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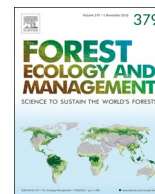
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## Temporal changes in fruit production between recurrent prescribed burns in pine woodlands of the Ouachita Mountains



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### ABSTRACT

The use of prescribed fire is integral to the restoration of open woodlands and savannas, including shortleaf pine (*Pinus echinata*) woodlands in the Ouachita Mountains of Oklahoma and Arkansas. Fire offers many potential benefits to numerous wildlife; however, short-term implications for understory fruit production are not fully understood, especially in stands subjected to frequent, recurrent burns. We examined the effects of dormant-season prescribed burns on woody fruit production ( $\text{kg ha}^{-1}$ ) and fruit producing vegetative cover in the understory of restored pine woodlands. We inventoried 32 stands during four temporal periods after dormant season prescribed fires: 1, 2, 3, and 5 growing seasons post-burn. We counted fruit ( $< 2\text{m}$  above the ground) throughout the summer and visually estimated vegetative cover of fruit producing plants. Fruit production was greatest in the 3rd year ( $18.2 \text{ kg ha}^{-1}$ ), followed by 5th ( $10.9 \text{ kg ha}^{-1}$ ) and 2nd ( $9.8 \text{ kg ha}^{-1}$ ) years after burns. Overall, 87% of total production consisted of three genera: American beautyberry (*Callicarpa americana* [38%]), *Vitis* spp. (summer grapes [*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 fruit producing species present during the 5th year post-burn, indicating that production diversity increased over time. Percent cover and species richness (26 taxa) of fruit producing taxa were greatest in the 3rd year post-burn. Taxa such as poison ivy (*Toxicodendron radicans*) and sumac (*Rhus* spp.) comprised a sizable percent of coverage ( $> 7\%$  each), but this did not translate into substantial fruit production. American beautyberry and summer grape had both substantial coverage and production. Results suggest that burning on a 3-year rotation maximizes and prolongs fruit production; however, occasional burning on a 5-year rotation will promote a higher diversity of woody mast-producing understory species.

### 1. Introduction

Fleshy-fruit (fruit hereafter) producing plants are an important food source and are critical in the seasonal diets for numerous wildlife species (Martin et al., 1951; Beeman and Pelton, 1980; Clapp, 1990; Greenberg and Levey, 2009). Fruit phenology and presence can affect the movements and activity of various wildlife species such as white-tailed deer (*Odocoileus virginianus*; Lay, 1965, 1969), wild turkeys (*Meleagris gallopavo*; Blackburn et al., 1975; Campo et al., 1989; 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), and many overwintering songbirds (Martin et al., 1951; McCarty et al., 2002; Greenberg and Levey, 2009). Black bears and wild turkeys are known to prefer areas characterized by a greater quantity and diversity of fruit production (Beeman and Pelton, 1980; Clark et al., 1994;

McCarty et al., 2002). Hard-mast (e.g., acorns) availability and production vary seasonally and annually, making soft-mast (fruit) production especially important as a buffer against years of low hard-mast production for many wildlife species (Clapp, 1990; Eiler, 1981; Eiler et al., 1989; Inman and Pelton, 2002). In addition to serving as a food source, many fruit producing plants form a dense shrub layer in the understory that provides escape and protective cover for many birds, mammals, and reptiles (Campo et al., 1989; Lashley et al., 2015; Martin et al., 1951; McCord et al., 2014). Particularly, areas with understory vegetation less than 2 m in height provide protection from avian predators (Campo et al., 1989; Cram et al., 2002).

The initial short-term response of fruit production after a silvicultural disturbance (e.g., fire, harvesting, and mid-story thinning or removal) has been well documented (Campo and Hurst, 1980; Greenberg et al., 2007; Johnson and Landers, 1978; Perry et al., 1999,

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2004; Stransky and Roese, 1984). However, silvicultural activities often occur only a few times in the life of a stand: during site preparation, mid-rotation thinning, and at harvest. Without routine disturbance, the forest canopy closes, less light reaches the understory, and understory growth is limited to shade-tolerant species, resulting in decreased fruit production in the understory (Hunter, 1990).

In the 1990s, habitat restoration for the red-cockaded woodpecker (RCW; *Picoides borealis*) was initiated within the Ouachita National Forest (ONF), which resulted in a contiguous landscape of open shortleaf pine (*Pinus echinata*) woodlands (Bukenhofer and Hedrick, 1997). Silvicultural activities (timber harvest, pre-commercial and commercial thinnings) and prescribed burns every 3–5 years are utilized to maintain the open woodland condition. Although the effects of woodland restoration on the ONF have been extensively studied for a variety of forest flora and fauna, the long-term impacts of these restoration activities on wildlife food production have yet to be defined.

Little information is available on how frequent controlled burns affect fruit production in areas dominated by fire-maintained woodlands. Our goal was to determine how dormant-season prescribed burns implemented on a 3 to 5-year return interval affect woody fruit production and cover by understory species (growth  $\leq 2$  m), and how this production changed during the interval between each burn. We sought to quantify the differences in understory fruit production ( $\text{kg ha}^{-1}$ ) and percent coverage of woody fruit producing species 1, 2, 3, and 5 growing seasons after dormant season prescribed burns in restored shortleaf pine woodlands.

## 2. Methods

### 2.1. Study area

The study was conducted on the Poteau-Cold Springs and Oklahoma Ranger Districts of the Ouachita National Forest of west-central Arkansas and east-central Oklahoma. The Ouachita Mountain range is ordinated east to west, creating mesic northern slopes and xeric southern slopes (Foti and Glenn, 1991; Guldin, 2007; Palmer, 1924). The Ouachita region is dominated by mixed pine-hardwood communities, with shortleaf pine being the dominant pine mixed with diverse hardwoods species, including oaks (*Quercus* spp.) and hickories (*Carya* spp.). The xeric southern slopes constitute a disturbance-driven ecosystem sustained primarily with fire, which historically occurred on a 3–5-year interval (Bukenhofer and Hedrick, 1997; Guldin, 2004; Runkle, 1991; Stambaugh and Guyette, 2006). Frequent fire, along with mechanical midstory reduction, maintains a relatively open overstory, a sparse midstory, and a diverse understory of woody and herbaceous species (Dale and Ware, 1999; Eyre, 1980; Foti et al., 1994; NatureServe, 2004). Many fruit 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).

We inventoried the understory of 32 stands, representing four temporal periods after dormant-season prescribed fires: 1st, 2nd, 3rd, and 5th growing seasons post-burn (hereafter burn year), with each burn year replicated 8 times. Data collection occurred during two field seasons (2015 and 2016); in both seasons, 16 stands were sampled with four stands representing each burn year. We selected stands that were located primarily on southern aspects (S, SW, or SE), with overstory basal area (BA) between 13.8 and 18.4  $\text{m}^2 \text{ha}^{-1}$ , and in areas that had previously received at least two dormant season burns. Stands were at least 70 years old and received wildlife stand improvement treatments (e.g., commercial thinning and midstory reduction/removal) between 5 and 26 years prior to sampling. The earliest initial prescribed burn on a stand after wildlife stand improvement occurred in 1992 and the most recent initial burn after wildlife stand improvement was in 2010.

### 2.2. Field methods

We randomly located 6 to 8 transects within each stand and systematically placed plots at 15-m intervals along these transects. The number and length of transects varied based on stand size and shape. All transects were placed perpendicular to the primary slope and  $\geq 25$  m apart. Transects were also placed 50 m from hard edges (e.g., roads and regeneration areas) and structurally different stands (e.g., young and unthinned forests).

We surveyed a total of 40, 9-m<sup>2</sup> semi-permanent plots within each stand for a total sample area of 0.036 ha per stand and 0.288 ha in each treatment or year post-burn (hereafter burn year). Plots were sampled 3 times during the growing season: early June, early July, and mid-August to correspond with ripening phenology of important fruit species. Greatest fruit count per plot was determined and used for species production and data analysis. All fruits up to 2-m in height were counted (regardless of growth habit), including green fruit and fruits that appeared to have been partially removed by frugivory (Table 1). Representative samples of each species were collected, counted, and dried to a constant mass (nearest 0.01 g). We developed species-specific conversion factors to estimate total mass produced by species in each stand. Percent cover of each fruit-producing species (< 2 m in height) was visually estimated in July, corresponding with peak growing season, using the Daubenmire method (Coulloudon et al., 1999; Daubenmire, 1959) in 1 m<sup>2</sup> subplots nested within the larger fruit plots.

When possible, fruits were counted individually; however, we estimated fruit counts for species with large or multiple clusters containing numerous individual fruits. Similar to Perry et al. (1999, 2004), we developed a cluster volume to fruit mass regression equation to estimate sumac fruit production. Multiple samples (> 40) of each sumac species (winged [*R. copallinum*] and smooth sumac [*R. glabra*]) were collected, measured in three dimensions, and weighed. American beautyberry and greenbrier (*Smilax* spp.) production was determined by extrapolating the mean drupe count per cluster (based on 10-cluster

**Table 1**  
Fruit producing taxa surveyed for coverage and production in 32 restored woodland stands under short-rotation burning in the Ouachita Mountains of Arkansas, 2015–2016.

| Species              | Scientific name                    |
|----------------------|------------------------------------|
| Alabama supplejack   | <i>Berchemia scandens</i>          |
| American beautyberry | <i>Callicarpa americana</i>        |
| American pokeberry   | <i>Phytolacca americana</i>        |
| Black cherry         | <i>Prunus serotina</i>             |
| Blackberry           | <i>Rubus</i> spp.                  |
| Blackgum             | <i>Nyssa silvatica</i>             |
| Blueberry            | <i>Vaccinium</i> spp.              |
| Carolina buckthorn   | <i>Frangula caroliniana</i>        |
| Coral berry          | <i>Symphoricarpos orbiculatus</i>  |
| Devil's walkingstick | <i>Aralia spinosa</i>              |
| Dewberry             | <i>Rubus flagellaris</i>           |
| Dogwood              | <i>Cornus florida</i>              |
| Fragrant sumac       | <i>Rhus aromatica</i>              |
| Greenbrier           | <i>Smilax</i> spp.                 |
| Hawthorn             | <i>Crataegus</i> spp.              |
| Holly                | <i>Ilex</i> spp.                   |
| Mulberry             | <i>Morus</i> spp.                  |
| Muscadine grape      | <i>Vitis rotundifolia</i>          |
| Persimmon            | <i>Diospyros virginiana</i>        |
| Plum                 | <i>Prunus</i> spp.                 |
| Poison ivy           | <i>Toxicodendron radicans</i>      |
| Rusty blackhaw       | <i>Viburnum rufidulum</i>          |
| Serviceberry         | <i>Amelanchier arborea</i>         |
| Sparkleberry         | <i>Vaccinium arboreum</i>          |
| Sumac                | <i>Rhus</i> spp.                   |
| Summer grape         | <i>Vitis aestivalis</i>            |
| Virginia creeper     | <i>Parthenocissus quinquefolia</i> |
| White fringetree     | <i>Chionanthus virginicus</i>      |
| Wild rose            | <i>Rosa</i> spp.                   |

subsample) by the total number of clusters per individual plant. This process was repeated for each plant within the plot to find the total production (g) per plot.

### 2.3. Data analysis

We grouped congeneric species (taxa hereafter) that had similar wildlife value, fruiting phenology, and growth habit, including: winged and smooth sumac (hereafter sumac), and sawtooth (*Smilax bona-nox*), lanceleaf (*S. smallii*), cat (*S. glauca*), and roundleaf (*S. rotundifolia*) greenbrier (hereafter greenbrier; Table 1). We conducted all fruit analyses on dry mass production ( $\text{kg ha}^{-1}$ ), hereafter production. We performed analyses on total production (all species) and individual taxa that together comprised 95% of total production: American beautyberry, blackberry (*Rubus* spp.), dewberry (*R. flagellaris*), summer grape (*Vitis aestivalis*), muscadine grape (*V. rotundifolia*), sumac, and greenbrier. We analyzed total vegetation cover and cover of individual taxa that occurred in at least 25% of all stands (8 out of 32 stands); species that fell below this 25% threshold were combined in the total cover for analyses.

We derived treatment (burn year) means for production and vegetation cover for each stand (8 stands per treatment;  $n = 32$ ). To improve normality, production means were log transformed ( $\log[x + 1]$ ; McCord et al., 2014; Perry et al., 1999; Zar, 1999) and vegetation cover were transformed using a square root transformation ( $\sqrt{x}$ ; Vitz and Rodewald, 2007; Zar, 1999). Non-transformed values are reported. We compared treatment means using analysis of variance (ANOVA) with PROC MIXED in SAS (v.9.2 SAS Institute, Cary, North Carolina) and the Kenward-Rogers method to determine the denominator degrees of freedom (Littell et al., 2006). We assessed fruit production and total vegetation coverage at the stand level. Burn year was the fixed effect. We used least square means with a Tukey adjustment to compare production means among burn years when ANOVAs were significant at  $\alpha = 0.05$ . We 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.

## 3. Results

### 3.1. Fruit production

The total number of taxa producing fruit was 13 in 2015 and 12 in 2016. The total number of taxa producing fruit increased from 5 the 1st burn year, to 12 in the 2nd and 3rd burn years, and 13 the 5th burn year. The mean fruit richness increased after the 1st burn year from 1 taxa, to 6 in the 2nd burn year, and 7 in the 3rd and 5th burn years. Similar quantities of total dry fruit production occurred in 2015 and 2016 ( $F_{1,27} = 1.65$ ;  $P = 0.2092$ ). Total production differed by burn year; production in the 2nd, 3rd, and 5th burn years was similar, but all were greater than the 1st burn year ( $F_{3,28} = 21.85$ ;  $P = 0.0001$ ; Table 2). Although not significant, total production peaked the 3rd burn year, but was similar the 2nd and 5th year after burning (Table 2).

Of the 13 taxa observed, production by 7 (American beautyberry, blackberry, dewberry, greenbrier, sparkleberry, muscadine grape, and summer grape) varied among burn years (Table 2). Production by most taxa was greater after the 1st burn year. American beautyberry had the greatest production value and contributed 38% of the total production averaged over all burn years. Blackberry was the second greatest producing taxa, comprising 20% of total production, followed by summer grape (12%), muscadine grape (10%), dewberry (8%), greenbrier (6%), and sumac (5%).

American beautyberry production was 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 years, accounting for approximately half of the total production in 1st, 2nd and 3rd burn years

(Table 2). In the 5th burn year, American beautyberry production declined, which coincided with a significant increase in blackberry production ( $P < 0.001$ ). 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 production was similar between the 5th and 3rd burn years ( $P < 0.001$ ). Blackberry production comprised 42% of the total production in the 5th burn year (Table 2).

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 produced more after the 1st ( $P = 0.976$  and  $P = 1.000$ ) burn year and production increased with time since burn (Table 2).

Production by most taxa followed similar burn year trends in 2015 and 2016. Only 2 of the 13 producing taxa (summer grape and greenbrier) differed; production by both was greater in 2016 (Table 3). In 2016, these two taxa accounted for approximately 29% of the total production compared to 1.4% in 2015. Total production of summer grape and greenbrier was 20 and 100 times higher, respectively, in 2016 than in 2015.

### 3.2. Vegetation cover

Of the 30 fruit producing taxa surveyed, burn year influenced the cover of 4 (Table 4). Ten taxa occurred in less than 25% of all stands (Table 4). Total percent cover was consistent across all burn years ( $F_{3,28} = 2.22$ ;  $P = 0.109$ ), and did not differ between 2015 and 2016 ( $F_{1,27} = 3.67$ ;  $P = 0.066$ ). Cover of only taxa that produced (fruit producers only) was impacted by burn year ( $F_{3,28} = 27.07$ ;  $P = 0.001$ ; Table 4). Similar to total production, cover of fruit plants was greater in the 2nd ( $P < 0.001$ ), 3rd ( $P < 0.001$ ), and 5th ( $P < 0.001$ ) burn year than the 1st ( $P = 0.087$ ; Table 4).

Although we observed greater species richness of shrubs (11 taxa) than vines (6 taxa), the cover of woody vines was approximately 1.7 times the cover of shrubs. Overall, taxa with the greatest cover across the landscape were poison ivy (7.4%), sumac (7.0%), dewberry (6.0%), muscadine grape (5.8%), and greenbrier (5.1%; Table 3). The 10 taxa in the 'other' group covered  $< 1\%$  of sampled areas.

## 4. Discussion

Shortleaf pine woodlands are a disturbance-driven community, in which prescribed burns are necessary to sustain the understory in early successional conditions (Guldin and Loewenstein, 1999; Reynolds-Hogland et al., 2006; Hanberry and Thompson, 2019). Many of the fruiting species we observed are closely associated with early to mid-seral succession forests within open or relatively open-canopies (Halls, 1977; Martin et al., 1951). Because of frequent fire, fruit production was limited to species that can respond and recover within the 3 to 5-year fire return interval. Shrubs and woody vines were the greatest producing taxa, reflecting a quick recovery following dormant season burns. Total production peaked in the 3rd burn year, which corresponded with greatest production by muscadine grape, summer grape, greenbrier, dewberry, and American beautyberry. The top producing species, American beautyberry, can re-establish and begin producing within 2 years following disturbance (Halls, 1973, 1977), resulting in a significant contribution to total production in the 2nd and 3rd burn year. Blackberry produced in all but the 1st burn year, with output greater after more growing seasons throughout the 5 years we measured after burn. Blackberries are floricanic fruiting and do not produce fruit on cane grown during the first year of plant growth (e.g., Krewer et al., 2004), but large fruiting events 4–5 years after disturbance are common (Campo and Hurst, 1980; Greenberg and Levey, 2009; Greenberg et al., 2011; Johnson and Landers, 1978; Perry et al., 2004; Stransky and Roese, 1984).

**Table 2**

Mean ( $\pm$  SE) fruit production ( $\text{kg ha}^{-1}$  dry mass) by burn year (1, 2, 3, and 5 years after burn) in the Ouachita National Forest of Arkansas and Oklahoma, 2015–2016.

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

<sup>a</sup> Within rows, means with like capital letters did not differ significantly ( $\alpha > 0.05$ ) among years after burn.

<sup>b</sup> Species only found in 2015.

**Table 3**

Mean ( $\pm$  SE) dry mass of fruit ( $\text{kg ha}^{-1}$ ) by species and year sampled (2015 [ $n = 16$ ] and 2016 [ $n = 16$ ]) in the Ouachita National Forest of Arkansas and Oklahoma.

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

<sup>a</sup> Species only found in 2015.

<sup>b</sup> Within rows, means with like capital letters did not differ significantly ( $\alpha > 0.05$ ) among years after burn.

The number of taxa producing fruit was greatest in stands 5 years after burns; indicating that diversity of producing species increases as more species recover or establish after disturbance (Johnson and Landers, 1978; Perry et al., 2004; Stransky and Roese, 1984). Delaying intervals between prescribed burns may allow more species to reach production age. However, longer intervals result in decreased fruit production due to increased competition for sunlight in the midstory (Greenberg and Levey, 2009; Perry et al., 1999, 2004). Increased woody competition could account for lower total production in the 5th burn year, despite higher species richness. Previous research found decreased fruit production as soon as 6 years after silvicultural treatment (Campo and Hurst, 1980; Johnson and Landers, 1978; Stransky and Roese, 1984). 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 (Brockway and Lewis, 1997; Haywood et al., 2001; Sparks et al., 1999; Waldrop et al., 1992).

In this study, production peaked in the 3rd burn year at  $18.2 \text{ kg ha}^{-1}$ . In stands harvested without burning, production peaked at  $100 \text{ kg ha}^{-1}$  in the 5th year after shelterwood harvest and  $48 \text{ kg ha}^{-1}$  in single-tree selection stands (Perry et al., 1999). However, shelterwood overstories in that study were thinned substantially more (residual BA =  $10.2 \text{ m}^2 \text{ ha}^{-1}$ ) than in our woodland stands (residual mean BA =  $16.4$ ; SE  $\pm 0.5 \text{ m}^2 \text{ ha}^{-1}$ ) and single-tree selection stands were thinned to  $15.9 \text{ m}^2 \text{ ha}^{-1}$ ), and greater reductions in overstory BA are

expected to increase fruit production (Perry et al., 1999, 2004). Perry et al. (2004) recorded low production ( $< 1 \text{ kg ha}^{-1}$ ) in unharvested and unburned forests. Nevertheless, understory fruit production in harvested stands is limited to the first few years after harvest as competition from tree saplings and overstory shading reduces light reaching the forest floor. Frequent fire retards understory tree growth and regeneration, resulting in long-term, sustained, fruit production although at relatively lesser levels compared to tree harvesting alone.

Responses of fruit species and production differ between dormant season prescribed burns and other silvicultural activities (e.g., timber harvest). Blackberry and sumac easily germinate and establish through seeds (Halls, 1977; Waldrop et al., 1992), allowing for greater production earlier and at higher rates after timber harvest (Perry et al., 2004; Stransky and Halls, 1980). In the 5th year following clearcuts, blackberry and sumac produced 10 to 19 times more fruit (Perry et al., 2004) than we observed in stands following dormant season burns. American beautyberry and greenbriers readily resprout after above-ground vegetation is removed or top-killed (Grelen and Duvall, 1966; Halls, 1977; Waldrop et al., 1992), resulting in greater production following dormant season burns (Halls, 1977; Waldrop et al., 1992). Without open conditions created by disturbances, presence of these taxa would be limited across forested landscapes (Halls, 1977; Greenberg et al., 2011; Waldrop et al., 1992).

Species coverage was not a good indicator of overall production, and species with substantial coverage often had minimal production.

**Table 4**

Mean ( $\pm$  SE) vegetation cover (%) of fruit producing taxa by burn year (1, 2, 3, and 5) in the Ouachita National Forest of Arkansas and Oklahoma, 2015–2016. Dissimilar letters within rows denote differences ( $\alpha = 0.05$ ) among growing seasons post burn.

| Taxon                             | Burn year                          |                       |                       |                       | F <sub>(3,27)</sub> | P      |
|-----------------------------------|------------------------------------|-----------------------|-----------------------|-----------------------|---------------------|--------|
|                                   | 1                                  | 2                     | 3                     | 5                     |                     |        |
| Alabama supplejack <sup>a</sup>   | 0.09 ( $\pm$ 0.06)                 | 0.00 ( $\pm$ 0.00)    | 0.07 ( $\pm$ 0.05)    | 0.01 ( $\pm$ 0.01)    | –                   | –      |
| American beautyberry              | 0.18 ( $\pm$ 0.13)                 | 1.05 ( $\pm$ 0.53)    | 1.37 ( $\pm$ 0.56)    | 0.22 ( $\pm$ 0.16)    | 2.09                | 0.1239 |
| American pokeberry <sup>a</sup>   | 0.05 ( $\pm$ 0.05)                 | 0.00 ( $\pm$ 0.00)    | 0.00 ( $\pm$ 0.00)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Black cherry                      | 0.65 ( $\pm$ 0.25)                 | 1.38 ( $\pm$ 0.52)    | 0.86 ( $\pm$ 0.49)    | 0.90 ( $\pm$ 0.29)    | 0.42                | 0.7391 |
| Blackberry                        | 1.98 ( $\pm$ 0.65)                 | 1.91 ( $\pm$ 0.36)    | 3.46 ( $\pm$ 1.19)    | 4.09 ( $\pm$ 1.05)    | 1.24                | 0.3155 |
| Blackgum                          | 0.57 ( $\pm$ 0.57)                 | 0.37 ( $\pm$ 0.27)    | 0.25 ( $\pm$ 0.10)    | 0.16 ( $\pm$ 0.10)    | 0.13                | 0.9385 |
| Blueberry                         | 1.38 ( $\pm$ 0.66)                 | 2.77 ( $\pm$ 1.26)    | 0.34 ( $\pm$ 0.24)    | 0.82 ( $\pm$ 0.37)    | 1.53                | 0.2283 |
| Carolina buckthorn <sup>a</sup>   | 0.12 ( $\pm$ 0.12)                 | 0.00 ( $\pm$ 0.00)    | 0.00 ( $\pm$ 0.00)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Coral berry <sup>a</sup>          | 0.00 ( $\pm$ 0.00)                 | 0.12 ( $\pm$ 0.12)    | 0.00 ( $\pm$ 0.00)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Devil's walkingstick <sup>a</sup> | 0.12 ( $\pm$ 0.12)                 | 0.00 ( $\pm$ 0.00)    | 0.32 ( $\pm$ 0.21)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Dewberry                          | 7.32 ( $\pm$ 1.76)                 | 3.54 ( $\pm$ 0.86)    | 7.69 ( $\pm$ 0.93)    | 5.41 ( $\pm$ 1.30)    | 2.30                | 0.0994 |
| Dogwood                           | 0.35 ( $\pm$ 0.28)                 | 0.34 ( $\pm$ 0.14)    | 1.20 ( $\pm$ 0.36)    | 1.25 ( $\pm$ 0.51)    | 1.91                | 0.1516 |
| Fragrant sumac                    | 0.27 AB <sup>b</sup> ( $\pm$ 0.17) | 0.00B ( $\pm$ 0.00)   | 0.98 A ( $\pm$ 0.28)  | 0.33 AB ( $\pm$ 0.24) | 4.94                | 0.0073 |
| Greenbrier                        | 3.13 ( $\pm$ 0.80)                 | 4.98 ( $\pm$ 1.28)    | 6.62 ( $\pm$ 1.21)    | 5.80 ( $\pm$ 1.35)    | 2.65                | 0.0688 |
| Hawthorn                          | 0.00 ( $\pm$ 0.00)                 | 0.20 ( $\pm$ 0.07)    | 0.20 ( $\pm$ 0.10)    | 0.09 ( $\pm$ 0.06)    | 2.24                | 0.1054 |
| Holly <sup>a</sup>                | 0.00 ( $\pm$ 0.00)                 | 0.05 ( $\pm$ 0.05)    | 0.05 ( $\pm$ 0.05)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Mulberry <sup>a</sup>             | 0.05 ( $\pm$ 0.05)                 | 0.00 ( $\pm$ 0.00)    | 0.10 ( $\pm$ 0.09)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Muscadine grape                   | 4.70 ( $\pm$ 1.29)                 | 7.53 ( $\pm$ 2.19)    | 6.85 ( $\pm$ 1.45)    | 4.12 ( $\pm$ 1.44)    | 1.01                | 0.4036 |
| Persimmon <sup>a</sup>            | 0.00 ( $\pm$ 0.00)                 | 0.02 ( $\pm$ 0.02)    | 0.00 ( $\pm$ 0.00)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Plum                              | 0.30 ( $\pm$ 0.12)                 | 0.63 ( $\pm$ 0.28)    | 0.67 ( $\pm$ 0.39)    | 0.94 ( $\pm$ 0.41)    | 0.42                | 0.7426 |
| Poison ivy                        | 4.48B ( $\pm$ 1.71)                | 5.50 AB ( $\pm$ 1.38) | 8.97 AB ( $\pm$ 1.59) | 10.66 A ( $\pm$ 2.62) | 3.33                | 0.0343 |
| Rusty blackhaw                    | 0.15 AB ( $\pm$ 0.10)              | 0.34 AB ( $\pm$ 0.13) | 0.01B ( $\pm$ 0.01)   | 0.92 A ( $\pm$ 0.41)  | 4.12                | 0.0157 |
| Serviceberry <sup>a</sup>         | 0.00 ( $\pm$ 0.00)                 | 0.01 ( $\pm$ 0.01)    | 0.05 ( $\pm$ 0.05)    | 0.00 ( $\pm$ 0.00)    | –                   | –      |
| Sparkleberry                      | 1.55 ( $\pm$ 0.46)                 | 1.97 ( $\pm$ 0.67)    | 1.39 ( $\pm$ 0.36)    | 2.38 ( $\pm$ 0.62)    | 0.68                | 0.5699 |
| Sumac                             | 7.16 ( $\pm$ 1.37)                 | 7.12 ( $\pm$ 1.84)    | 7.10 ( $\pm$ 0.91)    | 6.76 ( $\pm$ 3.49)    | 0.37                | 0.7771 |
| Summer grape                      | 0.56B ( $\pm$ 0.44)                | 0.38B ( $\pm$ 0.18)   | 2.44 A ( $\pm$ 1.00)  | 1.43 AB ( $\pm$ 0.59) | 3.93                | 0.0189 |
| Virginia creeper                  | 3.08 ( $\pm$ 1.31)                 | 1.07 ( $\pm$ 0.29)    | 2.95 ( $\pm$ 0.49)    | 3.22 ( $\pm$ 0.80)    | 2.04                | 0.1317 |
| White fringetree <sup>a</sup>     | 0.11 ( $\pm$ 0.07)                 | 0.05 ( $\pm$ 0.05)    | 0.05 ( $\pm$ 0.05)    | 0.05 ( $\pm$ 0.05)    | –                   | –      |
| Wild rose                         | 0.55 ( $\pm$ 0.18)                 | 0.51 ( $\pm$ 0.24)    | 0.27 ( $\pm$ 0.14)    | 0.50 ( $\pm$ 0.21)    | 0.22                | 0.8801 |
| Total (producers only)            | 1.77B ( $\pm$ 1.01)                | 30.54 A ( $\pm$ 5.86) | 37.41 A ( $\pm$ 5.55) | 33.20 A ( $\pm$ 4.27) | 27.07               | 0.0001 |
| Total                             | 38.89 ( $\pm$ 6.66)                | 41.82 ( $\pm$ 5.14)   | 54.26 ( $\pm$ 4.16)   | 50.05 ( $\pm$ 3.83)   | 2.22                | 0.1092 |

<sup>a</sup> Species occurred in < 25% surveyed stands, no analyses was conducted due to limited sample size.

<sup>b</sup> Within rows, means with like capital letters did not differ significantly ( $\alpha > 0.05$ ) among years after burn.

For example, poison ivy had the greatest cover (7.4%), but only minor production (< 0.2% of total). In contrast, American beautyberry had very low coverage (0.7%) but was the greatest producing species with approximately 38% of total production. For summer grape and greenbrier, the greater occurrence on the landscape related to greater production potential.

Many wildlife species, including black bears, benefit from a diverse floral community and forest structure; especially in late spring and in late summer when the greatest diversity of fruits are consumed (Clapp, 1990). Cycles between high and low crops are common in many fruit producing species, highlighting the importance of species richness and diversity in production throughout the forest. American beautyberry and blackberry both fruited prolifically ( $\geq 2$  kg ha<sup>-1</sup>), but the timing of their peak production differed. Blackberry peaked in mid-summer (July) and beautyberry in late summer-early fall (August/September). This 'relay' in phenology among prolific producers is similar to production of American pokeberry (*Phytolacca americana*) and blackberries in young forests (Greenberg et al., 2011). Maintaining a diverse phenology of maturing fruit-producing species provides food resources year-round for many wildlife species, mitigates potential negative impacts during critical times when other food resources are scarce, and contributes to overall habitat quality (Clapp, 1990; Eiler, 1981; Eiler et al., 1989; Greenberg and Levey, 2009; Inman and Pelton, 2002; McCarty et al., 2002).

We found 89% (9.3 kg ha<sup>-1</sup> across the landscape) of the total production consisted of preferred summer fruits. Preferred fruits are consumed quickly once ripe (Dalke et al., 1942; Martin et al., 1951; 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; Halls, 1973, 1977; Martin et al., 1951; McCarty et al., 2002). Sumac, wild rose (*Rosa* spp.), sparkleberry, greenbrier, and poison ivy fruits typically ripen and persist into the winter months (Halls, 1977). These taxa 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; McCarty et al., 2002).

In areas like the Ouachita National Forest where long-term management of woodlands is primarily focused on restoration of target species like the RCW, short-term implications of treatments such as burning are important for overall biodiversity and abundance of other species (e.g., game birds and mammals). Fruit production is one example that is important for a variety of wildlife species. Dormant season prescribed burns alone did not increase production as much as harvesting or thinning, but midstory removal followed by recurrent burning resulted in greater production than unburned and unthinned stands (e.g., Perry et al., 1999, 2004). Therefore, burning at a 3 to 5-year rotation can promote and prolong fruit production and vegetation diversity throughout the life of a stand, which benefits various wildlife. Burning on 3 to 5-year intervals allows important fruit producing species to mature and reach production age, which increases fruiting species richness along with maintaining fruit and vegetation biomass.

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