^{-1} ± 4.0m^2 ha^{-1}.

Of the 84 stands classified as forested 22 were loblolly pine plantations. The plantations ranged in age from 13 to 40 years. The SI_{50} for loblolly for all plantations ranged from 26 to 32m; although SI_{25} is normally used for plantations the SSURGO database only provides SI_{50}. Canopy cover, midstory cover, reproductive cover, and ground cover do not follow a discernable pattern with plantation age (Table 4). Average DBH increased with the age of the plantation (Table 4). There were on average 12.0 snags (± 11.0) per hectare for all plantations, however the number varied by plantation age.

Of the 84 stands 15 were classified as bottomland hardwoods (bottomlands). The bottomlands averaged 65.3% (± 23.2) canopy cover, had an average midstory cover of 72.4% (± 12.9), an average reproductive cover of 52.3% (± 19.1), and an average ground cover of 58.4% (± 16.5). There were on average 12.0 snags (± 14.0) per hectare. The tallest trees in these stands averaged 21.4m ± 7.1m (n=45). The average amount of duff was 1.6cm ± 1.0cm. The average basal area was 21.2 m^2 ha^{-1} ± 8.2 m^2 ha^{-1}. The SI_{50} for longleaf ranged from 23 to 24m while the SI_{50} for loblolly ranged from 27 to 32m.

The other 47 stands were mixed hardwood-pine and pine-hardwood stands. The only pine measured was loblolly pine. The mixed stands averaged 57.8% (± 21.3) canopy cover, had an average midstory cover of 61.3% (± 22.9), an average reproductive cover of 54.5% (± 22.2), and an average ground cover of 58.7% (± 22.8). There were on average 18.5 snags (± 29.0) per hectare. The tallest trees in these stands averaged 22.9m ± 8.4m (n=129). The average amount of duff was 2.1cm (± 1.1cm). The average basal area was 15.3 m^2 ha^{-1} ± 7.2 m^2 ha^{-1}. The SI_{50} for longleaf ranged from 21 to 24m while the SI_{50} for loblolly ranged from 26 to 32m.

Vegetative Cover Projections

The linear regression model generated and used for reproductive cover was:

Reproductive Cover = 36.7 + 0.397Midstory Cover – 0.412 Basal Area

Table 5 has a complete list of models with AIC and weight. The averaged model parameters from all the *a priori* models can be found in Table 6. Relative importance values for each parameter can be seen in Table 7.

For the reproductive cover model the variance inflation factors were 1.997 for canopy cover, 1.247 for midstory cover, 2.260 for basal area, and 1.355 for trees per hectare. Comparisons of r^2 values between each of these variables can be seen in Table 8.

The linear regression model generated and used for ground cover was:

Ground Cover = 69.3 + 0.171 Reproductive Cover – 0.292 Midstory Cover – 0.00861 Trees per Hectare

Table 9 has a complete list of models with AIC and weight. The averaged model parameters from all the *a priori* models can be found in Table 10. Relative importance values for each parameter can be seen in Table 11.

For the ground cover model the variance inflation factors were 3.139 for canopy cover, 2.675 for midstory cover, 1.402 for reproductive cover, 1.529 for percent basal area hardwood, 3.336 for basal area, and 1.438 for trees per hectare. Comparisons of r^2 values between each of these variables can be seen in Table 12.

Stand Structure

Diameter distributions were similar for all stands within each scenario. In the no management simulation diameters are essentially normally distributed throughout time, however, there are occasional spikes in the smaller size classes. Over the projection cycle the average stand diameter increases as the range of diameters increase, but the number of trees in each diameter class decreases, flattening the normal curve over time as can be seen in the truncated example presented in Figure 4; a full series of diameter distributions for a typical stand projected under the no management scenario can be found in Appendix A. In the Pro-B simulations a reverse j-shaped or negative exponential curve was typically achieved after 40-years and maintained throughout the remainder of the simulation. A truncated example is presented in Figure 5; a full series of diameter distributions for a typical stand projected under the Pro-B scenario can be found in Appendix B. The same result was obtained for stands converted from an even-aged structure. A truncated example presented in Figure 6; a full series of diameter distributions for a typical stand converted from an even-aged structure and then projected under the Pro-B scenario can be found in Appendix C. All three of the even-aged scenarios maintain normally distributed diameters throughout the projection as can be seen in the truncated example presented in Figure 7; a full series of diameter distributions for a typical stand projected under the even-aged scenario can be found in Appendix D. However, the diameter growth rate decreases with increased planting density.

Basal area increases to a stable point between 2043 and 2058 at around $46.8m^2ha^{-1}$ in the no management projections (Figure 8). In the Pro-B projections basal area is cut to $13.8m^2ha^{-1}$ at the lowest point and allowed to grow to 17.3 m^2ha^{-1} (Figure 8 and 9). When conversion takes place before Pro-B is implemented there is more variation seen during that period (Figure 9), approximately 20 years, after which the stand structure is basically stable.

When even-aged management is implemented stands follow the pattern seen in Figure 8, an sharp increase followed by a decline after thinning, then sharp increase followed by a decline after thinning, then a steady increase to the final cut in the rotation, regardless of planting density. However, with the change in the planting density, the thinning schedule is modified because thinning operations were triggered at a BA threshold of $18.3m^2ha^{-1}$ or when growth was being impeded. In the 741 trees per hectare simulation reached that threshold at 30-years and 40-years after initial planting; while in the 1112 trees per hectare simulation they were applied 25-years and 40-years. Finally, in the 1483 trees per hectare simulation thinning was applied at 25, 35, and 50-years after planting.

Canopy cover follows trends similar to basal area development for all scenarios (Figure 10). Midstory cover has an initial decrease from 40% to 20% in the no management projection, then a short period of increase from 2013 to 2048, after which it declines to about 6% at the end of the projection (Figure 11). The even-aged projection has no midstory cover after the initial clearcut. In the Pro-B projection the amount of midstory cover varies throughout (Figure 11). It steadily increases from 2038 to 2073, and then generally decreases as it oscillates between 30 to 40% for the remainder of the projection.

Reproductive cover does not change much between the projection scenarios for the first 50 years of the projection (Figure 12 and 13), staying within 10 to 20 percentage points of each other. After year 50 there is 20 to 25% more reproductive cover in the Pro-B scenario than the no management scenario. Differences in the amount of reproductive cover are a function of the amounts of cover present at the start of the projection (Figure 12 and 13). Ground cover exhibits similar trends among the scenarios (Figure 14); the amount of ground cover did not differ by more than 15 to 20 percentage points among scenarios. Ground cover always tended to increase throughout the projection, but only slightly.

Probability of Use

The pine warbler is predicted to use stands under both the no management and Pro-B scenarios 100% of the time for 100% of the projection cycles. Under the even-aged management scenarios, pine warbler probability of use was between 80 and 100% throughout the projection cycle (Figure 16). The yellow-breasted chat's probability of use varies with management scenario and the amount of edge. With 0% edge in forested stands, the yellow-breasted chat is more likely to use even-aged stands over time (Figure 17). When there is the 50% edge present, yellow-breasted chat is still more likely to use the even-aged projection (Figure 18). When there is the 100% edge present yellow-breasted chat is even more likely to use the even-aged projection (Figures 19). The wood thrush has less than a 30% probability of use under any management scenario (Figure 20). The prairie warbler has the highest probability of use in the even-aged scenarios over time, but will still use the other management scenarios between 20 to 30% of the time (Figure 21).

Table 3: Average height and age of trees measured on Barbour WMA.

Species	Average Height (m)	Range of Height (m)	Average Age (years)	Range of Ages (years)
Pinus tadea	20.9 (n=89)	8.5 to 47.2	32.8 (n=71)	12 to 86
Quercus nigra	23.6 (n=53)	9.7 to 40.0	51.8 (n=36)	15 to 95
Quercus alba	20.4 (n=11)	13.4 to 27.1	60.0 (n=9)	22 to 107
Quercus stellata	19.7 (n=7)	15.2 to 24.4	58.0 (n=7)	35 to 86
Quercus rubra	15.8 (n=5)	5.5 to 23.8	63.0 (n=2)	59 to 67
Carya spp.	21.8 (n=20)	12.5 to 40.2	52.1 (n=14)	23 to 97
Lirodendron tulipifera	25.1 (n=19)	11.6 to 50.3	N/A	N/A
Liquidambar styraciflua	19.5 (n=30)	3.0 to 35.1	N/A	N/A

Table 4: Average DBH, basal area, canopy cover (CC), midstory cover (MC), reproductive cover (RC), ground cover (RC), number of snags per hectare (Snags) and range of SI_{50} by loblolly pine plantation age.

Plantation Age (years)	N	DBH (cm)	Basal Area (m^2 ha^{-1})	CC (%)	MC (%)	RC (%)	GC (%)	Snags (per Hectare)	Range of SI_{50} (m)
≤ 15	4	16.5±1.7	5.3±3.6	46.0±34.8	55.5±14.7	41.0±24.1	60.0±11.2	7.5±11.9	27
15 to 20	2	17.5±3.5	9.8±5.9	73.0± 9.9	64.0± 5.7	41.0± 4.2	20.0±11.3	10.0±14.1	27
20 to 25	5	24.2±4.1	7.8±4.3	68.0±13.0	32.8±26.3	28.8±23.9	54.4±28.4	19.0±11.9	27 to 32
25 to 30	6	33.5±1.6	4.3±1.5	40.7±12.4	23.7± 9.1	41.3±14.6	80.3± 8.7	14.2±11.1	26 to 32
≥ 30	5	34.4±5.6	5.6±4.3	69.2±27.0	54.4±35.6	38.4±21.2	44.8±25.1	6.0±8.2	26 to 29

Table 5: Complete model list for the Reproductive Cover regression model.

Model	Intercept	BA[1] (m^2ha^{-1})	CC[2] (%)	MC[3] (%)	TPH[4]	k	AIC[5]	AICc[6]	Delta[7]	Weight
7	36.44	-1.5810		0.4084		4	748.5	749.0	0.000	0.312
9	38.06		-0.20390	0.4040		4	749.7	750.2	1.197	0.172
14	37.13	-1.9000		0.3988	0.003021	5	749.7	750.5	1.469	0.150
12	38.38	-1.1910	-0.09280	0.4234		5	750.1	750.9	1.816	0.126
4	30.60			0.3257		3	751.2	751.5	2.476	0.091
15	38.24		-0.21310	0.3988	0.001009	5	751.6	752.4	3.358	0.058
16	38.97	-1.5190	-0.08843	0.4234	0.002953	6	751.3	752.4	3.376	0.058
11	30.69			0.3306	-0.000556	4	753.2	753.7	4.651	0.031
1	49.79					2	760.5	760.6	11.590	0.001
5	48.17				0.002396	3	761.9	762.2	13.180	0.000
2	52.79	-0.4431				3	762.1	762.4	13.370	0.000
3	51.30		-0.02563			3	762.4	762.7	13.680	0.000
8	53.24	-0.9596			0.00451	4	762.6	763.1	14.080	0.000
10	51.31		-0.06004		0.00301	4	763.6	764.1	15.110	0.000
6	51.79	-0.6127	0.03623			4	764.1	764.6	15.520	0.000
13	52.21	-1.1350	0.03731		0.00452	5	764.6	765.3	16.280	0.000

[1] Basal Area (m^2ha^{-1})
[2] Canopy Cover (%)
[3] Midstory Cover (%)
[4] Trees per Hectare
[5] AIC ranks the models to provide the best model using the available information.
[6] AICc is the adjusted weight for small sample size.
[7] Delta is the change in AIC from the best model.

Table 6: Averaged model parameters for Reproductive Cover Regression Model.

Parameter	Coefficient	Variance	Standard Error
Intercept	36.7	2.67	7.14
Basal Area (m^2ha^{-1})	-0.412	1.09	0.0945
Canopy Cover (%)	-0.0642	1.88	0.106
Midstory Cover (%)	0.397	1.31	0.106
Trees per Hectare	0.00067	2.44	0.00404

Table 7: Relative variable importance for the Reproductive Cover Regression Model.

Variable	Importance[1]
Basal Area (m^2ha^{-1})	0.65
Canopy Cover (%)	0.41
Midstory Cover (%)	1.00
Trees per Hectare	0.30

[1] An importance value of greater than 0.5 was used to determine which variables should be included in the model.

Table 8: Comparison of r^2 values between variables modeled in the reproductive cover model.

	CC[1](%)	MC[2](%)	BA[3] (m^2ha^{-1})	TPH[4]
CC[1](%)	1.000	0.412	0.687	0.342
MC[2](%)	0.412	1.000	0.382	0.279
BA[3] (m^2ha^{-1})	0.687	0.382	1.000	0.502
TPH[4]	0.342	0.279	0.502	1.000

[1] Canopy Cover
[2] Midstory Cover
[3] Basal Area
[4] Trees per Hectare

Table 9: Complete model list for the Ground Cover regression model.

Model	Intercept	BA[1] (m^2ha^{-1})	CC[2] (%)	MC[3] (%)	%BAHW[4]	RC[5] (%)	TPH[6]	k	AIC[7]	AICc[8]	Delta[9]	Weight
41	69.26			-0.2863		0.21890	-0.008462	5	892.5	893.1	0.000	0.243
51	67.71	0.75860		-0.3404		0.23540	-0.009844	6	893.5	894.4	1.240	0.130
55	67.54		0.08177	-0.3367		0.22880	-0.009031	6	893.8	894.7	1.584	0.110
57	68.88			-0.3146	3.694	0.20770	-0.008286	6	894.1	895.0	1.866	0.095
19	74.59			-0.1938			-0.008593	4	895.4	895.9	2.733	0.062
62	67.40	0.73890		-0.3654	3.437	0.22470	-0.009644	7	895.1	896.3	3.207	0.049
63	67.09		0.08418	-0.3679	3.876	0.21750	-0.008864	7	895.4	896.6	3.457	0.043
60	67.38	0.61430	0.02979	-0.3485		0.23590	-0.009788	7	895.4	896.6	3.501	0.042
40	73.56			-0.2464	5.893		-0.008302	5	896.4	897.1	3.949	0.034
29	73.90	0.45940		-0.2223			-0.009436	5	897.1	897.7	4.584	0.025
35	73.64		0.05305	-0.2238			-0.008966	5	897.2	897.8	4.674	0.023
64	66.98	0.56120	0.03650	-0.3763	3.578	0.22480	-0.009568	8	897.0	898.6	5.491	0.016
50	72.89	0.44910		-0.2739	5.846		-0.009128	6	898.1	899.0	5.860	0.013
54	72.45		0.05908	-0.2816	6.093		-0.008708	6	898.1	899.0	5.869	0.013
18	68.25			-0.3713		0.22450		4	898.6	899.0	5.901	0.013
7	66.17						-0.011270	3	899.2	899.5	6.355	0.010
45	73.65	0.34620	0.02325	-0.2284			-0.009392	6	899.0	899.9	6.818	0.008
39	67.74			-0.4092	5.277	0.20850		5	899.9	900.5	7.360	0.006
16	69.67			-0.0820			-0.010050	4	900.3	900.7	7.577	0.005
22	63.17					0.07005	-0.011630	4	900.6	901.1	7.926	0.005
28	68.75	-0.22070		-0.3515		0.21940		5	900.5	901.2	8.021	0.004
12	68.17	-0.47580					-0.009985	4	900.7	901.2	8.023	0.004
34	67.98		0.01242	-0.3798		0.22610		5	900.6	901.2	8.103	0.004
59	72.49	0.27860	0.03498	-0.2843	5.982		-0.009055	7	900.0	901.2	8.104	0.004
21	67.62				-2.563		-0.011080	4	901.0	901.4	8.269	0.004
4	73.71			-0.2777				3	901.4	901.7	8.538	0.003
38	66.50		-0.09745			0.08942	-0.010290	5	901.3	902.0	8.839	0.003

Table 9: Complete model list for the Ground Cover regression model.

Model	Intercept	BA[1] (m^2ha^{-1})	CC[2] (%)	MC[3] (%)	%BAHW[4]	RC[5] (%)	TPH[6]	k	AIC[7]	AICc[8]	Delta[9]	Weight
17	72.43			-0.3409	7.487			4	901.9	902.3	9.200	0.002
42	64.46				-4.833	0.10380	-0.011450	5	901.9	902.5	9.363	0.002
32	65.10	-0.54160				0.07832	-0.010220	5	902.0	902.6	9.495	0.002
49	68.24	-0.22050		-0.3894	5.276	0.20340		6	901.8	902.7	9.527	0.002
53	67.35		0.01751	-0.4216	5.337	0.21050		6	901.8	902.7	9.594	0.002
37	70.13		-0.07601		-1.266		-0.010040	5	902.2	902.9	9.736	0.002
26	69.66	0.03224	-0.08506				-0.010090	5	902.3	902.9	9.793	0.002
44	68.08	-0.49620	0.05912	-0.3674		0.22050		6	902.3	903.2	10.090	0.002
31	68.84	-0.41140			-1.655		-0.010040	5	902.6	903.3	10.140	0.002
9	74.50	-0.46240		-0.2406				4	903.0	903.4	10.290	0.001
13	74.00		-0.01546	-0.2679				4	903.4	903.8	10.690	0.001
56	67.00		-0.08440		-3.565	0.11180	-0.010340	6	902.9	903.8	10.700	0.001
27	73.19	-0.43740		-0.3050	7.378			5	903.5	904.2	11.040	0.001
48	66.48	0.07137		-0.1042		0.08967	-0.010380	6	903.3	904.2	11.100	0.001
52	65.68	-0.41040			-3.925	0.10380	-0.010410	6	903.5	904.4	11.280	0.001
33	72.54		-0.00566	-0.3371	7.460			5	903.9	904.5	11.410	0.001
58	67.44	-0.53950	0.06844	-0.4095	5.513	0.20400		7	903.5	904.7	11.580	0.001
47	70.13	0.06381	-0.08183		-1.308		-0.010130	6	904.2	905.1	12.000	0.001
23	73.93	-0.70530	0.05188	-0.2541				5	904.9	905.5	12.370	0.001
61	66.97	0.17120	-0.10010		-3.708	0.11330	-0.010560	7	904.9	906.1	12.980	0.000
43	72.44	-0.74330	0.06550	-0.3240	7.611			6	905.3	906.2	13.070	0.000
2	68.30	-1.53800						3	907.1	907.4	14.260	0.000
3	69.19		-0.19130					3	908.3	908.5	15.380	0.000
11	66.09	-1.60300				0.05638		4	908.8	909.2	16.170	0.000

Table 9: Complete model list for the Ground Cover regression model.

Model	Intercept	BA[1] (m^2ha^{-1})	CC[2] (%)	MC[3] (%)	%BAHW[4]	RC[5] (%)	TPH[6]	k	AIC[7]	AICc[8]	Delta[9]	Weight
8	69.48	-1.14500	-0.06723					4	908.9	909.3	16.170	0.000
10	68.66	-1.50600			-0.898			4	909.1	909.5	16.400	0.000
15	66.86		-0.20450			0.06555		4	909.8	910.2	17.080	0.000
14	69.68		-0.18470		-1.367			4	910.2	910.6	17.490	0.000
25	67.17	-1.14200	-0.08073			0.06490		5	910.4	911.1	17.930	0.000
30	66.46	-1.53400			-2.454	0.07202		5	910.6	911.2	18.120	0.000
24	69.70	-1.13200	-0.06568		-0.614			5	910.9	911.5	18.380	0.000
1	59.30							2	911.7	911.8	18.700	0.000
36	67.30		-0.19350		-3.117	0.08498		5	911.5	912.2	19.020	0.000
5	62.40				-5.092			3	912.8	913.1	19.930	0.000
46	67.48	-1.09300	-0.07796		-2.269	0.07908		6	912.3	913.2	20.040	0.000
6	58.82					0.01046		3	913.7	913.9	20.810	0.000
20	60.60				-6.366	0.05618		4	914.5	914.9	20.810	0.000

[1] Basal Area (m^2ha^{-1})
[2] Canopy Cover (%)
[3] Midstory Cover (%)
[4] Percent Basal Area of Hardwoods (%)
[5] Reproductive Cover (%)
[6] Trees per Hectare
[7] AIC ranks the models to provide the best model using the available information.
[8] AICc is the adjusted weight for small sample size.
[9] Delta is the change in AIC from the best model.

Table 10: Averaged model parameters for Ground Cover Regression Model.

Parameter	Coefficient	Variance	Standard Error
Intercept	69.3000	9.75	5.550
Basal Area (m^2ha^{-1})	0.1820	1.02	0.428
Canopy Cover (%)	0.0157	2.14	0.0467
Midstory Cover (%)	-0.2920	2.63	0.120
Percent BA of HW	1.1800	2.21	2.850
Reproductive Cover(%)	0.1710	2.76	0.127
Trees per Hectare	-0.00861	1.75	0.00345

Table 11: Relative variable importance for the Ground Cover Regression Model.

Variable	Importance[1]
Basal Area (m^2ha^{-1})	0.31
Canopy Cover (%)	0.29
Midstory Cover (%)	0.95
Percent BA of HW	0.29
Reproductive Cover (%)	0.78
Trees per Hectare	0.95

[1] An importance value of greater than 0.5 was used to determine which variables should be included in the model.

Table 12: Comparison of r^2 values between variables modeled in the ground cover model.

	CC[1]	MC[2]	RC[3]	BA[4]	%BH[5]	TPH[6]
CC[1]	1.000	0.645	0.233	0.795	0.310	0.402
MC[2]	0.645	1.000	0.490	0.598	0.558	0.367
RC[3]	0.233	0.490	1.000	0.182	0.404	0.164
BA[4]	0.795	0.598	0.182	1.000	0.315	0.535
%BH[5]	0.310	0.558	0.404	0.315	1.000	0.129
TPH[6]	0.402	0.367	0.164	0.535	0.129	1.000

[1]Canop Cover (%)
[2]Midstory Cover (%)
[3]Reproductive Cover (%)
[4]Basal Area (m^2ha^{-1})
[5]Percent Basal Area Hardwood (%)
[6]Trees per Hectare

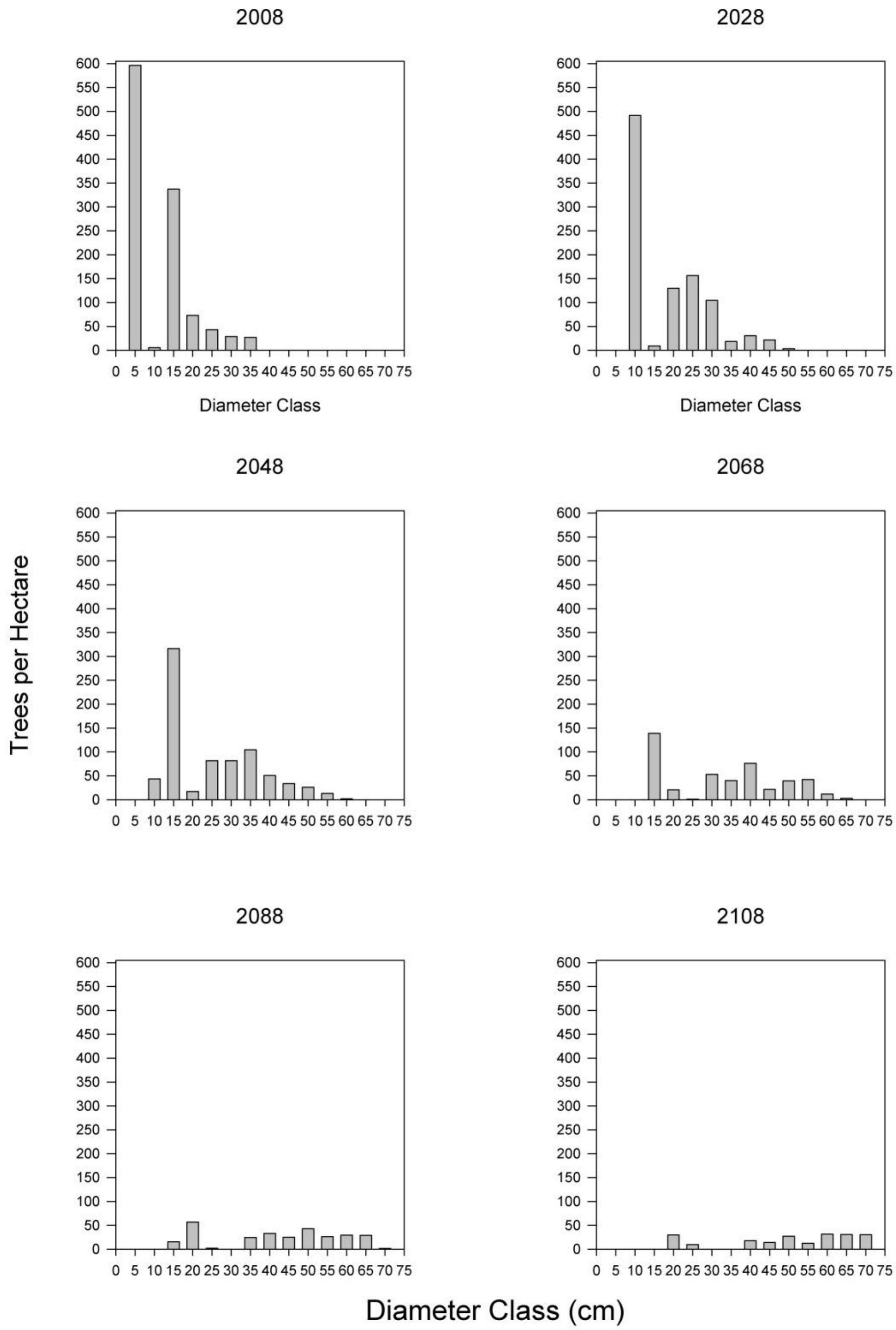

Figure 4: Diameter structure of a typical stand under the no management scenario at 20-year intervals during the 100-year projection.

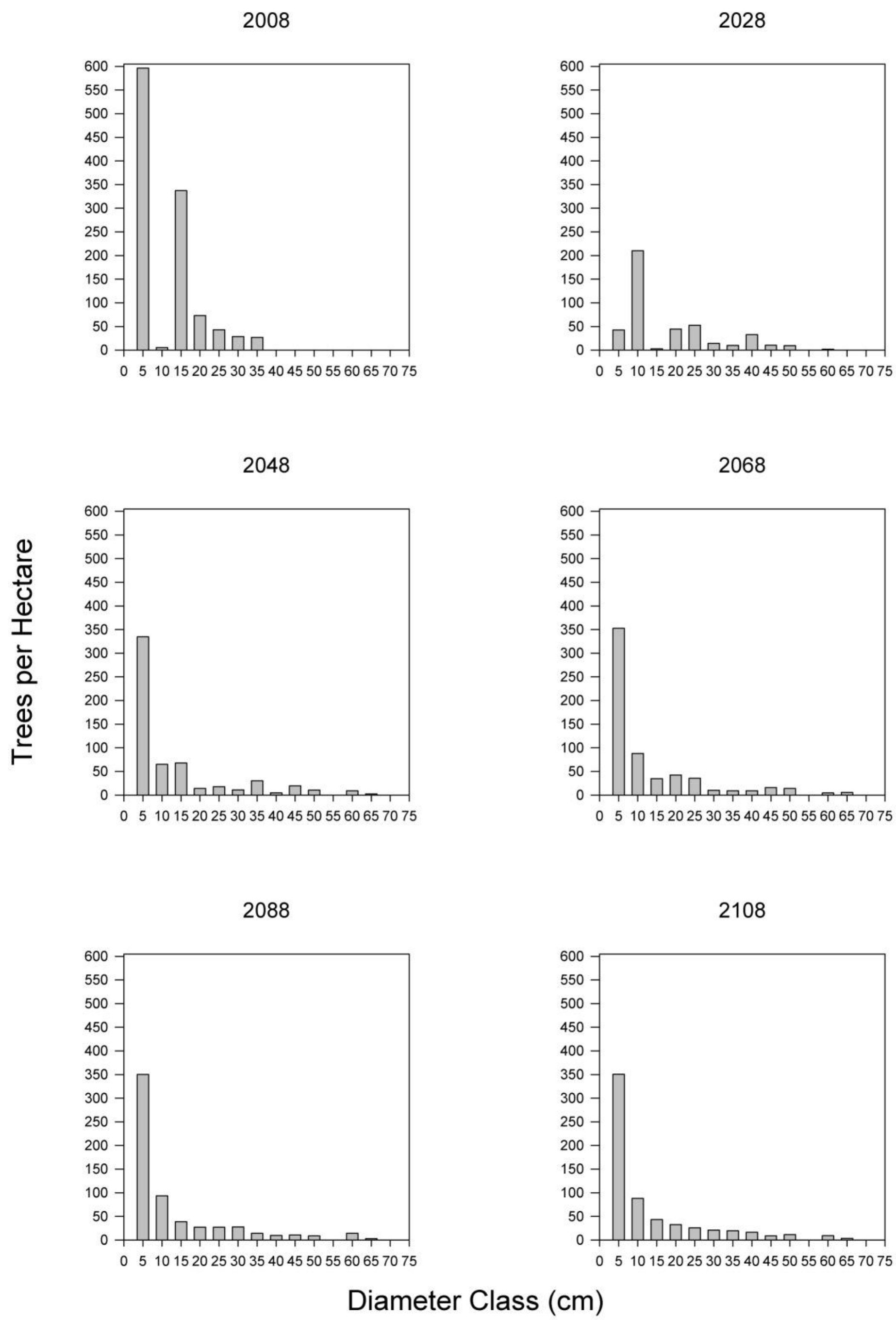

Figure 5. Diameter structure of a typical stand under the Proportional-B scenario at 20-year intervals during the 100-year projection.

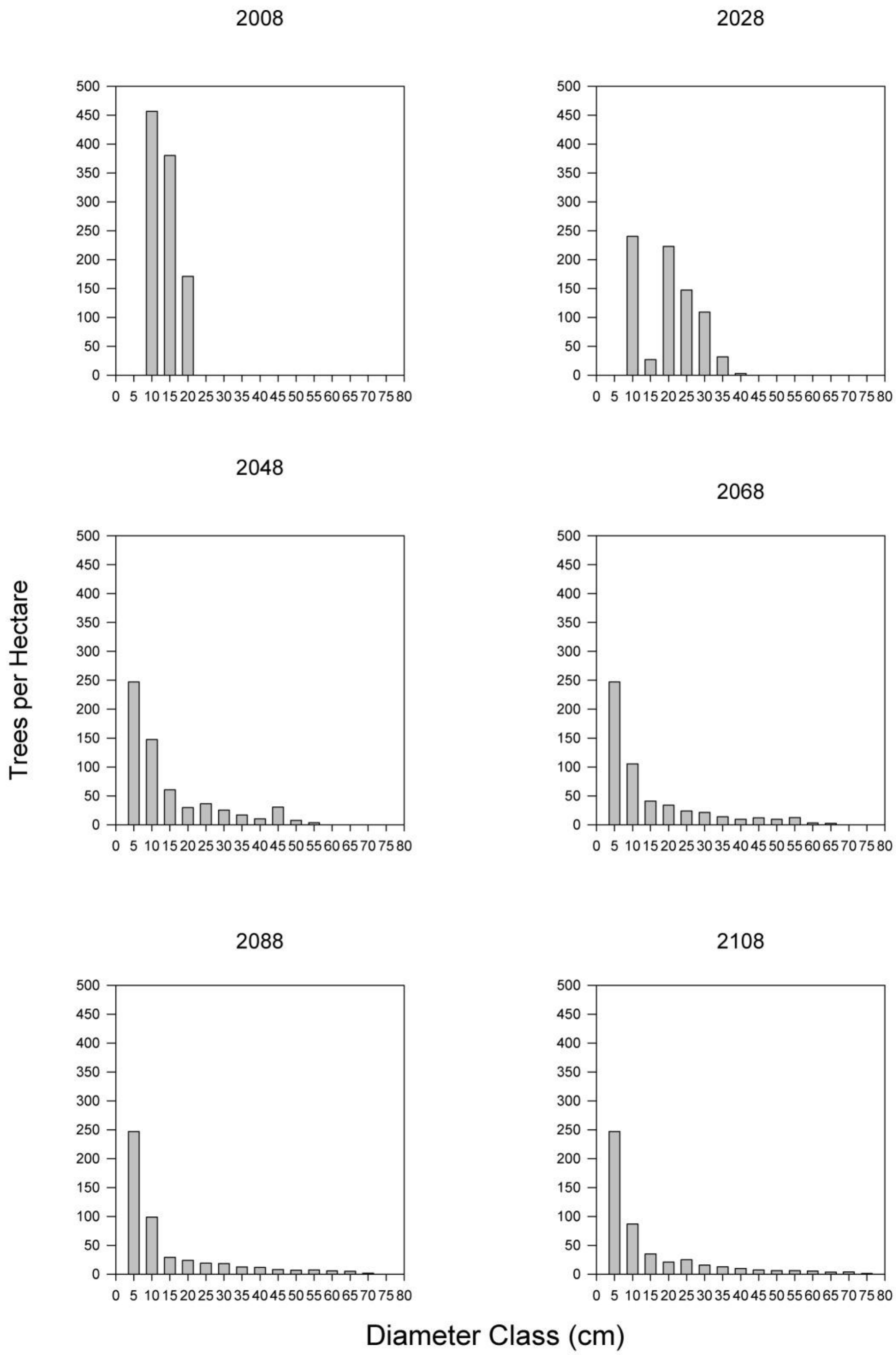

Figure 6: Diameter structure of a typical stand converted from an uneven-aged structure then utilizing the Proportional-B method at 20-year intervals during the 100-year projection.

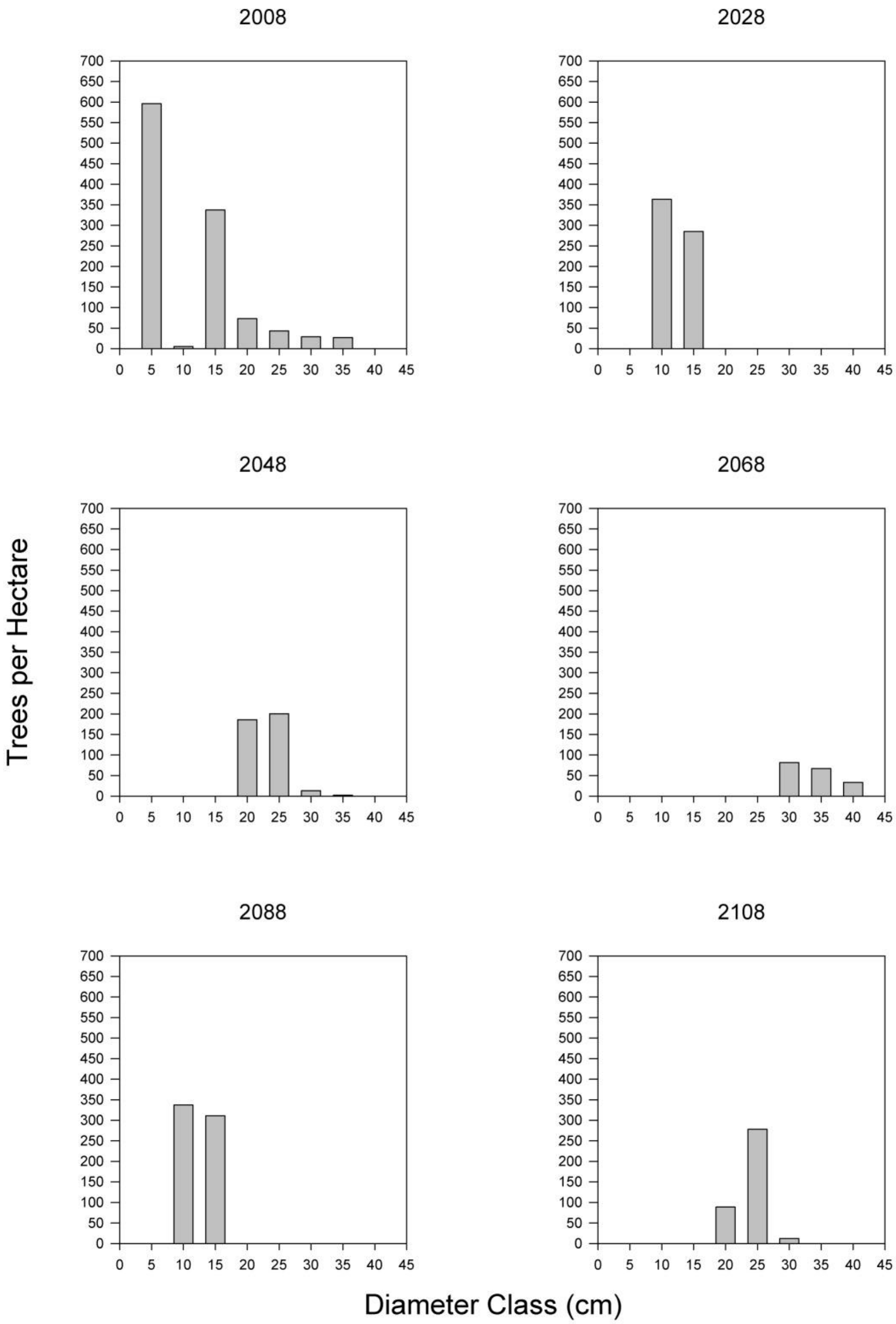

Figure 7: Diameter structure of a typical stand under the even-aged management scenario at 20-year intervals during the 100-year projection.

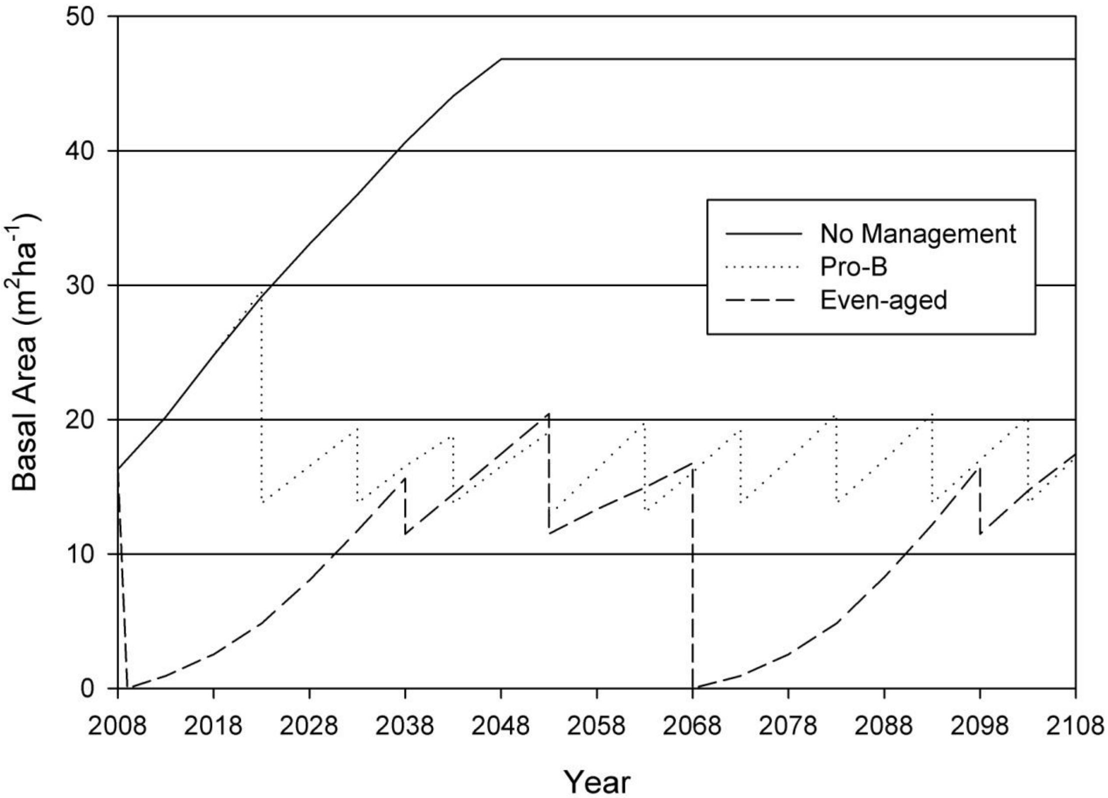

Figure 8: Basal Area in typical stands under each of the three management scenarios as affected by harvest operations.

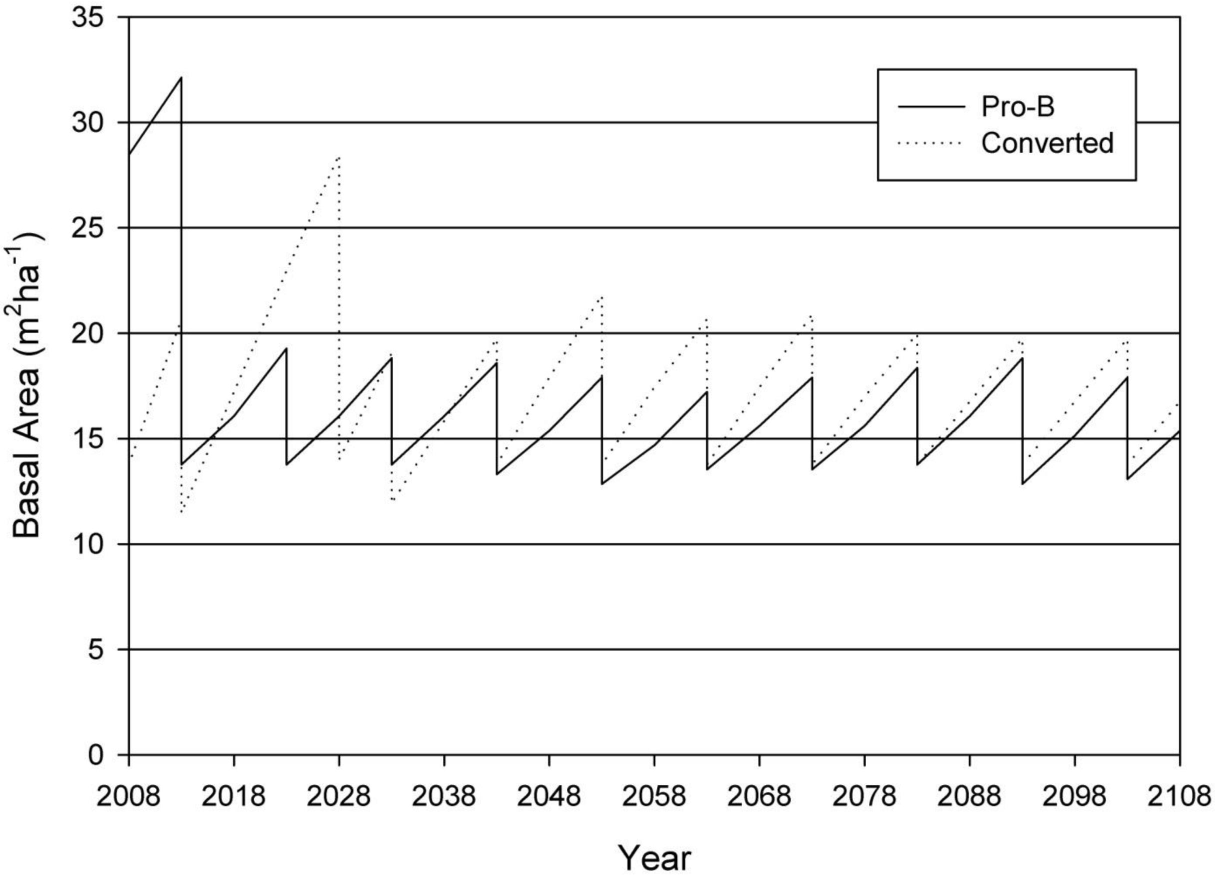

Figure 9: Basal Area in a stand that was converted from an even-aged structure before implementing proportional-B compared to a stand on which proportional-B was immediately implemented. Note the conversion period from 2008 to 2033.

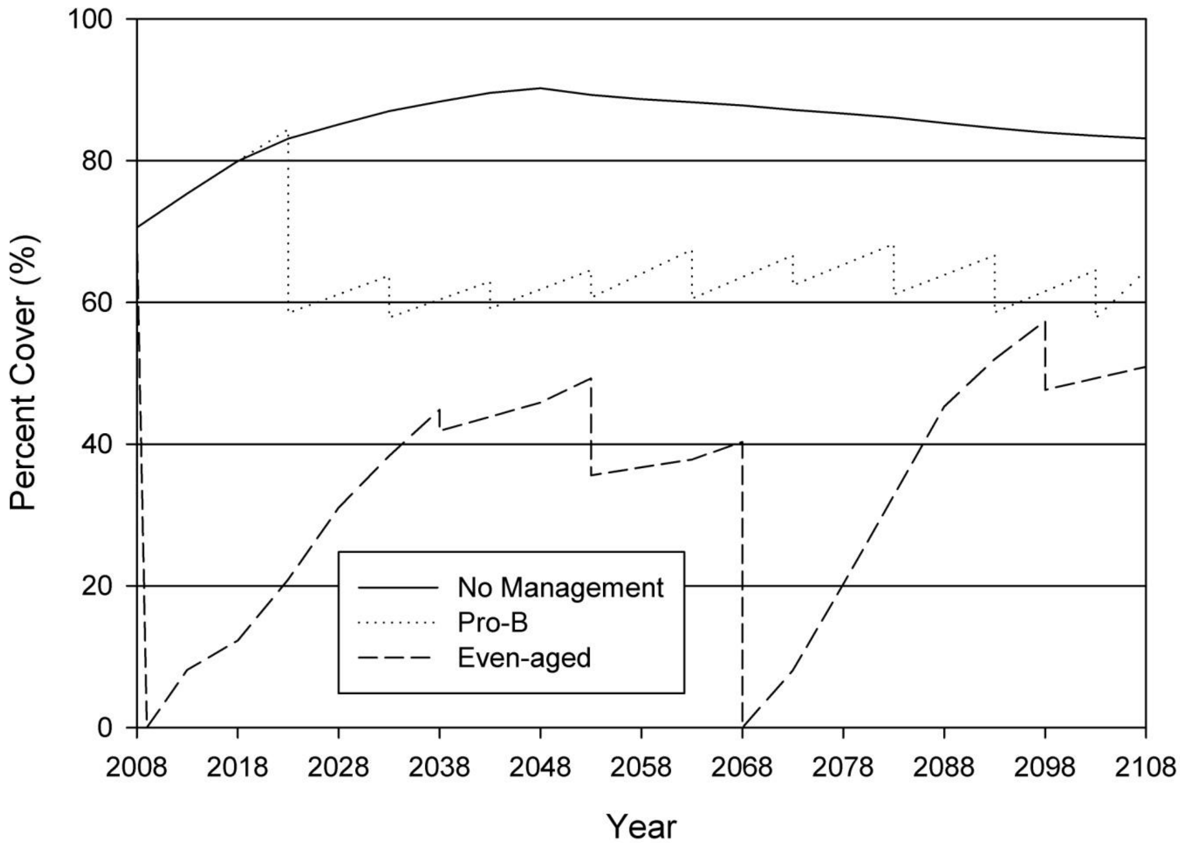

Figure 10: Canopy cover of a typical stand under each of the three management scenarios over the projection cycle.

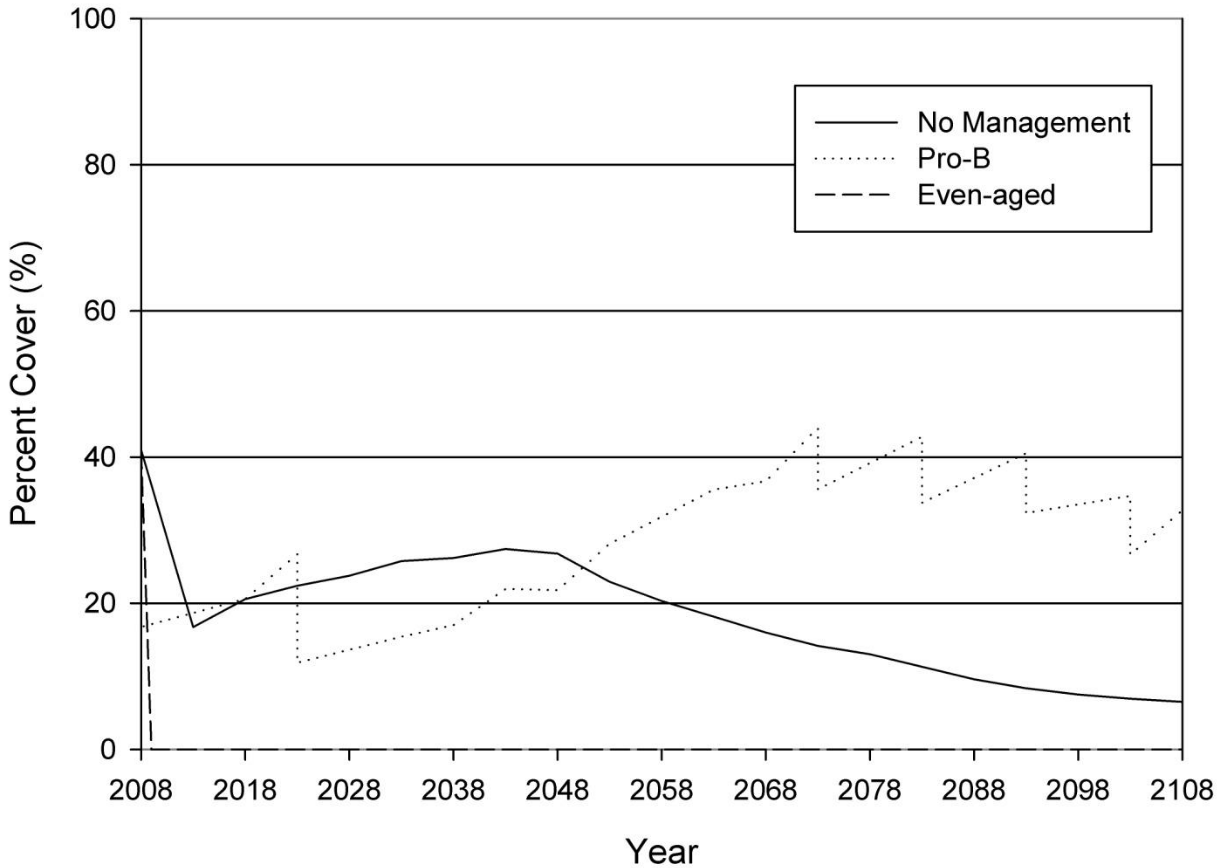

Figure 11: Midstory cover of a typical stand under each of the three management scenarios over the projection cycle.

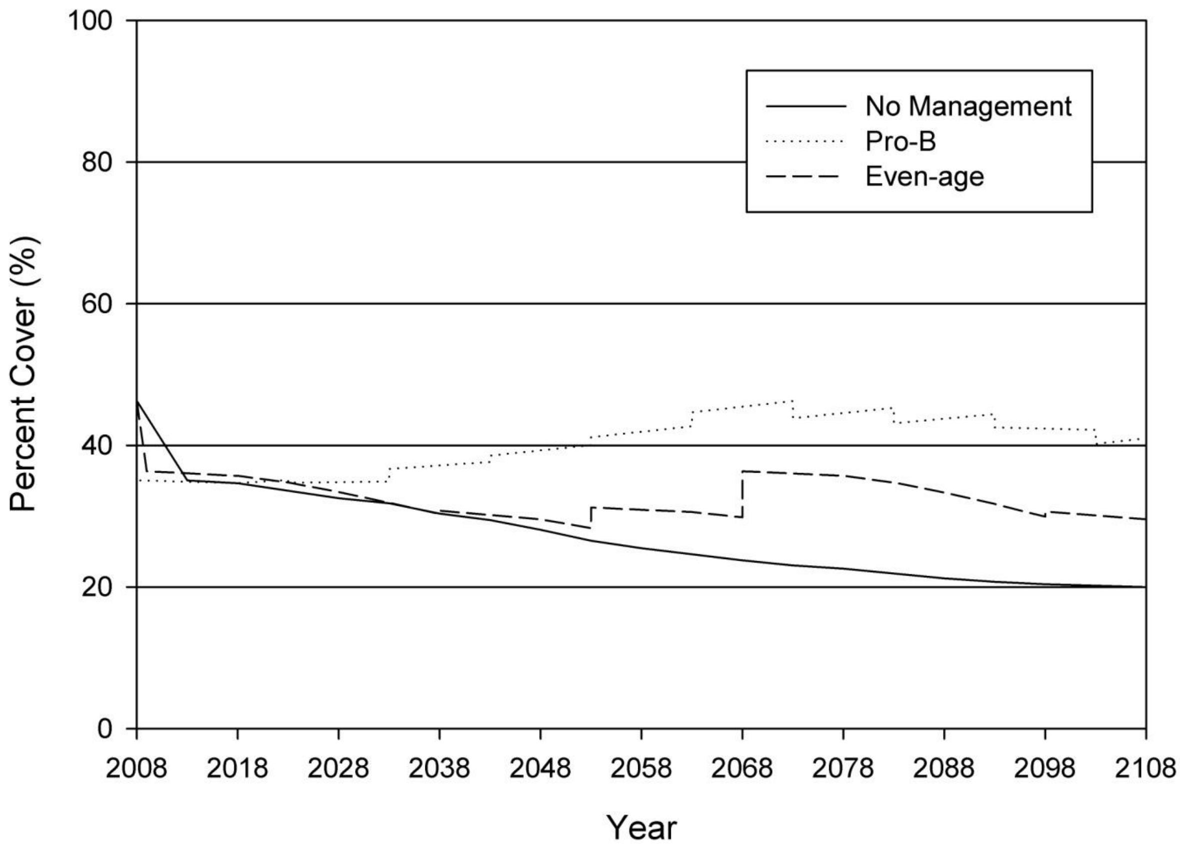

Figure 12: Reproductive cover found of a typical stand under each of the three management scenarios over the projection cycle.

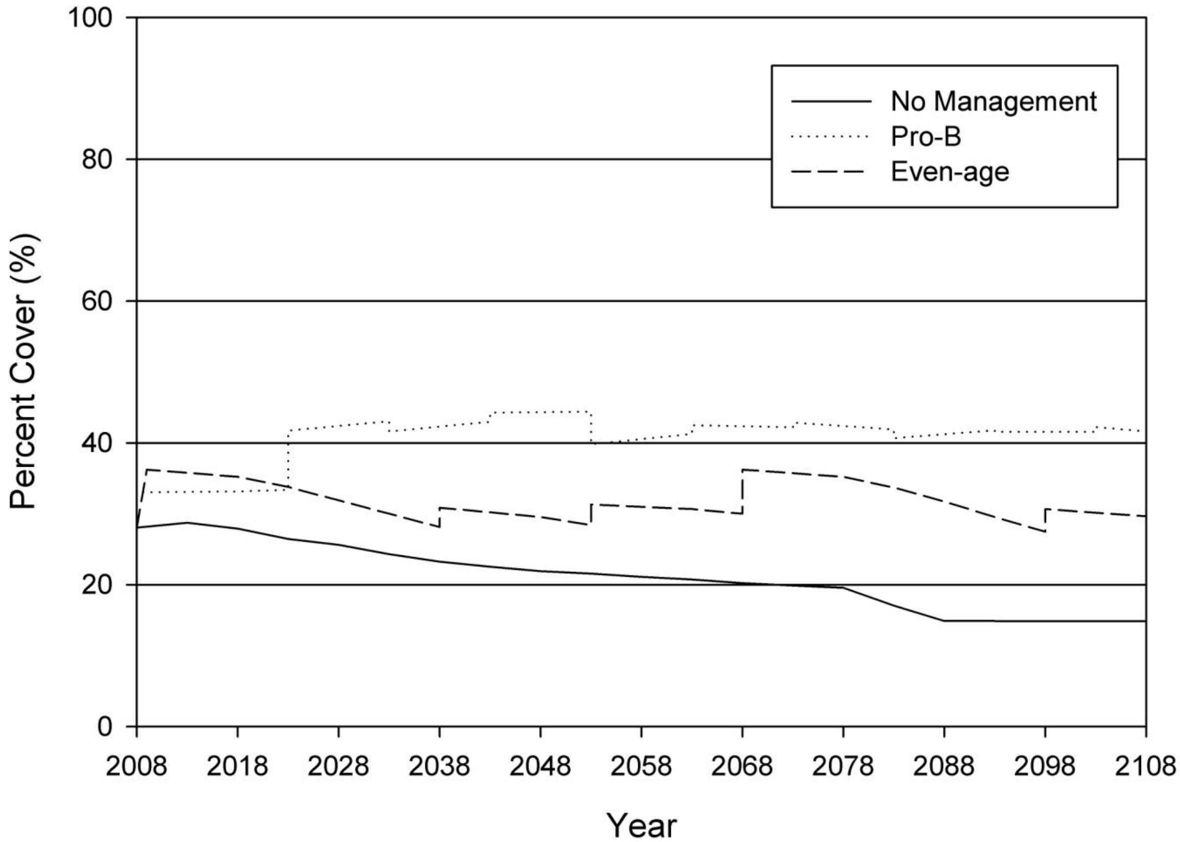

Figure 13: Reproductive cover of a typical stand under each of the three management scenarios over the projection cycle.

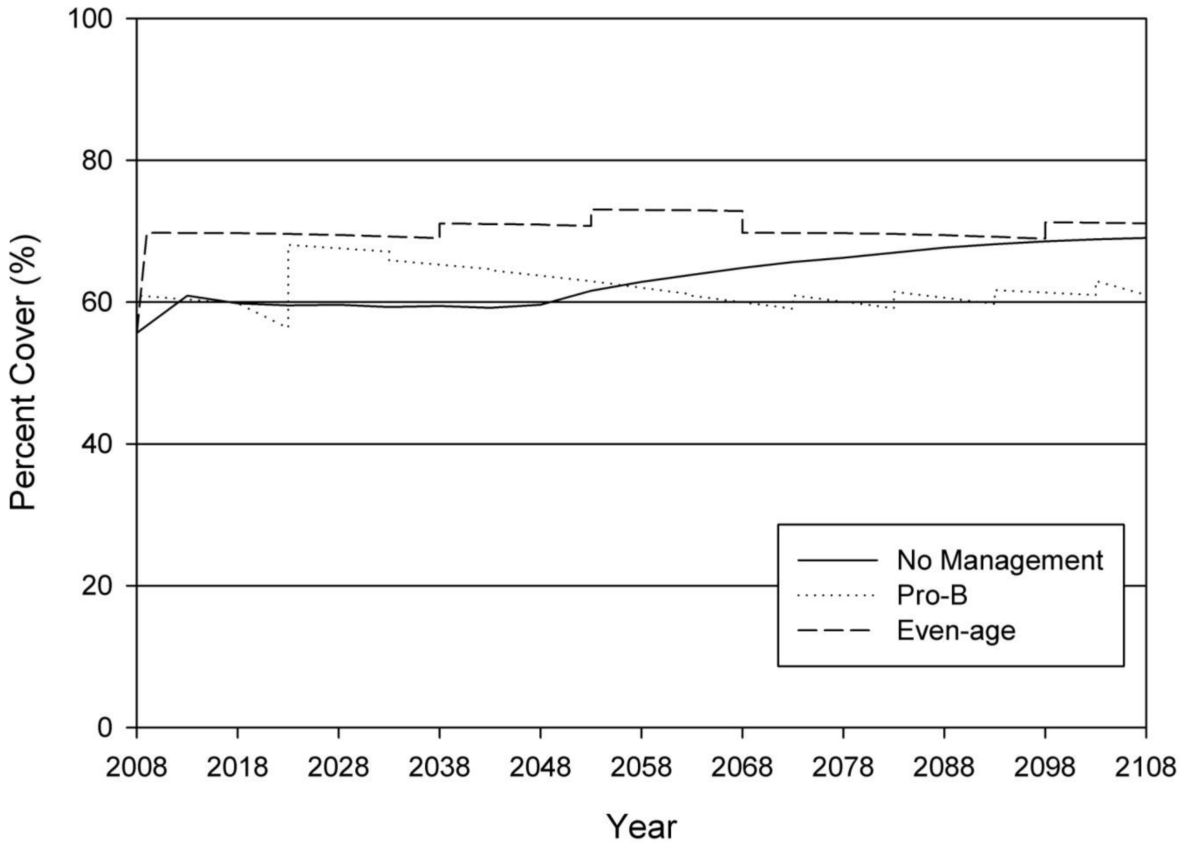

Figure 14: Ground cover of a typical stand under each of the three management scenarios over the projection cycle.

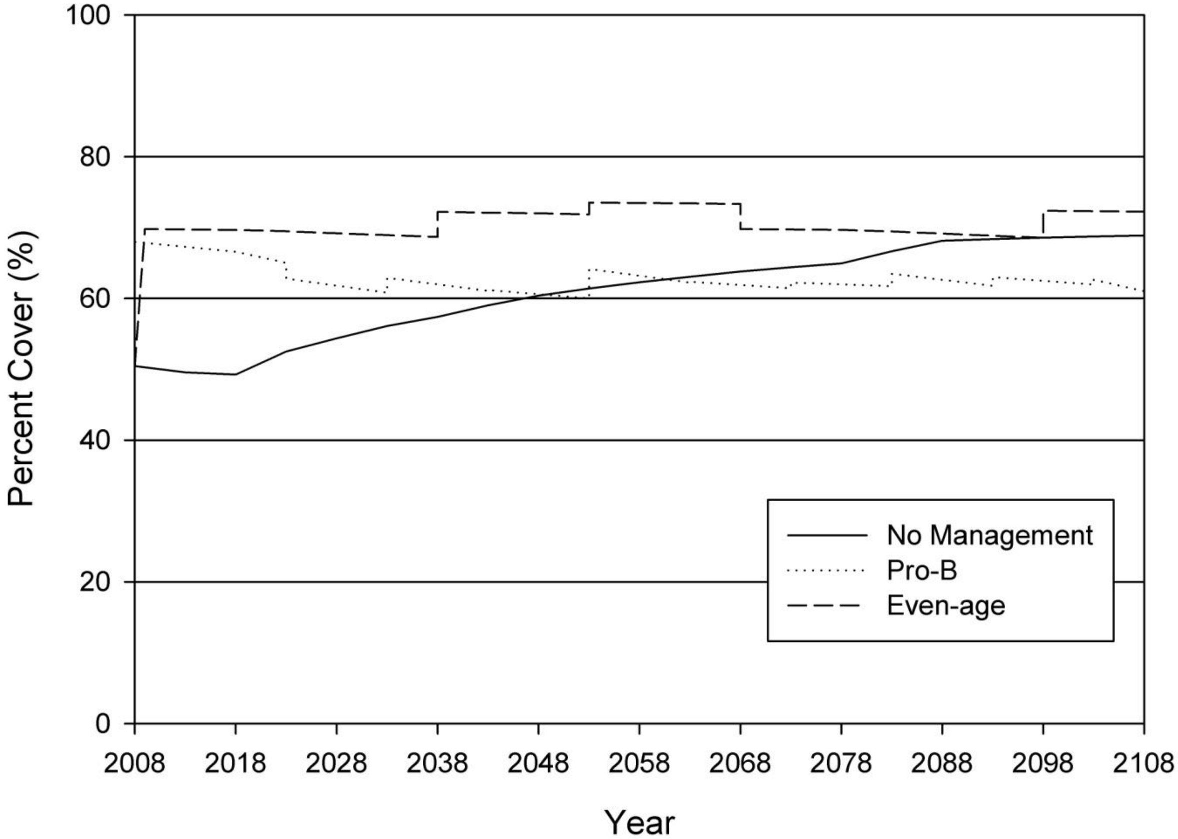

Figure 15: Ground cover of a typical stand under each of the three management scenarios over the projection cycle.

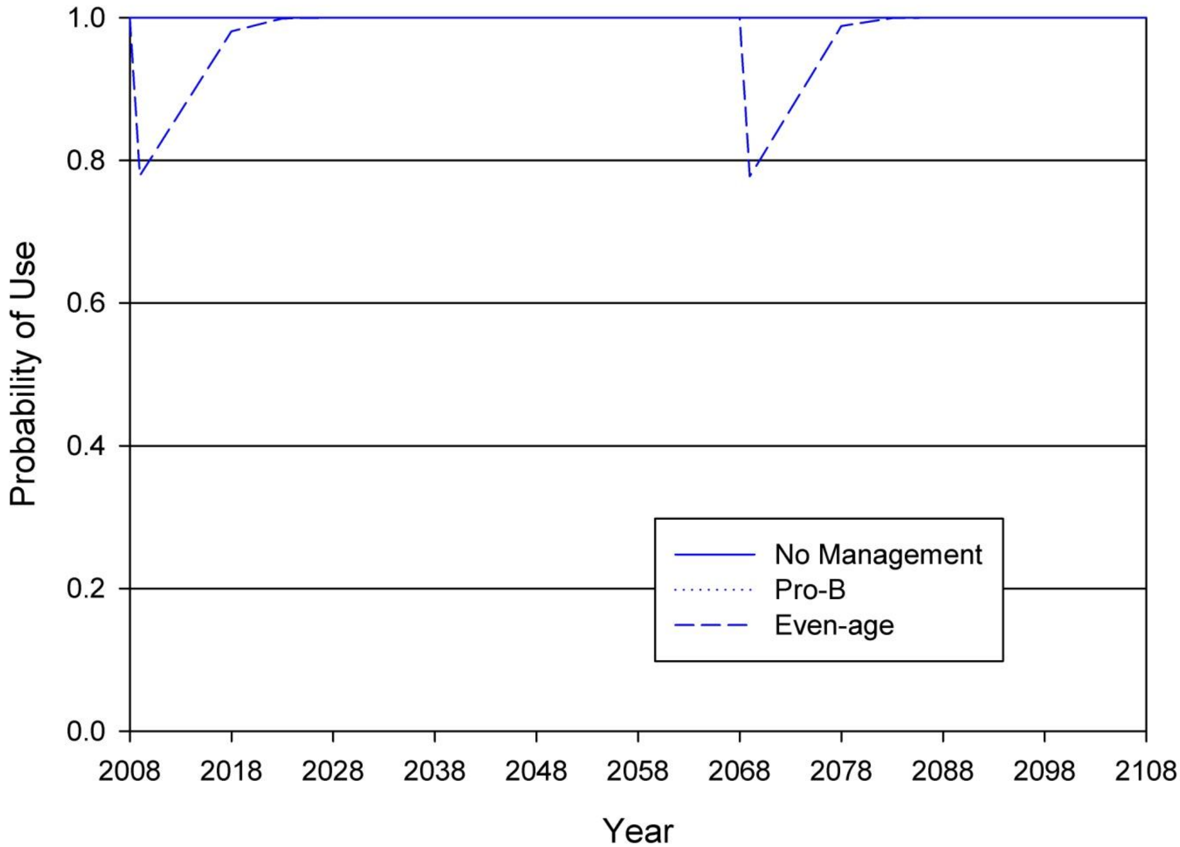

Figure 16: Probability of use by the pine warbler over the 100 year projection cycle under each of the three management scenarios.

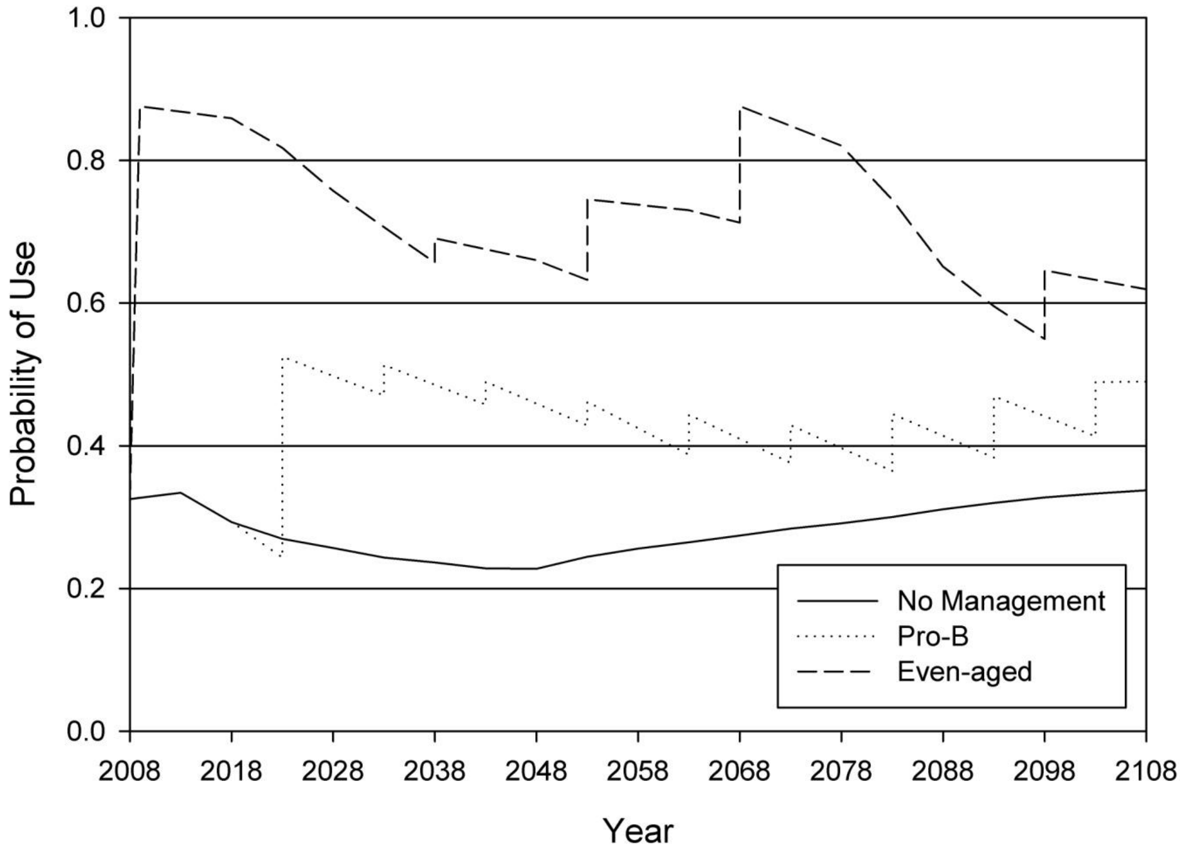

Figure 17: Probability of use by the yellow-breasted chat over the 100 year projection cycle under each of the three management scenarios. Edge density was held constant at 1 to simulate a forested stand with 0% edge.

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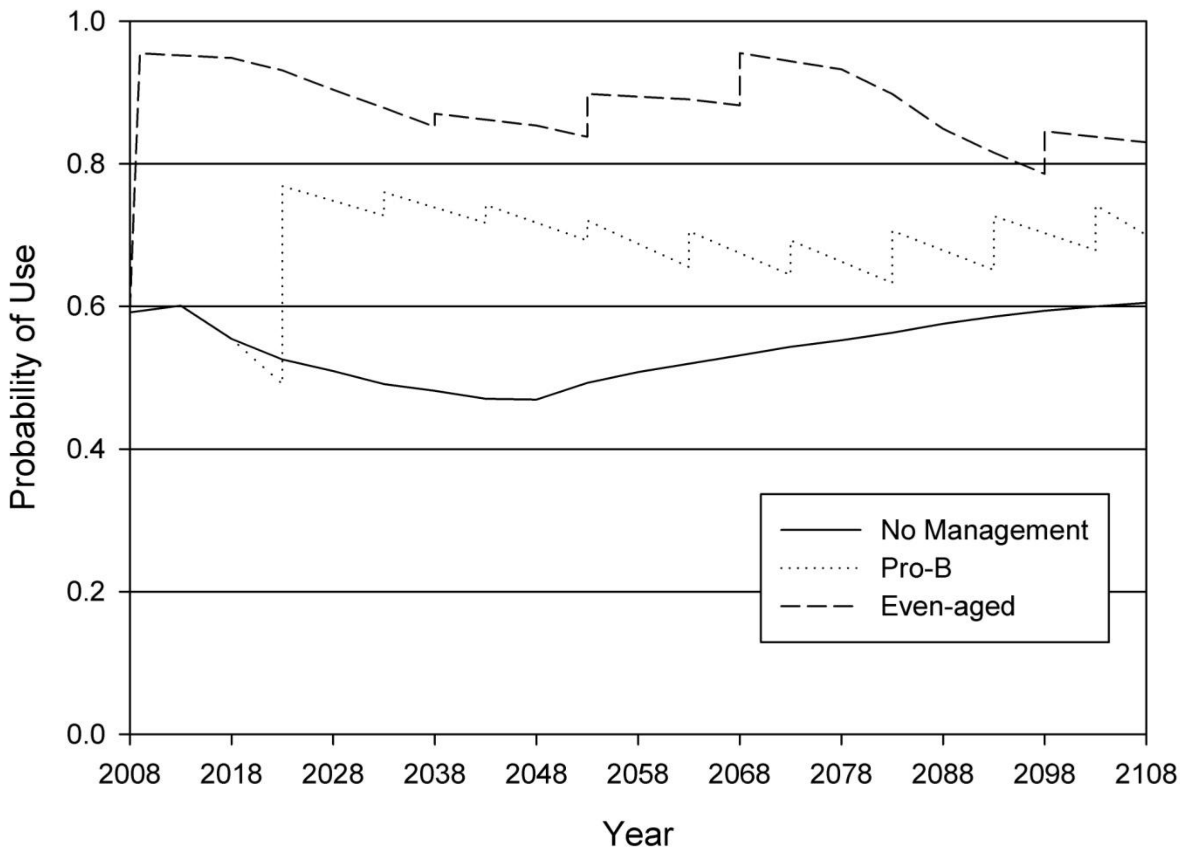

Figure 18: Probability of use by the yellow-breasted chat over the 100 year projection cycle under each of the three management scenarios. Edge density was held constant at 0.5 to simulate a forested stand with 50% edge.

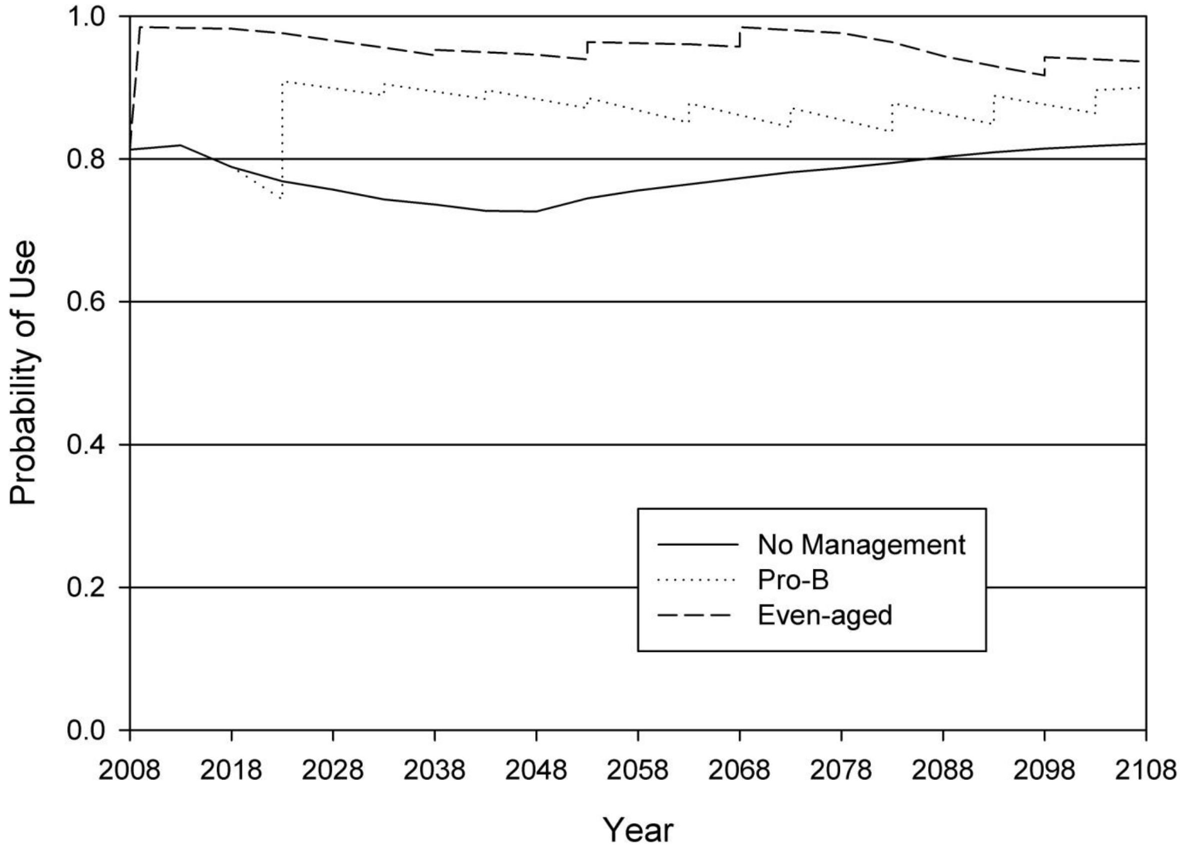

Figure 19: Probability of use by the yellow-breasted chat over the 100 year projection cycle under each of the three management scenarios. Edge density was held constant at 0 to simulate a forested stand with 100% edge.

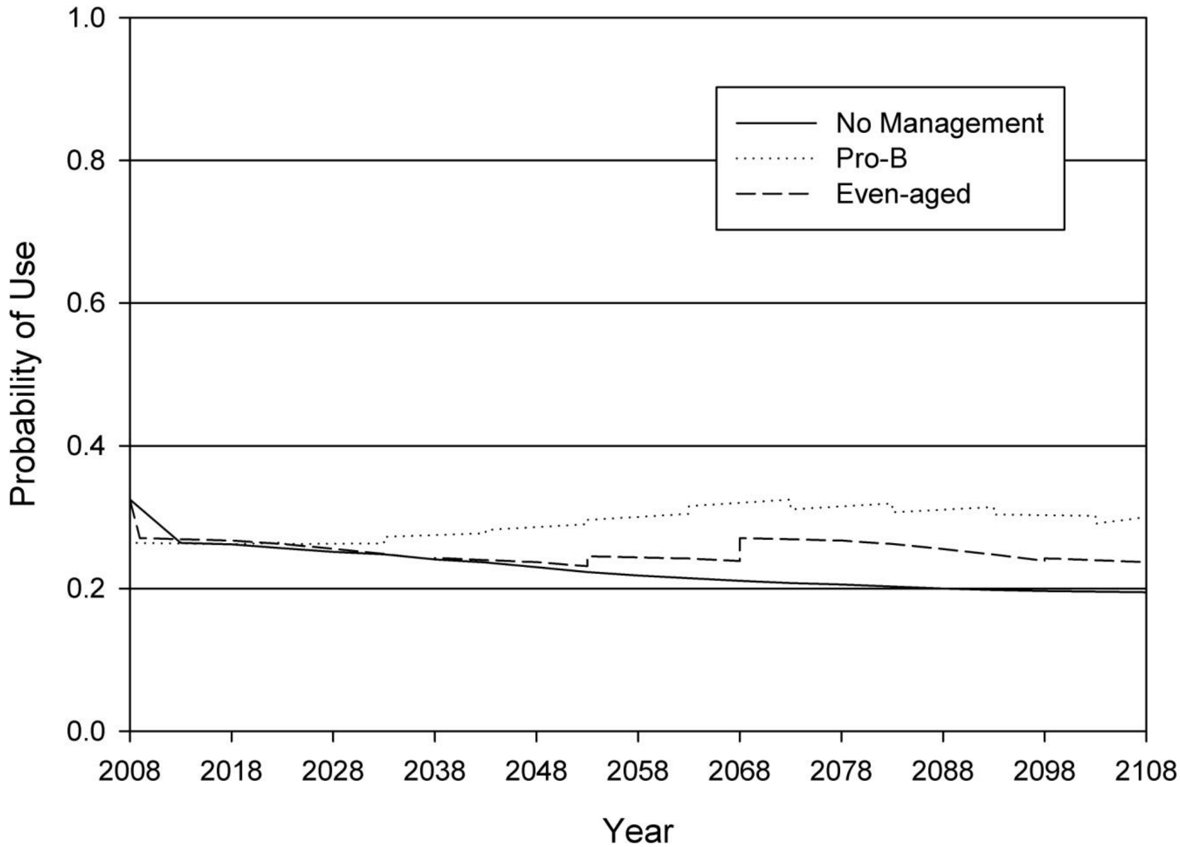

Figure 20: Probability of use by the wood thrush over the 100 year projection cycle under each of the three management scenarios.

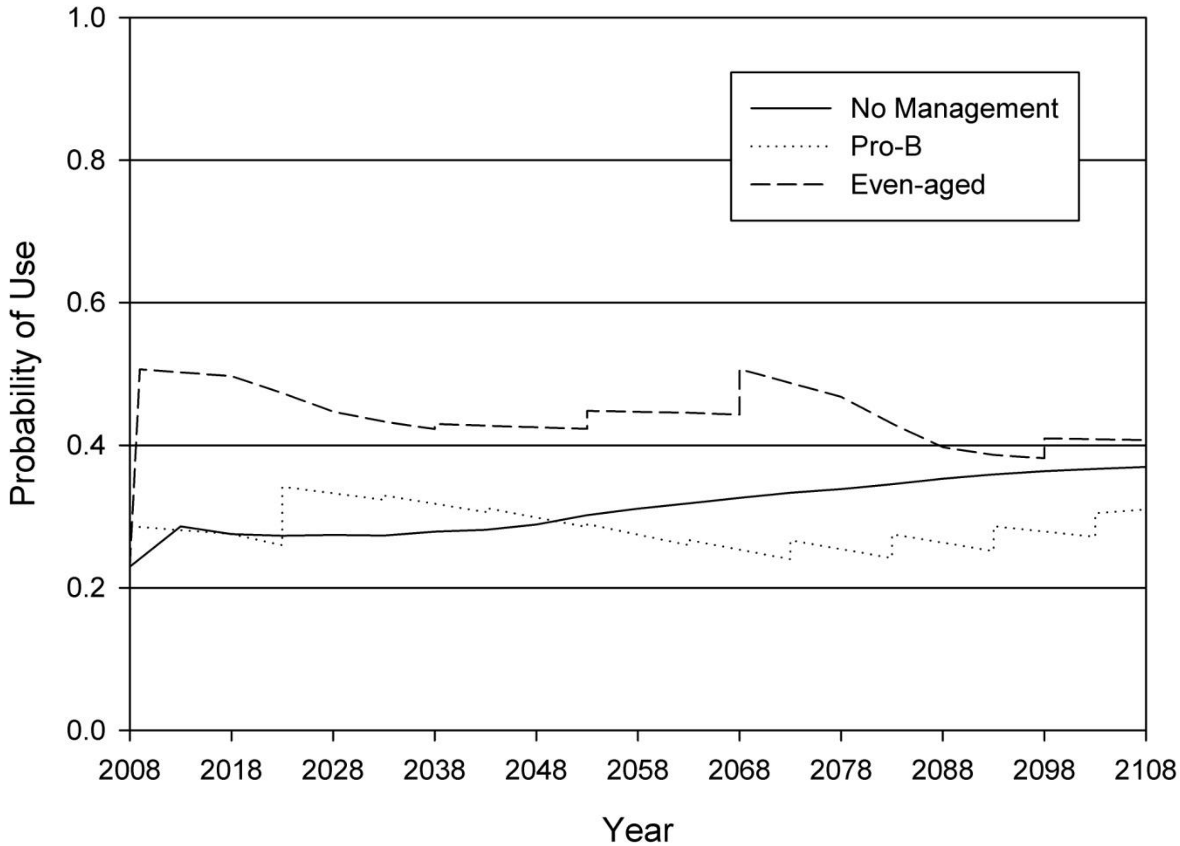

Figure 21: Probability of use by the prairie warbler chat over the 100 year projection cycle under each of the three management scenarios.

CHAPTER 5

DISCUSSION

The management scenarios used for this decision support tool were based upon current management objectives, or ideas for how management could potentially be implemented on Barbour WMA. Since, Barbour WMA is managed by the ALDCNR the stated objective is to promote statewide stewardship and enjoyment of the natural resources of Alabama and to ensure that future generations will be able to enjoy these resources. Specifically, Barbour WMA is using that over arching objective to restore the longleaf pine ecosystem. Longleaf pine is a valuable natural resource that without restoration will not be available for future generations. By utilizing two different management scenarios that incorporated longleaf pine restoration, we are able to show managers on Barbour WMA plausible alternatives.

Projecting a no management scenario allowed us to ascertain a baseline for what would happen on the property if no management were implemented. No management is always an option. However, even when management is planned, it is useful to know what successional direction nature would move the system in the absence of management or natural disturbance. The baseline that the no management projection provides allows for comparison to the other simulated management alternatives.

Nevertheless, the model has inherent flaws and assumptions that need to be recognized when projecting scenarios. Forest stands are dynamic (Oliver 1980, Franklin et al. 2002, Nyland 2002) and might have other changes that the model is unable to detect. Microhabitat conditions in a stand are constantly changing. Microhabitat features like down dead wood and snags can change rapidly over time. While the model is able to estimate average decay rates for snags and other dead wood, local weather conditions may increase or decrease those rates.

The process of stand development is complex and allows for disturbances that kill trees and establish new cohorts of trees. No natural events or disasters were simulated. Many natural disasters or events would have to be simulated on a landscape scale, because these events rarely affect just one stand. However, it is important to note that a hurricane or tornado would have an impact of the structure of the stand over time. A large wind throw event is capable of taking down large trees. Also, lightning strikes could start a catastrophic fire that is capable of changing the dynamics of the stand or the entire landscape.

Continually, the no management scenario shows that there is no reproduction being added to the stand over time. If this mirrored reality a stand of trees would eventually no longer exist. However, in reality a stand would produce reproduction. Generally, there would be a lot more small trees than large trees. Instead of a normal distribution a reverse j-shape curve would be created, but unlike in the Pro-B scenario the Q value would be extremely large.

Longleaf pine restoration is a major focus for the property as well as for government owned properties throughout the southeast coastal plain (Dohner 2009). Longleaf pine has traditionally been managed with even-aged silvicultural systems (Boyer 1979), which can use either natural or artificial regeneration. In the projections for even-aged management artificial regeneration was used for longleaf pine because no longleaf was present on the site at the time of inventory. The even-aged approach to management can offer a variety of advantages. For example, in even-aged management, because the stand is relatively homogeneous, intermediate cuttings can be applied uniformly across the entire stand.

In the even-aged management scenarios a uniform structure and distribution was established and maintained through time. Even-aged stands are expected to have a normal distribution (bell-shaped curve) through time. With three starting planting densities (741, 1112, and 1483 trees per hectare) used, all three had a normal distribution over time.

However, the diameter structure differed among the planting densities. Higher initial planting densities decrease the DBH of largest diameter tree in the stand. Higher densities result in more immediate competition among seedlings. The site may become overstocked quicker (Nyland 2002), meaning the trees effectively occupy all the growing space, so that growth has slowed. This may be a consideration when deciding which starting planting density to implement. However, intermediate thinning treatments help to reduce some of these problems.

Planting fewer trees per hectare drives the initial costs down. However, the seedlings may face more competition from herbaceous or shrub cover early in development causing slower juvenile growth. Instead of the available growing space being used for tree growth, herbaceous species, or weeds, are growing up into that available growing space. This can lead to delayed canopy closure, reduced tree production, and increased mortality in the planted seedlings.

Nevertheless, there is a benefit to the early stages of even-aged stands. They effectively create ephemeral early successional habitat for several bird species. Birds like the prairie warbler and yellow-breasted chat are often associated with early successional habitat and open areas. Early successional habitat, like early stages of plantations, has dense areas of vegetation cover. They are often highly diverse, which allows for several different food sources in these areas.

The uneven-aged scenarios were unable to focus on longleaf pine, because there were not any present on the property at the time of the inventory in 2008. Loblolly pine was present in many of the mixed stands in sufficient quantities to act as a surrogate for longleaf pine. Although, loblolly pine is unlike longleaf pine in several ways, loblolly is not as long lived and is less fire resistant as a seedling, they both can be the dominate species in an open pine savanna. Using the mature loblolly pine as a surrogate for longleaf gives managers time to under plant longleaf pine. Longleaf pine seedlings will be able to with stand the fire needed to create an open pine savanna, and will eventually replace loblolly as the dominate tree in the stands. Open pine savannas are known to be the preferred habitat of bird species like pine warbler. This intermediate treatment was designed to give the managers at Barbour WMA a way to create an open pine habitat while also restoring longleaf pine.

Continually, uneven-aged systems maintain a continuous mature canopy across the property, which often appeals to landowners with multiple management goals (Palik et al. 2003, Van Lear et al. 2005). In uneven-aged systems a portion of any given cohort is typically maintained on the site at all times, and this provides the stakeholder with a variety of benefits including aesthetics, steady timber revenues, natural plant communities, and wildlife habitat.

Specifically, single-tree selection imitates the smallest scale of disturbance, such as lightning or disease, which typically kills only one or two mature trees (Guldin 2006). Trees of all size-classes are individually selected for removal roughly uniform based on their condition and location in order to create the desired stand structure and to encourage the growth of the remaining trees (Johnson et al. 2002). The Proportional-B method is a type of single-tree selection that uses three broad size classes to proportionally distribute basal area. The Proportional-B method is sufficient for a variety of species and has been tested in a variety of settings (pers. comm. E. Loewenstein[4]).

[4] Dr. Edward F. Loewenstein, Associate Professor of Silviculture, Auburn University School of Forestry and Wildlife Science, December 10, 2010

However, some scientists would say that longleaf pine is not fit for single tree selection because regeneration of these shade intolerant species may be difficult to achieve in with insufficient sunlight (Wahlenberg 1946, Croker 1969, Croker and Boyer 1975). Wahlenberg (1946) stated that it would be impractical to use the selection system in longleaf pine forests because the selection system is designed to produce all-aged stands, and that longleaf pine could not reproduce itself under such conditions. However, Wahlenberg may have been unaware that a sustainable selection system may best be maintained with the episodic regeneration of a small number of regularly spaced age classes (Loewenstein et al. 2000, Loewenstein 2005).

Group selection is often recommended and applied as an uneven-aged management system for intolerant species (Guldin 2006). Group selection is another way of applying uneven-aged silviculture by removing groups of trees to create larger gaps in the canopy. Residual mature trees can hinder longleaf pine seedling growth and eventual recruitment, causing the surviving seedlings to cluster in canopy gaps (Brockway and Outcalt 1998, McGuire et al. 2001).

However, a single-tree or group selection method more closely mimics frequent natural mortality (Outcalt 2008) and allows for varying the scale of disturbance similar to natural stand dynamics (Palik and Pederson 1996). Mimicking natural disturbance helps to build or maintain the complex old-growth structure (Schwarz 1907, Platt et al. 1988, Noel et al. 1998, Varner et al. 2003). Palik et al. (2002) describe the use of natural disturbance as a guide for uneven-aged silviculture. Under this model, varying methods can be used to copy various natural disturbances, from single-tree selection, which mimics lightning mortality, to group selection which is more similar to larger-scale disturbances.

With the greater demand for ecosystem management and the broadened focus of forest management to include the production of other commodities such as recreation, wildlife and water, the Pro-B method lends itself to achieving these requirements. By managing stands using the uneven-aged management managers are more closely mimicking natural disturbances.

One of the main objectives of natural resource management is sustainability. To have sustainability natural resource managers need to balance natural resource utilization over a long time frame (Ascher 2001). Therefore, one of the many goals of natural resource management is to fulfill the demand for a resource without injuring the ecosystem or jeopardizing the future of the resource. The Proportional-B method allows for by creating a stable stand structure. However, it requires maintenance and may not be the right fit for all species needs.

Focal Species Responses

Reproductive cover is an important characteristic for the wood thrush; Mirarchi et al. (2004) state that having an understory of deciduous shrubs is important for this species breeding. The development of the stand with no management, or under natural conditions, follows known stages of stand development (Nyland 2002). Over time as the amount of canopy cover increases, less light is able to infiltrate into the other layers of cover. The amount of reproductive cover decreases (Figure 10 and 12), like in the stem exclusion phase of stand development (Oliver 1980, Franklin et al. 2002, Nyland 2002). Therefore, the no management scenario suppresses the amount of reproductive cover available to wood thrush. In general, without management, the shrub layer declines; thus, the wood thrush tends to not use the structure.

However, if the stand is uneven-aged most structural developmental processes actually operate throughout development and not at a single stage (Franklin et al. 2002). Nyland (2002) describes four stages of stand development. The first is stand initiation where the stand accumulates living vegetation. Second is the stem exclusion phase where trees compete for space and many stems die. Third is the transition phase where gaps in the canopy allow for the permanent creation of an understory. Lastly, the stand goes into a steady-state phase where the amount of biomass fluctuates but remains fairly stable over a long period.

The Pro-B method distributes basal area proportionally between the overstory, midstory, and understory (Loewenstein 2005). The development of the stand under a Pro-B management regime keeps the stand in the transition phase, which allows for the development of an understory. Reproductive cover, which is important to wood thrush, is able to form and be maintained over time (Figure 12). Even-aged management directly follows the known stages of stand development into the stem exclusion phase or part of the transition phase (Nyland 2002). Reproductive cover is created when the stand is initiated in 2009 but not but decreases throughout the entire rotation length that ends in 2068 (Figure 12).

The reproductive cover models show the projected change in cover over time (Figure 12 and 13). However, they do not always reflect reality. The no management prediction shows reproductive cover continuously declining over the projection (Figure 12 and 13). However, in uneven-aged stand most structural developmental processes actually operate throughout development and not at a single stage (Franklin et al. 2002).

The probability of use of the wood thrush declines in all management alternatives, when no management is implemented the largest decline is seen (Figure 20). The only parameter that the wood thrush is responding to in its best occupancy model is reproductive cover (See Table 2). If an averaged model was used, it is possible that the wood thrush might have a response to other structural characteristics.

Prairie warbler tends to inhabit areas which lack a closed canopy or pastures with shrubby growth (Nolan et al. 1999). While, none of the management scenarios maintain prairie warbler's ideal habitat, there are periods in the even-aged scenario where its ideal habitat, early successional habitat, is created. When the initial clearcut is performed an area lacking a closed canopy with shrubby growth is created (Figure 10). Stand initiation phase creates ideal habitat for prairie warbler (Nyland 2002). Early successional habitats, like those created in the early stages of a clearcut, have higher stem densities that produce more cover for species that in habitat them. Prairie warbler nests are often built within tree clumps of these early successional areas (Nolan et al. 1999) giving the nest protection.

The general increase in probability of use for each management scenario by prairie warbler is due to its negative response amount of reproductive cover, showing that higher amounts of reproductive cover are not beneficial. However, Nolan et al. (1999) note that the prairie warbler is typically found in southern pine forests where a shrub layer is present. However, the prairie warbler is also responding negatively to the amount of canopy cover; when the amount of canopy cover decreases the probability of use increases.

Landscape scale components are not included in most of the occupancy models. They way in which FVS was used do not have the capability to predict landscape scale characteristics. The prairie warbler is closely tied to early successional patches within in the forest matrix (Nolan et al. 1999). The matrix of landscape patches is important to the prairie warbler. The forest inventory that was conducted was not able to pick up on the matrix of the overall landscape on Barbour WMA. Hopefully incorporating other modeling techniques that include other variables this relationship can be further explained and included.

Yellow-breasted chat is considered a generalist, with a preference for edges (Eckerle and Thompson 2001). It is often found in low dense vegetation, like power-line corridors, fence rows, and forest edges (Eckerle and Thompson 2001). The way in which the stand is developing does not have an impact on the yellow-breasted chat, therefore management regime means little to this species. However, because of this bird's preference to edges, it has some association with early successional habitats, like the prairie warbler. Early successional habitats, like those created in the early stages of a clearcut, have higher stem densities that produce more cover for species that in habitat them. A wide variety of management regimes can be utilized if they are close to edges.

The yellow-breasted chat's probability of use varies with the amount of forested edge represented in the model. The occupancy model for yellow-breasted chat is negatively correlated to edge, therefore, the more edge available the more yellow-breasted chat is likely to use that stand. When edge is equal to 0, there is no difference between uses of the scenarios. When there is no forested edge present (edge=1) it has preference for the even-aged scenario, especially in its early development. Early stages of plantations are similar to edges or opening, which might explain its preference to the even-aged scenario.

In most of its range pine warbler is associated with a dense canopy layer and a sparse understory or a low density shrub layer (Rodewald et al. 1999). While species composition was not taken into account in the occupancy model, pine warbler is mostly associated with the North American pine forests. There is anecdotal evidence that it prefers tall dense canopies of pines (Rodewald et al. 1999). Both the no management and Pro-B scenarios provide pine warbler with a tall dense canopy layer. The Pro-B scenario provides constant canopy cover throughout the projection cycle (Figure 10). The development of the stand under a Pro-B management regime keeps the stand in the transition phase, which allows for the development of an understory, which is not ideal for the pine warbler. But as seen in Figure 16 both the no management and Pro-B scenarios are used 100% of the time.

The pine warbler's probability of use is 100% for the entire projection cycle for no management and Pro-B scenarios, and 80 to 100% for even-aged scenarios. The occupancy model created for pine warbler is responding to a multitude of parameters. It responds positively to canopy height and canopy cover, but negatively to midstory cover, reproductive cover, and ground cover (See Table 2). However, the negative response to these variables is not very strong, and is easily countered by the positive response to canopy height and cover. In many of the simulations canopy height and cover remain high over time, while midstory and reproductive cover decline. In the even-aged scenarios the probability of use for pine warbler decreases to 80% because structurally there is not a tall dense canopy present. The stand is in a phase of early successional habitat.

It is also necessary to look at the temporal effects management has on these species. Land managers often do not consider the temporal effects of the management they are implementing; short term goals may be achieved without any consideration for the long term challenges. Over the long term the management scenarios generally keep probability of use stable for the pine warbler, the wood thrush, and the prairie warbler. The pine warbler's probability of use does not experience changes over time with no management and Pro-B, and only slight decreases are seen in even-aged management. For the wood thrush and the prairie warbler little difference in the probability of use is seen from the beginning to the end of the projection in any scenario.

However, the temporal component is much more important for the yellow-breasted chat, especially in the even-aged scenario. Over time there are huge jumps in the probability of use (Figure 17) when looking at the even-aged scenario. Managers could look at the first ten years of the projection cycle where it has a more than 80% chance of using the stand in the absence of edge. However, in the next ten to twenty years the probability of use drops almost 20%. While it is still more than 50% likely to use the stand, it could change how management is applied into the future.

It is also important to look at what was included in the occupancy models that were used in this process. Only the best model was used to compare occupancy among management scenarios. However, in the model building process other covariates were considered, but were not in the best model. These other covariates that may influence occupancy were not included. For example, wood thrush is known to use hardwood stands that are adjacent to water. There was no covariate included in the model that was used which would show how those covariates would change occupancy. It is unlikely that wood thrush would use a pine dominated stand, like the ones created in both the even-aged and Pro-B scenarios. Continually, tree species composition, adjacency to water, and other parameters may change the probability of use for these species. With better models better predictions of probability of use can be made.

I hypothesized that pine warbler would use the structure created by the Pro-B projection over the other structures created. Pro-B maintains a tall covered canopy over the entire projection period. However, its probability of use is equal in all scenarios. Each scenario is able to provide the pine warbler with a tall canopy, with sufficient amounts of cover, while limiting midstory, reproductive, and ground cover. I hypothesized that wood thrush, prairie warbler, and yellow-breasted chat would use scenarios other then Pro-B proportionally more often. Yellow-breasted chat and prairie warbler are tied to early successional habitat, which is created fleetingly in these scenarios. Wood thrush needs understory and more hardwood oriented stands, which were not our focus. Yellow-breasted chat and prairie warble are more like to use the even-aged scenario, while wood thrush is more likely to use the Pro-B scenario. Even-aged management provides yellow-breasted chat and prairie warbler with low dense vegetation or shrub/scrub areas that they are often associated. However, this becomes less important for yellow-breasted chat as there is more edge. Wood thrush is more likely to use the Pro-B scenario because it is able to provide the most reproductive cover.

Each focal species has behaviors and microhabitat selection criteria of which little are known. For example, pine warbler is known to forage in the bark of the middle and upper forest strata (Rodewald et al. 1999), however little else has been studied about this behavior. There are unknown effects to the probability of use that cannot be accounted for when modeling. Microhabitat selection could influence site occupancy at the stand level and may warrant further investigation.

Many birds use specific stand characteristics, like snag species availability, when choosing nest sites. They may not use ideal habitat if these certain structures are not present. The red-cockaded woodpecker is an ideal example. This bird lives in mainly pine forests with large diameter pine trees with little or no understory. However, it requires there to be live trees with red-heart rot to excavate cavities, without the presence of this microhabitat feature they cannot persist (Jackson 1994). There may be other similar variables equally necessary for other species that are not captured with a standard stand inventory.

Advantages of Integrating a Growth and Yield Simulation with Probability of Use

FVS is a growth and yield model, which uses calibrated growth equations to project tree growth into the future. Therefore, mathematical assumptions are held constant for all forest growth simulations, allowing management alternatives to be compared without bias.

The most important advantage of combining stand projections in a growth and yield model, like FVS, with wildlife life occupancy models is the ability to develop and analyze many alternatives quickly. Stand level simulations can be made to assess and communicate the likely effects of proposed management regimes on animal population dynamics. The rapid analysis is important in the planning processes to determine the most efficient outputs such as volume, tree sizes and stands structures. Information can be presented in terms specific to the background and interests of the stakeholders and decision makers. Several alternative silvicultural pathways can be developed and compared to assess their potential effects. A hypothesis-testing framework can be used before they are applied to a stand or across the landscape. Immediate and long term effects of management can be seen and compared by the stakeholders and decision makers, which allows them to make a more informed decision.

The structural information produced by FVS is valuable for several other uses, not just wildlife habitat planning. Carbon sequestration is on the forefront of the scientific community because of the debate over global climate change. FVS has the capability to predict the amount of carbon sequestered by a forest stand. The management of the stand and the resulting structure of from that management impacts carbon storage potential. Another use, although not new, of the resulting structure provided by FVS is for timber planning. However, timber planning can be incorporated with habitat planning to offset the costs. Timber harvesting has the potential to improve habitat quality, but the addition of revenue.

Challenges of Integrating a Growth and Yield Simulation with Probability of Use

There are several limitations with using any growth and yield model approach. FVS is not able to produce predictions about reproductive or ground cover. However, any growth and yield model may have similar problems. In this case, regression models were created from inventory data. The parameters included in the models (i.e. canopy cover, midstory cover, basal area, trees per acre) were selected because they have influence on the amount of light that reaches the forest floor.

The parameters selected change how much light is present or absent within the forest stand. Ellsworth and Reich (1993) found that light attenuation occurs in the upper and middle portions of the canopy; furthermore, light may affect how vegetative structure forms throughout all canopy layers. However, development of cover layers may relate more to site productivity than to light availability (Liira et al. 2007). Liira et al. (2007) found a correlation between canopy closure and productivity, and an increase in abundance of shrubs with higher productivity. In the Pacific Northwest understory relationships have been studied at length. Studies have focused on developing relationships between overstory and understory structure and composition in a variety of forest types (Halpern and Spies 1995, VanPelt and Franklin 2000).

Also, fire should be more of a driving factor for understory change. Because the FFE in FVS tends to over predict mortality of trees in the stand it was turned off. Fire would contribute to tree mortality in a stand, as well as the composition and density of the understory components. However, fire was not included as a factor that contributes to understory cover.

Collinearity between the variables is also a major problem with the models created for reproductive and ground cover. Unfortunately, these were not tested for before analysis and were not removed from the models. However, it is important to discuss. In the reproductive cover model the variance inflation factor for basal area was greater than 2. There is a multicollinear relationship in the model. By looking at Table 8 you can see that basal area has a strong linear relationship with canopy cover. In the ground cover model the variance inflation factors for canopy cover, midstory cover, and basal area are all greater than 2. Looking at the r^2

values in Table 12 you can see that each of these variables has a strong relationship to the other. Because these relationships exist within these models they are not the best models to use in an analysis, and should be updated in the future.

Continually, the way final models that were built for reproductive and ground cover may not have been the best method to use. In the final models average coefficients were used, and only ones with a relative importance of 0.5 or greater were included. Instead of using average coefficients, average predictions could be used including all parameters not just the ones that are important. This could provide a better prediction for reproductive and ground cover models.

Spatial arrangement and size of habitat patches are important for some species. The integration of FVS and occupancy models does not take into account adjacency of stands on the property. Patch size was not included in any of the occupancy models used because it is a landscape scale metric that FVS can not measure. However it may be an issue for other species. Birds can occupy larger areas within a matrix of suitable and unsuitable habitat because they are capable of flight but other taxa may have size and spatial requirements that cannot be accounted for in FVS. The yellow-breasted chat had a landscape scale parameter within its model that was easily modeled. However, edge should also be considered within the matrix of the spatial landscape, and how it could change probability of use over time. However, at the stand scale the model is providing sound predictions for what is being looked at.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Project Summary

The management scenarios used for this decision support tool were based upon current management objectives, or current plans for how management will be implemented in the future on Barbour WMA. Projecting a no management scenario gave a baseline for comparisons with all of the other management alternatives. Nevertheless, the model has inherent flaws and assumptions that need to be recognized when projecting scenarios.

Longleaf pine restoration is a major focus for the property. However, there was no longleaf inventoried on the property. We projected an even-aged structure with three starting planting densities (741, 1112, and 1483 trees per hectare). There was little difference between the structures of the different planting densities. However, cost of planting and other treatments may come into play when deciding which density to plant.

Loblolly pine was present in many of the stands in sufficient quantities to act as a temporary surrogate for the absent longleaf pine. This intermediate treatment gives the managers at Barbour WMA a way to create desired habitat while restoring longleaf in other areas. The Pro-B method lends itself to achieving this while they include the production of other commodities such as recreation, wildlife and water.

Probability of use varies between scenario and species, which gives this tool predictive power. Although only three management alternatives were simulated in this example, there are many other possible scenarios that could be applied to these stands. Integrating these two models (stand projection and habitat occupancy) creates a unique tool that is available for land managers to gauge the efficacy of their management plans while also developing a timeline of predicted forest structure that can be compared with future inventory for use in adaptive management.

Management Implications

Land managers often do not consider the temporal effects of the management they are implementing; short term goals may be achieved without any consideration for the long term challenges. This decision support tool will allow for long term planning, not only for wildlife but also for any other resource that is effected by vegetation structure including (but not limited to): timber, carbon sequestration, recreation, water quality, and water yield. Optimistically, it will change the way management is preformed over the long term, and allow for careful planning for future natural resource use.

Future Research

Other management scenarios should be tested in the future to see if there is variation if different management is implemented. Also, other species could be included to show how they would respond to management scenarios. Although, FVS does not take into account landscape level parameters, outputs from the model could be used to feed into a decision support network that includes stand size and adjacency constraints. The models (occupancy, cover, and FVS) should be validated based on future inventories and revised as necessary. Continually, better models need to be created to predict reproductive and ground cover. The models used in this exercise have a lot of collinearity among the variables, and were not cross validated.

These models should be integrated into an adaptive management context as well. Models are only representations of what may exist in the future. With increasing time the likely accuracy of the model declines. Projections should be revised to be based on the most current data. These growth models are only considered valid for one to two steps into the future, therefore they will need to be constantly updated. The occupancy models presented here do not provide species abundance, only measures of probable use of the created habitat. Abundance of species should be quantified if possible to determine if there are sufficient quantities of species to persist on the landscape.

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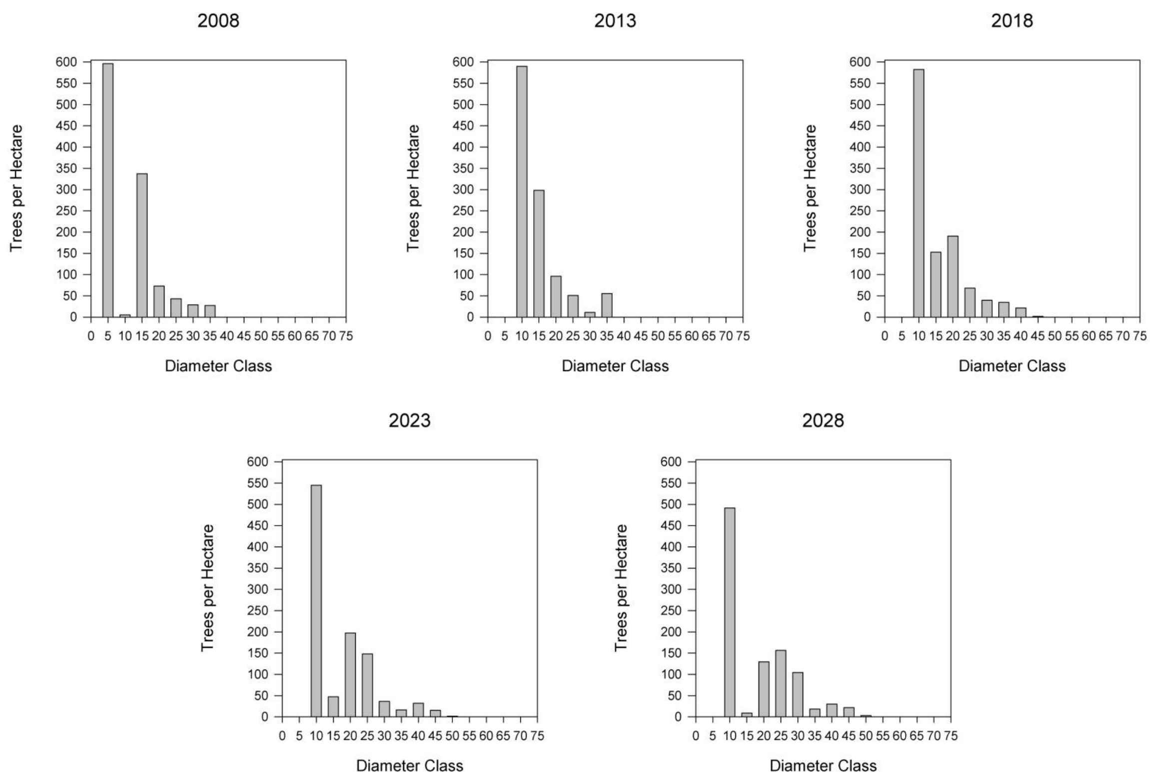
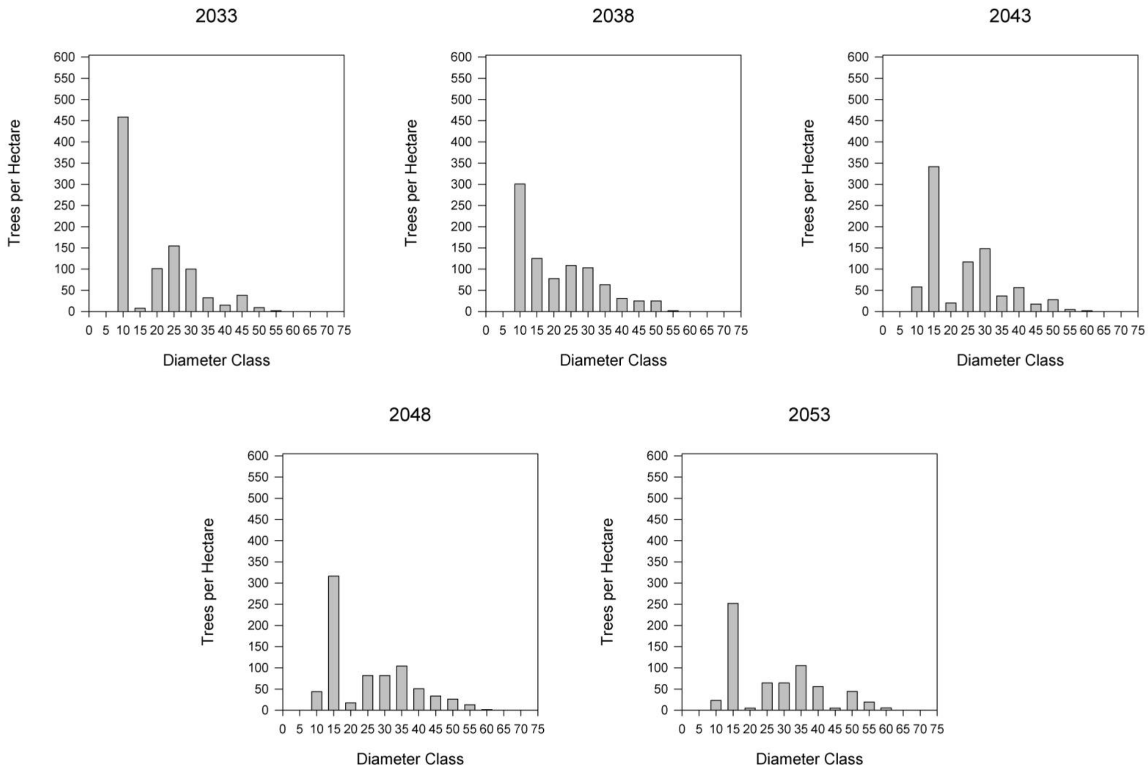
APPENDIX A

100-YEAR PROJECTIONS FROM FVS OF DIAMETER DISTRIBUTIONS OF A TYPICAL STAND UNDER NO MANAGEMENT.

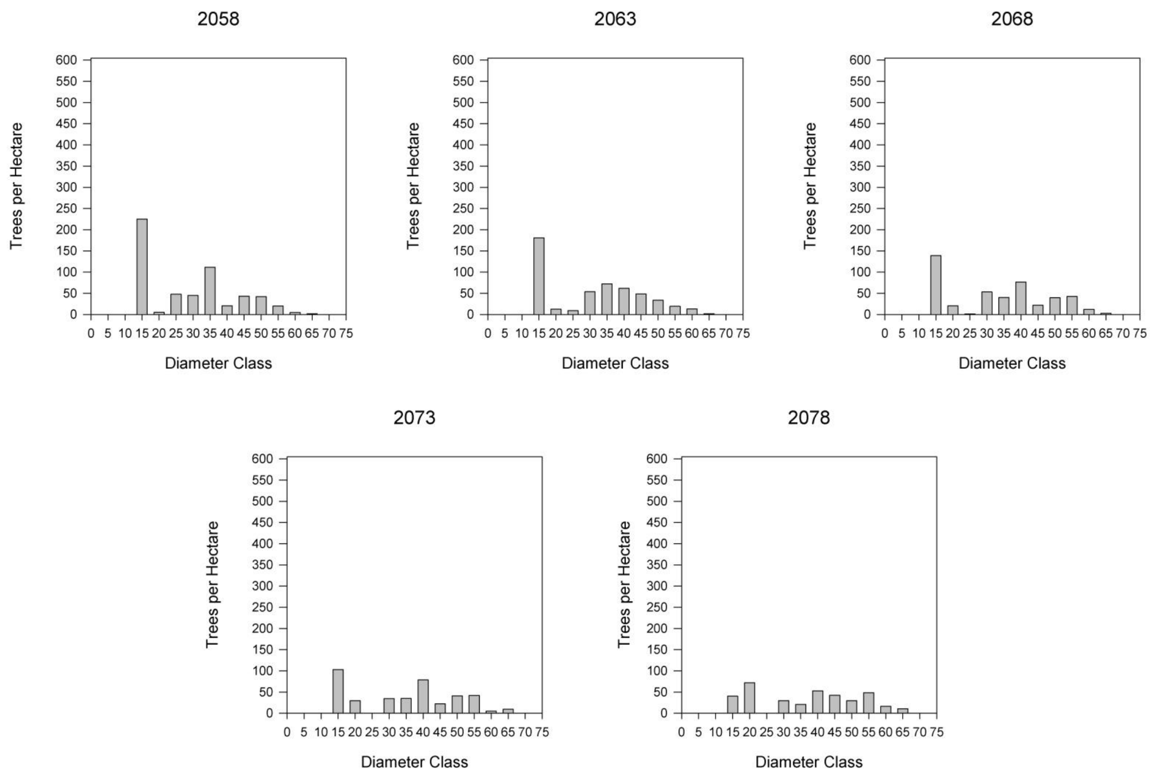
Appendix A: No management diamanter distribution over the 100-year projection cycle at 5-year intervals.



Appendix A: No management diamanter distribution over the 100-year projection cycle at 5-year intervals.



Appendix A: No management diamanter distribution over the 100-year projection cycle at 5-year intervals.



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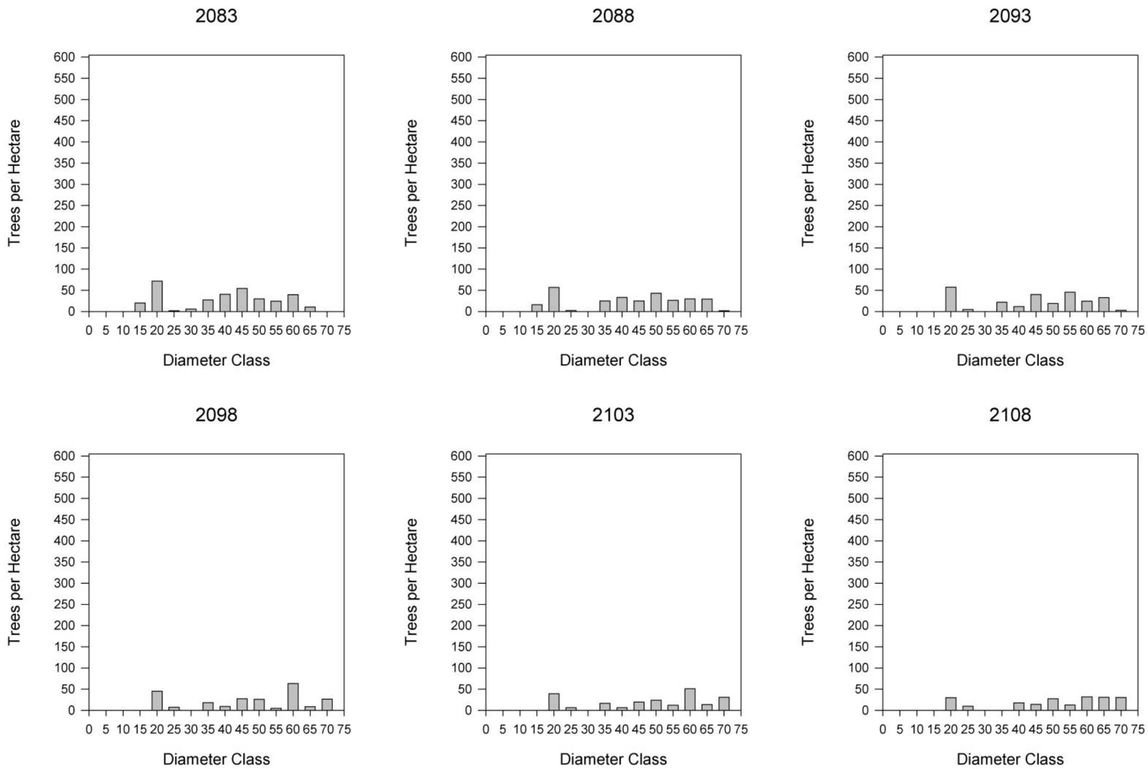
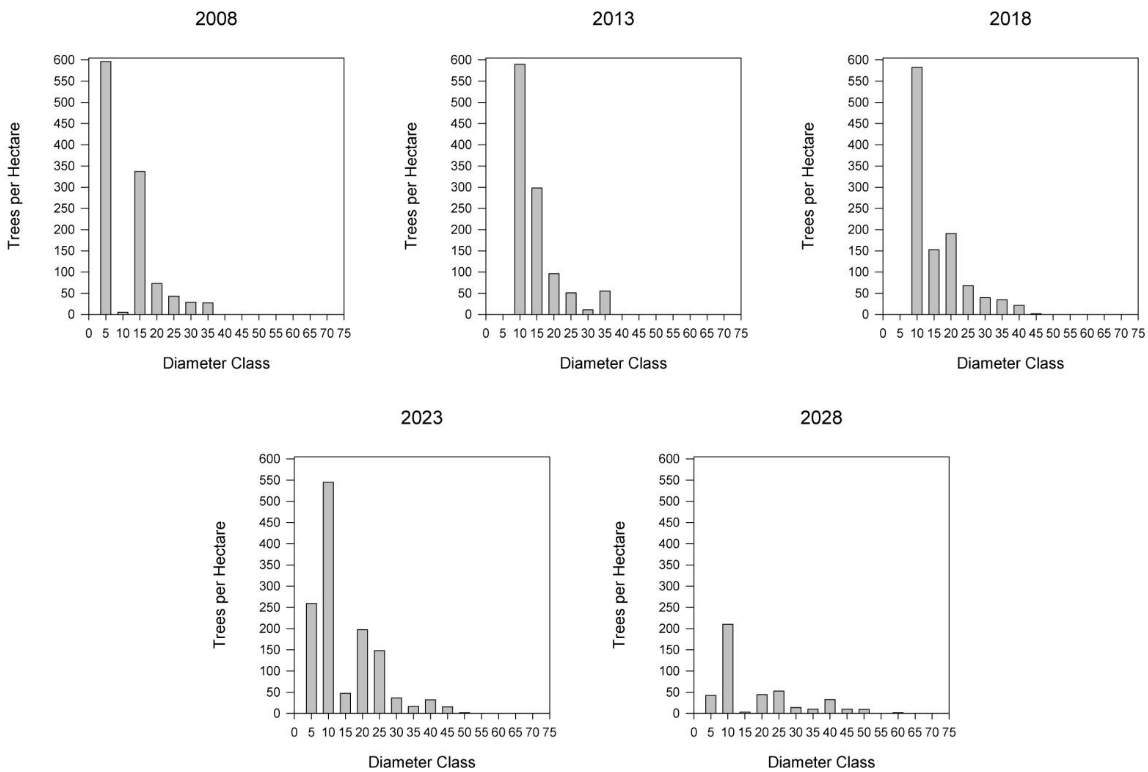
Appendix A: No management diamanter distribution over the 100-year projection cycle at 5-year intervals.



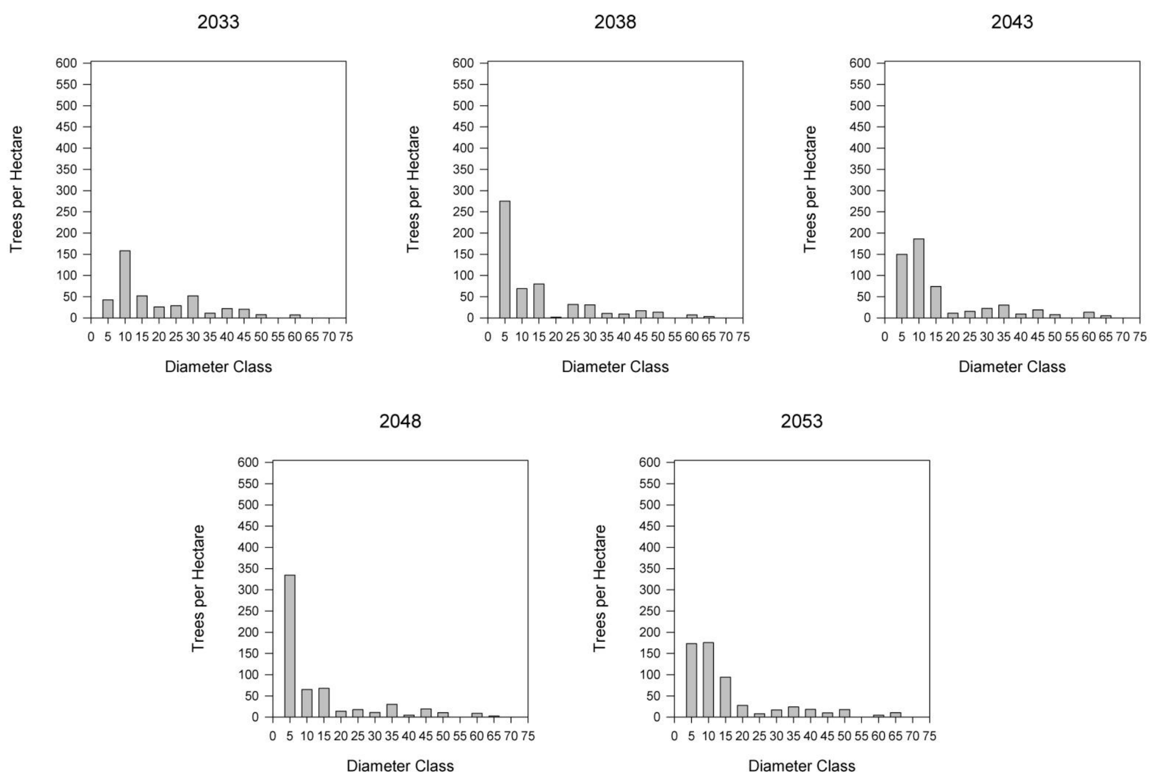
APPENDIX B

100-YEAR PROJECTIONS FROM FVS OF DIAMETER DISTRIBUTIONS OF A TYPICAL STAND UNDER PROPORTION-B MANAGEMT.

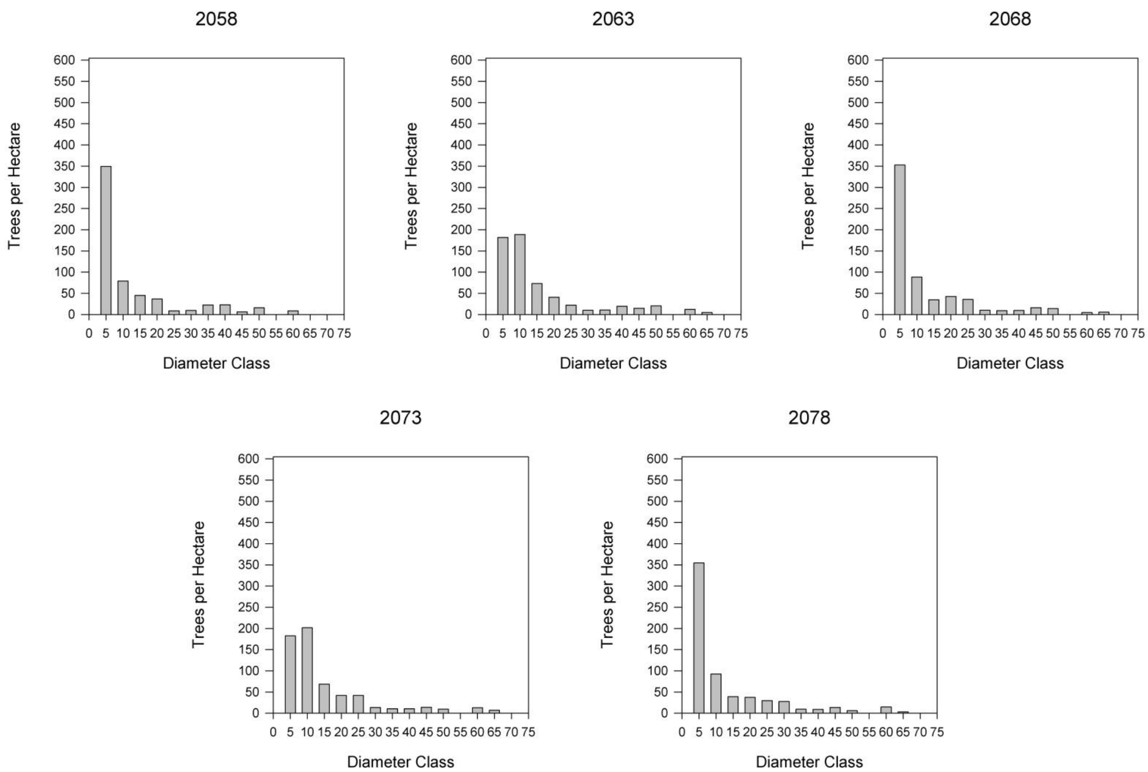
Appendix B : Pro-B distribution over the 100-year projection cycle at 5-year intervals.



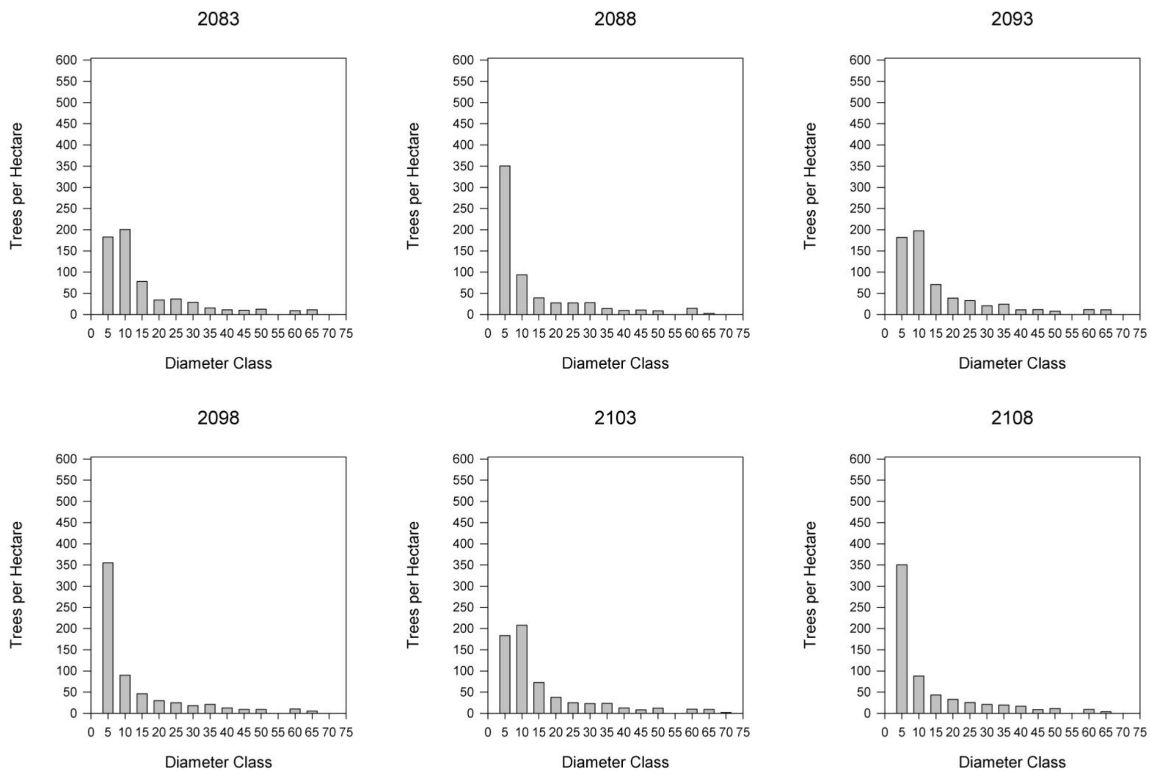
Appendix B: Pro-B distribution over the 100-year projection cycle at 5-year intervals.



Appendix B: Pro-B distribution over the 100-year projection cycle at 5-year intervals.



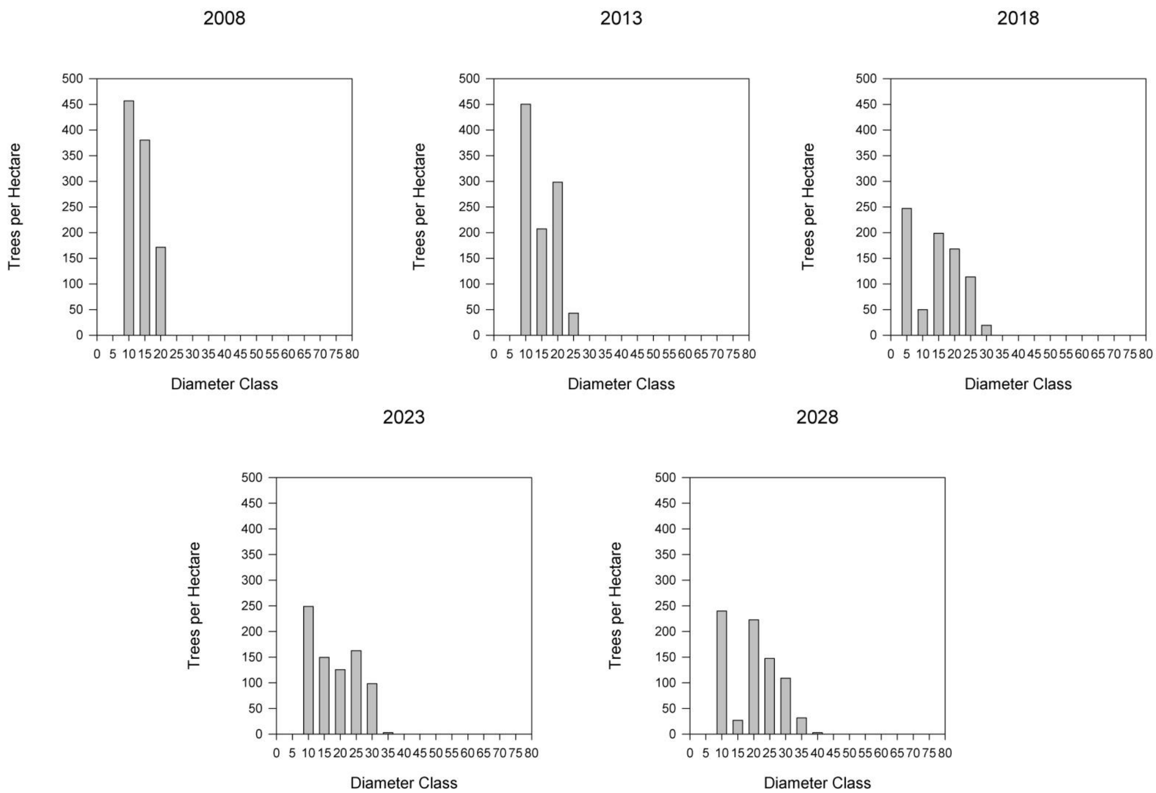
Appendix B: Pro-B distribution over the 100-year projection cycle at 5-year intervals.



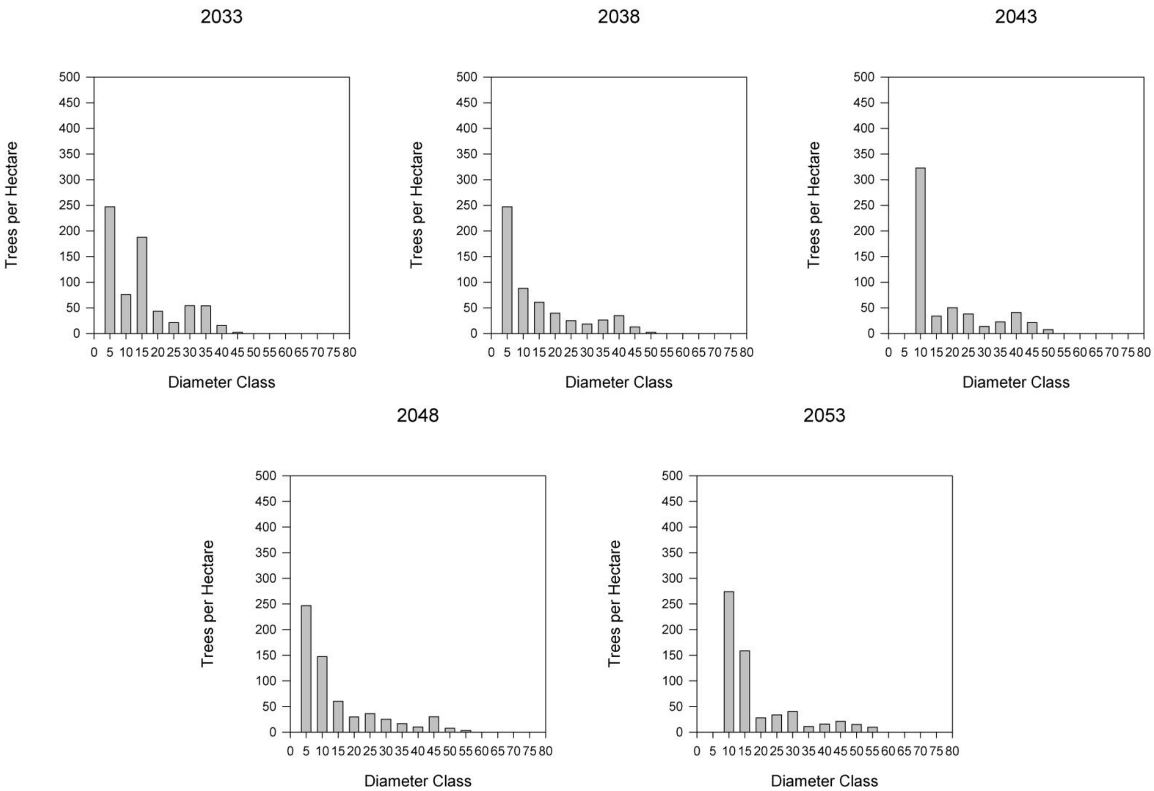
APPENDIX C

100-YEAR PROJECTIONS FROM FVS OF DIAMETER DISTRIBUTIONS OF A TYPICAL STAND CONVERTED BEFORE PRO-B WAS APPLIED.

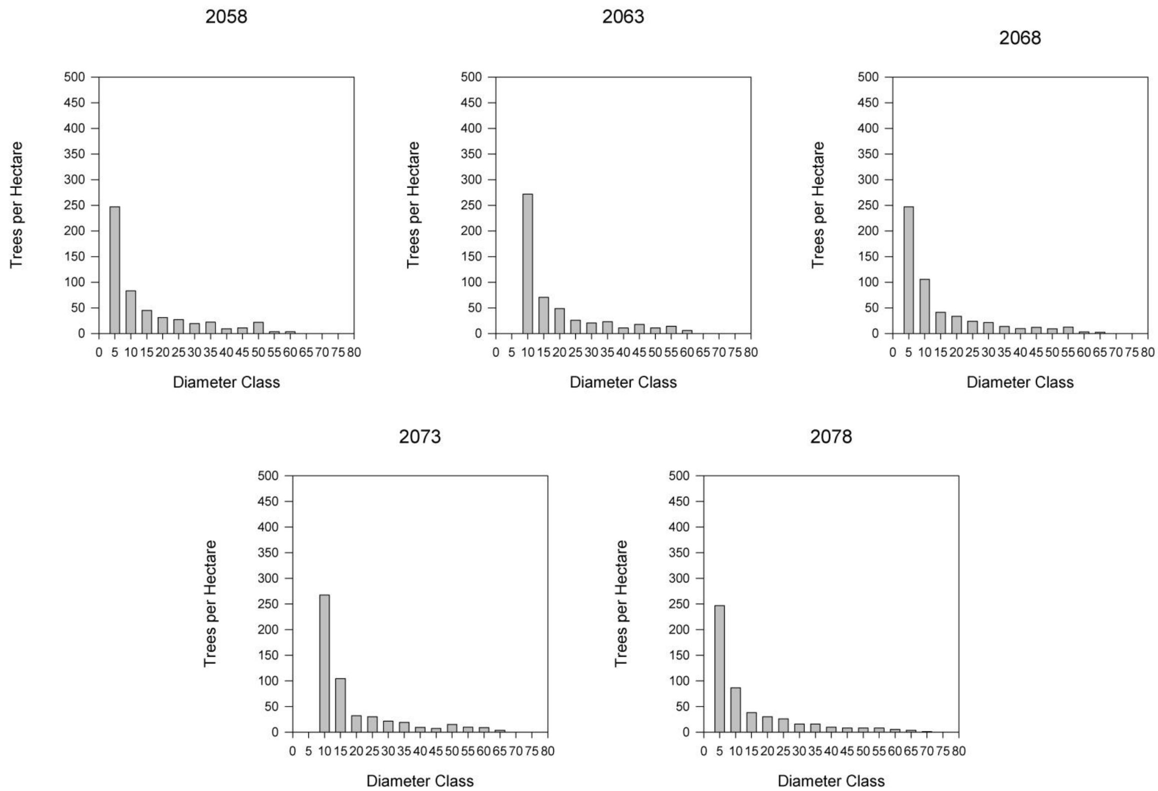
Appendix C : Diameter distribution of a stand converted from an even-aged structure before Pro-B was implemented over the 100-year projection cycle at 5-year intervals.



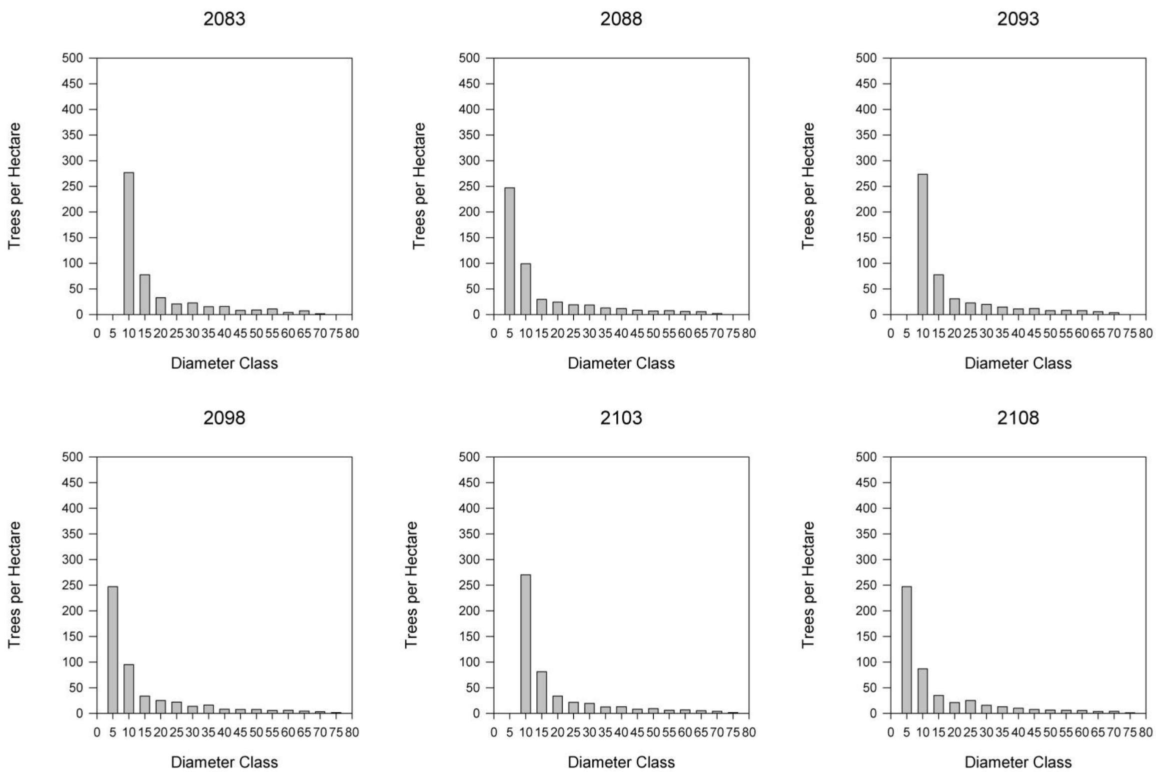
Appendix C: Diameter distribution of a stand converted from an even-aged structure before Pro-B was implemented over the 100-year projection cycle at 5-year intervals.



Appendix C : Diameter distribution of a stand converted from an even-aged structure before Pro-B was implemented over the 100-year projection cycle at 5-year intervals.



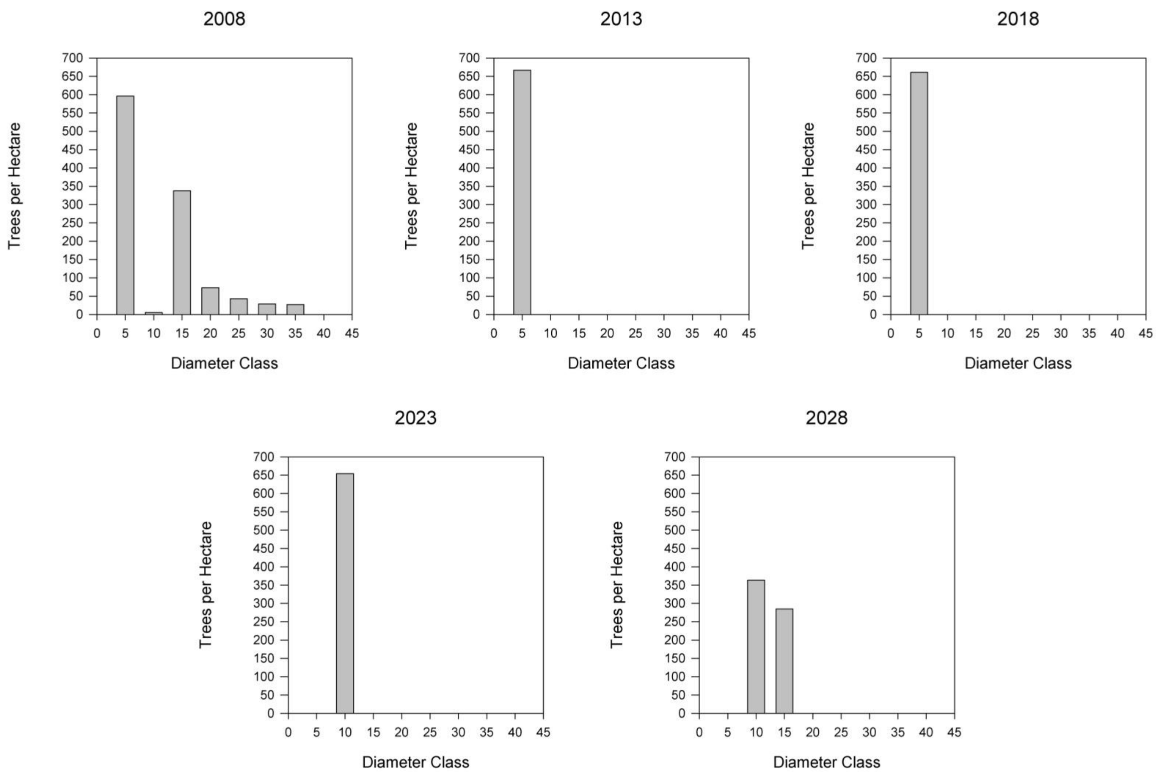
Appendix C: Diameter distribution of a stand converted from an even-aged structure before Pro-B was implemented over the 100-year projection cycle at 5-year intervals.



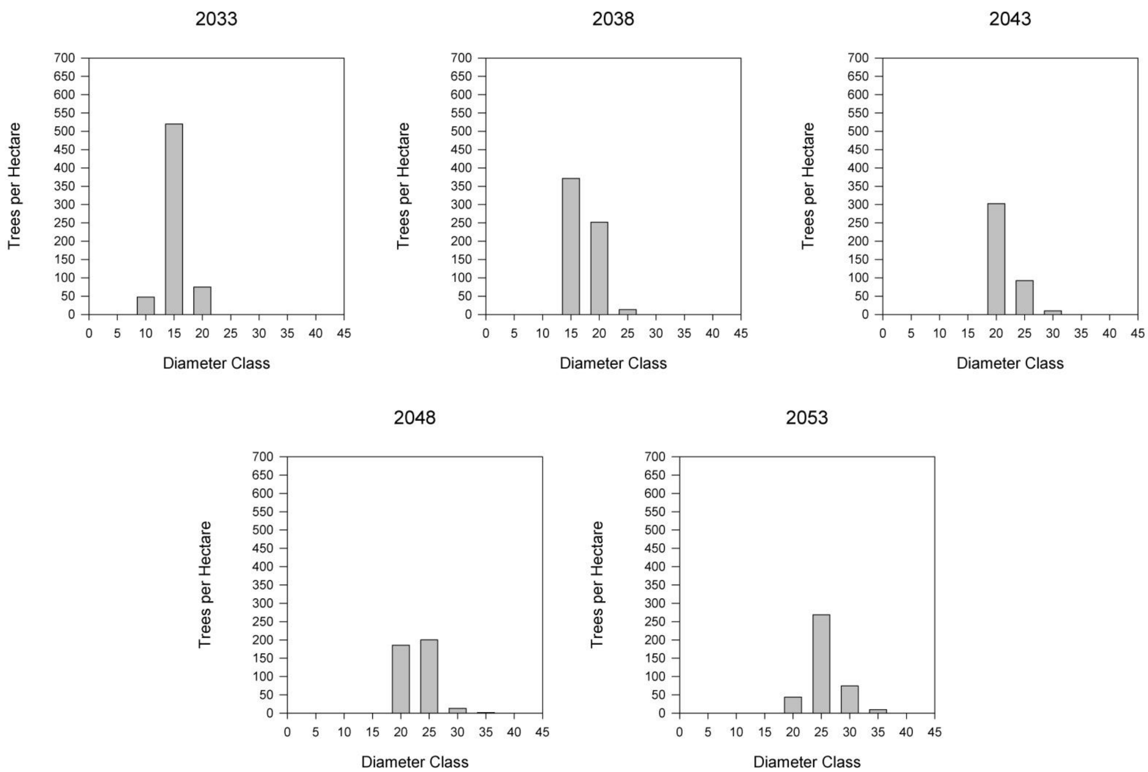
APPENDIX D

100-YEAR PROJECTIONS FROM FVS OF DIAMETER DISTRIBUTIONS OF A TYPICAL STAND UNDER EVEN-AGED MANAGEMENT.

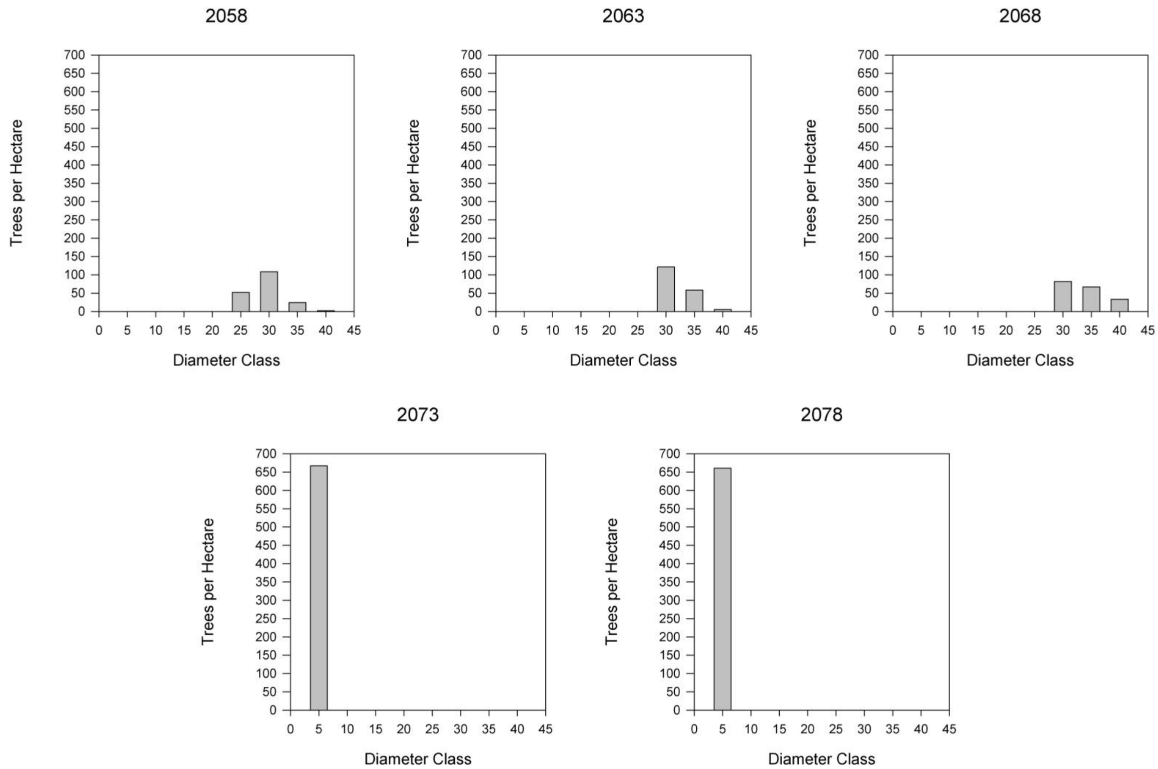
Appendix D: Diameter distribution of an even-aged stand planted at 741trees per hectare over the 100-year projection cycle at 5-year intervals.



Appendix D: Diameter distribution of an even-aged stand planted at 741 trees per hectare over the 100-year projection cycle at 5-year intervals.



Appendix D: Diameter distribution of an even-aged stand planted at 741 trees per hectare over the 100-year projection cycle at 5-year intervals.



Appendix D: Diameter distribution of an even-aged stand planted at 741 trees per hectare over the 100-year projection cycle at 5-year intervals.