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MONITORING SOFT-MAST PRODUCTION IN PINE WOODLAND RESTORATION AREAS ON THE OUACHITA NATIONAL FOREST

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By

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MONITORING SOFT-MAST PRODUCTION IN PINE WOODLAND RESTORATION AREAS ON THE OUACHITA NATIONAL FOREST

By

TAMARA BENNETT WOOD, Bachelor of Science in Forestry

Presented to the Faculty of the Graduate School of

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ABSTRACT

The use of prescribed fire is integral to the restoration of open woodland habitats in the southeast, including shortleaf pine (*Pinus echinata*) woodlands in the Ouachita Mountains. Mature pine habitats maintained with recurrent disturbances have an open understory with a rich floristic diversity that provides quality habitat for many wildlife species, including the endemic and endangered red-cockaded woodpecker (*Picoides borealis*). Fire has many potential benefits for wildlife; however, the effects of fire on several important woody soft-mast producing species are not fully understood. Soft-mast quantity and quality is a key component in determining year-round habitat quality for several wildlife species such as eastern wild turkeys (*Meleagris gallopavo silvestris*) and black bears (*Ursus americanus*). A greater diversity of fruit-producing species provides a range of available fruit throughout the year due to variations in fruiting phenology, which is particularly important for soft-mast dependent wildlife (Halls 1977).

To better understand the implications of prescribed burning within the restored shortleaf pine woodlands, I examined soft-mast production at various time intervals after dormant season prescribed fire. I also determined the influence of different forest structural characteristics on soft-mast production. I inventoried 32 stands, representing four temporal periods after dormant season prescribed fires: 1st, 2nd, 3rd, and 5th growing seasons after a dormant season prescribed burn. I sampled stands by systemically establishing 40, 9 m^2 semi-permanent plots along randomly selected transects. To capture the majority of soft-mast producing species, I conducted surveys three times each growing season (June, July, and August). In July (during peak growing season), I visually estimated soft-mast vegetation coverage in 1 m^2 nested subplots (0.004 ha per stand), each placed within the larger soft-mast plots. At all plot locations, I measured forest structure characteristics, such as total basal area, canopy closure, aspect, and the number of previous burns. I quantified the total and individual species of soft-mast production and vegetation cover and compared these results by growing season. Lastly, I identified the plot, stand, and landscape level differences that had the greatest impact on soft-mast production.

The number of species producing soft-mast increased with time since burn. Shrub (American beautyberry [*Callicarpa americana*]) and vine (grapes [*Vitis* spp.] and bramble [*Rubus* spp.]) species dominated soft-mast production as these species can establish and produce within 2 to 3 years after disturbance. In total, I detected a total of 14 species producing fruit, of these species 7 produced over 97% of the total production: American beautyberry, blackberry (*Rubus* spp.), summer grape (*V. aestivalis*), muscadine grape (*V. rotundifolia*), dewberry (*R. flagellaris*), greenbrier (*Smilax* spp.), and sumac (*Rhus* spp.). I determined similar levels of soft-mast production in the 2nd, 3rd, and 5th growing seasons post burn with production trends peaking in the 3rd season (18.2 kg ha^{-1}). Basal area and number of growing seasons since burn had the greatest influences and predictive value of individual species soft-mast production. These results indicate that soft-mast production was not inhibited within the 3 to 5-year dormant season fire return interval. Continuing to burn on this rotation will maximize and prolong soft-mast production and promote species diversity.

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CHAPTER I.

INTRODUCTION

Introduction

The now endangered red-cockaded woodpecker (RCW; *Picoides borealis*) was once prevalent across the southeastern United States in open pine (*Pinus* spp.) woodlands and savannahs (U.S Fish and Wildlife Service 2003). Fire maintained ecosystems that are maintained by routine and frequent disturbances limit hardwood encroachment and result in open and diverse understories (Waldrop et al. 1992, Masters 2007). By the 20th century, anthropogenic influences on fire regimes (Guyette and Spetich 2002, Stambaugh and Guyette 2006), timber harvest (Bukenhofer and Hedrick 1997, Guldin et al. 2004), and fire exclusion (Foti et al. 1999, Fowler and Konopik 2007) altered the landscape, causing a large shift in forest structure and plant communities. Without regular disturbance, the shortleaf pine cover type gave way to an oak-dominated overstory (Eyre 1980, Dale and Ware 1999), resulting in the transformation of open pine-bluestem ecosystem into dense, closed canopy forest (Master et al. 1996, Bukenhofer and Hedrick 1997, Guldin et al. 2004). The once prominent pine-woodland ecosystem was vanishing, and with it, the habitat upon which many species relied, including RCW (Masters et al. 2001, Guldin et al. 2004, Hedrick et al. 2007).

The decline of the RCW and its classification as an endangered species has influenced forest and wildlife management on public lands (i.e., National Forests) throughout the region. Wildlife managers in the Ouachita National

Forest in Arkansas and Oklahoma initiated a large-scale restoration project in the early 1990s to provide shortleaf pine (*Pinus echinata*) woodland habitat for the endemic woodpecker (Masters et al. 2001, Guldin et al. 2004, Hedrick et al. 2007). Restoration efforts have increased the use of prescribed fires on the landscape. Areas are burned on a 3 to 5-year rotation to maintain historic open forest structure and the understory conditions required for the woodpeckers and other soft-mast dependent wildlife species.

Areas that are 3-years post burn and have understory vegetation that is approximately 2-m in height provide escape and protective cover for many species of birds, mammals, and reptiles (Martin et al. 1951, Campo et al. 1989, Yarrow and Yarrow 1998, McCord et al. 2014, Lashley et al. 2015). In addition to providing protective cover, several woody understory species are an important food source for many wildlife species (Martin et al. 1951). For example, *Rubus* spp. (e.g., blackberry and dewberry) fruits provide important summer food (Martin et al. 1951, McCord et al. 2014), while their vegetation creates dense thickets that are preferred brood habitat for ground-nesting game birds like northern bobwhites (*Colinus virginianus*) and eastern wild turkeys (*Meleagris gallopavo silvestris*; Campo et al. 1989, Yarrow and Yarrow 1998, Burke et al. 2008, McCord et al. 2014).

Fleshy fruit production (e.g., soft-mast) by shrubs, vines, and trees are critical to forest ecosystems and the wildlife residing there. Soft-mast provides wildlife with an easily attainable source of energy, vitamins, and water (Martin et al. 1951, McCarty et al. 2002). The phenology and presence of fruits can affect and alter the movement of various wildlife species such as white-tailed deer (*Odocoileus virginianus*; Lay 1965, 1969), wild turkeys (Blackburn et al. 1975, Campo et al. 1989, Yarrow and Yarrow 1998, McCord et al. 2014), black bears (*Ursus americanus*; Beeman and Pelton 1980, Clark et al. 1994, Ryan et al. 2007), small mammals (Masters et al. 1998, Greenberg et al. 2011), and many overwintering songbirds (Martin et al. 1951, McCarty et al. 2002, Greenberg and Levey 2009). The quality of habitat is also dependent on the diversity of soft-mast producing species found within a forest (Beeman and Pelton 1980, Clark et al. 1994, McCarty et al. 2002). Preferred habitats typically provide fruit from a variety of soft-mast species (Beeman and Pelton 1980, Clark et al. 1994, McCarty et al. 2002). Soft-mast quantity and quality are key components in determining year-round habitat quality for these native wildlife species.

Although the importance of soft-mast production to wildlife management is well known, only a few studies have examined the effects of routine fires on soft-mast production, particularly the long-term effects (e.g., Greenberg et al. 2012, Lashley et al. 2015, Lashley et al. 2017). This lack of study is especially true of management practices (e.g., prescribed fires) focused on mimicking natural disturbances in ecosystems, such as shortleaf pine woodlands. Previous studies have focused on the initial soft-mast response after a variety of silvicultural practices such as timber harvest, mid-rotation thinning, and site preparation (Campo and Hurst 1980, Stransky and Roese 1984, Perry et al. 1999, Perry et al. 2004, Greenberg et al. 2007, Greenberg and Levey 2009). These practices impact and alter overstory structure (partial or complete removal), and application of fire is typically incorporated with site preparation. Understanding how native species endemic to fire-prone ecosystems respond to prescribed burning long-term is pivotal to the continuous, successful efforts for improving habitat management, especially for the endangered RCW. Response by soft-mast producing species are of particular importance because they are a significant component of a quality pine woodland ecosystem; however, few studies have addressed this issue (Greenberg et al. 2007, Lashley et al. 2015). Understanding and determining when key producers (e.g., American beautyberry [*Callicarpa americana*], blackberry, and grapes [*Vitis* spp.]) have significant soft-mast production and when production peaks following prescribed fires will allow managers to adjust burning regime or alter structural characteristics within the forest, to increase soft-mast production, if necessary.

While the effects of the shortleaf pine woodland restoration have been extensively monitored for a variety of forest flora and fauna, there are still unanswered questions about the long-term impacts on habitat quality and the impact on soft-mast production. In particular, the long-term effects of frequent dormant season prescribed fire and other forest structural characteristics on woody soft-mast producing species have yet to be determined. In this study, I surveyed fruit and vegetation cover from woody soft-mast producing species in the 1st, 2nd, 3rd, and 5th growing season post dormant season burns in restored shortleaf pine woodlands located in the Ouachita National Forest in Arkansas and Oklahoma. I examined species response and quantified soft-mast production and vegetation cover at various intervals after dormant season prescribed fires (Chapter II). I also identified variables that impact the forest structure at a landscape, stand, or plot level and the influence these characteristics have on soft-mast production in restored shortleaf pine forests (Chapter III). The results from Chapter II and III provide a better understanding of the overall habitat quality and the short-term response in a native pine-woodland ecosystem following the implementation of long-term recurring prescribed fire management. The results can be used to modify fire intervals and forest structural characteristics to increase, or at least maintain, viable levels of mast production in areas where habitat quality for target wildlife is an important management goal.

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CHAPTER II.

SOFT MAST PRODUCTION AND VEGETATIVE COVER OF UNDERSTORY SPECIES IN REGULARLY BURNED SHORTLEAF PINE WOODLANDS OF THE OUACHITA NATIONAL FOREST

Abstract

The use of prescribed fire is integral to the restoration of open woodlands and savannas in the southeast, including shortleaf pine (*Pinus echinata*) woodlands in the Ouachita Mountains. Fire offers many potential wildlife benefits; however, short-term implications for understory soft-mast production are not fully understood. This study examined the effects of recrurrent dormant season prescribed burns on woody soft-mast production (kg ha^{-1}) and soft-mast producing vegetative cover in the understory of restored pine woodlands. I inventoried 32 stands during four temporal periods after dormant season prescribed fires: 1, 2, 3, and 5 growing seasons post burn (burn year). To capture the majority of soft-mast producing species in the understory, I conducted surveys three times (June, July, and August) throughout the growing season. Vegetative cover was visually estimated in July (during peak growing season). Soft-mast production was greatest in the 3rd burn year (18.2 kg ha^{-1}), followed by the 5th (10.9 kg ha^{-1}) and 2nd (9.8 kg ha^{-1}) burn year. Overall, 87% of total production consisted of three genera: *Callicarpa americana* (American beautyberry [38%]), *Vitis* spp. (summer grape [*Vitis aestivalis*; 11%] and muscadine grape [*V. rotundifolia*; 10%]), and *Rubus* spp. (blackberry [20%] and dewberry [*R. flagellaris*; 8%]). Production was recorded in 13 of the 14 species present during the 5th burn year, indicating that production diversity increased over time. Percent cover of soft-mast producing species (54% cover) and species

richness (26) were greatest in the 3rd burn year. Species such as poison ivy (*Toxicodendron radicans*) and sumac (*Rhus* spp.) had a high percent cover (>7% each), but this did not translate into high mast production. American beautyberry and summer grape did not have a high presence on the landscape, but when they occurred were highly productive. Results suggest that burning on a 3-year rotation maximizes and prolongs soft-mast production; however, burning on a 5-year rotation will promote a higher diversity of woody mast producing understory species.

Introduction

It is well documented that soft-mast producing plants are important food sources for numerous wildlife species. Many species consume foliage and mature fruits (e.g., black bears [*Ursus americanus*]), and others may browse on twigs (e.g., white-tailed deer [*Odocoileus virginianus*]; Grelen and Duvall 1966, Beeman and Pelton 1980, Clapp 1990). Wildlife, including black bear and wild turkey (*Meleagris gallopavo*), prefer habitats characterized by a greater quantity and diversity of soft-mast production (Beeman and Pelton 1980, Clark et al. 1994, McCarty et al. 2002). Many wildlife species depend on soft-mast production as part of their seasonal diet (Martin et al. 1951, Beeman and Pelton 1980, Clapp 1990, Greenberg and Levey 2009). Hard mast (e.g., acorns) availability and production vary seasonally and annually, making soft-mast production especially important as a buffer against years of low hard mast production (Eiler 1981, Eiler et al. 1989, Clapp 1990, Inman and Pelton 2002). The phenology and presence of fruits can affect and alter the movement of various wildlife species such as white-tailed deer (Lay 1965, 1969), wild turkeys (Blackburn et al. 1975, Campo et al. 1989, Yarrow and Yarrow 1998, McCord et al. 2014), black bears (Beeman and Pelton 1980, Clark et al. 1994, Ryan et al. 2007), small mammals (Masters et al. 1998, Greenberg et al. 2011), and many overwintering songbirds (Martin et al. 1951, McCarty et al. 2002, Greenberg and Levey 2009).

Rubus fruits are one of the most important summer foods (Martin et al. 1951) and one of the most commonly consumed items in the summer diets of turkeys. *Rubus* spp. can comprise nearly half of poult diets (Blackburn et al. 1975, McCord et al. 2014). American beautyberry is readily consumed in the fall by white-tailed deer and upland game birds (Martin et al. 1951); and, due to its abundance, it is likely important in the diets of many other species. Movement, survival, and reproductive success of black bears (Beeman and Pelton 1980, Eiler et al. 1989, Clark et al. 1994, Ryan et al. 2007) and eastern wild turkeys (Dalke et al. 1942, Campo et al. 1989, Yarrow and Yarrow 1998) is directly related to habitat quality and resource availability, both of which depend heavily on soft-mast production.

In addition to serving as a food source, many soft-mast producing plants form a dense shrub layer in the understory that provides escape and protective cover for many birds, mammals, and reptiles (Martin et al. 1951, Campo et al. 1989, Yarrow and Yarrow 1998, McCord et al. 2014, Lashley et al. 2015*a*). Particularly, areas that have understory vegetation less than 2 m in height provide protection from avian predators (Campo et al. 1989, Cram et al. 2002).

In the 1990s, the Ouachita National Forest (ONF) initiated a large-scale restoration project to promote red-cockaded woodpecker (RCW; *Picoides borealis*) habitat by re-establishing historic open-forest conditions. Prior anthropogenic influences across the landscape, such as altered fire regimes

(Guyette and Spetich 2002, Stambaugh and Guyette 2006) and fire exclusion (Foti et al. 1999, Fowler and Konopik 2007), resulted in the transformation of open shortleaf pine woodlands to dense, closed-canopy forests.

Restoration of individual stands was initiated using a wildlife stand improvement (WSI) treatment which removed midstory trees and reduced overstory basal area. The resulting overstory basal area (BA) corresponded with the optimal BA for RCW habitat: approximately 13.7 m^2 ha^{-1} (60 ft^2 ac^{-1}; Tesky 1994, Hedrick et al. 2007). Following the initial WSI treatment, silvicultural activities (pre-commercial and commercial thinnings) and prescribed burns every 3 to 5 years are utilized to maintain the restored open shortleaf pine woodlands. When forest regeneration becomes necessary, managers implement shelterwood and seed tree regeneration methods to allow for natural regeneration. Harvest stands are staggered across the landscape to maintain a contiguous mature forest structure across the national forest. In addition to modifying altering harvest methods, the average harvest rotation was increased from 70 to 120 years.

The initial short-term response of soft-mast production after a silvicultural disturbance (e.g., fire, harvesting, and mid-story thinning or removal) has been well documented (Johnson and Landers 1978, Campo and Hurst 1980, Stransky and Roese 1984, Perry et al. 1999, Perry et al. 2004, Greenberg et al. 2007). However, silvicultural activities are often sporadic and happen only a few times in the life of a stand: during site preparation, mid-rotation thinning, and at harvest. Without routine disturbance, the canopy closes, less light reaches the understory, and growth is limited to shade-tolerant species, resulting in decreased understory soft-mast production.

Restoration efforts on the ONF have increased use of prescribed fire on the landscape. Prescribed burning is an essential tool for maintaining open pine woodland structure (Hodgkins 1958, Waldrop et al. 1992, Brockway and Lewis 1997, Sparks et al. 1998, NatureServe 2004), which fosters soft-mast production. Soft-mast production following a disturbance is impacted by various factors including season, plant community, disturbance type, forest structure, and other environmental factors (e.g., temperature, rainfall, and microclimate; Brockway and Lewis 1997, Sparks et al. 1998, Sparks et al. 1999, Greenberg et al. 2011, Greenberg et al. 2012, Lashley et al. 2015*a*). Dormant season burns top-kill small woody stems while without damaging rootstocks, increasing the sprouting potentials, and promoting herbaceous and woody diversity (Hodgkin 1958, Waldrop et al. 1992, Cain et al. 1998, Sparks et al. 1998). However, fires during the growing season (after carbohydrates have been spent producing foliage) produce higher rate of mortality and less height growth (Hodgkins 1958, Brose and Van Lear 1998).

Although effects of woodland restoration on the ONF have been extensively monitored for a variety of forest flora and fauna, there are unanswered questions about long-term impacts on habitat quality. In particular, little information is available regarding the implications of restoration treatments for soft-mast production. The goal of this research was to determine how dormant season prescribed burns implemented on a 3 to 5-year return interval affect woody soft-mast production and cover by understory species (growth ≤ 2 m) on the ONF. My objectives were to quantify the differences in understory soft-mast production (kg ha^{-1}) and percent cover of soft-mast producing species among woodlands 1, 2, 3, and 5 growing seasons after dormant season prescribed burns in restored shortleaf pine woodlands. These results can be used to modify fire intervals to increase, or at least maintain, viable levels of soft-mast production in areas where habitat quality for target wildlife is an important management goal. I hypothesized that production and vegetative cover by woody soft-mast producing species would increase with increasing number of growing seasons following dormant season burns. Furthermore, such increases in production would continue to occur until the midstory reaches a density where the amount of sunlight reaching the forest floor is reduced due to the increasing vegetation competition.

Methods

Study Area

The Ouachita Mountain range encompasses the ONF and stretches from southeastern Oklahoma to west-central Arkansas. The primary mountain ridges run east to west, creating mesic northern slopes and xeric southern slopes (Palmer 1924, Foti and Glenn 1991, Guldin 2007). The elevation is between 150 and 823 m (Bukenhofer and Hedrick 1997, Hedrick et al. 2007) and the annual rainfall ranges between 100 and 150 cm (Foti and Glenn 1991). The xeric southern slopes constitute a disturbance-driven ecosystem sustained primarily with fire, which historically occurred on a 3 to 5-year interval (Runkle 1990, Bukenhofer and Hedrick 1997, Guldin et al. 2004, Stambaugh and Guyette 2006). The Ouachita Mountains' bedrock is comprised largely of sandstone and shale, meaning soil groups of Ultisols, Inceptisols, and Alfisols, of which Ulitisol is the most abundant. Soils are generally sandy, highly weathered, well drained, and acidic with low fertility (Ouachita Ecoregional Assessment 2003, NatureServe 2004). Variations in soil depths, mixture, and fertility vary based on slope, aspect, and location (Ouachita Ecoregional Assessment 2003).

Traditionally, fire maintained a relatively open overstory, a sparse midstory, and a diverse understory (Smith et al. 1997, NatureServe 2004). Shortleaf pine dominates the overstory, and upland oak species (e.g., *Quercus alba, Q. stellata, Q. marilandica*) are also common (Palmer 1924, Eyre 1980, Foti et al.1994, Dale and Ware 1999, Hoagland 2000, NatureServe 2004). Grasses and forbs, such as little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), legumes (e.g*. Desmodium* spp., *Lespedeza* spp.), sunflowers (*Helianthus* spp.), goldenrods (*Solidago* spp.), bracken fern (*Pteridium aquilinum*), and crotons (*Croton* spp.) are common herbaceous species within this diverse community (Martin et al. 1951, Grelen and Duvall 1966, Haywood et al. 2001, NatureServe 2004). Many soft-mast producing species are also common, including American beautyberry (*Callicarpa americana*), hollies (*Ilex* spp.), sparkleberry (*Vaccinium arboreum*), poison ivy (*Toxicodendron radicans*) and sumacs (*Rhus* spp.; Grelen and Duvall 1966, NatureServe 2004).

The shortleaf pine woodland restoration project encompasses over 102,790 ha or approximately 25% of the total pine-dominated area of the forest and 14% of the entire ONF (Hedrick et al. 2007). I surveyed restored shortleaf pine woodlands within the Poteau-Cold Springs and Mena-Oden Ranger Districts of west-central Arkansas and the Oklahoma Ranger District of southeastern Oklahoma.

Study sites. During each of the two field seasons (2015 and 2016), I inventoried the understory of 16 stands, with four stands representing four temporal periods after dormant-season prescribed fires: 1st, 2nd, 3rd, and 5th growing seasons post-burn (hereafter burn year; Figure 2-1). In total, I inventoried 32 stands, with each burn year replicated 8 times. The stands were selected based on information provided by the USDA Forest Service (Southern Research Station and ONF). All stands were located primarily on southern aspects (S, SW, or SE) and in areas that had previously received at least two dormant season burns with overstory BAs between 13.8 and 18.4 m^2 ha^{-1}. Stands were at least 70 years old and received WSI treatments between 5 and 26 years prior to sampling. The earliest initial prescribed burn on a study stand occurred in 1992 and the most recent initial burn was in 2010 Thus, any given stand had a burn history of between 7 and 21 years.

Field methods

I randomly located 6 to 8 survey transects within each stand with a total of 40 plots systemically placed along those transects. I used ArcMap 10.3.1 and the fishnet tool from Arc Toolbox to overlay a 25-m by 15-m grid over each stand. I separated grid lines into horizontal and perpendicular lines, and then randomly assigned numbers to each line. Using a random number generator, I chose starting locations (intersections of two lines) and then placed transects (lines). The grid represented the minimal distance between transects (25-m) and plots (15-m) needed. The number of transects within each stand varied based on stand size, and I placed all transects perpendicular to the primary slope. I placed a 50-m buffer around hard edges (e.g., roads and regeneration areas) and edges adjacent to structurally different forests.

Soft-mast surveys. I surveyed 40, 9-m^2 semi-permanent plots within each stand for a total sample area of 0.036 ha per stand and 0.288 ha in each treatment (burn year). I sampled plots 3 times during the growing season: in early June, early July, and mid-August to correspond with ripening phenology of important soft-mast species. I counted all soft-mast fruits up to 2-m in height, including green fruit and fruits that appeared to have been removed by herbivory. To avoid double counting of fruits in multiple surveys, I used the highest monthly count for a given species to represent production for that species. Production survey methods followed Perry et al. (1999, 2004). Other methods are available to predict understory fruit biomass production, such as plant coverage and stem density; however, manually counting fruit at each plot provides results that are more accurate, and requires less time to evaluate the area (Lashley et al. 2014). Furthermore, coverage of soft-mast producing plants does not necessarily reflect production (Perry et al. 1999). I counted single drupes and berries individually. Larger and more numerous fruit clusters were measured and numbers of fruits within clusters were estimated. To quantify species with large compact fruit heads (e.g., sumac), I developed a regression equation relating fruit mass to cluster volume by collecting multiple samples of each species (winged [*Rhus copallinum*] and smooth sumac [*R. glabra*]; Perry et al. 1999). For American beautyberry, which contains numerous clusters, I estimated total fruit within each plot by determining mean fruit per plant. Based on a 10-cluster subsample, I calculated fruit production per plant by multiplying the number of clusters on each plant by the average cluster count, and repeated this process for each plant within the plot and combined totals to find total production per plot. If the plot contained less than 50 American beautyberry clusters, I counted berries individually.

Vegetation surveys. I visually estimated percent cover of each fruit-producing species in 1 m^2 square nested subplots using Daubenmire's six cover classes (Daubenmire 1959, Coulloudon et al.1999). I nested the smaller vegetation plots within the larger soft-mast production plots. I estimated vegetation cover for woody soft-mast producing species during July, which corresponded with the peak of growing season.

Mass and cover estimation

I combined production from all three sampling periods to determine the total mast production by each species and total production (all species combined) by stand. I grouped genera that have similar wildlife value, based on species fruiting phenology, growth habitat, and wildlife use. For analyses, I grouped species such as winged and smooth sumac (hereafter sumac), and sawtooth (*Smilax bona-nox*), lanceleaf (*S. smallii*), cat (*S. glauca*), and roundleaf (*S. rotundifolia*) greenbrier (hereafter greenbrier).

I collected fruit samples based on availability and opportunity in each stand. Using a conversion factor for each species, I coverted fruit counts to mass. I collected ≥119 representative berries of American beautyberry, wild rose, blackberry (*Rubus* spp.), dewberry (*R. flagellaris*), poison ivy, muscadine grape (*Vitis rotundifolia*), and summer grape (*V. aestivalis*). Species with smaller representative fruit samples occurred for two reasons within study areas: either ripe fruit was not as common (greenbrier [6-27 berries]) or the species fruited at lower rates (sparkleberry [15-70 berries], black cherry [3-17 berries], and American pokeberry [62 berries in 2015]). In both sample years, I collected and measured ≥38 clusters for each sumac species. I used a Fisher Scientific Isotemp oven to dry samples at 65°C to a constant mass. I weighed dried fruits (with seeds) to the nearest 0.01 g and used species-specific conversion factors to estimate total mass produced by species.

I conducted all soft-mast analyses on the dry mass production (kg ha^{-1}), hereafter production. I performed analyses on the total production (all species) and on individual species that together comprised 95% of total production: American beautyberry, blackberry, dewberry, summer grape, muscadine grape, sumac, and greenbrier. I analyzed total vegetation cover and individual species that occurred in at least 25% of all stands (8 out of 32 stands). I grouped species falling under the 25% threshold for analyses, hereafter referred to as ‘veg other’.

Data Analysis

I derived treatment means for production and vegetation cover for each stand (8 stands per treatment; *n*=32) and, when necessary, transformed to improve normality. Soft-mast production means underwent a log transformation (log[x+1]; Perry et al. 1999, Zar 1999, McCord et al. 2014), and a square root transformation ($\sqrt{x}$; Zar 1999, Vitz and Rodewald 2007) was used for vegetation cover. I present non-transformed values throughout. I compared treatment means using analysis of variance (ANOVA) with PROC MIXED in SAS (v.9.2 SAS Institute, Cary, North Carolina) using the Kenward-Rogers method to determine the denominator degrees of freedom (Littell et al. 2006). I assessed soft-mast production and total vegetation coverage (response variables) at the stand level (experimental unit). The number of burn year was the fixed effect (independent variable). I used least square means with a Tukey adjustment to compare production means among burn year when ANOVAs were significant at alpha=0.05. I accounted for potential variation in weather conditions (e.g., rainfall), and among stands selected in each year (e.g., soils or fire intensity) by including the calendar year and stand number as random effects in the models.

Results

Soft-mast production

The number of species producing soft-mast varied from 14 in 2015 to 12 in 2016 (Table 2-1). Similar quantities of total dry soft-mast production occurred in 2015 and 2016 ($F_{1,27}$=1.65; P=0.209; Table 2-3). Total production in 2015 and 2016 differed by burn year; production in the 2nd, 3rd, and 5th burn year was similar and all were greater than in the 1st burn year ($F_{3,28}$=21.85; P=0.0001; Table 2-2). Production in the 1st burn year was less than the 2nd (P<0.001), 3rd (P<0.001), and 5th burn year (P<0.001). Mean production peaked in the 3rd burn year at 18.2 (± 5.9) kg ha^{-1}, but production did not differ from the 5th (P=0.256) and 2nd (P=0.663) burn year, which produced 10.9 (± 2.6) kg ha^{-1} and 9.8 (± 2.6) kg ha^{-1} respectively (Table 2-2). Of the 14 species observed, 7 varied among burn year: American beautyberry, blackberry, dewberry, greenbrier, sparkleberry, muscadine grape, and summer grape (Table 2-2). American beautyberry had the greatest production value and contributed 38% of the total production averaged over all post-burn years. Blackberry was the second highest producing species with 20% of the total production value, followed by summer grape (12%), muscadine grape (10%), dewberry (8%), greenbrier (6%), and sumac (5%).

The number of species producing soft-mast increased with burn year from 5 species the 1st burn year to 12 species the 2nd and 3rd burn years, and 13 species the 5th burn year. American beautyberry production was much greater in the 2nd (P<0.001) and 3rd (P<0.001) burn year than in the 1st (P=0.520) and 5th (P=0.367) burn year, accounting for approximately half of the total production in these two growing seasons (Table 2-2). Although American beautyberry production was similar between the 2nd and 3rd burn year, greater production by climbing vines such as greenbrier, muscadine grape, and summer grape contributed to the peak in total production in the 3rd burn year. Summer grape and dewberry production peaked the 3rd (P=0.134) burn year; however, production was similar in the 2nd (P=0.821) and 5th (P=0.262) burn year. Muscadine grape and greenbrier had more production after the 1st (P=0.976 and P=1.000) burn year, production was greater with time since burn (Table 2-2). In the 5th burn year, American beautyberry production declined (P=0.367), which coincided with a significant increase in blackberry production (P<0.001). Blackberry production comprised 42% of the total production in the 5th burn year (Table 2-2).

Production by most species was greater after the 1st burn year. However, production in many of the top species stabilized after the 3rd burn year (Table 2-2). Production was similar in the 1st, 2nd, and 5th burn year for American beautyberry (P=0.520, P<0.001, P=0.367), dewberry (P=0.830, P=0.039, P=0.039), muscadine grape (P=0.973, P<0.001, P<0.001), and summer grape (P=1.000, P=0.821, P=0.262), all which had greater production in the 3rd burn year than the 1st burn year. Both blackberry and dewberry had more production in the 3rd burn year than the 1st burn year. Blackberry production in the 5th burn year ($P<0.001$) was higher than the 1st ($P<1.000$) and 2nd ($P<0.002$) burn year but similar to the 3rd burn year ($P<0.001$).

Production by most species followed similar burn year trends in the 2015 and 2016 sample years (e.g., American beautyberry, wild rose, blackberry, dewberry, sparkleberry, and muscadine grape); however, production for summer grape and greenbrier was greater in 2016 (Table 2-3). In 2016, these two species accounted for approximately 29% of the total production compared 1.4% in 2015. Total production of summer grape and greenbrier was 20 and 100 times higher, respectively, in 2016 than in 2015.

Vegetation cover

I recorded percent cover for 30 soft-mast producing species (28 species in 2015 and 26 in 2016). Ten species occurred in less than 25% of all stands and were collectively referred to as ‘veg other’ (Table 2-4). Total percent cover was consistent across all treatments ($F_{3,28}=2.2$; $P=0.1092$), and did not differ by year sampled ($F_{1,27}=4.9$; $P=0.0662$; Table 2-5). Of the 30 species surveyed, burn year appeared to influence the cover of 4 species (Table 2-5); however, these variations were erratic and perhaps caused by site-specific factors rather than burn year. Cover of species that produced was impacted by burn year ($F_{3,28}=27.1$; $P=0.0001$; Table 2-5). Similar to total production, vegetation cover that produced fruit was greater in the 2nd ($P<0.001$), 3rd ($P<0.001$), and 5th ($P<0.001$) burn year than the 1st ($P=0.0867$; Table 2-5).

Although I observed greater species richness of shrubs (11 species) than vines, the cover of woody vines was approximately 1.7 times the cover of shrubs. Overall, species with the highest cover across the landscape were poison ivy (7.4%), sumac (7.0%), dewberry (6.0%), muscadine grape (5.8%), and greenbrier (5.1%; Table 2-5). The 10 species in the ‘other’ group covered <1% of sampled areas.

Discussion

Shortleaf pine woodlands are a disturbance-driven community, in which prescribed burns are necessary to sustain quality habitat in the early to intermediate successional forest stages (Guldin and Loewenstein 1999, Reynolds-Hogland et al. 2006). Disturbances (silvicultural treatment or prescribed fire) retard understory and midstory vegetation growth, thereby increasing the sunlight able to reach the forest floor and stimulate new growth (Waldrop et al. 1992, Brockway and Lewis 1997, Sparks et al. 1999, Haywood et al. 2001). Following a disturbance, soft-mast producing species reestablish either by re-sprouting or seed germination (Hodgkins 1958, Waldrop et al. 1992, Cain et al. 1998). Frequently burning will promote low severity fires which will maintain the pine overstory while top killing and removing understory stems (Waldrop et al. 1992). Because the impact of fire on the landscape is spatially patchy, a mosaic understory is created within the forest (Cain et al. 1998, Greenberg et al. 2011), these variation in fire intensity was evident between burn years and sampled stands.

Many of the species I observed are closely associated with early to mid-seral succession within open or relatively-open canopy forests (Martin et al. 1951, Halls 1977). Prescribed burning in this study limited production to species that can respond and recover within the 3 to 5-year fire return interval. All of the top producing species were either shrubs or woody vines, and all produced in the

2nd, 3rd, and 5th year after burning; however, relative contributions varied by species. American beautyberry can re-establish and begin producing within 2 years (Halls 1973, Halls 1977), and largely contributed to production in all but the 5th burn year. Muscadine grape, summer grape, greenbrier, dewberry, and American beautyberry achieved their greatest production in the 3rd burn year, corresponding with the peak of total species production. In the 5th burn year, all but American beautyberry had sustained their production. Large fruiting events 4 to 5 years after disturbance are common for blackberry (Johnson and Landers 1978, Campo and Hurst 1980, Stransky and Roese 1984, Perry et al. 2004, Greenberg and Levey 2009, Greenberg et al. 2011). This trend was reflected in my study where blackberry production was greater after more growing seasons until the 5th burn year where production peaked.

The number of species producing soft-mast was greatest in stands 5 years after burns. A similar trend in species richness has been observed in previous studies, indicating that diversity of producing species increases as more species recover or establish after disturbance (Johnson and Landers 1978, Stransky and Roese 1984, Perry et al. 2004). Despite this, total production was lower in the 5th burn year. Fruiting by black cherry was rare and only happened in 2015, illustrating the impact a longer recovery time can have on individual production. Other soft-mast producing trees were present on the landscape, but they either did not reach production age within the 3 to 5-year interval between prescribed fires or did not occur within 2-m of the forest floor. Delaying intervals between burns would allow more species to reach production age and produce mature fruits; however, doing this could lead to a decline in the total mass of other soft-mast produced. Delaying prescribed burns would allows other species to reach production age, it may also allow other hardwood species to get large enough to compete and be fire resistant, which will permanently shade the understory and decrease production.

Delaying disturbances may lead to decreases in soft-mast production in as soon as 6 years after silvicultural treatment (Johnson and Landers 1978, Campo and Hurst 1980, Stransky and Roese 1984) due to increased competition for sunlight in the midstory (Perry et al. 1999, Perry et al. 2004, Greenberg and Levey 2009). The top producing species on the landscape vary from shade intolerant to moderately shade tolerant (Martin et al. 1951, Halls 1973; 1977). Under moderate shade, vegetation growth and production is limited for sumac and grapes; and species such as American beautyberry, blackberry, and greenbrier may be present but suffer from lower production (Martin et al. 1951, Halls 1973; 1977).

When compared to my study, other research on the production output in recently harvested stands (without burning) recorded higher production rates (Perry et al. 1999, Perry et al. 2004, Greenberg et al. 2007). For example, in upland pine stands in the Ouachita Mountains, soft-mast production peaked at

100 kg ha^{-1} in the 5th year following a shelterwood harvest (Perry et al. 1999). Similarly, Greenberg et al. (2007) found that production also peaked in the 5th year after a shelterwood harvest in young regenerated hardwood stands in the Appalachian Mountains. Conversely, in my study, production peaked in the 3rd burn year at 18.2 kg ha^{-1}. However, both Perry et al. (1999) and Greenberg et al. (2007) examined silvicultural treatments (i.e., timber harvest) that altered overstory structure by removing canopy trees without fire, which promoted more prolonged production. Perry et al. (2004) recorded low production (< 1 kg ha^{-1}) in unharvested and unburned forests, whereas thinning alone resulted in production rates that are comparable to the production rate of this study (burning alone). This indicates that burning alone may not increase production as greatly as harvesting with no burn, but it does substantially increase mast production compared to unharvested/unburned areas.

Previous studies investigating soft-mast production following silvicultural disturbances found similar species producing; however, individual species contributions to total production differed. Disturbance-driven species or species in disturbance-prone ecosystems will easily germinate and establish through seeds or re-sprout from root systems (Halls 1977, Waldrop et al. 1992). Presence of both American beautyberry and greenbrier increase following dormant season prescribed burns (Halls 1977, Waldrop et al. 1992). In the 3rd year after disturbances, both had greater or similar production following a dormant season burn than after silvicultural activities (Stransky and Halls 1980, Perry et al. 2004). However, Perry et al. (2004) and Stransky and Halls (1980) found species such as blackberries and sumacs produced earlier and at higher rates after timber harvest compared to burning alone. Blackberries and sumacs are well adapted to frequent disturbances and grow best in full sun (Martin et al. 1951, Halls 1977, Waldrop et al. 1992). Grapes also had higher production rates following harvests in Perry et al. (2004) and Stransky and Halls (1980). Vines are relatively shade intolerant, and are more likely to produce in the sunlight versus shaded areas (Martin et al. 1951, Shutts 1974, Halls 1977). Without open conditions created by disturbances, presence of these species would be limited across the landscape (Halls 1977, Waldrop et al. 1992, Greenberg et al. 2011). Unlike blackberry and sumac, which easily germinate and establish through seeds (Halls 1977, Waldrop et al. 1992), grapes, American beautyberry, and greenbriers readily resprout after aboveground vegetation is removed or top-killed (Grelen and Duvall 1966, Halls 1977, Waldrop et al. 1992). Grapes are not particularly associated with frequently disturbed uplands such as my study sites, but are typically found along creeks and bottomlands (Halls 1977). Because of this, the impact of repeated prescribed fires, prior land use, soil disturbance, and harvesting may influence the ability of grapes to recover (Stransky and Halls 1980).

Similar to Perry et al. (1999), species coverage was not a good indicator of overall production, and species with high overall coverage often did not produce large amounts of soft-mast in the ONF. For example, poison ivy had the greatest cover (7.4%), but only minor production (less than 0.2% of total). In contrast, American beautyberry had very low coverage (0.7%) but was the highest producing species with approximately 38% of total production. A few species had both high production and vegetation coverage, such as muscadine grape, sumac, and dewberry.

In general, a species coverage on the landscape is not a good indicator of production; however, the more prevalent a species was the greater production potential it has. For example, I found summer grape and greenbrier to have greater species coverage along with greater production in 2016 compared to 2015; which may have reflected differences (e.g., soil characteristics or burn intensity) among stands sampled in each year. Yearly variation in production and cover can occur for numerous reasons including environmental factors (e.g., temperature, rainfall, and microclimate), energy allocation, or nutrient competition (Greenberg et al. 2011, Greenberg et al. 2012). I did not observe any obvious differences in weather between years (i.e., rainfall in the summers of both 2015 and 2016 was slightly above long-term average) that could explain this variation.

Cycles between high and low mast crops are common in many fruit producing species and highlight the importance of species richness and production diversity throughout the forest. This could explain why summer grape's production varied significantly between 2015 and 2016. Although American beautyberry and blackberry both fruited prolifically ($\geq$ 2 kg ha^{-1}), the timing of their peak production differed, with blackberry peaking in mid-summer and beautyberry in late summer-early fall. Wildlife benefit when prolific producers are present over a longer period. This 'relay' in differing phenology among prolific producers is similar to American pokeberry and blackberries' production in young forests (Greenberg et al. 2011). Such differences in the phenology and maturing of fleshy fruit-producing species may provide food resources year round for many species and mitigate potential negative impacts during critical times when other food resources are scarce (Eiler 1981, Eiler et al. 1989, Clapp 1990, Inman and Pelton 2002, McCarty et al. 2002, Greenberg and Levey 2009).

Wildlife species benefit from a diverse floral community and forest structure. Therefore, maintaining a balance between palatable choices and persistent winter food will simultaneously provide adequate cover, both of which contribute to overall habitat quality (McCarty et al. 2002). Fruits of *Rhus* spp., wild rose, sparkleberry, greenbrier, and poison ivy typically ripen and persist into the winter months (Halls 1977). These species comprised approximately 11% of the total production. Fruits of summer grape have also been known to ripen and dry on the vine before being consumed by birds and mammals in winter (Halls 1977). Due to their high carbohydrate, vitamin, and water content, these fruits are valuable to wildlife, particularly for overwintering birds in late fall and winter when other food is scarce (Martin et al. 1951, Halls 1977, McCarty et al. 2002).

The presence of soft-mast also influences the diets of many wildlife species in late spring and especially in late summer when the greatest diversity of fruits are consumed (Clapp 1990). I found 89% (9.3 kg ha^{-1} across the landscape) of the total production consisted of preferred summer fruits. These include American beautyberry, blackberry, dewberry, summer grape, muscadine grape, and blueberries (Halls 1977, McCarty et al. 2002). Preferred fruits are consumed quickly once ripe (Dalke et al. 1942, Martin et al. 1951, McCarty et al. 2002, McCord et al. 2014) and tend to be more nutritious than winter/persistent fruits (McCarty et al. 2002). These preferred species ripen throughout the growing season: from late spring and early summer (blueberry and dewberry), through mid-summer (blackberry and summer grape) to late summer (American beautyberry and muscadine grape; Martin et al. 1951, Halls 1973, 1977).

Rubus and *Vitis* species are some of the most important summer fruiting species which can make up 25% of upland game and songbirds diets and 10% of small and game mammals (Martin et al. 1951). As winter or persistent fruits, sumacs provide an important food source and up to 10% of winter diets for upland gamebirds, songbirds, and white-tailed deer (Martin et al. 1951). Along with the fruit, sumac stems can up to 50% of diets other mammals, especially rabbits (*Sylvilagus* spp.; Martin et al. 1951). As the most productive species, American beautyberry is an integral food resource (e.g., foliage and twigs) to many wildlife species, although soft-mast production alone has the highest value. Fruit from American beautyberry is found to contribute between 2 and 10% of songbird’s diets (Martin et al. 1951).

Nutritional value differs by species, however moderate levels of calcium and phosphorus occurred in the majority of the top producing species (Halls 1977). Nitrogen value is greatest for *Rubus* and *Vitis* spp and lowest for sumac fruit (Halls 1977). Both fiber and crude fat have relatively high or moderate levels in several of the top producing species such as, sumac, blackberry, greenbrier, summer grape, and muscadine grape (Halls 1977). It is also important to note the high water content of summer fruits, which ranges between 80% (summer grape) and 87% (dewberry), as they may provide water in times when other sources are scarce (Martin et al. 1951).

It is well documented that cover is an important habitat component for an array of wildlife species (Clark et al. 1994, Vitz and Rodewald 2007, McCord et al. 2014, Lashley et al. 2015*b*). Wildlife utilize many of the soft-mast producing species found in this study as both a food source and structural cover component (Martin et al. 1951). In particular, *Rubus*, *Vitis*, and *Smilax* species form dense thickets that are used extensively for nesting and cover by birds and mammals (Martin et al. 1951, Yarrow and Yarrow 1998, Burke et al. 2008, McCord et al. 2014). While the limited cover following many types of disturbance may temporarily reduce availability for wildlife (Clark et al. 1994, Lashley et al. 2015*b*), the eventual revegetation provides protection and reproductive cover for many species (e.g., brooding wild turkeys [McCord et al. 2014]). In the absence of additional disturbance, canopy closure will eventually limit midstory growth and diversity, ultimately limiting wildlife use. Therefore, frequent and routine understory disturbances, such as dormant season burns, are important to promote woody species that provide food, cover and foster a diverse, dense herbaceous understory (Waldrop et al. 1992, Brockway and Lewis 1997, NatureServe 2004, McCord et al. 2014).

Management Implications

While long-term management of woodlands in our study area is focused on RCW habitat the short-term implications are equally important, as other wildlife species depend on soft-mast production. Dormant season prescribed burns alone did not increase production as much as silvicultural treatments but was higher than unharvested and unburned stands. Therefore, continuing to burn at a 3 to 5-year rotation will promote and prolong production and vegetation cover diversity throughout the life of a stand which benefits various wildlife species. Burning on 3 to 5-year intervals will allow important soft-mast producing species to mature and reach production age, in turn increasing species richness along with maintaining fruit and vegetation biomass. Using a burning regime that is adaptable to forest conditions ensures a mosaic landscape comprised of various stages of understory development that is beneficial to flora and fauna communities alike.

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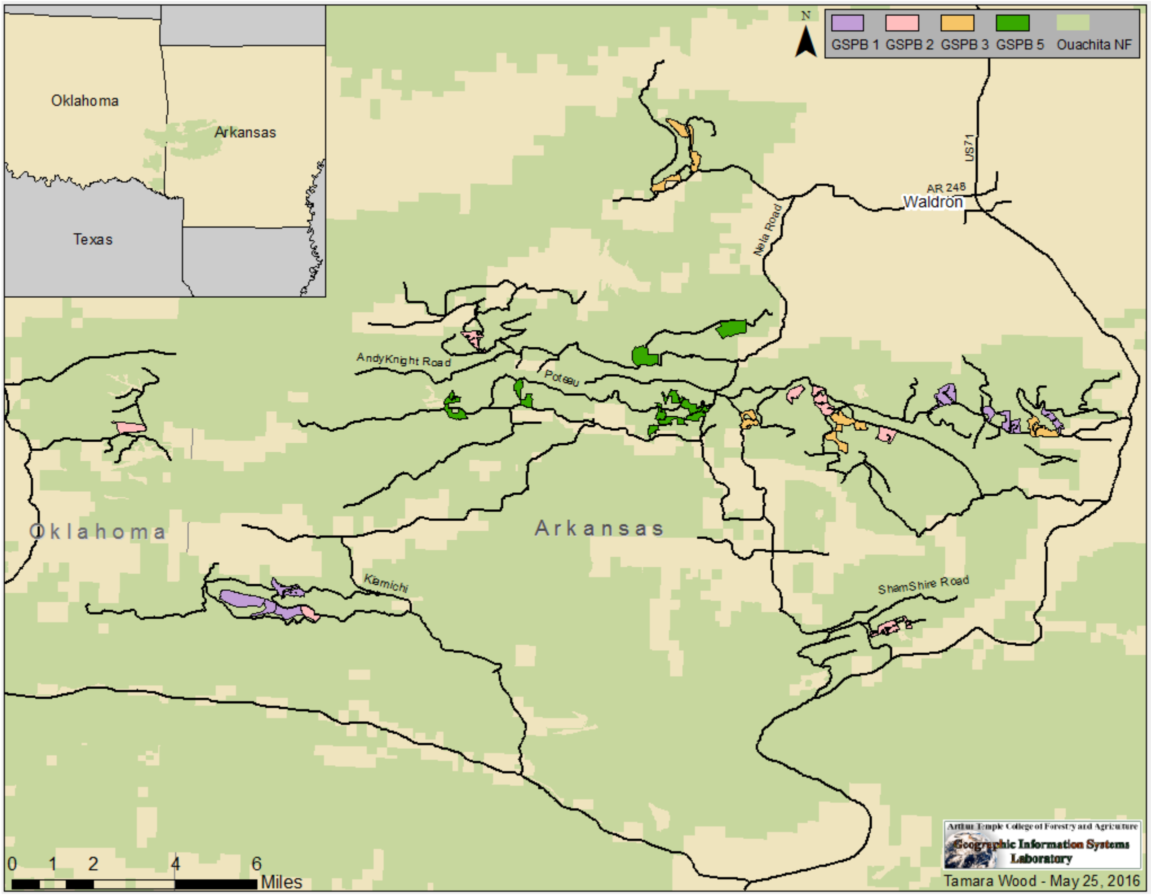

Tamara Wood - May 25, 2016

Figure 2-1. Location of stands surveyed for soft-mast production and cover in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma. Study stands were 1st (purple), 2nd (pink), 3rd (orange), or 5th (green) growing seasons since most recent dormant-season prescribed fire.

Table 2-1. Species producing soft-mast by growing seasons since burn (GSPB 1, 2, 3, and 5), sampled during summer in the Ouachita National Forest of Arkansas and Oklahoma, 2015−2016. Species presence indicated with an ‘X’.

	-- GSPB 1 --		-- GSPB 2 --		-- GSPB 3 --		-- GSPB 5 --	
Species	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
American beautyberry	X	X	X	X	X	X	X	X
American pokeberry*	X							
Black cherry*					X		X	
Blackberry			X	X	X	X	X	X
Blueberry			X	X	X	X	X	X
Dewberry	X		X	X	X	X	X	X
Greenbriers				X	X	X	X	X
Muscadine grape		X	X	X	X	X	X	X
Poison ivy			X	X		X	X	
Smooth sumac			X	X	X	X	X	X
Sparkleberry				X			X	X
Summer grape				X	X	X	X	X
Wild rose	X		X	X	X			X
Winged sumac			X	X	X	X	X	X
Total species	**4**	**2**	**9**	**12**	**11**	**10**	**12**	**11**

* species only found in 2015

Table 2-2. Mean (± SE) soft-mast production (kg ha^{-1} dry mass) by growing seasons since burn (1, 2, 3, and 5) in the Ouachita National Forest of Arkansas and Oklahoma, 2015−2016. Dissimilar letters within rows denote significant differences (α = 0.05) among growing seasons.

	Growing Seasons Post Burn					
Species	**1**	**2**	**3**	**5**	**$F_{(3,28)}$**	**P**
American beautyberry	0.38 ^{B} (±0.32)	6.17 ^{AB} (±2.74)	7.71 ^{A} (±3.05)	0.52 ^{B} (±0.33)	5.29	0.0051
American pokeberry*	0.01 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	1.00	0.4079
Black cherry*	0.00 (±0.00)	0.00 (±0.00)	0.01 (±0.01)	0.08 (±0.05)	2.54	0.0775
Blackberry	0.00 ^{C} (±0.00)	1.37 ^{BC} (±0.60)	1.70 ^{AB} (±0.34)	4.66 ^{A} (±1.91)	9.43	0.0002
Blueberry	0.00 (±0.00)	0.37 (±0.23)	0.09 (±0.07)	0.16 (±0.09)	1.68	0.1940
Dewberry	0.04 ^{B} (±0.04)	0.74 ^{AB} (±0.32)	1.48 ^{A} (±0.27)	0.75 ^{AB} (±0.34)	7.70	0.0007
Greenbrier	0.00 ^{B} (±0.00)	0.05 ^{AB} (±0.05)	1.01 ^{A} (±0.44)	1.13 ^{A} (±0.66)	5.15	0.0058
Muscadine grape	0.00 ^{C} (±0.00)	0.64 ^{BC} (±0.26)	1.87 ^{A} (±0.35)	1.53 ^{AB} (±0.59)	8.45	0.0004
Poison ivy	0.00 (±0.00)	0.04 (±0.02)	0.01 (±0.01)	0.01 (±0.01)	1.76	0.1779
Sparkleberry	0.00 ^{B} (±0.00)	0.00 ^{AB} (±0.00)	0.00 ^{B} (±0.00)	0.02 ^{A} (±0.01)	3.55	0.0269
Sumacs	0.00 (±0.00)	0.27 (±0.10)	0.54 (±0.19)	1.16 (±0.86)	2.27	0.1017
Summer grape	0.00 ^{B} (±0.00)	0.12 ^{AB} (±0.12)	3.77 ^{A} (±2.83)	0.88 ^{AB} (±0.38)	3.56	0.0272
Wild rose	0.00 (±0.00)	0.03 (±0.02)	0.05 (±0.04)	0.02 (±0.02)	0.75	0.5319
Total	0.43 ^{B} (±0.32)	9.80 ^{A} (±2.59)	18.24 ^{A} (±5.94)	10.93 ^{A} (±2.64)	21.85	0.0001

* species only found in 2015

Table 2-3. Mean (± SE) dry mass of soft-mast (kg ha^{-1}) by species and year sampled (2015 [n=16] and 2016 [n=16]) in the Ouachita National Forest of Arkansas and Oklahoma. Dissimilar letters within rows denote differences (α = 0.05) among sample years.

Species	Mean	2015	2016	$F_{(1,27)}$	P
American beautyberry	3.69 (±0.01)	4.12 (±1.74)	3.27 (±1.54)	0.16	0.6895
American pokeberry*	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	1.00	0.3262
Black cherry*	0.02 (±0.01)	0.04 (±0.03)	0.00 (±0.00)	3.30	0.0806
Blackberry	1.93 (±0.57)	1.50 (±0.42)	2.36 (±1.07)	0.20	0.6545
Blueberry	0.15 (±0.06)	0.23 (±0.12)	0.08 (±0.05)	1.42	0.2432
Dewberry	0.75 (±0.16)	0.52 (±0.16)	0.99 (±0.27)	3.07	0.0910
Greenbrier	0.55 (±0.21)	0.01 ^{B} (±0.01)	1.09 ^{A} (±0.38)	17.08	0.0003
Muscadine grape	1.01 (±0.22)	0.97 (±0.34)	1.05 (±0.29)	0.12	0.7321
Poison ivy	0.02 (±0.01)	0.02 (±0.01)	0.01 (±0.01)	0.37	0.5467
Sparkleberry	0.01 (±0.00)	0.00 (±0.00)	0.01 (±0.00)	0.40	0.5306
Sumacs	0.49 (±0.22)	0.60 (±0.44)	0.39 (±0.12)	0.02	0.8765
Summer grape	1.19 (±0.73)	0.10 ^{B} (±0.07)	2.28 ^{A} (±1.43)	7.55	0.0106
Wild rose	0.03 (±0.01)	0.03 (±0.02)	0.02 (±0.01)	0.01	0.9152
Total	9.85 (±2.02)	8.15 (±2.17)	11.55 (±3.42)	1.65	0.2092

* species only found in 2015

Table 2-4. Occurrence of soft-mast producing species by number of growing seasons since burn (GSPB 1, 2, 3, and 5) in the Ouachita National Forest of Arkansas and Oklahoma, 2015−2016. Species presence indicated with an ‘X’.

	GSPB 1		**GSPB 2**		**GSPB 3**		**GSPB 5**	
Species	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
Alabama supplejack*		X			X			X
American beautyberry	X	X	X	X	X	X	X	X
American pokeberry*	X							
Black cherry	X	X	X	X	X	X	X	X
Blackberry	X	X	X	X	X	X	X	X
Blackgum	X		X	X	X	X	X	X
Blueberry	X	X	X	X	X	X	X	X
Carolina buckthorn*	X							
Coral berry*			X					
Devil's walkingstick*		X			X			
Dewberry	X	X	X	X	X	X	X	X
Dogwood	X	X	X	X	X	X	X	X
Fragrant sumac		X			X	X		X
Greenbrier	X	X	X	X	X	X	X	X
Hawthorn			X	X	X	X	X	X
Holly*			X		X			
Mulberry*		X			X			
Muscadine grape	X	X	X	X	X	X	X	X
Persimmon*				X				
Plum	X		X	X	X	X	X	X
Poison ivy	X	X	X	X	X	X	X	X
Rusty blackhaw	X	X	X	X	X		X	X
Serviceberry*				X		X		
Smooth sumac	X	X	X	X	X	X	X	
Sparkleberry	X	X	X	X	X	X	X	X
Summer grape		X	X	X	X	X	X	X
Virginia creeper	X	X	X	X	X	X	X	X
White fringetree*		X		X		X	X	X
Wild rose	X	X	X	X	X	X	X	X
Winged sumac	X	X	X	X	X	X	X	X
Total	**19**	**21**	**21**	**22**	**24**	**21**	**20**	**21**

* species occurred in < 25% of surveyed stands

Table 2-5. Mean (± SE) vegetation cover (%) of soft-mast producing species by number of growing seasons since burn (GSPB 1, 2, 3, and 5) in the Ouachita National Forest of Arkansas and Oklahoma, 2015−2016. Dissimilar letters within rows denote differences (α = 0.05) among growing seasons post burn.

	Growing Season Post Burn					
Species	**1**	**2**	**3**	**5**	**$F_{(3,27)}$**	**P**
Alabama supplejack*	0.09 (±0.06)	0.00 (±0.00)	0.07 (±0.05)	0.01 (±0.01)	-	-
American beautyberry	0.18 (±0.13)	1.05 (±0.53)	1.37 (±0.56)	0.22 (±0.16)	2.09	0.1239
American pokeberry*	0.05 (±0.05)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	-	-
Black cherry	0.65 (±0.25)	1.38 (±0.52)	0.86 (±0.49)	0.90 (±0.29)	0.42	0.7391
Blackberry	1.98 (±0.65)	1.91 (±0.36)	3.46 (±1.19)	4.09 (±1.05)	1.24	0.3155
Blackgum	0.57 (±0.57)	0.37 (±0.27)	0.25 (±0.10)	0.16 (±0.10)	0.13	0.9385
Blueberry	1.38 (±0.66)	2.77 (±1.26)	0.34 (±0.24)	0.82 (±0.37)	1.53	0.2283
Carolina buckthorn*	0.12 (±0.12)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	-	-
Coral berry*	0.00 (±0.00)	0.12 (±0.12)	0.00 (±0.00)	0.00 (±0.00)	-	-
Devil's walkingstick*	0.12 (±0.12)	0.00 (±0.00)	0.32 (±0.21)	0.00 (±0.00)	-	-
Dewberry	7.32 (±1.76)	3.54 (±0.86)	7.69 (±0.93)	5.41 (±1.30)	2.3	0.0994
Dogwood	0.35 (±0.28)	0.34 (±0.14)	1.20 (±0.36)	1.25 (±0.51)	1.91	0.1516
Fragrant sumac	0.27 ^{AB} (±0.17)	0.00 ^{B} (±0.00)	0.98 ^{A} (±0.28)	0.33 ^{AB} (±0.24)	4.94	0.0073
Greenbrier	3.13 (±0.80)	4.98 (±1.28)	6.62 (±1.21)	5.80 (±1.35)	2.65	0.0688
Hawthorn	0.00 (±0.00)	0.20 (±0.07)	0.20 (±0.10)	0.09 (±0.06)	2.24	0.1054
Holly*	0.00 (±0.00)	0.05 (±0.05)	0.05 (±0.05)	0.00 (±0.00)	-	-
Mulberry*	0.05 (±0.05)	0.00 (±0.00)	0.10 (±0.09)	0.00 (±0.00)	-	-
Muscadine grape	4.70 (±1.29)	7.53 (±2.19)	6.85 (±1.45)	4.12 (±1.44)	1.01	0.4036
Persimmon*	0.00 (±0.00)	0.02 (±0.02)	0.00 (±0.00)	0.00 (±0.00)	-	-
Plum	0.30 (±0.12)	0.63 (±0.28)	0.67 (±0.39)	0.94 (±0.41)	0.42	0.7426

Table 2-5 Continued

Species	Growing Season Post Burn 1	2	3	5	$F_{(3,27)}$	P
Poison ivy	4.48 ^{B} (±1.71)	5.50 ^{AB} (±1.38)	8.97 ^{AB} (±1.59)	10.66 ^{A} (±2.62)	3.33	0.0343
Rusty blackhaw	0.15 ^{AB} (±0.10)	0.34 ^{AB} (±0.13)	0.01 ^{B} (±0.01)	0.92 ^{A} (±0.41)	4.12	0.0157
Serviceberry*	0.00 (±0.00)	0.01 (±0.01)	0.05 (±0.05)	0.00 (±0.00)	-	-
Sparkleberry	1.55 (±0.46)	1.97 (±0.67)	1.39 (±0.36)	2.38 (±0.62)	0.68	0.5699
Sumac	7.16 (±1.37)	7.12 (±1.84)	7.10 (±0.91)	6.76 (±3.49)	0.37	0.7771
Summer grape	0.56 ^{B} (±0.44)	0.38 ^{B} (±0.18)	2.44 ^{A} (±1.00)	1.43 ^{AB} (±0.59)	3.93	0.0189
Virginia creeper	3.08 (±1.31)	1.07 (±0.29)	2.95 (±0.49)	3.22 (±0.80)	2.04	0.1317
White fringetree*	0.11 (±0.07)	0.05 (±0.05)	0.05 (±0.05)	0.05 (±0.05)	-	-
Wild rose	0.55 (±0.18)	0.51 (±0.24)	0.27 (±0.14)	0.50 (±0.21)	0.22	0.8801
Total	38.89 (±6.66)	41.82 (±5.14)	54.26 (±4.16)	50.05 (±3.83)	27.07	0.0001

* species occurred in < 25% surveyed stands, no analyses due to limited sample size

CHAPTER III.

SITE FACTORS INFLUENCING SOFT-MAST PRODUCTION IN RESTORED OPEN PINE WOODLANDS MANAGED WITH PRESCRIBED FIRE

Abstract

Soft-mast production is a key component of wildlife habitat quality throughout a variety of terrestrial ecosystems, including shortleaf pine (*Pinus echinata*) woodlands in the Ouachita Mountains of Arkansas and Oklahoma. The precise relationship that forest structural characteristics (basal area, canopy cover, burn history, and aspect) and soft-mast production is not fully understood. In this study, I monitored 32 forested stands of similar age and history to identify the structural variables with the greatest impact on soft-mast production (kg ha^{-1}). To capture the majority of soft-mast producing species, I surveyed fruit production within each stand three times (June, July, and August) in the 2015 and 2016 growing seasons. I built *a priori* models using stand- (growing season post burn and number of previous burns) and plot-level (basal area, aspect, canopy cover) predictor variables and evaluated the models using an information theoretic approach. Variables with the greatest influence on overall production included basal area (m^2 ha^{-1}), growing season post burn, aspect, and the number of previous prescribed burns. I found individual species' production was best explained by simple univariate models, indicating production was associated with specific forest structure characteristics. Multivariate models best explained total production. Overall, basal area and aspect, both plot-level variables, had the greatest importance followed by growing season post burn as a stand-level factor. There was an inverse relationship between production and basal area,

95% of total production occurred in plots with basal area ≤20.7 m^2 ha^{-1}. I observed very low production in the 1st growing season following a prescribed fire, which appeared to influence modeling results. Once I removed plots sampled in the 1st growing season, the importance of the burn variables declined. Maintaining a mosaic of forest conditions across the landscape will maximize and prolong soft-mast production and promote species diversity.

Introduction

Soft-mast is an important dietary component for many species of wildlife using forests and woodlands. Preferred vegetation types have greater diversity and abundance of soft-mast producing species (Campo et al. 1989, Clark et al. 1994, McCarty et al. 2002). Vertebrates can consume 50 to 90% of fruit produced in a given year (McCarty et al. 2002); therefore, the importance of soft-mast production to overall habitat quality is difficult to overemphasize. The phenology and maturing of fleshy fruits provide resources during potentially critical times, especially when other food resources (e.g., insects or hard mast) are limited (Clapp 1990, Inman and Pelton 2002, McCarty et al. 2002). Fleshy fruits are typically high in carbohydrates, vitamins, and water (Martin et al. 1951, Halls 1977, Greenberg and Levey 2009) and provide an important high-energy food resource for migratory birds (Blake and Hoppes 1986). Ripe summer and fall fruits are typically consumed quickly, and late fall or winter fruit provide an over-winter food source (Martin et al. 1951, McCarty et al. 2002, McCord et al. 2014). Movement and survival of many wildlife species, including black bears (*Ursus americana*) and eastern wild turkeys (*Meleagris gallopavo silvestris*), are driven by seasonal changes in food (Beeman and Pelton 1980, Quigley 1982, Samson and Huot 1998). Management that promotes new growth and a dense understory along with renewing various food resources (i.e. soft-mast production, insects, and vegetation growth; Yarrow and Yarrow 1998, McCord et al. 2014), creates preferred spring and summer habitats for many species of wildlife, especially game birds (Campo et al. 1989, Miller and Conner 2007).

Soft-mast production is influenced by a variety of forest structural and other characteristics, both natural and human-induced. The most important factors governing soft-mast production are typically canopy coverage, fire, and forest age. Increased production occurs with disturbances that reduce canopy cover and basal area (e.g., fire, silvicultural treatments, gap succession) and allow sunlight to reach the forest floor (Thompson and Willson 1978, Perry et al. 1999, Greenberg et al. 2007, Greenberg et al. 2011). These open forested conditions promote highly productive early successional species (e.g., blackberry [*Rubus* spp.], American pokeberry [*Phytolacca americana*]) until competition becomes too great, typically after 5-7 years, and production declines (Johnson and Landers 1978, Perry et al. 1999, Greenberg et al. 2007). Without additional disturbances, the canopy closes and less light reaches the understory, resulting in decreased fruit production (Johnson and Landers 1978, Greenberg et al. 2007). In the Southern Appalachians, production potential in naturally regenerated stands remained low in intermediate aged forest up to 70 years, at which point natural disturbances (e.g., gap-phase succession) allowed for more sunlight to reach the forest floor (Reynolds-Hogland et al. 2006).

Past research has shown that factors influencing production vary depending on the plant species and various site characteristics. Production in recently disturbed areas is influenced by each species' ability to recover following a disturbance event (Greenberg et al. 2007). Burn history also impacts production. Some species may be eliminated over time without adequate time to recover and re-establish vegetative biomass (above and below ground). For example, American beautyberry (*Callicarpa americana*), common in fire-prone ecosystems, was eliminated after 20 growing season prescribed fires in 37 years in Louisiana longleaf pine stands; whereas, under the same conditions, blackberry and sumac (*Rhus copallinum*) persisted (Haywood et al. 2001). Previous research on the impact of fire regime to understory fruit production within a longleaf pine (*P. palustris*)-wiregrass ecosystems found little to no soft-mast production occurred in forests that are continually managed on a 1 or 2 fire-return interval (Lashley et al. 2017). Disturbance-adapted species, such as blackberry and sumac (*Rhus* spp.), quickly colonize and begin producing within 1 to 3 growing seasons following a disturbance (Martin 1951, Waldrop et al. 1992, Greenberg et al. 2011).

There is an abundance of information about the impacts of silvicultural activity such as timber harvests (e.g., clearcuts, shelterwood, etc.), site preparation, and past land use on soft-mast production (Johnson and Landers 1978, Campo and Hurst 1980, Stransky and Halls 1980, Stransky and Roese 1984, Perry et al. 1999, Perry et al. 2004, Greenberg et al. 2007). However, many of these studies have focused on broad stand-level impacts and have not accounted for the highly variable conditions found within a single forested system. Previous studies have also addressed fruit availability across mature and recently disturbed forest (McCarty et al. 2002, Reynolds-Hogland et al. 2006, Greenberg and Levey 2009); however, these have been concentrated in mature hardwood stands, pine plantations, and recently planted areas. The relationships between production and various forest characteristics are poorly understood in many areas, limiting our ability to design management strategies that optimize soft-mast production.

The influence of forest-stand characteristics within an upland pine (*Pinus* spp.) woodland on soft-mast production is unknown. My objectives were to identify forest structural characteristics that influence soft-mast production by various species in mature open pine woodlands. I examined these questions in the Ouachita National Forest of Arkansas and Oklahoma by quantifying soft-mast production and relating it to various stand structural characteristics at both plot and stand scale. The results will inform managers about effective ways to improve production (e.g., burning, thinning, basal area reduction, canopy reduction) and can be used to maintain viable levels of mast production in areas where habitat quality for target wildlife is an important management goal.

Methods

Study Area

I conducted this study within the Poteau-Cold Springs and Mena-Oden Ranger Districts of west-central Arkansas and the Oklahoma Ranger District of southeast Oklahoma within the Ouachita National Forest (ONF). The Ouachita Mountain range comprises over 3.2 million hectares (approximately 6.6 million acres) in southeastern Oklahoma and west-central Arkansas, with mountain ridges stretching east and west, spanning 150 to 823 meters (500 - 2,700 feet) in elevation (Bukenhofer and Hedrick 1997, Hedrick et al. 2007). Annual mean precipitation in the area ranges between 100 and 150 cm/year (40 to 60 in/year; Foti and Glenn 1991). Temperatures range from -1°C to 11°C (30°F to 52°F) in the winter and 19°C to 34°C (67°F to 94°F) in the summer (Skiles 1981). Bedrock is comprised largely of sandstone and shale, meaning soil groups such as Ultisols, Inceptisols, and Alfisols, are most abundant, especially Ulitisol. Soils are generally sandy, highly weathered, well drained, and acidic with low fertility (Ouachita Ecoregional Assessment 2003, NatureServe 2004).

The Ouachita Mountains are located in the Interior Highlands physiographic region, which is characterized by temperate evergreen and deciduous forests (Foti et al. 1994, Bukenhofer and Hedrick 1997, NatureServe 2004, Hedrick et al. 2007). The east-west orientation of the Ouachita Mountains creates long ridges with north and south facing slopes. The cool, moist, northern facing slopes are dominated by several species of oak (*Quercus* spp.), and shortleaf pine (*Pinus echinata*) typically dominates the dry-xeric, southern and western slopes (Palmer 1924, Foti and Glenn 1991, Guldin 2007). However, both pines and hardwoods are found throughout the forested mountains.

Due to anthropogenic influences in the 19th and 20th centuries, the once prominent pine-bluestem ecosystem declined,including the habitat upon which many species relied upon. This included the endangered red-cockaded woodpecker (*Picoides borealis*; RCW; Masters et al. 2001, Guldin et al. 2004, Hedrick et al. 2007). In the early 1990s, the ONF initiated a large-scale restoration project to re-establish historic forest conditions along with RCW habitat. Restoration efforts increased the use of prescribed fires on the landscape, reduced basal area, and implemented timber harvests using longer rotation ages. Restoration efforts now manage for the historical (pre-1800s) fire regime that typically occurred on a 3 to 5-year interval (Bukenhofer and Hedrick 1997, Guldin et al. 2004, Stambaugh and Guyette 2006).

Shortleaf pine is the dominant overstory species within Arkansas' highland ecosystem (e.g., Ouachita and Ozark mountain ranges; Guldin 1986, Lawson 1990, Hedrick et al. 2007). Various upland hardwood species are associated with shortleaf pine forests and are found throughout the canopy (e.g., *Quercus* spp., *Carya* spp., *Liquidambar styraciflua*) and subcanopy (e.g., *Cornus florida, Diospyros virginiana, Ulmus alata*; Palmer 1924, Eyre 1980, NatureServe 2004).

Primary understory vegetation in the shortleaf pine-bluestem ecosystems contained various species of grasses and forbs (NatureServe 2004). Many woody soft-mast producing species are also common throughout the woodland systems of Arkansas, including American beautyberry, blackberry, grapes (*Vitis* spp.), sumac, and greenbrier (*Smilax* spp.; Grelen and Duvall 1966, NatureServe 2004).

Production surveys

I surveyed soft-mast production in 32 shortleaf pine woodlands in June, July, and August of 2015 and 2016 (16 stands per year). Stands were selected based on information provided by the USDA Forest Service (Southern Research Station and ONF) biologists and foresters (Figure 3-1). All stands were located primarily on southern aspects (S, SW, or SE) in areas that had received at least two previous dormant season prescribed burns and had an overstory basal area between 13.8 to 18.4 m^2 ha^{-1} (60-80 ft^2 ac^{-1}). Stands were established at least 70 years ago, received wildlife stand improvement treatments between 5 and 26 years prior to sampling, and represented four temporal periods after an application of a dormant season prescribed fire: 1) one, 2) two, 3) three, and, 4) five growing seasons post-burn (GSPB or “burn year”). The earliest initial prescribed burn on a study stand occurred in 1992 and the most recent initial burn was in 2010 Thus, any given stand had a burn history of between 7 and 21 years.

I randomly placed six to eight survey transects within each stand and systemically placed 40 plots along those transects. I used the fishnet tool from Arc Toolbox in ArcMap 10.3.1 to create a 25-m by 15-m grid over each stand. The chosen grid spacing represents the minimal distance between transects (25-m) and plots (15-m) needed. Using the preset attributes, I separated grid lines into horizontal and perpendicular lines based on the assigned numbers. Utilizing a random number generator, I selected the starting location (intersections of two lines) and direction of each transect. Prior to transect and plot placement, I created a 50-m buffer zone around hard edges or edges adjacent to structurally different forests (e.g., roads and clearcuts) and a 15-20 m buffer around soft edges and structurally similar forests (e.g., streams, wildlife ponds, and RCW clusters). I used a handheld Garmin eTrex Legend H unit to navigate, locate, and mark plots once in the field.

Soft-mast surveys. I surveyed a total of 1,280, 3m x 3m (0.0009 ha) plots. To best follow maturing patterns of primary summer soft-mast producers, I sampled plots three times: once each in early June, early July, and mid-August. I counted all soft-mast fruits within the plots up to 2 m in height, including green fruit and fruits that appeared to have been removed by herbivory. Survey methods followed Perry et al. (1999, 2004). While other methods can be used to predict understory fruit biomass production, such as plant coverage and stem density, manually counting fruit at each plot provides more accurate results while requiring less time to evaluate the area (Lashley et al. 2014). When possible, I counted fruits individually, as with single drupes or berries (e.g., blackberry, dewberry (*Rubus flagellaris*), and grapes [*Vitis* spp.]). I used a volume to mass regression equation for large, compact fruit heads (e.g., sumac) to relate fruit mass to cluster volume. American beautyberry produces numerous clusters per plant, with between 19 and 49 berries per cluster. If a plot contained more than 50 American beautyberry clusters, I estimated fruit production by multiplying the number of clusters on each plant by the average cluster count for that plant based on 10 cluster subsamples. This process was repeated for each plant within the plot and totals were combined to find total production per plot. To avoid double counting of fruits in multiple surveys, I used the highest monthly count for a given species to represent production for that species.

Mass estimation. To estimate fruit mass, I collected representative samples from each species based on availability and opportunity in each stand. I used a Fisher Scientific Isotemp oven to dry samples at 65^{o}C until samples reached a constant mass. I weighed dried fruits (with seeds) to the nearest 0.01g, and used species-specific conversion factors to estimate total mass produced by species. I conducted all analyses on dry mass production per unit area (kg ha^{-1}).

For analyses, I grouped congeneric species that have similar wildlife use —such as winged and smooth sumac (hereafter sumac), and sawtooth (*Smilax* *bona-nox*), lanceleaf (*S. smallii*), cat (*S. glauca*), and roundleaf (*S. rotundifolia*) greenbrier (hereafter greenbrier). I conducted analyses on total observed dry soft-mast production (hereafter production) and on individual species that together contributed 95% of the total production. I combined the remaining species that fell under the 95% threshold for analyses (hereafter Other).

Stand structure characteristics

I measured the following plot-level variables at each plot location: total BA, pine BA, hardwood BA, and canopy closure. I used a 10 basal area factor prism to estimate BA and a standard limiting distance equation based on the prism factor (0.33 cm per centimeters of diameter at breast height) for borderline trees. Aspect was determined using a compass. Before analyses, I transformed aspect bearings using Beers et al. (1966) solution of A'=cos(45-A)+1, (A=aspect). Using a spherical densiometer, I estimated the overstory canopy closure, using the mean of four readings, one in each of the cardinal directions at the plot center. I used the information provided by the USDA Forest Service (Southern Research Station) to determine the burn history of each forest, which I recorded at stand-level. Burn history includes the burn year and the number of previous burns at each stand.

Data analysis

I used general linear models (GLM) and mixed effects models to evaluate the effects of various structural characteristics on soft-mast production. Dry soft-mast production was the response variable. Fixed effects included various covariates at the stand (burn year, number of previous burns) and plot (aspect, BA, canopy closure) level. To reduce collinearity between predictor variables, I used the Pearson's correlation coefficient (r) to eliminate highly correlated variables ($r < 0.6$). I determined a high correlation among the total, pine, and hardwood BA; therefore, I used total BA (hereafter BA) for model construction.

I used 5 predictor variables (aspect, burn year [i.e. GSPB], number of previous burns, total BA, and canopy closure) for *a priori* model construction. I used an information-theoretic approach to build and rank models containing covariates (fixed effects) relating to the stand and plot-level predictor variables (Table 3-1). I formulated candidate models based on available literature over plant-species habitat requirements (Burnham and Anderson 2002). Along with a global model, I created a set of 10 multivariate (M01-M10) and 5 univariate (U01-U05) candidate (*a priori*) models (Appendix 1, 2). I built multivariate models to capture a range of forest structure characteristics and scale-level variables and used the same set of models on all top producing species and total production.

I transformed production (response variable) values to improve normality using a log transformation (log[x+1]; Perry et al. 1999, Zar 1999), but report nontransformed values throughout. Due to the high proportion of true zeros (≥55%) normality was not achieved. However, I compared all models under the same conditions, allowing the high proportion of zeros to impact all the models equally (Burnham and Anderson 2002). I used PROC MIXED in SAS (v.9.2 SAS Institute., Cary, North Carolina) to perform analyses using Kenward-Rogers method to determine the denominator degrees of freedom (Littell et al. 2006). I accounted for variations in soil, rainfall, and fire intensity by established 3 additional categorical variables as random effects: stand number (1 to 32), field year (2015 and 2016), and transect number.

I ranked candidate models using Akaike's Information Criterion (AIC). Due to the large sample size (ratio of n/K > 40 [total sample size/number of parameters of the global model]), use of the corrected AIC (AIC_c) was not necessary (Burnham and Anderson 2002). Models with ΔAIC ($\Delta_i = AIC_{gi} - AIC_{min}$) of ≤2.0 were considered plausible (Burnham and Anderson 2002). To find the probability that i^{th} model is the best model, I calculated an Akaike weight (ω_i) for all candidate models (Burnham and Anderson 2002). I determined the relative importance of each variable by summing the weights ($\sum\omega_i$) of all models in which the variable occurred (Burnham and Anderson 2002).

After initial analyses on the full dataset (n=1,280 plots), I determined that there was extremely low production in the 1st burn year that may have affected the observed results. Therefore, I removed plots within the 1st burn year and re-ran all models using the reduced dataset (n=960) to assess factors affecting production without the impact of the low overall production in the 1st burn year. I analyzed the reduced datasets using the same candidate models.

Results

Production

Total production of all species ranged from 0.0 to 54.2 kg ha^{-1} ($\bar{x}$ = 9.9 kg ha^{-1}) with 7 species comprising over 97.7% of the total production (Appendix III, IV). Overall, stands in the 1st burn year contributed approximately 1% of the mean total production. As the highest producer with 36% of the total production, American beautyberry's production ranged from 0.0 to 22.3 kg ha^{-1} ($\bar{x}$ = 4.7 kg ha^{-1}). Together, blackberrry (2nd highest – 21%) and dewberry (5th highest – 8%) comprised 29% of the total production and ranged from 0.0 to 17.1 kg ha^{-1} ($\bar{x}$ = 1.9 kg ha^{-1}) and 0.0 to 3.0 kg ha^{-1} ($\bar{x}$ = 0.8 kg ha^{-1}), respectively. As the 3rd and 4th highest producing speices, summer grape (*Vitis aestivalis*; 12%) ranged from 0.0 to 23.2 kg ha^{-1} ($\bar{x}$ = 1.2 kg ha^{-1}) and muscadine grape (*V. rotundifolia*; 10%) ranged from 0.0 to 5.0 kg ha^{-1} ($\bar{x}$ = 1.0 kg ha^{-1}). Greenbrier comprised 6% of total production with 0.0 to 5.3 kg ha^{-1} ($\bar{x}$ = 0.6 kg ha^{-1}) and sumac produced 5% of the total production and ranged from 0.0 to 7.2 kg ha^{-1} ($\bar{x}$ = 0.5 kg ha^{-1}). I grouped the remaining species to form "Other" which comprised less than 2.3% of the total production. Species in Other included: blueberry (*Vaccinium* spp.), wild rose (*Rosa* spp.), poison ivy, sparkleberry, black cherry (*Prunus serotina*), and American pokeberry.

Stand structural characteristics

Basal area (m^2 ha^{-1}) and overstory canopy closure (% closure) varied considerably among plots, even within a given stand. Overall, overstory canopy coverage ranged from 3.5% to 96.6% among stands with a mean coverage of 61.2% (SE ± 0.05%). Basal area ranged from 0.0 to 50.51 m^2 ha^{-1} with mean 16.4 m^2 ha^{-1} (SE ± 0.5). Approximately 48% of all sample plots had a BA that fell within the target BA (13.77 -18.37 m^2 ha^{-1}) for the study stands. Plot-level variation in aspect also occurred, but there was less variation compared to other plot-level variables. The majority (83.4 %) of the plots I surveyed were located on a southern facing aspect (e.g., SE, S, SW); however, 9.7% occurred on a northern aspect (e.g., NE, N, NW), and another 4.5% had a predominant western aspect (e.g., WSW, W, WNW).

Stand-level impacts such as the number of previous burns and burn year sample (i.e., burn year) remained consistent within stands. Approximately 59% of the stands I sampled had received 4 or 5 dormant season prescribed burns; 25% had received 2 to 3 burns, and the remaining 15% of stands had a history between 6 and 10 burns. Removing the 1st burn year resulted in minor differences in the overall burn history, approximately 67% and 8% of stands received 4 to 5 and 6 to 10 burns, respectively. An equal number of plots (320 of 1,280 plots) represented each burn year (1, 2, 3, and 5); this proportion remained constant in both datasets.

Modeling results

As expected, there was low production in the 1st burn year. In both, full and reduced datasets, a large number of sample plots with zero production led to underfitted models. Herbaceous species are first to occupy an area after a disturbance, and many woody species will not start producing until the following year (Hodgkins 1958, Waldrop et al. 1992). I determined true zeros populated approximately 59% (750 of 1,280 plots) and 46% (441 of 960 plots) of plots for total production in the full and reduced datasets, respectively. However, I compared all species models under the same conditions, allowing the high proportion of zeros to impact all the models equally (Burnham and Anderson 2002).

Simplistic models best explained individual species' production, and more complex multivariate models best explained total production. This trend occurred in the full (Table 3-2) and reduced datasets (Table 3-3). With the full dataset, total production was explained by two equally plausible multivariate models, M10 (GSPB & BA) and M07 (GSPB & BA & Previous Burns). In the reduced dataset, models M07 and M10 appeared along with two additional multivariate models M01 (GSPB & BA & Aspect) and M06 (GSPB & BA & Previous Burns) and one univariate model U03 (BA). Model U03 received the lowest AIC and is 1.7 to 2.3 times more plausible than the other multivariate models in the reduced dataset.

Of the 5 variables I measured, all but canopy closure had an impact on production, either in a univariate model or as part of a multivariate model. Within the 7 species I analyzed, the top best-fit models for American beautyberry, sumac, greenbrier, and summer grape remained consistent between the full and reduced dataset. Overwhelmingly, univariate models were ranked highest for individual species production (Table 3-2; Table 3-3). Blackberry was the only exception in the full dataset, where production was best explained in three equally plausible (Δ AIC ≤ 2) models M10 (GSPB& BA), M07 (GSPB& BA& Previous Burns) and U03 (BA; Table 3-2). However, in the reduced dataset, blackberry only had U03 as the top model (Table 3-3).

In both the full and reduced datasets, BA had the greatest influence on production. Overall, I determined that 44% of all production occurred within the target BA (13.8 m^2 ha^{-1} to 18.4 m^2 ha^{-1}) and many of the top producing species reached peak production ± 2.3 m^2 ha^{-1} of the target BA. Production was negatively correlated with BA (Table 3-4; Table 3-5) and 96% of production occurred in plots with BA <20.7 m^2 ha^{-1}, 73% of plots occurred within this BA range. Plots with BA ≤ 18.4 m^2 ha^{-1} produced 12.3 times more soft-mast than stands with BA > 18.4 m^2 ha^{-1}. BA also had the highest relative importance ($\omega_{i+}[j]$) in the majority of candidate model sets, including sumac, blackberry, and summer grape production (Table 3-4; Table 3-5). Both sumac and summer grape production were 25% to 50% greater when BA was ≤ 9.2 m^2 ha^{-1}: 12% of plots occurred within this BA range. Blackberry production was also greater with less BA, however production was sustained under a larger BA range until production sharply declined once BA exceeded 20.7 m^2 ha^{-1}.

Burn year was positively correlated to production in both datasets. However, the overall relative importance of burn year was considerably less in the reduced dataset (Table 3-4; Table 3-5). High relative importance in the full dataset is likely due to the very low production I measured in the 1st burn year. This suggests that in the reduced dataset, production was similar across the remaining growing seasons (2nd, 3rd, and 5th). Burn year influenced dewberry, greenbrier, and muscadine grape production. In the reduced dataset, other variables (i.e., previous burns and aspect) impacted dewberry and muscadine grape production; however, greenbrier production was best explained by burn year in both datasets at similar relative importance (Table 3-6; Table 3-7). For all three species, over 98% of their total production occurred after the 1st burn year, with the 3rd burn year responsible for over 46% of production. Dewberry had similar production levels in the 2nd and 5th burn year; however, greenbrier and muscadine grape production in the 3rd and 5th burn year was similar.

Aspect and number of previous burns represent different spatial scales; however, the occurrence of both factors in highly ranked models increased in the reduced dataset (Table 3-3). This was especially true for dewberry and muscadine grape; however, the influence varied by species (Table 3-5).

Muscadine grape production was 1.3 times greater on plots located within a southern or eastern aspect, and 59.7% of dewberry production occurred on plots without predominant southern aspects. Both dewberry and muscadine had greater production in stands with 4 and 10 previous burns. However, aspect and number of previous burns only became important predictor variables in the reduced dataset. Aspect remained the most important variable for American beautyberry in both datasets, and production was 17.6 times greater on plots with southern aspects (Table 3-6; Table 3-7).

Discussion

Results suggest that plot-level variations in the forest structure, such as BA and aspect, have the greatest influence and predictive power for total soft-mast production within the ONF. However, effects of plot-level and stand-level characteristics varied by individual species, and even between congeneric species. For example, plot-level factors had the greatest influence on American beautyberry, sumac, blackberry, and summer grape production; whereas, production by greenbrier, muscadine grape, and dewberry was more impacted by stand-level factors.

American beautyberry, blackberry, sumac, muscadine grape, dewberry, greenbrier, and summer grape range from shade tolerant to shade intolerant (Halls 1977). A negative correlation between production quantity and competition is well documented for all of these species (Martin 1951, Halls 1973, Halls 1977). Changes in BA, even at a micro-habitat level, will promote or suppress the vegetation and fruit production for blackberry, sumac, and summer grape. Large variations in BA occurred among plots, regardless of proximity, and these changes in canopy primarily dictated production value within each plot.

Aspect was the most important factor for American beautyberry. Production was greatest in plots located between a southeast to southwest aspect, and minimal fruiting occurred on plots with a predominant northern aspect. Due to the east-west orientation of the mountain range, southern aspects have increased exposure to solar radiation with more xeric conditions and rocky soils (Foti and Glenn 1991, Guldin 2007). Increased sunlight, along with current management practices, promote species that commonly establish in sunny, recently disturbed areas. These species decline as competition increases and areas become more shaded (Martin et al. 1951, Hodgkin 1958, Core 1974, Halls 1977, Greenberg et al. 2011). Under current conditions in restored shortleaf-pine woodlands of the ONF, American beautyberry was the highest producing species (see Chapter II). After accounting for the low production in the 1st burn year, aspect also influenced muscadine grape and dewberry production. Both species fruited in plots located in a wide range of aspects; however, production was lower in plots with a predominant northern aspect.

In general, my results suggest production was greater in plots where BA did not exceed 13.8 m^2 ha^{-1}; however, more shade-tolerant species, such as American beautyberry, continued to produce until BA reached 18.4 m^2 ha^{-1}. Plots located between southern and western aspects had a higher BA threshold; this occurred for both American beautyberry and blackberry. Several species, including greenbrier and muscadine grape, had minor production after BA exceeded 20.7 m^2 ha^{-1} and dewberry continued to fruit until BA of 34.4 m^2 ha^{-1} was reached.

Although plot-level factors had some influence, burn history (burn year and number of previous burns) had the greatest impact on greenbrier, muscadine grape, and dewberry production. Burn year is of particular importance for greenbrier production, as the majority of production occurred in the 3rd and 5th burn year. The influence of burn year and the number of previous burns are closely tied to a species' ability to recover after a disturbance. Top-killing or removing aboveground vegetation causes many woody soft-mast species to forgo fruiting because energy is instead used for vegetative growth (Harlow and Van Lear 1989). The relationship between time since disturbance and production has been observed previously, and many early successional or disturbance-adapted species require a minimum recovery time of 1 to 2 years before producing (Johnson and Landers 1978, Harlow and Van Lear 1989, Reynolds-Hogland et al. 2006). Because the impact of fire on the landscape is spatially heterogenous, a patchy understory is created within the forest following a fire event (Cain et al. 1998, Greenberg et al. 2011). These variations in fire intensity were evident among burn years and sampled stands. Although stands are typically prescribed burned as a single unit, fire intensity and impacts vary due to micro-topographical changes within the stand. Therefore, the vegetation within a stand burns unevenly, creating a mosaic pattern within forested stands. Previous studies have indicated that soft-mast production was greatest on patches that were missed by previous fires (Lashley et al. 2017). This also may have affected my observation, as production was spatially patchy among stands with similar management history.

Excluding greenbrier, the influence of burn year on individual species and total production was reduced after removing the 1st burn year from my analyses, suggesting that after topkill, species were able to fully recover and produce at similar quantities across the 2nd, 3rd, and 5th burn year. Also, eliminating plots surveyed in the 1st burn year reduced potential biases due to the low production, which allowed the influence of plot-level factors, such as BA and aspect on species production, to be seen more distinctly.

Disturbances that alter the forest canopy at either a stand- (timber harvest or thinning) or plot-level (gap succession, single tree openings) stimulate production (Halls 1977, Thompson and Willson 1978, Blake and Hoppes 1986, Greenberg et al. 2011). Understanding how spatial-scale variations in the forest structure and site characteristics impact individual species differently provide insights into the factors that drive individual species production. Variables that impacted production differed, even among congeneric species. For example, stand-level variables had the greatest impact on muscadine grape (*Vitis rotundifolia*) and dewberry (*Rubus flagellaris*) production, while fine-scale changes in the micro-habitat had the greatest influence on summer grape (*Vitis aestivalis*) and blackberry (*Rubus* spp.) production. Not all species were equally impacted by variation in the overstory, but many soft-mast producing species have greater production in areas where more sunlight is available (Halls 1973, Sharp 1974, Halls 1977).

Young or recently disturbed forest conditions especially facilitate more production than mature closed canopy forests (Perry et al. 2004, Reynolds-Hogland et al. 2006, Greenberg et al. 2007). At the stand level, the shortleaf pine forest structure is maintained with regular, dormant season prescribed burns; therefore, many of the species present are fire-adapted (Sharp 1974, Waldrop et al. 1992, Cain et al. 1998). As disturbance driven species, blackberry and sumac easily germinate and establish through seeds or re-sprout from root systems (Halls 1977, Waldrop et al. 1992); however, they are unable to compete and will decline once overtopped by other vegetation (Halls 1977, Greenberg et al. 2011). Although summer grape is not typically associated with disturbances, I found the species' response to be closely aligned with that of disturbance-dependent species due to the important relationship between sunlight availability and fruit production (Shutts 1974, Trimble and Tryon 1979). Muscadine grape is not typically associated with frequently disturbed pine-uplands, but it is found most often in moist shady woodlands, bottomlands, and ravines (Halls 1977, Hunter 2004, Greenberg et al. 2011). However, my results suggest that muscadine grape can persist and fruit in the understory after 21 years of dormant season prescribed fire on a 3 to 5-year rotation. The long-term implementation of frequent prescribed fires helps maintain an open understory (Cain et al. 1998).

Over time, a decline in vertical cover occurs, but woody stems are rarely eliminated as rootstocks are protected below ground, especially from low-intensity dormant season burns (Stransky and Halls 1979, Cain et al. 1998). This promotes highly productive woody shrubs and vines (Waldrop et al. 1992, Sparks et al. 1998) that many wildlife species depend on for cover and food (Martin et al. 1951).

Many studies have only addressed the impact of production at a stand level by grouping or averaging production across each stand, and not addressing the fine or plot-level variations which may dictate production potential. Previous studies have focused on production following silvicultural disturbance or single tree opening; however, production under historic forest conditions and the influence of the structural characteristics was unclear. Reducing the overstory basal area (i.e., harvesting) alone has been found to increase soft-mast production for 4-6 years (Johnson and Landers 1978, Perry et al. 1999, Greenberg et al. 2007). However, these disturbances tend to have a considerable impact on overstory basal area (i.e., stand-replacing or stand altering) compared to burning alone. Silvicultural treatments, such as site preparation, can highly disturb the soil which destroys the root systems of pre-established woody species. This can delay production and prolong recovery especially for re-sprouting species (Campo and Hurst 1980, Stransky and Halls 1980, Stransky and Roese 1984).

Production will vary within a stand and if some general guidelines are followed the specific stand-level management decisions may not be that critical. Frequent and continual understory disturbances, along with an open overstory will create ideal conditions for production. Individual species soft-mast production is the result of several influential factors which occur at the plot or micro-habitat scale. Maintaining a range of BA and accounting for the impact of aspect on production will benefit total production within a forest stand. Resetting succession at a stand-level, either by prescribed fire or silvicultural practices, will promote early to mid-successional soft-mast species found in the understory of many open pine forests, such as the ONF.

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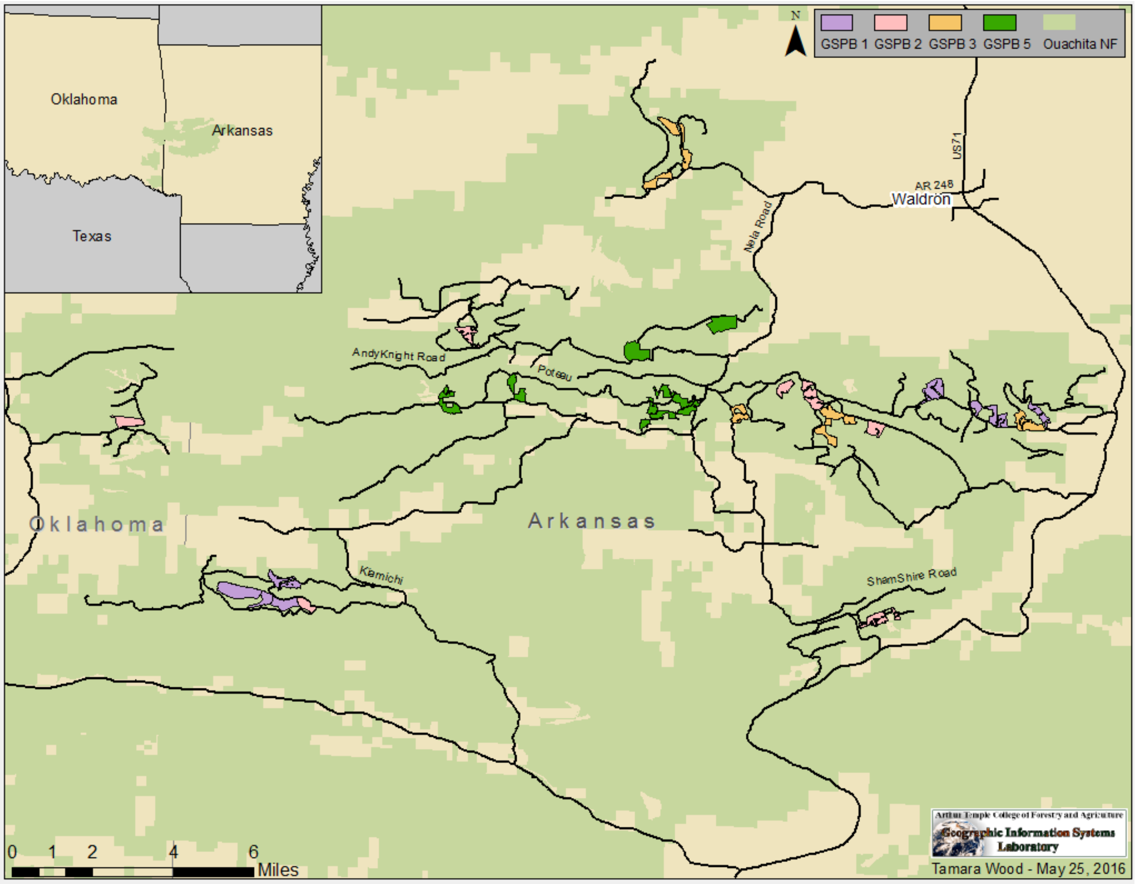

Figure 3-1. Location of stands surveyed for soft-mast production in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma. Study stands were 1 (purple), 2 (pink), 3 (orange), or 5 (green) growing seasons since most recent season prescribed fire.

Table 3-1. Plot and stand-level predictor variables used to build candidate models to identify the impact of various forest structural characteristics on soft-mast production in the Ouachita National Forest or Arkansas and Oklahoma, sampled in 2015-2016.

Level	**Variables**	**Abbreviation**
Stand	Growing Seasons Post Burn (no.)	GSPB
	Number of past burns (no.)	P.Burn
Plot	Total Basal Area (m^2 ha^{-1})	BA
	Canopy Closure (%)	Canopy
	Aspect (bearings)	Aspect

Table 3-2. Summary of soft-mast production models using the full dataset (all growing seasons [burn years] sampled). Production surveys were completed in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma. Only plausible models are shown (ΔAIC ≤ 2), Akaike weight (ω_i) is the relative likelihood of model given full dataset, and model likelihood $\mathcal{L}(g_i|x)$ versus other models within species.

Species	**Model**		**K**	**AIC**	**Δ AIC**	**Akaike weight** (ω_i)	**Model likelihood** $\mathcal{L}(g_i\|x)$
American beautyberry	U02	Aspect	1	1056.8	0.00	0.60	1.00
Other	U02	Aspect	1	-1412.2	0.00	0.57	1.00
	U05	P.Burn	1	-1410.7	1.50	0.27	0.47
Sumac	U03	BA	1	-674.1	0.00	0.82	1.00
Blackberry	M10	GSPB, BA	4	704.4	0.00	0.40	1.00
	M07	GSPB, BA, P.Burn	5	704.6	0.20	0.36	0.90
	U03	BA	1	706.3	1.90	0.16	0.39
Dewberry	U01	GSPB	3	77.4	0.00	0.94	1.00
Greenbrier	U01	GSPB	3	-570.2	0.00	0.51	1.00
Summer grape	U03	BA	1	-493.1	0.00	0.89	1.00
Muscadine grape	U01	GSPB	3	123.2	0.00	0.90	1.00
Total	M07	GSPB, BA, P.Burn	5	2052.5	0.00	0.40	1.00
	M10	GSPB, BA	4	2052.5	0.00	0.40	1.00

Table 3-3. Summary of soft-mast production models using the reduced dataset (without the 1st growing season [burn year] sampled). Production surveys were completed in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma. Only plausible models are shown ($\Delta AIC \leq 2$), Akaike weight (ω_i) is the relative likelihood of model given reduced dataset, and model likelihood $\mathcal{L}(g_i|x)$ versus other models within species.

Species	**Model**		**K** (reduced)	**AIC**	**Δ AIC**	**Akaike weight** (ω_i)	**Model likelihood** $\mathcal{L}(g_i\|x)$
American beautyberry	U02	Aspect	1	1013.7	0.00	0.87	1.00
Other	U02	Aspect	1	-796.1	0.00	0.48	1.00
	U05	P.Burn	1	-794.8	1.30	0.25	0.52
	U01	GSPB	2	-794.2	1.90	0.19	0.39
Sumac	U03	BA	1	-236.0	0.00	0.68	1.00
Blackberry	U03	BA	1	795.9	0.00	0.72	1.00
Dewberry	U02	Aspect	1	318.1	0.00	0.36	1.00
	U05	P.Burn	1	318.1	0.00	0.36	1.00
	U01	GSPB	2	318.8	0.70	0.25	0.70
Greenbrier	U01	GSPB	2	-154.1	0.00	0.52	1.00
Summer grape	U03	BA	1	-94.2	0.00	0.76	1.00

Table 3-3 Continued

Species		**Model**	**K** (reduced)	**AIC**	**Δ AIC**	**Akaike weight** (ω$_i$)	**Model likelihood** $\mathcal{L}(g_i \mid x)$
Muscadine grape	U02	Aspect	1	366.0	0.00	0.42	1.00
	U01	GSPB	2	366.9	0.90	0.27	0.64
	U05	P.Burn	1	367.5	1.50	0.20	0.47
Total	U03	BA	1	1783.0	0.00	0.30	1.00
	M07	GSPB, BA, P.Burn	4	1784.0	1.00	0.18	0.61
	M10	GSPB, BA,	3	1784.1	1.10	0.17	0.58
	M01	GSPB, Aspect, BA,	4	1784.5	1.50	0.14	0.47
	M06	GSPB, Aspect, BA, P.Burn	5	1784.7	1.70	0.13	0.43

Table 3-4. Summary table for production top model (ΔAIC ≤ 2) by species with the estimation values used to indicate relationship (larger absolute values indicate variable influence) and 95% confidence interval within the full dataset (all growing seasons [burn years] sampled). Production surveys conducted in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma.

Species	**Variable**	**Estimate**	**Standard error**	**95% CI**	
				Upper	**Lower**
American Beautyberry					
U02	Aspect	-0.0454	0.0183	-0.0095	-0.0813
Other					
U02	Aspect	0.0063	0.0070	0.0200	-0.0073
U05	P.Burn	-0.0020	0.0045	0.0068	-0.0108
Sumac					
U03	BA	-0.0053	0.0010	-0.0034	-0.0072
Blackberry					
M10	GSPB	.	.	.	.
	1	0.1404	0.0776	0.2926	-0.0118
	2	0.2019	0.0776	0.3539	0.0499
	3	0.2628	0.0775	0.4146	0.1109
	5	0.3074	0.0378	0.3815	0.2333
M10	BA	-0.0078	0.0017	-0.0045	-0.0111
M07	GSPB	.	.	.	.
	1	0.2623	0.0854	0.4297	0.0949
	2	0.3062	0.0840	0.4709	0.1415
	3	0.4128	0.0892	0.5877	0.2379
	5	0.3996	0.0484	0.4944	0.3048
M07	BA	-0.0078	0.0017	-0.0045	-0.0110
M07	P.Burn	-0.0262	0.0092	-0.0082	-0.0442
U03	BA	-0.0086	0.0017	-0.0052	-0.0119
Dewberry					
U01	GSPB	.	.	.	.
	1	0.0033	0.0689	0.1384	-0.1319
	2	0.0931	0.0690	0.2282	-0.0421
	3	0.1704	0.0689	0.3055	0.0353
	5	0.1025	0.0313	0.1638	0.0412

Table 3-4 Continued

Species	Variable	Estimate	Standard error	95% CI	
				Upper	Upper
Greenbrier					
U01	GSPB	.	.	.	.
	1	0.0000	0.0563	0.1103	-0.1103
	2	0.0082	0.0563	0.1185	-0.1021
	3	0.0612	0.0563	0.1715	-0.0491
	5	0.0672	0.0339	0.1336	0.0008
Summer grape					
U03	BA	-0.0035	0.0010	-0.0015	-0.0055
Muscadine grape					
U01	GSPB	.	.	.	.
	1	0.0012	0.0397	0.0790	-0.0766
	2	0.0604	0.0397	0.1382	-0.0174
	3	0.1051	0.0397	0.1829	0.0273
	5	0.0616	0.0164	0.0939	0.0294
Total					
M07	GSPB	.	.	.	.
	1	0.5349	0.1924	0.9120	0.1578
	2	0.8325	0.1887	1.2023	0.4627
	3	1.1227	0.2010	1.5167	0.7287
	5	0.9261	0.1054	1.1327	0.7195
M07	BA	-0.0169	0.0028	-0.0113	-0.0225
M07	P.Burn	-0.0428	0.0215	-0.0006	-0.0849
M10	GSPB	.	.	.	.
	1	0.3269	0.1637	0.6477	0.0061
	2	0.6564	0.1634	0.9767	0.3361
	3	0.8718	0.1634	1.1920	0.5516
	5	0.7716	0.0769	0.9223	0.6209
M10	BA	-0.0166	0.0029	-0.0109	-0.0222

Table 3-5. Summary table for production top model (ΔAIC ≤ 2) by species with estimation values used to indicate relationship (larger absolute values indicate variable influence) and 95% confidence interval within the reduced dataset (without 1st growing season [burn year] sampled). Production surveys conducted in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma.

Species	**Variable**	**Estimate**	**Standard error**	**95% CI**	
				Upper	**Lower**
American Beautyberry					
U02	Aspect	-0.0656	0.0227	-0.0210	-0.1102
Other					
U02	Aspect	0.0052	0.0088	0.0225	-0.0122
U05	P.Burn	-0.0010	0.0055	0.0098	-0.0117
U01	GSPB	.	.	.	.
	2	0.0528	0.0365	0.1243	-0.0188
	3	0.0169	0.0365	0.0885	-0.0546
	5	0.0352	0.0151	0.0648	0.0056
Sumac					
U03	BA	-0.0759	0.0014	-0.0732	-0.0786
Blackberry					
U03	BA	-0.0115	0.0023	-0.0069	-0.0160
Dewberry					
U02	Aspect	0.0208	0.0161	0.0522	-0.0107
U05	P.Burn	0.0184	0.0120	0.0419	-0.0051
U01	GSPB	.	.	.	.
	2	0.0932	0.0811	0.2521	-0.0657
	3	0.1705	0.0811	0.3293	0.0116
	5	0.1026	0.0383	0.1776	0.0276
Greenbrier					
U01	GSPB	.	.	.	.
	2	0.0082	0.0669	0.1393	-0.1229
	3	0.0612	0.0669	0.1923	-0.0699
	5	0.0672	0.0435	0.1524	-0.0180
Summer grape					
U03	BA	-0.0047	0.0014	-0.0020	-0.0075

Table 3-5 Continued

Species	Variable	Estimate	Standard error	95% CI	
				Upper	Lower
Muscadine grape					
U02	Aspect	0.0021	0.0151	0.0317	-0.0275
U01	GSPB	.	.	.	.
	2	0.0604	0.0458	0.1502	-0.0294
	3	0.1051	0.0458	0.1949	0.0153
	5	0.0616	0.0190	0.0988	0.0244
U05	P.Burn	0.0001	0.0070	0.0138	-0.0137
Total					
U03	BA	-0.0218	0.0039	-0.0141	-0.0295
M07	BA	-0.0221	0.0039	-0.0145	-0.0296
	GSPB	.	.	.	.
	2	0.9541	0.2191	1.3835	0.5247
	3	1.2588	0.2368	1.7229	0.7947
	5	1.0375	0.1283	1.2890	0.7860
	P.Burn	-0.0519	0.0272	0.0013	-0.1052
M10	BA	-0.0218	0.0039	-0.0141	-0.0295
	GSPB	.	.	.	.
	2	0.7429	0.1866	1.1087	0.3771
	3	0.9566	0.1865	1.3222	0.5910
	5	0.8523	0.0918	1.0323	0.6723
M01	BA	-0.0219	0.0039	-0.0142	-0.0296
	GSPB	.	.	.	.
	2	0.7644	0.1802	1.1177	0.4111
	3	0.9930	0.1798	1.3453	0.6407
	5	0.8913	0.0902	1.0681	0.7145
	Aspect	-0.0742	0.0350	-0.0057	-0.1428
M06	BA	-0.0221	0.0039	-0.0146	-0.0297
	GSPB	.	.	.	.
	2	0.9589	0.2102	1.3709	0.5469
	3	1.2712	0.2266	1.7153	0.8271
	5	1.0612	0.1235	1.3033	0.8191
	P.Burn	-0.0480	0.0259	0.0027	-0.0987
	Aspect	-0.0716	0.0348	-0.0035	-0.1397

Table 3-6. Summary of the Summed Akaike weights ($\Sigma(\omega_i+(j))$ and the relative importance of the explanatory variable (j_j) for species soft-mast production based on the full dataset (all growing season [burn years] sampled). Production surveys conducted in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma.

Species	**Variable** (j_j)	**Sum Akaike weight** $\Sigma(\omega_i+(j)$
American Beautyberry		
	Aspect	0.6381
Other		
	Aspect	0.5737
	P.Burn	0.2717
Sumac		
	BA	0.9729
Blackberry		
	GSPB	0.7999
	BA	0.9982
	P.Burn	0.4225
Dewberry		
	GSPB	0.9427
Greenbrier		
	GSPB	0.5231
Summer grape		
	BA	0.9296
Muscadine grape		
	GSPB	0.9116
Total		
	GSPB	0.9999
	BA	1.0000
	P.Burn	0.4993

Table 3-7. Summary of the Summed Akaike weights ($\Sigma(\omega_i+(j))$) and the relative importance of the explanatory variable (j_j) for species soft-mast production based on the reduced dataset (without 1st growing season [burn year] sampled). Production surveys conducted in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma.

Species	**Variable** (j_j)	**Sum Akaike weight** $\Sigma(\omega_i+(j))$
American Beautyberry		
	Aspect	0.8948
Other		
	Aspect	0.4819
	P.Burn	0.2523
	GSPB	0.1872
Sumac		
	BA	0.9843
Blackberry		
	BA	0.9996
Dewberry		
	Aspect	0.3591
	P.Burn	0.3607
	GSPB	0.2548
Greenbrier		
	GSPB	0.5414
Summer grape		
	BA	0.8622
Muscadine grape		
	Aspect	0.4206
	GSPB	0.2708
	P.Burn	0.1998
Total		
	BA	1.0000
	GSPB	0.6186
	P.Burn	0.3906
	Aspect	0.2940

APPENDIX

Appendix 1. List of all soft-mast production a priori models shown by AIC score with ΔAIC, Akaike weight (ω_i; relative likelihood of model given the dataset), and model likelihood $\mathcal{L}(g_i|x)$ versus other models within species using the full dataset (all growing seasons [burn years] sampled). Production surveys were completed in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma.

Model		K	AIC	Δ_i AIC	ω_i	$L(g_i \mid x))$
American beautyberry						
U02	Aspect	1	1056.8	0.0	0.5973	1.0000
U01	GSPB	3	1059.0	2.2	0.1988	0.3329
U03	BA	1	1060.3	3.5	0.1038	0.1738
M01	GSPB, Aspect, BA	5	1062.4	5.6	0.0363	0.0608
M10	GSPB, BA	4	1062.7	5.9	0.0313	0.0523
U05	P.Burn	1	1063.5	6.7	0.0210	0.0351
M03	BA, P.Burn	2	1067.1	10.3	0.0035	0.0058
M09	Aspect, BA, P.Burn	3	1067.6	10.8	0.0027	0.0045
M06	GSPB, Aspect, BA, P.Burn	6	1068.4	11.6	0.0018	0.0030
M07	GSPB, BA, P.Burn	5	1068.6	11.8	0.0016	0.0027
U04	Canopy	1	1069.1	12.3	0.0013	0.0021
M05	GSPB, Canopy	4	1071.4	14.6	0.0004	0.0007
M08	BA, Canopy	2	1072.7	15.9	0.0002	0.0004
M02	GSPB, BA, Canopy	5	1075.0	18.2	0.0001	0.0001
M04	GSPB, Canopy, P.Burn	5	1077.4	20.6	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	1080.7	23.9	0.0000	0.0000
Other						
U02	Aspect	1	-1412.2	0.0	0.5737	1.0000
U05	P.Burn	1	-1410.7	1.5	0.2710	0.4724
U01	GSPB	3	-1408.2	4.0	0.0776	0.1353
U03	BA	1	-1407.4	4.8	0.0520	0.0907
U04	Canopy	1	-1405.9	6.3	0.0246	0.0429
M03	BA, P.Burn	2	-1398.7	13.5	0.0007	0.0012
M10	GSPB, BA	4	-1395.9	16.3	0.0002	0.0003
M05	GSPB, Canopy	4	-1394.6	17.6	0.0001	0.0002
M08	BA, Canopy	2	-1393.6	18.6	0.0001	0.0001
M09	Aspect, BA, P.Burn	3	-1391.5	20.7	0.0000	0.0000
M01	GSPB, Aspect, BA	5	-1388.8	23.4	0.0000	0.0000
M07	GSPB, BA, P.Burn	5	-1387.4	24.8	0.0000	0.0000

Appendix I Continued

M04	GSPB, Canopy, P.Burn	5	-1386.1	26.1	0.0000	0.0000
M02	GSPB, BA, Canopy	5	-1382.2	30.0	0.0000	0.0000
M06	GSPB, Aspect, BA, P.Burn	6	-1380.3	31.9	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	-1366.6	45.6	0.0000	0.0000
Sumac						
U03	BA	1	-674.1	0.0	0.8222	1.0000
M08	BA, Canopy	2	-669.9	4.2	0.1007	0.1225
M03	BA, P.Burn	2	-667.6	6.5	0.0319	0.0388
U04	Canopy	1	-667.2	6.9	0.0261	0.0317
M10	GSPB, BA	4	-665.9	8.2	0.0136	0.0166
M02	GSPB, BA, Canopy	5	-662.5	11.6	0.0025	0.0030
M05	GSPB, Canopy	4	-660.6	13.5	0.0010	0.0012
M09	Aspect, BA, P.Burn	3	-660.6	13.5	0.0010	0.0012
M07	GSPB, BA, P.Burn	5	-659.4	14.7	0.0005	0.0006
M01	GSPB, Aspect, BA	5	-659.1	15.0	0.0005	0.0006
M04	GSPB, Canopy, P.Burn	5	-654.2	19.9	0.0000	0.0000
M06	GSPB, Aspect, BA, P.Burn	6	-652.6	21.5	0.0000	0.0000
U05	P.Burn	1	-651.4	22.7	0.0000	0.0000
U02	Aspect	1	-651.2	22.9	0.0000	0.0000
U01	GSPB	3	-650.4	23.7	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	-649.0	25.1	0.0000	0.0000
Blackberry						
M10	GSPB, BA	4	704.4	0.0	0.4025	1.0000
M07	GSPB, BA, P.Burn	5	704.6	0.2	0.3642	0.9048
U03	BA	1	706.3	1.9	0.1557	0.3867
M03	BA, P.Burn	2	708.9	4.5	0.0424	0.1054
M01	GSPB, Aspect, BA	5	710.8	6.4	0.0164	0.0408
M06	GSPB, Aspect, BA, P.Burn	6	711.1	6.7	0.0141	0.0351
M09	Aspect, BA, P.Burn	3	715.3	10.9	0.0017	0.0043
U01	GSPB	3	715.3	10.9	0.0017	0.0043
M02	GSPB, BA, Canopy	5	716.7	12.3	0.0009	0.0021
M08	BA, Canopy	2	718.9	14.5	0.0003	0.0007
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	723.4	19.0	0.0000	0.0001
U05	P.Burn	1	724.0	19.6	0.0000	0.0001
M05	GSPB, Canop	4	724.3	19.9	0.0000	0.0000
M04	GSPB, Canopy, P.Burn	5	725.5	21.1	0.0000	0.0000

Appendix I Continued

U02	Aspect	1	727.4	23.0	0.0000	0.0000
U04	Canopy	1	730.6	26.2	0.0000	0.0000
Dewberry						
U01	GSPB	3	77.4	0.0	0.9377	1.0000
U02	Aspect	1	83.6	6.2	0.0422	0.0450
U05	P.Burn	1	86.0	8.6	0.0127	0.0136
M10	GSPB, BA	4	88.7	11.3	0.0033	0.0035
U03	BA	1	90.0	12.6	0.0017	0.0018
M05	GSPB, Canopy	4	90.6	13.2	0.0013	0.0014
U04	Canopy	1	92.2	14.8	0.0006	0.0006
M01	GSPB, Aspect, BA	5	93.7	16.3	0.0003	0.0003
M07	GSPB, BA, P.Burn	5	96.0	18.6	0.0001	0.0001
M03	BA, P.Burn	2	97.1	19.7	0.0000	0.0001
M04	GSPB, Canopy, P.Burn	5	98.0	20.6	0.0000	0.0000
M06	GSPB, Aspect, BA, P.Burn	6	101.1	23.7	0.0000	0.0000
M09	Aspect, BA, P.Burn	3	101.7	24.3	0.0000	0.0000
M02	GSPB, BA, Canopy	5	101.8	24.4	0.0000	0.0000
M08	BA, Canopy	2	103.1	25.7	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	114.1	36.7	0.0000	0.0000
Greenbrier						
U01	GSPB	3	-570.2	0.0	0.5093	1.0000
U02	Aspect	1	-568.1	2.1	0.1782	0.3499
U05	P.Burn	1	-567.4	2.8	0.1256	0.2466
U03	BA	1	-567.3	2.9	0.1195	0.2346
U04	Canopy	1	-565.6	4.6	0.0511	0.1003
M05	GSPB, Canopy	4	-561.7	8.5	0.0073	0.0143
M10	GSPB, BA	4	-561.3	8.9	0.0059	0.0117
M03	BA, P.Burn	2	-559.3	10.9	0.0022	0.0043
M08	BA, Canopy	2	-555.1	15.1	0.0003	0.0005
M01	GSPB, Aspect, BA	5	-554.4	15.8	0.0002	0.0004
M04	GSPB, Canopy, P.Burn	5	-554.1	16.1	0.0002	0.0003
M07	GSPB, BA, P.Burn	5	-554.1	16.1	0.0002	0.0003
M09	Aspect, BA, P.Burn	3	-551.9	18.3	0.0001	0.0001
M02	GSPB, BA, Canopy	5	-550.5	19.7	0.0000	0.0001
M06	GSPB, Aspect, BA, P.Burn	6	-547.2	23.0	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	-535.8	34.4	0.0000	0.0000

Appendix I Continued

Summer grape						
U03	BA	1	-493.1	0.0	0.8925	1.0000
U02	Aspect	1	-486.2	6.9	0.0283	0.0317
M10	GSPB, BA	4	-485.9	7.2	0.0244	0.0273
U01	GSPB	3	-485.3	7.8	0.0181	0.0202
U04	Canopy	1	-484.6	8.5	0.0127	0.0143
M03	BA, P.Burn	2	-484.0	9.1	0.0094	0.0106
U05	P.Burn	1	-484.0	9.1	0.0094	0.0106
M05	GSPB, Canopy	4	-480.7	12.4	0.0018	0.0020
M01	GSPB, Aspect, BA	5	-479.9	13.2	0.0012	0.0014
M08	BA, Canopy	2	-479.8	13.3	0.0012	0.0013
M07	GSPB, BA, P.Burn	5	-478.4	14.7	0.0006	0.0006
M09	Aspect, BA, P.Burn	3	-476.9	16.2	0.0003	0.0003
M02	GSPB, BA, Canopy	5	-473.6	19.5	0.0001	0.0001
M04	GSPB, Canopy, P.Burn	5	-472.4	20.7	0.0000	0.0000
M06	GSPB, Aspect, BA, P.Burn	6	-472.3	20.8	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	-459.4	33.7	0.0000	0.0000
Muscadine grape						
U01	GSPB	3	123.2	0.0	0.9049	1.0000
U02	Aspect	1	128.9	5.7	0.0523	0.0578
U05	P.Burn	1	130.3	7.1	0.0260	0.0287
U03	BA	1	133.6	10.4	0.0050	0.0055
U04	Canopy	1	133.6	10.4	0.0050	0.0055
M05	GSPB, Canopy	4	134.5	11.3	0.0032	0.0035
M10	GSPB, BA	4	134.5	11.3	0.0032	0.0035
M07	GSPB, BA, P.Burn	5	141.3	18.1	0.0001	0.0001
M04	GSPB, Canopy, P.Burn	5	141.4	18.2	0.0001	0.0001
M01	GSPB, Aspect, BA	5	141.5	18.3	0.0001	0.0001
M03	BA, P.Burn	2	141.8	18.6	0.0001	0.0001
M08	BA, Canopy,	2	144.8	21.6	0.0000	0.0000
M02	GSPB, BA, Canopy	5	145.9	22.7	0.0000	0.0000
M06	GSPB, Aspect, BA, P.Burn	6	148.4	25.2	0.0000	0.0000
M09	Aspect, BA, P.Burn	3	148.6	25.4	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	159.9	36.7	0.0000	0.0000

Appendix I Continued

Total						
M07	GSPB, BA, P.Burn	5	2052.5	0.0	0.3964	1.0000
M10	GSPB, BA	4	2052.5	0.0	0.3964	1.0000
M01	GSPB, Aspect, BA	5	2055.2	2.7	0.1028	0.2592
M06	GSPB, Aspect, BA, P.Burn	6	2055.2	2.7	0.1028	0.2592
M02	GSPB, BA, Canopy	5	2063.7	11.2	0.0015	0.0037
Global	GSPB, Aspect, BA, Canopy, P.Burn	7	2068.9	16.4	0.0001	0.0003
U03	BA	1	2070.0	17.5	0.0001	0.0002
M03	BA, P.Burn	2	2074.6	22.1	0.0000	0.0000
U01	GSPB	3	2075.6	23.1	0.0000	0.0000
M05	GSPB, Canopy	4	2076.5	24.0	0.0000	0.0000
M09	Aspect, BA, P.Burn	3	2078.7	26.2	0.0000	0.0000
M04	GSPB, Canopy, P.Burn	5	2080.1	27.6	0.0000	0.0000
M08	BA, Canopy	2	2081.4	28.9	0.0000	0.0000
U02	Aspect	1	2096.6	44.1	0.0000	0.0000
U05	P.Burn	1	2097.5	45.0	0.0000	0.0000
U04	Canopy	1	2097.8	45.3	0.0000	0.0000

Appendix 2. List of all soft-mast production a priori models shown by AIC score with ΔAIC, Akaike weight (ω_i; relative likelihood of model given the dataset), and model likelihood $\mathcal{L}(g_i|x)$ versus other models within species using the full dataset (all growing seasons [burn years] sampled). Production surveys were completed in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma.

Model		K	AIC	Δ_i AIC	ω_i	$L(g_i\|x))$
American beautyberry						
U02	Aspect	1	1013.7	0.0	0.8717	1.0000
U01	GSPB	2	1018.6	4.9	0.0752	0.0863
M01	GSPB, Aspect, BA	4	1021.2	7.5	0.0205	0.0235
U03	BA	1	1022.2	8.5	0.0124	0.0143
U05	P.Burn	1	1022.5	8.8	0.0107	0.0123
M10	GSPB, BA	3	1024.0	10.3	0.0051	0.0058
M09	Aspect, BA, P.Burn	3	1025.7	12.0	0.0022	0.0025
U04	Canopy	1	1028.1	14.4	0.0007	0.0007
M03	BA, P.Burn	2	1028.4	14.7	0.0006	0.0006
M06	GSPB, Aspect, BA, P.Burn	5	1028.9	15.2	0.0004	0.0005
M07	GSPB, BA, P.Burn	4	1029.4	15.7	0.0003	0.0004
M05	GSPB, Canopy	3	1030.5	16.8	0.0002	0.0002
M08	BA, Canopy	2	1034.1	20.4	0.0000	0.0000
M04	GSPB, Canopy, P.Burn	4	1035.6	21.9	0.0000	0.0000
M02	GSPB, BA, Canopy	4	1036.0	22.3	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	1040.8	27.1	0.0000	0.0000
Other						
U02	Aspect	1	-796.1	0.0	0.4818	1.0000
U05	P.Burn	1	-794.8	1.3	0.2515	0.5220
U01	GSPB	2	-794.2	1.9	0.1863	0.3867
U03	BA	1	-791.6	4.5	0.0508	0.1054
U04	Canopy,	1	-790.4	5.7	0.0279	0.0578
M03	BA, P.Burn	2	-783.1	13.0	0.0007	0.0015
M10	GSPB, BA	3	-782.4	13.7	0.0005	0.0011
M05	GSPB, Canopy	3	-781.1	15.0	0.0003	0.0006
M08	BA, Canopy	2	-778.6	17.5	0.0001	0.0002
M09	Aspect, BA, P.Burn	3	-775.8	20.3	0.0000	0.0000
M01	GSPB, Aspect, BA	4	-775.3	20.8	0.0000	0.0000
M07	GSPB, BA, P.Burn	4	-774.7	21.4	0.0000	0.0000

Appendix 2 Continued

M04	GSPB, Canopy, P.Burn	4	-773.2	22.9	0.0000	0.0000
M02	GSPB, BA, Canopy	4	-769.3	26.8	0.0000	0.0000
M06	GSPB, Aspect, BA, P.Burn	5	-767.5	28.6	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	-754.2	41.9	0.0000	0.0000
Sumac						
U03	BA	1	-236.0	0.0	0.6849	1.0000
M08	BA, Canopy	2	-233.8	2.2	0.2280	0.3329
M03	BA, P.Burn	2	-229.7	6.3	0.0293	0.0429
M10	GSPB, BA	3	-229.5	6.5	0.0266	0.0388
U04	Canopy	1	-228.3	7.7	0.0146	0.0213
M02	GSPB, BA, Canopy	4	-227.8	8.2	0.0114	0.0166
M01	GSPB, Aspect, BA	4	-223.6	12.4	0.0014	0.0020
M09	Aspect, BA, P.Burn	3	-223.6	12.4	0.0014	0.0020
M07	GSPB, BA, P.Burn	4	-223.5	12.5	0.0013	0.0019
M05	GSPB, Canopy	3	-222.8	13.2	0.0009	0.0014
M04	GSPB, Canopy, P.Burn	4	-219.5	16.5	0.0002	0.0003
M06	GSPB, Aspect, BA, P.Burn	5	-217.5	18.5	0.0001	0.0001
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	-215.9	20.1	0.0000	0.0000
U01	GSPB	2	-211.0	25.0	0.0000	0.0000
U02	Aspect	1	-210.9	25.1	0.0000	0.0000
U05	P.Burn	1	-210.9	25.1	0.0000	0.0000
Blackberry						
U03	BA	1	795.9	0.0	0.7204	1.0000
M07	GSPB, BA, P.Burn	4	799.5	3.6	0.1191	0.1653
M10	GSPB, BA	3	800.1	4.2	0.0882	0.1225
M03	BA, P.Burn	2	801.0	5.1	0.0563	0.0781
M06	GSPB, Aspect, BA, P.Burn	5	805.5	9.6	0.0059	0.0082
M01	GSPB, Aspect, BA	4	806.0	10.1	0.0046	0.0064
M09	Aspect, BA, P.Burn	3	806.9	11.0	0.0029	0.0041
M08	BA, Canopy	2	807.8	11.9	0.0019	0.0026
M02	GSPB, BA, Canopy	4	811.7	15.8	0.0003	0.0004
U05	P.Burn	1	812.9	17.0	0.0001	0.0002
U01	GSPB	2	813.3	17.4	0.0001	0.0002
M04	GSPB, Canopy, P.Burn	4	814.7	18.8	0.0001	0.0001
U02	Aspect	1	816.2	20.3	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	816.7	20.8	0.0000	0.0000

Appendix 2 Continued

U04	Canopy	1	819.7	23.8	0.0000	0.0000
M05	GSPB, Canopy	3	821.6	25.7	0.0000	0.0000
Dewberry						
U02	Aspect	1	318.1	0.0	0.3588	1.0000
U05	P.Burn	1	318.1	0.0	0.3588	1.0000
U01	GSPB	2	318.8	0.7	0.2529	0.7047
U03	BA	1	324.0	5.9	0.0188	0.0523
U04	Canopy	1	326.0	7.9	0.0069	0.0193
M03	BA, P.Burn	2	328.8	10.7	0.0017	0.0047
M10	GSPB, BA	3	329.4	11.3	0.0013	0.0035
M05	GSPB, Canopy	3	331.4	13.3	0.0005	0.0013
M09	Aspect, BA, P.Burn	3	333.7	15.6	0.0001	0.0004
M01	GSPB, Aspect, BA	4	334.3	16.2	0.0001	0.0003
M07	GSPB, BA, P.Burn	4	335.9	17.8	0.0000	0.0001
M08	BA, Canopy	2	336.6	18.5	0.0000	0.0001
M04	GSPB, Canopy, P.Burn	4	337.8	19.7	0.0000	0.0001
M06	GSPB, Aspect, BA, P.Burn	5	340.9	22.8	0.0000	0.0000
M02	GSPB, BA, Canopy	4	341.9	23.8	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	353.3	35.2	0.0000	0.0000
Greenbrier						
U01	GSPB	2	-154.1	0.0	0.5203	1.0000
U02	Aspect	1	-152.0	2.1	0.1821	0.3499
U03	BA	1	-151.1	3.0	0.1161	0.2231
U05	P.Burn	1	-151.0	3.1	0.1104	0.2122
U04	Canopy	1	-149.3	4.8	0.0472	0.0907
M10	GSPB, BA	3	-146.4	7.7	0.0111	0.0213
M05	GSPB, Canopy	3	-146.0	8.1	0.0091	0.0174
M03	BA, P.Burn	2	-143.3	10.8	0.0023	0.0045
M01	GSPB, Aspect, BA	4	-140.4	13.7	0.0006	0.0011
M08	BA, Canopy	2	-139.5	14.6	0.0004	0.0007
M07	GSPB, BA, P.Burn	4	-138.7	15.4	0.0002	0.0005
M04	GSPB, Canopy, P.Burn	4	-138.4	15.7	0.0002	0.0004
M09	Aspect, BA, P.Burn	3	-136.7	17.4	0.0001	0.0002
M02	GSPB, BA, Canopy	4	-135.7	18.4	0.0001	0.0001
M06	GSPB, Aspect, BA, P.Burn	5	-132.7	21.4	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	-122.0	32.1	0.0000	0.0000

Appendix 2 Continued

Summer grape						
U03	BA	1	-94.2	0.0	0.7592	1.0000
M10	GSPB, BA	3	-89.7	4.5	0.0800	0.1054
U01	GSPB	2	-89.6	4.6	0.0761	0.1003
U02	Aspect	1	-87.9	6.3	0.0325	0.0429
U04	Canopy	1	-86.2	8.0	0.0139	0.0183
M03	BA, P.Burn	2	-85.9	8.3	0.0120	0.0158
U05	P.Burn	1	-85.9	8.3	0.0120	0.0158
M01	GSPB, Aspect, BA	4	-84.5	9.7	0.0059	0.0078
M05	GSPB, Canopy	3	-83.3	10.9	0.0033	0.0043
M09	Aspect, BA, P.Burn	3	-82.1	12.1	0.0018	0.0024
M07	GSPB, BA, P.Burn	4	-81.8	12.4	0.0015	0.0020
M08	BA, Canopy	2	-81.6	12.6	0.0014	0.0018
M02	GSPB, BA, Canopy	4	-77.7	16.5	0.0002	0.0003
M06	GSPB, Aspect, BA, P.Burn	5	-76.5	17.7	0.0001	0.0001
M04	GSPB, Canopy, P.Burn	4	-75.2	19.0	0.0001	0.0001
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	-64.4	29.8	0.0000	0.0000
Muscadine grape						
U02	Aspect	1	366.0	0.0	0.4205	1.0000
U01	GSPB	2	366.9	0.9	0.2681	0.6376
U05	P.Burn	1	367.5	1.5	0.1986	0.4724
U03	BA	1	369.9	3.9	0.0598	0.1423
U04	Canopy	1	370.3	4.3	0.0490	0.1165
M10	GSPB, BA	3	377.5	11.5	0.0013	0.0032
M05	GSPB, Canopy	3	377.7	11.7	0.0012	0.0029
M03	BA, P.Burn	2	378.0	12.0	0.0010	0.0025
M08	BA, Canopy	2	381.1	15.1	0.0002	0.0005
M07	GSPB, BA, P.Burn	4	383.6	17.6	0.0001	0.0002
M01	GSPB, Aspect, BA	4	384.1	18.1	0.0000	0.0001
M09	Aspect, BA, P.Burn	3	384.6	18.6	0.0000	0.0001
M04	GSPB, Canopy, P.Burn	4	386.5	20.5	0.0000	0.0000
M02	GSPB, BA, Canopy	4	388.5	22.5	0.0000	0.0000
M06	GSPB, Aspect, BA, P.Burn	5	390.1	24.1	0.0000	0.0000
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	403.8	37.8	0.0000	0.0000

Appendix 2 Continued

Total						
U03	BA	1	1783.0	0.0	0.2962	1.0000
M07	GSPB, BA, P.Burn	4	1784.0	1.0	0.1796	0.6065
M10	GSPB, BA	3	1784.1	1.1	0.1709	0.5769
M01	GSPB, Aspect, BA	4	1784.5	1.5	0.1399	0.4724
M06	GSPB, Aspect, BA, P.Burn	5	1784.7	1.7	0.1266	0.4274
M03	BA, P.Burn	2	1786.3	3.3	0.0569	0.1920
M09	Aspect, BA, P.Burn	3	1787.8	4.8	0.0269	0.0907
M08	BA, Canopy	2	1793.6	10.6	0.0015	0.0050
M02	GSPB, BA, Canopy	4	1794.6	11.6	0.0009	0.0030
Global	GSPB, Aspect, BA, Canopy, P.Burn	6	1795.3	12.3	0.0006	0.0021
U01	GSPB	2	1805.7	22.7	0.0000	0.0000
U02	Aspect	1	1805.9	22.9	0.0000	0.0000
U04	Canopy	1	1806.4	23.4	0.0000	0.0000
M05	GSPB, Canopy	3	1806.8	23.8	0.0000	0.0000
U05	P.Burn	1	1809.5	26.5	0.0000	0.0000
M04	GSPB, Canopy, P.Burn	4	1810.1	27.1	0.0000	0.0000

Appendix 3. Top producing species and production mean for 32 stands in the Ouachita National Forest of Arkansas and Oklahoma, surveyed in 2015 and 2016.

Stand Number	**Burn year**	**Mean Soft-mast Production** (kg ha^{-1})								
		American beautyberry	Blackberry	Dewberry	Greenbrier	Summer grape	Muscadine grape	Sumac	Other	Total
1	1	0.07	0.00	0.32	0.00	0.00	0.00	0.00	0.08	0.47
2	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	1	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
4	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63
6	1	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04
7	1	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23
8	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean		0.38	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.43
9	2	20.98	0.21	0.28	0.00	0.00	0.00	0.41	0.00	21.88
10	2	0.00	0.18	0.00	0.00	0.00	0.99	0.00	0.21	1.38
11	2	0.00	0.33	1.18	0.00	0.00	2.22	0.17	1.95	5.85
12	2	14.85	3.30	0.24	0.00	0.00	0.55	0.53	0.06	19.52
13	2	6.05	1.22	0.42	0.04	0.00	0.54	0.80	0.00	9.07
14	2	0.31	4.65	2.83	0.00	0.00	0.14	0.10	1.04	9.09
15	2	2.56	0.00	0.34	0.00	0.00	0.00	0.03	0.19	3.11
16	2	4.57	1.04	0.63	0.38	0.96	0.66	0.11	0.13	8.48
Mean		6.17	1.37	0.74	0.05	0.12	0.64	0.27	0.45	9.80

Appendix 3 Continued **Mean Soft-mast Production (**kg ha^{-1}**)**

Stand Number	**Burn year**	American beautyberry	Blackberry	Dewberry	Greenbrier	Summer grape	Muscadine grape	Sumac	Other	Total
17	3	2.89	2.19	0.27	0.00	0.00	0.62	0.00	0.00	5.96
18	3	3.12	0.44	1.67	0.00	0.00	2.40	0.10	0.69	8.43
19	3	2.37	2.70	0.55	0.00	0.00	0.52	0.17	0.02	6.32
20	3	17.43	2.93	2.00	0.06	0.08	1.89	0.45	0.36	25.18
21	3	22.28	0.92	1.12	3.15	23.22	2.92	0.61	0.00	54.22
22	3	13.07	1.40	1.69	2.11	4.54	3.18	1.26	0.04	27.29
23	3	0.49	0.66	2.55	0.87	1.08	2.07	0.32	0.10	8.14
24	3	0.00	2.38	1.99	1.92	1.21	1.38	1.44	0.05	10.38
Mean		7.71	1.70	1.48	1.01	3.77	1.87	0.54	0.16	18.24
25	5	1.95	5.35	0.16	0.04	1.19	5.00	7.16	0.17	21.03
26	5	2.07	0.91	0.02	0.00	0.00	0.34	0.00	0.10	3.44
27	5	0.00	1.95	1.19	0.00	0.16	0.00	0.15	0.87	4.32
28	5	0.00	3.58	0.44	0.07	0.22	1.04	0.42	0.73	6.50
29	5	0.15	5.69	0.27	0.61	0.00	2.01	0.37	0.00	9.10
30	5	0.00	17.13	0.42	0.65	1.01	1.38	0.00	0.00	20.60
31	5	0.00	2.26	3.00	5.25	3.19	2.49	0.66	0.35	17.19
32	5	0.00	0.42	0.52	2.45	1.26	0.00	0.49	0.10	5.24
Mean		0.52	4.66	0.75	1.13	0.88	1.53	1.16	0.29	10.93

Appendix 4. Summary of forest structure characteristics within stands: growing season post burn, past burns, aspect (mode), along with the range, mean, and standard error (SE) for total basal area, canopy closure, and production. Production surveys were completed in summer 2015 and 2016 within the Ouachita National Forest of Arkansas and Oklahoma.

Stand Number	**Burn year**	**Previous Burns**	**Aspect**	**Total Basal Area** (m2 ha^{-1})				**Canopy Closure** (Percent)				**SM Production** (kg ha^{-1})	
				Range		Mean	SE	Range		Mean	SE	Mean	SE
1	1	3	N	11.48	50.51	24.05	1.24	37.08	94.28	61.66	1.72	0.47	0.33
2	1	4	S	4.59	29.84	17.96	0.93	22.78	64.38	42.42	1.51	0.00	0.00
3	1	4	S	6.89	27.55	15.73	0.91	16.02	77.90	42.43	2.31	0.12	0.12
4	1	3	S	9.18	39.03	18.94	0.94	21.74	71.66	41.29	1.54	0.00	0.00
5	1	5	SW	6.89	27.55	17.62	0.87	42.80	92.20	70.41	1.71	2.63	1.51
6	1	6	S	6.89	20.66	13.60	0.60	30.58	93.76	67.59	3.07	0.04	0.04
7	1	7	S	6.89	27.55	18.25	0.70	43.58	93.24	80.27	2.02	0.23	0.23
8	1	6	S	6.89	29.84	18.25	0.86	24.08	89.08	74.69	2.29	0.00	0.00
9	2	5	S	2.30	22.96	14.52	0.62	16.54	75.82	42.55	1.80	21.88	12.39
10	2	5	S	9.18	34.44	18.48	0.90	37.34	76.60	57.26	1.23	1.38	0.87
11	2	5	S	11.48	27.55	17.10	0.67	31.88	60.48	45.21	1.25	5.85	1.99
12	2	4	S	11.48	27.55	17.39	0.71	17.06	74.00	41.75	1.87	19.52	9.86
13	2	2	S	2.30	22.96	14.23	0.88	29.80	79.20	61.79	1.68	9.07	3.84
14	2	3	S	6.89	36.73	16.64	1.05	30.58	93.24	63.91	3.12	9.09	3.53
15	2	5	SW	11.48	25.25	16.07	0.56	48.78	85.44	73.33	1.16	3.11	2.56
16	2	3	S	6.89	22.96	16.53	0.60	55.80	90.12	83.17	1.16	8.48	3.49

Appendix 4 Continued

Stand Number	**Burn year**	**Previous Burns**	**Aspect**	**Total Basal Area** (m^2 ha^{-1})				**Canopy Closure** (Percent)				**SM Production** (kg ha^{-1})	
				Range		Mean	SE	Range		Mean	SE	Mean	SE
17	3	6	SW	4.59	29.84	16.41	0.83	18.10	69.06	43.16	1.68	5.96	2.67
18	3	10	SE	9.18	25.25	16.59	0.72	43.06	70.10	56.55	1.06	8.43	3.23
19	3	5	S	9.18	32.14	18.88	0.82	33.18	68.54	48.18	1.41	6.32	2.75
20	3	5	S	9.18	27.55	16.59	0.70	25.12	88.30	57.02	2.55	25.18	8.70
21	3	5	S	2.30	22.96	14.92	0.72	32.40	90.38	70.56	2.32	54.22	20.59
22	3	5	S	2.30	22.96	13.89	0.71	35.78	89.86	71.45	2.15	27.29	9.32
23	3	5	SW	6.89	22.96	14.75	0.65	31.10	89.08	67.60	2.03	8.14	1.99
24	3	5	SE	6.89	22.96	16.47	0.58	54.50	91.68	75.63	1.64	10.38	2.31
25	5	4	S	0.00	22.96	8.03	1.12	3.54	96.62	36.62	3.82	21.03	5.68
26	5	5	S	11.48	34.44	21.12	0.89	47.74	85.70	66.50	1.40	3.44	1.64
27	5	5	N	4.59	29.84	15.78	0.83	25.12	71.14	46.56	1.66	4.32	1.83
28	5	2	S	11.48	34.44	20.60	0.94	32.14	81.80	60.58	1.68	6.50	1.96
29	5	2	SE	0.00	34.44	15.90	1.06	5.36	95.06	81.90	2.42	9.10	5.16
30	5	2	W	6.89	29.84	16.24	0.85	53.72	95.32	83.19	1.61	20.60	7.43
31	5	4	SW	4.59	18.37	11.71	0.57	46.96	96.10	70.75	2.07	17.19	4.27
32	5	4	S	4.59	20.66	12.97	0.55	44.88	87.00	72.21	1.91	5.24	2.40

VITA

Tamara Wood graduated from Bonham High School, Bonham, Texas, in 2009. She enrolled at Stephen F. Austin State University in the fall of 2009. As an undergraduate student, she held several jobs which included work at the Old Stone Fort Museum, the U.S. Army Corps of Engineers, as well as an international research assistant for SFA in Northumberland, England. She continued to work until graduating with a Bachelor of Science in Forestry Wildlife Management and a minor in Biology in December 2014. She entered the Graduate School of Stephen F. Austin State University in January 2015 and received a Masters of Science in Forestry with an emphasis in Wildlife Management in December 2017.

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