

**Avian Density and Nest Survival and Beef Production on Continuously-
Grazed Native Warm-Season Grass Pastures**

**A Dissertation Presented for the
Doctor of Philosophy
Degree
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ABSTRACT

Eastern grassland bird populations have been declining since the Breeding Bird Survey was initiated in 1966. The cause of the decline is the near-complete loss of their native grassland habitats. A driver of the loss of native grasslands in the East is the conversion of native grasses to the introduced species tall fescue (*Lolium arundinaceum*). Tall fescue, a cool-season grass, provides livestock forage during fall and spring, but does not provide habitat for most grassland bird species due to its dense, sod-forming structure. Wildlife biologists have recommended the incorporation of native warm-season grass (NWSG) pastures into grazing systems as a solution to the grassland bird decline that will also benefit beef cattle producers. However, little data exists on the efficacy of this practice for grassland bird conservation or beef cattle production when pastures are managed the way a typical producer is likely to manage them, with continuous, season-long (May – August) grazing. I designed an experiment to compare grassland bird density and nest survival in NWSG cattle pastures among two continuous, season-long stocking strategies: continuous (CONT) and heavy-early (HEAVY), and traditionally-managed tall fescue pastures (FESCUE) during summers 2015 – 2017. Animal performance of weaned steers, pasture production, and sward sustainability were recorded throughout the study. I developed an enterprise-level economic model to determine the impact of incorporating the perennial warm-season grasses switchgrass (*Panicum virgatum*) and bermudagrass (*Cynodon dactylon*) on profitability of beef cattle operations in the Fescue Belt. Grasshopper sparrow (*Ammodramus savannarum*) density was three times greater in NWSG (0.30 males/ha) than FESCUE pastures (0.11 males/ha), and both species selected to nest in NWSG and selected against nesting in FESCUE pastures. Average daily gain of steers was similar between CONT (0.98 kg/d) and HEAVY (0.89 kg/d) and was comparable to other NWSG grazing studies, and

both stocking strategies were sustainable over the study period. Incorporating switchgrass into simulated tall fescue forage systems increased profitability over fescue-only systems by 1,070% and 42% for spring- and fall-calving herds, respectively. The results of my study indicate that continuously-grazed NWSG pastures in the Fescue likely contribute to both grassland bird conservation and beef cattle production.

Keywords: Native warm-season grass, big bluestem, indiangrass, tall fescue, eastern grassland birds, conservation, grasshopper sparrow, field sparrow, beef cattle, continuous grazing, density, nest survival, economics, Fescue Belt

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Chapter 1 INTRODUCTION

Fifteen of 18 eastern grassland bird species have experienced significant population declines since the advent of the official Breeding Bird Survey in 1966 (Sauer et al. 2014). One of the drivers of these population declines in a region of the country known as the Fescue Belt (Figure 1.1; Belesky and West 2009) is the conversion of native grasslands to introduced species such as tall fescue (*Lolium arundinaceum*). Tall fescue is the dominant forage grass in the southeastern United States, planted on approximately 14 million ha of land, primarily for livestock forage (Kallenbach et al. 2012, Keyser et al. 2012, Kallenbach 2015). Tall fescue produces quality livestock forage in spring and fall, but the utility of tall fescue fields for grassland birds is low. Barnes et al. (2013) reported that tall fescue generally provides poor wildlife habitat due to its unsuitable structure, lack of bare ground, and low food availability and quality. Similarly, Barnes et al. (1995) found that the dense vegetative structure and lack of bare ground in tall fescue fields impeded northern bobwhite (*Colinus virginianus*) movement, making it unusable.

Tall fescue also poses management problems for beef cattle producers. One of the major problems associated with grazing tall fescue is that it is largely unproductive in summer, leaving a gap in forage availability known as the summer slump. Cattle grazing endophyte-infected fescue pastures in the summer are also likely to suffer from ill-effects of fescue toxicosis such as reduced weight gains and reproductive performance (Roberts and Andrae 2004). Fescue toxicosis, caused by an endophyte fungus (*Epichloe coenophiala*) living within infected plants, has been estimated to cost the beef cattle industry US\$2 billion annually (Hoveland 1993, Schmidt and Osborn 1993, Kallenbach 2015). A potential solution to both the grassland bird

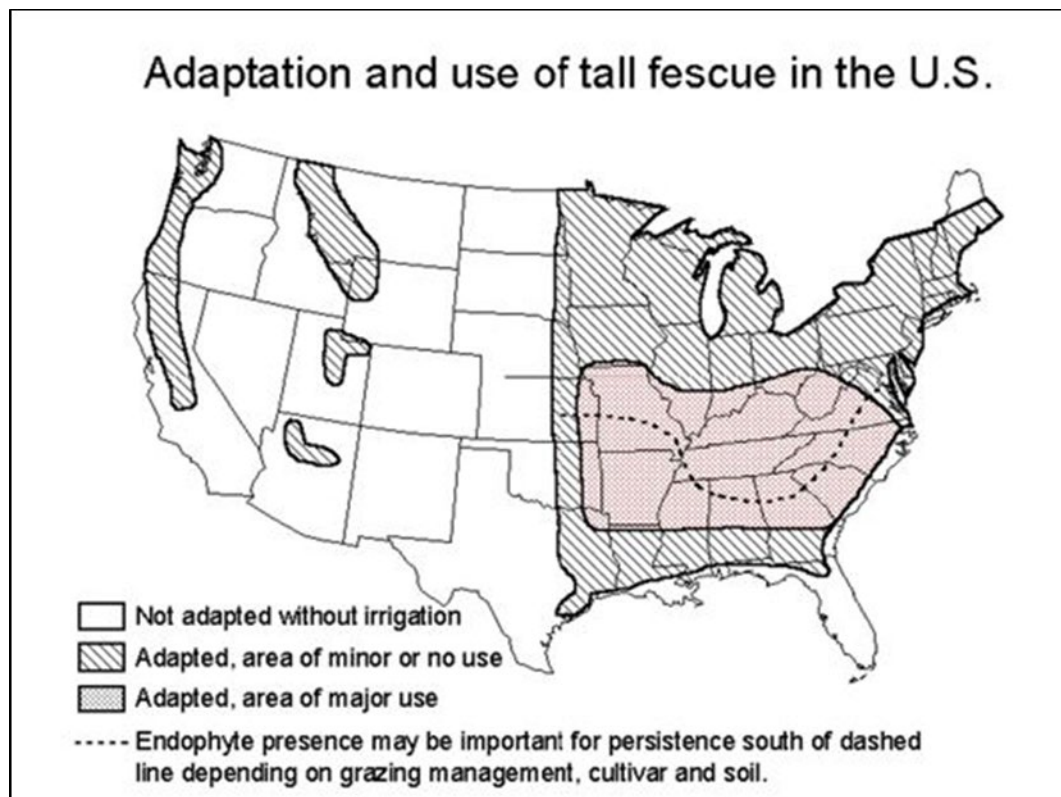


Figure 1.1. Tall fescue zone of adaptation in the United States (Belesky and West 2009).

decline and management challenges associated with grazing tall fescue is native warm-season grass (NWSG) pastures.

Native warm-season grasses are a natural habitat component for grassland bird species such as grasshopper sparrow (*Ammodramus savannarum*; Harper et al. 2007). The physical structure of these grasses provides essential cover for life history needs such as nesting, feeding, and escaping predators. Native warm-season grasses such as big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*), are also proven late-spring and summer forages for beef cattle, producing average daily gains of approximately 0.91 kg/d for growing animals (Keyser et al. 2012, Burns and Fisher 2013, Backus et al. 2017). In addition to providing good animal performance and pasture production, NWSG are economical alternative forages (Boyer et al. 2015, Lowe et al. 2015, Lowe et al. 2016). Most importantly, because they are warm-season grasses, NWSG are a natural complement to tall fescue because their peak growth is during late spring and summer when tall fescue, a cool-season grass, is semi-dormant (Figure 1.2). By integrating NWSG into tall fescue-based grazing systems, a producer can mitigate problems associated with the summer slump and fescue toxicosis (Anderson 2000, Moore et al. 2004, Keyser et al. 2016) by rotating cattle off endophyte-infected fescue and onto NWSG pasture during late spring and summer. Very rarely does a solution present itself that potentially benefits both agricultural production and wildlife conservation. Use of NWSG as an integral part of regional forage systems may provide the best tool available for improving habitat for grassland birds at a meaningful scale in the Fescue Belt. What's not known is if NWSG pastures can simultaneously provide grassland bird habitat and valuable beef cattle forage when managed with continuous season-long grazing.

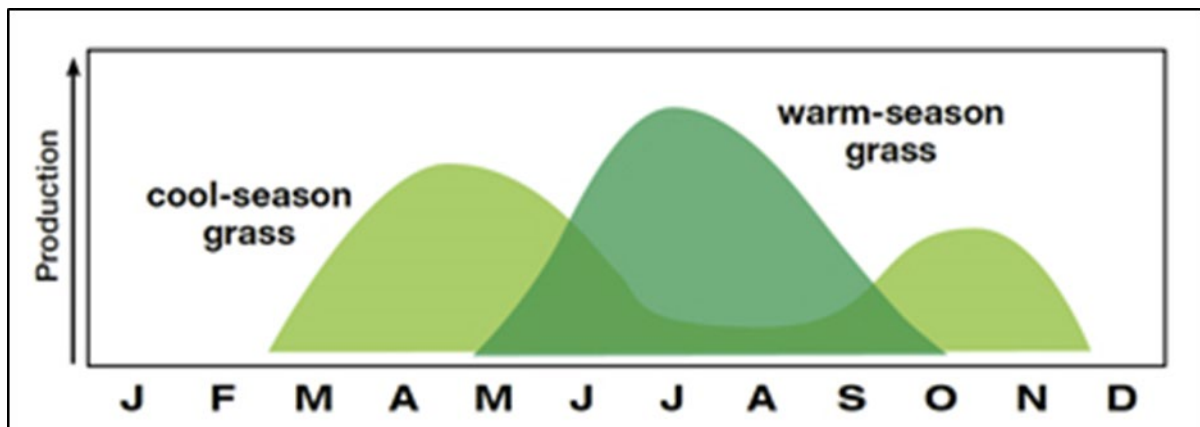


Figure 1.2. Phenology of growth and relative production of cool-season and warm-season grass in the mid-South United States.

Producer acceptance of NWSG in the Fescue Belt has been slow. One reason is that forage professionals have traditionally believed that NWSG must be managed with a rotational grazing system to avoid overgrazing and maintain consistent yields (Lacefield et al. 2002, Harper et al. 2007, Smith et al. 2009). The majority of producers in the Fescue Belt prefer continuous, season-long (May – August) grazing, though, because it is simpler and requires less infrastructure and labor than rotational grazing. Little to no production-scale data exists to support the assumption that NWSG must be rotationally grazed in the eastern United States, though. A recent study in Mississippi reported that continuous, season-long grazing of NWSG produced increased gains compared to mixed fescue and bermudagrass pastures (Monroe et al. 2017). One of the objectives of my study was to add to the body of knowledge regarding the feasibility of continuous, season-long grazing of NWSG with beef cattle in the Fescue Belt. If continuous grazing is sustainable, productive, and economical, then one more impediment to producer acceptance of these grasses will be removed.

Wildlife biologists have promoted NWSG pastures for decades as a way of creating habitat for grassland birds while also providing summer forage for livestock (Skinner 1975, George et al. 1979). However, data to support the efficacy of this practice in the humid East are limited, especially under production-scale, continuous, season-long beef cattle grazing (Harper et al. 2015, Moorman et al. 2017). Like beef and forage professionals, wildlife biologists have also traditionally recommended against the use of continuous grazing as a wildlife management tool, although with very little empirical support. An objective of my study was to begin to fill this knowledge gap by documenting density and nest survival of grassland birds in NWSG pastures under two continuous season-long grazing strategies, and compare them to those on traditionally managed tall fescue pastures. The vast majority of pastures in the Fescue Belt consist of tall

fescue. Therefore, if grassland bird density and nest survival are greater on continuously grazed NWSG than fescue pastures, that represents an improvement for grassland bird conservation. Conversely, if density and nest survival are not greater on NWSG pastures, then the wildlife community should consider reassessing the assumption that production NWSG pastures are a valuable tool for grassland bird conservation.

Stabilizing and reversing the grassland bird decline in the eastern United States will require creating and maintaining grassland habitat on working lands (Askins 1999, Vickery et al. 1999, Keyser et al. In press). Native warm-season grass pastures, if effective for both beef cattle production and grassland bird conservation, are unique among wildlife conservation tools because producers have an economic incentive to plant them, even in the absence of government subsidy programs such as the Environmental Quality Incentives Program (EQIP).

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**Chapter 2 DENSITY AND NEST SUCCESS OF GRASSHOPPER
SPARROW AND FIELD SPARROW ON CONTINUOUSLY GRAZED
NATIVE WARM-SEASON GRASS PASTURES**

ABSTRACT

Populations of most eastern grassland bird species have been declining for over a half century because of the loss and fragmentation of their grassland habitats. Increased use of native warm-season grasses (NWSG) as summer forage for beef cattle operations may provide valuable habitat for grassland birds in eastern United States areas where native grasslands have disappeared. I compared grasshopper (*Ammodramus savannarum*) and field sparrow (*Spizella pusilla*) density and nest success in NWSG pastures under two stocking strategies, continuous (CONT) and heavy-early (HEAVY), with those in tall fescue (FESCUE; *Lolium arundinaceum*) pastures, 2015-2017. I modelled avian density with a generalized linear mixed model (GLMM) following an integrated likelihood approach that evaluates the relationship of covariates to both detection probability and counts. Density of both sparrow species was more closely related to the presence of woody vegetation surrounding pastures than specific grazing strategy, although there was greater grasshopper sparrow density in NWSG (0.30 males/ha) than FESCUE (0.11 males/ha) pastures. Density of grasshopper sparrow, a grassland obligate, was negatively related to the amount of pasture perimeter consisting of woody vegetation, whereas density of field sparrow, a species with an affinity for woody cover, was positively related to the amount of forested landscape surrounding pastures. Both grasshopper sparrow and field sparrow selected to nest in NWSG (CONT and HEAVY) and against nesting in FESCUE. Grasshopper sparrow nest survival was related to distance from nests to woody edges, but the direction of the relationship differed depending on site, with daily survival rates (90% CI) ranging from 0.974 (0.849, 0.996) to 0.816 (0.704, 0.891), depending on site. The majority of pastures in the Fescue Belt are relatively small and surrounded by forested landscapes. Given this landscape context, the location of NWSG pastures appears to have a greater influence on density and nest survival,

especially of grasshopper sparrow, than grass type or stocking strategy. However, density of grasshopper sparrow was greater in NWSG than FESCUE pastures, and because of selection for NWSG, these pastures also produced more nests and fledglings than FESCUE.

INTRODUCTION

Fifteen of 18 grassland bird species nesting in the eastern United States have experienced steep and protracted population declines over the past five decades (Sauer et al. 2014), concurrent with the loss and fragmentation of their native grassland habitats (Knopf 1994, Vickery et al. 1999). Agricultural intensification in the form of conversion of native grasslands to non-native species such as tall fescue (*Schedonorus arundinaceus*) is one major cause of native grassland loss in the eastern United States (Knopf 1994, Askins 1999, Murphy 2003, Brennan and Kuvlesky 2005, Askins et al. 2007). Tall fescue, the dominant forage grass grown in the mid-South (Keyser et al. 2011), is a non-native, cool-season, sod-forming bunchgrass. As of 1991, tall fescue was established on 14 million ha in the United States, primarily for livestock forage, turf, and conservation cover (Ball et al. 1993). Fescue produces quality livestock forage in spring and fall, but its utility for most grassland bird species is low because of unsuitable structure, lack of bare ground, and low food availability (Barnes et al. 1995, Barnes et al. 2013). On small (0.8 – 2.9 ha) pastures and hayfields in Pennsylvania, relative abundance, species richness, and reproductive success of grassland-associated sparrows were all greater on native warm-season grass (NWSG) than cool-season grass (CSG; tall fescue and other CSG species) because of greater cover availability and lower disturbance rates from cattle grazing and farm equipment (Giuliano and Daves 2002). Wildlife biologists have promoted NWSG pastures as a way of increasing habitat for declining grassland bird species while also providing summer forage for livestock (Skinner 1975, George et al. 1979, Palmer et al. 2012, Harper et al. 2015).

However, there is very little data to support the efficacy of this practice, especially on production-scale pastures under typical production grazing management, within the humid eastern U.S. (Giuliano and Daves 2002, Harper et al. 2015, Moorman et al. 2017).

Grazing by domestic livestock affects ecosystems by altering vegetation structure, which in turn affects resource availability for songbirds (Derner et al. 2009). In addition to grass species, stocking rate and grazing system impact how grazing will affect vegetation structure (Payne and Bryant 1998, Briske et al. 2008). Grazing systems that enhance heterogeneity of habitats are recommended for grassland bird conservation (Fuhlendorf et al. 2006). However, traditional grazing management practices tend to decrease structural heterogeneity by emphasizing uniform use of vegetation (Fuhlendorf et al. 2006, Derner et al. 2009). Continuous grazing, on the other hand, typically increases structural heterogeneity (Holechek et al. 1995). Structurally diverse habitats tend to have more available niches, and therefore greater avian diversity and abundance (Askins et al. 2007, Ranellucci et al. 2012). Despite this, biologists typically recommend rotational grazing and discourage the use of continuous grazing for wildlife management. However, Harper et al. (2015) found that continuous, season-long (May-August) grazing created and maintained nesting and brood-rearing habitat for grassland birds in the mid-South, and recommended maintaining a stand height of 40 cm to balance stand vigor, livestock requirements, and grassland bird habitat needs. Monroe et al. (2016) found productivity and nest density of dickcissel (*Spiza americana*) to be greater on continuously grazed NWSG pastures than mixed bermudagrass (*Cynodon dactylon*) and fescue pastures in Mississippi, largely due to increased availability of nest sites in the taller NWSG. However, the authors noted that there may be a tradeoff in forage utilization and avian productivity; increased stocking rates may reduce the abundance of tall vegetation which is characteristic of dickcissel nest sites. A study

conducted in the Piedmont of North Carolina that used spot-mapping as an index of productivity concluded that rotationally grazed NWSG pastures were not a better alternative to exotic CSG pastures for grassland bird conservation, but that both forage types could be improved for grassland birds by grazing at a moderate intensity to maintain grass height ≥ 25 cm (Moorman et al. 2017).

Stabilizing and reversing the grassland bird decline in the eastern U.S. will require creating and maintaining additional grassland habitat on working lands (Askins 1999, Vickery et al. 1999, Monroe et al. 2016, West et al. 2016, Keyser et al. In press). Management practices implemented on private working lands must be economically viable to be adopted (Askins et al. 2007). The establishment of NWSG pastures is one such practice that may benefit both beef cattle production and grassland bird populations (Monroe et al. 2016). Beef cattle operations that rely primarily on tall fescue can increase forage production during hot summer months when tall fescue productivity is low by incorporating NWSG pastures. This strategy not only increases livestock gains and economic returns (Keyser et al. 2012, Lowe et al. 2015, Lowe et al. 2016), but also potentially benefits declining grassland bird populations.

My objective was to compare grassland bird density, nest success, and nest-site selection among three pasture management alternatives; season-long, continuously grazed NWSG, heavy-early continuously grazed NWSG, and conventionally-managed tall fescue pastures (FESCUE). Tall fescue is the dominant regional pasture grass, and beef cattle production is the primary use of regional grasslands (Keyser et al. 2011), therefore, NWSG pastures (CONT and HEAVY) will be considered beneficial for grasshopper sparrow and field sparrow conservation if density and nest survival are greater than on FESCUE, and birds select to nest in NWSG pastures.

METHODS

STUDY AREA

I conducted the study at the East Tennessee Research and Education Center (ETREC) Holston Unit (HOLSTON) near Knoxville, TN, the ETREC Blount Unit (BLOUNT) in Blount County, TN, and two private agricultural operations (LOUDON and SOUTH) in Loudon County, TN (Figure 2.1; all figures located in appendices). All sites were in the Appalachian Ridge and Valley physiographic region and Bird Conservation Region 28 – Appalachian Mountains (Babcock et al. 1998). The landscape surrounding these four sites was a mixture of forest, row crop production, CSG pasture, and developed areas. I used pastures that were either predominantly tall fescue or mixed NWSG. Tall fescue pastures were all comprised of endophyte-infected ‘Kentucky 31’ variety tall fescue interseeded with red and white clover (*Trifolium pratense* and *T. repens*, respectively). Tall fescue pastures at LOUDON and BLOUNT had naturally occurring common bermudagrass interspersed among the tall fescue, which was typical of area pastures. I conducted my study on NWSG pastures that had been planted to a mixture of big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), and little bluestem (*Schizachyrium scoparium*) in spring 2012. Researchers used a no-till drill to plant each pasture with 11.2 kg pure live seed (PLS) ha⁻¹ of a mixture that included 60% big bluestem, 30% indiangrass, and 10% little bluestem, based on seed mass, and was all KY Ecotype (Roundstone Native Seed, LLC, Upton, KY). Pastures were predominantly tall fescue before conversion. Three pastures had to be re-planted in 2013 due to unsatisfactory plant population densities resulting from severe drought following seeding in 2012. Plant population density was approximately 10 plants/m² at all sites following reestablishment. Experimental

NWSG (8.0 – 10.5 ha, $\bar{x}$ = 9.1 ha) and tall fescue (8.4 – 11.0 ha, $\bar{x}$ = 10.0 ha) pasture sizes were representative of the majority of pastures in the region.

GRAZING TREATMENTS

The three treatments I used were a combination of grazing system and forage type: season-long (May through August) continuous NWSG (CONT), heavy-early (HEAVY) NWSG, and conventional tall fescue (FESCUE). Pastures assigned to CONT were stocked with 3.2 272-kg steers ha⁻¹ based on Backus et al. (2017). Heavy-early was an experimental continuous grazing strategy developed to more closely match grazing pressure to the growth curve of NWSG (Backus et al. 2017) by incorporating a single cattle stocking rate adjustment during the summer grazing season and to provide an option for cattle producers that required less management than a rotational system. The target stocking rate for HEAVY at grazing initiation was approximately 1.25 times the CONT rate (4.0 steers/ha) to provide increased grazing pressure to match the rapid early-season growth of NWSG. The HEAVY stocking rate was reduced on 25 June each year to approximately 0.75 times the CONT rate (2.4 steers/ha) to match grazing pressure to slower mid- and late-season grass growth. I attempted to meet target stocking rates, but assumed they could vary based on logistics (e.g., cattle health and availability). I based stocking rates at SOUTH on weights of calves taken immediately prior to shipping and stocking, but actual weights were not provided during the experiment. For FESCUE, I left pasture management and stocking decisions to the discretion of the landowner. As such, they represented typical operational practices and prevailing pasture conditions against which both NWSG treatments were compared. Landowners grazed most FESCUE pastures until late spring, and BLOUNT grazed throughout spring and summer. Average FESCUE stocking density was 1.25 to 1.70 cow/calf pairs/ha. Landowners either cut FESCUE pastures for hay in

late May or mowed them to 15 – 20 cm in height to suppress seedhead growth as needed from May to July.

EXPERIMENTAL DESIGN

The experiment consisted of 3 treatments conducted over 3 years (2015, 2016, 2017), with four replicate pastures (experimental units) per treatment, with the exception of FESCUE in 2015 (Figure 2.2). In 2015, one FESCUE pasture had to be dropped from the study because it was dominated by mixed warm-season grasses such as johnsongrass (*Sorghum halepense*) and cool-season grasses such as Kentucky bluegrass (*Poa pratensis*). I replaced it in 2016 with another tall fescue pasture.

FOCAL BIRD SPECIES

Seven bird species that utilize grasslands during the breeding season were selected as focal species for the study: grasshopper sparrow (*Ammodramus savannarum*), eastern meadowlark (*Sturnella magna*), dickcissel, common yellowthroat (*Geothlypis trichas*), red-winged blackbird (*Agelaius phoeniceus*), indigo bunting (*Passerina cyanea*), and field sparrow (*Spizella pusilla*). Of these, grasshopper sparrow, eastern meadowlark, and dickcissel are considered obligate grassland species, and common yellowthroat and red-winged blackbird are facultative grassland species (Vickery et al. 1999). While not considered grassland species, both field sparrow and indigo bunting regularly utilize area pastures, and therefore were included. Breeding bird survey population trends from 1966 to 2013 for all focal species except dickcissel were negative in the Appalachian Mountains Bird Conservation Region (BCR), as well as throughout their ranges (Sauer et al. 2014). Trends in dickcissel population were unknown for the BCR because of insufficient data, but have been declining in the eastern United States.

SAMPLING METHODS

I sampled vegetation composition and structure at 25 randomly-selected points in each pasture three times during each year, mid-May, mid-June, and mid-July. I recorded percent cover of grass, forbs, bare ground, and litter to the nearest 5 percent using Daubenmire frames. I recorded height of vegetation (cm), litter depth (cm), and visual obstruction readings (VOR) using a Robel pole read from a distance of 4 m and height of 1 m (Robel et al. 1970) in each cardinal direction.

I used line-transect distance sampling to estimate avian density (Buckland et al. 2001). Distance sampling decreases bias and increases precision of density and abundance estimates by accounting for detection probability (Diefenbach et al. 2003). I used a systematic design with parallel transects and a random first start in each pasture (Buckland et al. 2001). Transects had a half-width of 50 m, and I placed them 110 m apart. I placed as many transects as possible within each pasture (range: 3 – 5). Total length of transects for each treatment was: CONT, 3,458 m; HEAVY, 3,472 m; FESCUE (2015), 2,874 m; and FESCUE 2016 – 2017, 3,836 m. I recorded both auditory and visual detections of all individuals of sexually dimorphic focal species within 50 m of either side of the transect line. To avoid biasing population estimates, I only recorded singing males of grasshopper sparrow and field sparrow because those species are not sexually dimorphic, and therefore singing was the only method to confirm sex (Diefenbach et al. 2003). I recorded perpendicular distance from the transect line to the detected individual using a laser rangefinder. Observers walked transects at a speed of 1 – 2 km/hr (Bibby et al. 2000). I conducted line transect counts five times each year from mid-May to mid-July from 0630 to 1000 h. I did not conduct surveys during precipitation, fog, or winds exceeding 14 km h⁻¹.

Observers were rotated among pastures and treatments to control for bias. Observers received training in bird identification, line transect distance sampling technique, and use of equipment.

I conducted nest searches in late April – July using behavioral cues (e.g., birds carrying nesting material, food, or fecal sacs, defending territory, or chipping), flushing locations of birds, and rope-dragging (Winter et al. 2003). Once I discovered a nest, I recorded its location (GPS) and spray painted a small mark on the ground 5 m to the north and south of the location. I monitored nests every 2 – 3 days until nest fate was determined. I recorded presence or absence of adult, number of host eggs, number of brown-headed cowbird (*Molothrus ater*) eggs, and number of young at each visit. I considered nests successful if at least one host nestling fledged.

I sampled vegetation at nest sites within one week after determining nest fate. I placed a Daubenmire frame immediately adjacent to the nest location in each of the four cardinal directions, and recorded percent cover of grass, forbs, litter, and bare ground. I recorded the plant species in which the nest was located, substrate height, nest height, and litter depth. I determined visual obstruction by placing a Robel pole (Robel et al. 1970) directly into the nest cup and taking a reading from a distance of 4 m and height of 1 m in each of the four cardinal directions.

I determined percent cover of forest within a 250-m radius of pasture boundaries (For250) using ArcGIS and the 2011 National Land Cover Dataset (30-m pixels) (Homer et al. 2015). I combined deciduous forest, evergreen forest, and mixed forest into a single forest class. I used a 250-m radius because West et al. (2016) found a negative relationship between forest cover and grassland bird occupancy at this scale in a similar landscape. Edge-density metrics have also been shown to explain variation in grassland bird density (Fletcher and Koford 2002). Therefore, I determined percent of pasture edge consisting of woody vegetation for each pasture

by having an observer walk pasture boundaries and record the length of pasture edge consisting of forest or tall, dense woody brush. I quantified distance from each nest location to the nearest woody edge (DistWdEd) and fence (DistFen) using aerial photographs in ArcGIS. Fences are often the only structures in close proximity to production NWSG pastures, which are managed to minimize woody vegetation and forbs, that were tall enough to provide singing perches for male field sparrows.

STATISTICAL ANALYSES

To analyze vegetation composition and structure, I used a mixed-model ANOVA with repeated measures (year) in R (R Core Team 2019) package nlme (Pinheiro et al. 2018). I ran orthogonal contrasts between CONT and HEAVY, and between NWSG treatments (CONT and HEAVY combined) and FESCUE, and used the mean of sampling periods within a year for each pasture. Statistical significance was determined at the $P < 0.10$ level.

Prior to modeling density, nest selection, and nest survival, I checked covariates for collinearity. When collinearity was detected, I retained the most biologically relevant covariate. Only two covariates, visual obstruction reading (VOR) and vegetation height, were collinear; I dropped vegetation height from the analysis. I declared statistical significance for density, nest selection, and nest survival at $P < 0.10$.

I modelled avian density with a generalized linear mixed model (GLMM) in R (R Core Team 2019) following an integrated likelihood approach and custom R code developed and provided by Oedekoven et al. (2013) that evaluates the relationship of covariates to both detection probability and counts. I converted counts (adjusted for detection probability and covariates) to density by dividing the average count per transect (standardized for a 200-m segment) by the transect area, and then extrapolated to a per hectare basis. Oedekoven et al.

(2013) built upon the two-stage approach to analyze designed distance sampling experiments of Buckland et al. (2009) and the integrated likelihood developed by Royle et al. (2004) by including covariates in the detection function, allowing replication across and within years, allowing a site to include multiple lines, and including site as a random effect in models. Including site as a random effect accounted for the correlation of repeat counts at a site and allowed a wider frame of inference for my results. I stratified observations by pasture and grouped them into 10-m distance bins from zero to 50 m to increase goodness of fit. Detection probability was adjusted for distance, but not time. I fit a global detection function for each species based on all observations pooled across treatments. I fit detection functions before modelling abundance. Candidate models for the shape of detection functions were half normal and hazard rate (Buckland et al. 2001). Covariates for the detection function were year, treatment, and forage type (NWSG or FESCUE).

I developed candidate models for density to determine if there was a treatment effect, and secondarily, if forage type influenced density. First, I modelled density using treatment, forage type, the nuisance variables year and site, and landscape variables. I added landscape variables to ensure that they did not obscure the relationship of treatment or forage type with density, and to determine if they affected density directly. Next, I modelled pasture-level vegetation structure and composition variables with the most supported models ($AIC < 2$) from my first step. However, if best-supported models from the first step included either treatment or forage type, I removed those terms before adding vegetation characteristics because these variables were likely confounded. If a relationship with treatment or forage type was lacking, I explored the effect of specific vegetation characteristics alone on density. The influence of grazing or plant species on grassland bird density is primarily a function of the effect of these factors on vegetation structure

and resource availability (Fondell and Ball 2004, Derner et al. 2009). Thus, my approach allowed me to explain any relationship treatment or forage type may have had with density by substituting vegetation structure and composition variables or, lacking a treatment or forage type effect, the independent effect vegetation composition and structure may have had on density. I used Akaike Information Criterion (AIC) values to determine models with the most support ($AIC < 2$) (Burnham and Anderson 2002).

I analyzed nest-site selection at both the treatment and nest-site levels using R (R Core Team 2019) package `adehabitatHS` (Calenge 2006). I used Manly selection ratios (Manly et al. 2007) to determine if grassland birds selected for or against nest sites in any of the three treatments based on use versus availability. Use was represented by the proportion of nests located in each treatment to total nests found throughout the study, and availability was the proportion of total area (ha) of all replicate pastures within each treatment to the total area of all pastures in the study. I used the same procedure to determine selection for NWSG and FESCUE. I used resource selection functions (Manly et al. 2007) and logistic regression in the `glm` function of the `lme4` package in R (Bates et al. 2015) to determine site selection for individual nests.

I used the nest survival model in Program MARK (White and Burnham 1999) to estimate daily survival rates (DSR) and identify covariates that affected nest survival. I also reported constant (Mayfield) DSR estimates so comparisons could be made to estimates from other studies that used this technique (Mayfield 1961), and to allow comparison of the constant DSR to DSR of models with environmental covariates. Nest survival modelling followed the same approach as density modelling, except that I used nest-site vegetation characteristics instead of pasture-level characteristics. I used Akaike Information Criterion with small sample adjustment

(AIC_c) values to determine models with the most support (AIC_c < 2) (Burnham and Anderson 2002).

RESULTS

VEGETATION COMPOSITION AND STRUCTURE

Three-year mean HEAVY:CONT initial stocking rate ratios were 1.15 (range 1.10 – 1.19) at HOLSTON and 1.19 (range 1.14 – 1.24) at LOUDON. There were no differences in vegetation composition and structure variables between CONT and HEAVY, whereas NWSG (CONT and HEAVY combined) and FESCUE differed ($P < 0.10$) for all vegetation variables except litter depth (Table 2.1; all tables located in appendices). Native warm-season grass pastures had greater bare ground (%), litter cover (%), vegetation height (cm), and VOR (cm), and less forb (%) and grass cover (%) than FESCUE. Red and white clover, which are commonly planted in tall fescue pastures to improve forage quality, largely accounted for the difference in forb cover.

DENSITY

Grasshopper sparrow and field sparrow were the only species with enough detections for density analyses (Table 2.2). Relative abundances (unadjusted counts) are presented for the remaining bird species (Table 2.3). Heavy-early had numerically greater relative abundance of all five remaining bird species, followed by CONT, except for red-winged blackbird, which was numerically greater in FESCUE than CONT.

The half-normal was the best fitting detection function for both grasshopper sparrow and field sparrow. Accounting for treatment, year, or forage type (NWSG or FESCUE) did not improve the fit of the detection function for either species, so the global half-normal detection function was used for all density models. Detection rates were 0.87 and 0.79 for grasshopper

sparrow and field sparrow, respectively. Density of both bird species was related to woody vegetation surrounding pastures, and grasshopper sparrow densities differed among forage types.

The best-supported grasshopper sparrow density model included {forage type + woody edge} (Table 2.4), although other models such as the null also had some support ($AIC < 2$). Density estimates ranged from almost 0.7 males/ha in the absence of woody edge, to < 0.1 males/ha at 88% woody edge ($P = 0.046$, 143 df; Figure 2.3A). Density of grasshopper sparrow was greater in NWSG than FESCUE pastures ($P = 0.100$, 142 df) (Table 2.5). The average density of grasshopper sparrow in NWSG and FESCUE pastures, with woody edge held constant at its mean value, was 0.30 and 0.11 males/ha, respectively. The {treatment + woody edge} model also had marginal support. The beta estimate 90% confidence interval (-0.26, 1.98) for HEAVY ($P = 0.205$, 141 df) overlapped zero (Table 2.5), but CONT ($P = 0.093$, 141 df) did not (0.03, 2.23), suggesting greater density in CONT (0.34 males/ha) than in either HEAVY (0.26 males/ha) or FESCUE (0.11 males/ha).

When vegetation composition and structure variables replaced forage type in the {forage type + woody edge} model, forbs and VOR, both in their quadratic forms, improved the AIC score (Tables 2.4 and 2.5). With woody edge held constant at its mean, grasshopper sparrow density was predicted to peak at approximately 15% forb cover (Figure 2.3B) and 28 cm VOR (Figure 2.3C). These optimum levels were similar to the mean vegetation composition and structure values for FESCUE (14.3% forb cover) and NWSG (25.5 cm VOR for HEAVY and 28.1 cm VOR for CONT) pastures (Table 2.1).

No field sparrow density model that included treatment was supported ($AIC_c > 2.0$). Field sparrow density was best explained by For250 ($P < 0.001$, 143 df) (Tables 2.4 and 2.6). The positive relationship predicted an increase in density from approximately 0.2 males/ha at 0%

For250 to almost 0.6 males/ha at 68% For250 (Figure 2.3D). The {For250 + forage type} model was also marginally supported, but the beta coefficient confidence interval for forage type ($P = 0.919$, 142 df) included zero (Table 2.6). The addition of forbs ($P = 0.062$, 142 df) or bare ground ($P = 0.055$, 142 df) to For250 resulted in AIC reductions (Table 2.4), and confidence intervals did not overlap zero (Table 2.6; Figure 2.3E and 2.3F).

NEST SELECTION

Based on Manly selection ratios, both species selected to nest in CONT, used HEAVY in proportion to availability, and selected against nesting in FESCUE (Figures 2.4A and 2.5A). Similarly, for forage-type, both grasshopper and field sparrow selected for nesting in NWSG pastures and selected against nesting in tall fescue (Figures 2.4B and 2.5B).

The most-supported nest-site selection model for grasshopper sparrow was {VOR + VOR² + grass (%)} (Figure 2.6). The relative probability of use of a location for grasshopper sparrow nesting was greatest when VOR (VOR $\beta = 0.50$, SE = 0.18; VOR² $\beta = -0.01$, SE = 0.00) was approximately between 20 and 30 cm and percent grass cover ($\beta = -0.05$, SE = 0.02) decreased below 50%. The optimal VOR is near both the annual VOR averages (Table 2.1) and the early-season VOR averages of both CONT (29.5 cm) and HEAVY (26.3 cm). In NWSG pastures, grasshopper sparrow nests were found in big bluestem ($n = 19$), indiangrass ($n = 7$), and other substrates ($n = 3$), respectively. In FESCUE, nests were found in tall fescue ($n = 1$), mixed tall fescue and red clover ($n = 1$), and mixed tall fescue and orchardgrass (*Dactylis glomerata*, $n = 1$).

The most-supported field sparrow nest-site selection model was {VOR + VOR² + DistFen} (Figure 2.7). Field sparrows were most likely to select nest sites with approximately 65 cm VOR (VOR $\beta = 0.17$, SE = 0.05; VOR² $\beta = 0.00$, SE = 0.00) and close to fences ($\beta = -$

0.04, SE = 0.01). Similar to grasshopper sparrow, big bluestem was the primary field sparrow nest substrate, although more field sparrow nests were located in forbs and semi-woody species than were grasshopper sparrow nests. In NWSG pastures, field sparrow nests were located in big bluestem ($n = 25$), indiagrass ($n = 1$), *Rubus* spp. ($n = 4$), and other substrates ($n = 8$). In FESCUE, nests were found in tall fescue ($n = 1$), Chinese privet (*Ligustrum sinense*, $n = 1$), and musk thistle (*Carduus nutans*, $n = 1$).

NEST SURVIVAL

Grasshopper sparrow and field sparrow were the only focal species with sufficient sample sizes for nest survival analyses (Table 2.7). Nest characteristics and fates are presented for the remaining bird species (Table 2.3). I found a total of 17, 12, and 3, grasshopper sparrow nests, and 23, 15, and 3, field sparrow nests in CONT, HEAVY, and FESCUE, respectively, over the three-year study. Two of those grasshopper sparrow nests (1 CONT, 1 HEAVY) and one field sparrow nest (HEAVY) were trampled by cattle. No nests were parasitized by brown-headed cowbirds. Of the species with insufficient sample sizes for nest survival analysis, only INBU nests were parasitized (3 of 13 nests; 10 HEAVY, 3 FESCUE), and no brown-headed cowbirds fledged. Average clutch sizes of grasshopper sparrow nests were 3.80 ($n = 15$), 3.40 ($n = 10$), 4.33 ($n = 3$), and 3.64 ($n = 25$) for CONT, HEAVY, FESCUE, and NWSG, respectively. Average clutch sizes of field sparrow nests were 3.21 ($n = 19$), 3.54 ($n = 13$), 3.67 ($n = 3$), and 3.34 ($n = 32$) for CONT, HEAVY, FESCUE, and NWSG, respectively.

The best-supported grasshopper sparrow daily survival rate (DSR) model prior to introducing vegetation covariates was {site + DistWdEd + site*DistWdEd} (Table 2.8). Adding treatment to this model resulted in a higher (but still competitive) AIC_c score, but beta value confidence intervals for both CONT and HEAVY included zero (Table 2.9). The constant DSR

(90% CI) for grasshopper sparrow nests was 0.913 (0.874, 0.941). The direction of the relationship of survival with DistWdEd depended on site (Figure 2.8A). Daily survival rate at Holston was greater for nests that were < 100 m (0.97) from woody edge, and much lower beyond 100 m from woody edge. Grasshopper sparrow nest DSR at LOUDON decreased gradually with increasing distance from woody edge (Figure 2.8A). Adding either VOR or VOR^2 to {site + DistWdEd + site*DistWdEd} improved model support indicating DSR increased with VOR at the nest location (Figure 2.8B). Pasture size, shape, proximity of woody edge to pasture boundaries, and amount of woody edge surrounding pastures varied by site. To account for this variation, overall nest success for each site was calculated using site-specific mean values for nest-site covariates. Daily survival rates (90% CI) and overall nest success (90% CI), based on a 24-day nesting cycle (11 days incubation and 9 days nestling), were 0.974 (0.851, 0.996) and 0.531 (0.021, 0.907), 0.816 (0.705, 0.892) and 0.008 (0.000, 0.064), 0.926 (0.801, 0.975) and 0.158 (0.005, 0.543), for HOLSTON, LOUDON, and SOUTH, respectively. With DistWdEd held constant at the mean value while VOR was varied, DSR exceeded the constant rate at all values of VOR at HOLSTON, ≥ 28 cm at LOUDON, and ≥ 15 cm at SOUTH. The number of young fledged per nesting attempt (SE) was 2.2 (0.7), 0.9 (1.8), and 1.7 (0.9), for CONT, HEAVY, and FESCUE, respectively. The mean number of young fledged/ha/yr (SE) based on the nests I found was 0.32 (0.15), 0.11 (0.08), and 0.05 (0.05), for CONT, HEAVY, and FESCUE, respectively.

Prior to accounting for nest-site vegetation covariates, treatment was the best-supported model for field sparrow nest DSR (Table 2.8). However, the constant model was also competitive with the treatment model, and there was limited support for landscape covariates in combination with treatment. No model had AIC_c weight > 0.12. Therefore, DSR estimates from

biologically relevant models within 2 AIC_c of the best-supported model were averaged. Model-averaged DSR (90% CI) were 0.948 (0.915, 0.969) for CONT, 0.924 (0.861, 0.960) for HEAVY, and 0.950 (0.882, 0.980) for FESCUE. The constant model DSR was 0.941 (0.917, 0.959). The most supported nest-site vegetation covariates were bare ground and substrate height (Tables 2.8 and 2.10). Daily survival rate was greatest at lower levels of bare ground (Figure 2.9). Substrate height was a supported model, but the confidence interval overlapped zero (Table 2.10). Overall nest success (90% CI), based on model-averaged treatment and best-supported nest-site vegetation models, and a 23-day nesting period (12 days incubation and 7 days nestling), was 0.221 (0.075 – 0.419), 0.171 (0.047 – 0.364), and 0.227 (0.053 – 0.478) for CONT, HEAVY, and FESCUE, respectively. The constant overall nest success was 0.247 (0.135 – 0.377). The number of young fledged per nesting attempt (SE) was 1.5 (1.4), 1.0 (1.9), and 2.3 (0.8), for CONT, HEAVY, and FESCUE, respectively. The mean number of young fledged/ha/yr (SE) based on the nests I found was 0.29 (0.11), 0.15 (0.08), and 0.07 (0.05), for CONT, HEAVY, and FESCUE, respectively.

DISCUSSION

Grasshopper sparrow density was greater in NWSG than FESCUE and both sparrow species selected NWSG over FESCUE for nesting. Nest survival was not related to forage type for either sparrow species, but grasshopper sparrow nest survival increased with visual obstruction, which was greater in NWSG than FESCUE. However, in my models, woody vegetation surrounding pastures and pasture-level vegetation characteristics had greater influence on density and nest survival of both grasshopper and field sparrow. Grasshopper sparrow density was generally negatively related to proximity to woody vegetation, whereas field sparrow density was positively associated with forested landscapes. Pasture-level vegetation

characteristics increased support for models and explained additional variation in density and nest survival parameters. The most influential vegetation characteristics were visual obstruction, forb cover, and bare ground. Both species selected nest sites in NWSG pastures and avoided fescue. Production NWSG pastures may benefit conservation of both species, but must be placed in the proper landscape context. Regardless, season-long continuous cattle stocking on NWSG provided grassland bird habitat that produced greater grasshopper sparrow density and more nesting opportunities for both grasshopper and field sparrow than fescue pastures which are typical of the region. However, NWSG pastures appear less beneficial to field sparrow than grasshopper sparrow, and both species appear to be more influenced by vegetation structure than grass species *per se*.

DENSITY

Grasshopper sparrow density was likely greater on NWSG than FESCUE because the NWSG pastures used in this study had structural qualities that predisposed them to providing breeding habitat for this species, especially when grazed. Grazing with livestock is an effective management technique for creating and maintaining habitat for grassland songbirds in NWSG pastures that otherwise grow to be too thick (Harper et al. 2015). By contrast, tall fescue is typically hayed or grazed to a low, uniform height immediately prior to and into the nesting season when male birds arrive and establish territories (Giuliano and Daves 2002). Field sparrow density, on the other hand, was not associated with forage type, likely because of their affinity for shrubs they were more influenced by conditions along pasture edges and in the surrounding landscape than my study pastures, which lacked any woody cover. The lack of a stronger association between forage type and grasshopper sparrow density, and treatment or

forage type and field sparrow density, may also be attributed to the overwhelming influence of woody vegetation around pastures and in the surrounding landscape.

Multiple studies have found density of grasshopper sparrow and other grassland obligates to be negatively related to woody vegetation (Bakker 2003, Irvin et al. 2013, Vos and Ribic 2013). Field sparrow density, on the other hand, increased with the amount of forested landscape surrounding pastures, likely because areas I classified as forest contained a matrix of early successional forest and edge, both of which are components of their habitat (Johnston 1947, Lanyon 1981, Dechant et al. 2002b).

Neither landscape nor local vegetation structure alone can typically account for all variation in grassland bird density; rather a combination of factors such as landscape, vegetation characteristics, and perimeter:area ratios, among other factors, are typically needed (Fletcher and Koford 2002, Cunningham and Johnson 2006, Winter et al. 2006). In my study, specific pasture-level vegetation composition and structure covariates better explained grasshopper sparrow density than the more general term, forage type. Pasture-level vegetation covariates, however, were related to forage type, as evidenced by the results of the vegetation composition and structure analysis from this study (Table 2.1); mean values of all vegetation metrics except for one differed between NWSG and FESCUE. For instance, the slope of VOR, which positively influenced grasshopper sparrow density, was greater in NWSG than FESCUE. Visual obstruction in FESCUE fell below levels that maximized grasshopper sparrow density. Pastures that had greater forb cover typically had higher avian density regardless of forage type. FESCUE had greater forb cover (Table 2.1), but there was overlap in forb cover means among individual NWSG and FESCUE pastures. If NWSG pastures had greater forb cover, the relationship between NWSG and grasshopper sparrow density would likely have been stronger.

The same could be said of increasing VOR in FESCUE, but typical pasture management maintains fescue height that is too short to provide suitable visual obstruction. As it was, in terms of density, VOR and forbs worked in opposite directions with the two forage types.

NEST-SITE SELECTION

Grasshopper and field sparrow selected to nest in CONT, and used HEAVY in proportion to availability, likely because of the inherently tall, structurally diverse nature of NWSG, which can persist under season-long continuous grazing (Harper et al. 2007, Harper et al. 2015). Continuous may have been selected because the lighter initial grazing pressure, relative to HEAVY, resulted in more appropriate vegetation structure for nesting. Tall fescue pastures are typically hayed or clipped for seedhead suppression during the peak of nesting season (late May – mid-June) or grazed intensively to a short, relatively uniform height before and during the beginning of nesting season. For NWSG, haying does not occur until later in the nesting season, and grazing is not initiated until later in spring (Giuliano and Daves 2002) once many territories have already been established.

The impacts of grazing on bird density and nest success results from the combined effect of forage type (species) and grazing management (Monroe et al. 2016). Visual obstruction helped explain nest selection in NWSG for both grasshopper and field sparrow. Grasshopper sparrow nest-site selection was maximized within the range of mean pasture-level VOR of CONT and HEAVY. Grasshopper sparrows avoid dense, thick vegetation (Dechant et al. 2002a, Ribic et al. 2012), and appropriate grazing, as in this study, can create and maintain grass height and structure that provides nest sites for grasshopper sparrow and other grassland birds throughout the grazing season (Harper et al. 2015, Moorman et al. 2017). Visual obstruction is a structural characteristic of vegetation that influences nest site selection by grassland birds

(Fondell and Ball 2004) because it affects nest concealment. In fescue pastures, VOR is limited both by the physical characteristics of the plant and typical grazing management, which maintains a relatively short and uniform grass height. Similarly, percent grass cover is lower in NWSGs, which are bunch grasses, than fescue, which is managed as a sod-forming grass, making NWSGs more amenable to grassland bird nesting (Dion et al. 2000). In addition to selecting for greater VOR, field sparrow nests were preferentially placed near fences in this study. Field sparrows select tall forbs, saplings, or trees that stand higher than the surrounding vegetation for male singing perches (Johnston 1947, Lanyon 1981, Dechant et al. 2002b). All pastures used in this study were managed to limit forb and woody plant cover, so fence posts were often the only features within pastures tall enough to serve as singing perches.

NEST SURVIVAL

No brown-headed cowbird parasitism of grasshopper or field sparrow nests was documented during my study. Several Fescue Belt studies have also reported an absence of parasitism of grasshopper sparrow nests including those in southwestern MO ($n = 23$; Winter 1998), on small airports in IL ($n = 12$; Kershner and Bollinger 1998), and in western TN ($n = 131$; Giocomo et al. 2008). Outside the Fescue Belt, in the more open landscape of the Great Plains, 50% ($n = 18$) of grasshopper sparrow nests were parasitized in grazed pastures in northeastern KS (Elliott 1978). Brown-headed cowbird parasitism of field sparrow nests ranged from 1% ($n = 276$) on Fort Campbell in TN (Giocomo et al. 2008) to 80% ($n = 20$) in IA, slightly outside the Fescue Belt (Crooks 1948, Shaffer et al. 2003).

Neither treatment nor forage type was related to grasshopper sparrow nest survival. The unexpected negative relationship between grasshopper sparrow nest survival and distance to woody edge observed at LOUDON and HOLSTON may reflect the influence of landscape on

local predator populations. The primary nest predators at those sites may be small mammals that used pasture interiors because their predators were associated with woody edges (Grant et al. 2006, Ribic et al. 2012), or the highly fragmented landscapes surrounding the study sites may have supported a large number of generalist predators not strongly associated with edges (Renfrew et al. 2005).

Visual obstruction is an index of vegetation height and density (Robel et al. 1970, Johnson et al. 2011) and presumably, how well a nest can be hidden on or near the ground. Despite the fact that NWSG had greater mean pasture-level VOR than FESCUE, grasshopper sparrow nest survival was better explained by nest-site level VOR than forage type. This could be a function of the low sample size of grasshopper sparrow nests in FESCUE ($n = 3$), or the ability of grasshopper sparrow to find nest sites with suitable visual obstruction in either forage type, regardless of mean pasture-level visual obstruction. The constant DSR (0.913) of grasshopper sparrow nests in my study is at the lower extreme of published rates. Only two studies, Hovick et al. (2012) and Lyons et al. (2015), both conducted in southern Iowa on grazed and burned pastures, documented lower DSRs, 0.907 and 0.906, respectively. The pastures used in those studies were dominated by tall fescue and were situated in less forested landscapes than pastures in my study. Working on a considerably less forested site in western Tennessee, Giocomo et al. (2008) reported DSR up to 0.958. Nest success varied widely among my study sites, though, with HOLSTON (0.531) nearing the upper extreme of published figures, whereas success at LOUDON (0.008) and SOUTH (0.158) were both toward the lower. Although I did not collect the demographic parameters necessary to model population growth, the low grasshopper sparrow nest success at LOUDON and SOUTH is a concern. I was unable to

account for renesting rates in my study, which precludes a more thorough evaluation of productivity on these two sites.

There was a great deal of ambiguity among models for field sparrow DSR. Field sparrow DSR for CONT and FESCUE was on the upper end of published values in eastern states (Galligan et al. 2006, Giocomo et al. 2008, Schill and Yahner 2009), while DSR for HEAVY was among the lowest. At the nest-site, field sparrow DSR was greatest at the lowest levels of bare ground, perhaps because it was more difficult for predators to travel through thicker vegetation or harder for them to locate nests because they were better concealed. The evidence from this study suggests that CONT was generally beneficial for field sparrow. Results should be interpreted with caution due to the low sample size of nests of both species in all treatments, but especially FESCUE.

While landscape better explained variation in density than treatment, forage type, or within-pasture vegetation composition and structure, grasshopper sparrow density was higher on NWSG, and both grasshopper sparrow and field sparrow selected to nest in NWSG while avoiding fescue, suggesting potential conservation benefit for these two sparrow species. Although nest survival was not associated with forage type, it was positively associated with vegetation characteristics typical of NWSG pastures. Nest sites also may be chosen to maximize postfledging survival, as opposed to nest survival, as has been reported with golden-winged warblers (*Vermivora chrysoptera*), which may influence the overall productivity of the habitat (Streby et al. 2016). Grasshopper sparrow and field sparrow may be selecting nest sites in NWSG because it benefits fledgling survival. Further research should explore the implications of nest-site selection on postfledging survival.

MANAGEMENT IMPLICATIONS

Grasshopper sparrow and field sparrow may both benefit from NWSG pastures in the mid-South, although they are more important to the former than the latter species. However, attention must be paid to pasture management and placement. Conventional season-long continuous grazing with appropriate stocking is consistent with promoting grassland bird conservation. Proper vegetation structure, in particular visual obstruction, should be maintained by grazing with a stocking rate that maintains average grass canopy height of 45 – 50 cm, especially during peak nesting season. This grass height, the approximate average grass canopy height of CONT from grazing initiation through mid-July, should result in visual obstruction that maximizes grasshopper sparrow density and increases nest survival. Greater grass canopy heights will provide additional nest sites for field sparrow, but may be detrimental to grasshopper sparrow density. A better approach to providing habitat for field sparrow may be to provide additional nest sites and perches by allowing tall forbs and shrubby vegetation to increase around pasture perimeters. Increasing forb cover in production NWSG pastures will increase abundance of both species and create more perch sites for field sparrows, although producers may need incentives to adopt this practice. To maximize grasshopper sparrow abundance, NWSG pastures should be established in locations that minimize the amount of woody edge around pasture boundaries. Conversely, field sparrow abundance will benefit most in landscapes with more edge and/or early successional forest.

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APPENDICES

TABLES

Table 2.1. Pasture-level vegetation composition and structure characteristics of conventional continuous (CONT) season-long (May – Aug), or heavy-early (HEAVY) continuous stocking of native warm-season grass (NWSG) pastures, and traditionally managed tall fescue (FESCUE) pastures in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

Variable	Contrast	<i>P</i>	Treatment	$\bar{X}$	SE	(90% CI)
Bare ground ^a	CONT vs. HEAVY	0.914	FESCUE	3.5	6.02	(-11.29, 18.11)
	NWSG ^b vs. FESCUE	0.038	CONT	13.1	5.84	(-1.10, 27.32)
			HEAVY	12.6	5.84	(-1.56, 26.86)
Forbs ^c	CONT vs. HEAVY	0.325	FESCUE	14.3	3.71	(5.17, 23.43)
	NWSG vs. FESCUE	0.043	CONT	6.3	3.56	(-2.44, 15.12)
			HEAVY	9.4	3.56	(0.66, 18.22)
Grass ^d	CONT vs. HEAVY	0.875	FESCUE	69.1	3.33	(62.45, 75.71)
	NWSG vs. FESCUE	< 0.001	CONT	48.5	3.16	(42.17, 54.77)
			HEAVY	49.1	3.16	(42.84, 55.44)
Litter ^e	CONT vs. HEAVY	0.750	FESCUE	13.8	6.17	(1.21, 26.35)
	NWSG vs. FESCUE	0.018	CONT	31.7	5.86	(19.72, 43.60)
			HEAVY	29.5	5.86	(17.59, 41.47)
Litter depth ^f	CONT vs. HEAVY	0.751	FESCUE	1.1	0.30	(0.47, 1.82)
	NWSG vs. FESCUE	0.286	CONT	1.4	0.29	(0.78, 2.08)
			HEAVY	1.3	0.29	(0.70, 2.00)
Vegetation ht ^g	CONT vs. HEAVY	0.338	FESCUE	22.8	3.14	(16.47, 29.15)
	NWSG vs. FESCUE	0.019	CONT	35.2	2.96	(29.19, 41.13)
			HEAVY	31.3	2.96	(25.32, 37.26)
VOR ^h	CONT vs. HEAVY	0.592	FESCUE	13.2	4.19	(4.75, 21.57)
	NWSG vs. FESCUE	0.012	CONT	28.1	3.97	(20.12, 36.04)
			HEAVY	25.5	3.97	(17.54, 33.45)

^a Pasture-level percent bare ground.

^b Native warm-season grass treatments CONT and HEAVY.

^c Pasture-level percent forb cover at ground-level.

^d Pasture-level percent grass cover at ground-level.

^e Pasture-level percent litter cover at ground-level.

^f Pasture-level litter depth.

^g Pasture-level vegetation ht.

^h Visual obstruction reading (Robel et al., 1970).

Table 2.2. Density of grasshopper sparrow and field sparrow by year and treatment in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

Species	Treatment ^a	Year	Density (males/ha)
Grasshopper sparrow	CONT	2015	0.42
		2016	0.38
		2017	0.41
	HEAVY	2015	0.31
		2016	0.28
		2017	0.30
	FESCUE	2015	0.15
		2016	0.14
		2017	0.15
Field sparrow	CONT	2015	0.13
		2016	0.15
		2017	0.15
	HEAVY	2015	0.14
		2016	0.16
		2017	0.16
	FESCUE	2015	0.08
		2016	0.10
		2017	0.10

^a Traditional continuous (CONT) season-long (May – Aug), or heavy-early (HEAVY) continuous stocking of native warm-season grass, and traditionally-managed tall fescue (FESCUE).

Table 2.3 Summary of line-transect distance sampling counts and nest results of bird species with insufficient sample sizes for formal analysis. Line-transect counts and nest searching and monitoring were conducted on conventional continuous (CONT) season-long (May – Aug), or heavy-early (HEAVY) continuous stocking of native warm-season grass, and traditionally managed tall fescue (FESCUE) pastures in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

Species	Treatment	Count	Nests	Successful	Failed	Trampled ^a	Clutch		Fledglings	(n)	Fledglings/attempt
							Size	(n)			
Dickcissel	CONT	4	1	1	0	0	4.00	(1)	4.00	(1)	4.0
	HEAVY	31	9	4	5	1	4.00	(8)	3.25	(4)	0.4
	FESCUE	1	0								
Red-winged blackbird	CONT	10	2	0	2	0	3.50	(2)			
	HEAVY	25	22	7	15	4	3.10	(16)	3.00	(7)	0.1
	FESCUE	3	2	0	2	0	2.50	(2)			
Eastern meadowlark	CONT	5	1	1	0	0	NA	NA	5.00	(1)	5.0
	HEAVY	26	1	0	1	0	5.00	(1)			
	FESCUE	25	1	1	0	0	NA	NA	3.00	(1)	3.0
Indigo bunting	CONT	33	0								
	HEAVY	53	10	1	9	0	3.11	(9)	4.00	(1)	0.4
	FESCUE	27	3	1	2	0	3.00	(1)	3.00	(1)	1.0
Common yellowthroat	CONT	2	0								
	HEAVY	6	0								
	FESCUE	1	0								

^a Number of nests that failed due to being stepped on, laid on, or otherwise disturbed by cattle.

Table 2.4. Null, treatment, forage type, and most supported density models, based on Akaike information criterion (AIC; $\Delta AIC \leq 2.00$), for grasshopper sparrow and field sparrow in production native warm-season grass pastures in Knox, Loudon, and Blount counties, TN, during spring and summer 2015 - 2017. Densities are based on line transect distance sampling. All models used half-normal global detection functions. Delta AIC and AIC weights are based on the full model set. Model ID corresponds to Model ID for beta values in Table 2.5 (grasshopper sparrow) and Table 2.6 (field sparrow).

Species							
Model ID	Model	Log-likelihood	K ^a	AIC	ΔAIC	AICw ^b	
Grasshopper sparrow							
1	$B_0^c + b_j^d + \text{woody edge}^e + \text{forbs}^f + \text{forbs}^2$	-615.32	6	1242.64	0.00	0.41	
2	$B_0 + b_j + \text{woody edge} + \text{VOR}^g + \text{VOR}^2$	-616.16	6	1244.33	1.69	0.17	
3	$B_0 + b_j + \text{forage type}^h + \text{woody edge}$	-619.16	5	1248.31	5.68	0.02	
4	$B_0 + b_j + \text{woody edge}$	-620.24	4	1248.49	5.85	0.02	
5	$B_0 + b_j$	-622.00	3	1249.99	7.36	0.01	
6	$B_0 + b_j + \text{treatment}^i + \text{woody edge}$	-619.09	6	1250.19	7.55	0.01	
Field sparrow							
1	$B_0 + b_j + \text{forest 250}^j + \text{forbs}$	-365.19	5	740.38	0.00	0.28	
2	$B_0 + b_j + \text{forest 250} + \text{bare ground}^k$	-365.80	5	741.59	1.22	0.15	
3	$B_0 + b_j + \text{forest 250}$	-366.88	4	741.75	1.38	0.14	
4	$B_0 + b_j + \text{forage type} + \text{forest 250}$	-366.87	5	743.74	3.37	0.05	
5	$B_0 + b_j$	-372.20	3	750.39	10.02	0.00	
6	$B_0 + b_j + \text{treatment}$	-371.78	5	753.56	13.18	0.00	

^a No. of parameters in model.

^b AIC weight.

^c Intercept.

^d Random effects term for pasture (experimental unit).

^e Percent pasture perimeter that consisted of trees or thick, tall brush.

^f Pasture-level % forbs at ground-level.

^g Visual obstruction reading (cm) (Robel et al., 1970).

^h Native warm-season grass or tall fescue.

ⁱ Traditional continuous stocking NWSG, heavy-early continuous NWSG, and traditionally-managed tall fescue.

^j Percent forested land within a 250 m buffer of pasture perimeter.

^k Pasture-level % bare ground.

Table 2.5. Grasshopper sparrow density model beta estimates, based on line transect distance sampling conducted May through June, in native warm-season grass (NWSG) pastures grazed with conventional continuous (CONT) season-long (May – Aug) or heavy-early (HEAVY) continuous stocking, and tall fescue pastures under traditional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Model ID corresponds to Model ID in Table 2.4.

Model ID	1		2		3		4		5		6	
Parameter	MLE ^a	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)
Random effects												
SD	0.02	(-0.44, 0.48)	-0.11	(-0.64, 0.42)	-0.08	(-0.56, 0.40)	0.07	(-0.37, 0.51)	0.13	(0.10, 0.16)	-0.10	(-0.58, 0.38)
Fixed effects												
Intercept	-0.96	(-1.96, 0.04)	-1.42	(-2.51, -0.33)	-0.95	(-1.97, 0.07)	-0.35	(-1.30, 0.61)	-1.19	(-1.22, -1.16)	-0.97	(-1.96, 0.02)
Woody edge ^b	-3.14	(-5.53, -0.75)	-2.34	(-4.36, -0.33)	-2.72	(-4.94, -0.50)	-2.86	(-5.20, -0.52)			-2.62	(-4.77, -0.47)
Forbs ^c	0.17	(0.07, 0.27)										
Forbs ²	-0.01	(-0.01, 0.00) [†]										
VOR ^d			0.09	(0.03, 0.16)								
VOR ²			0.00	(0.00, 0.00) [†]								
Forage type ^e												
NWSG					0.98	(0.01, 1.95)						
Treatment ^f												
CONT											1.13	(0.03, 2.23)
HEAVY											0.86	(-0.26, 1.98)

^a Maximum likelihood estimate.

^b Percent pasture perimeter that consisted of trees or thick, tall brush.

^c Pasture-level % forbs at ground-level.

^d Visual obstruction reading (cm) (Robel et al., 1970).

^e Native warm-season grass or tall fescue pasture.

^f Conventional continuous stocking NWSG, heavy-early continuous NWSG, and traditionally-managed tall fescue.

[†] CI round to zero, but do not overlap zero.

Table 2.6. Field sparrow density model beta estimates, based on line transect distance sampling conducted May through June, in native warm-season grass (NWSG) pastures grazed with conventional continuous (CONT) season-long (May – Aug) or heavy-early (HEAVY) continuous stocking, and tall fescue pastures under traditional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Model ID corresponds to Model ID in Table 2.4.

Model ID	1		2		3		4		5		6	
Parameter	MLE ^a	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)	MLE	(90 % CI)
Random effects												
SD	-1.40	(-2.95, 0.15)	-2.42	(-2.78, -2.06)	-1.17	(-2.11, -0.23)	-1.18	(-2.13, -0.23)	-0.31	(-0.38, -0.24)	-0.34	(-0.82, 0.14)
Fixed effects												
Intercept	-2.54	(-3.03, -2.05)	-2.71	(-3.24, -2.18)	-2.43	(-2.94, -1.92)	-2.41	(-2.99, -1.83)	-1.60	(-1.67, -1.53)	-1.94	(-2.71, -1.17)
Forest 250 ^b	2.48	(1.23, 3.74)	3.47	(2.54, 4.40)	3.20	(1.99, 4.40)	3.23	(1.94, 4.51)				
Forbs ^c	0.03	(0.00, 0.06)										
Bare ground ^d			0.02	(0.00, 0.04)								
Forage type ^e												
NWSG							-0.04	(-0.63, 0.56)				
Treatment ^f												
CONT											0.44	(-0.56, 1.45)
HEAVY											0.52	(-0.46, 1.50)

^a Maximum likelihood estimate.

^b Percent forested land within a 250 m buffer of pasture perimeter.

^c Pasture-level % forbs at ground-level.

^d Pasture-level % bare ground.

^e Native warm-season grass or tall fescue pasture.

^f Conventional continuous stocking NWSG, heavy-early continuous stocking NWSG, and traditionally-managed tall fescue.

Table 2.7. Daily survival rate of grasshopper sparrow and field sparrow nests by year and treatment in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

Species	Treatment ^a	Year	DSR	SE	90% Confidence Interval	
					Lower	Upper
Grasshopper sparrow	CONT	2015	0.9587	0.0315	0.8625	0.9885
		2016	0.9702	0.0166	0.9268	0.9882
		2017	0.8818	0.0531	0.7633	0.9453
	HEAVY	2015	0.8519	0.0822	0.6634	0.9438
		2016	0.8896	0.0442	0.7935	0.9441
		2017	0.6490	0.1414	0.3997	0.8370
	FESCUE	2015	0.8979	0.0845	0.6588	0.9757
		2016	0.9250	0.0528	0.7790	0.9773
		2017	no nests found			
Field sparrow	CONT	2015	no nests found			
		2016	0.9446	0.0204	0.8996	0.9701
		2017	0.9717	0.0131	0.9400	0.9869
	HEAVY	2015	0.8701	0.0631	0.7279	0.9437
		2016	0.8801	0.0449	0.7847	0.9367
		2017	0.9367	0.0298	0.8663	0.9713
	FESCUE	2015	0.9591	0.0418	0.8023	0.9927
		2016	0.9625	0.0392	0.8109	0.9935
		2017	0.9811	0.0212	0.8880	0.9971

Table 2.8. Daily survival rate models for grasshopper sparrow and field sparrow nests in native warm-season grass pastures grazed with either conventional continuous season-long (May – Aug) or heavy-early stocking, and traditionally-managed tall fescue pastures in Knox, Loudon, and Blount counties, TN, 2015 – 2017. The constant (null) model, most supported treatment and forage type models, and most-supported overall models based on Akaike information criterion corrected for small sample size (AIC_c ; $\Delta AIC_c \leq 0.00$) are included. Delta AIC and AIC weights are based on full model sets. Model ID corresponds to Model ID for beta values in Table 2.9 (grasshopper sparrow) and Table 2.10 (field sparrow).

Species					
Model ID	Model	K ^a	AIC_c	ΔAIC_c	AIC_{cw}^b
Grasshopper sparrow ($n = 32$ nests)					
1	Site + DistWdEd ^c + site*DistWdEd + VOR ^{2 d}	7	65.64	0.00	0.39
2	Site + DistWdEd + site*DistWdEd + VOR	7	66.57	0.93	0.25
3	Site + DistWdEd + site*DistWdEd	6	71.51	5.86	0.02
4	Treatment ^e + site + DistWdEd + site*DistWdEd	8	73.13	7.49	0.01
5	Constant	1	81.79	16.15	0.00
6	Forage type ^f + site	4	82.22	16.57	0.00
Field sparrow ($n = 42$ nests)					
1	Bare ground ^g (%) + bare ground ² (%)	3	118.55	0.00	0.20
2	Treatment	3	120.19	1.64	0.09
3	Substrate ht	2	120.38	1.83	0.08
4	Constant	1	120.60	2.05	0.07
5	Forage type	2	122.29	3.73	0.03

^a No. of parameters in model.

^b Distance (m) to woody edge from nest location.

^c Visual obstruction reading (cm) (Robel et al., 1970) at nest.

^d Traditional continuous stocking NWSG, heavy-early continuous stocking NWSG, and traditionally-managed tall fescue.

^e Native warm-season grass or tall fescue pasture.

^f Percent bare ground at the nest site.

Table 2.9. Daily survival rate model beta estimates for grasshopper sparrow nests in native warm-season grass (NWSG) pastures grazed with either conventional continuous (CONT) season-long (May – Aug) or heavy-early (HEAVY) stocking, and traditionally-managed tall fescue pastures in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Betas for the null (constant) model, most supported treatment and forage type models, and most-supported overall models based on Akaike information criterion corrected for small sample size (AIC_c ; $\Delta AIC_c \leq 0.00$) are included. Model ID corresponds to Model ID in Table 2.8.

Model ID	1		2		3		4		5		6	
Parameter	Beta	(90 % CI)	Beta	(90 % CI)	Beta	(90 % CI)	Beta	(90 % CI)	Beta	(90 % CI)	Beta	(90 % CI)
Intercept	-4.28	(-9.85, 1.28)	-5.65	(-11.60, 0.30)	-2.29	(-7.45, 2.87)	-1.01	(-6.60, 4.57)	0.97	(0.85, 1.09)	3.21	(1.59, 4.84)
Site ^f												
HOLSTON	13.62	(5.62, 21.62)	14.01	(5.85, 22.17)	11.22	(3.93, 18.51)	9.94	(2.33, 17.55)			0.81	(-0.48, 2.11)
LOUDON	5.86	(0.03, 11.70)	6.33	(0.43, 12.24)	5.74	(0.23, 11.26)	4.05	(-2.08, 10.18)			-0.77	(-1.85, 0.30)
DistWdEd ^b	0.05	(0.00, 0.10)	0.05	(0.00, 0.11)	0.04	(-0.01, 0.10)	0.04	(-0.01, 0.09)				
Site*DistWdEd												
HOLSTON*DistWdEd	-0.12	(-0.19, -0.05)	-0.12	(-0.19, -0.05)	-0.10	(-0.16, -0.04)	-0.10	(-0.16, -0.03)				
LOUDON*DistWdEd	-0.06	(-0.11, -0.01)	-0.06	(-0.12, -0.01)	-0.05	(-0.10, 0.00)	-0.05	(-0.10, 0.00)				
VOR ^c			0.12	(0.04, 0.20)								
VOR ²	0.00	(0.00, 0.01)										
Treatment ^d												
CONT							0.04	(-1.82, 1.91)				
HEAVY							-1.28	(-3.41, 0.86)				
Forage type ^e												
NWSG											-0.83	(-2.21, 0.54)

^a No nests were located at BLOUNT.

^b Distance (m) to woody edge from nest location.

^c Visual obstruction reading (cm) (Robel et al., 1970).

^d Conventional continuous stocking NWSG, heavy-early continuous stocking NWSG, and traditionally-managed tall fescue.

^e Native warm-season grass or tall fescue pasture.

Table 2.10. Daily survival rate model beta estimates for field sparrow nests in native warm-season grass (NWSG) pastures grazed with either conventional continuous (CONT) season-long (May – Aug) or heavy-early (HEAVY) stocking, and traditionally-managed tall fescue pastures in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Betas for the null (constant) model, most supported treatment and forage type models, and most-supported overall models based on Akaike information criterion corrected for small sample size (AIC_c ; $\Delta AIC_c \leq 0.00$) are included. Model ID corresponds to Model ID in Table 2.8.

Model ID	1		2		3		4		5	
Parameter	Beta	(90 % CI)	Beta	(90 % CI)	Beta	(90 % CI)	Beta	(90 % CI)	Beta	(90 % CI)
Intercept	3.35	(2.76, 3.94)	3.29	(1.62, 4.97)	1.95	(1.00, 2.91)	1.08	(0.99, 1.17)	3.29	(1.62, 4.97)
Bare ground ^a	-0.09	(-0.16, -0.03)								
Bare ground ²	0.00	(0.00, 0.00)								
Treatment ^b										
CONT			-0.15	(-1.92, 1.62)						
HEAVY			-1.10	(-2.86, 0.66)						
Substrate ht ^c					0.01	(0.00, 0.02)				
Forage type ^d										
NWSG									-0.56	(-2.28, 1.16)

^a Percent bare ground at the nest site.

^b Conventional continuous stocking NWSG, heavy-early continuous stocking NWSG, and traditionally-managed tall fescue.

^c Height (cm) of substrate in which nest was constructed.

^d Native warm-season grass or tall fescue pasture.

FIGURES

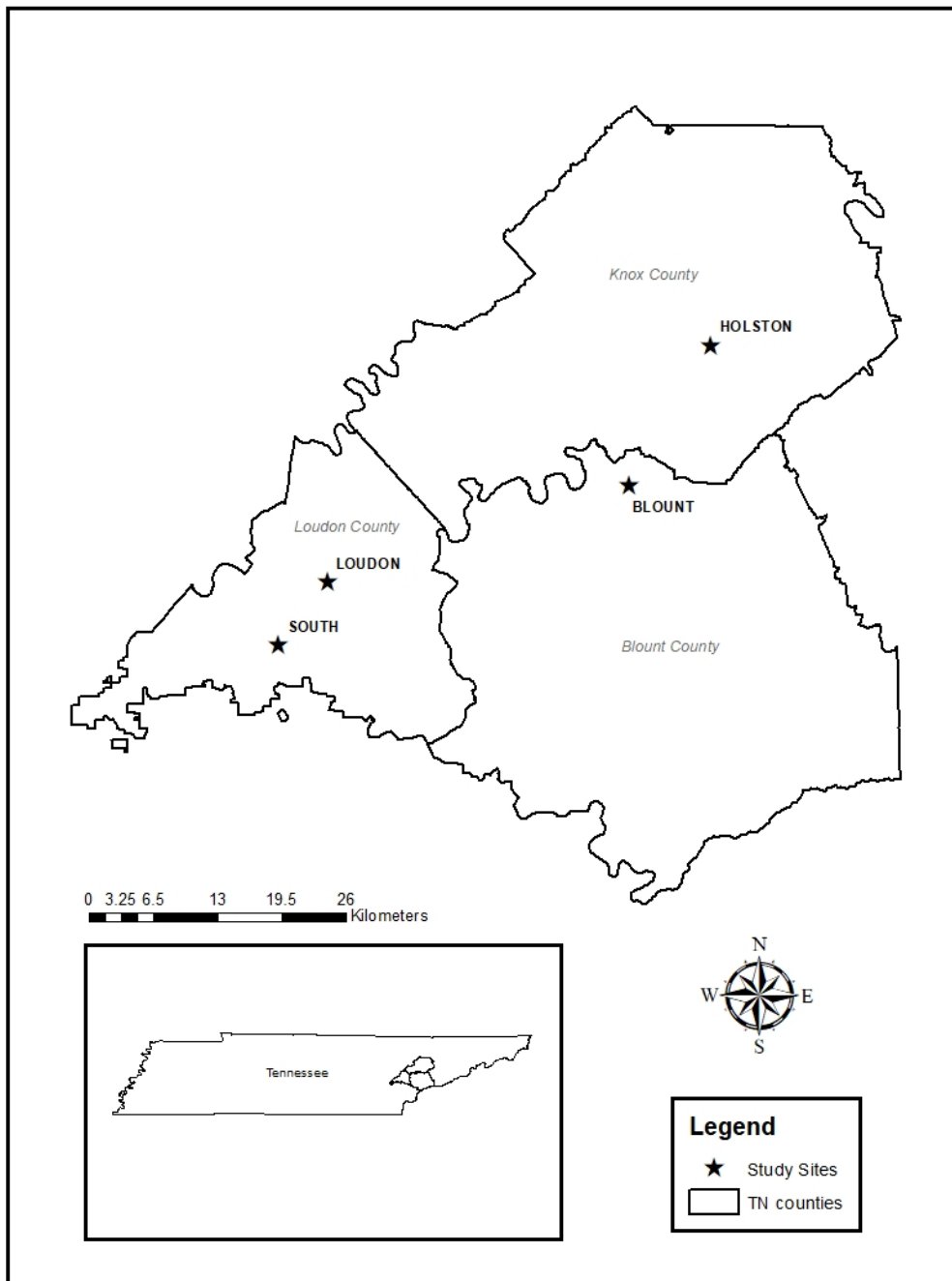


Figure 2.1. Study sites for avian density and nest success study on native warm-season grass pastures grazed with conventional season-long (May – Aug) continuous or heavy-early stocking, and tall fescue pastures under traditional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

		TREATMENT			
		CONT	HEAVY	FESCUE	
REPLICATE	1				2015
	2				
	3				
	4				
	1				2016
	2				
	3				
	4				
	1				2017
	2				
	3				
	4				

Figure 2.2. Illustration of treatments and replicates across years (2015 – 2017) of avian density and nest success study in native warm-season grass pastures grazed with conventional season-long (May – Aug) continuous or heavy-early stocking, and tall fescue pastures under traditional management in Knox, Loudon, and Blount counties, TN.

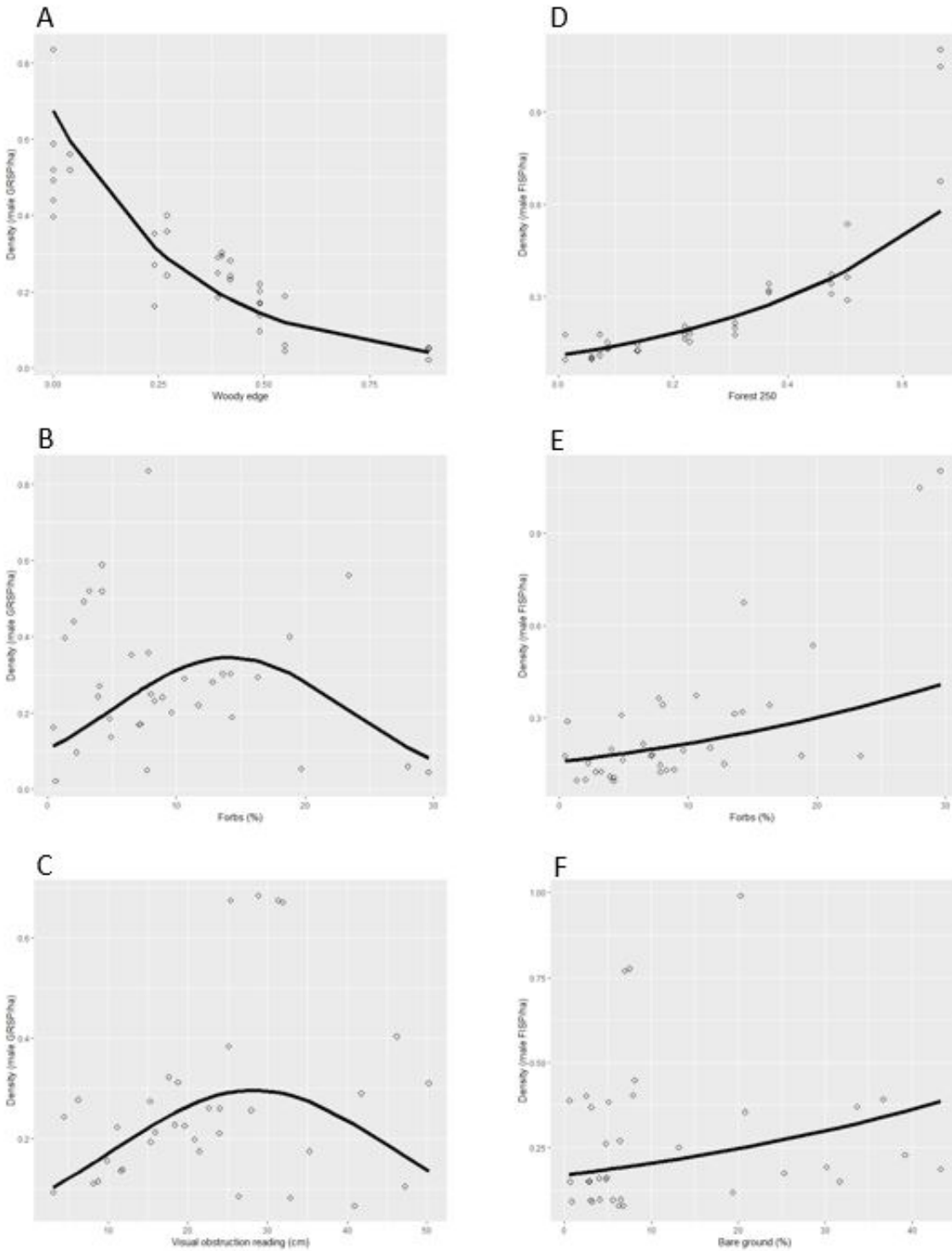
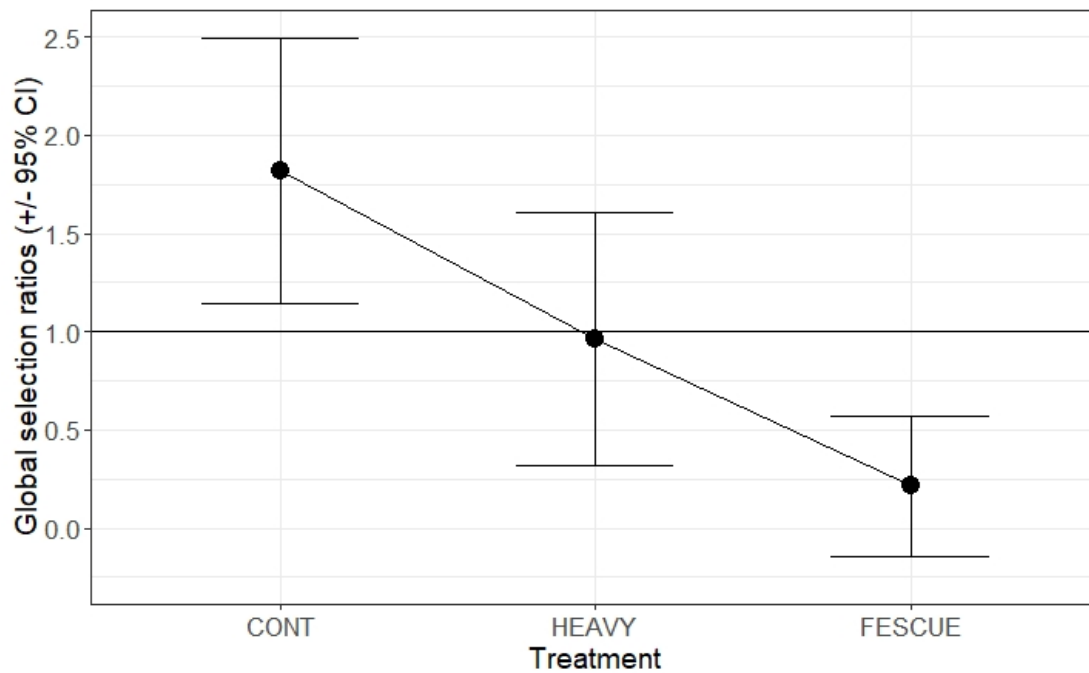


Figure 2.3. Relationship of covariates to grasshopper (GRSP; A – C) and field sparrow (FISP; D – F) density (no. males/ha) in native warm-season grass pastures grazed with conventional season-long (May – Aug) continuous or heavy-early stocking, and tall fescue pastures under traditional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Dots are predicted densities based on observed values for all independent variables in model. The line is formed by partialling all independent variables except for the one being graphed.

A



B

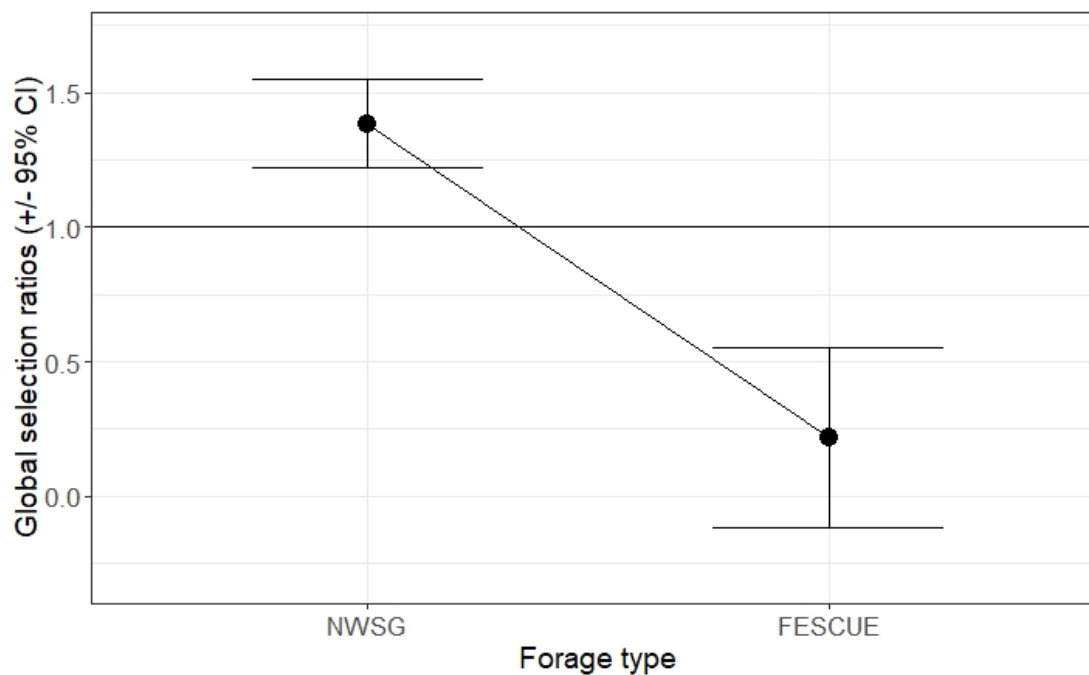
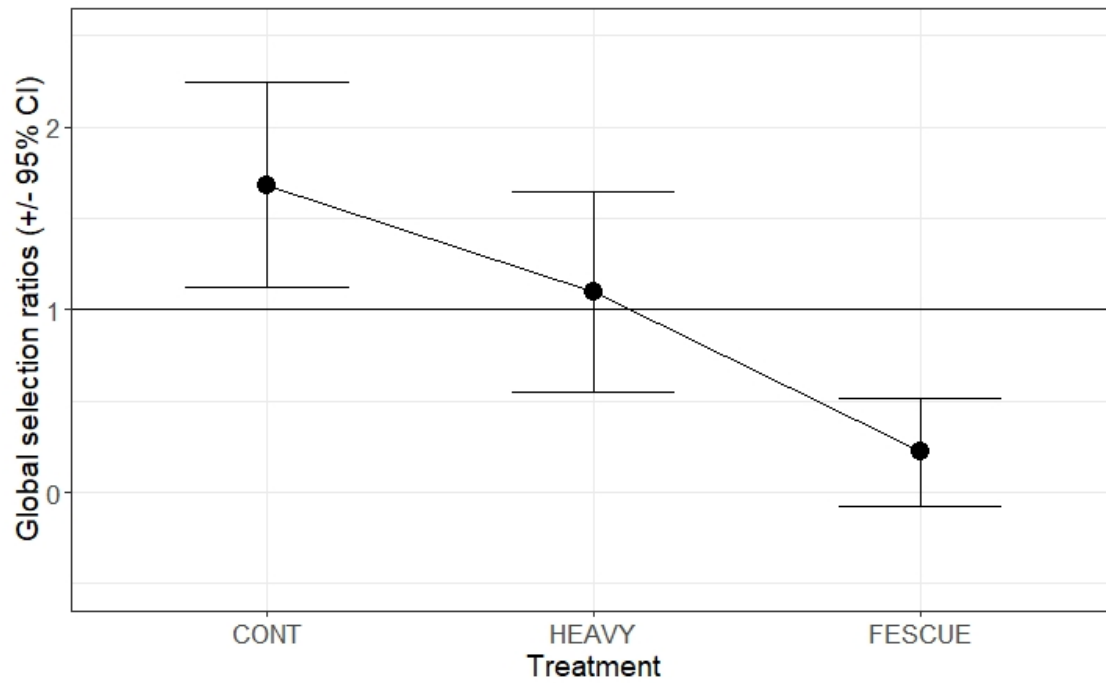


Figure 2.4. Manly selection ratios for grasshopper sparrow coarse-scale nest site selection for A) treatment and B) forage type (NWSG and FESCUE). Treatments were conventional season-long (May – Aug) continuous (CONT) or heavy-early (HEAVY) stocking of native warm-season grass (NWSG) pastures, and tall fescue (FESCUE) pastures under conventional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

A



B

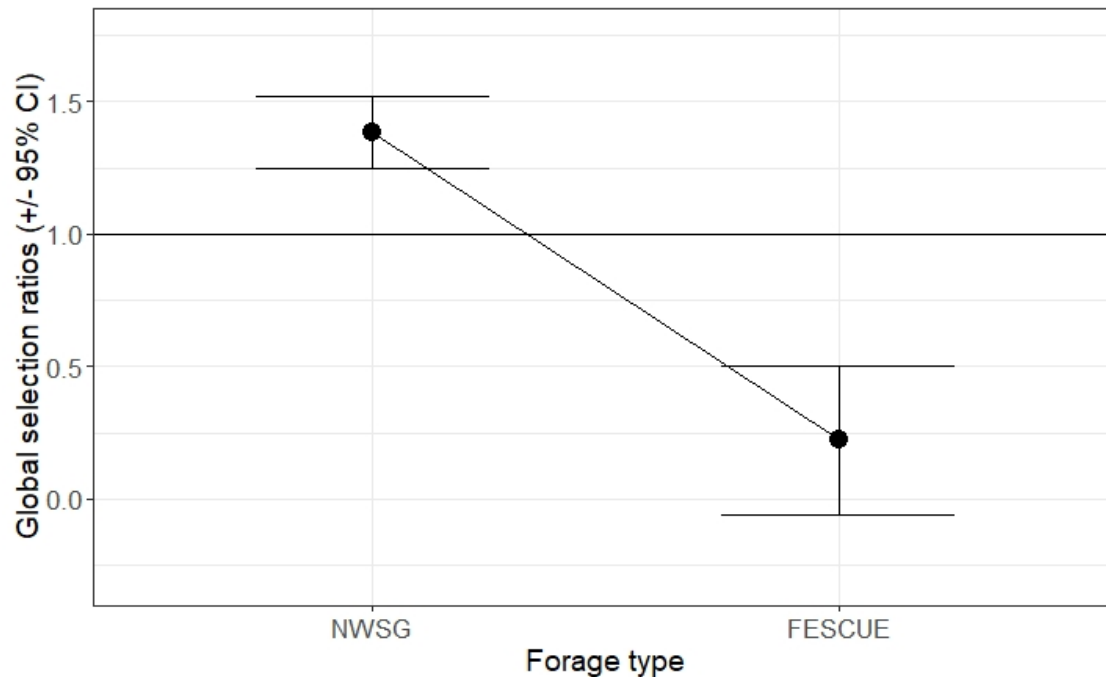
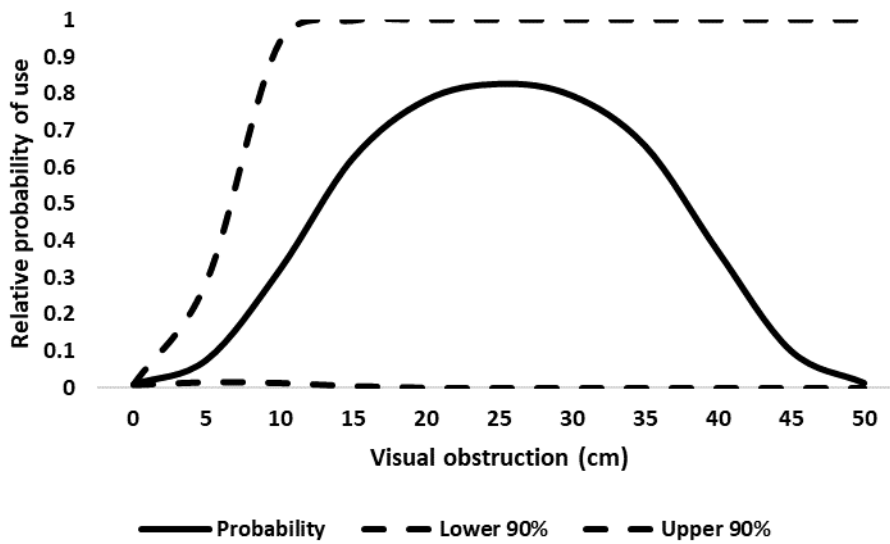


Figure 2.5. Manly selection ratios for field sparrow coarse-scale nest site selection for A) treatment and B) forage type (NWSG and FESCUE). Treatments were conventional season-long (May – Aug) continuous (CONT) or heavy-early (HEAVY) stocking of native warm-season grass (NWSG) pastures, and tall fescue (FESCUE) pastures under conventional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

A



B

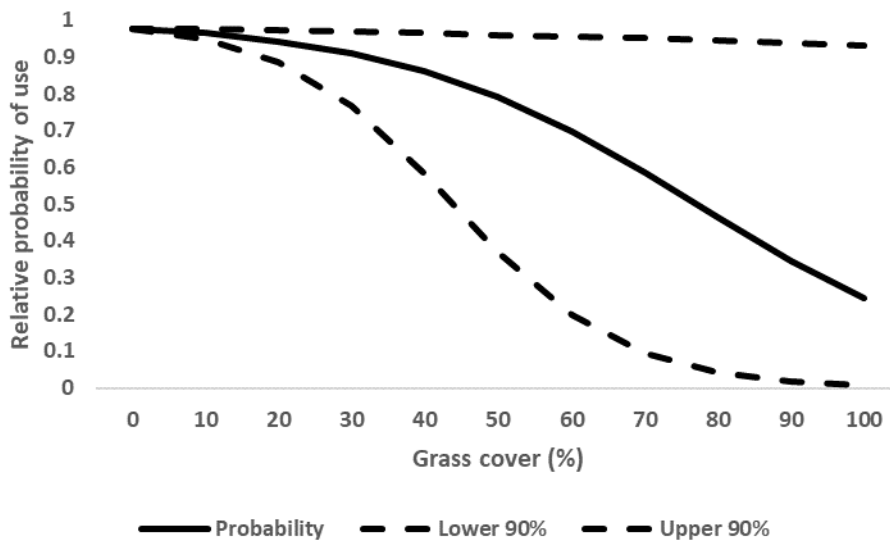
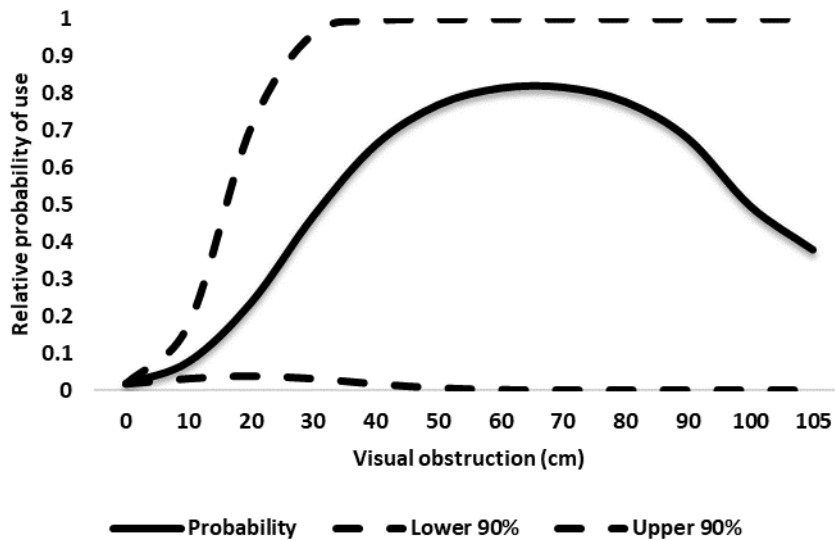


Figure 2.6. Grasshopper sparrow nest site selection within native warm-season grass (NWSG) pastures for A) visual obstruction reading (cm) at nests, and B) grass (%) immediately surrounding nests, based on resource selection functions, in NWSG pastures grazed with conventional season-long (May – Aug) continuous or heavy-early stocking, in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Only nests within NWSG pastures were included based on the results of coarse-scale grasshopper sparrow nest selection for NWSG pastures. The covariate not being graphed was held constant at its mean.

A



B

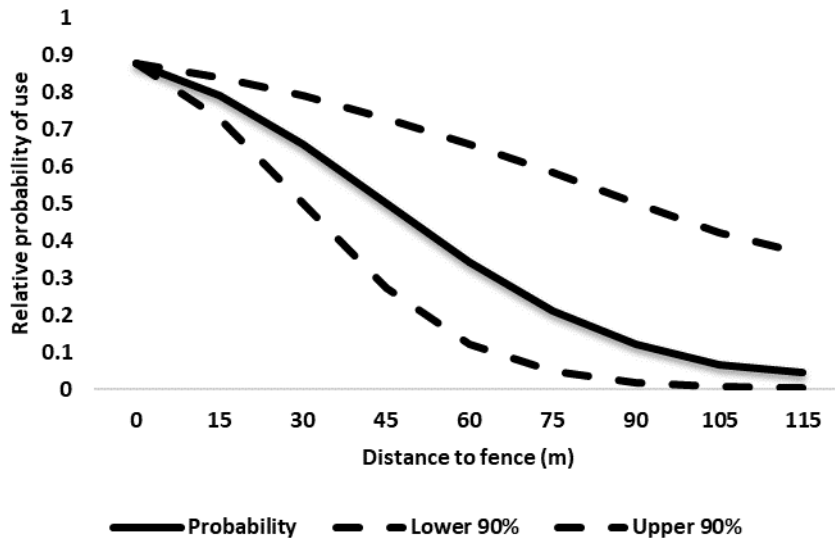
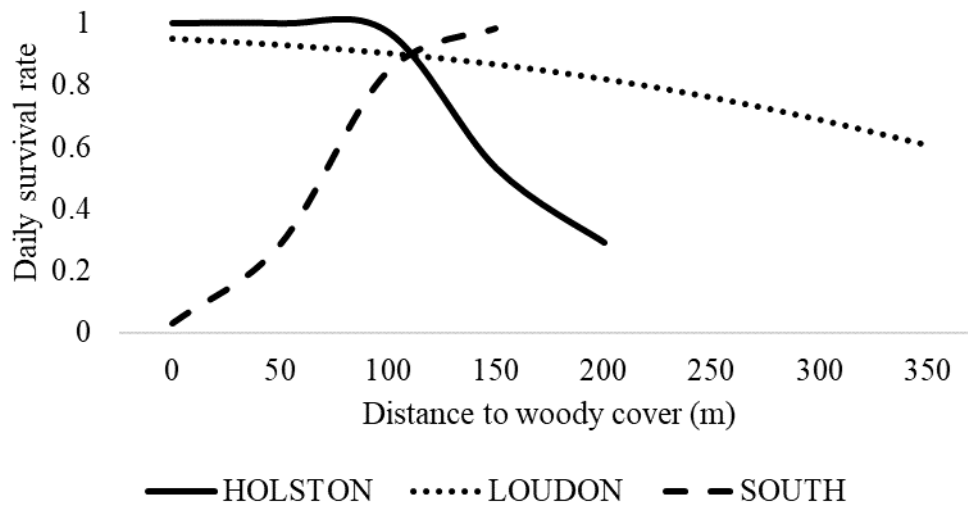


Figure 2.7. Field sparrow nest site selection within native warm-season grass (NWSG) pastures for A) visual obstruction reading (cm) at nests, and B) distance to fences (m) from nests, based on resource selection functions, in NWSG pastures grazed with conventional season-long (May – Aug) continuous or heavy-early stocking, in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Only nests within NWSG pastures were included based on the results of coarse-scale field sparrow nest selection for NWSG pastures. The covariate not being graphed was held constant at its mean.

A



B

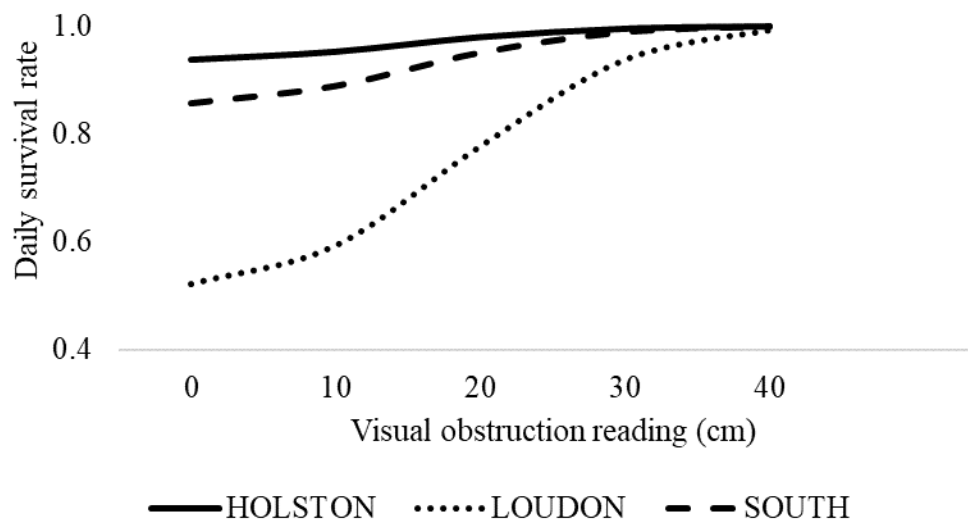


Figure 2.8. Relationship between grasshopper sparrow nest daily survival rate and A) interaction of study site and distance to woody cover (m) from the nest location, and B) visual obstruction reading (cm), for nests in native warm-season grass pastures grazed with conventional season-long (May – Aug) continuous or heavy-early stocking, and tall fescue pastures under traditional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017. Distance to woody edge was plotted only within the range present at each site, and the covariate not being plotted was held constant at its mean.

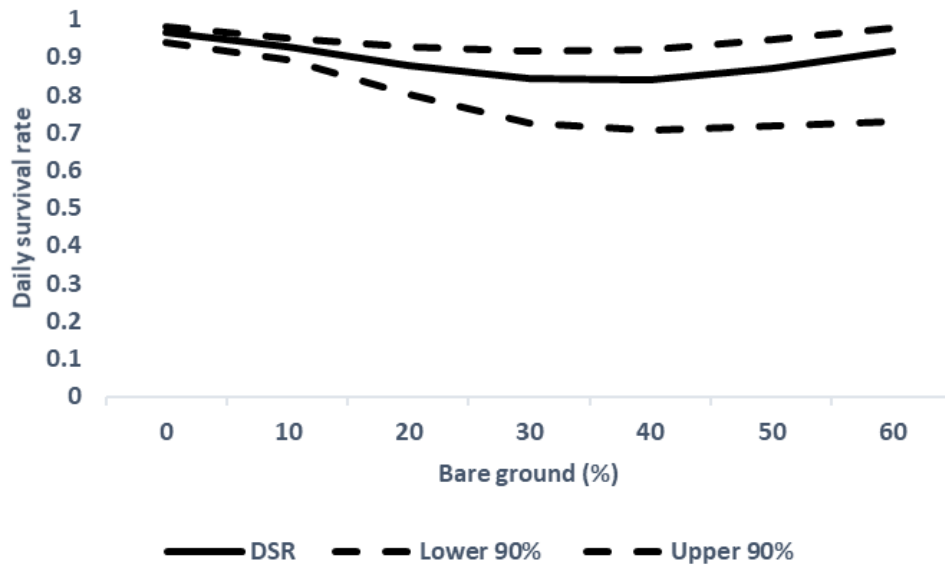


Figure 2.9. Relationship between field sparrow nest daily survival rate (DSR) and bare ground (%) measured at the nest site for nests in in native warm-season grass pastures grazed with conventional season-long (May – Aug) continuous or heavy-early stocking, and tall fescue pastures under traditional management in Knox, Loudon, and Blount counties, TN, 2015 – 2017.

Chapter 3 CONTINUOUS GRAZING OF MIXED NATIVE WARM- SEASON GRASS IN THE FESCUE BELT

ABSTRACT

Continuous, or nearly continuous, season-long (May – August) grazing is the most commonly used grazing strategy among tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] belt beef (*Bos taurus*) producers. However, little information is available regarding the feasibility of managing native warm-season grass (NWSG) pastures in this region with continuous, season-long grazing. The objective of my research was to compare stand sustainability, beef cattle performance, and pasture production between continuous (CONT), season-long grazing and heavy-early (HEAVY), a modified continuous grazing strategy, on mixed-NWSG pastures. Heavy-early was designed to more closely match the growth curve of NWSG, with an initial stocking target of 1.25 times the CONT rate from grazing initiation until 25 June, at which time stocking was reduced to 0.75 times the CONT rate. Pastures were mixed big bluestem (*Andropogon gerardii* Vitman), indiangrass [*Sorghastrum nutans* (L.) Nash], and little bluestem [*Schizachyrium scoparium* (Michx.)]. The overall plant population (plants m⁻²) was similar between treatments, but differed among years ($P < 0.001$), with a 35% reduction from 2017 to 2018, largely driven by a decline in indiangrass plants. Despite the decline in plant density, overall tiller density (tillers m⁻²) increased 14% from 2017 to 2018, indicating that the grazing strategies were likely sustainable. The grazing strategies had similar ($P > 0.05$) average daily gain (ADG; kg d⁻¹), animal days ha⁻¹ (AD), and total gain (kg ha⁻¹). Weaned steer ADG was 0.98 kg d⁻¹ for CONT and 0.89 kg d⁻¹ for HEAVY. The average grazing season was 105 d, with 382 AD ha⁻¹ for CONT and 368 d ha⁻¹ for HEAVY. Total gain was 379 kg ha⁻¹ for CONT and 334 kg ha⁻¹ for HEAVY. Both continuous grazing strategies appear to be appropriate for managing NWSG pastures in the Fescue Belt.

INTRODUCTION

Native warm-season grass (NWSG) has been used as livestock forage in North America since European settlement. However, it has had limited use in the eastern United States in recent decades. Tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] is the primary forage grass grown across a region of the eastern United States known as the Fescue Belt. Tall fescue is grown on approximately 14 million ha (Stuedemann and Hoveland, 1988) with most of that planted to the KY-31 cultivar (Schmidt and Osborn, 1993; Stuedemann and Hoveland, 1988). Tall fescue (hereafter; fescue), a perennial cool-season grass (CSG), has many positive attributes as a forage species. However, fescue also presents grazing managers with a number of challenges. One such challenge is referred to as the summer slump (Burns and Fisher, 2013; Burns et al., 1984), the slowdown in growth of CSG caused by warm summer temperatures and compounded by fescue toxicosis (Kallenbach, 2015; Schmidt and Osborn, 1993; Stuedemann and Hoveland, 1988). Fescue toxicosis, caused by an endophyte fungus (*Epichloe coenophiala*) living within infected plants, has been estimated to cost the beef (*Bos taurus*) cattle industry US\$2 billion annually (Hoveland, 1993; Kallenbach, 2015; Schmidt and Osborn, 1993). The effects of fescue toxicosis are most apparent during spring and summer (Kallenbach, 2015; Roberts and Andrae, 2004).

One way to mitigate problems associated with the summer slump and fescue toxicosis is to integrate perennial warm-season grasses into fescue-based grazing systems (Anderson, 2000; Keyser et al., 2016; Moore et al., 2004). Cattle may then be rotated off endophyte-infected fescue and onto warm-season grass pasture during late spring and summer. Perennial warm-season grass forage options in the Fescue Belt include bermudagrass (*Cynodon dactylon* L.) and NWSG such as switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* Vitman;

BB), indiagrass [*Sorghastrum nutans* (L.) Nash; IG], little bluestem [*Schizachyrium scoparium* (Michx.); LB], and eastern gamagrass [*Tripsacum dactyloides* (L.) L.]. Native warm-season grasses are low-input, endophyte-free, persistent, productive during summer, and drought tolerant (Anderson, 2000; Keyser et al., 2012; Keyser et al., 2011).

Producer acceptance and utilization of NWSG in the Fescue Belt has been slow. One reason may be that continuous grazing, the most common grazing strategy of Fescue Belt beef producers, has long been considered incompatible with NWSG forages in the eastern United States (Anderson, 2000). Continuous grazing is simpler, and requires less labor and infrastructure than rotational grazing. However, recommendations for Fescue Belt producers state that NWSG must be rotationally grazed to be productive and sustainable (Henning, 1993; Lacefield et al., 1997; Smith et al., 2009). The increased labor and infrastructure associated with rotational grazing may serve as an impediment to adoption of NWSG for typical producers. However, data on production-scale continuous, season-long grazing of NWSG in the eastern United States is very limited. Working in Mississippi, Monroe et al. (2017) reported that continuous, season-long (May – Sep), grazing of NWSG with steers resulted in increased average daily gain (ADG) compared to mixed fescue and bermudagrass pastures.

The objective of my research was to assess the feasibility of continuous, season-long grazing of mixed stands of BB, IG, and LB (hereafter, mixed NWSG) in the Fescue Belt. Specifically, my objective was to compare forage mass and nutritive value, stand sustainability, beef cattle performance, and pasture production between continuous, season-long grazing and heavy-early (HEAVY), a modified continuous grazing strategy, on mixed NWSG pastures.

METHODS

STUDY AREA

The study was conducted at the East Tennessee Research and Education Center Holston Unit (HOLSTON) near Knoxville, TN (35°58' N, 83°51' W, 253 m above MSL), in Knox County, and a private agricultural operation (LOUDON) in Loudon County, TN (35°45' N, 84°18' W, 259 m above MSL). Experimental NWSG pastures ranged from 8.0 to 10.5 ha (mean = 9.1 ha), which is typical of pastures used for beef production in the region. Soils at HOLSTON were primarily Shady-Whitwell complex (fine-loamy, mixed, subactive, thermic Typic Hapludults; fine-loamy, siliceous, semiactive, thermic Aquic Hapludults; respectively). LOUDON soils were primarily Alcoa loam (fine, parasesquic, thermic Rhodic Paleudults), Cumberland silty clay loam (fine, mixed, semiactive, thermic Rhodic Paleudalfs), and Emory silt loam (fine-silty, siliceous, active, thermic Fluventic Humic Dystrudepts; Soil Survey Staff, 2019).

ESTABLISHMENT

Pastures were planted to mixed NWSG in 2012. The seed mix consisted of 60% BB, 30% IG, and 10% LB based on seed mass, all 'KY Ecotype' (Roundstone Native Seed, LLC, Upton, KY). Indiangrass (IG) and LB were added to the seed mix to create a more diverse forage base, and better distribute forage availability over space, grazing season, and years. Pastures were soil tested prior to planting. Soil pH was > 5.2 and P and K were medium, so no amendments were applied. A no-till drill was used to plant each pasture with 11.2 kg pure live seed (PLS) ha⁻¹. All pastures were predominantly fescue before conversion, and were treated with glyphosate [N-(phosphonomethyl) glycine] at 2.24 kg a.i. ha⁻¹ in fall 2011 and again in spring 2012 to control grass and broad-leaf weed competition prior to planting. Immediately

after planting, all pastures were treated with imazapic {2-[[[(RS)-4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl]]-5-methylnicotinic acid} at 70 g a.i. ha⁻¹ for pre-emergent control of grass and broadleaf weed competitors. Drought conditions in 2012 resulted in unsatisfactory plant populations in LOUDON pastures, so pastures were replanted in 2013 following the same protocols.

TREATMENTS

Native warm-season grasses grow rapidly from mid-April through late June, at which point growth rates slow for the remainder of the growing season. The difference in productivity between early and late season presents a dilemma for producers who utilize continuous grazing systems. If they stock heavily enough to keep up with rapid early-season grass growth they may overutilize the slower-growing forage later in the summer or, conversely, if they stock more lightly to accommodate the late season, early-season growth will lead to overmature swards (Backus et al., 2017). The HEAVY continuous grazing strategy was developed to address this issue by more closely matching grazing pressure to the growth curve of NWSG by incorporating a single stocking rate adjustment during the grazing period. The initial target stocking rate for HEAVY was set at 1.25 times the continuous, season-long rate to provide increased grazing pressure to match rapid early-season grass growth. On 25 June, stocking was reduced to 0.75 times the continuous rate to reduce grazing pressure to match slowing grass growth. The HEAVY strategy is one step up in management effort relative to continuous, season-long grazing, but is less intensive than rotational grazing. Heavy-early grazing may benefit producers by increasing total beef production without sacrificing sustainability of the grass sward. Sustainability may be improved by reducing grazing pressure later in the grazing season when

grass growth has slowed and plants are building carbohydrate reserves leading into winter dormancy.

Two grazing treatments were used in the study, season-long (May through August) continuous stocking (CONT) and HEAVY. All stocking was on a 272-kg steer basis. Stocking was adjusted to match carrying capacity at each site, but the target ratio of HEAVY:CONT stocking rates remained constant. Cattle at HOLSTON were Angus or Angus cross and cattle at LOUDON were Angus cross. Weaned steers were the model animal, although heifers and cow-calf pairs (grazers only) were used as necessary, with stocking rate adjusted to the metabolic weight of a 272-kg steer. Tester animals were all weaned steers except for 2016 and 2017 when weaned heifers were also used, but analyzed separately from the steers. Pastures assigned to HEAVY were reduced to 0.75 times the initial CONT stocking rate on 25 June each year, based on actual weights.

EXPERIMENTAL DESIGN

The experiment was a randomized complete block design with 3 replicate pastures per treatment conducted over 3 years (2015 – 2017). Sites (HOLSTON and LOUDON) were blocks and pastures were experimental units. Blocks contained each treatment, although replicates were not balanced within each block. Treatments (CONT or HEAVY) were maintained throughout the study (i.e., not re-randomized each year) to allow sustainability of the grazing strategies to be assessed.

GRAZING MANAGEMENT

Initial stocking occurred once average grass canopy height reached approximately 40 cm, which was between 28 April and 10 May, depending on the year. Stocking rates were intended to maintain average canopy height between 30 and 46 cm over the majority of a pasture. If

appreciable proportions of any pasture dropped and remained below 30 cm average canopy height, grazing was terminated. No adjustments were made to animal numbers during the grazing period. For HEAVY, animals removed from test on 25 June were randomly selected. All animal care was in accordance with UT-IACUC Protocol No. 2258 approved on April 14, 2014 and April 5, 2017, by the Institutional Animal Care and Use Committee. Free access to shade, water, and mineral supplement were provided in all pastures.

PASTURE MANAGEMENT

Prior to onset of grazing in year one of the experiment, basic soil tests were conducted for all pastures. All pastures had soil pH above 5.2, and P and K at or above medium levels, so no amendments were applied. No N was applied during the study. Pastures required occasional weed control and where needed, metsulfuron methyl [Methyl 2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate] and chlorsulfuron [2-Chloro-N-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl]benzenesulfonamide], and aminopyralid (2-pyridine carboxylic acid, 4-amino-3,6-dichloro-) and 2,4-D [(2,4-dichlorophenoxy) acetic acid] were applied. Pastures at LOUDON were burned annually in mid-to-late March. HOLSTON pastures were not burned.

SAMPLING METHODS

Forage samples were taken corresponding to each weigh day throughout the grazing season. Fifteen samples (0.25 m² each) were clipped and weighed per pasture. For each sample, two cuts were made. First, forage within the grazing horizon was clipped, then all remaining vegetation below the grazing horizon was clipped to 5 cm to allow for estimation of total forage mass. Grazing horizon was determined by observing grazing behavior, and it generally included the material in the upper canopy of the grass plant. Studies in the Great Plains documented

preferential grazing of some NWSG species, such as BB, over other less preferred species (Fahnestock and Knapp, 1993; Hartnett et al., 1996; Tomanek et al., 1958). If strong height differences developed among grass species due to cattle forage preferences (e.g., if BB became much shorter than IG), an appropriate adjustment was made to ensure that forage samples appropriately reflected the actual grazing horizon of each species. The grazing horizon was separated from lower forage strata to more accurately represent what animals were eating and to avoid biasing forage nutritive values low by including material from lower strata that is not typically consumed (Backus et al., 2017; Keyser et al., 2016).

Both samples (grazing horizon and below grazing horizon) were dried in a forced-air drying oven (Model EWN-68-7G2, Wisconsin Oven Corporation, East Troy, WI) at 55° C for 72 hr, then weighed to determine dry weight portion of the forage mass. The dried grazing horizon samples were ground using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) grinder to 2-mm, then ground using a UDY Mill to pass through a 1-mm screen (UDY Corporation, Fort Collins, CO). Near-infrared spectroscopy (NIRS) technology (FOSS 5000, FOSS NIRSystems, Inc., Laurel, MD) was used to determine forage nutritive values. Equations for the forage nutritive analysis and biomass quality were standardized and checked for accuracy using the grass hay equation developed by the NIRS Forage and Feed Consortium (Hillsboro, WI) (McIntosh et al., 2016). WinISI II (Infrasoft International LLC, State College, PA) software was used for NIRS analysis. The Global H statistical test compared the samples against the model and other samples within the database for accurate results; all forage samples fit the equation with $H < 3.0$ and are reported accordingly (Murray and Cowe, 2004). Forage nutritive analyses included crude protein (CP), in-vitro true dry matter digestibility 48 hr (IVTDMD48H), acid detergent fiber

(ADF), and neutral detergent fiber (NDF). All reported nutritive values were on a dry matter basis and are presented accordingly.

Plant and tiller counts were conducted annually (2015 – 2018) in the spring at grazing initiation at 25 randomly selected points distributed throughout each pasture. At each point, the total number of plants of all mixed NWSG combined (BB, IG, and LB) within a 0.25-m² quadrat was recorded in 2015 and 2016. In addition to the combined (all species) plant count, plant counts were conducted by species in 2017 and 2018. For each species, tillers of the plant closest to the right rear corner of the sampling frame were counted and recorded. Grass canopy height (not extended leaf length) was taken bi-weekly throughout the grazing period beginning immediately prior to grazing initiation. Heights were recorded per species to the nearest cm at 25 randomly selected points per pasture.

Cattle were weighed at grazing initiation, at 28-day intervals throughout the grazing season, and at termination of grazing. Weights at initiation and termination of grazing were taken on two consecutive days and the average used as “on” and “off” weight, respectively. Scales were calibrated annually. Average daily gain (kg d⁻¹), was calculated based only on tester animals, and averaged across testers in each pasture and year. The ADG of individual testers was the difference between initial and final weight, divided by the total number of days on test. Pasture productivity was measured by animal use days (AD; d ha⁻¹) and total gain (GAIN; kg ha⁻¹). Animal days were the total number of grazing days ha⁻¹ for testers and grazers based on conversion of all animals based on metabolic weight to a single standard, a 272-kg steer. Total gain was calculated by multiplying ADG by AD. For HEAVY pastures, GAIN was calculated as the weighted average of gains for the period from initiation of grazing to partial destocking on 25 June (early-season), and 25 June to termination of grazing (late-season).

PASTURE BUDGETS

Enterprise budgets were developed to estimate establishment and operational costs for grazing mixed NWSG. The University of Tennessee Switchgrass Budget (University of Tennessee Department of Agricultural and Resource Economics, 2009) was used to calculate establishment and production costs, based on a 10-year useful production life. Establishment costs were annualized across the 10-year pasture life using an equivalent annual annuity formula and a 6% annual interest rate. The annualized establishment cost was added to the annual operational costs to determine total annual production cost. Establishment costs included seed, herbicide, custom application of herbicide, custom no-till planting, custom mowing, and annual land rent. Finally, a 10% cost of re-establishment was included in the establishment budget to account for the risk of initial establishment failure and replanting. In addition to pro-rated establishment cost, operational costs included herbicide, fertilizer, custom application of herbicide and fertilizer, prescribed burning, and annual land rent. All costs were based on observed prices in Tennessee in 2018. Seed cost was US\$28.49 kg⁻¹ for BB, US\$24.20 kg⁻¹ for IG, and US\$35.20 kg⁻¹ for LB. Cost of P was US\$1.19 kg⁻¹; no N, K, or lime were budgeted. I assumed 91 kg ha⁻¹ P in the form of diammonium phosphate would be applied every three years over the course of a 10-year stand life. Cost of GAIN is as important to producers as is animal performance or pasture production. Total annual pasture production cost (\$ ha⁻¹) was divided by GAIN (kg ha⁻¹) to calculate cost of GAIN (\$ kg⁻¹) for mixed NWSG.

STATISTICAL ANALYSES

Forage mass was analyzed using a repeated-measures, mixed-effects ANOVA with split-plot arrangement of treatments with replication in the whole plot, in SAS 9.4 (SAS Institute, Cary, NC). Repeated measures analysis was used because pastures received the same treatment

each year of the study. Pasture was the whole-plot factor, year was the sub-plot factor, and sampling period was the repeated measures factor. Fixed effects were treatment, year, period, and all combinations of treatment, year, and period. Random effects were block, block*treatment, pasture (block*treatment), block*year*treatment, year*pasture (block*treatment), and block*period*year*treatment. Forage nutritive values (CP, IVTDMD48H, NDF, and ADF) were analyzed using a mixed model ANOVA with repeated measures in SAS 9.4 (SAS Institute, Cary, NC). For forage nutritive values, I was interested in differences among periods, so years were pooled, and the repeated measures factor was period. Fixed effects were treatment, period, and treatment*period. The random effects in the models were block, and block*treatment*pasture (pooled to conserve degrees of freedom). Plant population and tiller counts were analyzed similarly to forage nutritive values, but the repeated measures factor was year, because these metrics were measured annually. Fixed effects were treatment, year, and treatment*year. Random effects were the same as for forage nutritive values. Grass heights were analyzed with indicator-variable regression to determine if cattle preferentially grazed any grass species. Grass species (BB, IG, and LB) were converted to indicator variables which were tested for different intercepts, and linear and quadratic slopes. If slopes of the indicator variables were different, contrasts were run to determine where the differences occurred. Cattle performance (ADG, AD, and GAIN) was analyzed with a similar mixed-model ANOVA as forage nutritive values except that sampling periods within years were pooled.

Testing for fixed effects was done at the $\alpha = 0.05$ level of significance. If tests for fixed effects were significant, least squares means were compared using LSD. Dependent variables were checked for equal variance and normality by inspecting residual plots and Levene's and

Shapiro-Wilk test statistics. All models were run with and without repeated measures, and the -2 Residual Log Likelihoods compared. If the more complex repeated measures models did not improve the -2 Residual Log Likelihood by at least five, repeated measures was dropped in favor of the simpler split-split-plot model for forage mass, and split-plot models for all other variables.

RAINFALL AND TEMPERATURE

Weather data was recorded at the East Tennessee Research and Education Center Plant Science Unit near Knoxville, TN (35°54'7.39"N, 83°57'26.81"W), in Knox County, which was the closest weather station to both study sites. Weather data for the study period (2015 – 2017) was compared with long-term (30-yr) averages at the same location.

RESULTS & DISCUSSION

Temperature for all three years was slightly above average or average for almost all spring and summer months. Rainfall was above average for all months in 2015 except May, which was drier than normal. Spring and summer rainfall in 2016 were below average for all months except June, and March and August were very dry (-53% and -82% of average, respectively). March and April 2017 were wet (82% and 102% above average, respectively), and August was dry (-82%; National Weather Service, 2019).

Due to logistical constraints (e.g., animal health and animal availability), actual stocking ratios differed from targets (1.25 ratio of HEAVY:CONT initial stocking rates). The three year mean initial stocking rates for HOLSTON and LOUDON were 939 kg ha⁻¹ (range 920 – 964) and 999 kg ha⁻¹ (range 861 – 1,141), respectively, for CONT, and 1,083 kg ha⁻¹ (range 1,026 – 1,130) and 1,184 kg ha⁻¹ (range 1,025 – 1,296), respectively, for HEAVY (Table 3.1; all tables located in appendices). Actual three year mean HEAVY:CONT initial stocking rate ratios were 1.15 (range 1.10 – 1.19) at HOLSTON and 1.19 (range 1.14 – 1.24) at LOUDON.

PASTURE CHARACTERISTICS

Despite the different stocking strategies, CONT and HEAVY had similar forage mass (Tables 3.2 and 3.3). Forage mass was greater in the first year, 2015, of the study than the two subsequent years, 2016 and 2017, which were similar (Table 3.2). Pastures at LOUDON were burned annually in mid-to-late March, and as a result greened up approximately 10 – 14 days earlier than pastures at HOLSTON, which were not burned. In 2015, grazing initiation date was not adjusted to account for this early grass growth. As a result, much of the sward became overly mature, but animal performance and pasture production did not suffer, suggesting sufficient palatable forage was still available. In subsequent years, cattle were stocked earlier to compensate for earlier grass growth on burned pastures. Keyser et al. (2016) documented average forage mass of 2.79 MG DM ha⁻¹ for a three-year big bluestem/indiangrass (BBIG) grazing experiment, which is within the range observed during this experiment.

Seasonal forage mass reflected the growth curve of NWSG. Mass differed by 28-day sampling period (Tables 3.2 and 3.3), with less at grazing initiation (period 1; early May) and grazing termination (period 5, late August). Backus et al. (2017) also found that forage mass of BBIG pastures generally increased after early spring. Forage mass was similar (range 2-4 Mg DM ha⁻¹) at their north-central TN study site and generally higher (range 2-6 Mg DM ha⁻¹) at their southwest TN study site compared with that observed in my study. In my study, without the flexibility to reduce stocking later in the summer, forage mass declined. The overall similarity in forage mass between treatments is likely because the difference in stocking rate between treatments, especially given the lighter than intended initial HEAVY stocking, was not large relative to the productivity of the grass, and the imbalance in replication between sites. LOUDON, which generally had greater grass growth, had two CONT and one HEAVY pasture,

whereas HOLSTON had one CONT and two HEAVY pastures. The effect of the relatively lighter early-season stocking of CONT on forage mass may have been offset by the greater grass growth and replications of CONT at LOUDON. Similarly, any relative increase in late-season forage mass in HEAVY pastures because of reduced stocking may have been offset by the lesser grass growth of HEAVY at HOLSTON. Regardless of patterns within or among years, ample forage mass was available, which is crucial during hot summer months in the Fescue Belt, because fescue is largely unproductive during this time period (Roberts et al., 2009).

There were no differences in forage nutritive values between CONT and HEAVY for CP, IVTDMD48H, ADF, or NDF (Tables 3.2 and 3.3). However, all forage nutritive values differed among 28-d sampling periods within grazing seasons (Tables 3.2 and 3.3). Crude protein and IVTDMD48H were both greatest during early May, the beginning of the grazing season (Table 3.3). Crude protein declined from period one to period two, then remained generally level for the remainder of the grazing season. The IVTDMD48H declined from period one to period two, remained level for periods two and three, and declined at the end of the grazing season. Neutral detergent fiber (Table 3.3) increased from period 1 to period two, remained level during periods two and three, and again increased slightly at the end of the grazing season. Response of ADF across periods varied by grazing strategy ($P < 0.001$). Acid detergent fiber increased throughout the grazing season for both treatments with the greatest increase between the first two periods. Heavy-early had greater ADF concentration than CONT for period three (Table 3.3, Figure 3.1; all figures located in appendices), but was similar for periods four and five. The greatest change in all forage nutritive variables was between the first two periods. In Pennsylvania, Griffin and Jung (1983) reported that forage nutritive values of BB were greatest in June, and decreased as the ratio of leaf:stem area decreased throughout the grazing season. Warmer spring temperatures

in Tennessee relative to Pennsylvania resulted in earlier grass growth, with peak forage nutritive values of mixed NWSG occurring in May in Tennessee. High CP and IVTDMD48H, and low fiber levels early in the grazing season make mixed NWSG appropriate forage for growing animals such as steers and heifers. By front-loading stocking, the HEAVY strategy maximizes grazing days during the early-season periods of rapid, high quality forage production, and decreases grazing pressure as grass growth slows and decreases in quality later in the summer. The limited differences in forage nutritive values between treatments suggests that both stocking strategies maintained swards in a similar physiological state, resulting in similar forage nutritive values as well as mass. The pattern of change in mixed NWSG forage nutritive values across sample periods in this study were similar to those observed by Backus et al. (2017) in BBIG, with highest quality early in the grazing season. Backus et al. (2017) documented declining crude protein values throughout the grazing season though, perhaps partly because of including coarse stems and other less palatable plant parts in the sample as opposed to just the grazing horizon, as in my study. Burns and Fisher (2013) also found similar mean values (g kg^{-1}) for CP (90), IVTDMD48H (660), NDF (743), and ADF (418) for BB despite BB having received at least 312 kg N ha^{-1} during their study.

Plant population densities of CONT ($11.76 \text{ plant m}^{-2}$) and HEAVY ($10.79 \text{ plants m}^{-2}$) were similar ($P = 0.221$), but there was a difference among years ($P < 0.001$; Table 3.4). Populations were similar for the first three years (2015-17; $\bar{X} = 12.47 \text{ plants m}^{-2}$), but declined by 35% from 2017 to 2018 (Table 3.5). The majority of the plant population density decline from 2017 to 2018 was due to a reduction of IG plants (-65%), with a lesser reduction of BB (-25%) and LB (-14%; no data available per grass species prior to 2017). Loss of IG occurred at both sites, with HOLSTON and LOUDON losing 63% and 67% of IG plants, respectively.

LOUDON lost 36% and 46% of BB and LB plants, respectively, as opposed to HOLSTON, which lost 10% of BB, but gained 59% for LB plants.

Tiller density is a quantifiable method that can be used to gauge sward status (Matthew et al., 1996). Tillers plant⁻¹ of all three grass species varied by year but not by treatment (Table 3.4). Big bluestem (BB) tillers decreased by 39% from 2015 to 2016 and increased by 78% from 2017 to 2018 (Table 3.5). Despite the decline in the BB plant population, the increase in BB tillers per plant resulted in a net increase in BB tillers m⁻² of 38% from 2017 (448 tillers m⁻²) to 2018 (618 tillers m⁻²). Indiangrass tillers per plant decreased by 52% from 2015 to 2016, then remained stable for the duration of the study (Table 3.5), and IG tillers m⁻² decreased by 64% from 2017 (145 tillers m⁻²) to 2018 (52 tillers m⁻²). Similar to BB, and despite the decline in the LB plant population, LB tillers m⁻² increased 21% from 2017 (100 tillers m⁻²) to 2018 (121 tillers m⁻²) because of an increase in tillers per plant (Table 3.5).

The decline in plant population observed in 2018 was largely driven by loss of IG plants between 2017 and 2018. Indiangrass plant populations decreased despite apparently receiving less grazing pressure than either BB or LB (Figure 3.2, also see selective grazing below). The IG decline may have resulted from competition with larger BB plants that increased in tiller numbers, or to a lesser extent, weed pressure at HOLSTON. Another possibility is that weather and the late-maturing phenology of IG relative to BB (Ball et al., 2007; Keyser et al., 2012) may have contributed to poor detection of IG plants, rather than an actual population decline. East Tennessee experienced a cool spring in 2018, which may have further delayed the growth of already later-maturing IG plants. Plant counts were conducted in early May 2018, possibly before sufficient IG growth had occurred, making detection of IG plants more difficult than in previous years. The decline in BB plants was likely because large BB plants outcompeted

smaller BB plants due to an increase in tiller numbers. Another possibility is that observers “lumped” smaller BB plants that were growing close to one another together in 2018, artificially driving down plant numbers, while increasing the number of tillers plant⁻¹. Regardless, the increase in BB tiller numbers in 2018 more than offset the loss of BB plants. Likewise, total tillers m⁻² (all three grass species combined) increased by 14% from 2017 (693 tillers m⁻²) to 2018 (791 tillers m⁻²), more than offsetting the decline in plant population density. Despite the decrease in plants, the total increase in tillers m⁻² indicated that both continuous, season-long grazing systems were sustainable over the study period.

Grass canopy heights of the two experimental grazing strategies were similar at the beginning of the grazing season (Figure 3.2). The heavier early-season stocking of HEAVY resulted in canopy heights of all three grass species decreasing until partial destocking on 25 June. After partial destocking, HEAVY grass canopy heights stabilized, and BB and IG canopies subsequently increased in height late in the growing season. The lighter early-season stocking of CONT allowed for selective grazing of the grass species; BB in CONT decreased in height through August while IG increased during this period. Cattle in CONT appeared to begin grazing IG more later in the growing season, causing IG canopy heights to decline during that time (Figure 3.2). This pattern likely reflects the later maturing nature of IG relative to the bluestems, and perhaps that availability of palatable bluestem forage was limited later in the grazing season. The pattern of heavy utilization early in the growing season when forage production is rapid, and lower utilization later in the season when NWSG growth slows, may allow HEAVY to maximize grazing while still providing sufficient recovery time so grass plants can maintain or increase leaf area for carbohydrate production and storage prior to dormancy.

Despite the difference in stocking, grass heights of CONT and HEAVY were similar at the end of the grazing period.

The grass height regression model explained 97.7% ($P < 0.001$) of the variation in grass height, and provided empirical evidence of selective grazing of both bluestems over IG. The model indicated grass species had different intercepts ($P < 0.001$), that the average slope for all species differed from zero ($P = 0.018$), the linear slopes of the species differed ($P < 0.001$), and all species shared the same quadratic slope ($P = 0.017$). Average canopy heights of BB and LB were 47.5 cm and 32.0 cm, respectively, at the beginning of the grazing season, and declined at a similar rate ($P = 0.058$; -0.55 and -1.13 cm period⁻¹, respectively; Figure 3.3). The rate of decline of both species differed from IG (BB vs. IG, $P < 0.001$; LB vs. IG, $P < 0.001$), which began the grazing season at 39 cm and increased 0.63 cm period⁻¹ throughout the grazing season. The quadratic slope was 0.17 cm period⁻¹ and did not differ among the three species. Preferential grazing of LB and BB by cattle over other NWSG has been documented on native range in the Great Plains (Fahnestock and Knapp, 1993; Hartnett et al., 1996; Tomanek et al., 1958), but this may be the first time it has been documented in planted mixed NWSG pasture.

ANIMAL PERFORMANCE

Average daily gain of steers was similar between treatments with no year effect or treatment x year interaction (Table 3.6). Steers gained 0.98 kg d⁻¹ on CONT and 0.89 kg d⁻¹ on HEAVY, which is within the range of ADG reported in other studies. Steer ADG has ranged from 0.70 kg d⁻¹ on BB in South Dakota (Krueger and Curtis, 1979) to 1.08 kg d⁻¹ in North Carolina under heavy N fertilization ($234 - 360$ kg N ha⁻¹; Burns and Fisher, 2013). Average daily gains in my study approached those of Burns and Fisher (2013), but without N fertilization. Reported steer ADG on IG monocultures include 1.08 kg d⁻¹ (Krueger and Curtis, 1979) and 0.57

kg d⁻¹ (Monroe et al., 2017). In Tennessee, Backus et al. (2017) documented steer ADG at two different sites of 0.82 kg d⁻¹ and 0.96 kg d⁻¹ on BBIG. Steer ADG in a similar continuous, season-long mixed NWSG grazing experiment conducted in Mississippi was lower (0.55 kg d⁻¹) (Monroe et al., 2017) than ADG in this or other studies. Heifer calves on CONT and HEAVY had similar ADG (0.89 and 0.81 kg d⁻¹, respectively), and there was no year effect or year x treatment interaction (Table 3.6). Average daily gains in this range are appropriate for heifer development (Bagley, 1993; Hoffman, 1997) or adding additional weight to growing animals before marketing (Burns and Fisher, 2013). The lack of difference among ADG in this and other studies is likely because neither continuous grazing strategy negatively impacted forage mass or nutritive quality.

PASTURE PRODUCTIVITY

Average length of all grazing seasons across treatments, years, and sites was 105 days, and ranged from 99 (HOLSTON, 2017) to 112 days (HOLSTON, 2015). LOUDON was more consistent, with grazing days ranging from 105 (2015 and 2017) to 106 days (2016). Monroe et al. (2017) reported mean grazing season length of 112 days on continuously grazed mixed NWSG in Mississippi and Burns and Fisher (2013) reported mean grazing season length of 137 days on BB in North Carolina. Animal-use days were similar between treatments (CONT, 382 d ha⁻¹; HEAVY, 368 d ha⁻¹), but differed among years ($P = 0.021$). Animal days for 2015 (393 d ha⁻¹) and 2016 (382 d ha⁻¹) were similar with both differing from 2017 (350 d ha⁻¹). Initiation of grass growth in spring 2017 was later and growth remained slightly slower compared to previous years. One explanation for this growth pattern, and subsequently shorter 2017 grazing season, is that a severe fall (August through November) drought in 2016 resulted in pre-dormancy stress that may have, along with the unusually cool spring in 2017, reduced early season growth.

Furthermore, both sites were more heavily stocked in 2017 than in previous years. In North Carolina, Burns and Fisher (2013) reported 698 steer days ha⁻¹ on small (0.3 ha) BB plots using put-and-take stocking and N fertilization rates up to 360 kg ha⁻¹. In Tennessee, Backus et al. (2017) reported full season (May through August) animal unit days ha⁻¹ equivalent to 333 and 427 at two locations for steers grazing small (1.2 ha) BBIG paddocks using put-and-take stocking and fertilized with 67 kg ha⁻¹ N annually.

Total GAIN did not differ between treatments (CONT, 379 kg ha⁻¹; HEAVY, 334 kg ha⁻¹) or among years, and there was no treatment x year interaction (Table 3.6). Backus et al. (2017) reported lower GAIN of 257 at their West Tennessee study area and somewhat greater GAIN (415 kg ha⁻¹) at their Middle Tennessee study site while grazing steers on BBIG. Total gain on BB monocultures has been reported from 138 kg ha⁻¹ (Krueger and Curtis, 1979) to 732 kg ha⁻¹ (Burns and Fisher, 2013) with heavy (312 to 360 kg ha⁻¹) N fertilization. If the initial stocking ratio target of 1.25 (HEAVY:CONT) had been met each year, the GAIN between treatments would have likely been similar. Within sites, the percent difference in annual GAIN between CONT and HEAVY decreased from 41% to 0% as the initial stocking ratio increased from 1.10 (HOLSTON 2016) to 1.24 (LOUDON 2016), respectively. Initial stocking ratios, from least to greatest, were 1.10 (HOLSTON 2016), 1.14 (LOUDON 2017), 1.17 (HOLSTON 2017), 1.19 (HOLSTON 2015), and 1.24 (LOUDON 2016), with percent differences in annual gain of 41%, 28, 14, 11, and 0. Stocking HEAVY too lightly early in the grazing season numerically reduced its overall grazing days relative to CONT, grazing days during the time period with the greatest forage mass and nutritive quality.

Despite the different stocking strategies, CONT and HEAVY had similar ADG, AD, and GAIN. The major difference between the two continuous grazing strategies was the distribution

of grazing pressure. Lower early-season stocking rates for CONT allowed selective grazing of the most palatable and nutritious plant material. This resulted in greater early-season ADG for CONT (1.22 kg d⁻¹) than HEAVY (0.92 kg d⁻¹). Animals on HEAVY had greater competition for forage, which led to less selective grazing, resulting in lower early-season ADG. The opposite was true for late-season (i.e., June 25 – late Aug) ADG when forage was lower in quality and grass growth was slower; animals on HEAVY (0.84 kg d⁻¹) had less competition for forage than those on CONT (0.64 kg d⁻¹). The reduced grazing pressure on HEAVY also allowed the sward to begin to recover and provided more fresh leaves for grazing. Animal-use days were similar between treatments by design. A greater percentage of AD occurred in the early season on HEAVY (62%) than CONT (54%). Greater early-season ADG but fewer early-season AD on CONT, and lower early-season ADG but greater early-season AD for HEAVY, resulted in a similar percentage of season-long GAIN being accounted for in the early-season for each treatment (CONT, 67%; HEAVY, 64%). Lower grazing pressure resulted in a slightly numerically greater percentage of season-long GAIN occurring during late-season for HEAVY (36%) than CONT (33%), which maintained the same stocking rate throughout the grazing season.

Total establishment cost in 2018 dollars for mixed NWSG was US\$652.36 ha⁻¹. Seed cost (US\$313.08 ha⁻¹) was the largest component of establishment cost for mixed NWSG, accounting for over 50% of cost before addition of the 10% re-establishment risk cost (US\$59.31 ha⁻¹). Annualized establishment cost over the 10-year stand life was US\$88.64 ha⁻¹. Total annual pasture cost was US\$240.06 ha⁻¹, which included annualized establishment cost, US\$36.03 ha⁻¹ for P, US\$5.93 ha⁻¹ for custom fertilizer application, US\$8.53 ha⁻¹ for herbicide, US\$8.53 ha⁻¹ for custom herbicide application, US\$46.33 ha⁻¹ for prescribed burning, and

US\$49.42 ha⁻¹ for annual land rent. Cost of steer GAIN on mixed NWSG was US\$0.63 kg⁻¹ for CONT and US\$0.72 kg⁻¹ for HEAVY. The difference in cost of GAIN between treatments was because CONT and HEAVY produced numerically different amounts of GAIN (CONT, 379 kg ha⁻¹; HEAVY, 334 kg ha⁻¹). This is considerably less than cost of GAIN for BBIG (US\$0.87 kg⁻¹) and similar to the cost for switchgrass (US\$0.69 kg⁻¹) reported by Keyser et al. (2016). The difference in cost of GAIN between this study and Keyser et al. (2016) is likely due to the lower BB and IG seed cost and the faster-gaining weaned steers used in this study, as opposed to pregnant heifers. Seed cost accounted for 34% of total annual BBIG pasture cost in Keyser et al. (2016) (US\$36.72 kg⁻¹ for BB, US\$50.05 kg⁻¹ for IG; US\$417.17 ha⁻¹), but only 15% in this study (US\$28.49 kg⁻¹ for BB, US\$24.20 kg⁻¹ for IG, and US\$35.20 kg⁻¹ for LB; US\$313.08 ha⁻¹).

CONCLUSIONS

Animal performance and pasture production of both CONT and HEAVY mixed NWSG grazing strategies were at levels acceptable for backgrounding weaned calves or heifer development. They are also greater than that reported on fescue/clover pastures during late spring and summer and offer relief from infected tall fescue during this period (Thompson et al., 1993; Kallenbach et al., 2012; Keyser et al., 2016). Furthermore, these continuous grazing strategies appear to be economical and sustainable, although sustainability should continue to be monitored over a longer time period. Producers who wish to graze NWSG, but are not willing or able to rotationally graze, may choose either CONT or HEAVY continuous grazing strategies. Although both strategies produce similar animal performance and pasture production, CONT may be more feasible due to reduced management requirements, less animal handling time and transportation costs, and familiarity to producers.

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APPENDICES

TABLES

Table 3.1. Stocking at initiation of grazing seasons, 2015 – 2017, for evaluation of continuous grazing strategies for native warm-season grass (NWSG) pastures at two study areas, HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively. All stocking was on a 272-kg steer basis.

	Treatment	
	CONT ¹ (kg ha ⁻¹)	HEAVY ² (kg ha ⁻¹)
2015		
HOLSTON	920	1,092
LOUDON	861	1,025
2016		
HOLSTON	933	1,026
LOUDON	994	1,231
2017		
HOLSTON	964	1,130
LOUDON	1,141	1,296

¹ Traditional continuous, season-long, stocking of mixed NWSG pasture.

² Heavy-early continuous, season-long, stocking of mixed NWSG pasture.

Table 3.2. Mixed model ANOVA results for forage mass and forage nutritive values of mixed big bluestem, indiangrass, and little bluestem (mixed NWSG) forage, 2015 – 2017, during mixed NWSG continuous grazing experiment at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively.

Variable	Effect	Num ¹ df	Den ² df	F Value	P > F
Forage Mass	Treatment ³	1	5.94	0.57	0.479
	year	2	12.33	12.32	0.001
	treatment*year	2	12.33	0.08	0.922
	Period ⁴	4	25.85	5.92	0.002
	treatment*period	4	25.85	0.47	0.760
	year*period	8	25.85	2.17	0.065
	treat*year*period	8	25.85	0.46	0.874
CP ⁵	treatment	1	3.45	0.13	0.741
	period	4	14.70	101.13	< 0.001
	treatment*period	4	14.70	2.34	0.103
NDF ⁶	treatment	1	3.59	0.06	0.827
	period	4	14.70	127.16	< 0.001
	treatment*period	4	14.70	1.78	0.187
ADF ⁷	treatment	1	4.82	2.60	0.170
	period	4	15.50	103.30	< 0.001
	treatment*period	4	15.50	4.08	0.019
IVTDMD ⁸	treatment	1	4.39	0.01	0.916
	period	4	15.30	55.05	< 0.001
	treatment*period	4	15.30	2.26	0.110

¹ Numerator.

² Denominator.

³ Treatments represent traditional continuous, season-long (May – Aug), and heavy-early continuous stocking of mixed NWSG pasture.

⁴ Forage mass was collected at grazing initiation, every 28-day period thereafter, and at termination of grazing.

⁵ Crude protein.

⁶ Neutral detergent fiber.

⁷ Acid detergent fiber.

⁸ In-vitro true dry matter digestibility.

Table 3.3. Mean forage mass and nutritive values of mixed big bluestem, indiangrass, and little bluestem (mixed NWSG) forage for treatments and summer sampling periods (2015 – 2017; years pooled) at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively.

		Forage Mass	CP ¹	NDF ²	ADF ³	IVTDMD ⁴
		Mg ha ⁻¹	g kg ⁻¹			
Treatment ⁵	CONT	3.205	98	644	414	702
	HEAVY	2.955	96	647	425	703
Year	2015	4.020 ^a				
	2016	2.635 ^b				
	2017	2.586 ^b				
Period ⁶	1	2.340 ^b	147 ^a	557 ^c	347 ^c	805 ^a
	2	3.413 ^a	85 ^{bc}	655 ^b	423 ^b	689 ^{bc}
	3	3.909 ^a	92 ^b	653 ^b	423 ^b	689 ^b
	4	3.376 ^a	81 ^c	681 ^a	450 ^a	669 ^{cd}
	5	2.362 ^b	82 ^c	683 ^a	454 ^a	661 ^d

¹ Crude protein.

² Neutral detergent fiber.

³ Acid detergent fiber.

⁴ In-vitro true dry matter digestibility.

⁵ Treatments represent conventional continuous (CONT), season-long (May – Aug), and heavy-early (HEAVY) continuous, season-long, stocking of mixed NWSG pasture.

⁶ Forage was sampled concurrent with cattle weigh days, approximately every 28 d.

^{a-b} Means within columns and model factor without common letters differ (P < 0.05).

Table 3.4. Mixed model ANOVA results for plant population (all species combined) and big bluestem (BB), indianguass (IG), and little bluestem (LB) tillers plant⁻¹, 2015 – 2017, during mixed native warm-season grass (NWSG) grazing experiment at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively.

Variable	Effect	Num ¹ df	Den ² df	F Value	P > F
Plant population	treatment ³	1	16.00	1.62	0.2207
	year	3	16.00	10.25	< 0.0010
	treatment*year	3	16.00	2.32	0.1139
BB tillers	treatment	1	16.00	2.20	0.1571
	year	3	16.00	4.75	0.0149
	treatment*year	3	16.00	2.26	0.1210
IG tillers	treatment	1	16.00	0.22	0.6469
	year	3	16.00	17.84	< 0.0010
	treatment*year	3	16.00	0.52	0.6745
LB tillers	treatment	1	3.11	0.43	0.5576
	year	2	8.00	6.88	0.0182
	treatment*year	2	8.00	3.29	0.0906

¹ Numerator.

² Denominator.

³ Treatments represent traditional continuous, season-long (May – Aug), and heavy-early continuous stocking of mixed NWSG pasture.

Table 3.5. Overall plant population and tillers plant⁻¹, 2015 – 2017, during mixed big bluestem, indiangrass, and little bluestem (mixed NWSG) forage grazing experiment at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively.

			Tiller Counts (tillers plant ⁻¹)		
			BB ¹	IG ²	LB ³
Treatment ⁴	CONT	11.8	103	67	84
	HEAVY	10.8	84	63	78
Year	2015	12.4 ^a	113 ^a	116 ^a	79 ^{ab}
	2016	13.1 ^a	69 ^b	56 ^b	—
	2017	11.9 ^a	69 ^b	44 ^b	65 ^b
	2018	7.7 ^b	123 ^a	44 ^b	97 ^a

¹ BB = big bluestem.

² IG = indiangrass.

³ LB = little bluestem.

⁴ Treatments represent traditional continuous (CONT), season-long (May – Aug) and heavy-early (HEAVY) continuous stocking of mixed NWSG pasture.

^{a-b} Means within columns without common letters differ (P < 0.05).

Table 3.6. Mixed model ANOVA results for ADG (average daily gain), animal days, and total gain, of steers, and ADG of heifers, 2015 – 2017, during mixed big bluestem, indiangrass, and little bluestem (mixed NWSG) forage grazing experiment at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively.

Variable	Effect	Steers				Heifers			
		Num ¹ df	Den ² df	F Value	P > F	Num df	Den df	F Value	P > F
ADG	treatment ³	1	3.82	3.24	0.150	1	3.65	1.15	0.350
	year	2	7.29	0.89	0.452	1	4.00	0.79	0.426
	treatment*year	2	7.29	3.30	0.096	1	4.00	3.84	0.122
Animal days	treatment	1	2.92	0.86	0.425	–	–	–	–
	year	2	6.58	7.37	0.021	–	–	–	–
	treatment*year	2	6.58	1.77	0.243	–	–	–	–
Total gain	treatment	1	10.20	3.45	0.092	–	–	–	–
	year	2	10.01	1.41	0.288	–	–	–	–
	treatment*year	2	10.01	2.33	0.147	–	–	–	–

¹ Numerator.

² Denominator.

³ Treatments represent traditional continuous, season-long (May – Aug) and heavy-early continuous stocking of mixed NWSG pasture.

FIGURES

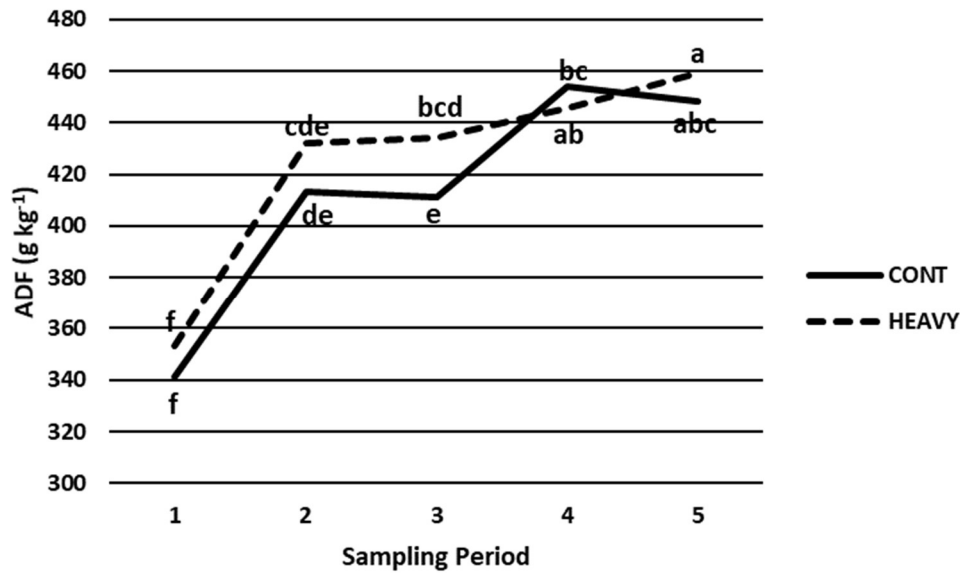


Figure 3.1. Acid detergent fiber (ADF) of mixed big bluestem, indiangrass, and little bluestem (mixed NWSG) forage, sampled every 28 days, 2015 – 2017 (years pooled), during mixed NWSG grazing experiment at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively. There was a treatment x period interaction ($P = 0.019$). Treatment means within periods without a letter in common differ.

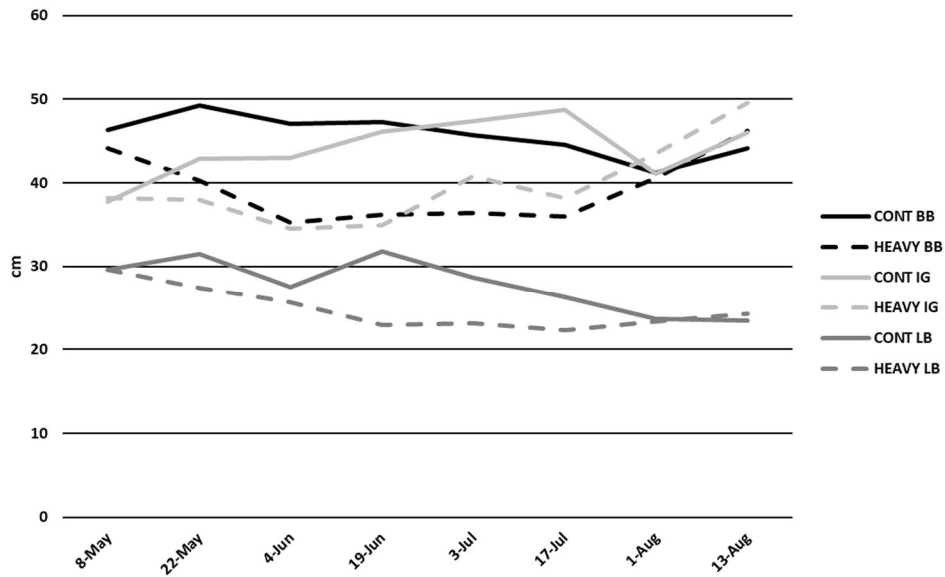


Figure 3.2. Bi-weekly grass heights of big bluestem (BB), indiangrass (IG), and little bluestem (LB), for traditional continuous (CONT), season-long (May – Aug), and heavy-early (HEAVY) continuous stocking of mixed native warm-season grass pastures (2015 – 2017; years pooled) at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively.

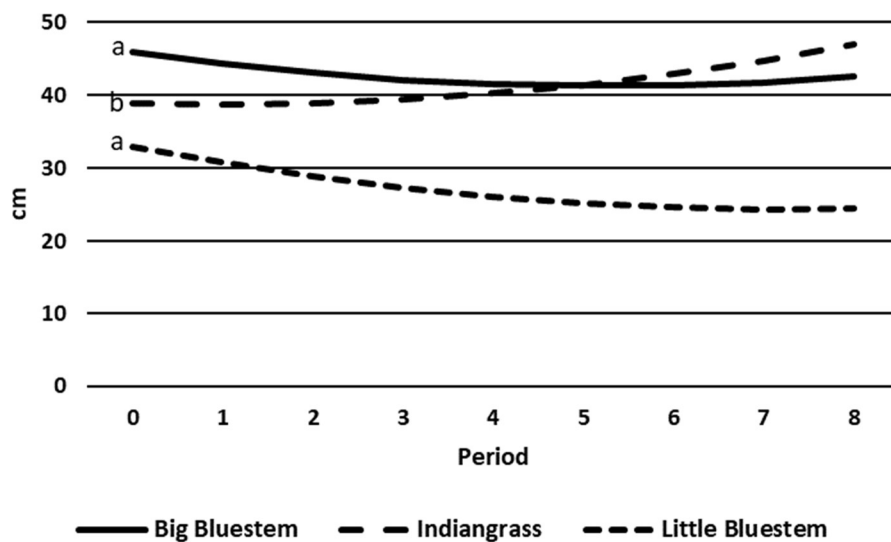


Figure 3.3. Regression lines for big bluestem, indiangrass, and little bluestem grass heights, taken bi-weekly, 2015 – 2017, during mixed big bluestem, indiangrass, and little bluestem forage grazing experiment at HOLSTON and LOUDON, in Knox and Loudon Counties, TN, respectively. Regression lines without a letter in common differ.

**Chapter 4 IMPACT OF PERENNIAL WARM-SEASON GRASS FORAGES
ON PROFITABILITY OF BEEF CATTLE OPERATIONS IN THE FESCUE
BELT**

ABSTRACT

Incorporating a perennial warm-season grass (WSG) into tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] forage systems in the Fescue Belt can help avoid the effects of fescue toxicosis on beef cattle (*Bos taurus*) reproduction and animal performance and provide forage during summer when fescue production is low. However, little information is available on the economics of incorporating WSG into fescue-based forage systems. I developed a simulation model to compare profitability of three forage systems, 100% tall fescue, 70% tall fescue/30% bermudagrass (*Cynodon dactylon*), and 70% tall fescue/30% switchgrass (*Panicum virgatum*), while also comparing spring- and fall-calving seasons on model beef cattle cow-calf operations (with a 40-ha forage base) in the Fescue Belt. Incorporating switchgrass increased profitability of tall fescue forage systems in both spring- and fall-calving herds, while adding bermudagrass increased profitability in spring- but not fall-calving herds. Spring-calving herds benefitted the most from incorporating WSG, with profitability increases of 454% and 1,070%, for switchgrass and bermudagrass, respectively, over the 100% tall fescue system. Profitability of spring-calving systems was insensitive to a 10% decrease in assumed calving rate (from 82% to 73%), but increased substantially when the baseline calving rate was increased by 10% (from 82% to 90%). The order of profitability of forage systems did not change with randomly simulated decreases in rainfall and associated increased hay-feeding days, but with annual rainfall > 88% of the long-term average, fall-calving 100% tall fescue was more profitable than fall-calving 70% tall fescue/30% bermudagrass. The results of the simulation suggest that a profit-maximizing producer would utilize a spring-calving herd and a 70% tall fescue/30% switchgrass forage system.

INTRODUCTION

Profitability of beef cattle operations is heavily influenced by forage cost, quality, and quantity (Keyser et al. 2016, Lowe et al. 2016). Within the tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] belt, forage production during hot summer months is limited and animal productivity may be further compromised by fescue toxicosis (Stuedemann and Hoveland 1988, Hoveland 1993, Schmidt and Osborn 1993, Smith et al. 2012). Fescue is a perennial cool-season grass (CSG) with a long growing season that is well-adapted to the Mid-South (Fribourg et al. 2009), and is the primary forage grown across much of the southeastern United States (Keyser et al. 2011). However, during hot summer months, fescue becomes semi-dormant and has poor productivity (Harper et al. 2007, Doxon et al. 2012). The “summer slump,” as this gap in forage production is commonly referred to, presents a major management problem to beef cattle operations. Fescue toxicosis, caused by the fungal endophyte *Neotyphodium coenophialum*, also affects animal productivity and performance by reducing conception and calving rates (Stuedemann and Hoveland 1988, Hoveland 1993, Schmidt and Osborn 1993, Smith et al. 2012), milk production (Schmidt and Osborn 1993), and weight gains of growing animals (Stuedemann and Hoveland 1988, Hoveland 1993, Schmidt and Osborn 1993, Smith et al. 2012). Fescue toxicosis results in losses to beef cattle producers estimated at over \$2 billion annually (Hoveland 1993), adjusted to 2019 dollars. Forage professionals recommend incorporating perennial warm-season grasses (WSG) into cool-season forage systems to provide grazing during hot summer months and avoid problems caused by grazing toxic fescue (Tracy et al. 2010, Kallenbach et al. 2012, Burns and Fisher 2013, Keyser et al. 2016, Backus et al. 2017).

Profitability for cow herds grazing toxic fescue has also been reported to differ based on calving seasons. Caldwell et al. (2013) reported that fall-calving herds had greater calving rates

and weaning weights than spring-calving herds in Arkansas. An economic analysis using the production data presented by Caldwell et al. (2013) reported that fall-calving herds in Arkansas were more profitable as well as more productive (Smith et al. 2012). Production and income for both calving-seasons benefitted from adding non-toxic, novel-endophyte fescue to toxic fescue-based grazing systems, but spring-calving systems benefitted the most. On fescue-dominated pastures in Tennessee, analysis of long-term herd records revealed that spring-born calves had greater ADG and weaning weights, but fall-calving was more profitable because more calves were produced per cow and fewer replacement heifers were needed (Campbell et al. 2013). Fall-calving cows had greater calving rates, because they were bred during winter when the effects of fescue toxicosis were at a minimum, whereas spring cows were bred in late spring or early summer when the effects of fescue toxicosis were more pronounced (Campbell et al. 2013). Henry et al. (2016) expanded on the analysis of Campbell et al. (2013) by evaluating profitability and risk of both calving seasons, as well as least-cost feed rations. They determined that fall-calving was more profitable and risk-preferred and that greater prices for fall calves was the main factor in the difference.

The difference in profitability of fescue-based grazing systems with and without a perennial WSG component is not currently known. Information on profitability of different WSG options in such complementary grazing systems is also lacking, as is information on which calving season, spring or fall, will benefit the most, if at all, from incorporating a WSG into grazing systems. Nutritional needs of spring- and fall-calving cows peak at different times of year. The nutritional needs of spring-calving cows more closely match WSG production curves, while fall-calving nutrient requirements match more closely with CSG production (Bagley et al. 1987). The objective of my research was to model the profitability of fescue-based grazing

systems with and without a perennial WSG component and determine which perennial WSG (bermudagrass or switchgrass) was most profitable, while exploring the effect of calving season on profitability of these systems. This information will enable Fescue Belt beef cattle producers to make better-informed forage and calving season decisions that reduce costs and increase profits.

METHODS

ASSUMPTIONS

Enterprise budgets were constructed to compare profit among three forage systems. Model beef cattle farms consisted of 40 hectares (ha) of pasture stocked at the traditional tall fescue (hereafter, fescue) rate of 0.81 ha/cow-calf pair. All pastures were assumed to initially consist of poor condition fescue. Pastures were renovated and established to three forage systems that were modelled with both spring- and fall-calving commercial beef herds. Model forage systems were 100% toxic endophyte-infected fescue/clover (TF100), 70% toxic endophyte-infected fescue/clover with 30% bermudagrass (BG30), and 70% toxic endophyte-infected fescue/clover with 30% switchgrass (SG30). The perennial warm-season grass (WSG) component of the latter two systems falls within the 10 – 35% range of WSG currently recommended for complementary grazing systems in the Fescue Belt (Keyser et al. 2012). Establishment techniques (e.g., seeding rate and technique, fertilizer, and lime) and pasture management followed University of Tennessee guidelines (Bates et al. 2008, Savoy and Joines 2009). Establishment and pasture costs (Table 4.1; all tables located in appendices) were based on University of Tennessee forage budgets (University of Tennessee Department of Agricultural and Resource Economics 2007) and May 2018 local prices for seed, fertilizer and other inputs.

Soil tests for phosphorous and potassium prior to seeding were assumed to be medium. Useful stand life was conservatively assumed to be ten years.

During the establishment year, stocking rates on fescue were limited to 75% of the traditional rate of 0.81 ha/cow-calf pair. No grazing occurred on switchgrass until the year following establishment. Stocking rates on bermudagrass are typically reduced during the establishment year. However, given the higher productivity of bermudagrass during summer relative to fescue, it was assumed to support 75% of the standard tall fescue rate (0.81 ha/cow-calf pair) during the establishment year. The same assumption was made for switchgrass for the year following establishment. Cattle grazed WSG from 1 May to 1 September for BG30 and SG30. Calving rates (Table 4.2) and weaning weights (Table 4.3) were based on pertinent, peer-reviewed literature. Because of a lack of studies that included spring-calving cow herds grazing switchgrass, or fall-calving herds grazing either bermudagrass or switchgrass, the average of fall-calving rates for fescue and non-toxic fescue treatments (which did not differ) from Caldwell et al. (2013) were used for fall-calving BG30 and SG30 herds. For SG30, the fall-calving rate was assumed to be the same as BG30. No calf death loss was assumed. All replacement heifers were retained from the herd. Remaining calves, open cows, and open replacement heifers were marketed at weaning, (1 September and 1 April for spring- and fall-calving herds, respectively). I did not find weaning weights for BG30 and SG30 in the literature for either calving season. Therefore, weaning weights from the 75% toxic/25% non-toxic fescue system from Caldwell et al. (2013) were used for the spring-calving herd. This assumption was made because spring-born calves on both complementary toxic-fescue/WSG and toxic-fescue/non-toxic fescue systems are pastured on non-toxic forages from 1 May to their weaning date on 1 September. Because of a lack of studies with appropriate fall-calving weaning weights for BG30 and SG30, the average

205-d adjusted weaning weight of the 100% toxic fescue fall-calving herd from Caldwell et al. (2013) was used for all fall-calving herds, regardless of forage system. Cows and calves in fall-calving herds and complementary forage systems are on toxic fescue almost exclusively from birth to weaning, so using weaning weights from a 100% toxic fescue system was appropriate. Steers and heifers were assumed to have the same average weaning weight.

Daily nutritional requirements of cows (Table 4.4) and replacement heifers were estimated using the University of Nebraska Lincoln Extension BeefNRC macro, which is based on the *Nutrient Requirements of Beef Cattle* (National Academies of Sciences 2016). Requirements were based on month, animal class and lactation status, body weight, and reproductive status (Table 4.5). Spring-calving herds were bred on 1 May, calved on 1 Feb, and weaned calves on 1 Sep. Fall-calving herds were bred on 1 Dec, calved on 1 Sep, and weaned calves on 1 Apr. Model cows were 60 months old, had condition scores of 5, and weighed 635 kg. Replacement heifer age and weight were adjusted on a monthly basis to determine nutritional requirements. The nutritional requirements of calves were estimated following Fox et al. (1988). Early-bloom orchardgrass hay was used for all supplemental feed requirements. The amount of dry matter orchardgrass hay needed to fulfill an animal's daily nutritional requirements was given by the *Nutrient Requirements of Beef Cattle* (National Academies of Sciences 2016). Hay requirements were converted from dry matter to an as-fed basis for the simulation (Table 4.6). All hay was assumed purchased, and four months (Dec – Mar) of supplemental winter hay feeding was assumed necessary for all forage systems and calving seasons. Length of summer hay feeding periods were based on precipitation (Table 4.7). Precipitation levels were simulated based on 71 years (1948 – 2018) of historic monthly summer rainfall indices for Knoxville, TN (United States Department of Agriculture Risk Management

Agency 2018). The average index for the months of July, August, and September was taken each year, then assigned length (2 – 8 weeks) of supplemental summer hay feeding based on the forage system and randomly generated percent of average summer rainfall (see *Simulation* below). No summer hay feeding was budgeted for any forage system if percent average summer rainfall was > 100%. During winter and summer hay feeding periods, I assumed that cattle received 100% of their nutritional requirements from hay. Hay prices (Table 4.6) were based on five-year averages of monthly winter and summer prices for USDA good quality early-bloom orchardgrass in Harrisonburg, VA (USDA Virginia Department of Agriculture Market News 2018). Cattle prices were based on the 17-year (2001 – 2017) average monthly sale prices for Tennessee (USDA Tennessee Department of Agriculture Market News 2018), adjusted for inflation to 2017 prices. Spring- and fall-calving sale prices (Table 4.8) for steers, heifers, and cull cows were based on average prices in September, October, and November, and April, May, and June, respectively. Open heifers that failed to breed were assumed to have the same market price (US\$ kg⁻¹) as cull cows.

PROFITABILITY ANALYSIS

Net present value (NPV) was calculated for spring- and fall-calving beef cow herds for each of the forage systems using enterprise budgets and annual net returns. Revenue for a cow-calf operation is generated through the sale of weaned steers, heifers, and culled animals (open replacement heifers and cows). Costs for each system include land rent, pasture costs (annualized establishment and operational costs), and supplemental hay. A producer's expected annual net returns for a cow-calf operation with either a spring- or fall-calving herd grazing one of the three forage systems are determined by subtracting production costs from revenue, and are expressed as

$$(1) E[\pi_{ift}] = p_{ift}^s y_{ift}^s \left(\frac{CR_{if}}{2} \right) + p_{ift}^h y_{ift}^h \left(\frac{CR_{if}}{2} - RR_{ift} \right) + p_{ift}^c y_{ift}^c (RR_{ift}) + p_{ift}^{oh} y_{ift}^{oh} (HRR_{ift}) - PC_{ift}$$

Where π_{ift} is the expected annual net return (\$/ha) for the i^{th} calving season (i = spring, fall) and f^{th} forage system (f = TF100, BG30, SG30) in time period t ($t = 1, \dots, 10$); p_{ift}^s is the price of steer calves (\$/kg); y_{ift}^s is the weight of steer calves (kg/head); CR_{if} is the calving rate $0 \leq CR \leq 1$; p_{ift}^h is the price of heifer calves (\$/kg); y_{ift}^h is the weight of heifer calves (kg/head); RR_{ift} is the replacement rate of the cow herd $0 \leq RR \leq 1$; p_{ift}^c is the price of culled animals (\$/kg); y_{ift}^c is the weight of culled animals (kg/head); p_{ift}^{oh} is the price of open heifers (\$/kg); y_{ift}^{oh} is the weight of open heifers (kg/head); HRR_{ift} is the replacement rate of open heifers; and PC_{ift} is the annualized cost of production.

Annual net returns were discounted with the rate of 5% to find the NPV over the assumed 10-year useful stand life. Net present value is expressed as

$$(2) E[NPV_{if}] = \sum_{t=1}^{10} \pi_{ift} / (1 + R)^t$$

Where NPV_{if} is the sum of the discounted annual net returns; and R is the discount rate.

SIMULATION

Simulation and Econometrics to Analyze Risk (SIMETAR©) (Richardson et al. 2008) was used to simulate NPV of each combination of calving season and forage system. Summer droughts reduce forage production, especially of CSG, and increase the amount of supplemental feeding required. Summer precipitation data was used to determine the number of feed days for each system, with rainfall data randomly bootstrapped with replacement. Hay prices were randomly drawn from a normal distribution, and cattle prices were drawn from a multivariate

empirical distribution. A total of 5,000 NPV observations were simulated for each combination of calving season and forage type.

Calving rate assumptions for spring-calving BG30 and SG30 were a limitation of this exercise. To address the potential impact of this limitation, a sensitivity analysis was conducted with spring-calving BG30 and SG30 in which the assumed calving rate (0.82) was varied by plus and minus 10%, simulations conducted, and resulting NPVs were compared to those generated using the baseline assumed calving rate and the NPV of spring-calving TF100. A spring-calving herd with access to WSG may have higher calving rates than a similar herd with access to only CSG, regardless of endophyte infection status, because of increased late spring and summer forage production and quality. Fall-calving herds were excluded from the sensitivity analysis because herds of all forage systems, including those assigned to systems with a WSG component, would be grazing supplemental hay or dormant fescue prior to and during the breeding season.

The effect of hay feeding on annual net returns of each forage system within a calving season was isolated and explored by varying annual rainfall (%) while holding all other independent variables constant at their means. The number of weeks of hay feeding in the simulation was determined by the average annual rainfall (%).

RESULTS AND DISCUSSION

Simulated 40-ha forage production systems with a WSG component were more profitable than 100% fescue systems with the exception of the fall-calving BG30 system, which underperformed fall-calving TF100 (Table 4.9, Figure 4.1; all figures located in appendices). The SG30 system was more profitable than BG30 in both calving seasons. The most profitable calving-season depended on the forage system. Fall-calving was more profitable than spring-

calving for TF100, while spring-calving was more profitable for BG30 and SG30 (Table 4.9, Figure 4.1). Average NPV (pooled across calving seasons) of the TF100 system was \$14,324 (\$358/ha), compared with \$16,848 (\$421/ha) and \$37,197 (\$930/ha) for BG30 and SG30, respectively. Average profitability of spring-calving herds increased with the addition of a WSG, and spring-calving SG30 was the most profitable system overall. Spring-calving herds grazing BG30 and SG30 had 454% and 1,070% greater net returns, respectively, than spring-calving TF100 (Figure 4.2). In addition to providing non-toxic forage, the production curve of WSG growth closely matches the increased nutritional demand of lactating spring-calving cows (Bagley et al. 1987). The fall-calving SG30 produced an increase (42%) in profitability over fall-calving TF100, but the fall-calving BG30 system was 39% less profitable than fall-calving TF100 (Figure 4.2). Incorporating switchgrass increased profitability of fescue-based grazing systems due to increased calving rates (spring-calving only) (Table 4.2), weaning weights (spring-calving only) (Table 4.3), reduced demand for hay during summer (Table 4.7), and lower overall annual pasture cost. Despite greater pasture cost of BG30, greater calving rates and weaning weights resulted in an increase in profit for spring-calving herds relative to TF100. However, the only production advantage of BG30 over TF100 for fall-calving herds was reduced summer hay demand, which by itself did not result in great enough savings to offset the increased pasture cost.

The results of the calving rate sensitivity analysis showed that spring-calving forage systems that include a WSG were relatively insensitive to a 10% decrease in calving rate, yet profits increased substantially when the calving rate was increased by 10% (Figure 4.3). Both BG30 and SG30 were still substantially more profitable (384 and 965%, respectively) than spring-calving TF100, even when their calving rates were lowered by 10% (Figure 4.3).

However, profitability over spring-calving TF100 increased by an additional 500 and 700% for BG30 and SG30, respectively, when the calving rate was increased by 10% (Figure 4.3).

Profitability of all forage systems decreased as annual rainfall decreased and the number of hay-feeding days increased (Figure 4.4). For spring-calving herds, the order of profitability of the systems did not change over the range of average annual rainfall (Figure 4.4A). Notably, for the spring-calving herd, both BG30 and SG30 remained profitable regardless of the severity of the drought and associated hay feeding. Even with four weeks hay feeding, the TF100 system was no longer profitable. However, at annual rainfall levels $\geq 88\%$ of the long-term average, fall-calving TF100 was more profitable than fall-calving BG30 (Figure 4.4B). All three systems remained profitable for fall calving herds, regardless of summer hay feeding requirements.

Spring-calving cows grazing toxic fescue during the breeding season are likely to experience reduced reproductive rates as the result of ingesting toxic fescue (Waller 2009). Removing animals from toxic fescue pre- and post-breeding has been shown to increase reproductive rates (Burns 2012, Caldwell et al. 2013). Warm-season grasses are generally ready to be stocked by the time spring-calving breeding season begins, enabling spring-calving cows to be moved off toxic fescue and onto WSG pastures prior to and immediately subsequent to breeding, improving calving rates. Greater calving rates reduce the number of cows that must be culled, and therefore, the number of replacement heifers that must be retained and developed. Developing replacement heifers is one of the most expensive components of operating a cow-calf herd (McFarlane 2018). Furthermore, higher calving rates result in increased revenue because more calves are produced and a greater proportion of calves are marketed. Weaning weights of WSG systems in each calving season had to be estimated from studies comparing toxic fescue grazing systems to those that included either non-toxic fescue or another CSG.

Spring-calving herds grazing WSG, as opposed to non-toxic CSG, prior to weaning calves may produce even greater weaning weights than those assumed in this study. Weaning weights of fall-born calves may also be greater on forage systems that include a WSG due to the ability to stockpile additional fescue going into winter. Increasing stockpiles of fescue for winter grazing has the additional benefit of reducing hay feeding requirements, which reduces cost of production and, in turn, increases profitability.

Cost of production is more important to profitability of many small farms than marketing strategy (Lacy et al. 2012). The SG30 system (US\$335.05/ha) had the lowest cost of production of the three forage systems, followed by TF100 (US\$366.36/ha) and BG30 (US\$412.53/ha). The lower cost of production was the primary reason SG30 was more profitable than TF100 for fall-calving herds. Lower cost of production is also why SG30 was more profitable than BG30 in both calving seasons. The difference in annual pasture cost was driven by lower establishment and fertilizer costs for SG (Table 4.1). Bermudagrass establishment was more expensive because of higher seed cost and seeding rate relative to SG. Annual input requirements were also greater for BG, with higher frequency of application and application rates of N, P, K, and lime.

Several studies and economic analyses have determined that fall-calving is more profitable than spring-calving for 100% fescue forage systems (Smith et al. 2012, Caldwell et al. 2013, Campbell et al. 2013, Henry et al. 2016). Reasons include greater weaning weights and calving rates (Smith et al. 2012, Caldwell et al. 2013), and greater market prices for fall-born calves (Griffith et al. 2017).

CONCLUSIONS

One of the least profitable systems, spring-calving TF100, is the most widely used in the Fescue Belt. A profit-maximizing producer in the Fescue Belt would utilize a complementary forage system with 70% fescue and 30% switchgrass. Producers who prefer to maintain all-fescue forage systems can maximize profitability by utilizing a fall-calving season.

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APPENDICES

TABLES

Table 4.1. Pasture establishment and annual operational costs for tall fescue (TF), bermudagrass (BG), and switchgrass (SG) based on University of Tennessee Department of Agricultural and Resource Economics (2007) forage budgets.

Pasture costs	TF	BG	SG
	US\$/ha		
Establishment costs			
Seed ^a	\$109.58	\$261.24	\$140.85
Establishment ^b	\$473.60	\$573.11	\$363.83
Risk of re-establishment	\$58.32	\$83.44	\$50.47
Total	\$641.50	\$917.79	\$555.15
Annualized establishment ^c	\$87.15	\$124.69	\$75.42
Operational costs			
Fertilizer	\$157.38	\$300.43	\$118.85
Herbicide	\$9.64	\$45.71	\$18.29
Red & white clover seed	\$8.08	—	—
Mowing (clipping)	\$54.68	—	—
Land rent	\$49.42	\$49.42	\$49.42
Total annual pasture cost	\$366.36	\$520.26	\$261.98

^a Tall fescue seed includes tall fescue, red clover, and white clover seed. Seed varieties were "KY-31," "Cheyenne II," and "Alamo" for tall fescue, bermudagrass, and switchgrass, respectively.

^b Other establishment costs include herbicide, fertilizer, custom applications, custom no-till planting, and land rent for establishment year.

^c Includes 5% annual interest.

Table 4.2. Calving rates (%) used in economic simulation, by calving season and forage system.

Calving season	Calving Rates		
	TF100 ^a	BG30 ^b	SG30 ^c
Spring	72% ^d	82% ^e	82% ^e
Fall	93% ^f	93% ^g	93% ^g

^a Tall fescue-only forage system.

^b 70% tall fescue, 30% bermudagrass forage system.

^c 70% tall fescue, 30% switchgrass forage system.

^d Average of calving rates from Brown et al. (1992), Watson et al. (2004), Looper et al. (2010), Burns (2012), and Caldwell et al. (2013).

^e Brown et al. (1992) and Looper et al. (2010).

^f Average fall calving rate reported by Caldwell et al. (2013).

^g Average fall calving rate of toxic and non-toxic tall fescue treatments from Caldwell et al. (2013).

Table 4.3. Weaning weights (kg) of calves used in economic simulation, by calving season and forage system.

Calving season	Weaning weight (kg)		
	TF100 ^a	BG30 ^b	SG30 ^c
Spring	210 ^d	228 ^d	228 ^d
Fall	215 ^e	215 ^e	215 ^e

^a Tall fescue-only forage system.

^b 70% tall fescue, 30% bermudagrass forage system.

^c 70% tall fescue, 30% switchgrass forage system.

^d Average of spring-calving weaning weights from Peters et al. (1992), Burke et al. (2001), Watson et al. (2004), and Caldwell et al. (2013). There was insufficient data in peer-reviewed literature for spring-calving weaning weights for bermudagrass and switchgrass, so substituted average of the toxic fescue/non-toxic forage systems.

^e Caldwell et al. (2013); insufficient data in peer-reviewed literature for fall-calving weaning weights of toxic fescue/bermudagrass and toxic fescue/switchgrass systems, so fall-calving weaning weight of 100% toxic fescue system used.

Table 4.4. Dry matter intake (DMI; kg/day) of early-bloom orchardgrass hay, metabolized protein (MP; g/day), and energy (NEm; mcal/day) requirements of 635 kg cows by calving season and month. Summer values are the average requirements of cows for the months of July through September.

Month	Spring-calving season			Fall-calving season		
	DMI (kg/day)	MP (g/day)	NEm (mcal/day)	DMI (kg/day)	MP (g/day)	NEm (mcal/day)
December	13.3	570	11.7	15.4	1038	19.2
January	13.3	631	13.0	14.9	901	17.4
February	14.1	877	17.0	14.4	784	15.8
March	15.3	1177	21.1	14.1	696	14.6
Summer (Jul - Sep)	13.9	659	13.5	13.6	693	13.9

Source: National Academies of Sciences (2016)

Table 4.5. Straightbred Angus animal description parameters used in the Nutrient Requirements of Beef Cattle University of Nebraska Lincoln Extension Beef NRC program to develop hay feeding requirements for the economic simulation.

Variables	Units	Spring-calving season					Fall-calving season				
		December	January	February	March	Summer	December	January	February	March	Summer
Age	months	60	60	60	60	60	60	60	60	60	60
Body wt	kg	635	635	635	635	635	635	635	635	635	635
Body Condition	value	5	5	5	5	5	5	5	5	5	5
Peak milk Production	kg/day	14	14	14	14	14	14	14	14	14	14
Calf birth wt	kg	36	36	36	36	36	36	36	36	36	36
Days pregnant	days	225	255	0	0	105 ^a	15	45	75	105	160 ^a
Days in milk	days	0	0	15	45	120 ^b	105	135	165	195	5 ^b

^a Mean of days pregnant for July, August, and September.

^b Mean of days in milk for July, August, and September.

Table 4.6. Monthly USDA good quality early-bloom orchardgrass hay prices (\$/kg) in Harrisonburg, VA, and amount of hay (kg/day) needed to fulfil a 635 kg cow's nutritional requirements. Hay requirements are on an as-fed basis.

Month	Price (\$/kg)	Spring-calving	Fall-calving
		Hay (kg/day, as fed)	
December	\$0.11	15.6	18.1
January	\$0.10	15.6	17.5
February	\$0.13	16.6	17.0
March	\$0.11	18.0	16.5
Summer	\$0.07	16.4	16.0

Source: USDA Virginia Department of Agriculture Market News (2018).

Table 4.7. Percent average summer (Jul – Sep) monthly precipitation and associated weeks of summer hay feeding assumed for forage systems in simulation.

Percent (%) Average Summer Monthly Rainfall ^a	Weeks of Hay Feeding	
	TF100	BG30 & SG30
0-59	8	3
60-73	6	2
74-87	4	1
88-100	2	0
>100	0	0

Source: ^aUnited States Department of Agriculture Risk Management Agency (2018)

Table 4.8. Sale prices (\$/kg) for spring- and fall-calving season calves and cull animals. Spring-calving prices are averages of prices for September through November, and fall-calving prices are averages of prices for April through June, in Nashville, TN, 2001-2017.

Animal type	Spring-calving	Fall-calving
	Price (\$/kg)	
Cull	\$1.48	\$1.59
Steer	\$3.17	\$3.35
Heifer	\$2.90	\$3.02

Source: USDA Tennessee Department of Agriculture Market News (2018)

Table 4.9. Simulated average net present value (NPV) over a ten-year simulated period for three 40-ha forage systems, toxic endophyte-infected tall fescue (TF100), toxic endophyte-infected tall fescue with 30% bermudagrass (BG30), and toxic endophyte-infected tall fescue with 30% switchgrass (SG30), and two calving seasons. Means were based on 1,000 iterations of the simulation models. Difference in NPV from incorporating warm-season grass (Δ TF100) is difference in NPV of WSG system (BG30 or SG30) and TF100.

Forage System	Calving season	
	Spring	Fall
TF100	\$3,279.12	\$25,368.46
BG30	\$18,156.07	\$15,540.02
Δ TF100	\$14,876.94	(\$9,828.43)
SG30	\$38,359.90	\$36,034.76
Δ TF100	\$35,080.78	\$10,666.31

FIGURES

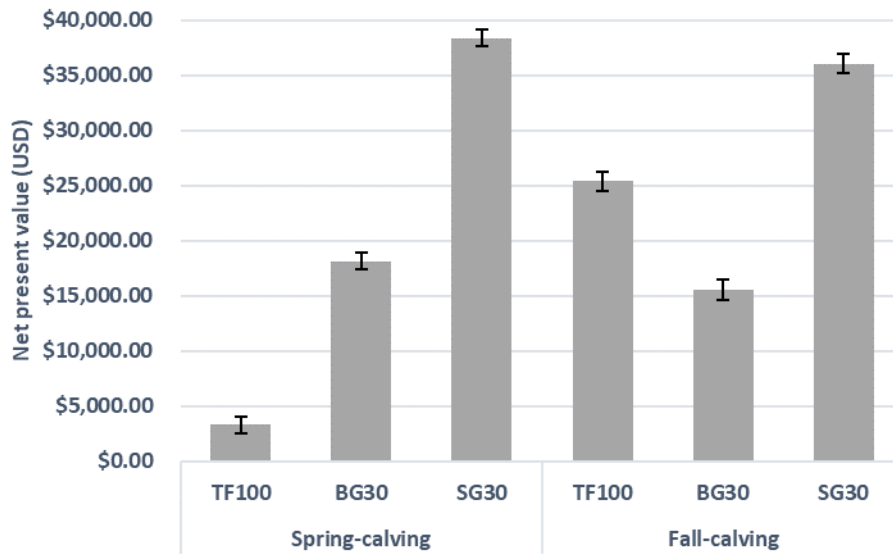


Figure 4.1. Average net present value of simulated 40 ha forage systems with both spring- and fall-calving beef cow-calf herds. Net present values were calculated using an assumed 10-year useful stand life. Forage systems consisted of 100% tall fescue (TF100), 70% tall fescue with 30% bermudagrass (BG30), and 70% tall fescue with 30% switchgrass (SG30). Vertical bars are ± 1 SE.

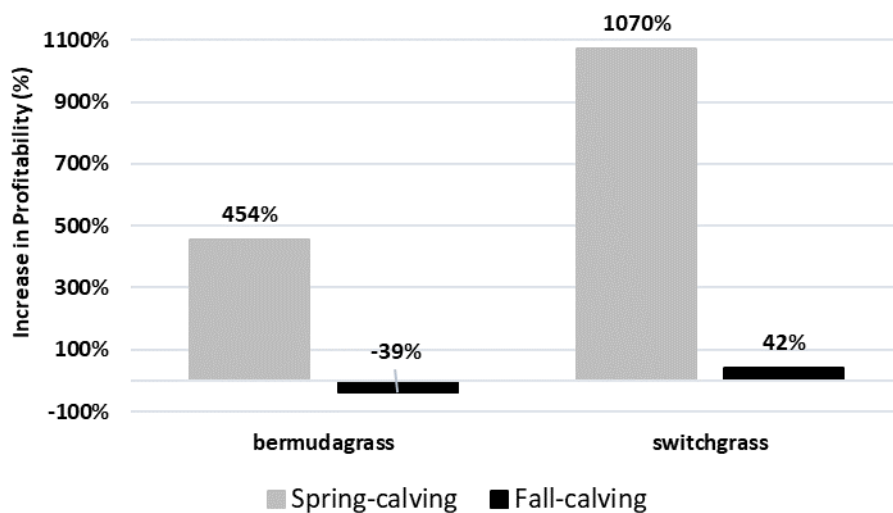


Figure 4.2. Average percent increase in profitability (net present value) of simulated 40 ha forage systems from adding either bermudagrass or switchgrass to tall fescue-based forage systems with both spring- and fall-calving beef cow-calf herds.

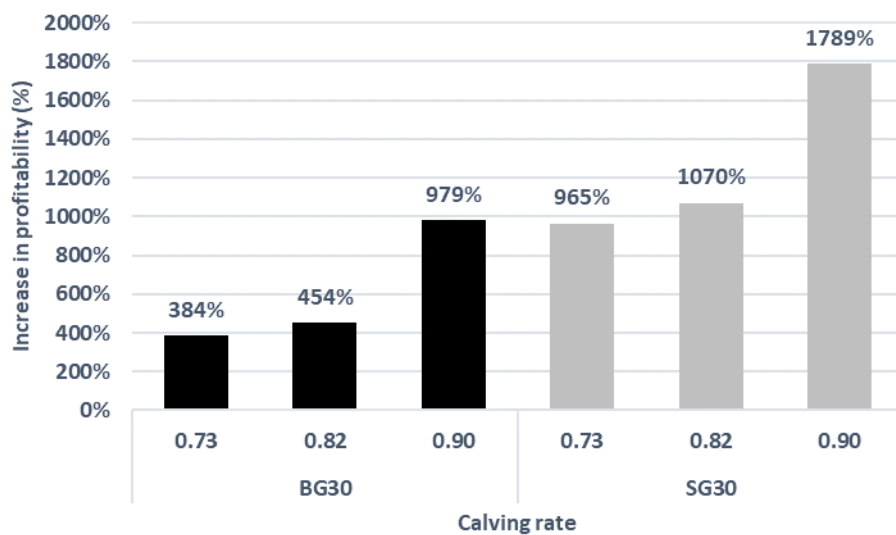
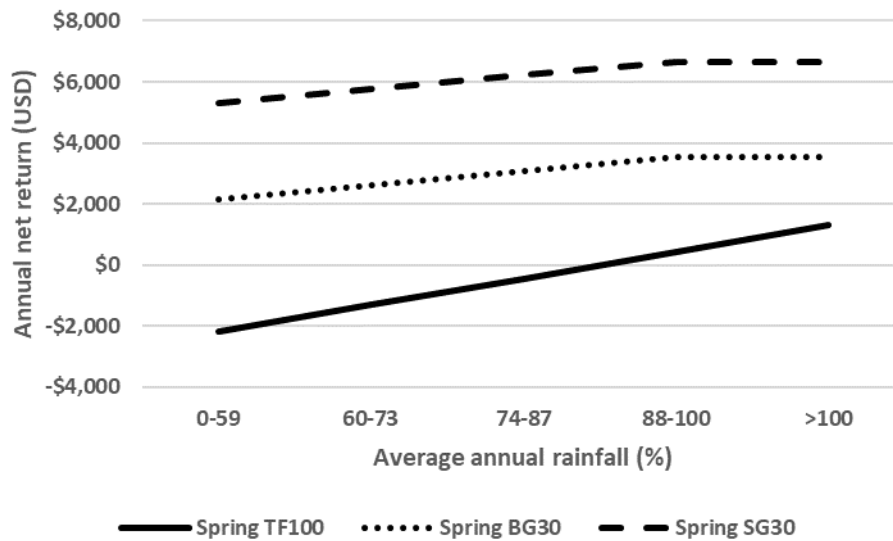


Figure 4.3. Average percent increase in profitability (net present value) of simulated spring-calving beef cow-calf herds grazing 30% bermudagrass/70% fescue (BG30) and 30% switchgrass/70% fescue (SG30) 40 ha forage systems, relative to a fescue-only 40-ha forage system, at three different calving rates.

A



B

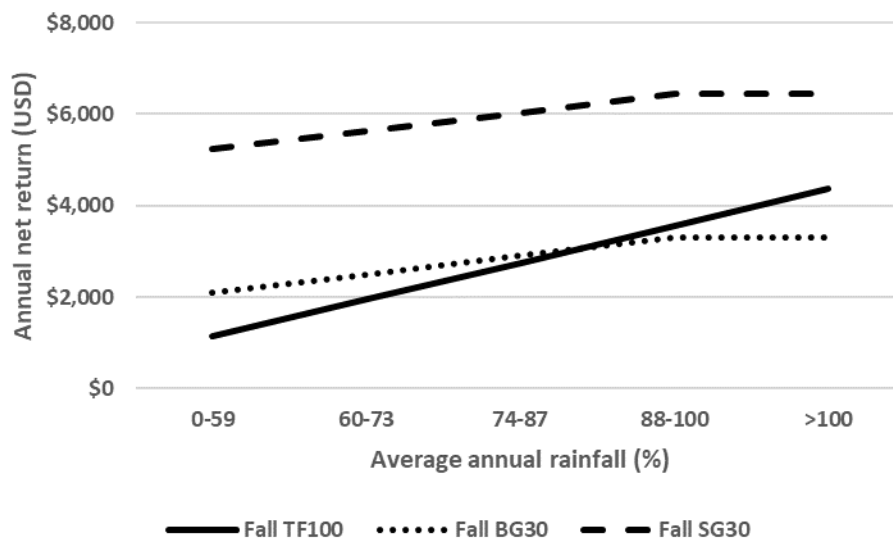


Figure 4.4. Annual net returns of A) spring-calving beef cow-calf herds grazing 30% bermudagrass/70% fescue (Spring BG30), 30% switchgrass/70% fescue (Spring SG30), and 100% fescue 40-ha forage systems (Spring TF100), and B) fall-calving beef cow-calf herds grazing 30% bermudagrass/70% fescue (Fall BG30), 30% switchgrass/70% fescue (Fall SG30), and 100% fescue 40-ha forage systems (Fall TF100), across varying average annual rainfall (%) levels, with all other independent variables held constant at their means.

Chapter 5 CONCLUSION

Agricultural production and wildlife conservation are rarely mutually beneficial. Indeed, agricultural intensification is one of the primary factors responsible for the near-complete elimination of native grassland habitats from the eastern United States, and consequently, the decline of grassland bird populations (Knopf 1994, Noss et al. 1995, Brennan and Kuvlesky 2005, Askins et al. 2007). Specifically, in the region known as the Fescue Belt (Belesky and West 2009), the conversion of native grasslands to the introduced species tall fescue (*Lolium arundinaceum*) drove the loss of grassland bird habitat (Brennan and Kuvlesky 2005, Askins et al. 2007).

Almost all grasslands in the eastern United States are privately owned and utilized for beef cattle production (Keyser et al. In press). Therefore, stabilizing and reversing the grassland bird decline will require creating habitat on private working lands (Askins 1999, Vickery et al. 1999, Keyser et al. In press). Keyser et al. (In press) proposed an economically-driven working-lands approach to creating a critical mass of habitat on private working grasslands. This approach has also been called land-sharing, because the land is used for both agricultural production and wildlife conservation, as opposed to land-sparing, where land is set aside solely for conservation purposes (Phalan et al. 2011). For this approach to work, NWSG pastures must benefit beef cattle producers and grassland birds, and be profitable. Furthermore, NWSG pastures must be sustainable when managed with continuous grazing, the grazing management strategy utilized by the majority of Fescue Belt producers. The evidence presented in the preceding chapters supports the contention that continuously-grazed NWSG pastures are an economical dual-purpose tool for benefitting both beef cattle production and grassland bird conservation in the Fescue Belt. Use of NWSG as an integral part of regional forage systems

may provide the best tool available for improving habitat for grassland birds at a meaningful scale in the Fescue Belt.

Over the three years of the study, continuous grazing of NWSG pastures appeared to be sustainable. Despite an apparent decrease in plant population density from 2017 to 2018, overall tiller density increased, as did tillers/plant of big bluestem and little bluestem. Animal performance and pasture production were also good, with average daily gain of 0.94 kg/day (average of CONT and HEAVY), and total gain of 357 kg/ha (average of CONT and HEAVY). The native grass was also forgiving of management mistakes, such as temporary overutilization due to overstocking. If a NWSG canopy gets too low, stocking can be temporarily reduced, and the sward can recover. The ability to manage NWSG pastures with continuous, season-long (May – August) beef cattle grazing is important because it eliminates one of the major hurdles facing producer acceptance of NWSG forages, the assumption that NWSG pastures must be rotationally grazed to be sustainable. It is also worth noting that the gain produced by the NWSG in my study was very inexpensive, \$0.68 kg⁻¹ (average of CONT and HEAVY).

Equally important to the success of the land-sharing concept is that both sparrow species appeared to benefit from the NWSG pastures compared to fescue. Once landscape was accounted for, grasshopper sparrow density was three times greater on NWSG than fescue pastures. More striking, though, was that both species selected to nest in NWSG pastures and selected against nesting in fescue leading to more fledglings produced per ha from the NWSG. Although I was only able to develop sample sizes large enough for analysis of these two species, it is likely that other species with similar general habitat needs that use pastures within the Fescue Belt will also benefit.

Finally, the economic simulation model illustrated the benefits of incorporating a perennial warm-season grass into tall fescue forage systems. Incorporating switchgrass (*Panicum virgatum*) into fescue systems increased profitability of simulated cow-calf beef cattle operations by 1,070% for spring-calving herds and 42% for fall-calving herds. Incorporating bermudagrass (*Cynodon dactylon*), the most commonly used perennial warm-season grass in the Fescue Belt (Taliaferro et al. 2004), increased profitability of spring-calving herds to a lesser degree (454%), but reduced profitability of fall-calving herds. Native warm-season grasses increased profitability more than bermudagrass because they have lesser cost of production. Specifically, the difference in operating cost of switchgrass (\$261.98 ha⁻¹) and bermudagrass (\$520.26 ha⁻¹) was because switchgrass had lower establishment and fertilizer costs.

Continuous, season-long grazing of NWSG pastures appeared to be feasible, was sustainable over the course of the study, and is profitable for regional beef cattle producers. It also resulted in much-needed habitat for grasshopper sparrow and field sparrow, two declining grassland bird species (Sauer et al. 2014), especially compared to the dominant regional forage grass, tall fescue. Additionally, yet another impediment to producer acceptance of NWSG forages, the necessity of rotational grazing, has been removed. Based on cost of gain in the grazing experiment, the output from my economic model, and the response of the two sparrow species, it appears that in a land-sharing approach, conservation would not represent a net cost, but rather could produce conservation benefit as a by-product of more profitable forage-based agriculture. Such a scenario stands in stark contrast to existing conservation models that rely on costly land-sparing approaches.

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VITA

Kyle Brazil is a Certified Wildlife Biologist originally from Wichita Falls, TX, who specializes in grassland habitat and wildlife management and building working relationships with diverse stakeholders. He earned a BS in Wildlife and Fisheries Ecology from Oklahoma State University in 2002 and a MS in Range and Wildlife Management with the Caesar Kleberg Wildlife Research Institute at Texas A&M University - Kingsville in 2006. Kyle has held numerous positions including Program Manager for the Audubon Texas Quail and Grassland Birds Program, Regulatory Biologist for the Texas Parks & Wildlife Department, Agriculture Policy Coordinator for the National Bobwhite Conservation Initiative, and Program Director for the Wildlife Habitat Federation, specializing in cooperative grassland bird habitat restoration on private lands. In January 2015, Kyle broke a lifelong pledge to never pursue a PhD, moved to Knoxville, Tennessee, and began working for the Center for Native Grasslands Management at the University of Tennessee, Knoxville. Kyle is currently employed by the American Bird Conservancy as the Central Hardwoods Joint Venture Conservation Delivery Coordinator.