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Article

Harvesting Effects on Species Composition and Distribution of Cover Attributes in Mixed Native Warm-Season Grass Stands

Vitalis W. Temu [1,*], Brian S. Baldwin [2], K. Raja Reddy [2] and Samuel K. Riffell [3,†]

[1] Agricultural Research Station, Virginia State University, 238 M.T. Carter Bldg, Box 9061, Petersburg, VA 23806, USA

[2] Plant and Soil Sciences Department, Mississippi State University, Mississippi State, MS 39762, USA; E-Mails: BBaldwin@pss.msstate.edu (B.B.); krreddy@pss.msstate.edu (K.R.)

[3] Wildlife, Fisheries, & Aquaculture Department, Mississippi State University, Mississippi State, MS 39762, USA

[†] Deceased.

* Author to whom correspondence should be addressed; E-Mail: vtemu@vsu.edu; Tel.: +1-804-524-6717; Fax: +1-804-524-5186.

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Abstract: Managing grasslands for forage and ground-nesting bird habitat requires appropriate defoliation strategies. Subsequent early-summer species composition in mixed stands of native warm-season grasses (Indiangrass (IG, *Sorghastrum nutans*), big bluestem (BB, *Andropogon gerardii*) and little bluestem (LB, *Schizachyrium scoparium*)) responding to harvest intervals (treatments, 30, 40, 60, 90 or 120 d) and durations (years in production) was assessed. Over three years, phased May harvestings were initiated on sets of randomized plots, ≥90 cm apart, in five replications (blocks) to produce one-, two- and three-year-old stands. Two weeks after harvest, the frequencies of occurrence of plant species, litter and bare ground, diagonally across each plot (line intercept), were compared. Harvest intervals did not influence proportions of dominant plant species, occurrence of major plant types or litter, but increased that of bare ground patches. Harvest duration increased the occurrence of herbaceous forbs and bare ground patches, decreased that of tall-growing forbs and litter, but without affecting that of perennial grasses, following a year with more September rainfall. Data suggest that one- or two-year full-season forage harvesting may not compromise subsequent breeding habitat for bobwhites and other ground-nesting birds in similar stands. It may take longer than a year's rest for similar stands to recover from such changes in species composition.

Keywords: native grass; species composition; distribution; harvest interval; harvest duration; ground cover; grassland birds; wildlife habitat; ground-nesting

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1. Introduction

Tall-grass prairies once covered most of central North America and parts of the southeast [1,2] extending as far north as Canada and east into Mississippi and Alabama [3]. In the southeastern U.S., these tall-grass prairies were formed by native warm-season grasses (NWSG) dominated by perennials, such as big bluestem (BB, *Andropogon gerardii* Vitman), switchgrass (SG, *Panicum virgatum* L.), little bluestem, (LB, *Schizachyrium scoparium* (Michx) Nash), eastern gamagrass (EG, *Tripsacum dactyloides* (L.) L.) and Indiangrass (IG, *Sorghastrum nutans* (L.) Nash) interspersed with forbs and shrubs [1,3]. Other major grasses included Canada wildrye (*Elymus canadensis* L.) and prairie cordgrass (*Spartina pectinata* Bosc ex Link). In Mississippi, forbs, most of which are classified as wildflowers, comprised about one-third of plants in the prairies [1]. There were also sideoats grama (*Bouteloua curtipendula* (Michx) Torr.), Florida paspalum (*Paspalum floridanum* Michx), panicgrasses (*Dichanthelium* sp.), rivercane (*Arundinaria gigantea* (Walter) Muhl.) and purpletop (*Tridens flavus* (L.) Hitchc) [1].

These tall-grass prairies provided food and cover to grassland birds (northern bobwhite (*Colinus virginianus*), hereafter "bobwhite", dickcissel (*Spiza americana*) and eastern meadowlark (*Sturnella magna*)) [4,5]. These structurally diverse plant communities had voids close to the ground for easy movements of young birds and provided good nest-building materials [1,6,7]. For livestock and wild ungulates, the NWSGs provided high quality forages during summer months [8,9]. Some workers on NWSGs have reported 6%–12% crude protein and ≥70% dry matter digestibility [10,11]. Following agricultural intensification, most forage NWSGs were replaced with species lacking the most desirable wildlife habitat quality features. These introduced grasses were often planted in monocultures, creating spatially uniform short thick stands, which made poor wildlife habitat [5,12–15]. In the southeastern U.S., this impacted ground-nesting birds, especially bobwhites, which suffered rapid population declines [16]. Incorporating NWSGs in managed grasslands is now intended to improve both summer forage production and habitat for ground-nesting birds.

1.1. Floristic Composition for Ground-Nesting Birds

A typical habitat for bobwhites and other ground-nesting birds should have a diversity of plant species, with bunch grasses accounting for about 70% cover, interspersed with forbs and legumes (≥20% cover), scattered shrubs, seed producers, and insect-attracting wild flowers for year-round food availability [1]. For brood rearing, however, bobwhites prefer habitats characterized by native bunch grasses (about 30% cover) with about 40% forbs and legumes interspersed with scattered shrubs or brushes. In mixed stands, forbs may either be food (seeds and leaves) to birds or bear flowers that attract insects to be eaten. Bobwhites also require about 20%–50% bare ground for good visibility and access to food [1,17]. This is also consistent with their nesting preference for grassy areas located in dead NWSG clumps of the previous year's growth.

1.2. Managing Floristic Composition

Before agricultural intensification, extensive grazing by buffalo (*Bison bison*) coupled with periodic natural disturbances maintained the tall-grass prairies at the early vegetation succession [1,18,19]. Such disturbances favored structural heterogeneity and floristic diversity in the prairies. Grazers, for example, selectively fed on specific plant parts and/or growth stages [20–22]. Thus, grazing removed the apical meristems of lead tillers and stimulated the growth of axillary buds and vegetative tillers [23,24]. This likely suppressed growth of the more competitive tall-growing species in favor of their shorter companions [25,26].

In managed NWSG communities, sustaining a desirable floristic composition is challenging and requires strategic ecological manipulations [27]. In mixed stands, for example, defoliation influences the survival of plant species differently, depending on their ability to recover from the tissue damages [28,29]. Over time, however, this may lead to notable changes in species composition and/or diversity [28,30,31]. Thus, mowing can be used to improve grassland bird habitat by setting back vegetation succession [32]. Other management practices, such as disking and prescribed burning, may also be used to meet desirable basic habitat quality requirements of particular grassland birds [33].

1.3. Justification and Objectives

In the southeastern U.S., a growing recognition of the ecological importance of tall-growing NWSGs in managed grasslands has aroused interest in their management requirements. Various stakeholders are working on incorporating NWSGs in managed grasslands to increase summer forage availability, promote soil and water conservation and/or improve wildlife habitat quality. While most NWSGs are good for both forage and wildlife habitat, a typical management approach for one aspect may compromise the other. For example, conventional forage harvesting often destroys breeding habitat for ground-nesting birds. However, information on appropriate management strategies to improve forage production without severe negative effects on critical ground-nesting bird habitat is scarce. Therefore, this study was aimed at evaluating the effects of harvest intervals and duration (years in production) on subsequent species composition, spatial distribution of dominant plant types and ground cover in mixed NWSG stands dominated by IG, BB, and LB.

2. Experimental Section

2.1. Location and Sequential Field Layout

The study was conducted at Bryan Farms, Clay County (33°39′ N; 88°34′ W), Mississippi, USA, in unfertilized conservation field buffers planted with mixed NWSG stands, which were only two years old and basically at their early vegetation succession stage. Dominant soils in the study area were Griffith silty clay, classified as fine, smectitic, thermic Aquic Hapludert with a pH ranging from

5.0 to 5.6 and Okolona silty clay, classified as fine, smectitic, thermic Oxyaquic Hapludert with a pH range of 6.0 –7.8. The crop fields were rotationally planted in corn or soybean.

In 2005, a seed mixture of 1.12 kg BB, 2.24 kg LB and 1.12 kg IG hectare^{-1} was sown in prepared seedbeds and allowed to grow without such anthropogenic disturbances as harvesting, cultivation or machine traffic for two years. All field buffers were seeded in a single operation, and extended post-emergence herbicide (imazapic at 0.28 kg active ingredient ha^{-1}) ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid) was applied, to control weeds. In late spring 2007, five 7.5 × 1-m parallel strips, at least 3 m apart, were randomly assigned to five, four and three harvests at 30-, 40- and 60-d intervals, respectively, or only two harvests at 90- or 120-d intervals (Figure 1), giving five harvest intervals per block. A 1 meter-wide Carter Flail Forage Harvester (Carter Manufacturing Company, Inc.; Brookston, IN, USA) was used to cut and remove the biomass. Cutting height was set at 10–12 cm. The 90-d interval mimicked a standard practice of harvesting a hay crop early in the growing season and then stockpiling the regrowth for late-season grazing or conservation uses. In a randomized complete block design, these five harvest intervals (treatments) were replicated in five blocks, differing in species composition, three in two buffers of one crop field and two in another field, about 5 km away. With each harvest operation, plants in separating alleys were also trimmed to the same height to avoid shading.

During the spring of 2008, other 7.5 × 1-m plots were marked next to each previous-year plot with 90-cm alleys between the first- and second-year plots, for each harvest interval. Plots harvested first in 2007 were designated Y207, indicating that they were in their second harvest year (Y2), but started in 2007 (07). Plots harvested first in 2008 adjacent to Y207 plots were designated Y108, indicating that they were in their first harvest year (Y1), but started in 2008 (08). In 2009, a third set of five 7.5 × 1-m plots were marked on one end of each block. This made a total 45 treatment plots; three for each of the five treatments in the five blocks. In each block and between the third year set of plots and the older ones, a reference area (control) was defined and protected from foot and machine traffic (Figure 1). Adding the third set of plots on respective block-ends was necessary to avoid possible negative effects of the two-year foot and machine traffic on plant growth around the first- and second-year plots. For each block, however, an area with relatively uniform species composition, terrain and plant vigor, large enough to accommodate all three sets of plots, was clearly defined in the first harvest year. This minimized within-block non-experimental variations. Plots started in 2009 were designated Y109. Their 2008 and 2007 counterparts were re-designated Y208 and Y307, respectively (Figure 1). By the third year (2009), there were plots with one, two and three years in production.

In mid-May of each year, all treatment-plots received a common/equalizing first harvest, after which regrowth was harvested on assigned dates throughout the summer. By the end of each growing season, all first- and second-year plots had 1, 2, 3 or 4 additional harvest(s), according to treatment. Occasionally, harvesting was hastened by one to two or delayed for up to six days to avoid major rainfall events, thus allowing optimum machine operation [34]. In spring 2009, the Y307 plots, with two years in production, were harvested only once in May to assess subsequent early-season recovery before being removed from the harvest regime (retired). There was no plot added in 2010, but existing ones were re-designated as Y209, Y308, and Y407, in order of their respective harvest initiation (Figure 1). By this designation, the Y407 experienced two consecutive harvest-years between May

2007 and 2009, inclusively, and likewise, the Y308 between May 2008 and 2010, while Y209 experienced only one complete harvest year between May 2009 and 2010.

2.2. Data Collection

For two consecutive years (2009 and 2010), floristic composition was estimated based on frequency of occurrence of plant species two weeks following the mid-May harvest [35]. A transect was stretched diagonally across each plot, between two fixed markers (painted wooden pegs), and plant species, litter or bare ground (bare) hits by a vertical pin lowered against one side of the tape tallied at 15-cm intervals. Tallies were recorded on 50 such points per plot. A prepared list of plant species identified in the study plots (Table 1) was used, against which the occurrences on sampling points (hits) were tallied. For grasses and short-growing (short) forbs, a species was recorded if the pin touched a stem. A tall-growing (tall) forb was recorded if the pin touched its stem or the mid-rib of a leaf. This tallying approach was necessary to minimize the chances of overestimating the occurrence of grasses and highly-branched short forbs or underestimating that of tall forbs, which were mostly at the seedling stage. Where plant parts of different species were superimposed, the topmost one touched by the pin was tallied. A hit on any fallen dead plant material found on the ground was tallied as litter. Likewise, dead plant parts, but still attached to their mother plants, were also counted as litter if recumbent on the ground. Bare was recorded if the pin did not touch any plant part. For each plot, the total number of hits per species, litter or bare ground was doubled and considered the respective percentage of occurrence.

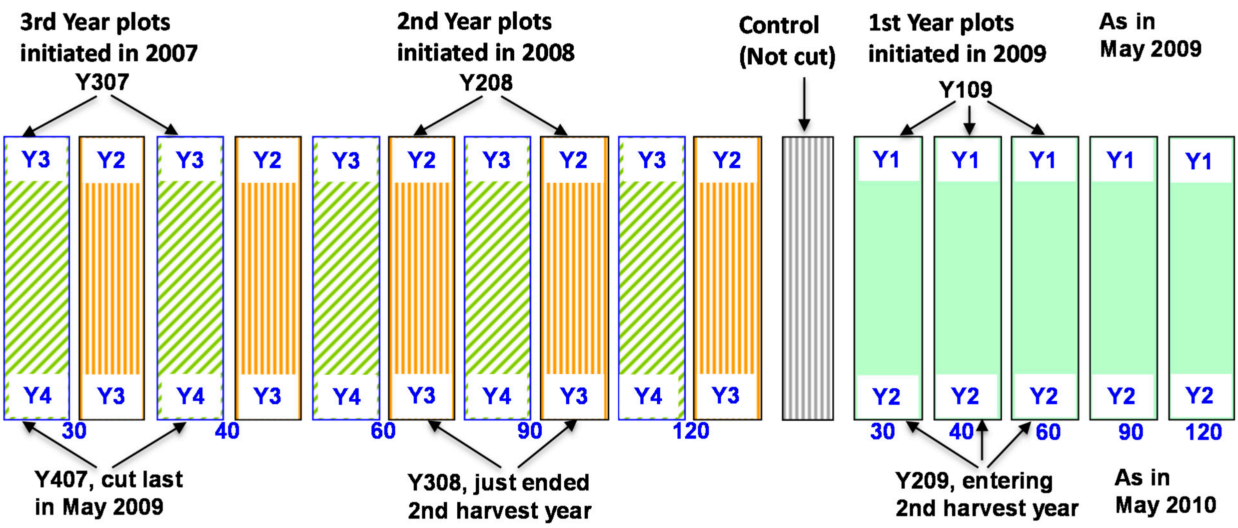

Figure 1. Schematic field layout of 7.5 m-long and 1 m-wide plots, in one replication, assigned to 30-, 40-, 60-, 90- and 120-d harvest intervals and sequentially introduced into the respective harvest regimes between May of 2007 and 2009. As in May 2009, plots labeled Y1, Y2, and Y3, were entering their first, second and third year, while in May 2010, the same plots were in their second, third, and fourth year in the trial, respectively.

2.3. Data Analyses

For statistical analyses, with respect to species composition, frequencies of occurrence of four dominant perennial grasses (perennials) were sorted by species, while other perennials, annual grasses (annuals), and grass-like species were grouped as such. The frequencies of the six most frequent forbs were entered by species, while other less frequent ones were grouped as other forbs and shrub-likes as such. With respect to plant type distribution, all plants were categorized as perennial grasses, annual grasses, short and tall forbs, grass-like and shrub-like. Data were subjected to analysis of variance (ANOVA) for the effects of harvest interval, harvest year, and harvest duration, on the subsequent early-season spatial distribution of major plant species and types, based on the frequencies of occurrence, using the general linear model of SAS [36]. Harvest duration compared stands in first and second harvest year plots assigned to a harvest interval, within a harvest year. A randomized complete block design with five replications was adopted. Mean separation was by Fisher's protected least significant difference (LSD) at $\alpha = 0.05$. For mean comparison, the data were first arcsine transformed, but the results are presented as the means of the original data.

Data for each habitat quality attribute (species, plant type, litter and bare patches) were first analyzed to check for interactions: harvest interval × year, harvest interval × harvest duration and harvest duration × year. Significant harvest interval × year interactions were detected and treatment effects re-analyzed separately, by year, and the results are presented as such. There was no significant harvest interval × harvest duration or harvest duration × year interaction, so respective data were pooled across harvest intervals and years for comparing means between harvest durations. To assess if harvest durations affected species and plant-type distribution in 2009, respective mean frequencies of occurrence in Y109, Y208 and Y307 were compared. There being no more plots added in 2010, harvest duration comparisons were based on data from the same Y209 plots, which had just completed their first year, the Y308, ready to be retired, and the Y407, already retired in 2009.

3. Results and Discussion

3.1. Effects of Harvesting on Species Composition

A list of 36 plant species belonging to 14 families identified in the study area is presented in Table 1. The families and their order of species richness in brackets were: Poaceae (14), Asteraceae (five), Fabaceae (four), Cyperaceae (two), Rosaceae (two), Brassicaceae (one), Campanulaceae (one), Convolvulaceae (one), Geraniaceae (one), Onagraceae (one), Oxalidaceae (one), Polygonaceae (one), Solanaceae (one) and Ranunculaceae (one).

3.1.1. Proportions of Perennial Grass Species

Because responses to defoliation often differ among plant species [29], the compositions of mixed stands are usually influenced by their most frequent species. Monitoring how key species respond to harvest regimes is, therefore, helpful to managers interested in improved and/or sustained diversity of desirable species [37]. Except for BB, the occurrence of perennials showed significant year differences (Table 2). However, between harvest plots, treatment differences were only significant ($p < 0.05$) for broom sedge (BS) with greater values for 30 than 60 d in 2009 and both BS and other perennials in 2010. It is likely that the dominant perennials in the more frequently harvested plots posed less obstruction to wind-borne seeds of BS and other perennials. This was consistent with earlier reported lack of differences in percentage of ground cover for grasses in the early-season growth, attributable to previous harvest intervals [34]. While the percentage of occurrence of IG in 2009 averaged about 25 below ($p < 0.01$) the control (62%), corresponding values for LB were about twice the 8% in the control. In descending order, the subsequent occurrence of the perennials had greater values for BS > LB > BB > IG, indicating that frequent harvesting suppressed the performance of IG to create a better environment for the growth of BS seedlings and LB tillers, which are usually shorter than BB and IG, thus improving species diversity.

There was no treatment × year interaction effect on the occurrence of perennials (Table 2). With the data pooled across years, the frequencies of occurrence of the four dominant perennials showed differences attributable to harvest duration. The occurrence of BB in the Y308 (29%) plots being retired exceeded, by 10 and 13, that in the second year (Y209) and previously-retired (Y407) ones, respectively ($p < 0.01$). The Y407 values were not different from the control (23%). For IG, values from the control and Y209 were similar and both greater ($p < 0.01$) than those from the Y308 and Y407. The trend was opposite for LB, whose values in Y308 and Y407 were similar (about 16.5%) and greater ($p < 0.01$) than the 7.5% in Y209 and the control. The frequency of occurrence of BS was the greatest (30%) in previously-retired (Y407) plots, being about three-times ($p < 0.01$) the Y308 value and seven-times that of Y209 plots or the control. The occurrence of other perennials showed no effect of harvest duration, and all were ≤4%.

Table 1. Plant species and their respective families, grouped by plant type, recorded in the mixed native warm-season grass stands in June 2009 and 2010.

Scientific Name (Common Name)	Family	Scientific Name (Common Name)	Family
PERENNIAL GRASSES			
Andropogon gerardii (big bluestem)	Poaceae	*Panicum virgatum* (Switchgrass)	Poaceae
Andropogon virginicus (broomsedge)	Poaceae	*Schizachyrium scoparium* (little bluestem)	Poaceae
Elymus virginicus (Virginia wildrye)	Poaceae	*Sorghastrum nutans* (Indiangrass)	Poaceae
ANNUAL GRASSES			
Agrostis hyemalis (winter bentgrass)	Poaceae	*Digitaria sanguinalis* (hairy crabgrass)	Poaceae
Brachiaria platyphylla (broadleaf signalgrass)	Poaceae	*Phalaris caroliniana* (Carolina canarygrass)	Poaceae
Bromus tectorum (cheatgrass)	Poaceae	*Sorghum halepense* (Johnsongrass)	Poaceae
Dichanthelium spp. (Gould rosette grass)	Poaceae	*Sphenopholis obtusata* (prairie wedgescale)	Poaceae
SHORT-GROWING FORBS			
Geum canadense (white avens)	Rosaceae	*Ranunculus sardous* (hairy buttercup)	Ranunculaceae
Ipomoea lacunose (whitestar)	Convolvulaceae	*Rumex crispus* (curly dock)	Polygonaceae
Lepidium virginicum (Virginia pepperweed)	Brassicaceae	*Trifolium dubium* (suckling clover)	Fabaceae

Table 1. *Cont.*

Scientific Name (Common Name)	Family	Scientific Name (Common Name)	Family
		SHORT-GROWING FORBS	
Oenothera speciosa (pinkladies)	Onagraceae	*Triodanis biflora* (small Venus' looking glass)	Campanulaceae
Oxalis stricta (common yellow oxalis)	Oxalidaceae	*Vicia* spp. (vetch)	Fabaceae
Pyrrhopappus carolinianus (Carolina desert-chicory)	Asteraceae	*Geranium carolinianum* (Carolina geranium)	Geraniaceae
		TALL-GROWING FORBS	
Ambrosia trifida (great ragweed)	Asteraceae	*Iva annua* (annual mash elder)	Asteraceae
Cassia obtusifolia (sicklepod)	Fabaceae	*Solanum* spp. (nightshade)	Solanaceae
Helianthus maximiliani (Maximilian sunflower)	Asteraceae	*Solidago Canadensis* (goldenrod)	Asteraceae
		GRASS-LIKE PLANTS	
Carex vulpinoidea (fox sedge)	Cyperaceae	*Cyperus* spp. (sedge)	Cyperaceae
		SHRUB-LIKE PLANTS	
Lespedeza bicolor (shrub lespedeza)	Fabaceae	*Rubus* spp. (blackberry)	Rosaceae
Chamaecrista fasciculata (Partridge pea)	Fabaceae		

Table 2. Proportional distribution response of dominant perennial grass species † to harvest intervals in mixed native warm-season grass stands ‡, harvested for one or two years, and harvest durations in stands starting (Y2) or ending (Y3) a second harvest year and those rested for a year (Y4), recorded two weeks after the mid-May harvest in 2009 and 2010.

Treatment	Subsequent Occurrence of Perennial Grasses				
	BB §	IG	LB	BS	OP
	%				
Harvest interval					
			Year 2009		
Control	24	62a ¶	8b	4c	2
120(2) #	28	35b	16a	18ab	3
90(2)	21	36b	14a	22ab	7
60(3)	27	41b	15a	16bc	1
40(4)	22	36b	20a	21ab	1
30(5)	15	36b	19a	27a	3
CV	55	45	61	82	115
Pr > α ††	0.36	0.03	0.01	0.05	0.20
			Year 2010		
Control	23	62	8	4c	2ab
120(2)	25	43	12	14ab	6a
90(2)	19	46	12	17ab	6a
60(3)	24	50	13	12bc	1b
40(4)	22	45	16	16ab	1b
30(5)	16	45	14	22a	2ab
CV	49	28	63	93	127
Pr > α	0.47	0.31	0.45	0.04	<0.01

Table 2. *Cont.*

Treatment	Subsequent Occurrence of Perennial Grasses				
	BB §	IG	LB	BS	OP
	%				
Harvest duration					
	Year 2009 and 2010				
Control	23b	62a	8b	4c	2
Y209	19b	63a	7b	9b	3
Y308	29a	38b	18a	10b	4
Y407	16b	36b	15a	30a	3
CV	52	36	62	87	121
Pr > α	<0.01	<0.01	<0.01	<0.01	0.46

† Based on the frequencies of occurrence of perennial grasses along a diagonal line transect from 50 sampling points at 15-cm intervals across a plot. ‡ Stands of Indiangrass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*). § BB, big bluestem; IG, Indiangrass; LB, little bluestem; BS, broom sedge (*Andropogon virginicus*); OP, other perennial grasses. ¶ Means within a column followed by different letters differ significantly, $\alpha = 0.05$. # Days between successive harvests with the number of cuts per season in brackets. †† The probability of the difference between means within a column.

3.1.2. Proportions of Forbs

In mixed stands, defoliation often impacts forbs more heavily due to their growing points being mostly above the cutting heights. This often reduces their proportions in recovering stands, as reflected in their reported contribution to ground cover [34]. During 2009 and 2010, the six most frequent forbs were *Chamaecrista fasciculata* (CHFA), *Ipomoea lacunosa* (IPLA), *Rumex crispus* (RUCR), *Cassia obtusifolia* (CAOB), *Helianthus maximiliani* (HEMA) and *Solidago canadensis* (SOCA). Other forbs (OFRB), listed in Table 1, but not in Table 3, occurred less frequently. There were significant harvest interval × year interactions causing year differences in the frequencies of occurrence of the identified forbs, so the results are presented separately by year. The effects of harvesting were only significant for IPLA, CAOB and SOCA ($p < 0.01$). However, treatment effects on the occurrence of IPLA were only observed in 2009 and between the control and all harvested plots, which did not differ. In both 2009 and 2010, CAOB was never sampled in the control, and its frequencies in the harvested plots were in no discernable trend. Values for CAOB were lowest (5%) and highest (24%) in 30 d and 90 d, respectively, for the 2009 data. In a similar pattern, values in 2010 were lowest (4%) and highest (16%) for the 30- and 90-d plots, respectively. The occurrence of SOCA was at significantly ($p < 0.01$) higher frequencies in the control than all harvested plots with greater values for the 30-, but not different from the 40-d intervals. Over all, species differences were reflected in the subsequent frequencies of occurrence of forbs in early-season regrowth after mid-May harvest.

In both 2009 and 2010, the occurrence of SOCA was most frequent in the control (57%), surpassing the 30-d plots by >20 and all others by 38–49 (Table 3). Generally, CHFA, IPLA and RUCR were the least frequent forbs. However, it was not clear how prolonged harvesting might affect their proportions in the stand.

Table 3. Relative distributional response of dominant forbs † to harvest intervals in mixed native warm-season grass stands ‡, harvested for one or two years, and harvest durations in stands starting (Y2) or ending (Y3) a second harvest year and those rested for a year (Y4), after the last harvest event recorded two weeks after the mid-May harvest in 2009 and 2010.

Treatment	**Subsequent Early-Season Occurrence of Forbs**						
	CHFA §	IPLA	RUCR	CAOB	HEMA	SOCA	OFRB
	%						
Harvest interval							
	Year 2009						
Control	1	12a ¶	1	0d	0	57a	29
120(2) #	6	3b	12	10bc	18	19bc	32
90(2)	4	5b	7	24a	13	14c	33
60(3)	10	0b	7	19a	13	8c	43
40(4)	8	1b	11	16ab	14	16bc	34
30(5)	9	1b	10	5cd	10	30b	33
Pr > α ††	0.09	<0.01	0.62	<0.01	0.16	<0.01	0.45
	Year 2010						
Control	1	12	1	0c	0	57a	28
120(2)	4	12	8	6abc	12	17c	41
90(2)	5	11	6	16a	9	18c	34
60(3)	7	8	5	13a	9	18c	40
40(4)	5	7	7	11ab	10	19bc	42
30(5)	6	7	7	4bc	7	32b	37
Pr > α	0.44	0.59	0.90	0.01	0.60	<0.01	0.78
Harvest duration							
	Year 2009 and 2010						
Control	1c	12a	1bc	0b	0b	57a	29b
Y209	2bc	20a	0c	1b	0b	28b	49a
Y308	8a	3b	7b	17a	15a	11c	39ab
Y407	6ab	2b	13a	13a	13a	23b	30b
Pr > α	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

† Based on the frequencies of occurrence of herbaceous and tall-growing forbs from 50 sampling points at 15-cm intervals along a diagonal line transect. ‡ Stands of Indiangrass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*). § CHFA, partridge pea (*Chamaecrista fasciculata*); IPLA, whitestar (*Ipomoea lacunosa*); RUCR, curly dock (*Rumex crispus*); CAOB, sicklepod (*Cassia obtusifolia*); HEMA, Maximilian sunflower (*Helianthus maximiliani*); SOCA, goldenrod (*Solidago canadensis*); OFRB, other forbs. ¶ Means within a column followed by different letters differ significantly, α = 0.05. # Days between successive harvests with the number of cuts per season in brackets. †† The probability of the difference between means in a column.

To sustainably manage mixed stands for forage and wildlife habitat, information on the distributional response of forbs to harvest duration (years) is also important. There was no significant treatment × year interaction effect on the occurrence of forbs across harvest durations ($p > 0.05$). From data pooled across years, CHFA occurred more frequently ($p < 0.01$) in the Y308 plots than in both

Y209 and the control plots, but not the Y407 ones (Table 3). Harvesting did not affect the occurrence of IPLA in the following year, but after two consecutive harvest seasons, the frequency decreased ($p < 0.01$) sharply from 20% to ≤3 in the Y308 and Y407 plots. However, harvesting seemed to favor the establishment of RUCR in recovering stands, which even had greater frequencies in the plots retired after two consecutive harvest seasons. Harvesting also increased the occurrence of CAOB and HEMA, whose frequencies in the Y308 and Y407 plots were similar and ≥10-times that in Y209 plots or the control. The occurrence of SOCA was greatly reduced by successive harvesting, but values seemed to increase again in the retired plots. Harvesting tended to increase the combined occurrence of all other forbs by about 40%, but in plots rested for a year, values were low and similar to the control.

3.2. Effects of Harvest Interval on Plant Types and Ground Cover

When mixed NWSG stands are managed for multiple uses, changes in the spatial distribution of major plant types may affect both forage production and associated wildlife habitat quality attributes. In 2009 and 2010, the frequencies of perennials, annuals, short and tall forbs, grass-like, shrub-like plants and litter, two weeks after mid-May first harvest, showed no treatment or year effect (Table 4). While the frequency of bare ground was 0% in the control plots, however, in harvested plots, it averaged 9% in 2009 and as high as 13% for 120 d in 2010.

3.2.1. Occurrence of Perennial Grasses

Lack of treatment effects on the occurrence of perennials, which averaged 45%, suggested that defoliation was not severe enough to impose irreparable damages. This further demonstrated the ability of the NWSGs to withstand defoliation. The results are consistent with the reported defoliation response of native perennials, in coastal prairies [38]. Usually, cutting NWSGs too frequently or late in summer often results in increasingly poor regrowth and, finally, plant deaths, which may alter the plant type distribution [39,40]. Similarly, NWSGs cut too low lose most of their growing points, making recovery more dependent on new leaves or axillary tillers, which usually take longer [39]. On the contrary, harvesting NWSGs appropriately stimulates vegetative growth through faster leaf blade expansion and axillary tiller development [40]. These results, like earlier reports on ground cover [34], suggest that harvesting regimes did not compromise subsequent early-season recovery. Therefore, forage harvesting alone may not decrease the proportions of these perennials in similar stands.

3.2.2. Occurrence of Annual Grasses, Grass-Like and Shrub-Like

Increased proportions of annuals, grass-like and shrub-like species in mixed stands harvested intensively is also another reason keeping managers from incorporating NWSGs into forage systems. Yet, species diversity in managed grasslands is usually a desirable habitat quality attribute, associated with food availability [12,13]. Harvesting did not affect the occurrence of annuals (averaged 5%), grass-like or shrub-like (frequency ≤ 2%) (Table 4). These results also suggest that the 1–2 year defoliation was not severe enough to alter species distribution. Although frequent harvesting might have kept annual species from setting seeds, it also facilitated germination from seed banks [41]. This may explain the lack of differences in the occurrence of annuals and forbs in the current study.

Table 4. Effects of harvest intervals on distribution of major plant types †, litter and bare ground patches in mixed native warm-season grass stands ‡, previously harvested for one or two years (pooled means), recorded two weeks after mid-May harvest in 2009 and 2010.

Treatment	**Frequency of Live Vegetation, Litter and Bare Ground**							
	PG §	AG	SF	TF	GL	SL	LT	BG
	%							
	Year 2009							
Control	52	3	12	17	0	1	14	0b ¶
120(2) #	41	4	16	12	2	2	13	11a
90(2)	43	5	17	13	2	2	13	7a
60(3)	39	7	15	14	2	1	14	9a
40(4)	43	6	15	12	3	1	10	10a
30(5)	45	6	9	12	4	1	15	7a
CV	19	69	41	41	160	143	55	47
Pr > α ††	0.13	0.08	0.12	0.49	0.64	0.32	0.92	0.01
	Year 2010							
Control	52	3	13	18	0	1	14	0c
120(2)	43	3	15	12	3	1	10	13a
90(2)	44	4	18	12	2	1	11	8b
60(3)	43	6	18	11	2	1	10	9ab
40(4)	46	6	16	11	4	0	7	10ab
30(5)	47	6	11	11	4	1.2	11	9ab
CV	16	57	34	44	108	165	168	64
Pr > α	0.36	0.22	0.06	0.30	0.50	0.26	0.55	<0.01

† Based on the frequencies of occurrence of plant types from 50 sampling points at 15-cm intervals along a diagonal transect. ‡ Stands of Indiangrass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*). § PG, perennial grasses; AG, annual grasses; SF, short forbs; TF, tall-growing forbs; GL, grass-like; SL, shrub-like; LT, litter; BG, bare ground. ¶ Means within a column followed by different letters differ significantly, α = 0.05. # Days between successive cuts and (total cuts per season). †† The probability of the difference between means within a column.

These results also suggest that proportions of annuals in the stands were less influenced by competition from the perennials. Otherwise, harvesting would have rapidly increased the occurrence of minor plant types. For the same reason, grass-like and shrub-like species might not compete with forbs in similar mixed stands. However, how other environmental factors (weather, drainage, soils, herbivory, *etc.*) may impact their survival cannot be overlooked.

3.2.3. Occurrence of Forbs

There were no treatments or year effects reflected in the frequencies of occurrence of forbs, which averaged about 15% and ≤14% for the short and tall ones, respectively (Table 4). These results also suggest that forage harvesting alone may not compromise subsequent early-season wildlife habitat quality attributes associated with the spatial distribution of forbs in the stands.

3.2.4. Occurrence of Litter and Bare Ground

With regards to wildlife habitat, mowing mixed native grass stands often increases the cover of perennials, thus reducing that of forbs and bare patches [27,29]. In the current study, harvesting had no effect on the occurrence of litter (Table 4). Values averaged 13% and about 10% in 2009 and 2010, respectively. However, differences in litter between harvested and control plots were not expected, since most of the cut material was removed.

Harvesting increased the frequency of bare patches by about 9% in 2009 and up to 13 in 2010, but not in discernable treatment trends. For ground-nesting birds, this has implications on habitat quality, because bare patches facilitate their movement and feeding on the ground [1,13]. Since treatments had no effect on the occurrence of plant types, lack of bare patches in the control plots mostly reflected litter buildup. For forage production, changes in the distribution of bare patches may indicate the range condition and trend in biomass productivity, susceptibility to surface runoff or available room for undesirables [1,42,43]. In mixed prairies, such increases in the occurrence of bare patches might result from plant deaths following excessive defoliation, often accompanied by increased proportions of undesirables [42]. Since that was not the case in the current study, the increased occurrence of bare patches indicated improvement in habitat quality for grassland birds. This implies that mixed NWSG stands can be strategically managed for forage production and ground-nesting bird habitat.

3.3. Effects of Harvest Duration on Plant Types and Ground Cover

Although, within-season, harvest intervals may not alter spatial plant type distribution significantly, harvest duration may. With time, tall-growing plants, whose growing points are mostly above the cutting height, suffer more damages compared to their low-growing counterparts, as observed in the current study (Table 5).

3.3.1. Occurrence of Perennial Grasses

While the occurrence of perennials was more frequent in the control than all plots harvested for two years, values tended to be less for longer harvest durations, but only significantly so between Y307 and Y109 in 2009 ($p < 0.01$) and between Y407 and Y209 (Table 5) in 2010. Values for Y109 plots in 2009 were not different from the control or the Y208, which also compared the same in 2010, as Y209 and Y308. The frequency of perennials in the Y407 plots (retired in 2009) was not different from the control either. Usually, harvested perennials exhibit reduced root growth due to preferential resource allocation to leaf growth [39]. Additionally, grasses defoliated late in fall fail to initiate enough tillers for the next year's growth [44]. These effects of defoliation may influence subsequent early-season growth and tiller density. In mixed stands harvested for longer durations, changes in species composition and spatial distribution may also result from deaths of perennials, being in favor of annuals.

3.3.2. Occurrence of Annual Grasses, Grass-Like and Shrub-Like

Harvest duration had no effect on the frequencies of occurrence of annuals, grass-like or shrub-like plants in any year (Table 5). Lack of differences in the occurrence of annuals probably resulted from their rich seed banks in the area and/or improved conditions for germination and survival of inferior species. Since the early-May harvest was common to all plots, the observed uniformity in the occurrence of annuals was not surprising. With time, however, continued suppression of perennials might lead to greater frequencies of annuals. Still, close monitoring of species responses to harvesting allows for timely necessary adjustments.

Depending on the significance of species affected, changes in the occurrence of plant types in June would imply fluctuating availability of plant-based feed resources to bobwhites. For example, altering the proportions of range flowers, which usually attract insects, would influence the availability of food to bobwhites in the community. The results of the current study suggest that these NWSG stands dominated by BB, IG, and LB could withstand frequent forage harvesting without compromising subsequent breeding habitat quality for bobwhites and similar ground-nesting birds.

Table 5. Effects of harvest duration on the distribution of major plant types †, litter and bare ground patches in mixed native warm-season grass stands ‡, previously harvested for one to two years (pooled means), recorded two weeks after mid-May harvests in 2009 and 2010.

Treatment	**Frequency of Live Vegetation, Litter and Bare Ground**							
	PG §	AG	SF	TF	GL	SL	LT	BG
				%				
				Year 2009				
Control	52a ¶	3	13ab	17a	0	1	14a	0c
Y109 #	49ab	4	17a	9b	3	1	4b	12a
Y208	43bc	6	17a	10b	2	1	6b	14a
Y307	41c	5	12b	15a	3	1	10a	3b
CV	19	69	41	41	160	143	55	47
Pr > α ††	<0.01	0.18	<0.01	<0.01	0.28	0.98	<0.01	<0.01
				Year 2010				
Control	52a	3	13ab	18a	0	1	14a	0c
Y209	42c	5	12b	15a	3	1	19a	3b
Y308	43bc	4	17a	9b	3	1	4b	12a
Y407	49ab	6	17a	10b	2	1	6b	14a
CV	16	57	34	44	108	165	168	64
Pr > α	<0.01	0.31	<0.01	<0.01	0.25	0.50	<0.01	<0.01

† Based on the frequencies of occurrence of plant type forbs from 50 sampling points at 15-cm intervals along a diagonal transect across a plot. ‡ Stands of Indiangrass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*). § PG, perennial grasses; AG, annual grasses; SF, short forbs; TF, tall-growing forbs; GL, grass-like; SL, shrub-like; LT, litter; BG, bare ground. ¶ Means within a column followed by different letters differ significantly, α = 0.05. # Days between successive cuts and total cuts per season. # Y109, Y208 and Y307 are first, second and third harvest year plots established in 2009, 2008 and 2007, respectively. †† The probability of the difference between means within a column.

3.3.3. Occurrence of Forbs

There were significant year differences in how the occurrence of short forbs responded to harvest duration. In 2009, short forbs were less frequent in the third-year (Y307) plots than in the first- and second-year ones ($p < 0.01$), but not the control. In 2010, however, values were greater ($p < 0.01$) for the Y308 (just retired) and the Y407 (previously retired) than the second-year (Y209) plots, which were also not different from the control (Table 5). Annual variations in weather conditions, mainly rainfall and ambient temperatures, may partly explain the differences in the occurrence of major plant types. While monthly rainfall totals in September 2007 and 2008 were about 130 mm, it was about 240 mm in 2009 [34]. Additionally, differences in the occurrence of forbs between Y208 and Y307 probably reflected their growth habits and the decrease in voids at longer harvest durations (Table 5). It is possible that short forbs in Y208 plots enjoyed more exposed voids (14%), which were filled by axillary tillers and grass-like plants in Y307 plots.

Year differences in the occurrence of both short and tall forbs by harvest duration were also observed (Table 5). While, in both years, the frequency of short forbs in the control remained 13% and statistically the same as the harvested plots, in 2009 values, the first- (Y109) and second-year (Y208) plots (17%) were greater ($p < 0.01$) than for the Y307 (12%) being retired. In 2010, however, short forbs were less frequent in the second-year (Y209) plots than both Y308 and Y407 (previously retired). This likely resulted from the fact that harvesting improved the seed germination and growth of annual short forbs by opening up canopies, thus allowing more light to the ground. Similarly, in 2010, differences in the occurrence of short forbs between Y208 and Y307 plots were not observed. These results are contrary to findings on native forbs in California coastal prairies being largely unaffected by clipping [38]. This was probably due to the fact that the study compared natives to exotic species, focusing on defoliation frequencies alone. For no apparent reason, the patterns of occurrence of tall forbs were basically reversed. However, from the forage production standpoint, tall forbs, such as SOCA and HEMA, are undesirable. Their decreased occurrence in plots being harvested and resurgence in the retired ones would be desirable for dual-purpose management.

3.3.4. Occurrence of Litter and Bare Ground

There were year differences in the effect of harvest duration on the occurrence of litter and bare patches (Table 5). As expected, harvesting reduced the occurrence of litter in the regrowth for the Y109 and Y208 plots, in 2009 ($p < 0.01$). Liter frequency in the Y307 plots was notably increased, which also matched the occurrence of tall forbs. In June 2010, however, litter occurred at greater frequencies ($p < 0.01$) in the Y209 plots than a 5% average in Y308 (being retired) and the Y407 (previously retired). Furthermore, in 2009, the mean occurrence of litter in the control (14%) was greater ($p < 0.01$) than the average of 5% in the Y208 and Y109 plots, but not different from the second-year ones (Y209) in 2010. The greater occurrence of litter in Y209 probably resulted from the increased growth of tall forbs, whose senescent fallen leaves were sampled more frequently in June. In the Y308 and Y407 plots, however, the greater occurrence of short forbs probably minimized the chances for litter being sampled. Likewise, the mean frequency of bare patches in Y208 was more than four-times that in the Y307 plots, but the reverse was true in 2010, the values being four-times greater for Y308 than the Y209 plots ($p < 0.01$). The fact that the occurrence of bare patches was not different between Y308 and Y407 also suggests that following two consecutive years of haying, bobwhite chicks may experience easier movements through the field and better visibility of food on the ground.

In managed prairies, litter buildup is usually undesirable for several reasons. It inhibits germination of desirable species, reduces species diversity, and obstructs movement for young chicks [1]. Although mowing usually maintains restored prairies at early vegetation succession, its effectiveness also depends on whether or not the cut biomass is removed. The results of this study show that forage harvesting in one season improves subsequent early-season ground-nesting bird habitat by preventing litter buildup while increasing the occurrence of bare patches.

4. Conclusions

These results suggest that harvesting similar NWSG stands for up to two successive years may increase floristic diversity by favoring the occurrence of less competitive species and suppressing their competitors. It may take longer than a year's rest for similar stands to recover from such changes in species composition. Although continuous harvesting may not cause significant changes in the spatial distribution of the dominant grasses, grass-like or shrub-like, it may reduce the occurrence of tall forbs, such as SOCA in the current study, while increasing that of short forbs and bare patches. Due to the differences in species responses to harvest duration, as in the case of BS and LB, occurring at greater frequencies in plots harvested longer and, with corresponding lower values for IG, there is a need for management to closely monitor subsequent species dynamics and make timely adjustments as necessary. However, changes in growing conditions, such as rainfall regimes between years, may influence species responses to defoliation enough to impact subsequent species composition and spatial distribution in the early-season growth. Over all, strategic forage harvesting in similar NWSG stands may not compromise their grassland-bird breeding habitat quality features associated with species composition and plant type distribution.

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Author Contributions

Vitalis W. Temu and Brian Baldwin had original ideas for the study and with all co-authors carried out the design. The first author was responsible for organizing and supervising all field activities, data cleaning, and statistical analyses and drafted the manuscript which was revised by all co-authors. Brian Baldwin was responsible for recruitment and follow-up of study participants. All listed authors except for the late Samuel Riffell read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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