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RESEARCH ARTICLE

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Vegetation structure and food availability following disturbance in recently restored early successional plant communities

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Abstract

Fields dominated by nonnative grasses, such as tall fescue (*Schedonorus arundinaceus*), are being restored to native plant communities across the eastern U.S. Upon restoration, disturbance is necessary to maintain native communities in an early seral stage, and plant response to different management practices is of interest to managers to guide habitat enhancement for various wildlife species. We evaluated effects of burning and mowing following restoration of native plant communities via 2 methods (planting native grasses and forbs and seedbank response without planting), across 11 replicated sites in Tennessee and Alabama, 2019–2020. We compared vegetation composition and structure, openness at ground level, forage availability, and nutritional carrying capacity (NCC) following 4 treatments (Seedbank Burned, Seedbank Mowed, Planted Burned, Planted Mowed, and tall fescue Control), and we related these measurements to the food and cover requirements for 3 popular game species: white-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), and northern bobwhite (*Colinus virginianus*). The combination of planting and mowing increased grass coverage, whereas units that were established via seedbank response and managed by burning had greater forb coverage. Visual obstruction above 25 cm was greater in all treatments than Control, which provided cover that has been described as selected nesting cover by wild turkey and bedding cover for deer. Openness at ground level, which is especially important for bobwhite and wild turkey broods, was 30% greater in Seedbank Burned than Planted Mowed where we recorded the least openness among treatments by the second year of treatment. Similarly, coverage of bobwhite food and deer forage plant species was greatest in Seedbank Burned. Biomass (kg/ha) of plant species known to be selected as forage by deer was greater in all treatments than in Control, and NCC (deer days/ha) was greatest in Seedbank Burned by year 2. Our results highlight differences in plant composition and structure following management of early successional communities. Where possible, we encourage managers to use fire instead of mowing to maintain plant communities, especially if food plants and enhanced structure at multiple levels for bobwhite, wild turkey, and deer are management objectives. Furthermore, our results illustrate planting native grasses and forbs is not necessary to restore native early successional plant communities on most sites.

KEYWORDS

burning, early succession, mowing, native plant restoration, northern bobwhite, seedbank response, white-tailed deer, wild turkey

Federal and state agencies have worked to reverse the decline of native early successional communities in recent years. Shifts in land use practices, urbanization, fire suppression, and forest maturation all have contributed to significant landscape changes across the eastern U.S. and a decline of early successional communities (Brennan 1991, Noss et al. 1995, Askins 2001, Noss 2013). The loss of native early successional plant communities has corresponded with a decline in wildlife populations that require those communities (Brady et al. 1998, Kirkland and Hart 1999, Pruitt 2000, Askins 2001, Mcchesney and Anderson 2015). In response, the USDA-Natural Resources Conservation Service and Farm Services Agency offer cost-share programs that provide technical and financial assistance to landowners to restore plant communities on private lands (USDA 2016). In addition, many state wildlife agencies also have included early-succession management in their State Wildlife Agency Action Plans (North Carolina Wildlife Resources Commission 2005, Kentucky Department of Fish and Wildlife Resources 2013, Georgia Department of Natural Resources 2015, Tennessee Wildlife Resources Agency 2015), which guide wildlife management practices on state-owned lands and influence private lands management through their private lands biologists. All of these programs commonly promote use of herbicides to kill nonnative grasses and subsequent planting of native grasses and forbs (hereafter plantings) to restore native plant communities. However, research has highlighted problems commonly associated with planting, especially planting failure, cost, and the relative inability to control nonnative invasive plants without harming planted species (Barnes 2004, Rowe 2010). A more practical and efficient approach to restoring native plant communities on sites previously dominated by nonnative species involves managing natural revegetation from the seedbank (hereafter seedbank response) instead of planting (GeFellers et al. 2020). Selective spot-spray applications of herbicide in areas with only a seedbank response restored native plant communities and improved cover and food resources for various wildlife species equal to or better than planting and was 3.7 times less expensive (Harper et al. 2021).

Regardless of restoration technique, disturbance is necessary to maintain early successional plant communities in the eastern U.S., but the type of disturbance can influence the resulting plant community (MacDougall and Turkington 2007, Gruchy and Harper 2014, Harper 2017). Burning and mowing are common practices used to maintain early successional plant communities, and herbicides may be used in conjunction with disturbance to promote these communities (Harper 2007, Nanney et al. 2018, GeFellers et al. 2020). The most common method for maintaining early successional plant communities is mowing, and it is often chosen as an alternative to prescribed fire (Dykes 2005). However, mowing can be expensive because of labor, fuel, and depreciation of equipment (Wigginton and Meyerson 2018). Early successional plant communities managed by mowing often are dominated by grasses and lack openness at ground level (McCoy et al. 2001, Dykes 2005, Gruchy and Harper 2014). Litter build-up is encouraged by mowing in planted fields, which suppresses forb occurrence and contributes to the lack of openness at ground level, which impedes movement for many small wildlife species (McCoy et al. 2001, Harper et al. 2007, Doxon and Carroll 2010).

Prescribed fire is commonly promoted to maintain early successional plant communities, and the use of prescribed fire has increased considerably in the past 20 years (Stephens 2005, Weir et al. 2019). Prescribed fire sets back succession, consumes debris, creates openness at ground level, and stimulates the seedbank, which may enhance foraging conditions for various wildlife species (Buckner and Landers 1979, Lashley et al. 2011, Gruchy and Harper 2014, Nanney et al. 2018, Glow et al. 2019). Despite the potential advantages, there are challenges associated with burning, including technical expertise usually involving multiple people to burn safely, complications related to smoke management that often limit application of prescribed fire in many areas, and the legal liability associated with fire getting onto unintended areas (Haines et al. 2001, Weir 2009, Waldrop and Goodrick 2012). Considering both the advantages and potential disadvantages of common disturbance techniques, an evaluation of how they affect habitat quality for various wildlife in restored early successional plant communities is warranted to provide public and private land managers information needed to meet management objectives.

We developed a field experiment to assess plant community composition and structure in fields that were previously dominated by tall fescue and subsequently restored by planting native grasses and forbs or by seedbank response using strategic herbicide applications to control undesirable plant species (GeFellers et al. 2020). We used mowing or burning to maintain the restored communities, as both methods commonly are used to manage native early successional plant communities in the eastern U.S. Our research objective was to compare the effects of burning and mowing in combination with strategic herbicide applications as approaches for maintaining early successional communities that had been established using the two different methods (i.e., planting and seedbank response). Specifically, we wanted to evaluate plant communities following mowing or burning and assess the resulting food and cover values for the two most popular game species identified in State Wildlife Agency Action Plans in the region, white-tailed deer (hereafter deer; *Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*), as well as a conservation-priority gamebird species, northern bobwhite (*Colinus virginianus*), which has experienced a significant population decline over the past 5 decades (Brennan 1991, Church et al. 1993, Hernández et al. 2013, Olsen et al. 2016). We hypothesized burning would stimulate increased deer forage, increased coverage of bobwhite food plants, greater openness at ground level, and greater visual obstruction above 1 m compared to mowing because the thatch resulting from mowing suppresses seedbank response and plant growth. We hypothesized seedbank-response treatment units would have greater deer forage availability, greater coverage of bobwhite food plants, and increased openness at ground level than planted treatment units, regardless of disturbance technique, because planted units would have greater grass coverage and fewer forbs. Lastly, we hypothesized tall fescue-dominated controls would have the least deer forage availability, coverage of bobwhite food species, openness at ground level, and visual obstruction above 1 m because sod-forming grasses suppress germination of the seedbank and reduce relative abundance of forbs.

STUDY AREA

We conducted our study at 11 sites in Tennessee and Alabama, USA. Each site was represented by a 2.5 to 5.5-ha field dominated by tall fescue. Nine of the study sites were in Bedford, Blount, Cocke, Cumberland, Hamblen, Jefferson, Monroe, Sevier and White Counties, TN on Tennessee Valley Authority (TVA), Tennessee Wildlife Resources Agency (TWRA), and Great Smoky Mountains National Park property. Two additional study sites were on TVA and Alabama Department of Conservation and Natural Resources (ADCNR) property in Franklin and Jackson Counties, AL. A previous study was initiated in 2015 by partitioning each field into 3 equally-sized treatment units (Planted, Seedbank, and tall fescue Control; GeFellers et al. 2020). Treatment units varied in size from 0.5 to 1.0 ha. Tall fescue was controlled with broadcast applications of glyphosate (2.8 kg ai ha^{-1}) in all study areas in November 2015 prior to initiating 2 establishment treatments (Planted and Seedbank) in spring 2016 as described by GeFellers (2019). Evaluation of the plant community responding to the establishment techniques was described by GeFellers et al. (2020), and a comparison of the establishment techniques on habitat quality for several wildlife species was described by Harper et al. (2021). Elevation at study sites ranged from 180 m at the Franklin County, AL site to 658 m above mean sea level at the Cumberland County, TN site. Soils at 10 of the 11 sites were loam or silt/loam, whereas one site (Jackson County, Alabama) had silt clay (Soil Survey Staff 2021).

METHODS

In spring 2019, we divided each of the establishment treatment units (Planted and Seedbank) at each site into 2 units and randomly assigned a management treatment (Mow and Burn) to each. Thus, we created four treatment units that varied in size from 0.36 to 0.95 ha at each of the 11 sites: Planted Burn, Planted Mow, Seedbank Burn, and Seedbank Mow. We also maintained the tall fescue-dominated Control at each site.

Burning treatments

Prescribed fires were conducted by location managers at each site in the appropriate units. Location managers installed firebreaks around units that were selected to burn using either disking, tilling, or application of water. Backing fires were used at each site to establish a blackened area on the downwind side of the burn unit adjacent to the firebreak, and all units were burned with backing fire for complete fine fuel consumption unless conditions demanded heading fires to consume fuels. Average flame lengths were 0.8 m and all fires were low to moderate intensity. We conducted prescribed fire at each site in 2019 and 2020 during the late dormant season (February-early April), which is consistent with when most prescribed fire is implemented to maintain fields enrolled in conservation programs (Dryden 2001, Harper et al. 2007). All burns were conducted within the following prescription parameters: relative humidity 20–50%, wind speed 0–16km/h, temperature −1–24°C, and cloud cover <50%.

Mowing treatments

Mowing was conducted in 2019 and 2020 by location managers or contractors using a tractor-mounted rotary mower during the dormant season (February–March). All units were mowed to a height of approximately 25.4 cm. Control units were maintained by annual late-winter mowing, consistent with how fallow fields dominated by tall fescue are commonly managed in the region (Dykes 2005).

Herbicide treatments

We used selective herbicide applications in 2019 and 2020 to control undesirable species throughout the study in all treatment units. We used spot-spray applications with 15-L (4 gal) backpack sprayers (Solo USA, Newport News, VA, USA) or a 95-L (25-gal) ATV sprayer (Cabelas, Sydney, NE, USA) equipped with a spray gun (Green Garde®, H.D. Hudson Manufacturing Company, Chicago, IL, USA). We used imazapic, glyphosate, imazapyr, clethodim, triclopyr, and triclopyr + fluroxypyr to control undesirable nonnative species in both Seedbank and Planted units. We used selective spot-spray herbicide applications once during spring and once during summer to control undesirable warm-season species, such as johnsongrass (*Sorghum halepense*), sericea lespedeza (*Lespedeza cuneata*), or bermudagrass (*Cynodon dactylon*). We made one application during fall/winter to control undesirable cool-season species, such as common henbit (*Lamium amplexicaule*) or purple deadnettle (*Lamium purpureum*), if needed. We controlled nonnative invasive species in Seedbank units regardless of plant coverage. We controlled nonnative invasive species in Planted units when those plants approached 30% coverage in accordance with recommendations of private lands biologists with ADCNR and TWRA to remain in compliance with what is permitted and recommended to landowners enrolled in state and USDA conservation programs. We controlled nonnative invasive species when possible with herbicides that would not damage planted species in Planted units; however, there are no options to control some invasive species, such as bermudagrass or sericea lespedeza, without harming planted native grasses and forbs. Undesirable vegetation was categorized as nonnative invasive plants, but we also controlled 2 native species, blackberry (*Rubus* spp.) and black locust (*Robinia pseudoacacia*), when coverage approached 30%. We spot-sprayed Control units with a mixture of triclopyr (0.10 kg ai/ha) and fluroxypyr (0.31 kg ai/ha) using an ATV sprayer in May 2019 to control woody encroachment. No additional herbicide treatment was used in Control units.

Vegetation composition

We recorded vegetation composition, measured vegetation structure and litter depth, and collected deer forage species in each treatment and control mid-June-early August 2019 and 2020 (once at each site each year). We used line-point intercept sampling along 4, 50-m transects placed systematically in all treatment units. We recorded vegetation to species at 2-m intervals. We calculated percent coverage of various plants or plant groups by dividing the number of detections by the total number of sampling points ($n = 25$) on that transect. We split plants into 6 plant groups including grass, forbs, native grasses, nonnative grasses, semi-woody, and woody. Grass included all grass species detected. We further divided grass into native and nonnative grasses which included all native grasses detected and nonnative grasses detected. Forb included all broadleaf herbaceous species. Woody included tree and shrub species. Semi-woody included brambles and vines. We then calculated percent coverage of each plant or plant group for each unit by averaging percent cover of all 4 transects in that unit (Table 1). Vegetation coverage was used to calculate and observe changes in percent coverage of bobwhite food and deer forage plant species following management. We considered plants producing either seed or soft mast readily consumed by bobwhite as bobwhite food plants, and we included plants that have been identified as selected by deer in our region of study as deer forage plant species (Rosene and Freeman 1988, Lashley et al. 2011, Johnson et al. 2018, Nanney et al. 2018, Harper et al. 2021).

Forage samples

We collected 2 forage samples along each transect in a 0.5 m^2 PVC frame (total of 8 per treatment unit). We positioned the frame adjacent to the transect at random locations between 0 and 50 m. All live portions of plants at

TABLE 1 Mean coverage (%) and standard error (SE) of plant groups detected in 5 early successional plant community treatments across all study sites (n = 11) in Tennessee and Alabama, USA, June–August 2019 and 2020.

	Treatment[a]														
	CL[b]			PB[c]			PM[d]			SB[e]			SM[f]		
Life form	$\bar{x}$[a]	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
2019[g]															
Grass[h]	98.8	(0.4)	Aa	69.2	(5.21)	Ba	66.4	(6.95)	Bb	57.6	(6.42)	Ba	61.9	(6.26)	Ba
NWSG[i]	20.2	(6.16)	Ba	44.5	(6.63)	Aa	39.9	(7.32)	Ab	40.2	(6.88)	Aa	42.3	(7.97)	Aa
NNG[j]	87.2	(5.1)	Aa	26.8	(7.04)	Ba	26.0	(6.42)	Ba	17.3	(5.76)	Ba	16.8	(6.29)	Ba
Forb[k]	8.8	(4.71)	Ba	64.4	(5.48)	Aa	58.7	(7.0)	Aa	75.8	(4.73)	Aa	63.1	(6.79)	Aa
Semi-woody[l]	1.9	(0.98)	Ba	20.6	(5.23)	Aa	15.8	(4.64)	Aa	18.1	(4.24)	Aa	21.3	(5.37)	Aa
Woody[m]	0.3	(0.14)	Aa	2.4	(0.78)	Aa	3.8	(1.39)	Aa	5.3	(3.08)	Aa	5.2	(2.3)	Aa
BFP[n]	2.36	(0.96)	Ca	32.0	(6.93)	Ba	24.4	(5.55)	Ba	40.0	(8.17)	Aa	35.1	(8.4)	ABa
DFP[o]	3.4	(1.78)	Ca	52.8	(7.77)	Ba	44.4	(7.61)	Ba	67.2	(7.15)	Aa	60.9	(6.81)	ABa
2020															
Grass	98.0	(1.8)	Aa	80.7	(4.16)	ABCa	89.0	(3.51)	ABa	67.2	(2.84)	Ca	72.3	(5.80)	BCa
NWSG	9.7	(3.27)	Ba	56.6	(6.64)	Aa	69.2	(5.52)	Aa	50.7	(5.27)	Aa	54.6	(6.99)	Aa
NNG	96.5	(2.28)	Aa	30.0	(7.14)	Ba	26.1	(5.35)	Ba	15.5	(3.53)	Ba	17.7	(5.27)	Ba
Forb	12.2	(4.64)	Ca	52.3	(7.25)	Ba	44.6	(6.59)	Ba	81.9	(4.78)	Aa	60.9	(6.41)	ABa
Semi-woody	2.5	(1.22)	Ba	15.6	(3.89)	Aa	16.5	(3.77)	Aa	22.6	(4.76)	Aa	21.5	(4.04)	Aa
Woody	2.3	(1.19)	Aa	2.3	(0.81)	Aa	3.8	(1.31)	Aa	5.4	(1.78)	Aa	5.8	(1.73)	Aa
BFP	9.6	(2.56)	Ca	35.6	(5.79)	Ba	26.6	(3.73)	Ba	57.4	(5.86)	Aa	41.1	(4.18)	ABa
DFP	8.7	(3.53)	Ca	48.3	(6.79)	Ba	43.5	(7.47)	Ba	78.7	(3.91)	Aa	57.3	(6.37)	ABa

[a]Within year, treatments with the same uppercase letter did not differ ($P > 0.05$).

[b]Control.

[c]Planted Burned.

[d]Planted Mowed.

[e]Seedbank Burned.

[f]Seedbank Mowed

[h]Percent coverage of all grasses present in each treatment ($F^{4,40} = 3.21$, $P < 0.02$).

[i]Percent coverage of native warm-season grasses (>90%) including broomsedge bluestem (*Andropogon virginicus*), little bluestem (*Schizachyrium scoparium*), purpletop (*Tridens flavus*), and beaked panicgrass (*Panicum anceps*) ($F^{4,50} = 7.92$, $P < 0.001$).

[j]Percent coverage of non-native grasses (>90%), including tall fescue (*Schedonorus arundinaceus*), johnsongrass (*Sorghum halepense*), bermudagrass (*Cynodon dactylon*), and Japanese stiltgrass (*Microstegium vimineum*) ($F^{4,40} = 75.2$, $P < 0.001$).

[k]Percent coverage of forbs ($F^{4,50} = 2.79$, $P < 0.035$).

[l]Percent coverage of semi-woody includes brambles and vines ($F^{4,40} = 7.57$, $P < 0.001$).

[m]Percent coverage of trees and shrubs ($F^{4,40} = 2.38$, $P < 0.067$).

[n]Percent coverage of bobwhite food plants ($F^{4,40} = 19.17$, $P < 0.001$).

[o]Percent coverage of deer forage plants. Plant species that have been identified as selected by deer in our region of study were included as deer forage plants. ($F^{4,40} = 32.03$, $P < 0.001$).

and below 2 m were collected in each frame. We placed samples in forage collection bags and sorted them in the lab. We removed all stems and lignified portions of the plants during sorting. Leaves and tender growing portions of herbaceous plants and brambles, as well as twig ends and leaves of woody species and vines, were retained for weighing and nutrition analysis. Retained plant parts represented what is normally selected by deer (Lashley et al. 2014). We collected and identified plant species selected by deer and we separated young and old portions of leaves and stems for nutritional analysis. Selectivity of plant species by deer at each site was based on Harper et al. (2021). Young, tender growing portions of vegetation are more palatable and nutritious than older, more lignified plant parts; therefore, we weighed and analyzed young and old portions of the plants we collected separately.

We dried forage samples in walk-in drying ovens at 50°C for 72 hours and shipped dried samples to the Agriculture Service Laboratory at Clemson University for wet chemistry nutrient analysis (Ondarza and Ward 2013). We used forage biomass calculations and nutrient analysis results to estimate deer days/ha using an explicit nutritional constraints model (Hobbs and Swift 1985). Constraints for the model were set at crude protein (CP) levels of 14%. Crude protein levels of 14% represents nutritional requirements needed to support adult females during late pregnancy and peak lactation and exceed nutritional requirements for adult body maintenance in adult females during summer and requirements for adult males that are growing antlers and gaining body mass during summer (Asleson et al. 1996, NRC 2007, Lashley et al. 2011, Nanney et al. 2018, Harper et al. 2021).

Vegetation structure

We measured vegetation structure by estimating visual obstruction using a vertical vegetation profile board (Nudds 1977). The vegetation profile board was 2 m in height from the ground up and was separated into 5 alternating orange and white sections. The bottom stratum was from ground level up to 0.25 m, represented visual obstruction at the level where bobwhite and other small wildlife species occur. Visual obstruction from ground level up to 0.5 m represented cover that provides concealment for brooding wild turkey (Metzler and Speake 1985, Peoples et al. 1996). The upper 1.5 m was separated into 3 0.5-m strata which were used to evaluate structure important for deer fawns and adult deer (Huegel et al. 1986, DePerno et al. 2003). We recorded 2 visual obstruction measurements along each transect at the 14 and 34 m mark. One member of the research crew knelt at plot center (24 m) and estimated visual obstruction by placing each of the 5 profile board sections into 1 of 6 categories (e.g., 0 = no vegetation, 1 = 1–20% obstruction, 2 = 21–40% obstruction, etc.). We calculated average visual obstruction for each of the 5 profile board sections and compared across treatment units and years.

We recorded ground-sighting distance measurements to provide an index of openness at ground level (Gruchy and Harper 2014). We recorded a reading at the 14 m mark and at the 34 m mark on the transect tape. We used a sight-tube made of PVC pipe 5.1 cm in diameter to measure horizontal sighting distance at 10.2 cm above ground (approximate height of northern bobwhite). The observer looked through the sight-tube while another team member placed an orange target made of PVC in front of the sight-tube. The target was moved away from the sight-tube until the target was completely obscured by vegetation. The distance between the tube and target was recorded and averaged for each treatment unit.

Data analysis

We used a randomized block, repeated measures study design with treatment unit serving as the experimental unit. We averaged measurements from the 4 transects in each treatment unit to calculate the mean for each treatment unit. Results were obtained using analysis of variance (ANOVA), with linear models fit using package nlme (Pinheiro et al. 2021) in program R (v. 3.1.1 R Core Team 2020). Autocorrelation between remeasurements was checked and considered negligible for all models. Analysis determined the effects of treatment, year, and treatment × year interactions on plant composition, coverage of bobwhite and deer food plant species, visual obstruction, openness at ground level, deer forage estimates, and NCC estimates. If we documented treatment × year effects, we created interaction plots to assist with interpretation. If only treatment or year effects were significant, we used package emmeans (Lenth 2018) to compare means within year among treatments and between years within treatments using Tukey's Honest Significant Difference (HSD) p-value adjustment. We used a significance level of $\alpha = 0.05$ for all contrasts.

RESULTS

We detected treatment, year, and treatment × year effects for grass coverage. By the second year of treatment, the Planted treatments were similar to Control in total grass coverage (Table 1). Grass coverage increased 17% from 2019 to 2020 in all treatments except Planted Mowed, which increased by 34%. Coverage of native grass was greater in all treatment units than Control, and increased 26–29% in all treatments except Planted Mowed, which increased 73% (Table 1). Coverage of nonnative grass was greatest in Control, and remained similar across years by treatment, but was approximately 60% greater in the Planted treatments than Seedbank treatments. We detected treatment and treatment × year effects for forb coverage. Forb coverage was greater in all treatment units than Control, and ranged from 12% in Control to 82% in Seedbank Burned in 2020 (Table 1). Forb coverage decreased 24% in Planted Mowed, 19% in Planted Burned, and 3% in Seedbank Mowed, but increased 8% in Seedbank Burned from 2019 to 2020. All treatment units had greater semi-woody coverage than Control. Semi-woody and woody coverage remained similar among treatment units; we did not detect differences across years.

Visual obstruction at the <25 cm stratum was >97% and similar among all treatments and Control in 2019 and 2020 ($F_{1,50} = 0.64$, $P = 0.636$). However, visual obstruction at the 26–50 cm strata was 19%–30% greater in treatment units than Control ($F_{1,50} = 11.62$, $P < 0.001$). Similarly, visual obstruction at the 51–100 cm strata ($F_{1,50} = 10.54$, $P < 0.001$) was 55%–119% greater in treatment units than Control. In general, burning tended to maintain taller structure than mowing at the 51–100 cm stratum and above following the second management treatment (Figure 1). Openness at ground level was 30% greater in Seedbank Burned than Planted Mowed. In 2020, openness at ground level averaged 71.5 cm in Control, 68.2 cm in Planted Burned, 66.4 cm in Planted Mowed, 86.2 cm in Seedbank Burned, and 76.1 cm in Seedbank Mowed ($F_{1,50} = 1.69$, $P < 0.17$) and though the effect size was >30% greater in Seedbank Burned than Planted Mowed, openness at ground level was statistically similar among treatments.

We detected treatment and year effects for coverage of bobwhite food plants, and we detected treatment effects for coverage of deer forage plants (Table 1). Coverage of bobwhite food plants and deer forage plants were greater in all treatment units than Control. Coverage of bobwhite food plants and deer forage plants tended to be greater in Seedbank units than Planted units and greater in Burned units than Mowed units. Following two years of treatment, coverage of bobwhite food plants ($F_{1,50} = 19.17$, $P < 0.001$) and deer forage plants ($F_{1,50} = 32.03$, $P < 0.001$) were greater in Seedbank Burned than in either Planted treatments.

We also detected treatment effects for availability of selected deer forage biomass as well as NCC (Tables 2 and 3). Availability of selected deer forage and NCC were greater in all treatments than Control. Almost all of the deer forage collected in Planted units was from plants germinating from the seedbank as ≤6% of the deer forage collected in Planted Mowed and Planted Burned was represented by planted species. The most common species that responded from the seedbank in Planted units included common ragweed (*Ambrosia artemisiifolia*), Canada goldenrod (*Solidago canadensis*), blackberry, obtuse-leaved tick trefoil (*Desmodium obtusum*), and hairy white oldfield aster (*Symphyotrichum pilosum*). These species represented 75% of the coverage of species included as deer forage plants in Planted units. Deer days/ha were approximately 8 times greater in Seedbank Burned than Control (Table 3).

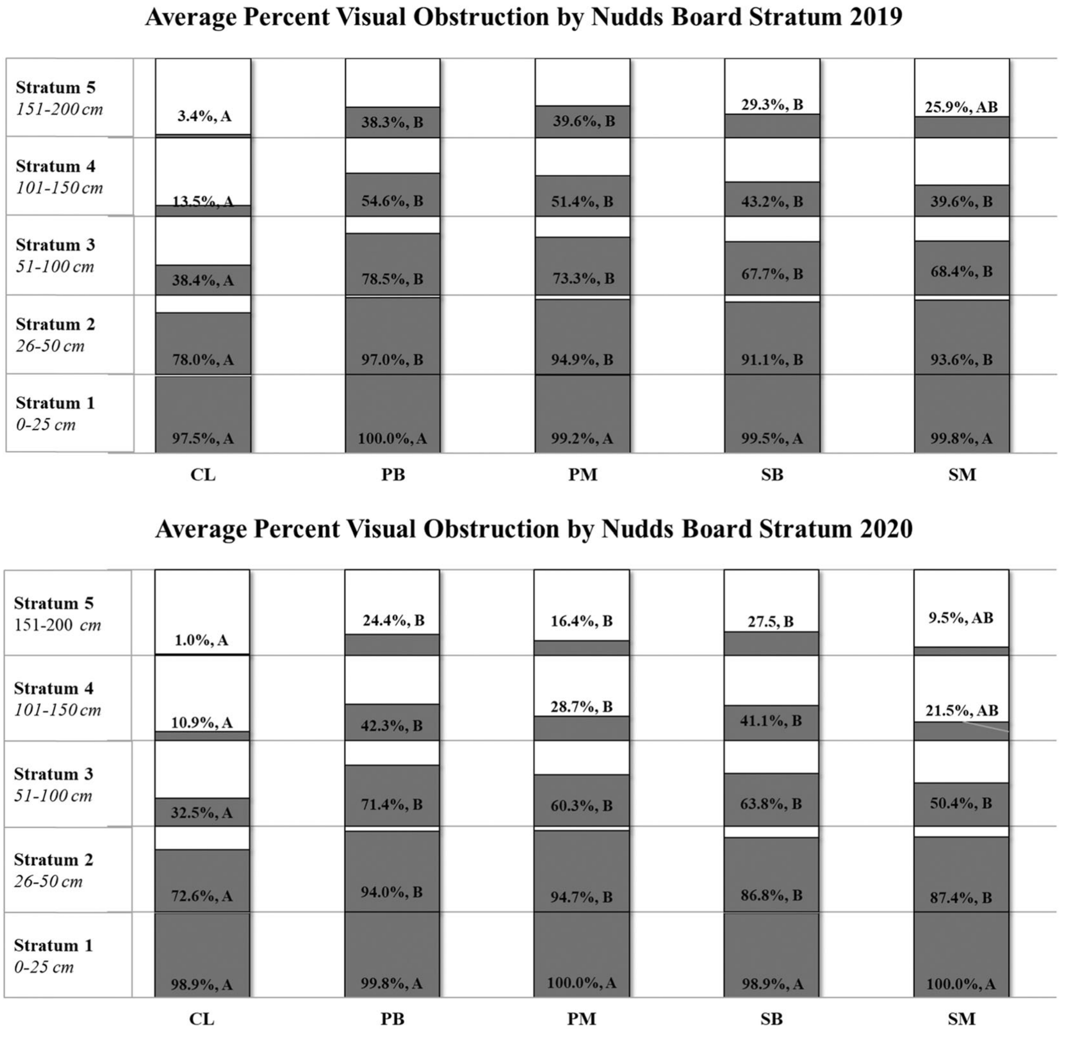

FIGURE 1 Mean percent visual obstruction during June–August 2019 and 2020 at all study sites ($n = 11$) in Tennessee and Alabama, USA, following burn and mow treatments. Different letters between treatments within a stratum represent significant differences in visual obstruction.

DISCUSSION

Our study compared effects of the 2 most common management techniques to maintain early successional plant communities in the eastern U.S., and we related those effects to habitat conditions for the 2 most common game species and an iconic gamebird undergoing precipitous population decline. By the second year of treatment, burning produced increased forb coverage and taller structure compared to mowing, which supported our hypotheses. Burning also resulted in greater coverage of bobwhite food plants and deer forage plants, also supporting our original hypotheses. Planting native grasses, in contrast, increased grass coverage, limited forb coverage, and reduced food availability for focal species. Although the effect size was 20% greater in Seedbank Burned than Control, we did not detect a significant treatment effect for openness at ground level, which was counter to our hypothesis. Following GeFellers et al. (2020) and Harper et al. (2021), our data continue to demonstrate that planting native grasses and forbs, whether managed by mowing or burning, is not necessary to enhance the food or

TABLE 2 Mean ± SE deer forage biomass (kg/ha) by treatment for all study sites ($n = 11$) in Tennessee and Alabama, USA, June–August 2019 and 2020.

Treatment[a]	2019[b]		2020
CL[c]	104 ± 73 A		102 ± 50 A
PB[d]	707 ± 161 B		523 ± 118 B
PM[e]	623 ± 211 B		548 ± 127 B
SB[f]	629 ± 168 B		745 ± 154 B
SM[g]	647 ± 120 B		604 ± 108 B
$F_{4,40}$		9.58	
P		<0.001	

[a]Treatments with the same uppercase letter did not differ ($P > 0.05$).
[b]No effect of year ($P = 0.211$).
[c]Control.
[d]Planted Burned.
[e]Planted Mowed.
[f]Seedbank Burned.
[g]Seedbank Mowed.

TABLE 3 Mean ± SE nutritional carrying capacity (deer days/ha) by treatment for all study sites ($n = 11$) in Tennessee and Alabama, USA, June–August 2019 and 2020.

Treatment[a]	2019[b]		2020
CL[c]	37 ± 16 A		19 ± 8 A
PB[d]	192 ± 42 B		206 ± 48 B
PM[e]	164 ± 39 B		185 ± 41 B
SB[f]	212 ± 50 B		279 ± 57 B
SM[g]	209 ± 51 B		171 ± 34 B
$F_{4,40}$		7.04	
P		0.0002	

[a]Treatments with the same uppercase letter did not differ ($P > 0.05$).
[b]No effect of year ($P = 0.42$).
[c]Control.
[d]Planted Burned.
[e]Planted Mowed.
[f]Seedbank Burned.
[g]Seedbank Mowed.

structural requirements of deer, wild turkey, or bobwhite when converting fields dominated by nonnative grasses to native early successional plant communities.

Coverage of grass tended to increase in all treatments from 2019 to 2020, but especially in Planted Mowed. By the second year of treatment, grass coverage in the Planted treatments averaged 85%, far in excess of what bobwhite require or use (Brooke et al. 2016). Unger et al. (2015) reported planted native grass coverage increased from 49% to 77% following burning, and bobwhite avoided those areas. In our Seedbank treatment units where native grasses were never planted, total grass coverage increased from approximately 60% in 2019 to nearly 70% in 2020, and native grass coverage averaged 52% by the second year. Bobwhite nest and brood locations in Kentucky averaged 15% and 5% coverage of native grasses, respectively (Brooke et al. 2016). Additionally, deer do not select grass to eat during the growing season (Korschgen et al. 1980, Lashley et al. 2011, Nanney et al. 2018, Harper et al. 2021), and wild turkeys select forb-dominated plant communities when available for brooding, similar to bobwhite (Healy 1985, Campo et al. 1989, Peoples et al. 1996), further supporting the belief that early successional plant communities managed for these species should not have >20–30% grass coverage. Gruchy and Harper (2014) and Brooke and Harper (2016) evaluated techniques to reduce density of planted native grasses and recommended heavy disking following burning or applications of glyphosate or imazapyr to achieve 10–30% grass coverage.

As grass coverage increased, forb coverage tended to decrease in Planted Burned and Planted Mowed, remained similar in Seedbank Mowed, but forbs increased 8% in Seedbank Burned from 2019 to 2020. Grman et al. (2020) reported planted native grasses suppressed forb coverage and reduced plant diversity. We observed similar effects on forb coverage after management in units that were restored by planting. All prescribed burns used during our work took place during the dormant season. Varying the season of burning may elicit changes in plant composition (Howe 1995, Gruchy et al. 2009, Gruchy and Harper 2014, Weir and Scasta 2017). However, forb coverage in areas with dense planted native grass may remain suppressed (<10% coverage) regardless of timing of burning (Holcomb et al. 2014). Before we applied management treatments, the planted units averaged 64% coverage of forbs (Harper et al. 2021). By 2020, Planted Burned averaged 52% and Planted Mowed averaged 45% forb coverage. Mowing also led to reduced forb coverage. Fields restored via seedbank response averaged 72% forb coverage before any management occurred (Harper et al. 2021). By 2020, forb coverage averaged 82% in Seedbank Burned and 61% in Seedbank Mowed.

Coverage of semi-woody and woody plants was similar among treatments and semi-woody coverage was greater in treatment units than Control. Coverage of semi-woody and woody plants is considered desirable for deer, wild turkey, and bobwhite. Blackberry and raspberry (*Rubus occidentalis*) were included in semi-woody, and several woody species we detected were selected deer forages, and the structure these woody species provide is important for nesting wild turkey (Badyaev 1995, Moore et al. 2010). Coverage of semi-woody/woody species is requisite for bobwhite, which has been characterized as a shrubland-obligate species (Crosby et al. 2015). Brooke et al. (2015) reported bobwhite locations averaged <40 m from woody cover during both the breeding and nonbreeding seasons, and Klimstra and Roseberry (1975) identified preferred nesting cover as idle fields in the perennial weed/bramble/early shrub phase of succession, which is consistent with the vegetation present in our Seedbank treatment units.

Visual obstruction as influenced by the structure of vegetation may determine occupancy and use of an area by various wildlife species (Swanson et al. 1999, Lashley et al. 2015, Kroeger et al. 2020). Visual obstruction and habitat use by certain wildlife species may vary as vegetation type, density, and height changes (Winter et al. 2005). Deer bedsites generally are located where taller vegetation provides greater visual obstruction (Huegel et al. 1986, Uresk et al. 1999, DePerno et al. 2003, Chitwood et al. 2017). Wild turkeys typically select nest locations with greater visual obstruction from 50–150 cm, and nest success has been reported greater with increased visual obstruction from 50–100 cm (Badyaev 1995, Kilburg et al. 2014, Johnson et al. 2022). All of our treatments provided greater visual obstruction at the 50–100 cm level than Control. Visual obstruction at the 125–150 cm level was most influential on microsite selection by bobwhite during the breeding season in Kentucky (Brooke et al. 2015), and our burned treatments had the same structure, more so than mowed treatments.

Openness at ground level is important for bobwhite and wild turkey, especially for broods. Insect and seed availability are inconsequential when adult bobwhites and broods cannot effectively forage because of thick, impeding vegetation (Barnes et al. 1995, Taylor et al. 1999, Collins et al. 2009, Moorman et al. 2013). Although we did not detect differences among treatments, Seedbank Burned tended to have greater openness at ground level than planted units by the second year of treatment. Burning removes accumulated litter and further facilitates movement of bobwhites and their broods (Kamps et al. 2017, Sinnott et al. 2021). Gruchy and Harper (2014) and

McCoy et al. (2001) reported mowing increased litter depth and reduced openness at ground level when compared to disking or burning. Our data also indicate an increase in grass coverage to the extent present in our treatments, and especially the Planted treatments, reduces openness at ground level and may limit movement of young bobwhites and wild turkey broods.

Increased forb coverage can improve components of habitat for many wildlife species. Coverage of bobwhite food plants is important for bobwhite during winter months when energy requirements are high and food limitations during this time can result in decreased survival (Robel 1963, Roseberry 1964, Madison et al. 2002). We considered 113 plants as bobwhite food plants, the majority of which were forbs. Grasses only comprised 19% of bobwhite food plants. The combination of seedbank response and burning resulted in greater coverage of bobwhite food plants than any other restoration/management combination. Additionally, cover provided by forb-dominated communities typically facilitates movement of bobwhite and wild turkey broods while supporting more insects than grass-dominated communities (Hill 1985, Burger et al. 1993, Harper et al. 2001, Fettinger et al. 2002, Jamison et al. 2002).

Deer forage biomass estimates were similar among all treatment units, however >95% of deer forages collected in planted units in 2020 were not planted species, but were species that responded from the seedbank. Previous studies conducted in the same region as our study reported deer selected forbs during spring and summer when individuals are lactating and growing (Lashley et al. 2011, Nanney et al. 2018, Harper et al. 2021). We stress the importance of forbs for deer because more private landowners and state agencies manage property for deer in the eastern U.S. than any other species (McShea 2012), and if managing early successional communities for deer benefits a wide array of wildlife, then attention to deer management is warranted even if deer is not a species of conservation concern (Harper et al. 2021). Simply eliminating coverage of nonnative grass and allowing the seedbank to respond allowed greater forb coverage and increased the NCC for deer by approximately 800%.

MANAGEMENT IMPLICATIONS

Disturbance is required to maintain early successional communities in the eastern U.S., regardless of establishment technique. Following 2 years of evaluating the effects of burning and mowing on vegetation composition and structure, we recommend managers use fire over mowing to set back succession and maintain early seral-stage communities, especially if increased food for bobwhite and deer and enhanced structure at multiple levels for deer, wild turkey, and bobwhite are management objectives. Fire frequency should be determined by plant community response. We recommend selective spot-spray herbicide applications to reduce undesirable plant species and encourage colonization of additional desirable species, and we encourage managers to consider using seedbank response and natural colonization of plants instead of planting native grasses and forbs to more effectively and efficiently promote and enhance habitat for bobwhite, wild turkey, and deer. Athough planting is increasingly justified as a means to ensure the availability of nectar resources for pollinators, fostering and maintaining the seedbank response with prescribed fire encourages a range of desirable forbs that benefit pollinators along with the species addressed in this study (GeFellers et al. 2020, Harper et al. 2021). Natural Resources Conservation Service in Tennessee allows restoration of native plant communities without planting in the Conservation Reserve Program, and we encourage other state NRCS technical committees to allow natural revegetation via seedbank response without mandating planting native grasses and forbs.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

No ethical information provided.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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Additional supporting material may be found in the online version of this article at the publisher's web-site.

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