An evaluation of early seral plant communities following tall fescue eradication and crop field abandonment

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DEDICATION

I dedicate this thesis first and foremost to my parents, Gene and Peggy GeFellers. The support and encouragement I have received from my parents throughout my life, and especially during my time working on my M.S. degree, has been much more than I deserve. I could never repay for everything I have been given, and I will never forget the encouragement and love I have been shown. I also dedicate this thesis to my very close friends, Cody Caraway, Eric Metcalf, and Richard Myers. I have spent many days afield with each of these individuals, which strengthened my passion for all things outdoors and my pursuit of a career in wildlife management.

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ABSTRACT

Declines in early successional plant and wildlife communities are widely documented throughout the eastern USA; hence, restoration efforts have increased in recent years. Conservation programs encourage establishment of these communities by providing financial and technical assistance to landowners. Planting native grasses and forbs is the common establishment approach, but improper planting and weed competition are common barriers to planting success. Using the seedbank to naturally revegetate a site could be a viable alternative to circumvent common problems associated with planting. We compared planting to seedbank response at 18 sites to evaluate early successional plant community establishment in fields previously dominated by tall fescue (*Schedonorus arundinaceus*) and row-crop agriculture. We established planted (PL) treatment units following recommendations of Private Land Wildlife Biologists who worked with conservation programs administered by the Tennessee Wildlife Resources Agency, Alabama Department of Conservation and Natural Resources, and the Natural Resources Conservation Service. Natural revegetation treatment units (NR) were established from the seedbank and included strategic herbicide applications to remove undesirable plant species. The NR and PL treatments produced plant communities that were similar in plant structure, plant species richness, diversity, and evenness, coverage of native and nonnative plants, coverage of northern bobwhite food plants, available selected white-tailed deer (*Odocoileus virginianus*; hereafter deer) forage (kg/ha), deer nutritional carrying capacity (NCC; deer days/ha), and coverage of native flowering forbs important to pollinators. There was less coverage of sericea lespedeza (*Lespedeza cuneata*) in NR than in PL. Multivariate analyses of nest-site vegetation data for 6 bird species indicated all treatment units provided vegetative structure within the range of conditions found at nest sites of each species. Natural revegetation

was 4.4 times less expensive than planting. Imazapic was the only herbicide that could be used in PL that would not harm planted species. Johnsongrass (*Sorghum halapense*) was the most problematic undesirable species imazapic would control. Considering costs, control options for undesirable species, impacts on habitat quality for various wildlife species, and species diversity, evenness, and richness, land managers should consider natural revegetation techniques as an effective alternative to planting NWSGs and forbs when establishing or restoring early successional plant communities.

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INTRODUCTION

Ecological succession (hereafter succession) is the change in plant species composition and plant community structure and function over time (Smith 2001). Succession can be categorized as early (seral stages 1 and 2), mid (seral stage 3), and late succession (seral stages 4 and 5) in the eastern United States (Harper 2017). Each seral stage is a distinct plant community represented by a different suite of plant species (Smith 2001).

Early successional plant communities are dominated by disturbance-dependent, annual and perennial herbaceous plant species that provide important cover, structure, and food for various wildlife species (Pyne 1982, Brennan 1991, Harper 2017) such as songbirds (Whitmore 1981, Dechant et al. 2002, Hull 2002), northern bobwhite (*Colinus virginianus*; Schroeder 1985), native pollinators (Hanula et al. 2016) white-tailed deer (*Odocoileus virginianus*; hereafter deer; Teer 1996, Hewitt 2011), wild turkey (*Meleagris gallopavo*; Healy 1985), and eastern cottontail (*Sylvilagus floridanus*; Allen 1984). However, a long-standing and ongoing pattern of land-use changes has greatly reduced the distribution of these communities throughout the eastern United States and continue to impact plant and wildlife species that require such areas (Lorimer 2001). From 1982–2015, there was a 60% increase (17.8 million hectares) in the conversion of rural land to developed land in the United States (USDA 2018), and such changes have contributed to declines of early successional plant communities (Brennan 1991, Noss et al. 1995, Noss 2013).

Most fields in the eastern United States are dominated by the Kentucky 31 (KY-31) variety of tall fescue (*Schedonorus arundinaceus*; hereafter tall fescue), a nonnative invasive grass species that severely reduces habitat quality for many wildlife species. Tall fescue has been planted widely for livestock production (hay and pasture) and erosion control since the early 1940’s (Rogers and Locke 2013). However, tall fescue thatch blocks openness at ground level, which is important for travel, feeding, and access to cover for many wildlife species (Harper 2007, Barnes et al. 2013). Tall fescue also lacks the vertical structure many wildlife species require (Washburn et al. 2000, Barnes et al. 1995). Additionally, bobwhite eating tall fescue seed have shown increased mortality rates and cloacal swelling (Barnes et al. 2000). Eastern cottontail have shown avoidance of areas containing tall fescue (Betsill et al. 1979), and a reduction of small mammal populations has been linked to tall fescue presence (Coley et al. 1995). Allelopathic properties (Walters and Gilmore 1976) of tall fescue arrests the successional trajectory, and tall fescue thatch also prevents desirable plants from germinating and growing by shading the soil surface (Henson 2001, Harper et al. 2007). Hence, removal of tall fescue aids in restoration of compositionally and structurally diverse early successional plant communities that are better suited for numerous wildlife species.

Recent research has focused on conservation and management of early successional communities because of declines of wildlife species that require these plant communities (Brennan 1991, Askin 2001, Harper 2007). Conservation and management plans for both private and public lands commonly include management for wildlife species that benefit from early successional plant communities (North Carolina 2005, Kentucky 2013, Georgia 2015, Tennessee 2015). The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) has played a lead role in promoting management of early successional communities on private lands through conservation programs and practices funded by the federal Farm Bill (USDA 2016). Conservation practices for establishing early successional plant communities require planting a native seed mix following eradication of invasive grasses such as tall fescue and bermudagrass (*Cyndon dactylon*). Planting has become the default method for restoring early successional plant communities on both private and public lands (Washburn et al. 2000, Surrency and Owsley 2006, Harper et al. 2007).

Fallow crop fields also are common and provide an opportunity for early successional vegetation establishment. Traditional tillage farming, modern no-till farming, and extensive use of herbicides in these fields often produce fallow plant communities very different from those in fallow hay fields or pastures (Wrucke and Arnold 1985, Ball 1992, Cramer et al. 2008). Arrested succession is rarely a problem in fallow crop fields because of a lack of perennial sod grasses like those in old pastures or hay fields. However, species composition in the seedbank usually is altered by practices used in agricultural management systems (Menalled et al. 2001). Fallow crop fields typically have little residual vegetation immediately following the crop harvest. Availability of resources (i.e., sunlight, nutrients, and moisture) in fallow fields allows colonization by early pioneering species, such as annual foxtails (*Setaria* spp.), common ragweed (*Ambrosia artemisiifolia*), American burnweed (*Erechtites hieraciifolius*), chickweed (*Stellaria* spp.), horseweed (*Conyza candensis*), and henbit (*Lamium amplexicaule*).

Various plant community variables were measured to compare early successional plant communities established via planting and natural revegetation from the seedbank. Data were collected at 18 study sites in 3 states (AL, KY, TN) to measure several plant community variables following tall fescue eradication and planting a native seed mix (planted treatment unit or PL), tall fescue eradication and seedbank response (natural revegetation treatment unit or NR), and in a tall fescue-dominated control (CNTL). Fifteen sites were dominated by tall fescue prior to the study, and 3 were fallow crop fields. Plant communities were compared among treatments and then related to various habitat requirements for field sparrow (*Spizella pusilla*), dickcissel (*Spiza americana*), grasshopper sparrow (*Ammodramus savannarum*), eastern meadowlark

(*Sturnella magna*), Henslow's sparrow (*Ammodramus henslowii*), northern bobwhite, wild turkey, and deer (Chapter I). Additionally, comparisons were made to assess how treatments impacted plant community composition, richness, diversity, and evenness along with how they impacted the number and coverage of flowering forbs important to pollinators (Chapter II). Chapter I is formatted for the Journal of Wildlife Management and chapter II is formatted for Restoration Ecology.

Plant communities in CNTL were predicted to be grass-dominated, mostly by tall fescue, and to provide less structure, coverage of quail food plants, available deer forage, NCC, and species diversity, richness, and evenness, and have a greater coverage of nonnative species compared to NR and PL treatments. Natural revegetation and PL treatment units were hypothesized to be similar in structural measurements. Additionally, it was predicted that percent coverage of nonnative species would be least in NR compared to PL and CNTL because of the ability to use various herbicides applications in NR.

LITERATURE CITED

Allen, A. W. 1984. Habitat suitability index models: Eastern cottontail. U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Division of Biological Science, Fort Collins, Colorado, USA.

Askins, R. A. 2001. Sustaining biological diversity in early successional communities: the challenge of managing unpopular habitats. Wildlife Society Bulletin 20:407–412.

Ball, D. A. 1992. Weed seedbank response to tillage, herbicides, and crop rotation sequences. Weed Science 40:654–659.

Barnes, T. G., L. A. Madison, J. D. Sole, and M. J. Lacki. 1995. An assessment of habitat quality for northern bobwhite in tall fescue-dominated fields. Wildlife Society Bulletin 23:231–237.

Barnes, T. G., J. S. Lane, A. Pescatore, and A. Cantor. 2000. The effects of endophyte-infected KY 31 tall fescue seed on northern bobwhite reproduction. Fourth National Quail Symposium Proceedings.

Barnes, T. G., S. J. Demaso, and M. A. Bahm. 2013. The impact of three exotic, invasive grasses in the southeastern United States on wildlife. Wildlife Society Bulletin 37:497–502.

Betsill, C. W., W. L. Matthews, and L. G. Webb. 1979. Cottontail rabbit habitat utilization of a seeded and mechanically maintained power line right-of-way. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 33:2 0–24.

Brennan, L. A. 1991. How can we reverse the northern bobwhite population decline? Wildlife Society Bulletin 19:544–555.

Coley, A. B., H. A. Fribourg, M. R. Pelton, and K. D. Gwinn. 1995. Effects of tall fescue endophyte infestation on relative abundance of small mammals. Journal of Environmental Quality 24:472–475.

Cramer, V. A., R. J. Hobbs, and R. J. Standish. 2008. What's new about old fields? Land abandonment and ecosystem assembly. Trends in Ecology and Evolution 23:104–112.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, M. P. Nenneman, and B. R. Euliss. 2002. Effects of management practices on grassland birds: grasshopper sparrow. United States Geological Survey, Northern Prairie Wildlife Research Center. Jamestown, North Dakota.

Georgia Department of Natural Resources. 2015. Georgia state wildlife action plan. Social Circle, Georgia, USA.

Hanula, J. L., M. D. Ulyshen, and S. Horn. 2016. Conserving pollinators in North American forests: a review. Natural Areas Journal 36:427–439.

Harper, C. A. 2007. Strategies for managing early succession habitat for wildlife. Weed Technology 21:93 2–937.

Harper, C. A. 2017. Managing early successional plant communities for wildlife in the eastern US. University of Tennessee, Institute of Agriculture, Knoxville, Tennessee, USA.

Healy, W. M. 1985. Turkey poult feeding activity, invertebrate abundance, and vegetation structure. Journal of Wildlife Management 49:466–472.

Henson, J. F. 2001. Tall fescue. Plant Guide. U.S. Department of Agriculture Plant Guide. Natural Resources Conservation Service. National Plant Data Center, Baton Rouge, Louisiana, USA.

Hewitt, D. G. 2011. Biology and management of white-tailed deer. CRC Press, Boca Raton, Florida, USA.

Hull, S. D. 2002. Effects of management practices on grassland birds: eastern meadowlark. United States Geological Survey, Northern Prairie Wildlife Research Center. Jamestown, North Dakota.

Kentucky Department of Fish and Wildlife Resources. 2013. Kentucky's Comprehensive Wildlife Conservation Strategy. http://fw.ky.gov/WAP/Pages/Default.aspx (updated 2/5/2013).

Lorimer, C. G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9000 years of change. Wildlife Society Bulletin 29:425-439.

Menalled, F. D., K. L. Gross, and M. Hammond. 2001. Weed aboveground and seedbank community responses to agricultural management systems. Ecological Applications 11:1586–1601.

North Carolina Wildlife Resources Commission. 2005. North Carolina Wildlife Action Plan. Raleigh, North Carolina, USA.

Noss, R. F. 2013. Forgotten grasslands of the South: natural history and conservation. Island Press, Washington, D.C., USA.

Noss, R. F., E. T. LaRoe III, and J. M. Scott. 1995. Endangered ecosystems of the United States; a preliminary assessment of loss and degradation. National Biological Service Biological Report 28. U.S. Department of the Interior, Washington, D.C., USA.

Pyne, S. J. 1982. Fire in America: a cultural history of wildland and rural fire. Princeton University Press, Princeton, New Jersey, USA.

Rogers, J. K. and J. M. Locke. 2013. Tall fescue: history, application, establishment, and management. The Samuel Roberts Noble Foundation. Ardmore, Oklahoma, USA.

Schroeder, R. L. 1985. Habitat suitability index models: Northern bobwhite. United States Fish and Wildlife Service. Bio1ogical Report 82. Fort Collins, Colorado.

Smith, R. L. 2001. Ecology and Field Biology. Sixth edition. Benjamin Cummings, New York, New York, USA.

Surrency, D., and C. M. Owsley. 2006. Native Warm-Season Grasses in Georgia, Alabama, South Carolina. USDA-NRCS Jimmy Carter Plant Materials Center. Americus, Georgia, USA.

Teer, J. G. 1996. The white-tailed deer: natural history and management. In Rangeland Wildlife, ed. P. R. Krausman, 193–210. Society of Range Management. Denver, Colorado, USA.

Tennessee State Wildlife Action Plan Team. 2015. Tennessee State Wildlife Action Plan 2015. Tennessee Wildlife Resources Agency. Nashville, Tennessee, USA.

U.S. Department of Agriculture (USDA). 2016. Conservation Cover – Permanent Wildlife Planting FY 2016 Environmental Quality Incentives Program Requirement Sheet. Publication 327. Washington, DC, USA.

U.S. Department of Agriculture (USDA). 2018. Summary Report: 2018 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa, USA.

Walters, D. T. and A. R. Gilmore. 1976. Allelopathic effects of tall fescue on the growth of sweetgum. Journal of Chemical Ecology 2:469–479.

Washburn, B. E., T. G. Barnes, and J. D. Sole. 2000. Improving northern bobwhite habitat by converting tall fescue fields to native warm-season grasses. Wildlife Society Bulletin 28:97–104.

Whitmore, R. C. 1981. Structural characteristics of grasshopper sparrow habitat. Journal of Wildlife Management 45:81 1–814.

Wrucke, A. W., and W. E. Arnold. 1985. Weed species distribution as influenced by tillage and herbicides. Weed Science 33:853–856.

CHAPTER I. EFFECTS OF PLANT COMMUNITY RESPONSE ON HABITAT QUALITY FOR VARIOUS WILDLIFE SPECIES FOLLOWING TALL FESCUE ERADICATION

ABSTRACT Tall fescue (*Schedonorus arundinaceus*) has been planted on millions of hectares throughout the eastern United States for agricultural purposes and is a major contributor to declines in the quantity and quality of early successional communities. Restoring early successional communities on retired tall fescue pastures and hayfields is a central focus of several conservation programs that require planting native species. There are numerous establishment and management problems associated with planting, including weedy competition with few control options, expensive seed, slow establishment, and dominance of native warm-season grasses (NWSG) after establishment. These problems warrant the need to develop alternative approaches for establishing native early successional plant communities. We compared early successional plant communities established by natural revegetation from the seedbank (NR), early successional plant communities established by planting (PL), and tall fescue-dominated controls (CNTL) at 15 replicated study sites in Tennessee and Alabama, USA. Natural revegetation and PL treatments produced similar plant communities. Nesting and brooding structure for northern bobwhite (*Colinus virginianus*) and wild turkey (*Meleagris gallopavo)* was similar between NR and PL treatment units except greater openness at ground level was detected in NR treatment units. Additionally, coverage of northern bobwhite food plants, selected white-tailed deer (*Odocoileus virginianus*) forage, and white-tailed deer nutritional carrying capacity were not different between NR and PL treatments. Coverage of NWSG was greatest in PL treatment units. Multivariate analyses indicated treatments provide compositional and structural characteristics like those at nest sites of dickcissel, field sparrow, grasshopper sparrow, Henslow's sparrow, and northern bobwhite. Control treatments most represented nest-sites of eastern meadowlark. Natural revegetation produced a plant community

that provided habitat for many wildlife species equal to or better than planted fields and was 4.4 times cheaper than planting.

KEY WORDS early successional communities, tall fescue, native grass plantings, natural revegetation, seedbank, northern bobwhite, white-tailed deer, wild turkey, songbirds.

The eastern United States has experienced substantial land-use changes that have reduced coverage of native early successional plant communities and created unfavorable conditions for wildlife that require or use them (Brennan 1991, Kirkland and Hart 1999, Pruitt 2000, Mader et al. 2011, Mcchesney and Anderson 2015). Urbanization, forest maturation, intensified agriculture, and commercial forestry have had negative impacts on these plant communities (Williams 1989, Brennan 1991, Ramankutty and Foley 1999, Drummond and Loveland 2010). In addition, nonnative invasive species, many of which were planted, have had considerable negative impacts on the diversity and function of these plant communities (Rudgers and Clay 2007, Barnes et al. 2013).

Most open areas in the eastern United States were planted to tall fescue (*Schedonorus arundinaceus*) for grazing and hay production, replacing higher-quality native early successional plant communities. Tall fescue is an introduced cool-season grass that became popular because of its adaptability, use as a livestock forage, and aid in protection against soil erosion (Rogers and Locke 2013). Tall fescue covers approximately 15 million hectares in the United States, and greater than 90% is infected with an endophytic fungus (*Neotyphodium coenophialum*) that gives the grass many traits desirable for agriculture (Bacon and Siegel 1988, Hoveland 2009, Rogers and Locke 2013). However, the endophyte releases toxic ergot alkaloids known to cause serious health issues in livestock (Bacon and Siegel 1988, Stuedemann and Hoveland 1988, Ball et al.

2003) and can have negative effects on wildlife (Betsill et al. 1979, Madej and Clay 1991, Clay et al. 1993, Coley et al. 1995, Conover and Messmer 1996).

Tall fescue primarily impacts wildlife by altering the plant community through its unique growth habits and suppression of the native seedbank (Barnes et al. 1995, Harper et al. 2007, Barnes et al. 2013). The endophyte gives tall fescue many competitive advantages over native plant species (Clay 1990, Latch 1993, Hill et al. 1996, Salminen et al. 2005, Rudgers et al. 2010). Additionally, tall fescue thatch decomposes slowly, prevents germination and growth of potentially desirable plants, and reduces plant diversity through allelopathy (Walters and Gilmore 1976, Henson 2001, Lemons et al. 2005). The dense structure of tall fescue inhibits openness at ground level, restricting movement of small wildlife species, and causes a lack of vertical structure important for northern bobwhite (*Colinus virginianus*; hereafter bobwhite) chicks, wild turkey (*Meleagris gallopavo*) poults, and numerous other ground-feeding wildlife species (Barnes et al. 1995, Washburn et al. 2000, Harper 2007, Barnes et al. 2013).

Many state and federal agencies promote establishment of native early successional communities, especially on private lands, primarily through programs such as the Natural Resources Conservation Service (NRCS) Conservation Reserve Program (CRP) and Environmental Quality Incentives Program (EQIP). Regulations in these programs require landowners to plant a native seed mix following eradication of nonnative grasses, such as tall fescue. Several problems are commonly associated with planting, including improper site preparation and equipment setup, lack of weed control options that will not harm planted species, and high seed costs, which are paid with taxpayer and sportsman dollars in conservation programs. An alternative approach to circumvent such issues may be to allow the seedbank to respond and revegetate a site naturally following eradication of tall fescue. A natural revegetation approach could allow more options for controlling undesirable vegetation (e.g., nonnative invasive species), eliminate planting and site preparation issues, and reduce costs because seed purchase would not be necessary.

We conducted a field experiment to evaluate plant community response and associated effects on habitat quality for selected wildlife species following tall fescue eradication. We hypothesized that structure of early successional plant communities would not differ between fields naturally revegetated from the seedbank (NR) and fields that were planted (PL). We hypothesized that PL and NR treatment units would provide similar nesting cover for 6 focal bird species because plant communities in the two treatment units would be similar. We hypothesized that NR treatment units would provide more selected white-tailed deer (*Odocoileus virginianus*; hereafter deer) forage than the PL treatment units because of greater coverage of forbs. We hypothesized that tall fescue-dominated controls would provide plant communities favorable for nesting eastern meadowlark and grasshopper sparrow, less vertical structure because of tall fescue's growth habits, and reduced nutritional carrying capacity estimates because of less forb coverage.

STUDY AREA

We collected data from June–August 2016–2018 across 15 study sites in Tennessee and north Alabama, USA (Figure 1.1 and Table 1.1). Seven study sites were on Tennessee Wildlife Resources Agency property in Cocke, Cumberland, Lawrence, Roane, Union, White, and Williamson Counties. Six study sites were located on Tennessee Valley Authority properties in Bedford, Hamblem, Jefferson, Monroe, and Sevier Counties, Tennessee, and Franklin County, Alabama. One study site was on Alabama Department of Conservation and Natural Resources property in Jackson County, and one was in Cades Cove within the Great Smoky Mountains

National Park (hereafter Park) in Blount County, Tennessee. Elevations ranged from 181 m to 658 m. Mean daily temperature across the study area ranged from -4°C to 33°C with mean annual precipitation that ranged 114 cm to 152 cm (National Oceanic and Atmospheric Administration 2019).

METHODS

Study design

We selected tall fescue-dominated fields in 2015. Those fields had been mowed to maintain openings and prevent woody encroachment, hayed through hay leases with farmers, or burned to maintain openings in an early successional plant community for wildlife management purposes prior to project initiation (Table 1.1). Each study site was divided into 3 similar-sized treatment units and each randomly assigned 1 of 3 treatments (control [CNTL], natural revegetation [NR], and planted [PL]). Treatment units varied in size from 0.8 to 1.6 ha. We systematically assigned 5 transects in each unit at each site maintaining an average 10-m buffer between transects and unit edges. We collected data to determine average litter depth, visual obstruction, ground-level sighting distance, available selected deer forage, deer nutritional carrying capacity, and percent coverage of vegetation groups and bobwhite food plants during June–August 2018. It is important to note that though CNTL units were dominated at ground level by tall fescue, they were undergoing succession with various forbs (e.g., Canada goldenrod [*Solidago canadensis*] and wingstem [*Veresina alternifolia*]) and brambles (*Rubus* spp.) pioneering from the seedbank, providing a different structure than that found in tall fescue fields maintained for hay or pasture production.

Tall fescue eradication

We mowed all study sites in fall 2015 and allowed them to regrow to 15.2–25.4 cm (Harper 2017). We then broadcast sprayed glyphosate (2.8 kg ai/ha) applications in PL and NR treatment units to eradicate tall fescue in November–December 2015. We used follow-up spot-spray glyphosate applications in February–March 2016 to eradicate any tall fescue missed during initial applications. Herbicide applications were made when temperatures were at or above 10°C to ensure effectiveness of the herbicide because tall fescue actively grows at temperatures as low as 3°C (Gastal et al. 1992, Rogers and Locke 2013).

Planting treatments

We planted a native warm-season grass (NWSG) and forb seed mix in PL treatment units in April–May 2016 following recommendations from Private Lands Wildlife Biologists with Tennessee Wildlife Resources Agency and Alabama Department of Conservation and Natural Resources who implement their conservation programs. All sites were planted with the same seed mixture (Table 1.2) excluding the Park site because the National Park Service prohibited introduction of outside genotypic seed sources. Seed planted there were collected from within Cades Cove by National Park Service personnel (Table 1.3). No-till drills (Truax™ Flex II Series drills [Truax Company Inc., New Hope, MN, USA] and Haybuster® drills [Duratech Industries International Inc., Jamestown, ND, USA]) were used to plant seed. We calibrated and adjusted drills to ensure seed were planted at the recommended seeding rate of 7.3 kg/ha pure live seed (PLS) and that planting depth was ≤0.635 cm (Harper et al. 2007). We made preemergence imazapic (Plateau®, BASF) applications (0.07–0.105 kg ai/ha) within seven days of planting to control competition (Washburn et al. 1999, Harper et al. 2007).

Natural revegetation treatments

We allowed the seedbank to naturally revegetate NR units following tall fescue eradication. We used herbicide applications to remove undesirable vegetation and to promote a desirable early successional plant community in NR treatment units (Table 1.4). Undesirable vegetation was most often classified as species identified by the Southeast Exotic Pest Plant Council as nonnative invasive species. Any nonnative species not labeled as invasive but increased in coverage ≥ 30% also were considered undesirable. Certain native species such as *Rubus* spp., broomsedge bluestem (*Andropogon virginicus*), and black locust (*Robinia pseudoacacia*) were considered undesirable once they reached 30% coverage and were thinned with herbicide applications to prevent dominance of these species. The areas opened by herbicide applications naturally revegetated again. This cycle of herbicide application and natural revegetation continued until desirable species established.

Herbicide applications in natural revegetation and planted treatment units

We made spot-spray applications using 15-L backpack sprayers (Solo USA, Newport News, Virginia) and/or a 95-L ATV sprayer (Cabelas, Sydney, Nebraska) equipped with a spray gun (Green Garde®, H.D. Hudson Manufacturing Company, Chicago, Illinois). Spot-spray applications were used most often (69% and 86% of all applications made in NR and PL, respectively) and were defined as any herbicide application that did not impact the entire treatment unit. Spot-spray applications on average impacted ≤20% of any single treatment unit. Broadcast applications impacted 100% of any single treatment unit (31% and 14% of all applications made in NR and PL, respectively). We made broadcast applications with a tractor and 3-point boom sprayers, ATV sprayer with boom attachment, or 4-nozzle handheld booms (R&D Sprayers, Opelousas, Louisiana). Broadcast applications were used during fall/winter when ≥50% of the treatment unit was comprised of undesirable cool-season species and during summer when ≥90% of a treatment unit was comprised of undesirable warm-season species. Spot-spray applications were used otherwise.

We determined which herbicides and application rates to use based on plant species targeted for removal (Table 1.5). Planted treatment units simulated plantings made on lands enrolled in conservation programs (e.g., CRP and EQIP), and management activities (i.e., mowing and herbicide applications) were conducted according to Private Lands Biologists' recommendations to remain in compliance with conservation program rules. These biologists commonly worked on lands enrolled in conservation programs and recommended we spot-spray PL treatment units containing ≥30% coverage of johnsongrass (*Sorghum halapense*), crabgrass (*Digitaria* spp.), and/or Japanese stiltgrass (*Microstegium vimineum*) with imazapic because these species were controlled by imazapic and planted species were resistant. We sprayed undesirable species in NR treatment units regardless of coverage. Bermudagrass (*Cynodon dactylon*) invasion is a common problem in plantings, and we sprayed bermudagrass regardless of percent coverage in both NR and PL treatment units, excluding PL treatment units at the Sevier, Tennessee and Franklin, Alabama sites. Bermudagrass coverage at those sites was >50% in the first growing season and dispersed in a way that could only effectively be controlled via broadcast herbicide applications that would also have killed all planted species. We continued collecting data in those treatment units without controlling bermudagrass to monitor how the plant communities responded. Biologists recommended allowing up to 5% coverage of woody species (i.e., trees and shrubs) in PL treatment units. We recorded the number of herbicide applications made and how much of each herbicide was applied to later calculate average costs.

Mowing

We maintained CNTL units by an annual late-winter (February) mowing, representing default management practices common in tall fescue fields (Dykes 2005). Annual mowing was not used in NR or PL treatment units. However, we mowed PL treatment units as necessary and according to biologist recommendations to either prepare PL units for a broadcast herbicide application or to help control competing vegetation and allow planted species to establish.

Measuring vegetation composition

We conducted line-point intercept sampling to quantify vegetation composition in all treatments (Herrick et al. 2009). We established 5 50-meter transects in each treatment unit beginning at predetermined locations that were systematically assigned using Google Earth. Every plant species that intercepted each transect was recorded at 2-m intervals. We calculated percent coverage of species and vegetative life forms (bramble, forb, grass, and woody) by dividing the number of hits of each species or life form by the total number of sampling points per transect. We then averaged percent coverage of each species or life form across all transects for each treatment to calculate percent coverage.

Measuring vegetation structure

We measured visual obstruction (VO) of vegetation using a modified vegetation profile board (Nudds 1977). The vegetation profile board was 2 m tall and divided into 5 alternating-colored rectangular sections. The bottom 0.5 m was divided into 2 0.25-m x 0.25-m sections, whereas the upper 1.5 m was divided into 3 0.5-m x 0.25-m sections. The bottom 0.25 m represented visual obstruction at the level where bobwhite and other small ground-dwelling wildlife species occur. Visual obstruction 0–0.5 m represented that occurring at the upper end of vegetation height important to brooding wild turkey (Metzler and Speake 1985, Peoples et al. 1995). Huegel et al.

(1986) indicated that VO ≥1 m was important at deer fawn bedsites but may have been associated with more stable temperatures in taller vegetation compared to shorter vegetation. We recorded 2 VO measurements along each transect 10 m on either side of center. One person knelt at plot center and estimated visual obstruction by placing each of the 5 sections into 1 of 6 categories (0 = no vegetation, 1 = 1–20% VO, 2 = 21–40% VO, 3 = 41–60% VO, 4 = 61–80% VO, and 5 = 81–100% VO). We qualitatively compared VO measurements across treatment units to VO used by wild turkey, bobwhite, and deer in other studies.

We used measurements from a ground-sighting tube to provide an index of openness at ground level (Gruchy and Harper 2014). We recorded 2 sight-tube measurements along each transect at 14 and 34 meters. The observer looked through the sighting tube while another team member placed a 5.08-cm diameter PVC pole in front of the tube. The pole was moved away until the bottom 15 cm was completely obscured by vegetation and then the distance from the pole to the sighting tube was recorded. Openness at ground level is an important habitat component for several wildlife species, as it allows mobility to access food resources and escape predation (Rosene 1969, Harper et al. 2007).

We measured litter depth at 10 m on either side of center along each transect. We collected measurements using a 30.48-cm metal ruler to the nearest 0.5 centimeter from mineral soil to the top of accumulated plant litter.

Quantifying plant community characteristics at grassland and shrubland bird nest sites

We used data from 2 previous studies conducted near our study sites to determine variables characteristic of nest sites of dickcissel (*Spiza americana*), eastern meadowlark (*Sturnella magna*), field sparrow (*Spizella pusilla*), grasshopper sparrow (*Ammodramus savannarum*), Henslow's sparrow (*Ammodramus henslowii*), and bobwhite. Songbird nest-site vegetation characteristics were collected at Fort Campbell Army Installation (FCAI) in Hopkinsville, Kentucky, USA (Giocomo 2005) and bobwhite nest-site characteristics at Peabody Wildlife Management Area (PBWMA) in west-central Kentucky (Brooke et al. 2016). We classified bobwhite food plants as those producing seed and/or soft mast commonly consumed by bobwhite (Rosene and Freeman 1988, Johnson et al. 2018).

Deer forage sampling and analysis

We randomly placed 2 1-m^2 frames along each transect (450 annually), and all vegetation ≤2 m in height within each frame was cut with a hedge trimmer (Stihl HS 45, Virginia Beach, Virginia) at ground level (Lashley et al. 2014). We placed all cut vegetation in a cloth sack and assigned unique labels to each sample. Forage samples were later separated into selected and non-selected deer forages. Selectivity of forages was determined by literature and observations of what deer had eaten in our study sites. We combined non-selected forages and labeled as "other." We separated selected forages by species and by young and old plant portions because deer are concentrate selectors and select the youngest and most nutritious portions of plants (Hewitt 2011, Lashley et al. 2014). We dried all forage samples to constant mass at 50°C in a forced-air oven dryer. We weighed each sample with calibrated digital scales to the nearest 0.1 gram. We then packaged samples and shipped them to the Agriculture Service Laboratory at Clemson University for wet chemistry nutritional analysis.

Foraging selectivity

We recorded evidence of deer foraging along transects to determine selectivity. The ratio of the number of stems eaten to the number of stems available of each eaten plant was used to calculate a measurement of browse intensity using the Chesson index (Chesson 1983, Shaw et al. 2010). A fifteenth percentile cut-off value was used to rank species selection because that cut-off value closely matched field observations of deer selectivity and has previously been used by other researchers (Nanney et al. 2018). Species determined to be selected by deer were included in nutritional carrying capacity calculations.

Nutritional carrying capacity

We calculated estimates of nutritional carrying capacity (NCC) for deer using a mixed-diet approach with nutritional constraints according to Hobbs and Swift (1985). Nutritional constraints were set at 12% and 14% crude protein (CP). We used a 12% CP constraint and a 1.36 kg/day intake rate to capture the greater estimate of deer maintenance needs (Edwards et al. 2004, Lashley et al. 2011). We used 14% CP constraint with a 2.4 kg/day intake rate to represent nutritional needs at peak lactation of a 50-kg doe with twin fawns (NRC 2007, Hewitt 2011, Nanney et al. 2018). These two constraint models represented a standardized carrying capacity estimate across an average nutritional plane and a nutritionally demanding plane.

DATA ANALYSIS

Our experimental design was a Randomized Complete Block Design with replication. We conducted one-way ANOVAs with blocking using program R version 3.5.1 (R Core Team 2016) to detect differences among treatments in percent coverage of brambles, forbs, grasses, woody plants, and quail food plants, litter depth, ground-sighting distances, visual obstruction, deer forage availability, and deer nutritional carrying capacity at $\alpha = 0.05$. We used post-hoc Tukey HSD tests to compare treatment estimates when a significant effect of treatment was observed. Nonnormal data were transformed using arcsine square root and square root transformations to meet assumptions of normality and equal variance. We analyzed 2018 data (third growing season) to most accurately compare treatment effects and the resulting habitat quality for the wildlife species considered in our analysis. Only 2018 data were used because NWSG and forb communities require 2–3 years to establish (Fransen et al. 2006, Harper et al. 2007, Rushing 2014), and because we used herbicides and mowing to promote native species-dominated plant communities in both NR and PL treatment units during 2016–2017.

We determined vegetative characteristics that best explained grassland and shrubland bird nest sites using multivariate factor analyses (FA) in program R. We first performed principal component analysis to determine how many factors to include in the FA. Vegetative characteristics assigned to factors 1 and 2 by FA were then plotted on a biplot with 50% and 95% confidence ellipses around the multivariate centroid for each species. The 50% confidence ellipse represented the core factor values of the variables determined by FA to be most important at nest sites. We standardized treatment data from our study with data from the bird nest datasets and conducted identical FA procedures, so results were comparable across the 2 datasets. Factor scores for treatments were then plotted with 95% confidence ellipses on the biplot with the bird nest-site factor scores. Using ArcMap 10.5 (ESRI, Redlands, California, USA), we calculated percent overlap between treatment ellipses and nest-site core and 95% confidence ellipses. We plotted factor 1 on the x-axis and factor 2 on the y-axis of biplots for all species, excluding grasshopper sparrow. Grasshopper sparrow factor 2 was explained by vegetation height variables, which were not measured in our study. Factor 3 was plotted instead because it was explained by variables also collected in our study and explained nearly as much variability (12.8%) as did factor 2 (14.8%).

RESULTS

Vegetation composition

Tall fescue coverage was greatest ($F_{2,28} = 213.11$, $P \leq 0.001$) in CNTL (75% ± 2.1%[SE]), with minimal coverage in NR (6% ± 1.1%) and PL (2% ± 0.6%) by the third growing season. Forb coverage in NR (72% ± 2%) and PL (64% ± 3%) was 1.5 and 1.3 times greater than in CNTL (48% ± 3%), respectively. Overall grass coverage was greatest in CNTL (92%). Native warm-season grass coverage was 1.8 and 1.5 times greater in PL and NR, respectively, than in CNTL and 1.2 times greater in PL than in NR. Percent coverage of brambles and woody species was ≤12% and ≤9% across all treatments, respectively (Table 1.6). Percent coverage of plant species producing bobwhite foods (NR = 43% ± 2.7%, PL = 41% ± 2.7%, and CNTL = 32% ± 2.9%) did not differ among treatments ($F_{2,28} = 2.93$, $P = 0.070$).

Vegetation structure

Visual obstruction did not vary among any treatments in stratum 1, and it did not vary between NR and PL in strata 2–5 (S2[$P = 0.117$], S3[$P = 0.695$], S4[$P = 0.993$], and S5[$P = 0.840$]. However, CNTL had less VO in strata 2–4 compared to both NR (S2[$P = 0.034$], S3[$P = 0.030$], S4[$P = 0.033$]) and PL (S2[$P \leq 0.001$], S3[$P = 0.004$], S4[$P = 0.043$]) and was only different from PL in stratum 5 ($P = 0.023$) (Table 1.7). We detected a treatment effect ($F_{2,28} = 4.79$, $P = 0.016$) for ground-sighting distance. Average ground-sighting distance was similar in PL (66 ± 3 cm) and CNTL (63 ± 2 cm; $P = 0.916$) and greatest in NR (85 ± 5 cm). Litter depth (CNTL = 3.5 ± 1.2 cm, NR = 2.6 ± 1.5 cm, PL = 3.5 ± 2.2 cm) did not differ among treatments ($F_{2,28} = 2.83$, $P = 0.076$).

Relationships with bird nest site selection

All treatment ellipses were fully encompassed in the dickcissel 95% confidence ellipse (Figure 1.2). Warm-season grass and forb cover (Factor 1 [F1]) and bareground, woody, and vertical cover (Factor 2 [F2]) were important variables at dickcissel nests (Table 1.8). Treatment confidence ellipses for all other bird species in our analyses were largely contained within the bird nest 95% confidence ellipses (Figures 1.3–1.7). Cool-season and warm-season grass cover

(F1) and litter cover (F2) were important variables at eastern meadowlark nests (Table 1.8). Warm-season grass and forb cover (F1) and litter and bareground cover (F2) were important variables at field sparrow nests (Table 1.8). Litter cover (F1) and forb and cool-season grass cover (F3) were important variables at grasshopper sparrow nests (Table 1.8). Warm-season grass and cool-season grass cover (F1) and forb cover (F2) were important variables at Henslow's sparrow nests (Table 1.8). Cool-season grass coverage and litter depth (F1) and warm-season grass coverage (F2) were important variables at bobwhite nests (Table 1.8).

Selectivity by deer

We documented 290 plant species across all sites and years. We classified 14 species as moderately and highly selected by deer using a selection index and a cut-off value of $\alpha = 0.005$ (Chesson 1978). Selected species included 9 forbs, 2 brambles, 2 trees, and 1 vine. No graminoids were selected (Table 1.9). All 14 plant species were included in nutritional carrying capacity calculations.

Deer forage availability and NCC

Forage availability did not differ ($F_{2,28} = 2.49$, $P = 0.101$) among any treatment (NR = 570 ± 54 kg/ha, PL = 452 ± 58 kg/ha, CNTL = 429 ± 60 kg/ha). The 5 forb species planted in PL were considered selected deer forages and contributed only 26 ± 9 kg/ha, indicating 94.2% of the deer forages in PL were naturally occurring from the seedbank (Figure 1.8). Nutritional carrying capacity at the 12% crude protein (CP) constraint also did not differ ($F_{2,28} = 2.42$, $P = 0.107$) among treatments (NR = 397 ± 38 deer days/ha, PL = 320 ± 49 deer days/ha, and CNTL = 305 ± 44 deer days/ha). However, at the 14% CP constraint, NR (145 ± 14 deer days/ha) had greater NCC than CNTL (66 ± 10 deer days/ha; $P = 0.013$) but was not different from PL (88 ± 11 deer days/ha; $P = 0.090$), and CNTL was not different from PL ($P = 0.668$).

Treatment costs and effort

Average cost for PL treatments was $468.98 per hectare. Glyphosate applications to prepare PL treatments were $20.26 per hectare, the preemergence imazapic application was $16.61 per hectare, seed cost $400.38 per hectare, and post-planting herbicides for weed control averaged $31.73 per hectare. Costs of herbicide application in NR were variable because of differences in seedbank responses at each site. The range of costs for NR was $35.48–$269.02 per hectare and averaged $106.43 per hectare, excluding the initial $20.26 per hectare glyphosate application. On average, PL treatment units required 0.4 entries per site per year, excluding the initial herbicide treatment to remove tall fescue, planting, mowing, and spot-spray applications. Natural revegetation units required 1.3 entries per site per year.

DISCUSSION

The NR and PL treatments were similar despite the use of different establishment approaches. However, openness at ground level was greatest in NR treatment units, and coverage of NWSG was greatest in PL treatment units. Multivariate analyses of vegetation characteristics at nest sites of 6 bird species and treatment data produced similar results with considerable overlap of all treatment ellipses, especially NR and PL ellipses. Because of these similarities and the much-reduced establishment cost of NR, it is questionable if planting is warranted to provide or improve habitat for various wildlife species that need or require early successional plant communities.

Glyphosate treatments effectively controlled tall fescue by the third growing season. Plant phenology is an important consideration when making any herbicide application, and November glyphosate applications obviously impacted tall fescue at a susceptible growth stage. Long-term commitments often required to control nonnative invasive species can be a discouraging factor for many wildlife managers. However, our data indicate tall fescue can be controlled with a single herbicide application made during November after 2–3 frosts when most warm-season plants are dead or dormant.

It was not surprising that treatment ellipses were completely or largely contained within the 95% nest-site ellipses for all 6 bird species. These species commonly nest within a wide range of structural and compositional conditions provided by a variety of grasses and forb. Birds in our study nested in areas with a wider range of variables than what we detected in our treatments. This ability to nest under a relatively wide range of conditions is highlighted by the fact that the 95% nest-site ellipses occupied a larger area on biplots than did treatment ellipses. Variability in nest-site selection is even greater on a larger geographic scale (Winter 1999, Dechant et al. 2002*a*, Dechant et al. 2002*b*). Because treatment ellipses were largely contained within 95% nest-site ellipses of all bird species, we concluded our sites and treatment units provided plant community characteristics consistent with nesting structure of all 6 species.

Variables that our analyses indicated as important at nest sites of the bird species in our study corroborated with previous studies. Dickcissels select areas with large amounts of vertical cover, which can be increased with woody vegetation, and less coverage of bare ground (Dechant et al. 2002*a*). Additionally, forbs provide singing perches for dickcissels. Although both warm- and cool-season grasses were considered important at Henslow’s sparrow nest sites, other studies did not detect a preference for either (Herkert 1994), but forb cover is common at Henslow’s sparrow nest sites (Schulenberg et al. 1994, Winter 1999). Litter cover and the structure provided by cool-season grasses such as tall fescue can be important components at eastern meadowlark nest sites (Hull 2002, Moorman et al. 2017). The structure provided by cool-season grasses also may be selected by grasshopper sparrows (Moorman et al. 2017). However, all treatment ellipses in our study were contained within the 95% nest-site ellipse of grasshopper sparrows suggesting that all treatments provided structure and composition similar to grasshopper sparrow nest sites at FCAI. Interestingly, all treatment ellipses for both eastern meadowlark and grasshopper sparrow overlapped considerably, suggesting all 3 treatments provided similar nest-site potential.

Cool-season grasses loading on factor 1 at bobwhite nest-sites was surprising. However, nearly 60% of bobwhite nests at PBWMA were constructed of field brome (*Bromus arvensis*), which was a dominant cool-season grass at PBWMA (Brooke et al. 2016). Cool-season grass coverage in CNTL units was represented by tall fescue, which does not provide the same structure as field brome. Tall fescue is a perennial sod-forming grass that creates a dense mat on the ground surface, whereas field brome is an annual grass with more open structure near the ground and slender stems that bobwhite may use to create nests (Brooke et al. 2016).

Metrics of bobwhite habitat, including food plant coverage, forb coverage, and litter depth, were not different between NR and PL treatments. However, ground-sighting distance was greatest in NR units and NWSG coverage greatest in PL units. The 49% coverage of NWSG in NR treatment units more closely resembled that documented at bobwhite nest sites in previous studies than the 61% coverage in PL treatment units (Taylor and Burger 2000, Collins et al. 2009, Martin et al. 2009, Brooke et al. 2016). Furthermore, our data clearly indicate NWSGs do not need to be planted to meet nesting requirements for bobwhite because there are no data that suggest bobwhite need more than approximately 35% coverage of grass for nesting (Collins et al. 2009, Brooke et al. 2016). Although all 5 forb species planted in PL treatment units were considered bobwhite food plants, they represented only 4% of the quail food plants detected in PL treatment units. Coverage of forbs in both NR and PL treatment units were within the 25–

75% coverage of food plants at sites used by bobwhite (Schroeder 1985, Rosene and Freeman 1988, Martin et al. 2015, Johnson et al. 2018). It is important to note that even though we detected 32% coverage of bobwhite food plants in CNTL units, any seed produced or insects associated with the plants would not be readily accessible because of the dense structure of tall fescue at ground level (Barnes et al. 1995). Openness at ground level is required for bobwhite chicks to gain easy access to invertebrates during the first 2 weeks of life (Taylor et al. 1999, Collin et al. 2009), and was greatest in NR treatment units.

Visual obstruction measurements in NR and PL were consistent with sites selected by turkeys. However, because of the suppressive effects of tall fescue, visual obstruction ≤1 m aboveground in CNTL (82%) was below the 85–98% range reported at successful nests (Cook 1972, Lazarus and Porter 1985, Badyaev 1995, Isabelle et al. 2016). Visual obstruction <0.5 m with minimal VO above 0.5 m and openness at ground level allows hens to detect predators and is important for survival and movement of wild turkey broods (Healy 1985, Metzler and Speake 1985, Peoples et al. 1996, Spears et al. 2007). All treatments in our study had ≥94% VO below 0.5 m, but VO estimates above 0.5 m averaged ≥57% in PL and NR treatment units and may have been greater than that selected by brooding hens. Frequent management to set-back succession is necessary to maintain desirable brooding cover, whereas less frequent management will increase shrubby vegetation height and coverage important for wild turkey nesting structure (Moore et al. 2010, Isabelle et al. 2016, Wood et al. 2018).

The quantity and quality of selected deer forages was highly variable among treatments. Blackberry and goldenrod were considered selected deer forages, and both pioneered into the CNTL units at many sites and resulted in greater forage estimates in CNTL than was suspected. In general, seedbank response was highly variable across sites and resulted in considerable differences in deer forage estimates among treatments. Although all 5 planted forb species were considered selected deer forages, they contributed only 26 of the 452 kg/ha detected in PL treatment units (Figure 1.8). Spot-spray applications to reduce coverage of undesirable species in NR allowed high-quality annual forbs to establish and contribute to the greater NCC in NR. Although NCC did not differ in NR and PL, dominance of NWSG, such as that in PL treatment units, leads to reduced NCC for deer because of forb suppression (Weber 1999, Dickson and Busby 2009).

Planting was on average 4.4-times more expensive than NR, providing additional evidence that planting may not be an efficient use of conservation funds. Although we made fewer entries into PL treatment units relative to NR treatment units, a greater number of entries would have allowed better control of undesirable vegetation. However, conservation program policy, suggesting coverage of undesirable vegetation be ≥30% before herbicide applications are warranted, reduced the average number of entries made in PL treatment units. Our study sites were widely distributed geographically and occurred in areas with differing site histories and soil types. Therefore, we believe establishment costs from this study are representative for what would be required to establish native early successional communities in tall fescue fields throughout a large portion of the eastern United States. Planting costs can vary greatly depending on species planted. Forbs are more expensive than NWSG, and forb-dominated pollinator seed mixes are now commonly planted in many CRP and EQIP projects. Pollinator seed mixes require a minimum of 9 flowering species (3 flowering in spring, summer, and fall), and the cost is considerably greater than general wildlife seed mixes. Our data indicated that even when planting a more traditional (i.e., relatively low cost) wildlife seed mixture, such as the one used in this study, 4.4-times more land could have been converted to native early successional plant communities using natural revegetation for the same cost of planting per unit area.

MANAGEMENT IMPLICATIONS

Managers working to increase or enhance early successional plant communities for wildlife should consider using the natural revegetation approach instead of planting. Even with considerable variation in site histories, vegetation characteristics were similar between NR and PL treatments. Perennial cool-season grasses should be treated in fall with the appropriate application of glyphosate, followed by a preemergence or postemergence application of imazapic where warranted for controlling undesirable plant species. Strategic spot-spray herbicide applications should be used at least once each growing season to reduce coverage of undesirable species. Planting may be considered at sites with severely depleted seedbanks, such as reclaimed mine sites and highly eroded soils. Based on our study across a wide array of sites and management histories, planting NWSG should be avoided where species such as broomsedge bluestem, little bluestem, splitbeard bluestem (*Andropogon ternarius*), big bluestem (*Andropogon gerardi*), yellow indiangrass (*Sorghastrum nutrans*), or other NWSGs are present. There was 49% coverage of NWSG in NR treatment units, indicating NWSGs are readily available on most sites and did not need to be included in seed mixtures for most management objectives.

LITERATURE CITED

Bacon, C. W., and M. R. Siegel. 1988. Endophyte parasitism of tall fescue. Journal of Production Agriculture 1:45–55.

Badyaev A. V. 1995. Nesting habitat and nesting success of eastern wild turkeys in the Arkansas Ozark Highlands. Condor 97:221–232.

Ball, D. M., S. P. Schmidt, G. D. Lacefield, C. S. Hoveland, and W. C. Young, III. 2003. Tall fescue endophyte concepts. Oregon Tall fescue Commission Special Publication 1–03. Salem, Oregon, USA.

Barnes, T. G., L. A. Madison, J. D. Sole, and M. J. Lacki. 1995. An assessment of habitat quality for northern bobwhite in tall fescue-dominated fields. Wildlife Society Bulletin 23:231–237.

Barnes, T. G., S. J. Demaso, and M. A. Bahm. 2013. The impact of three exotic, invasive grasses in the southeastern United States on wildlife. Wildlife Society Bulletin 37:497–502.

Betsill, C. W., W. L. Matthews, and L. G. Webb. 1979. Cottontail rabbit habitat utilization of a seeded and mechanically maintained power line right-of-way. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 33:2 0–24.

Brennan, L. A. 1991. How can we reverse the northern bobwhite population decline? Wildlife Society Bulletin 19:544–555.

Brooke, J. M., E. P. Tanner, D. C. Peters, A. M. Tanner, C. A. Harper, P. D. Keyser, J. D. Clark, and J. J. Morgan. 2016. Northern bobwhite breeding season ecology on a reclaimed surface mine. Journal of Wildlife Management 81:73–85.

Chesson, J. 1978. Measuring preference in selective predation. Ecology 59:21 1–215.

Chesson, J. 1983. The Estimation and Analysis of Preference and Its Relationship to Foraging Models. Ecology 64:1297–1304.

Clay, K. 1990. Comparative demography of three graminoids infected by systemic, clavicipitaceous fungi. Ecology 71:558–570.

Clay, K., S. Marks, and G. P. Cheplick. 1993. Effects of insect herbivory and fungal endophyte infection on competitive interactions among grasses. Ecology 74:1767–1777.

Coley, A. B., H. A. Fribourg, M. R. Pelton, and K. D. Gwinn. 1995. Effects of tall fescue endophyte infestation on relative abundance of small mammals. Journal of Environmental Quality 24:472–475.

Collins, B. M., C. K. Williams, and P. K. Castelli. 2009. Reproduction and microhabitat selection in a sharply declining northern bobwhite population. The Wilson Journal of Ornithology 121:688–695.

Conover, M. R., and T. A. Messmer. 1996. Feeding preferences and changes in mass of Canada geese grazing endophyte-infected tall fescue. Condor 98:859–862.

Cook, R. L. 1972. A study of nesting turkeys in the Edwards Plateau of Texas. Proceeding of the Annual Conference of the Southeastern Association of Game and Fish Commissions, 26:236–244.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, A. L. Zimmerman, and B. R. Euliss. 2002*a*. Effects of management practices on grassland birds: dickcissel.

United States Geological Survey, Northern Prairie Wildlife Research Center. Jamestown, North Dakota.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, B. D. Parkin, and B. R. Euliss. 2002*b*. Effects of management practices on grassland birds: field sparrow. United States Geological Survey, Northern Prairie Wildlife Research Center. Jamestown, North Dakota.

Dickson, T. L. and W. H. Busby. 2009. Forb species establishment increases with decreased grass seeding density and with increased forb seeding density in a northeast Kansas, U.S.A., experimental prairie restoration. Restoration Ecology 17:597-605.

Drummond, M. A., and T. R. Loveland. 2010. Land-use pressure and a transition to forest-cover loss in the eastern United States. Bioscience 60:286–298.

Dykes, S. A. 2005. Effectiveness of native grassland restoration in restoring grassland bird communities in Tennessee. Thesis, University of Tennessee, Knoxville, USA.

Edwards, S. L., S. Demarais, B. Watkins, B. K. Strickland. 2004. White-tailed deer forage production in managed and unmanaged pine stands and summer food plots in Mississippi. Wildlife Society Bulletin 32:739–745.

Fransen, S.C., H.P. Collins, and R.A. Boydston. 2006. Perennial warm-season grasses for biofuels. Proceedings of Western Alfalfa and Forage Conference. Reno, Nevada, USA.

Gastal, F., G. Bellanger and G. Lemaire. 1992. A model of leaf extension rate of tall fescue in response to nitrogen and temperature. Annals of Botany 70:437–442.

Giocomo, J. J. 2005. Conservation of grassland bird populations on military installations in the eastern United States with special emphasis on Fort Campbell Army Base, Kentucky. Dissertation. The University of Tennessee, Knoxville, Tennessee, USA.

Gruchy, J. P., and C. A. Harper. 2014. Effects of management practices on northern bobwhite habitat. Journal of the Southeastern Association of Fish and Wildlife Agencies 1:133–141.

Harper, C. A. 2007. Strategies for managing early succession habitat for wildlife. Weed Technology 21:93 2–937.

Harper, C. A. 2017. Managing early successional plant communities for wildlife in the eastern US. University of Tennessee, Institute of Agriculture, Knoxville, Tennessee, USA.

Harper, C. A., G. E. Bates, M. P. Hansbrough, M. J. Gudlin, J. P Gruchy, and P. D. Keyser. 2007. Native warm-season grasses: identification, establishment and management for wildlife and forage production in the Mid-South. University of Tennessee, Institute of Agriculture, Knoxville, Tennessee, USA.

Healy, W. M. 1985. Turkey poult feeding activity, invertebrate abundance, and vegetation structure. Journal of Wildlife Management 49:466–472.

Henson, J. F. 2001. Tall fescue. Plant Guide. U.S. Department of Agriculture Plant Guide. Natural Resources Conservation Service. National Plant Data Center, Baton Rouge, Louisiana, USA.

Herkert, J. R. 1994. Status and habitat selection of the Henslow's Sparrow. Wilson Bulletin 106:35–45.

Herrick, J. E., J. W. Van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2009. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume I: Quick Start. U. S. Department of Agriculture: ARS Jornado Experimental Range. Las Cruces, New Mexico, USA.

Hewitt, D. G. 2011. Biology and management of white-tailed deer. CRC Press, Boca Raton, Florida, USA.

Hill, N. S., J. G. Pachon, and C. W. Bacon. 1996. Acremonium coenophialum-mediated short- and long-term drought acclimation in tall fescue. Crop Science 36:665–672.

Hobbs, N. T., and D. M. Swift. 1985. Estimates of habitat carrying capacity incorporating explicit nutritional constraints. Journal of Wildlife Management 49:814–822.

Hoveland, C. S. Origin and history of tall fescue. 2009. In H. A. Fribourg, D. B. Hannaway, C. P. West, editors. pages 3–10. Tall fescue for the twenty-first century: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. Madison, Wisconsin, USA.

Huegel, C. N., R. B. Dahlgren, and H. Lee Gladfelter. 1986. Bedsite selection by white-tailed deer fawns in Iowa. Journal of Wildlife Management 50:474–480.

Hull, S. D. 2002. Effects of management practices on grassland birds: eastern meadowlark. United States Geological Survey, Northern Prairie Wildlife Research Center. Jamestown, North Dakota.

Isabelle, J. L., W. C Conway, C. E. Comer, G. E. Calkins, and J. B. Hardin. 2016. Reproductive ecology and nest-site selection of eastern wild turkeys translocated to east Texas. Wildlife Society Bulletin. 40:88–96.

Johnson, K., D. Elmore, and L. Goodman. 2018. A guide to plants important for quail in Oklahoma. Oklahoma Cooperative Extension Service Publication E-1047. Oklahoma State University, Stillwater, USA.

Kirkland, G. L., Jr., and J. A. Hart. 1999. Recent distributional records for ten species of small mammals in Pennsylvania. Northeastern Naturalist 6: 1–18.

Lashley, M. A., C. A. Harper, G. A. Bates, and P. D. Keyser. 2011. Forage availability for white-tailed deer following silvicultural treatments in hardwood forests. Journal of Wildlife Management 75:1467–1476.

Lashley, M. A., M. C. Chitwood, C. A. Harper, C. E. Moorman, C. S. DePerno. 2014. Collection, handling and analysis of forages for concentrate selectors. Wildlife Biology in Practice 10:6–15.

Latch, G. C. 1993. Physiological interactions of endophytic fungi and their hosts. Biotic stress tolerance imparted to grasses by endophytes. Agriculture, Ecosystems & Environment 44:143–156.

Lazarus J. E., and W. F. Porter. 1985. Nest habitat selection by wild turkeys in Minnesota. Proceedings of the National Wild Turkey Symposium 5: 67–81.

Lemons, A., K. Clay, and J. A. Rudgers. 2005. Connecting plant-microbial interactions above and belowground: a fungal endophyte affects decomposition. Oecologia 145:595–604.

Madej, C. W. and K. Clay. 1991. Avian seed preference and weight loss experiments: the effect of fungal endophyte-infected tall fescue seeds. Oecologia 88:296–302.

Mader, E., M. Shepherd, M. Vaughan, S. H. Black, and G. Lebuhn. 2011. Attracting native pollinators: protecting North America's bees and butterflies. Story Publishing, North Adams, Massachusetts, USA.

Martin, J. A., J. K. Burkhart, R. E. Thackston, and J. P. Carroll. 2015. Exotic grass alters micro-climate and mobility for northern bobwhite chicks. Wildlife Society Bulletin 39:834–839.

Martin, N. C., J. A. Martin, and J. P. Carroll. 2009. Northern bobwhite brood habitat selection in South Florida. Pages 88–97 *In* S. B.Cederbaum, B. C. Faircloth, T. M. Terhune, J. J. Thompson, J. P. Carroll, editors. Gamebird 2006: Quail VI and Perdix XII. Warnell School of Forestry and Natural Resources, Athens, Georgia.

Mcchesney, H. M., and J. T. Anderson. 2015. Reproductive success of field sparrows (Spizella pusilla) in response to invasive Morrow's honeysuckle: does Morrow's honeysuckle promote population sinks? The Wilson Journal of Ornithology 127:22 2–232.

Metzler, R., and D. W. Speake. 1985. Wild turkey mortality rates and their relationship to brood habitat structure in northeast Alabama. Proceedings of the National Wild Turkey Symposium 5:103–111.

Moore, W. F., J. C. Kilgo, W. D. Carlisle, D. C. Guynn, Jr., and J. R. Davis. 2010. Nesting success, nest site characteristics, and survival of wild turkey hens in South Carolina. Proceedings of the Southeastern Association of Fish and Wildlife Agencies 64: 24–29.

Moorman, C. E., R. L. Klimstra, C. A. Harper, J. F. Marcus, and C. E. Sorenson. 2017. Breeding songbird use of native warm-season and nonnative cool-season grass forage fields. Wildlife Society Bulletin 41:4 2–48.

Nanney, J. S., C. A. Harper, D. A. Buehler, and G. A. Bates. 2018. Nutritional carrying capacity for cervids following disturbance in hardwood forests 82:1219–1228.

National Oceanic and Atmospheric Administration. 2019. Climatological data annual summary Alabama and Tennessee. National Climatic Data Center, Asheville, North Carolina, USA.

National Research Council (NRC). 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. National Academy Press, Washington, D.C. USA.

Nudds, T. D. 1977. Quantifying the Vegetative Structure of Wildlife Cover. Wildlife Society Bulletin 5:113–117.

Peoples, J. C., D. C. Sisson, and D. W. Speake. 1996. Wild turkey brood habitat use and characteristics in coastal plain pine forests. Proceedings of the National Wild Turkey Symposium. 7:89–98.

Pruitt, L. 2000. Loggerhead shrike: status assessment. U.S. Fish and Wildlife Service. Bloomington, Indiana, USA.

Ramankutty, N. and J. A. Foley. 1999. Estimating historical changes in land cover: North American croplands from 1850 to 1992. Global Ecology and Biogeography:38 1–396.

Rogers, J. K. and J. M. Locke. 2013. Tall fescue: history, application, establishment, and management. The Samuel Roberts Noble Foundation. Ardmore, Oklahoma, USA.

Rosene, W. 1969. The bobwhite quail: its life and management. Rutgers University Press, New Brunswick, New Jersey, USA.

Rosene, W. and J. D. Freeman. 1988. A guide to and culture of flowering plants and their seed important to bobwhite quail. 2005, Reprint. Morris Communications Corporation. Augusta, Georgia, USA.

R Core Team. 2016. RStudio: Integrated Development for R. RStudio, Inc., Boston, Massachusetts, USA. URL: http://www.rstudio.com/.

Rudgers, J. A., and K. Clay. 2007. Endophyte symbiosis with tall fescue: how strong are the impacts on communities and ecosystems? Fungal Biology Reviews 21:107–124.

Rudgers, J. A., S. Fischer, and K. Clay. 2010. Managing plant symbiosis: fungal endophyte genotype alters plant community composition. Journal of Applied Ecology 47:468–477.

Rushing, B. 2014. Native warm-season grasses: establishment issues. Mississippi State University Coastal Research and Extension Center. Biloxi, Mississppi, USA.

Salminen, S. O., D. S. Richmond, S. K. Grewal, and P. S. Grewal. 2005. Influence of temperature on alkaloid levels and fall armyworm performance in endophytic tall fescue and perennial ryegrass. Entomologia Experimentalis Et Applicata 115:417–426.

Schroeder, R. L. 1985. Habitat suitability index models: Northern bobwhite. United States Fish and Wildlife Service. Bio1ogical Report 82. Fort Collins, Colorado.

Schulenberg, J. H., G. L. Horak, M. D. Schwilling, and E. J. Finck. 1994. Nesitng of Henslow's Sparrow in Osage County, Kansas. Kansas Ornithological Society Bulletin 45:25–28.

Shaw, C.E., C.A. Harper, M.W. Black, and A.E. Houston. 2010. Initial effects of prescribed burning and understory fertilization on browse production in closed-canopy hardwood stands. Journal of Fish and Wildlife Management 1:64–72.

Spears, B. L., M. C. Wallace, W. B. Ballard, R. S. Phillips, D. P. Holdstock, J. H. Brunjes, R. Applegate, M. S. Miller, and P. S. Gipson. 2007. Habitat use and survival of preflight wild turkey broods. Journal of Wildlife Management 71:69–81.

Stuedemann, J. A., and C. S. Hoveland. 1988. Tall fescue endophyte: history and impact on animal agriculture. Journal of Production Agriculture 1:39–44.

Taylor, J. D., II, and L. W. Burger, Jr. 2000. Habitat use by breeding northern bobwhites in managed old-field habitats in Mississippi. Pages 7–15 *in* L. A. Brennan, W. E. Palmer, L. W. Burger, Jr., and T. L. Pruden, editors. Proceedings of the Fourth National Quail Symposium. Tall Timbers Research Station, Tallahassee, Florida.

Taylor, J. S., K. E. Church, and D. H. Rusch. 1999. Microhabitat selection by nesting and brood-rearing northern bobwhite in Kansas. Journal of Wildlife Management 63:686–694.

Walters, D. T. and A. R. Gilmore. 1976. Allelopathic effects of tall fescue on the growth of sweetgum. Journal of Chemical Ecology 2:469–479.

Washburn, B. E., T. G. Barnes, and J. D. Sole. 1999. No-till establishment of native warm-season grasses in tall fescue fields: first-year results indicate value of new herbicide. Ecological Restoration 17:144–149.

Washburn, B. E., T. G. Barnes, and J. D. Sole. 2000. Improving northern bobwhite habitat by converting tall fescue fields to native warm-season grasses. Wildlife Society Bulletin 28:97–104.

Weber, S. 1999. Designing seed mixes for prairie restoration: revisiting the formula. Ecological Restoration 17:196- 201.

Williams, M. 1989. Americans and their forests: a historical geography. Cambridge University Press, Cambridge, United Kingdom.

Winter, M. 1999. Nesting biology of Dickcissels and Henslow's Sparrows in Missouri prairie fragments. Wilson Bulletin 111:515–527.

Wood, J. D., B. S. Cohen, L. M. Conner, B. A. Collier, and M. J. Chamberlain. 2018. Nest and brood site selection of eastern wild turkeys. Journal of Wildlife Management 83:19 2–204.

APPENDIX I: Chapter I tables and figures

Table 1.1. Descriptive details of 15 study site locations in Alabama and Tennessee, USA.

site name	county, state	physiographic province	surrounding vegetation	soils associates[a]	previous land use[b]
Bridgestone	White, TN	Cumberland Plateau	Early successional fields surrounded by closed-canopy forest	Lonewood loam and Ramsey-Lily-Rock outcrop complex	wildlife management/old-field
Cades Cove	Blount, TN	Blue Ridge Mountains	Early successional and old pasture fields surrounded by closed-canopy forest	Allegheny loam, Cades silt loam, and Lonon silty clay loam	maintained opening[c]
Catoosa	Cumberland, TN	Cumberland Plateau	Closed-canopy forest with scattered openings	Lily loam	maintained opening
Cedar Creek	Franklin, AL	East Gulf Coastal Plain	Scattered pasture and hay fields surrounded by closed-canopy forest	Colbert silt loam	hay
Cherokee Dam	Jefferson, TN	Appalachian Ridge and Valley	Pasture and hay fields with small patches of wooded land intermixed; occasional crops fields	Dunmore silt loam and Fullerton gravelly silt loam	hay
Cherokee North	Hamblen, TN	Appalachian Ridge and Valley	Pasture and hay fields with small patches of wooded land intermixed; residential areas	Fullerton gravelly silt loam	hay

Table 1.1. Continued

site name	county, state	physiographic province	surrounding vegetation	soils associates[a]	previous land use[b]
Chuck Swan	Union, TN	Appalachian Ridge and Valley	Closed-canopy and regenerating forest with scattered fields	Clarksville cherty silt loam, Claiborne silt loam, and Fullerton silt loam	maintained opening
Douglas Dam	Sevier, TN	Appalachian Ridge and Valley	Pasture/hay fields and forested land evenly mixed; residential areas	Decatur silt loam, Dewey silt loam, and Fullerton gravelly silt loam	hay
Haley Jacqueth	Williamson, TN	Outer Central Basin	Agriculture (crop, hay, and pasture fields); wooded property and stream borders with a few small wooded areas intermixed	Armour silt loam, Captina silt loam, Culleoka silt loam, Egam silt loam, and Stiversville silt loam	maintained opening
Laurel Hill	Lawrence, TN	Western Highland Rim	Agriculture (pasture, hay fields, and a few crop fields); strong presence of forested land and woodlots	Etowah silt loam and Greendale silt loam	maintained opening
Normandy	Bedford, TN	Eastern Highland Rim	Mostly forested; some pasture, hay, and some crop fields	Armour silt loam, and Huntington silt loam	hay
Oak Ridge	Roane, TN	Appalachian Ridge and Valley	Closed-canopy forest	No Data available	maintained opening
Rankin	Cocke, TN	Appalachian Ridge and Valley	Closed-canopy forest mixed with pasture, hay, and a few crop fields	Holston loam and Nonaburg channery silt loam	maintained opening

Table 1.1. Continued

site name	county, state	physiographic province	surrounding vegetation	soils associates[a]	previous land use[b]
Skyline	Jackson, AL	Cumberland Plateau	Hay and crop fields surrounded by closed-canopy forest	Colbert silty clay	maintained opening
Tellico	Monroe, TN	Appalachian Ridge and Valley	Hay fields surrounded by closed-canopy hardwoods and residential	Etowah silt loam, Holston loam, and Whitwell loam	maintained opening

[a]Source: NRCS Web Soil Survey

[b]maintained opening = fields kept in open state by ≥1 annual mowing for "wildlife openings" and/or to prevent woody encroachment

[c]maintained via mowing and prescribed fire

Table 1.2. Species and planting rate used to plant all study sites excluding Blount Co., TN. Rates are pure live seed (PLS). Seed source: Roundstone Native Seed, LLC (Upton, Kentucky, USA).

		Planting rate (PLS)
Common name	Scientific name	kg per ha
Little bluestem	*Schizachyrium scoparium*	3.36
Sideoats grama	*Bouteloua curtipendula*	1.12
Switchgrass	*Panicum virgatum*	0.56
Partridge pea	*Chamaecrista fasciculata*	0.71
Purple coneflower	*Echinacea purpurea*	0.84
Illinois bundleflower	*Desmanthus illinoensis*	0.21
Gray-headed coneflower	*Ratibida pinnata*	0.28
Black-eyed susan	*Rudbeckia hirta*	0.21

Table 1.3. Plant species and seeding rate (PLS) used to plant Blount Co., TN study site. Seed collected from within Great Smoky Mountains National Park.

		Planting rate (PLS)
Common name	Scientific name	kg per ha
Big bluestem	*Andropogon gerardii*	0.95
Little bluestem	*Schizachyrium scoparium*	0.75
Swamp sunflower	*Helianthus angustifolius*	0.09
Mountain mint	*Pycnanthemum sp*	0.25
Sneezeweed	*Helenium autumnale*	0.28
Wild bergamont	*Monarda fistulosa*	0.24
Wild quinine	*Parthenium integrifolium*	0.40
Roundhead lespedeza	*Lespedeza capitata*	0.46

Table 1.4. Plant species detected along transects across all study sites and whether they were considered desirable or undesirable and their contribution to bobwhite or deer food resources, June–August 2016–2018.

life form[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
B	*Rubus occidentalis*	black raspberry	x		x	L
B	*Rubus* spp.	blackberry[e]	x			H
B	*Smilax glauca*	cat greenbrier	x		x	H
B	*Smilax rotundifolia*	common greenbrier	x		x	H
B	*Mimosa microphylla*	littleleaf sensitive-briar	x		x	
B	*Rosa multiflora*	multiflora rose		x		
B	*Rubus flagellaris*	northern dewberry	x		x	H
B	*Smilax bonanox*	saw greenbrier	x		x	H
B	*Rubus trivialis*	southern dewberry	x		x	H
F	*Trifolium hybridum*	alsike clover	x		x	H
F	*Solanum americanum*	American black nightshade	x		x	M
F	*Erechtites hieraciifolius*	American burnweed	x			L
F	*Teucrium canadense*	American germander	x			
F	*Amphicarpaea bracteata*	American hog peanut	x		x	L
F	*Phytolacca americana*	American pokeweed	x		x	H
F	*Matelea gonocarpos*	angularfruit milkvine	x			
F	*Erigeron annuus*	annual fleabane	x			L
F	*Commelina communis*	Asiatic dayflower		x		
F	*Cardiospermum halicacabum*	balloon vine		x		
F	*Valerianella radiata*	beaked cornsalad	x			
F	*Sesbania herbacea*	bigpod sesbania	x		x	
F	*Ipomoea pandurata*		x		x	L

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
F	*Medicago lupulina*	black medic		x		
F	*Rudbeckia hirta*	black-eyed susan	x			M
F	*Conoclinium coelestinum*	blue mistflower	x			
F	*Plantago aristata*	bracted plantain[e]	x		x	
F	*Verbena brasiliensis*	Brazilian vervain		x		
F	*Rumex obtusifolius*	broadleaf dock		x		
F	*Cirsium vulgare*	bullthistle		x		
F	*Aster dumosus*	bushy aster	x			M
F	*Ranunculus* spp.	buttercup		x		
F	*Asclepias tuberosa*	butterfly milkweed	x			
F	*Clitoria mariana*	butterfly pea	x		x	L
F	*Solidago canadensis*	Canada goldenrod	x			M
F	*Elephantopus carolinianus*	Carolina elephantsfoot	x			
F	*Pyrrhopappus carolinianus*	Carolina false dandelion	x			
F	*Geranium carolinianum*	Carolina geranium	x		x	H
F	*Solanum carolinense*	Carolina horsenettle[e]	x		x	
F	*Silene antirrhina*	catchfly	x			
F	*Stellaria* spp.	chickweed spp.		x		
F	*Physalis heterophylla*	clammy groundcherry	x		x	
F	*Pilea pumila*	clearweed	x			L
F	*Galium aparine*	cleavers	x			M
F	*Xanthium strumarium*	cocklebur	x			L
F	*Potentilla simplex*	common cinquefoil	x			L
F	*Taraxacum officinale*	common dandelion[f]	x			L
F	*Oenothera biennis*	common evening primrose	x		x	L
F	*Kummerowia striata*	common lespedeza		x		

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
F	*Asclepias syriaca*	common milkweed	x		x	
F	*Verbascum thapsus*	common mullein		x		
F	*Ambrosia artemisiifolia*	common ragweed	x		x	
F	*Prunella vulgaris*	common selfheal	x		x	M
F	*Rumex acetosella*	common sheep sorrel		x		
F	*Sonchus oleraceus*	common sowthistle[f]	x			M
F	*Hypericum perforatum*	common st. johnswort		x		
F	*Vicia sativa*	common vetch		x		
F	*Achillea millefolium*	common yarrow[f]	x			
F	*Rorippa sylvestris*	creeping yellow cress		x		
F	*Rumex crispus*	curly dock		x		
F	*Oenothera laciniata*	cutleaf eveningprimrose	x		x	L
F	*Erigeron strigosus*	daisy fleabane	x			L
F	*Dianthus armeria*	deptford pink		x		
F	*Cuscuta* spp.	dodder	x			
F	*Eupatorium capillfolium*	dogfennel	x			
F	*Lobelia puberula*	downy lobelia	x			M
F	*Lathyrus latifolius*	everlasting pea[f]	x		x	L
F	*Boehmeria cylindrica*	false nettle	x			M
F	*Torilis arvensis*	field hedge parsley		x		
F	*Sherardia arvensis*	field madder[f]	x			
F	*Cirsium discolor*	field thistle	x			
F	*Euphorbia corollata*	flowering spurge	x			
F	*Solidago gigantea*	giant goldenrod	x			M
F	*Ambrosia trifida*	giant ragweed	x		x	M
F	*Solidago nemoralis*	gray goldenrod	x			L

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
F	*Ratibida pinnata*	gray-headed coneflower	x			L
F	*Cardamine hirsuta*	hairy bittercress[f]	x			
F	*Desmodium ciliare*	hairy small leaf ticktrefoil	x		x	M
F	*Agrimonia parviflora*	harvestlice	x			M
F	*Calystegium sepium*	hedge bindweed		x		
F	*Pycnantheum incanum*	hoary mountainmint	x		x	
F	*Acalypha ostryifolia*	hophornbeam copperleaf	x		x	
F	*Eupatorium hyssopifolium*	hyssopleaf thoroughwort	x			
F	*Desmanthus illinoensis*	Illinois bundleflower	x		x	M
F	*Apocynum cannabinum*	Indianhemp	x			
F	*Lobelia inflata*	Indian-tobacco	x			M
F	*Ipomoea hederacea*	ivyleaf morning-glory		x		
F	*Coreopsis lanceolata*	lanceleaf coreopsis	x			L
F	*Eupatorium serotinum*	lateflowering boneset	x			
F	*Salvia lyrata*	lyreleaf sage	x			
F	*Conyza canadensis*	marestail	x			L
F	*Iva annua*	marsh elder	x			
F	*Chrysopsis mariana*	Maryland goldenaster	x			
F	*Rhexia mariana*	Maryland meadowbeauty	x			L
F	*Anthemis cotula*	mayweed chamomile[f]	x			
F	*Mosla dianthera*	miniature beefsteakplant		x		
F	*Duchesnea indica*	mock strawberry		x		
F	*Cerastium fontanum*	mouse-ear chickweed[f]	x			L
F	*Carduus nutans*	musk thistle		x		
F	*Pycnanthemum tenuifolium*	narrowleaf mountain mint	x			
F	*Plantago lanceolata*	narrowleaf plantain		x		

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
F	*Verbena simplex*	narrowleaf vervain	x			
F	*Chamaesyce nutans*	nodding spurge	x			
F	*Symphyotrichum pilosum*	oldfield aster	x			H
F	*Leucanthemum vulgare*	oxeye daisy		x		
F	*Amaranthus palmeri*	Palmer pigweed	x		x	L
F	*Desmodium paniculatum*	panicledleaf ticktrefoil	x		x	M
F	*Chamaecrista fasciculata*	partridge pea	x		x	M
F	*Polygonum pennsylvanicum*	Pennsylvania smartweed	x		x	
F	*Perilla frutescens*	perilla mint		x		
F	*Veronica persica*	Persian speedwell		x		
F	*Coreopsis tinctoria*	plains coreopsis	x			
F	*Diodia teres*	poorjoe	x			L
F	*Croton monanthogynus*	prairie tea	x		x	L
F	*Lactuca serriola*	prickly lettuce[f]	x			M
F	*Sida spinosa*	prickly sida	x		x	M
F	*Chamaesyce maculata*	prostrate spurge	x			
F	*Echinacea purpurea*	purple coneflower	x			L
F	*Gamochaeta purpurea*	purple cudweed	x			L
F	*Passiflora incarnata*	purple passionflower	x		x	
F	*Daucus carota*	Queen Anne's lace		x		
F	*Pseudognaphalium obtusifolium*	rabbit-tobacco	x			L
F	*Trifolium pratense*	red clover[f]	x		x	H
F	*Lespedeza capitata*	roundhead lespedeza	x		x	L
F	*Eupatorium rotundifolium*	roundleaf thoroughwort	x			
F	*Chamaecrista nictitans*	sensitive partridgepea	x		x	M

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
F	*Potentilla norvegica*	rough cinquefoil	x			
F	*Lespedeza cuneata*	sericea lespedeza		x		
F	*Solidago speciosa*	showy goldenrod	x			
F	*Senna obtusifolia*	sicklepod	x		x	
F	*Agalinis tenuifolia*	slender gerardia	x			M
F	*Lespedeza virginica*	slender lespedeza	x		x	L
F	*Packera anonyma*	Small's ragwort	x			
F	*Desmodium marilandicum*	smooth small-leaf ticktrefoil	x		x	M
F	*Desmodium laevigatum*	smooth ticktrefoil	x		x	M
F	*Helenium autumnale*	sneezeweed	x			
F	*Bidens bipinnata*	Spanish needles	x		x	H
F	*Hypericum punctatum*	spotted St. Johnswort	x			
F	*Desmodium obtusum*	stiff ticktrefoil	x		x	M
F	*Potentilla recta*	sulphur cinquefoil		x		
F	*Cynanchum laeve*	swallowort honeyvine	x			
F	*Helianthus angustifolius*	swamp sunflower	x		x	M
F	*Melilotus officinalis*	sweet clover		x		
F	*Vernonia altissima*	tall ironweed	x			
F	*Acalypha* spp.	threeseed mercury	x		x	M
F	*Lespedeza procumbens*	trailing lespedeza	x		x	L
F	*Abutilon theophrasti*	velvetleaf[f]	x			
F	*Triodanis perfoliata*	Venus' looking-glass	x			L
F	*Viola* spp.	violet	x		x	L
F	*Lespedeza intermedia*	violet lespedeza	x		x	L
F	*Clematis virginiana*	virgin bowers	x			

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
F	*Diodia virginiana*	Virginia buttonweed	x			L
F	*Geum canadense*	white avens	x			
F	*Trifolium repens*	white clover[f]	x			H
F	*Verbesina virginica*	white crownbeard	x		x	
F	*Verbena urticifolia*	white vervain	x			
F	*Polymnia canadensis*	whiteflower leafcup	x			
F	*Coreopsis major*	whorled coreopsis	x			L
F	*Polygala verticillata*	whorled milkwort	x			
F	*Clinopodium vulgare*	wild basil	x		x	L
F	*Strophostyles helvola*	wild bean	x		x	M
F	*Monarda fistulosa*	wild bergamot	x		x	
F	*Lactuca canadensis*	wild lettuce	x			H
F	*Ruellia* spp.	wild petunia	x		x	L
F	*Parthenium integrifolium*	wild quinine	x			
F	*Symphyotrichum praealtum*	willowleaf aster	x			L
F	*Veresina alternifolia*	wingstem	x		x	
F	*Sedum ternatum*	woodland stonecrop	x			
F	*Croton capitatus*	wooly croton	x		x	L
F	*Solidago rugosa*	wrinkleleaf goldenrod	x			L
F	*Trifolium campestre*	yellow hop clover[f]	x			L
F	*Barbarea vulgaris*	yellow rocket		x		
F	*Oxalis stricta*	yellow woodsorrel	x		x	L
F	*Eclipta prostrata*	yerba de tajo	x			L
FR	*Pteridium aquilinum*	bracken fern	x			
FR	*Botrychium biternatum*	grape fern	x			
G	*Poa annua*	annual blue grass		x		

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
G	*Setaria* spp.	annual foxtail		x	x	
G	*Paspalum notatum*	bahiagrass		x		
G	*Echinochloa crus-galli*	barnyardgrass		x	x	
G	*Panicum anceps*	beaked panicgrass	x		x	
G	*Agrostis* spp.	bentgrass		x		
G	*Cynodon dactylon*	bermudagrass		x		
G	*Andropogon gerardii*	big bluestem[e]	x			
G	*Sisyrinchium* spp.	blue-eyed grass	x			
G	*Poa* spp.	bluegrass sp.		x		
G	*Eleocharis obtusa*	blunt spikerush	x			
G	*Urochloa platyphylla*	broadleaf signalgrass	x			
G	*Bromus* spp.	*Bromus sp.*		x		
G	*Andropogon virginicus*	broomsedge[e]	x			
G	*Bromus tectorum*	cheatgrass		x		
G	*Holcus lanatus*	common velvetgrass		x		
G	*Digitaria* spp.	crabgrass		x		
G	*Paspalum dilatatum*	dallisgrass[f]	x			
G	*Dichanthelium clandestinum*	deertounge	x		x	
G	*Dicanthelium* spp.	*Dicanthelium* spp.	x			
G	*Panicum dichotomiflorum*	fall panicum	x		x	
G	*Festuca* spp.	fine fescue		x		
G	*Carex frankii*	Frank's sedge	x		x	
G	*Setaria faberi*	giant foxtail		x		
G	*Saccharum giganteum*	giant plumegrass	x			
G	*Carex perglobosa*	globe sedge	x			

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
G	*Eleusine indica*	goosegrass		x		
G	*Microstegium vimineum*	Japangrass		x		
G	*Sorghum halepense*	johnsongrass		x		
G	*Setaria parviflora*	knotroot foxtail[e]	x		x	
G	*Schizachyrium scoparium*	little bluestem	x			
G	*Dichanthelium* spp.	low panicgrass	x		x	
G	*Piptochaetium avenaceum*	needlegrass	x			
G	*Muhlenbergia schreberi*	nimblewill[e]	x			
G	*Allium vineale*	onion	x			
G	*Dactylis glomerata*	orchardgrass		x		
G	*Lolium perenne*	perennial ryegrass		x		
G	*Danthonia spicata*	poverty oatgrass	x			
G	*Juncus tenuis*	poverty rush	x			
G	*Tridens flavus*	purpletop	x			
G	*Leptochloa panicea*	red sprangletop	x			
G	*Leersia oryzoides*	rice cutgrass	x		x	
G	*Bouteloua curtipendula*	sideoats grama	x			
G	*Arthraxon hispidus*	small carpetgrass		x		
G	*Andropogon ternarius*	splitbeard bluestem	x			
G	*Eragrostis cilianensis*	stinkgrass		x		
G	*Anthoxanthum odoratum*	sweet vernalgrass[f]	x			
G	*Panicum virgatum*	switchgrass	x		x	
G	*Schedonorus arundinacea*	tall fescue		x		
G	*Paspalum setaceum*	thin paspalum	x		x	
G	*Phleum pratense*	timothy		x		
G	*Paspalum urvillei*	Vasey's grass[f]	x			

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
G	*Elymus virginicus*	Virginia wild rye	x			
G	*Eragrostis curvula*	weeping lovegrass		x		
G	*Allium canadense*	wild garlic		x		
G	*Panicum capillare*	witchgrass	x			
G	*Sorghastrum nutans*	yellow indiangrass	x			
G	*Cyperus esculentus*	yellow nutsedge		x		
G	*Iris pseudacorus*	yellowflag grass		x		
G	*Yucca* spp.	yucca	x		x	
S	*Callicarpa americana*	American beautyberry	x		x	M
S	*Prunus americana*	American plum	x		x	L
S	*Lespedeza bicolor*	bicolor lespedeza		x		
S	*Cephalanthus occidentalis*	common buttonbush	x			L
S	*Symphoricarpos orbiculatus*	corralberry	x		x	
S	*Sambucus nigra*	elderberry	x		x	L
S	*Ligustrum* spp.	privet		x		
S	*Rhus copallinum*	winged sumac	x		x	L
T	*Ulmus americana*	American elm	x			H
T	*Platanus occidentalis*	American sycamore	x			
T	*Prunus serotina*	black cherry	x			L
T	*Robinia pseudoacacia*	black locust[e]	x			L
T	*Quercus velutina*	black oak	x			
T	*Juglans nigra*	black walnut	x			
T	*Nyssa slyvatica*	blackgum	x			H
T	*Acer negundo*	box elder	x			L
T	*Pyrus calleryana*	callery pear		x		

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[f]
T	*Celtis occidentalis*	common hackberry	x			H
T	*Diospyros virginiana*	common persimmon	x			M
T	*Carya* spp.	hickory	x			
T	*Juniperus virginiana*	eastern red cedar	x			
T	*Cornus florida*	flowering dogwood	x			M
T	*Fraxinus pennsylvanica*	green ash	x			L
T	*Gleditsia triacanthos*	honey locust	x			M
T	*Pinus taeda*	loblolly pine	x			L
T	*Carya illinoinensis*	pecan	x			
T	*Acer rubrum*	red maple	x			M
T	*Sassafras albidum*	sassafras	x			
T	*Quercus acutissima*	sawtooth oak		x		
T	*Ulmus rubra*	slippery elm	x			H
T	*Liquidambar styraciflua*	sweetgum	x			
T	*Ailanthus altissima*	tree-of-heaven		x		
T	*Ulmus alata*	winged elm	x			M
T	*Liriodendron tulipifera*	yellow poplar	x			
V	*Brunnichia ovata*	American buckwheat vine	x			
V	*Cocculus carolinus*	Carolina moonseed	x			
V	*Bignonia capreolata*	crossvine	x			M
V	*Ampelopsis cordata*	heartleaf peppervine	x			
V	*Lonicera japonica*	Japanese honeysuckle		x		
V	*Toxicodendron radicans*	poison ivy	x			L
V	*Vitis aestivalis*	summer grape	x			M
V	*Campsis radicans*	trumpet creeper	x			M

Table 1.4. Continued

group[a]	scientific name	common name	desirable[b]	undesirable[c]	bobwhite food[d]	deer forage[d]
V	*Parthenocissus quinquefolia*	Virginia creeper	x			L

[a]B = bramble, F = forb, FR = fern, G = graminoid, S = shrub, T = tree, V = woody vine

[b]species that were designated as desirable with no indication of bobwhite food or deer forage contributed to cover and structure for various wildlife species and/or were native

[c]species identified by the Southeast Exotic Pest Plant Council as nonnative invasive or invasive status unknown; otherwise nonnative and widely distributed throughout any single site and showed ability to maintain or increase coverage after ≥3 growing seasons

[d] selected deer forages (L = low selected, M = moderately selected, H = highly selected, blank = not selected)

[e]native species that persisted at or increase beyond 30% coverage and were treated with herbicides to reduce coverage

[f]nonnative species but did not increase coverage beyond 30% in the plant community after ≥3 growing seasons

Table 1.5. Herbicides and adjuvants used for control of undesirable plant species in NR and PL treatment units, June–August 2016–2018.

Herbicides			
Active ingredient	Trade name	Manufacturer	Selectivity
imazapic	Plateau®	BASF	broad-spectrum selective
glyphosate	Accord® XRT II	Dow AgroSciences	broad-spectrum
imazapyr	Arsenal® AC Arsenal® PowerLine™	BASF	broad-spectrum selective
clethodim	Clethodim 2E	Agri Star®	grass-selective
triclopyr	Garlon® 3A Remedy Ultra	Dow AgroSciences	forb-selective woody
triclopyr + fluroxypyr	Pasturegard ®	Dow AgroSciences	forb-selective woody
Adjuvants			
Alkylarypolyoxyethlene glycols, free fatty acids and IPA	90/10 Surfactant	ProSolutions LLC	
Parafifin oil, surface active compounds and coupling agents	Basal Oil	Alligare	
Phytobland paraffinic oil	Prime Oil®	Agrisolutions™	
Methylated seed oil	MSO	Alligare	

Table 1.6. Percent coverage of plant groups detected (mean ± SE) in 3 early successional plant community treatments across all study sites (n = 15), June–August 2018.

	treatment[a]							
life form[b]	CNTL		NR		PL		$F_{2,28}$	P
B[c]	9 ± 2	A	10 ± 2	A	12 ± 2	A	2.35	0.114
F	48 ± 3	B	72 ± 2	A	64 ± 3	A	7.53	0.002
G	92 ± 2	A	63 ± 3	B	76 ± 3	B	10.96	≤ 0.001
NWSG	33 ± 4	C	49 ± 4	B	61 ± 3	A	15.11	≤ 0.001
W	9 ± 2	A	7 ± 1	A	7 ± 1	A	0.57	0.575

[a]CNTL = control, NR = natural revegetation, PL = planted

[b]B = bramble, F = forb, G = grass, NWSG = native warm-season grass, W = woody (shrubs, trees, and woody vines)

[c]row means with the same letter were not different (α = 0.05)

Table 1.7. Vegetation profile board estimates (mean ± SE) by treatment for individual strata at all study sites (n = 15), June–August 2018.

treatment[a]	S1[bc]		S2		S3		S4		S5	
CNTL	100 ±	A	88 ±	B	60 ±	B	35 ±	B	20 ±	B
NR	99 ±	A	95 ±	A	77 ±	A	54 ±	A	34 ±	AB
PL	100 ±	A	99 ±	A	82 ±	A	53 ±	A	37 ±	A
$F_{2,28}$	1.70		11.17		6.82		4.52		4.45	
P	0.201		0.004		0.004		0.020		0.021	

[a]CNTL = control, NR = natural revegetation, PL = planted

[b]S1 (stratum 1) = 0–25 cm, S2 = 26–50 cm, S3 = 51–100 cm, S4 = 101–150 cm, and S5 = 151–200 cm aboveground

[c]column means with the same letter are not different (α = 0.05)

Table 1.8. Factor loading results of multivariate factor analyses for nest-site data from 6 bird species, Fort Campbell Army Installation, Hopkinsville, Kentucky, USA, 2001–2003.

	dickcissel		eastern meadowlark		field sparrow		grasshopper sparrow		Henslow's sparrow		northern bobwhite	
variable	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 3	Factor 1	Factor 2	Factor 1	Factor 2
% litter cover	0.329	0.527		0.989		0.65	0.972		0.267			
% bareground cover	0.275	0.799	-0.16	0.167	0.178	0.649		-0.105	0.471	-0.169		
% woody cover	0.143	-0.686		-0.113			-0.118					
% dead woody cover						0.38	-0.201	0.152		0.11		
% CS grass cover			0.716	-0.179		-0.107		-0.709	0.863	-0.436	0.642	-0.215
% WSG cover	0.829	0.325	-0.984		0.878				-0.807	-0.174	-0.170	0.974
% forb cover	-0.918				-0.863	-0.196	-0.324	0.895	-0.117	0.986		
% vertical cover		-0.636	0.223	-0.389		-0.278	-0.453	0.161	-0.181		-0.496	0.114
herbaceous height (cm)		-0.321	0.164	0.209		0.263	0.155	-0.113				
grass height (cm)	0.552		0.102	-0.102	0.413	0.369				-0.179		
litter depth (cm)	0.473	0.198		0.591	0.173	0.539	0.56	-0.137	-0.223	-0.168	0.839	
SS loadings	2.272	2.053	1.614	1.612	1.776	1.623	1.653	1.403	1.792	1.306	1.411	1.022
proportional variance	0.207	0.187	0.147	0.147	0.161	0.148	0.15	0.128	0.163	0.119	0.176	0.128
cumulative variance	0.207	0.393	0.147	0.293	0.161	0.309	0.15	0.425	0.163	0.282	0.176	0.304

Table 1.9. Plant species determined to be moderate- to highly-selected deer forages by selectivity index (Chesson 1983) across all study sites (n=15), June–August 2017–2018.

common name	scientific name	life form[a]	IV[b]	CP%[c]
common hackberry	*Celtis occidentalis*	T	0.034	11.9
stiff ticktrefoil	*Desmodium obtusum*	F	0.025	19.7
common selfheal	*Prunella vulgaris*	F	0.025	12.1
hairy white oldfield aster	*Symphyotrichum pilosum*	F	0.022	14.7
American pokeweed	*Phytolacca americana*	F	0.014	28.0
trumpet creeper	*Campsis radicans*	V	0.013	12.6
panicledleaf ticktrefoil	*Desmodium paniculatum*	F	0.011	17.0
ticktrefoil	*Desmodium* spp.	F	0.011	18.4
aster	*Symphyotrichum* spp.	F	0.009	14.7
northern dewberry	*Rubus flagellaris*	B	0.008	10.6
red clover	*Trifolium pretense*	F	0.008	21.6
common persimmon	*Diospyros virginiana*	T	0.008	16.2
white clover	*Trifolium repens*	F	0.006	22.1
blackberry	*Rubus* spp.	B	0.006	13.2

[a]B = bramble, F = forb, T = tree, V = vine

[b]index value (IV) cut-off – 0.005

[c]reported crude protein (CP) values from only selected (i.e., young) portions of plants averaged across site and year

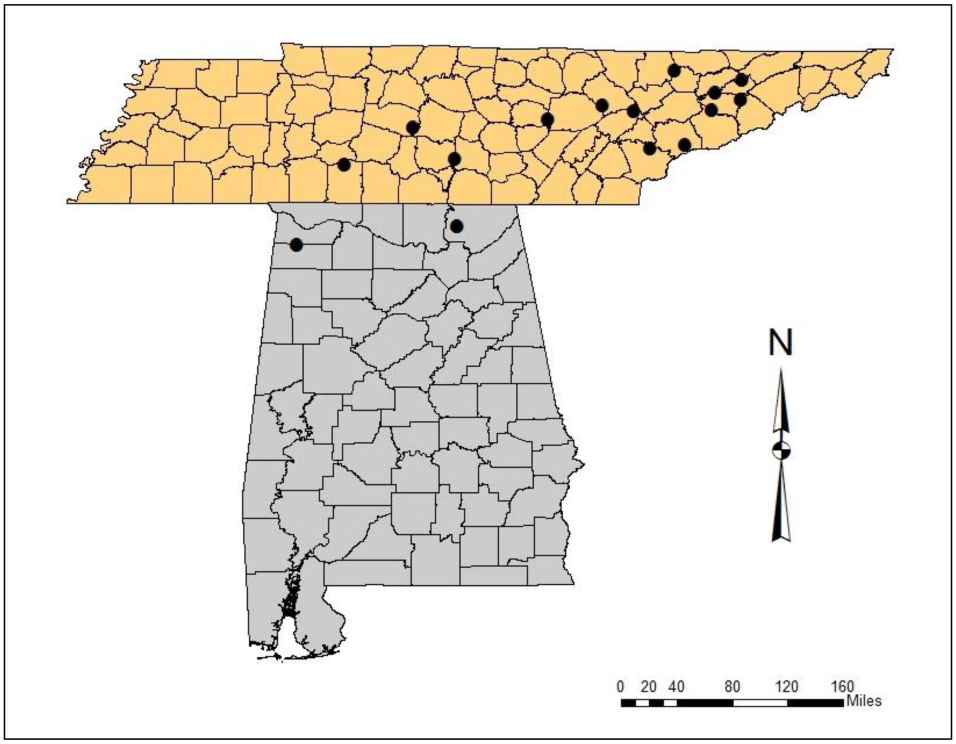

Figure 1.1. Map of 15 study site locations in Tennessee and Alabama, USA (2016-2018).

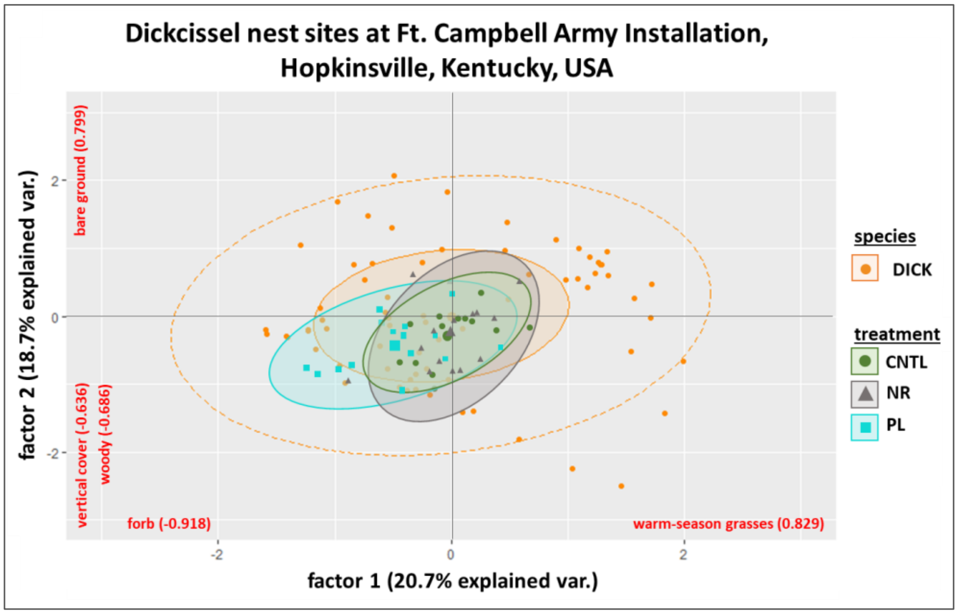

Figure 1.2. Multivariate biplot of vegetation variables important at dickcissel nest-sites at Ft. Campbell Army Installation, Kentucky, USA, as determined by factor analysis (FA). The orange-filled 50% confidence ellipse indicates core factor values and the orange dashed line indicates the 95% confidence ellipse for dickcissel nests. Plot axes are explained by the factors and their loading values as indicated in red text. Control (CNTL), natural revegetation (NR), and planted (PL) treatment ellipses are plotted at 95% confidence. All treatment ellipses were completely contained within the 95% dickcissel nest-site ellipse and 94%, 80%, and 70% of the CNTL, NR, and PL treatment ellipses, respectively, were contained within the nest-site core ellipse.

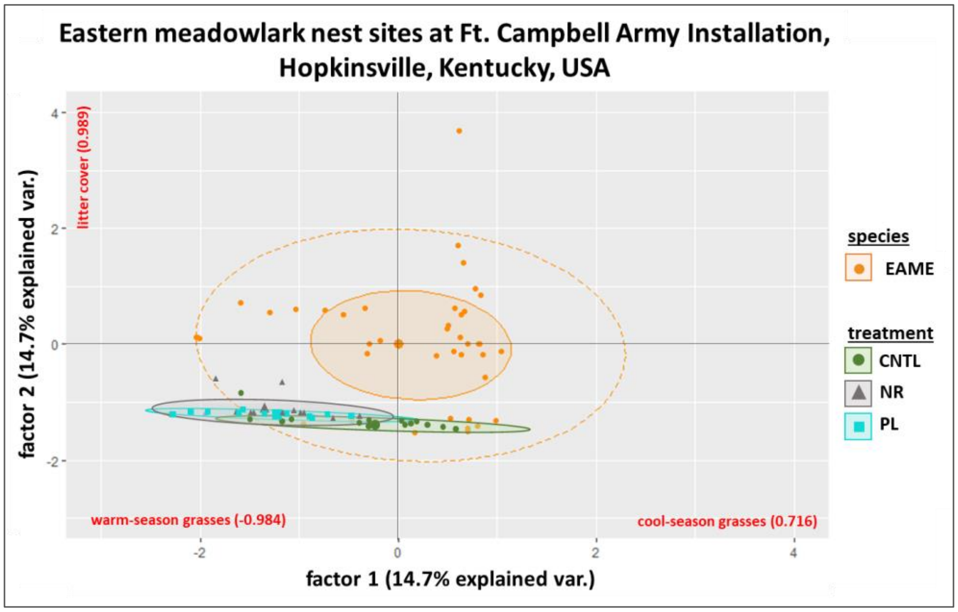

Figure 1.3. Multivariate biplot of vegetation variables important at eastern meadowlark nest-sites at Ft. Campbell Army Installation, Kentucky, USA, as determined by factor analysis (FA). The orange-filled 50% confidence ellipse indicates core factor values and the orange dashed line indicates the 95% confidence ellipse for eastern meadowlark nests. Plot axes are explained by the factors and their loading values as indicated in red text. Control (CNTL), natural revegetation (NR), and planted (PL) treatment ellipses are plotted at 95% confidence. The core nest-site ellipse did not overlap with any treatment. Control, NR, and PL treatment units were 98%, 64%, and 60%, respectively, contained within the 95% nest-site confidence ellipse.

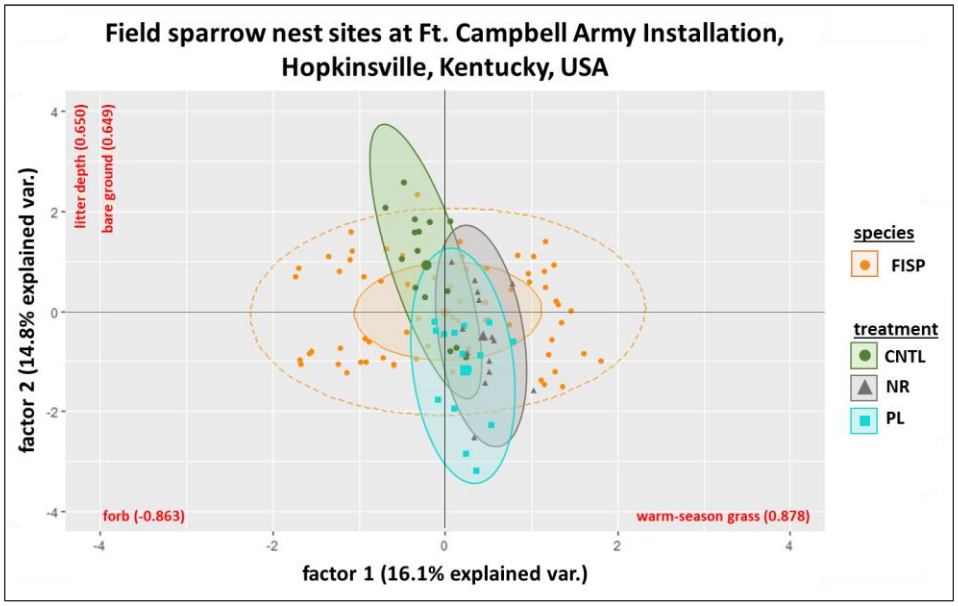

Figure 1.4. Multivariate biplot of vegetation variables important at field sparrow nest-sites at Ft. Campbell Army Installation, Kentucky, USA, as determined by factor analysis (FA). The orange-filled 50% confidence ellipse indicates core factor values and the orange dashed line indicates the 95% confidence ellipse for field sparrow nests. Plot axes are explained by the factors and their loading values as indicated in red text. Control (CNTL), natural revegetation (NR), and planted (PL) treatment ellipses are plotted at 95% confidence. A large proportion of NR (90%), PL (75%), and CNTL (74%) treatment ellipses were contained within the 95% nest-site ellipse, and 48%, 43%, and 40% of NR, PL, and CNTL, respectively, were contained within the core-nest site ellipse.

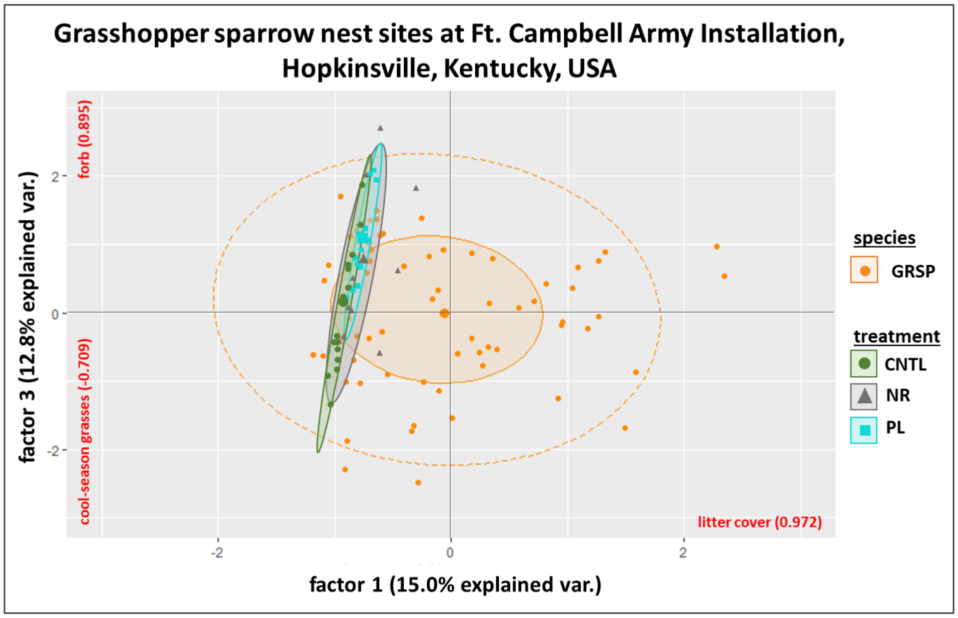

Figure 1.5. Multivariate biplot of vegetation variables important at grasshopper sparrow nest-sites at Ft. Campbell Army Installation, Kentucky, USA, as determined by factor analysis (FA). The orange-filled 50% confidence ellipse indicates core factor values and the orange dashed line indicates the 95% confidence ellipse for grasshopper sparrow nests. Plot axes are explained by the factors and their loading values as indicated in red text. Control (CNTL), natural revegetation (NR), and planted (PL) treatment ellipses are plotted at 95% confidence. Natural revegetation (98%), CNTL (95%), and PL (94%) treatment units were almost entirely inside the 95% nest-site confidence ellipse, and 39%, 38%, and 28% of PL, NR, and CNTL treatment units were contained within the 50% nest-site confidence ellipse, respectively.

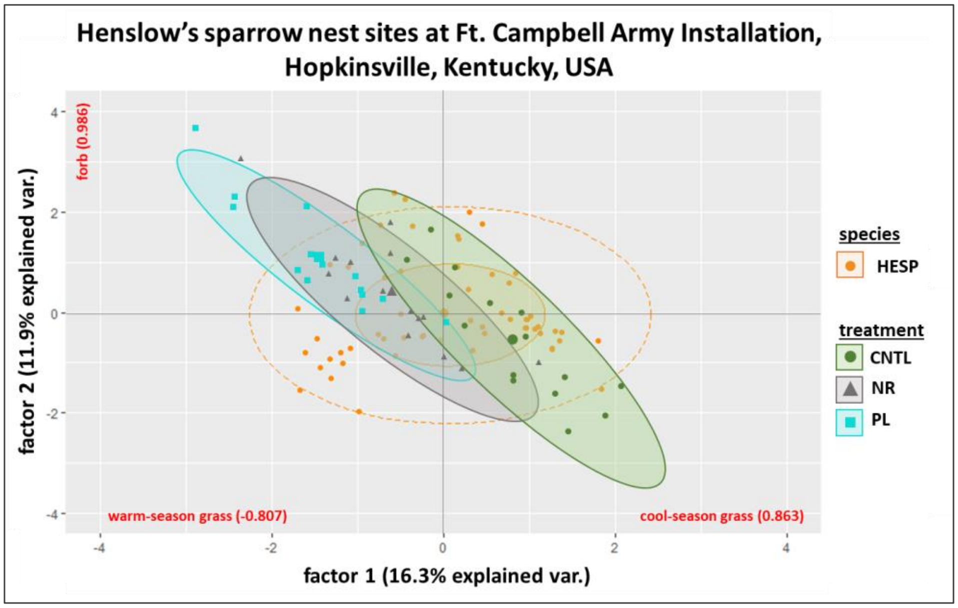

Figure 1.6. Multivariate biplot of vegetation variables important at Henslow's sparrow nest-sites at Ft. Campbell Army Installation, Kentucky, USA, as determined by factor analysis (FA). The orange-filled 50% confidence ellipse indicates core factor values and the orange dashed line indicates the 95% confidence ellipse for Henslow's sparrow nests. Plot axes are explained by the factors and their loading values as indicated in red text. Control (CNTL), natural revegetation (NR), and planted (PL) treatment ellipses are plotted at 95% confidence. Natural revegetation (82%) was most contained within the 95% nest-site confidence ellipse compared to CNLT (72%) and PL (63%). Natural revegetation, CNTL, and PL treatment units were 35%, 30%, and 29% contained within the core nest-site ellipse.

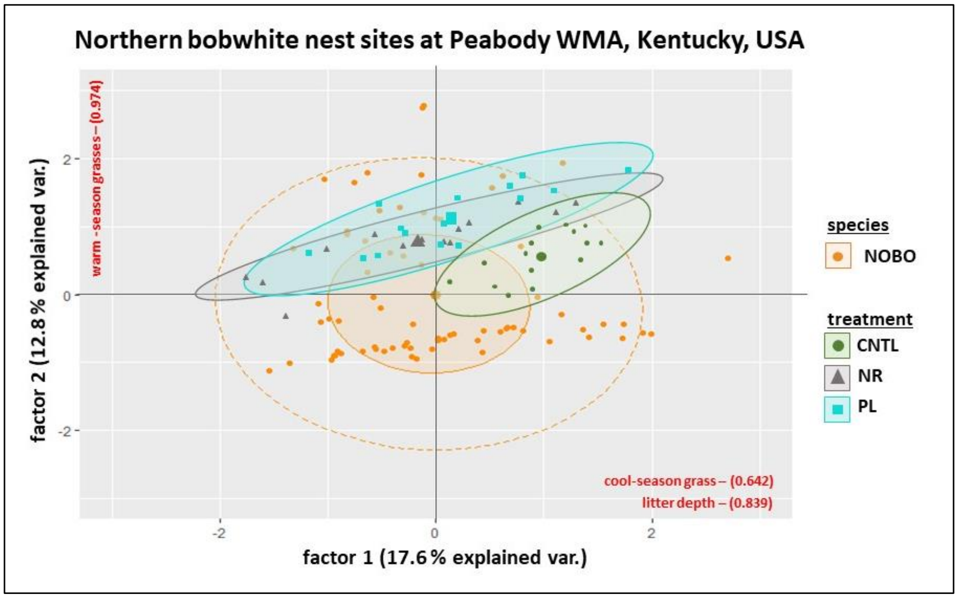

Figure 1.7. Multivariate biplot of vegetation variables important at northern bobwhite nest-sites at Ft. Campbell Army Installation, Kentucky, USA, as determined by factor analysis (FA). The orange-filled 50% confidence ellipse indicates core factor values and the orange dashed line indicates the 95% confidence ellipse for northern bobwhite nests. Plot axes are explained by the factors and their loading values as indicated in red text. Control (CNTL), natural revegetation (NR), and planted (PL) treatment ellipses are plotted at 95% confidence. Similar amounts of NR (86%), CNTL (85%), and PL (79%) treatment units were contained within the 95% nest-site confidence ellipse, and 31%, 20%, and 16% of CNTL, NR, and PL were contained with the core nest-site ellipse, respectively.

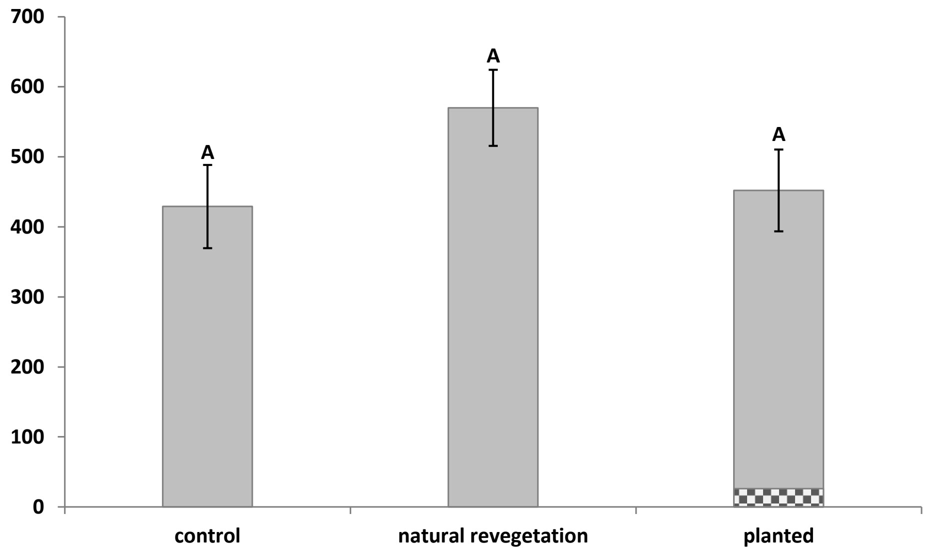

Figure 1.8. Selected deer forage (kg/ha) by treatment (n = 15), June–August 2018. Solid-colored bars indicate deer forage contributed by the seedbank, and the checkerboard pattern indicates forage available from the 5 planted forb species. Means with the same letter are not different.

CHAPTER II. RESTORING EARLY SUCCESSIONAL PLANT COMMUNITIES: IS PLANTING NECESSARY?

ABSTRACT Restoration of native early successional plant communities has been identified as a conservation priority because plants and wildlife associated with these communities have been declining for decades in the eastern United States. Restoration typically involves planting native grasses and forbs, which can be fraught with establishment problems including weedy competition, expensive seed, slow establishment, and dominance of planted native warm-season grasses. Using the seed bank response paired with strategic herbicide applications may be an alternative approach for restoring native early successional plant communities. We selected 18 study sites in Tennessee, Alabama, and Kentucky, USA, to compare early successional plant communities restored on fallow crop and tall fescue-dominated sites via planting (PL) and natural revegetation (NR) from the seed bank. We did not detect any differences between NR and PL treatments in species diversity, species richness, coverage of non-native grasses and forbs, or number and coverage of native flowering forb species important for pollinators at tall fescue or fallow crop sites. Species evenness, coverage of native warm-season grasses, and coverage of sericea lespedeza (*Lespedeza cuneata*) differed between PL and NR treatments at tall fescue sites but not at fallow crop sites. Controls were different from both NR and PL treatments in all variables except species evenness, coverage of native forbs, coverage and number of native summer flowering forbs, and coverage of native fall flowering forbs at tall fescue sites. Planted grasses dominated and reduced the evenness of the plant community in PL treatment units. More flexibility to use herbicides in NR resulted in reduced coverage of sericea lespedeza in NR units at tall fescue sites. Natural revegetation was 4.4-times less expensive than planting. Land managers should consider using the seed bank combined with strategically applied herbicides to establish native-dominated early successional plant communities instead of planting.

KEY WORDS early successional communities, restoration, native grass planting, seed bank, pollinator, tall fescue, species diversity, non-native species control.

The eastern United States has a long history of changing land uses, which continue today and impact the plant communities that occur across the landscape (Hart 1968; Lorimer 2001; Steyaert & Knox 2008). Native early successional plant communities in this region have been undergoing declines in both quantity and quality for decades (Noss et al. 1995). From 1982–2015, approximately 17.4 million hectares in the United States was developed and 5.7 million hectares of early successional communities were lost (USDA 2018). Many wildlife species are associated with these early successional plant communities and some have undergone concomitant declines (Brennan 1991; Knopf 1994; Brennan & Kuvlesky 2005; USDA 2009). Most recently, potential global declines in pollinator populations, keystone species in most ecosystems, have triggered large-scale interest in establishing early successional plant communities because they provide habitat for pollinators (NRC 2007). It has been suggested that habitat loss is closely associated with pollinator declines at the global scale and that even small fragments of pollinator habitat may be beneficial to many pollinator species (Tscharntke et al. 2002; Winfree et al. 2009)

Most open areas that remain throughout the eastern United States were once used for pasture, hay, or row-crop production. Because of management histories, these fields are typically dominated by non-native grasses and forbs, most of which were planted for livestock or erosion control, and often through government-sponsored programs (Carmichael 1997; Houck 2009). The non-native species often outcompete native plants and can arrest succession once fields are abandoned. Tall fescue (*Schedonorus arundinaceus*) is the most commonly planted non-native grass in the eastern United States and was widely planted as part of the Conservation Reserve Program (CRP) (Buckner et al. 1979; Carmichael 1997; Rogers & Locke 2013). Other non-native plant species common throughout the southeastern United States that can reduce the quality of native plant communities in abandoned fields include bermudagrass (*Cynodon dactylon*), johnsongrass (*Sorghum halepense*), bahiagrass (*Paspalum notatum*), and sericea lespedeza (*Lespedeza cuneata*).

Restoring native early successional plant communities has become a conservation priority throughout the United States (Washburn et al. 2000; Askin 2001; Brennan & Kuvlesky 2005; Smith 2007). Restoration efforts typically consist of eradicating non-native grasses and forbs in abandoned hay or pasture fields, followed by planting a native seed mixture (Barnes 2004; Burger 2005; Mittelhauser et al. 2011; Wortley et al. 2013). Fallow crop fields can have altered soil nutrients and seed bank composition because of management history, and planting is commonly thought necessary to restore native plant communities on these sites (Menalled et al. 2001; Koger et al. 2004; McLauchlan 2006). Additionally, programs such as the Natural Resources Conservation Service's (NRCS) CRP and the Environmental Quality Incentives Program (EQIP) prioritize funding to contracts that include planting, ultimately making planting a contract requirement. Even though planting can be successful and is widely used, several issues often arise when planting native seed.

Weedy competition is considered the number one reason for planting failure (Barnes 2004; Rowe 2010). Sericea lespedeza and bermudagrass are two common non-native species that often invade plantings in the southeastern United States for which there are no control options that will not also harm planted species. Additionally, fields are often inadequately prepared before planting (Rushing 2014). Establishment commonly takes two to three growing seasons and can initially appear to landowners as a planting failure (Harper et al. 2007; Rushing 2014). Lastly, native seed, especially forbs, are expensive, and seed mixes can cost hundreds to thousands of dollars per hectare. Certain seed mixes (e.g., pollinator mixes) rely heavily on forb species. CRP, EQIP, and state-sponsored programs are funded with tax dollars and revenue from hunting and fishing license sales.

Planting to establish native early successional plant communities may not be necessary (Middleton 2003; Harper & Gruchy 2009). Natural revegetation from the seed bank may be a viable option to achieve a desirable plant community (Prach et al. 2018). Because no seed would be needed to implement natural revegetation, land managers would have more options to control invasive species without fear of harming planted species. Selective herbicides and applications targeting certain plants could be used to encourage a specific plant community composition to meet management objectives. Using natural revegetation would eliminate the need to purchase seed and could potentially save money that could then be allocated to conserving and restoring larger areas of early successional plant communities.

We conducted a field experiment across a broad array of sites to compare early successional plant communities established by natural revegetation and planting following tall fescue eradication and crop field abandonment. We analyzed fallow crop field and tall fescue field data separately because of different management histories and because fallow crop fields did not have a tall fescue control. We hypothesized that using natural revegetation from the seed bank, paired with strategic herbicide applications, would produce a plant community dominated by native plants with species diversity, evenness, and richness similar to planted fields. We hypothesized that planted fields would have greater coverage of non-native species because of the lack of available control options. We hypothesized that naturally revegetated fields would have less coverage of native and non-native grasses and greater coverage of native forbs than planted fields. We hypothesized tall fescue-dominated controls would provide less plant diversity, evenness, and richness and contain greater coverage of non-native species than naturally revegetated and planted treatment units.

STUDY AREA

We collected data from June–August 2016–2018 at 18 study sites (15 tall fescue-dominated and three fallow crop sites) in Tennessee, Alabama, and Kentucky, USA (Figure 2.1). Eight study sites were on Tennessee Wildlife Resources Agency property in Cocke, Cumberland, Lawrence, Roane, Union, White, Williamson, and Wilson counties. Six study sites were located on Tennessee Valley Authority properties in Bedford, Hamblen, Jefferson, Monroe, and Sevier Counties, Tennessee, and Franklin County, Alabama. One study site was on Alabama Department of Conservation and Natural Resources property in Jackson County, one was in Cades Cove within the Great Smoky Mountains National Park (hereafter Park) in Blount County, Tennessee, one on United States Fish and Wildlife Service (USFWS) property in Fulton County, Kentucky, and one on private property in Haywood County, Tennessee. Elevations ranged from 86 m to 658 m. Mean daily temperature across the study area ranged from -4°C to 33°C with mean annual precipitation that ranged 114 cm to 152 cm (National Oceanic and Atmospheric Administration 2019).

METHODS

Study design

We selected fields in 2015 that were dominated by tall fescue or crop fields that were fallowed within two years prior to our study. Tall fescue sites were divided into three similar-sized treatment units and each randomly assigned one of three treatments (control [CNTL], natural revegetation [NR], and planted [PL]) and fallow crop sites were divided into two similar-sized treatment units and each randomly assigned one of two treatments (natural revegetation [NR] and planted [PL]). Treatment units varied in size from 0.8–1.6 ha. Controls at tall fescue sites had on average 75% coverage of tall fescue. We systematically assigned five transects in each unit at each site maintaining an average 10-m buffer between transects and unit edges. We measured coverage of native and non-native plant species, community richness, diversity, and evenness, and coverage and number of species of native flowering forbs beneficial to pollinators during June–August 2018. Although CNTL units were dominated at ground level by tall fescue, they were undergoing succession with various forbs and brambles pioneering from the seed bank, which produced a different species composition than would be found in tall fescue fields maintained for hay or pasture.

Tall fescue eradication

We mowed tall fescue sites in fall 2015 and allowed them to regrow to 15.2–25.4 cm (Harper et al. 2007). We then broadcast sprayed glyphosate (2.8 kg ai/ha) applications in PL and NR treatment units to eradicate tall fescue in November–December 2015. We used follow-up spot-spray glyphosate applications in February–March 2016 to eradicate any tall fescue missed during initial applications. Herbicide applications were made when temperatures were at or above 10°C to ensure effectiveness of the herbicide because tall fescue actively grows at temperatures as low as 3°C (Gastal et al. 1992, Rogers and Locke 2013).

Planting treatments

We planted a native warm-season grass (NWSG) and forb seed mix in PL treatment units in April–May 2016 following recommendations from Private Lands Wildlife Biologists with Tennessee Wildlife Resources Agency and Alabama Department of Conservation and Natural Resources who implement their conservation programs. All sites were planted with the same seed mixture (Table 1.2) excluding the Park site because the National Park Service prohibited introduction of outside genotypic seed sources. Seed planted there were collected from within Cades Cove by National Park Service personnel (Table 1.3). No-till drills (Truax™ Flex II Series drills [Truax Company Inc., New Hope, MN, USA] and Haybuster® drills [Duratech Industries International Inc., Jamestown, ND, USA]) were used to plant seed. We calibrated and adjusted drills to ensure seed were planted at the recommended seeding rate of 7.3 kg/ha pure live seed (PLS) and that planting depth was ≤0.635 cm (Harper et al. 2007). We made preemergence imazapic (Plateau®, BASF) applications (0.07–0.105 kg ai/ha) within seven days of planting to control competition (Washburn et al. 1999, Harper et al. 2007).

Natural revegetation treatments

We allowed the seed bank to naturally revegetate NR units following tall fescue eradication. We used herbicide applications to remove non-native invasive species and to promote a desirable early successional plant community in NR treatment units (Table 2.4). Undesirable vegetation was most often classified as species identified by the Southeast Exotic Pest Plant Council as nonnative invasive species. Any nonnative species not labeled as invasive but increased in coverage ≥ 30% also were considered undesirable. Certain native species such as *Rubus* spp., broomsedge bluestem (*Andropogon virginicus*), and black locust (*Robinia pseudoacacia*) were considered undesirable once they reached 30% coverage and were thinned with herbicides to prevent dominance of these species. The areas opened by herbicide applications naturally revegetated again. This cycle of herbicide application and natural revegetation continued until desirable species established.

Herbicide application in natural revegetation and planted treatment units

We made spot-spray applications using 15-L backpack sprayers (Solo USA, Newport News, Virginia) and/or a 95-L ATV sprayer (Cabelas, Sydney, Nebraska) equipped with a spray gun (Green Garde®, H.D. Hudson Manufacturing Company, Chicago, Illinois). Spot-spray applications were used most often (69% and 86% of all applications made in NR and PL, respectively) and were defined as any herbicide application that did not impact the entire treatment unit. Spot-spray applications on average impacted ≤20% of any single treatment unit. Broadcast applications impacted 100% of any single treatment unit (31% and 14% of all applications made in NR and PL, respectively). We made broadcast applications with a tractor and 3-point boom sprayers, ATV sprayer with boom attachment, or 4-nozzle handheld booms (R&D Sprayers, Opelousas, Louisiana). Broadcast applications were used during fall/winter when ≥50% of the treatment unit was comprised of undesirable cool-season species and during summer when ≥90% of a treatment unit was comprised of undesirable warm-season species. Spot-spray applications were used otherwise.

We determined which herbicides and application rates to use based on plant species targeted for removal (Table 1.5). Planted treatment units simulated plantings made on lands enrolled in conservation programs (e.g., CRP and EQIP), and management activities (i.e., mowing and herbicide applications) were conducted according to Private Lands Biologists' recommendations to remain in compliance with conservation program rules. These biologists commonly worked on lands enrolled in conservation programs and recommended we spot-spray PL treatment units containing ≥30% coverage of johnsongrass (*Sorghum halapense*), crabgrass (*Digitaria* spp.), and/or Japanese stiltgrass (*Microstegium vimineum*) with imazapic because these species were controlled by imazapic and planted species were resistant. We sprayed undesirable species in NR treatment units regardless of coverage. Bermudagrass (*Cynodon dactylon*) invasion is a common problem in plantings, and we sprayed bermudagrass regardless of percent coverage in both NR and PL treatment units, excluding PL treatment units at the Sevier, TN and Franklin, AL sites. Bermudagrass coverage at those sites was >50% in the first growing season and dispersed in a way that could only effectively be controlled via broadcast herbicide applications that would also have killed all planted species. We continued collecting data in those treatment units without controlling bermudagrass to track how the plant communities responded. Biologists recommended allowing up to 5% coverage of woody species (i.e., trees and shrubs) in PL. We recorded the number of herbicide applications made and how much of each herbicide was applied to later calculate average costs.

Mowing

We maintained CNTL units by mowing annually in late-winter (February), representing default management practices common in tall fescue fields (Dykes 2005). Annual mowing was not used in NR or PL treatment units. However, we mowed PL treatment units as necessary and according to biologist recommendations to either prepare PL units for a broadcast herbicide application or to help control competing vegetation and allow planted species to establish.

Measuring vegetation composition

We conducted line-point intercept sampling to quantify vegetation composition in all treatments (Herrick et al. 2009). We established five 50-meter transects in each treatment unit beginning at predetermined locations that were systematically assigned using Google Earth. Every plant species that intercepted each transect was recorded at 2-m intervals. We calculated percent coverage of species and vegetative life forms (bramble, forb, grass, and woody) by dividing the number of hits of each species or life form by the total number of sampling points per transect.

We then averaged percent coverage of each species or life form across all transects for each treatment to calculate percent coverage.

Measuring spatial and temporal coverage of flowering forbs important to pollinators

We compared treatment effects against common seeding requirements of conservation programs such as CP–42 (Pollinator Habitat, USDA Farm Service Agency), which require the inclusion of ≥3 flowering species in each season (spring, summer, and fall). We calculated average number and coverage of native forbs across all treatments, and to better understand the temporal continuum of bee food resources available throughout the growing season within treatments, we calculated the average number and coverage of spring- (NSPFF), summer- (NSUFF), and fall-flowering forbs (NFFF) (Steffan-Dewenter & Tscharntke 2001).

Measuring success of planting and restoration

Gauging the success of restoration projects is important to aid in decision making and planning for future projects, as well as research. However, success is still a relatively undefined term in restoration ecology (Wortley et al. 2013). Even conservation programs, such as CRP and EQIP, do not have a clearly defined standard of planting success or failure (R. Mayberry, Natural Resources Conservation Service, 2018, personal communication). Therefore, we were unaware of any standard of successful establishment of planted native seed mixtures, though planting is a common theme throughout the restoration ecology literature (Ruiz-Jaen & Aide 2005; Foster et al. 2007; Zedler 2007; Wortley et al. 2013). We defined successful establishment of planted species in PL treatment units as having ≥25% coverage of planted species by the third growing season (2018). Diversity indices are one of the most commonly used metrics to gauge restoration success (Ruiz-Jaen & Aide 2005; Wortley et al. 2013), so we defined overall successful restoration as having statistically greater species diversity, evenness, and richness than CNTL units and having ≥80% coverage of native species. We were unable to use this metric at retired crop fields because no tall fescue control was present. As suggested by Applestein et al. (2018), success should be based on long-term monitoring, and a single assessment within a few years after restoration should be used cautiously. Even 10 years may not be long enough to fully realize restoration success (Martin et al. 2005).

Measuring costs and effort

We recorded the amount and type of herbicides applied and the number of visits at each site required to establish early successional plant communities in both NR and PL treatment units. We then calculated average costs and effort required for each treatment unit.

DATA ANALYSIS

Our experimental design at tall fescue sites was a Randomized Complete Block Design with replication. We conducted one-way analysis of variance (ANOVA) with blocking using program R version 3.5.1 (R Core Team 2016) to compare means of plant species richness, diversity, and evenness, percent cover of native and non-native plants, and coverage and number of species of native spring-, summer-, and fall-flowering forbs among the three treatments at $\alpha = 0.05$. We used post-hoc Tukey HSD tests to identify specific differences among treatments when significant treatment effects were observed. We used arcsine square root, square root, and fourth root transformations on non-normal data to meet assumptions of normality and equal variance. We analyzed 2018 data (third growing season) to most accurately compare treatment effects and the resulting plant communities because NWSG and forb communities often require two to three years to establish (Fransen et al. 2006, Harper et al. 2007, Rushing 2014), and because we used herbicides and mowing to promote native species-dominated plant communities in both NR and PL treatment units during 2016–2017.

The experimental design at fallow crop sites was a Randomized Complete Block Design with repeated measures. The limited number of fallow crop sites (n=3), and the fact that these fields lacked a tall fescue control, limited the amount of data available for analysis. We used a repeated measures study design to increase sample size and statistical power compared to only analyzing 2018 data. We excluded 2016 data from fallow crop field analysis because 100% of the plant communities in PL were suppressed by broadcast imazapic applications made across all sites as part of the planting protocol. Because of the small sample size and differences in analytical procedures, comparisons between the fallow crop sites and the tall fescue sites should be interpreted with caution.

We calculated the average Shannon-Weiner index and Simpson's E index values for each treatment to determine plant species diversity and evenness, respectively. The Shannon-Weiner index was scored on a range from zero to four, with greater values implying greater plant diversity. The maximum value for Simpson's E index is one, with index values nearer one representing greater plant community evenness (i.e., how evenly abundance is distributed among species).

RESULTS

Shannon's diversity index, Simpson's evenness index, and species richness

Tall fescue sites: The Shannon index value was less in CNTL than in NR ($P \leq 0.001$) and PL units ($P \leq 0.001$). Simpson's index value in NR was greater than in CNTL ($P \leq 0.001$) and PL treatment units ($P = 0.033$). We detected fewer species in CNTL than in NR ($P = 0.022$) and PL treatment units ($P = 0.004$) (Table 2.6).

Fallow crop sites: No treatment differences were detected for Shannon index values (NR = 2.3 ± 0.2 [SE], PL = 2.6 ± 0.1; P = 0.305), Simpson's evenness index values (NR = 0.28 ± 0.05, PL = 0.31 ± 0.02; P = 0.456), or species diversity (NR = 24 ± 3, PL = 28 ± 3; P = 0.439).

Native and non-native species coverage

Tall fescue sites: Coverage of native species was less in CNTL than in NR ($P \leq 0.001$) and PL treatment units ($P \leq 0.001$), and coverage of non-native species was greater in CNTL than in PL ($P \leq 0.001$) and NR treatment units ($P \leq 0.001$). Tall fescue coverage was greater in CNTL than in NR ($P \leq 0.001$) and PL treatment units ($P \leq 0.001$). Native grass coverage was less in CNTL than in NR (P = 0.013) and PL treatment units ($P \leq 0.001$) and greatest in PL treatment units. Non-native grass coverage was greater in CNTL than in NR ($P \leq 0.001$) and PL treatment units ($P \leq 0.001$) (Table 2.7). We detected 4, 2, and 6% coverage of bermudagrass in CNTL, NR, and PL, respectively (P = 0.253). Native forb coverage was less in CNTL than in NR (P = 0.009) and PL treatment units (P = 0.050) (Table 2.7). We detected 12, 11, and 5% coverage of sericea lespedeza in PL, CNTL, and NR, respectively, with NR having less than PL (P = 0.044).

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Fallow crop sites: We did not detect a treatment effect for native species coverage, non-native species coverage, native grass coverage, non-native grass coverage, native forb coverage, or non-native forb coverage. Sericea lespedeza coverage (NR = 2 ± 0.6%, PL = 2 ± 0.6%) was not different (P = 0.827) between treatments, nor was bermudagrass coverage (NR = 0 ± 0%, PL = 0.1 ± 0.1%; P = 0.422) (Table 2.8). There was a year effect for non-native species coverage (P = 0.028), with greater coverage in 2017 (36 ± 5%) than in 2018 (8 ± 2%), and there was a year effect for non-native grass coverage (P = 0.023), with greater coverage in 2017 (15 ± 4%) than in 2018 (5 ± 2%).

Coverage of native flowering forbs important to pollinators

Tall fescue sites: Coverage of NSPFF was greater in NR (P = 0.006) and PL (P = 0.017) than in CNTL units, and number of NSPFF species was greater in PL (P = 0.002) and NR (P = 0.001) than in CNTL units. The number of NSUFF species was greater in PL than in CNTL units (P = 0.002), and the number of NFFF was greater in NR (P = 0.001) and PL (P = 0.002) than in CNTL units (Table 2.9).

Fallow crop sites: Average coverage and number of NSPFF, NSUFF, or NFFF species was not different between treatments (Table 2.10).

Treatment costs and effort

Average cost for PL treatments was $468.98 per hectare. Glyphosate applications to prepare PL treatments were $20.26 per hectare, the preemergence imazapic application was $16.61 per hectare, seed cost $400.38 per hectare, and post-planting herbicides for weed control averaged $31.73 per hectare. Costs of herbicide application in NR were variable because of differences in seedbank responses at each site. The range of costs for NR was $35.48–$269.02 per hectare and averaged $106.43 per hectare, excluding the initial $20.26 per hectare glyphosate application. On average, PL treatment units required 0.4 entries per site per year, excluding the initial herbicide treatment to remove tall fescue, planting, mowing, and spot-spray applications. Natural revegetation units required 1.3 entries per site per year.

DISCUSSION

Both NR and PL treatments were effective in converting tall fescue-dominated fields and fallow crop fields into a native species-dominated early successional plant community. Natural revegetation and PL treatment units did not differ from each other in 14 of the 17 variables measured at tall fescue sites, and no variable differed between treatments at fallow crop sites. Because of the similarities in PL and NR treatment units, our data indicate no plant community benefits were realized from planting compared to natural revegetation, with planting costing 4.4 times more than natural revegetation.

Our results agree with previous studies that suggest tall fescue is effectively controlled by fall glyphosate applications (Fribourgh et al. 1988; Vogel & Waller 1990; Harper & Gruchy 2009). We detected 2 and 6% coverage of tall fescue in PL and NR treatment units, respectively, in the third growing season, compared to 75% in CNTL units. This level of reduction in tall fescue coverage indicates properly timed and applied glyphosate application can nearly eradicate tall fescue coverage with a single application.

Native grasses were plentiful in the seed bank and planting native grass led to the greatest coverage of NWSG in PL treatment units. Planting native grasses may increase their coverage above that needed for many objectives, especially when managing for certain wildlife species where no more than 35% coverage of grass may be needed (Brooke et al. 2016). Some native grass species, such as broomsedge bluestem (*Andropogon virginicus*), are very competitive and possess allelopathic properties that can impede species richness and outcompete many forbs (Rice 1972; Schramm 1990; Weber 1999; Dickson & Busby 2009). The 61% coverage of native grasses in PL treatment units at tall fescue sites was great enough to result in the lower evenness index score detected in PL compared to NR units.

Native plant species dominated NR and PL treatment units at both tall fescue and fallow crop sites. Strategic herbicide applications in NR treatment units promoted a species composition that was evenly represented by grasses and forbs, whereas the plant community in PL treatment units were more strongly represented by grass coverage as a result of planting native grasses.

Native species dominance in NR treatment units at tall fescue sites also was influenced by the reduction in cover of non-native sericea lespedeza compared to CNTL and PL treatment units. Fallow crop sites had relatively little sericea lespedeza, and any changes in coverage would have been difficult to detect. A variety of forbs is essential for providing nectar and pollen resources for pollinators, and these forbs contribute to increased plant community diversity, evenness, and richness (Steffan-Dewenter & Tscharntke 2001; Dickson & Busby 2009; Mader et al. 2011). Abundance of forbs and plant diversity often decline in planted fields over time because of dominance of planted grasses (Dickson & Busby 2009; Carter & Blair 2011; Willand et al. 2013).

Seasonal availability of floral resources (coverage and number of species) is an important consideration when restoring native early successional plant communities for pollinators (Steffan-Dewenter & Tscharntke 2001). The greatest coverage of native flowering forb species was expected for NSUFF because all planted forbs were summer-flowering species. However, only 4 and 2% coverage of NSUFF in PL treatment units were from planted species at tall fescue and fallow crop sites, respectively. The remaining 13 and 16% coverage of NSUFF in tall fescue and fallow crop sites, respectively, established from the seed bank. We also expected greater coverage of spring- and fall-flowering forbs than what was detected at tall fescue and fallow crop sites in both PL and NR treatment units. An exception was NFFF at fallow crop sites (45–46%). However, in agreement with Weber (1999) and Dickson and Busby (2009), we believe coverage of NWSGs, especially in PL treatment units, suppressed forb coverage. Suppression of the seed bank because of active tall fescue growth in spring certainly decreased coverage of NSPFF in CNTL units compared to NR and PL treatment units.

To compare our treatments with NRCS pollinator planting guidelines, we quantified the number of native flowering forb species by flowering season. Interestingly, even CNTL met the NRCS 3-species requirement for summer- and fall-flowering periods at tall fescue sites, and no treatment at either site type met the 3-species requirement for the spring-flowering period. Although the seed mixture used in our study was not as diverse as some used in pollinator-specific plantings or other restoration projects (Foster et al. 2007), it is a commonly used seed mixture in early successional plant community conservation programs and was developed by state and NRCS wildlife biologists responsible for carrying out conservation programs on private lands. However, there is evidence to suggest that more diverse seed mixtures may not lead to more diverse plant communities (Geaumont et al. 2019).

Even though we considered NR and PL plant communities established in 2018, they were still relatively young in a restoration context. We would expect continued changes in both NR and PL treatment units because early successional plant communities are dynamic, and management strongly influences composition and structure of the plant community (Harper 2017). Annual spot-spray herbicide applications would be necessary beyond the third growing season, regardless of establishment method, to maintain a diverse native species-dominated community. Future research is needed to focus on long-term monitoring of plant community characteristics in early successional communities established using the natural revegetation approach.

Our results contradict other studies that have indicated planting native species is necessary to restore degraded ecosystems and that the seed bank may not be a viable option for most restoration projects (Foster & Tilman 2003; Foster et al. 2007; Beatrijs & Olivier 2008; Sharma et al. 2018). Our data also indicate fallow crop sites with a history of herbicide applications and tillage contained seed banks for restoring native early successional plant communities. A key difference between our study and other studies is that we paired seed bank response with continued spot-spray herbicide applications to remove non-native vegetation as it established. Herbicides are commonly used only for preparing a site to plant (Barnes 2004; Carter & Blair 2011). However, problematic species such as bermudagrass and sericea lespedeza have hard seed that are long-lived in the seed bank, allowing them to establish well after initial herbicide applications and planting native species (Offutt & Baldridge 1973; Cary 1995). In addition, non-native species will continue to colonize in any area as they are brought in by wind, water, and/or animals. Perpetual diligence is requisite if native plant communities are maintained over time. We discovered multiple herbicide applications (especially spot-spray applications) were needed to remove "layers" of non-native species in the seed bank in NR treatment units. This discovery corroborates with Warr et al. (1993) and Sharma et al. (2018) who reported seed bank composition can be depth dependent, with more desirable species often found deeper in the soil profile. Continued spot-spray herbicide applications helped deplete the seed bank of non-native species and released more desirable species. We emphasize that herbicide applications were key to establishing native early successional communities that were ecologically functional and provided habitat for many declining wildlife species.

Natural revegetation treatment units at all tall fescue sites had ≥80% coverage of native species and species diversity, richness, and evenness that was greater than that recorded in CNTL units, thus meeting our criteria to be considered successfully restored. Evenness in the PL treatment units was the only variable not different from CNTL units at tall fescue sites and therefore resulted in PL treatment units not being considered successfully restored. Dominance of only a few species in PL treatment units, such as little bluestem (*Schizachyrium scoparium*) and broomsedge bluestem, reduced evenness index values. We believe evenness would continue to decline and plateau at a relatively low index value in PL treatments because of the planted NWSG. Some studies have reported success rates of ≤10% coverage of planted species two to three years after planting (Wilson et al. 2004; Buisson et al. 2006; Holl et al. 2014). We detected an average of 33 and 38% coverage of planted species at tall fescue and fallow crop sites, respectively, and both were considered successfully established plantings. Considering sites individually, 11 of 18 sites met our success metric of ≥25% coverage of planted species in PL treatment units.

Diverse native early successional plant communities could have been restored on 4.4-times more land using a natural revegetation approach compared to planting, which suggests planting may not be the best use of restoration funding. The widespread geographic distribution of study sites, and their different management histories, suggests the restoration costs associated with the NR approach in our study are representative of the costs likely to be incurred when restoring native early successional plant communities on idle tall fescue and crop fields throughout a large portion of the eastern United States. Much variability existed in seed bank response in NR treatment units across all sites. The most expensive herbicide costs per hectare incurred at a single NR treatment unit was still 2.6-times less expensive than the average cost to plant one hectare ($437.24). The costs and plant community characteristics in PL versus NR treatments in our study suggests that few, if any, benefits are gained by planting expensive seed mixtures when restoring native early successional plant communities.

MANAGEMENT IMPLICATIONS

When restoring native early successional plant communities on idle tall fescue fields in the eastern United States, managers should use a fall application of glyphosate to eradicate tall fescue followed by a spring imazapic application where appropriate and needed. Only the spring imazapic application would need to be considered when working on fallow crop fields. The plant community that establishes following herbicide applications provides a glimpse into the seed bank composition and an opportunity to control non-native vegetation, which is an essential step even when planting. Seed bank composition can be highly variable from site to site and even from field to field on the same property. Steady decreases in non-native species coverage following targeted herbicide applications suggests the seed bank at many locations has several layers of non-native invasive species that must be controlled before an established native plant community is realized. The desired level of reduction of non-native species is objective-driven and depends upon the invasiveness of certain species because some are more problematic than others. Some of the most common problematic species (narrowleaf plantain [*Plantago lanceolata*], johnsongrass, and musk thistle [*Carduus nutans*]) in NR treatments could have been partially or completely controlled with a preemergence imazapic application that also would have reduced the number of follow-up herbicide applications required to establish native vegetation. However, prior to application, it is important to consider potential impacts of soil-active herbicides on both native and non-native species. Proper field preparation, proactive monitoring, and targeted herbicide applications over three growing seasons should produce a diverse native early successional community without planting. Monitoring and herbicide applications should be conducted for both cool- and warm-season species. Our study suggests that restoration and cost benefits of natural revegetation may warrant use of this technique and preclude costly and often failed attempts to plant native grasses and forbs.

LITERATURE CITED

Applestein, C, Bakker, JD, Delvin, EG, Hamman, ST (2018) Evaluating seeding methods and rates for prairie restoration. *Natural Areas Journal* **38**: 347- 355

Askins, RA (2001) Sustaining biological diversity in early successional communities: the challenge of managing unpopular habitats. *Wildlife Society Bulletin* **20**: 407- 412

Barnes, TG (2004) Strategies to convert exotic grass pastures to tall grass prairie communities. *Weed Technology* **18**: 1364- 1370

Beatrijs, B, Olivier, H (2008) Can the seed bank be used for ecological restoration? An overview of seed bank characteristics in European communities. *Journal of Vegetation Science* **19**:8 75- 884

Brennan, LA (1991) How can we reverse the northern bobwhite population decline? *Wildlife Society Bulletin* **19**: 544- 555

Brennan, LA, Kuvlesky, WP, Jr. (2005) North American grassland birds: an unfolding conservation crisis? *Journal of Wildlife Management* **69**: 1- 13

Brooke, JM, Tanner, EP, Peters, DC, Tanner, AM, Harper, CA, Keyser, PD, Clark, JD, Morgan, JJ (2016) Northern bobwhite breeding season ecology on a reclaimed surface mine. *Journal of Wildlife Management* **81**: 73- 85

Buckner, RC, Powell, JB, Frakes, RV (1979) Historical development. Pages 1- 8. In R Buckner, L Bush (eds). *Tall fescue. Agronomy Monograph 20.* Madison, Wisconsin, USA.

Buisson, E, Holl, KD, Corcket, C, Hayes, GF, Torre, F, Peteers, A, Dutoit, T (2006) Effects of seed source, topsoil removal, and plant neighbor removal on restoring California coastal prairies. *Restoration Ecology* **14**: 569- 577

Burger, LW, Jr. (2005) The Conservation Reserve Program in the Southeast: Issues affecting wildlife habitat value. Pages 135- 141. In: AW Allen, MW Vandever (eds) *The Conservation Reserve Program: Planting for the Future. Proceedings of a National Conference*. Washington, D.C., USA

Carey, JH (1995) Cynodon dactylon. In: *Fire Effects Information System.* U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.fs.fed.us/database/feis/plants/graminoid/cyndac/all.html (accessed 12 Dec 2018)

Carmichael, DB, Jr. (1997) The conservation reserve program and wildlife habitat in the southeastern United States. *Wildlife Society Bulletin* **25**: 773- 775

Carter, DL, Blair JM (2011) Recovery of native plant community characteristics on a chronosequence of restored prairies seeded into pastures in west-central Iowa. *Restoration Ecology* **20**: 170- 179

Dickson, TL, Busby, WH (2009) Forb species establishment increases with decreased grass seeding density and with increased forb seeding density in a northeast Kansas, U.S.A., experimental prairie restoration. *Restoration Ecology* **17**: 597-605

Dykes, SA (2005) Effectiveness of native grassland restoration in restoring grassland bird communities in Tennessee. Thesis, University of Tennessee, Knoxville, U.S.A.

Foster, BL, Tilman, D (2003) Seed limitation and the regulation of community structure in oak savanna grassland. *Journal of Ecology* **9**: 999- 1007

Foster, BL, Murphy, CA, Keller KR, Aschenbach, TA, Questad EJ, Kindscher, K (2007) Restoration of prairie community structure and ecosystem function in an abandoned hayfield: A sowing experiment. *Restoration Ecology* **15**: 652- 661

Fransen, SC, Collins HP, Boydston RA (2006) Perennial warm-season grasses for biofuels. *Proceedings of Western Alfalfa and Forage Conference*. Reno, Nevada, USA.

Fribourgh, HA, Wilkinson SR, Rhodes, GN, Jr. (1988) Switching from fungus-infected to fungus-free tall fescue. *Journal of Production Agriculture* **1**: 122- 127

Gastal, F, Bellanger, G, Lemaire, G (1992) A model of leaf extension rate of tall fescue in response to nitrogen and temperature. *Annals of Botany* **70**: 437- 442

Geaumont, BA, Norland, J, Stackhouse, JW (2019) The influence of species richness and forb seed density on grassland restoration in the Badlands of North Dakota, USA. *Ecological Restoration* **37**: 123- 130

Harper, CA (2017) Managing early successional plant communities for wildlife in the eastern US. University of Tennessee Institute of Agriculture, Knoxville, Tennessee, USA.

Harper, CA, Gruchy, JP (2009) Eradicating tall fescue and other non-native, perennial, cool-season grasses for improved early successional wildlife habitat. In: LW Burger Jr., KO Evans (eds) *Managing working lands for northern bobwhite*: *The USDA NRCS Bobwhite Restoration Project.* Washington, D.C.

Harper, CA, Bates, GE, Hansbrough, MP, Gudlin, MJ, Gruchy, JP, Keyser, PD (2007) Native warm-season grasses; identification, establishment and management for wildlife and forage production in the Mid-South. University of Tennessee Institute of Agriculture, Knoxville, Tennessee, USA.

Hart, JF (1968) Loss and abandonment of cleared farm land in the eastern United States. *Annals of the Association of American Geographers* **58**: 417- 440

Herrick, JE, Van Zee, JW, Havstad, KM, Burkett, LM, Whitford, WG (2009) *Monitoring manual for grassland, shrubland and savanna ecosystems.* Volume I: Quick Start. U. S. Department of Agriculture: ARS Jornado Experimental Range. Las Cruces, New Mexico, USA

Holl, KD, Hayes, GF, Brunet, C, Howard, EA, Reed, LK, Tang, M, Vasey, MC (2014) Constraints on direct seeding of coastal prairie species: Lessons learned from restoration. *Grasslands* **24**: 8- 12

Houck, M (2009) *Plant fact sheet for bahiagrass (Paspalum notatum)*. United States Department of Agriculture-Natural Resources Conservation Service, Louisiana State Office, Alexandria

Knopf, FL (1994) Avian assemblages on altered grasslands. *Studies in Avian Biology* **15**: 247- 257

Koger, CH, Poston, DH, Hayes, RM, Montgomery, RF (2004) Glyphosate-resistant horseweed (Conyza canadensis) in Mississippi. *Weed Technology* **18**: 820- 825

Lorimer, CG (2001) Historical and ecological roles of disturbance in eastern North American forests: 9000 years of change. *Wildlife Society Bulletin* **29**: 425- 439

Mader, E., Shepherd, M, Vaughan, M, Black, SH, Lebuhn, G (2011) *Attracting native pollinators: protecting North America's bees and butterflies.* Story Publishing, North Adams, Massachusetts, USA.

Martin, LM, Moloney, KA, Wilsey, BJ (2005) An assessment of grassland restoration success using species diversity components. *Journal of Applied Ecology* **42**: 327- 336

McLauchlan, K (2006) The nature and longevity of agricultural impacts on soil carbon and nutrients: A review. *Ecosystems* **9**: 1364- 1382

Menalled, FD, Gross, KL, Hammond, M (2001) Weed aboveground and seedbank community responses to agricultural management systems. *Ecological Applications* **11**: 1586- 1601

Middleton, BA (2003) Soil seed banks and the potential restoration of forested wetlands after farming. *Journal of Applied Ecology* **40**: 1025- 1034

Mittelhauser, JR, Barnes, PW, Barnes, TG (2011) The effect of herbicide on the re-establishment of native grasses in the blackland prairie. *Natural Areas Journal* **31**: 500-507

National Oceanic and Atmospheric Administration. 2019. Climatological data annual summary Alabama and Tennessee. National Climatic Data Center, Asheville, North Carolina, USA.

National Research Council (NRC) (2007) *Status of Pollinators in North America*. The National Academies Press. Washington, D.C., USA.

Noss, RF, LaRoe, ET, III, Scott, JM (1995) Endangered ecosystems of the United States; a preliminary assessment of loss and degradation. National Biological Service Biological Report 28. U.S. Department of the Interior, Washington, D.C.

Offutt, ML, Baldridge, JD (1973) The Lespedezas. In: ME Heath, DS Metcalfe, RF Barnes (eds) *Forages: The science of grassland agriculture*. 3rd ed. The Iowa State University Press. Ames, U.S.A.

Prach, K, Chenoweth, J, Del Moral, R (2018) Spontaneous and assisted restoration of vegetation on the bottom of a former water reservoir, the Elwha River, Olympic National Park, WA, U.S.A. *Restoration Ecology* **0**: 1- 8

Rice, EL (1972) Allelopathic effects of Andropogon virginicus and its persistence in old fields. *American Journal of Botany* **59**: 752- 755

Rogers, JK, Locke, JM (2013) Tall fescue: history, application, establishment, and management. The Samuel Roberts Noble Foundation. Ardmore, Oklahoma, U.S.A.

Rowe, HI (2010) Tricks of the trade: techniques and opinions from 38 experts in tallgrass prairie restoration. *Restoration Ecology* **18**: 253- 262

RStudio Team (2016) RStudio: Integrated Development for R. RStudio, Inc., Boston, Massachusetts, U.S.A. URL: http://www.rstudio.com/

Ruiz-Jaen, MC, Aide, TM (2005) Restoration success: How is it being measured? *Restoration Ecology* **13**: 569- 577

Rushing, B (2014) Native warm-season grasses: establishment issues. Mississippi State University Coastal Research and Extension Center. Biloxi, Mississppi, U.S.A.

Schramm, P (1990) Prairie restoration: A twenty-five year perspective on establishment and management. Proceedings of the North American Prairie Conference **12**: 169- 178

Sharma, A, Bohn, KK, Jose, S, Miller, DL (2018) Seed bank – vegetation dynamics along a restoration management gradient in pine flatwoods ecosystems of the Florida Gulf Coast. *Natural Areas Journal* **38**: 26- 43

Smith, ET (2007) Early Successional Habitat. Fish and Wildlife Habitat Management Leaflet. United States Depart of Agriculture, Natural Resources Conservation Service. Publication 41. Washington, D.C.

Steffan-Dewenter, I, Tscharntke, T (2001) Succession of bee communities on fallows. *Ecography* **24**: 83- 93

Steyaert, LT, Knox, RG (2008) Reconstructed historical land cover and biophysical parameters for studies of land-atmosphere interactions within the eastern United States. *Journal of Geophysical Research* **113**: 1- 27

Tscharntke, T, Steffan-Dewenter, I, Kruess, A, Thies, C (2002) Contribution of small habitat fragments to conservation of insect communities of grassland–cropland landscapes. *Ecological Applications* **12**: 354- 363.

United States Department of Agriculture (USDA) (2009) Pollinator biology and habitat. *New England pollinator handbook*. Natural Resources Conservation Service. Washington, D.C.

United States Department of Agriculture (USDA) (2018) Summary Report: 2018 National Resources Inventory, Natural Resources Conservation Service, Washington, D.C., and Center for Survey Statistics and Methodology, Iowa State University, Ames.

Vogel, KP, Waller, SS (1990) Suppression of cool-season grasses with glyphosate and atrazine. *Proceedings of the Forage and Grassland Conference*. Pages 29– 31. American Forest and Grassland Council. Elmhurst, Illinois, U.S.A.

Warr, SJ, Thompson, K, Kent, M (1993) Seed banks as a neglected area of biogeographic research: A review of literature and sampling techniques. *Progress in Physical Geography* **17**: 329- 347

Washburn, BE, Barnes, TG, Sole, JD (1999) No-till establishment of native warm-season grasses in tall fescue fields: first-year results indicate value of new herbicide. *Ecological Restoration* **17**: 144- 149

Washburn, BE, Barnes, TG, Sole, JD (2000) Improving northern bobwhite habitat by converting tall fescue fields to native warm-season grasses. *Wildlife Society Bulletin* **28**: 97- 104

Weber, S (1999) Designing seed mixes for prairie restoration: revisiting the formula. *Ecological Restoration* **17**: 196- 201

Willand, JE, Baer, SG, Gibson, DJ, Klopf, RP (2013) Temporal dynamics of plant community regeneration sources during tallgrass prairie restoration. *Plant Ecology* **214**: 1169- 1180

Wilson, MV, Ingersoll, CA, Wilson, MG, Clark, DL (2004) Why pest plant control and native plant establishment failed: A restoration autopsy. *Natural Areas Journal* **24**: 23- 31

Winfree, R, Aguilar, R, Vazquez, DP, LeBuhn, G, Aizen, MA (2009) A meta-analysis of bees' responses to anthropogenic disturbance. *Ecology* **90**: 2068- 2076

Wortley, L, Hero, J, Howes, M (2013) Evaluating ecological restoration success: A review of the literature. *Restoration Ecology* **21**: 537- 543

Zedler, JB (2007) Success: An unclear, subjective descriptor of restoration outcomes. *Ecological Restoration* **25**: 162- 168

APPENDIX II: Chapter II tables and figures

Table 2.1. Land use at 18 study site locations prior to study initiation.

site name	county, state	previous land use[a,b]	fallow crop site
Bridgestone	White, TN	wildlife management/old-field	
Cades Cove	Blount, TN	maintained opening[c]	
Catoosa	Cumberland, TN	maintained opening	
Cedar Creek	Franklin, AL	hay	
Cherokee Dam	Jefferson, TN	hay	
Cherokee North	Hamblen, TN	hay	
Chuck Swan	Union, TN	maintained opening	
Douglas Dam	Sevier, TN	hay	
Haley Jacqueth	Williamson, TN	maintained opening	
Laurel Hill	Lawrence, TN	maintained opening	
McCool	Haywood, TN	corn and soybean production	x
Normandy	Bedford, TN	hay	
Oak Ridge	Roane, TN	maintained opening	
Percy Priest	Wilson, TN	corn and soybean production	x
Rankin	Cocke, TN	maintained opening	
Reelfoot	Fulton, KY	corn and soybean production	x
Skyline	Jackson, AL	maintained opening	
Tellico	Monroe, TN	maintained opening	

[a]prominent land use within five years prior to study

[b]maintained opening = fields kept in open state by ≥1 annual mowing for "wildlife openings" and/or to prevent woody encroachment

[c]maintained via mowing and prescribed fire

Table 2.2. Species and planting rate used for all study sites excluding Blount County, Tennessee. Rates are pure live seed (PLS). Seed source: Roundstone Native Seed, LLC (Upton, Kentucky, USA).

common name	scientific name	planting rate (kg/ha)
little bluestem	*Schizachyrium scoparium*	3.36
sideoats grama	*Bouteloua curtipendula*	1.12
switchgrass	*Panicum virgatum*	0.56
partridge pea	*Chamaecrista fasciculata*	0.71
purple coneflower	*Echinacea purpurea*	0.84
Illinois bundleflower	*Desmanthus illinoensis*	0.21
gray-headed coneflower	*Ratibida pinnata*	0.28
black-eyed susan	*Rudbeckia hirta*	0.21

Table 2.3. Plant species and seeding rate (PLS) used at Blount County, Tennessee study site. Seed source: seed collected within the Great Smoky Mountains Nations Park.

common name	scientific name	planting rate (kg/ha)
big bluestem	*Andropogon gerardii*	0.95
little bluestem	*Schizachyrium scoparium*	0.75
swamp sunflower	*Helianthus angustifolius*	0.09
mountain mint	*Pycnanthemum sp*	0.25
sneezeweed	*Helenium autumnale*	0.28
wild bergamont	*Monarda fistulosa*	0.24
wild quinine	*Parthenium integrifolium*	0.40
roundhead lespedeza	*Lespedeza capitata*	0.46

Table 2.4. Plant species detected along line-point intercept transects across all sites (*n*=18), nativity status, and season of floral resources available to pollinators, June–August 2016–2018.

life form[a]	scientific name	common name	native	non-native	pollinator[b]
B	*Rubus occidentalis*	black raspberry	x		S
B	*Rubus* spp.	blackberry[c]	x		S
B	*Smilax glauca*	cat greenbrier	x		S
B	*Smilax rotundifolia*	common greenbrier	x		S
B	*Mimosa microphylla*	littleleaf sensitive-briar	x		Su
B	*Rosa multiflora*	multiflora rose		x	
B	*Rubus flagellaris*	northern dewberry	x		S
B	*Smilax bonanox*	saw greenbrier	x		S
B	*Rubus trivialis*	southern dewberry	x		S
F	*Trifolium hybridum*	alsike clover		x	
F	*Solanum americanum*	American black nightshade	x		Su
F	*Erechtites hieraciifolius*	American burnweed	x		Su
F	*Teucrium canadense*	American germander	x		Su
F	*Amphicarpaea bracteata*	American hog peanut	x		Su
F	*Phytolacca americana*	American pokeweed	x		Su
F	*Matelea gonocarpos*	angularfruit milkvine	x		Su
F	*Erigeron annuus*	annual fleabane	x		S
F	*Commelina communis*	Asiatic dayflower		x	
F	*Cardiospermum halicacabum*	balloon vine		x	
F	*Valerianella radiata*	beaked cornsalad	x		S
F	*Sesbania herbacea*	bigpod sesbania	x		Su
F	*Ipomoea pandurata*	bigroot morningglory	x		Su
F	*Medicago lupulina*	black medic		x	
F	*Rudbeckia hirta*	black-eyed susan	x		S
F	*Conoclinium coelestinum*	blue mistflower	x		F
F	*Plantago aristata*	bracted plantain[c]	x		S
F	*Verbena brasiliensis*	Brazilian vervain		x	
F	*Rumex obtusifolius*	broadleaf dock		x	
F	*Cirsium vulgare*	bullthistle		x	

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
F	*Aster dumosus*	bushy aster	x		F
F	*Ranunculus* spp.	buttercup		x	
F	*Asclepias tuberosa*	butterfly milkweed	x		Su
F	*Clitoria mariana*	butterfly pea	x		Su
F	*Solidago canadensis*	Canada goldenrod	x		F
F	*Elephantopus carolinianus*	Carolina elephantsfoot	x		Su
F	*Pyrrhopappus carolinianus*	Carolina false dandelion	x		S
F	*Geranium carolinianum*	Carolina geranium	x		S
F	*Solanum carolinense*	Carolina horsenettle[c]	x		Su
F	*Silene antirrhina*	catchfly	x		S
F	*Stellaria* spp.	chickweed spp.		x	
F	*Physalis heterophylla*	clammy groundcherry	x		Su
F	*Pilea pumila*	clearweed	x		
F	*Galium aparine*	cleavers	x		S
F	*Xanthium strumarium*	cocklebur	x		Su
F	*Potentilla simplex*	common cinquefoil	x		S
F	*Taraxacum officinale*	common dandelion		x	
F	*Oenothera biennis*	common evening primrose	x		Su
F	*Kummerowia striata*	common lespedeza		x	
F	*Asclepias syriaca*	common milkweed	x		Su
F	*Verbascum thapsus*	common mullein		x	
F	*Ambrosia artemisiifolia*	common ragweed	x		
F	*Prunella vulgaris*	common selfheal	x		Su
F	*Rumex acetosella*	common sheep sorrel		x	
F	*Sonchus oleraceus*	common sowthistle		x	
F	*Hypericum perforatum*	common st. johnswort		x	
F	*Vicia sativa*	common vetch		x	
F	*Achillea millefolium*	common yarrow		x	
F	*Rorippa sylvestris*	creeping yellow cress		x	
F	*Rumex crispus*	curly dock		x	

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
F	*Oenothera laciniata*	cutleaf eveningprimrose	x		Su
F	*Erigeron strigosus*	daisy fleabane	x		S
F	*Dianthus armeria*	deptford pink		x	
F	*Desmodium laevigatum*	*Desmodium laevigatum*	x		F
F	*Desmodium marilandicum*	*Desmodium marilandicum*	x		Su
F	*Desmodium obtusum*	*Desmodium obtusum*	x		Su
F	*Desmodium paniculatum*	*Desmodium paniculatum*	x		F
F	*Cuscuta* spp.	dodder	x		Su
F	*Eupatorium capillfolium*	dogfennel	x		
F	*Lobelia puberula*	downy lobelia	x		F
F	*Lathyrus latifolius*	everlasting pea		x	
F	*Boehmeria cylindrica*	false nettle	x		
F	*Torilis arvensis*	field hedge parsley		x	
F	*Sherardia arvensis*	field madder		x	
F	*Cirsium discolor*	field thistle	x		F
F	*Euphorbia corollata*	flowering spurge	x		Su
F	*Solidago gigantea*	giant goldenrod	x		F
F	*Ambrosia trifida*	giant ragweed	x		
F	*Solidago nemoralis*	gray goldenrod	x		F
F	*Ratibida pinnata*	gray-headed coneflower	x		Su
F	*Cardamine hirsuta*	hairy bittercress		x	
F	*Desmodium ciliare*	hairy small leaf tick trefoil	x		Su
F	*Agrimonia parviflora*	harvestlice	x		Su
F	*Calystegium sepium*	hedge bindweed		x	
F	*Pycnantheum incanum*	hoary mountainmint	x		Su
F	*Acalypha ostryifolia*	hophornbeam copperleaf	x		Su
F	*Eupatorium hyssopifolium*	hyssopleaf thoroughwort	x		F
F	*Desmanthus illinoensis*	Illinois bundleflower	x		Su

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
F	*Apocynum cannabinum*	Indianhemp	x		Su
F	*Lobelia inflata*	Indian-tobacco	x		Su
F	*Ipomoea hederacea*	ivyleaf morning-glory		x	
F	*Coreopsis lanceolata*	lanceleaf coreopsis	x		S
F	*Eupatorium serotinum*	lateflowering boneset	x		F
F	*Lespedeza intermedia*	*Lespedeza intermedia*	x		Su
F	*Salvia lyrata*	lyreleaf sage	x		Su
F	*Conyza canadensis*	marestail	x		F
F	*Iva annua*	marsh elder	x		
F	*Chrysopsis mariana*	Maryland goldenaster	x		F
F	*Rhexia mariana*	Maryland meadowbeauty	x		Su
F	*Anthemis cotula*	mayweed chamomile		x	
F	*Mosla dianthera*	miniature beefsteakplant		x	
F	*Duchesnea indica*	mock strawberry		x	
F	*Cerastium fontanum*	mouse-ear chickweed		x	
F	*Carduus nutans*	musk thistle		x	
F	*Pycnanthemum tenuifolium*	narrowleaf mountain mint	x		Su
F	*Plantago lanceolata*	narrowleaf plantain		x	
F	*Verbena simplex*	narrowleaf vervain	x		Su
F	*Chamaesyce nutans*	nodding spurge	x		Su
F	*Symphyotrichum pilosum*	oldfield aster	x		Su
F	*Leucanthemum vulgare*	oxeye daisy		x	
F	*Amaranthus palmeri*	Palmer pigweed	x		
F	*Chamaecrista fasciculata*	partridge pea	x		Su
F	*Polygonum pennsylvanicum*	Pennsylvania smartweed	x		Su
F	*Perilla frutescens*	perilla mint		x	
F	*Veronica persica*	Persian speedwell		x	
F	*Coreopsis tinctoria*	plains coreopsis	x		Su
F	*Diodia teres*	poorjoe	x		Su

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
F	*Croton monanthogynus*	prairie tea	x		Su
F	*Lactuca serriola*	prickly lettuce		x	
F	*Sida spinosa*	prickly sida	x		Su
F	*Chamaesyce maculata*	prostrate spurge	x		Su
F	*Echinacea purpurea*	purple coneflower	x		Su
F	*Gamochaeta purpurea*	purple cudweed	x		F
F	*Passiflora incarnata*	purple passionflower	x		Su
F	*Daucus carota*	Queen Anne's lace		x	
F	*Pseudognaphalium obtusifolium*	rabbit-tobacco	x		F
F	*Trifolium pratense*	red clover		x	
F	*Potentilla norvegica*	rough cinquefoil	x		Su
F	*Lespedeza capitata*	roundhead lespedeza	x		Su
F	*Eupatorium rotundifolium*	roundleaf thoroughwort	x		F
F	*Chamaecrista nictitans*	sensitive partridgepea	x		Su
F	*Lespedeza cuneata*	sericea lespedeza		x	
F	*Solidago speciosa*	showy goldenrod	x		F
F	*Senna obtusifolia*	sicklepod	x		Su
F	*Agalinis tenuifolia*	slender gerardia	x		Su
F	*Lespedeza virginica*	slender lespedeza	x		F
F	*Packera anonyma*	Small's ragwort	x		S
F	*Helenium autumnale*	sneezeweed	x		Su
F	*Bidens bipinnata*	Spanish needles	x		Su
F	*Hypericum punctatum*	spotted St. Johnswort	x		Su
F	*Potentilla recta*	sulphur cinquefoil		x	
F	*Cynanchum laeve*	swallowort honeyvine	x		Su
F	*Helianthus angustifolius*	swamp sunflower	x		Su
F	*Melilotus officinalis*	sweet clover		x	
F	*Vernonia altissima*	tall ironweed	x		F
F	*Acalypha* spp.	threeseed mercury	x		

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
F	*Lespedeza procumbens*	trailing lespedeza	x		Su
F	*Abutilon theophrasti*	velvetleaf		x	
F	*Triodanis perfoliata*	Venus' looking-glass	x		S
F	*Viola* spp.	violet	x		S,Su
F	*Clematis virginiana*	virgin bowers	x		Su
F	*Diodia virginiana*	Virginia buttonweed	x		Su
F	*Geum canadense*	white avens	x		S
F	*Trifolium repens*	white clover		x	
F	*Verbesina virginica*	white crownbeard	x		F
F	*Verbena urticifolia*	white vervain	x		Su
F	*Polymnia canadensis*	whiteflower leafcup	x		Su
F	*Coreopsis major*	whorled coreopsis	x		Su
F	*Polygala verticillata*	whorled milkwort	x		Su
F	*Clinopodium vulgare*	wild basil	x		Su
F	*Strophostyles helvola*	wild bean	x		Su
F	*Monarda fistulosa*	wild bergamot	x		Su
F	*Lactuca canadensis*	wild lettuce	x		Su
F	*Ruellia* spp.	wild petunia	x		Su
F	*Parthenium integrifolium*	wild quinine	x		Su
F	*Symphyotrichum praealtum*	willowleaf aster	x		F
F	*Veresina alternifolia*	wingstem	x		F
F	*Sedum ternatum*	woodland stonecrop	x		S
F	*Croton capitatus*	wooly croton	x		F
F	*Solidago rugosa*	wrinkleleaf goldenrod	x		F
F	*Trifolium campestre*	yellow hop clover		x	
F	*Barbarea vulgaris*	yellow rocket		x	
F	*Oxalis stricta*	yellow woodsorrel	x		Su
F	*Eclipta prostrata*	yerba de tajo	x		Su
FR	*Pteridium aquilinum*	bracken fern	x		
FR	*Botrychium biternatum*	grape fern	x		
G	*Poa annua*	annual blue grass		x	

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
G	*Setaria* spp.	annual foxtail		x	
G	*Paspalum notatum*	bahiagrass		x	
G	*Echinochloa crus-galli*	barnyardgrass		x	
G	*Panicum anceps*	beaked panicgrass	x		
G	*Agrostis* spp.	bentgrass		x	
G	*Cynodon dactylon*	bermudagrass		x	
G	*Andropogon gerardii*	big bluestem[c]	x		
G	*Sisyrinchium* spp.	blue-eyed grass	x		S
G	*Poa* spp.	bluegrass sp.		x	
G	*Eleocharis obtusa*	blunt spikerush	x		
G	*Urochloa platyphylla*	broadleaf signalgrass	x		
G	*Bromus* spp.	*Bromus sp.*		x	
G	*Andropogon virginicus*	broomsedge[c]	x		
G	*Bromus tectorum*	cheatgrass		x	
G	*Holcus lanatus*	common velvetgrass		x	
G	*Digitaria* spp.	crabgrass		x	
G	*Paspalum dilatatum*	dallisgrass		x	
G	*Dichanthelium clandestinum*	deertounge	x		
G	*Dicanthelium* spp.	*Dicanthelium* spp.	x		
G	*Panicum dichotomiflorum*	fall panicum	x		
G	*Festuca* spp.	fine fescue		x	
G	*Carex frankii*	Frank's sedge	x		
G	*Setaria faberi*	giant foxtail		x	
G	*Saccharum giganteum*	giant plumegrass	x		
G	*Carex perglobosa*	globe sedge	x		
G	*Eleusine indica*	goosegrass		x	
G	*Microstegium vimineum*	Japanese stiltgrass		x	
G	*Sorghum halepense*	johnsongrass		x	
G	*Setaria parviflora*	knotroot foxtail[c]	x		

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
G	*Schizachyrium scoparium*	little bluestem	x		
G	*Dichanthelium* spp.	low panicgrass	x		
G	*Piptochaetium avenaceum*	needlegrass	x		
G	*Muhlenbergia schreberi*	nimblewill[c]	x		
G	*Allium vineale*	onion	x		
G	*Dactylis glomerata*	orchardgrass		x	
G	*Lolium perenne*	perennial ryegrass		x	
G	*Danthonia spicata*	poverty oatgrass	x		
G	*Juncus tenuis*	poverty rush	x		
G	*Tridens flavus*	purpletop	x		
G	*Leptochloa panicea*	red sprangletop	x		
G	*Leersia oryzoides*	rice cutgrass	x		
G	*Bouteloua curtipendula*	sideoats grama	x		
G	*Arthraxon hispidus*	small carpetgrass		x	
G	*Andropogon ternarius*	splitbeard bluestem	x		
G	*Eragrostis cilianensis*	stinkgrass		x	
G	*Anthoxanthum odoratum*	sweet vernalgrass		x	
G	*Panicum virgatum*	switchgrass	x		
G	*Schedonorus arundinacea*	tall fescue		x	
G	*Paspalum setaceum*	thin paspalum	x		
G	*Phleum pratense*	timothy		x	
G	*Paspalum urvillei*	Vasey's grass		x	
G	*Elymus virginicus*	Virginia wild rye	x		
G	*Eragrostis curvula*	weeping lovegrass		x	
G	*Allium canadense*	wild garlic		x	
G	*Panicum capillare*	witchgrass	x		
G	*Sorghastrum nutans*	yellow indiangrass	x		
G	*Cyperus esculentus*	yellow nutsedge		x	
G	*Iris pseudacorus*	yellowflag grass		x	
G	*Yucca* spp.	yucca	x		

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
S	*Callicarpa americana*	American beautyberry	x		Su
S	*Prunus americana*	American plum	x		S
S	*Lespedeza bicolor*	bicolor lespedeza		x	
S	*Cephalanthus occidentalis*	common buttonbush	x		Su
S	*Symphoricarpos orbiculatus*	corralberry	x		Su
S	*Sambucus nigra*	elderberry	x		Su
S	*Ligustrum* spp.	privet		x	
S	*Rhus copallinum*	winged sumac	x		Su
T	*Ulmus americana*	American elm	x		S
T	*Platanus occidentalis*	American sycamore	x		
T	*Prunus serotina*	black cherry	x		S
T	*Robinia pseudoacacia*	black locust[c]		x	Su
T	*Quercus velutina*	black oak	x		
T	*Juglans nigra*	black walnut	x		
T	*Nyssa slyvatica*	blackgum	x		S
T	*Acer negundo*	box elder	x		S
T	*Pyrus calleryana*	callery pear		x	
T	*Carya* spp.	hickory	x		
T	*Diospyros virginiana*	common persimmon	x		S
T	*Juniperus virginiana*	eastern red cedar	x		
T	*Cornus florida*	flowering dogwood	x		S
T	*Fraxinus pennsylvanica*	green ash	x		
T	*Celtis occidentalis*	hackberry	x		S
T	*Gleditsia triacanthos*	honey locust	x		S
T	*Pinus taeda*	loblolly pine	x		
T	*Carya illinoinensis*	pecan	x		
T	*Acer rubrum*	red maple	x		S
T	*Sassafras albidum*	sassafras	x		S
T	*Quercus acutissima*	sawtooth oak		x	
T	*Ulmus rubra*	slippery elm	x		S

Table 2.4. Continued

life form[a]	scientific name	common name	native	non-native	pollinator[b]
T	*Liquidambar styraciflua*	sweetgum	x		
T	*Ailanthus altissima*	tree-of-heaven		x	
T	*Ulmus alata*	winged elm	x		S
T	*Liriodendron tulipifera*	yellow poplar	x		S
V	*Brunnichia ovata*	American buckwheat vine	x		Su
V	*Cocculus carolinus*	Carolina moonseed	x		Su
V	*Bignonia capreolata*	crossvine	x		S
V	*Ampelopsis cordata*	heartleaf peppervine	x		Su
V	*Lonicera japonica*	Japanese honeysuckle		x	
V	*Toxicodendron radicans*	poison ivy	x		Su
V	*Vitis aestivalis*	summer grape	x		Su
V	*Campsis radicans*	trumpet creeper	x		Su
V	*Parthenocissus quinquefolia*	Virginia creeper	x		Su

[a]B = bramble, F = forb, FR = fern, G = graminoid, S = shrub, T = tree, V = woody vine

[b]indicates peak-flowering period when nectar and pollen resources are available for pollinators (i.e., bee, butterflies, moths, flies, beetles, wasps, and/or hummingbirds); S = spring (February–May), Su = summer (June–August), F = fall (September–November); native species with no flowering season designated indicates a wind-pollinated species

[c]indicates native species that showed ability to persist at or increase beyond 30% coverage after two growing seasons and were treated with herbicides to maintain coverage at or below that threshold

Table 2.5. Herbicides and adjuvants used for control of undesirable plant species in NR and PL treatment units.

herbicides			
active ingredient	trade name	manufacturer	selectivity
imazapic	Plateau®	BASF	broad-spectrum selective
glyphosate	Accord® XRT II	Dow AgroSciences	broad-spectrum
imazapyr	Arsenal® AC Arsenal® PowerLine™	BASF	broad-spectrum selective
clethodim	Clethodim 2E	Agri Star®	grass-selective
triclopyr	Garlon® 3A Remedy Ultra	Dow AgroSciences	forb-selective woody
triclopyr + fluroxypyr	Pasturegard ®	Dow AgroSciences	forb-selective woody
adjuvants			
alkylarypolyoxyethlene glycols, free fatty acids & IPA	90/10 Surfactant	ProSolutions LLC	
Parafifin oil, surface active compounds and coupling agents	Basal Oil	Alligare	
phytobland paraffinic oil	Prime Oil®	Agrisolutions™	
methylated seed oil	MSO	Alligare	

Table 2.6. Species diversity (Shannon-Wiener index [H']), evenness (Simpson's E index [E]), and richness (S) (mean ± SE) across treatments at tall fescue sites (n=15), June–August 2018.

treatment[a]	$F_{[2,28]}$	P-value	H'[b]	
CNTL	21.58	≤ 0.001	2.2 ± 0.04	B
NR			2.7 ± 0.05	A
PL			2.6 ± 0.04	A
			E	
CNTL	10.19	≤ 0.001	0.22 ± 0.01	B
NR			0.31 ± 0.01	A
PL			0.26 ± 0.01	B
			S	
CNTL	6.97	0.004	25 ± 1	B
NR			31 ± 1	A
PL			32 ± 1	A

[a] CNTL = control, NR = natural revegetation, PL = planted

[b] column means with the same letter group are not different (α = 0.05)

Table 2.7. Percent coverage of native and non-native species (mean ± SE) by treatment at tall fescue sites (n=15), July–August 2018.

treatment[a]	$F_{[2,28]}$	P-value	native species[b]	
CNTL	16.01	≤ 0.001	63 ± 3	B
NR			85 ± 2	A
PL			89 ± 2	A
			non-native species	
CNTL	48.75	≤ 0.001	88 ± 2	A
NR			40 ± 2	B
PL			41 ± 3	B
			tall fescue	
CNTL	213.10	≤ 0.001	75 ± 2	A
NR			6 ± 1	B
PL			2 ± 1	B
			native grasses	
CNTL	15.24	≤ 0.001	33 ± 4	B
NR			49 ± 4	A
PL			61 ± 3	A
			non-native grasses	
CNTL	137.06	≤ 0.001	81 ± 2	A
NR			12 ± 1	B
PL			17 ± 3	B
			native forbs	
CNTL	5.60	0.009	33 ± 3	B
NR			53 ± 2	A
PL			48 ± 3	A
			non-native forbs	
CNTL	1.30	0.286	22 ± 2	A
NR			30 ± 2	A
PL			28 ± 3	A

[a] CNTL = control, NR = natural revegetation, PL = planted

[b] column means within vegetation groups and with the same letter are not different (α = 0.05)

Table 2.8. Percent coverage of native and non-native species (mean ± SE) by treatment at fallow crop sites (n=3), July–August 2018.

treatment[a]	$F_{[1,4]}$	*P*-value	native species[b]	
NR	3.35	0.141	94 ± 2	A
PL			92 ± 2	A
			non-native species	
NR	0.08	0.802	21 ± 5	A
PL			24 ± 4	A
			native grasses	
NR	1.42	0.356	50 ± 6	A
PL			65 ± 3	A
			non-native grasses	
NR	1.63	0.323	3 ± 1	A
PL			16 ± 4	A
			native forbs	
NR	1.01	0.0422	66 ± 5	A
PL			55 ± 5	A
			non-native forbs	
NR	0.97	0.428	18 ± 5	A
PL			7 ± 1	A

[a] CNTL = control, NR = natural revegetation, PL = planted

[b] column means within vegetation groups and with the same letter are not different (α = 0.05)

Table 2.9. Percent coverage and number of species (mean ± SE) of native spring-, summer-, and fall-flowering forbs by treatment at tall fescue sites (n=15), June–August 2018.

percent cover				
treatment[a]	$F_{[2,28]}$	P-value	spring[b]	
CNTL	6.81	0.004	3 ± 1	B
NR			9 ± 1	A
PL			9 ± 2	A
			summer	
CNTL	2.20	0.130	13 ± 2	A
NR			16 ± 2	A
PL			17 ± 1	A
			fall	
CNTL	1.99	0.156	21 ± 3	A
NR			35 ± 3	A
PL			28 ± 3	A
number of species				
			spring	
CNTL	10.70	≤ 0.001	1 ± 0.2	B
NR			2 ± 0.3	A
PL			2 ± 0.4	A
			summer	
CNTL	7.79	0.002	4 ± 0.4	B
NR			6 ± 0.4	AB
PL			7 ± 0.3	A
			fall	
CNTL	9.88	≤ 0.001	3 ± 0.7	B
NR			5 ± 0.8	A
PL			5 ± 0.7	A

[a]CNTL = control, NR = natural revegetation, PL = planted

[b]column means within analyses categories and within season with the same letter are not different (α = 0.05)

Table 2.10. Percent coverage and number of species (mean ± SE) of native spring-, summer-, and fall-flowering forbs by treatment at fallow crop sites (*n*=3), June–August 2018.

treatment[a]	$F_{[1,4]}$	*P*-value		
percent cover				
			spring[b]	
NR	3.08	0.221	1 ± 0.3	A
PL			2 ± 0.4	A
			summer	
NR	1.02	0.418	36 ± 2	A
PL			18 ± 1	A
			fall	
NR	≤ 0.01	0.994	46 ± 3	A
PL			45 ± 4	A
number of species				
			spring	
NR	1.92	0.300	1 ± 0.1	A
PL			1 ± 0.1	A
			summer	
NR	2.28	0.270	5 ± 0.3	A
PL			7 ± 0.4	A
			fall	
NR	0.74	0.480	4 ± 0.3	A
PL			5 ± 0.1	A

[a]CNTL = control, NR = natural revegetation, PL = planted

[b]column means within categories and within season with the same letter are not different (α = 0.05)

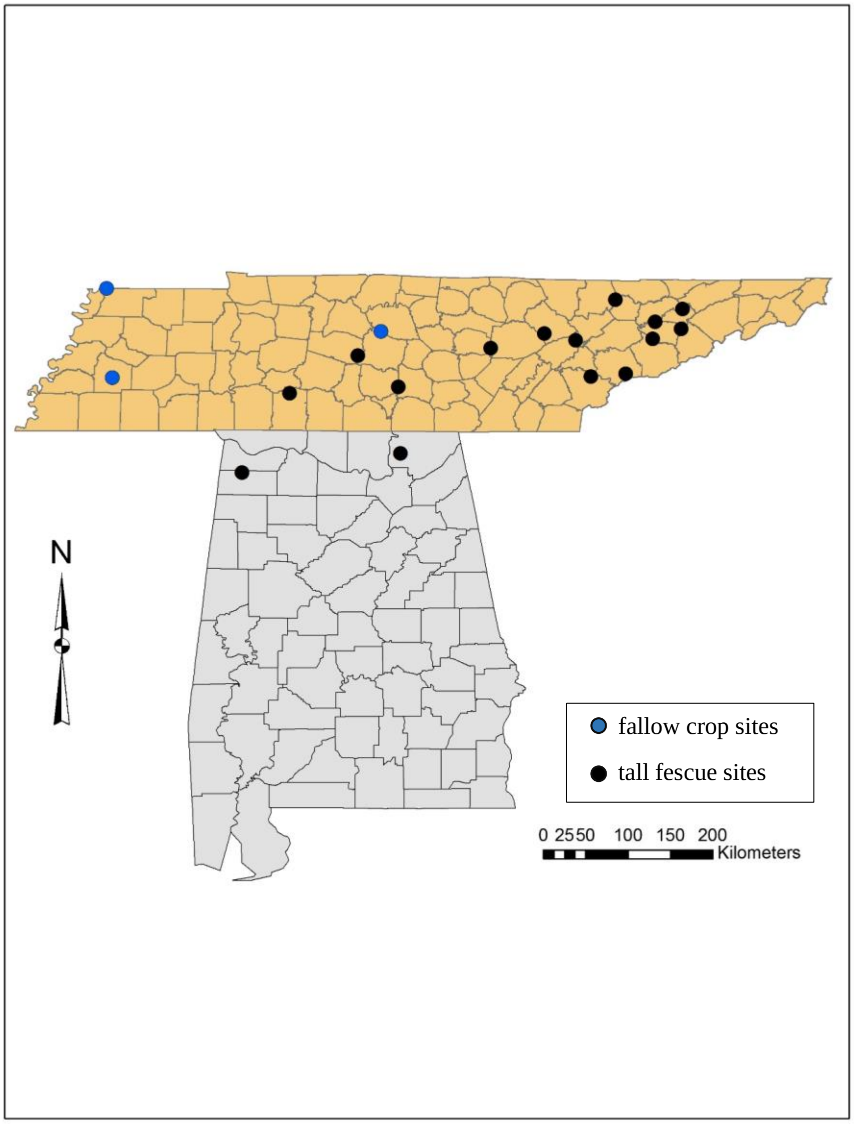

Figure 2.1. Map of 18 study sites locations in Tennessee, Alabama, and Kentucky, USA (2016-2018).

APPENDIX III: Supplemental summary statistics for chapter II (2016-2018)

Table 3.1. Summary statistics (mean ± SE) of species diversity (Shannon-Wiener index [H']), evenness (Simpson's E index [E]), and richness (S) of all treatments across three growing seasons at tall fescue sites (*n*=15), June–August 2016–2018.

	year		
	2016	2017	2018
treatment[a]		H'[b]	
CNTL	2.29 ± 0.05	2.26 ± 0.05	2.19 ± 0.04
NR	2.60 ± 0.03	2.66 ± 0.05	2.70 ± 0.04
PL	2.23 ± 0.06	2.56 ± 0.04	2.63 ± 0.04
		E[b]	
CNTL	0.23 ± 0.01	0.23 ± 0.01	0.22 ± 0.01
NR	0.29 ± 0.01	0.30 ± 0.01	0.31 ± 0.01
PL	0.26 ± 0.01	0.30 ± 0.01	0.26 ± 0.01
		S[b]	
CNTL	28 ± 1.0	27 ± 1.0	25 ± 0.8
NR	32 ± 0.8	30 ± 1.1	31 ± 0.8
PL	26 ± 0.9	28 ± 0.9	32 ± 0.9

[a]CNTL = control, NR = natural revegetation, and PL = planted

[b]statistical significance is not indicated because herbicide applications and mowing during 2016–2017 caused considerable changes to NR and PL plant communities; these data show trends in the dataset

Table 3.2. Summary statistics (mean ± SE) of species diversity (Shannon-Wiener index [H’]), evenness (Simpson’s E index [E]), and richness (S) of all treatments across three growing seasons at fallow crop sites (*n*=3), June–August 2016–2018.

	year		
	2016	2017	2018
treatment[a]		H’[b]	
NR	2.29 ± 0.20	2.33 ± 0.18	2.18 ± 0.15
PL	2.41 ± 0.08	2.79 ± 0.07	2.46 ± 0.08
		E[b]	
NR	0.24 ± 0.03	0.32 ± 0.04	0.24 ± 0.03
PL	0.30 ± 0.02	0.31 ± 0.00	0.31 ± 0.02
		S[b]	
NR	29 ± 4	25 ± 3	24 ± 2
PL	24 ± 2	32 ± 3	24 ± 1

[a]CNTL = control, NR = natural revegetation, and PL = planted

[b]statistical significance is not indicated because herbicide applications and mowing during 2016–2017 caused considerable changes to NR and PL plant communities; these data show trends in the dataset

Table 3.3. Summary statistics (mean ± SE) of native and non-native species percent coverage in all treatments across three growing seasons at tall fescue sites (*n*=15), June–August 2016–2018.

	year		
	2016	2017	2018
treatment[a]	native species[b]		
CNTL	60 ± 3.5	62 ± 3.5	63 ± 3.5
NR	86 ± 2.4	86 ± 2.4	85 ± 1.6
PL	76 ± 3.1	88 ± 2.4	89 ± 1.7
	non-native species[b]		
CNTL	90 ± 1.7	91 ± 1.2	88 ± 1.6
NR	61 ± 3.7	49 ± 2.7	40 ± 2.5
PL	31 ± 3.3	50 ± 2.9	41 ± 2.8
	native grasses[b]		
CNTL	35 ± 3.5	34 ± 3.5	33 ± 3.5
NR	49 ± 4.1	49 ± 3.8	49 ± 3.5
PL	43 ± 4.0	55 ± 3.9	61 ± 3.0
	non-native grasses[b]		
CNTL	85 ± 2.3	84 ± 2.0	81 ± 2.2
NR	26 ± 3.7	18 ± 2.5	12 ± 1.4
PL	19 ± 3.3	23 ± 3.4	17 ± 2.6
	native forbs[b]		
CNTL	31 ± 2.6	30 ± 2.9	33 ± 3.3
NR	52 ± 3.1	56 ± 2.8	53 ± 2.5
PL	39 ± 3.7	56 ± 3.0	48 ± 3.0
	non-native forbs[b]		
CNTL	29 ± 2.8	30 ± 2.8	22 ± 2.4
NR	45 ± 3.5	34 ± 2.4	30 ± 2.4
PL	14 ± 2.1	31 ± 2.9	28 ± 2.7

[a]CNTL = control, NR = natural revegetation, and PL = planted

[b]statistical significance is not indicated because herbicide applications and mowing during 2016–2017 caused considerable changes to NR and PL plant communities; these data show trends in the dataset

Table 3.4. Summary statistics (mean ± SE) of native and non-native species percent coverage in all treatments across three growing seasons at fallow crop sites (n=3), June–August 2016–2018.

	year		
	2016	2017	2018
treatment[a]	native species[b]		
NR	93 ± 2	90 ± 1	99 ± 7
PL	60 ± 2	89 ± 4	94 ± 2
	non-native species[b]		
NR	36 ± 6	37 ± 8	4 ± 1
PL	32 ± 8	35 ± 5	12 ± 3
	native grasses[b]		
NR	14 ± 4	40 ± 6	60 ± 9
PL	8 ±2	64 ± 4	65 ± 5
	non-native grasses[b]		
NR	13 ± 3	5 ± 1	2 ± 13
PL	27 ± 8	25 ± 7	8 ± 3
	native forbs[b]		
NR	87 ± 3	62 ± 9	70 ± 5
PL	52 ± 4	58 ± 8	56 ± 8
	non-native forbs[b]		
NR	21 ± 2	33 ± 3	2 ± 1
PL	7 ± 4	9 ± 2	4 ± 1

[a]CNTL = control, NR = natural revegetation, and PL = planted

[b]statistical significance is not indicated because herbicide applications and mowing during 2016–2017 caused considerable changes to NR and PL plant communities; these data show trends in the dataset

Table 3.5. Summary statistics (mean ± SE) of percent coverage and number of species of native flowering forbs by flowering season in all treatments across three growing seasons at tall fescue sites (*n*=15), June–August 2016–2018.

	year		
	2016	2017	2018
	percent cover[b]		
treatment[a]	native spring-flowering forbs		
CNTL	4.7 ± 1.0	2.6 ± 0.5	3.0 ± 0.8
NR	4.0 ± 0.9	6.7 ± 1.3	8.9 ± 1.2
PL	1.3 ± 0.3	3.6 ± 1.7	9.0 ± 1.7
	native summer-flowering forbs		
CNTL	15.4 ± 1.7	14.7 ± 1.9	12.9 ± 1.6
NR	36.9 ± 2.9	24.2 ± 2.0	15.6 ± 1.7
PL	26.6 ± 3.5	22.0 ± 1.9	16.8 ± 1.4
	native fall-flowering forbs		
CNTL	8.5 ± 1.6	14.0 ± 2.0	20.7 ± 3.0
NR	16.0 ± 2.1	29.1 ± 2.8	34.9 ± 3.1
PL	13.1 ± 2.0	35.4 ± 3.0	28.3 ± 2.9
	number of species[b]		
	native spring-flowering forbs		
CNTL	0.9 ± 0.1	0.6 ± 0.1	0.8 ± 0.1
NR	0.9 ± 0.1	0.9 ± 0.1	2.1 ± 0.2
PL	0.8 ± 0.1	1.3 ± 0.2	2.0 ± 0.2
	native summer-flowering forbs		
CNTL	4.9 ± 0.3	3.9 ± 0.3	3.8 ± 0.3
NR	7.1 ± 0.4	6.4 ± 0.5	5.6 ± 0.4
PL	6.5 ± 0.4	6.5 ± 0.3	6.8 ± 0.3
	native fall-flowering forbs		
CNTL	2.0 ± 0.2	3.1 ± 0.2	3.1 ± 0.3
NR	3.5 ± 0.3	4.7 ± 0.3	5.4 ± 0.3
PL	2.9 ± 0.2	4.0 ± 0.2	5.3 ± 0.2

[a]CNTL = control, NR = natural revegetation, and PL = planted

[b]statistical significance is not indicated because herbicide applications and mowing during 2016–2017 caused considerable changes to NR and PL plant communities; these data show trends in the dataset

Table 3.6. Summary statistics (mean ± SE) of percent coverage and number of species of native flowering forbs by flowering season in all treatments across three growing seasons at fallow crop sites (*n*=3), June–August 2016–2018.

	year		
	2016	2017	2018
	percent cover[b]		
treatment[a]	native spring-flowering forbs		
NR	5.1 ± 3.8	0.0 ± 0.0	1.1 ± 0.6
PL	0.5 ± 0.4	8.3 ± 2.0	1.6 ± 0.9
	native summer-flowering forbs		
NR	73 ± 5	36 ± 6	36 ± 5
PL	45 ± 3	35 ± 7	18 ± 3
	native fall-flowering forbs		
NR	24 ± 6	37 ± 7	46 ± 6
PL	8 ± 3	30 ± 3	45 ± 8
	number of species[b]		
	native spring-flowering forbs		
NR	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.4
PL	0.3 ± 0.1	1.7 ± 0.1	0.7 ± 0.1
	native summer-flowering forbs		
NR	9 ± 1.3	5 ± 1.0	4 ± 0.6
PL	6 ± 0.3	8 ± 0.9	5 ± 0.9
	native fall-flowering forbs		
NR	3 ± 0.3	4 ± 0.9	4 ± 1.2
PL	3 ± 0.5	6 ± 0.3	4 ± 0.1

[a]CNTL = control, NR = natural revegetation, and PL = planted

[b]statistical significance is not indicated because herbicide applications and mowing during 2016–2017 caused considerable changes to NR and PL plant communities; these data show trends in the dataset

CONCLUSION

Eradicating tall fescue in November with glyphosate (2.8 kg ai/ha) is essential to establishing early successional plant communities where tall fescue is present. A broadcast application of imazapic 0.105 kg ai/ha) is recommended in April–May the following spring to help control undesirable vegetation where needed and appropriate. The seedbank will naturally revegetate a site following tall fescue eradication and crop-field abandonment. Site history will determine which plant species emerge and dominate the community first. After assessing the initial plant community composition, land managers can make informed decisions on how to best achieve the desired plant community. Data from this study indicated that land managers should primarily use spot-spray applications to remove undesirable species. However, broadcast applications may be warranted if no desirable species are present upon initial revegetation by the seedbank. Patience and persistence are required to establish native species-dominated early successional plant communities regardless of establishment method. The seedbank at most sites likely will require multiple herbicide applications to remove undesirable species. However, in 3 growing seasons, a native species-dominated plant community can be established using the natural revegetation approach. A single monitoring and spot-spray application in spring-summer and one during fall will maintain high-quality early successional communities that are ecologically functional and provide habitat for many wildlife species. Although planting a native seed mixture may be necessary in specific situations, data from this study suggests planting rarely is needed. It is important to remember that herbicide and mowing will be necessary to establish a desirable plant community even when planting, and weedy competition can result in a failed planting. Natural revegetation and planting at both tall fescue and fallow crop sites produced similar plant communities, and resulted in desirable habitat for white-tailed deer, wild turkey, northern bobwhite, and several species of grassland and shrubland birds. Natural revegetation and PL treatments produced plant communities dominated by native species at both tall fescue and fallow crop sites. Planting NWSG increased grass coverage beyond that needed by most wildlife species, and NWSG in PL treatment units competed heavily with native forbs. Coverage of nonnative species was not different between NR and PL because the main problematic species was johnsongrass, which was treated with imazapic in some PL units and effectively reduced its coverage without harming planted species. However, sites where sericea lespedeza and bermudagrass occur, no treatment options would be available in planted fields, whereas they could easily be controlled in fields managed under the natural revegetation approach.

VITA

Wade GeFellers grew up in Greene County, Tennessee where he gained a fascination for the outdoors early in life. His fascination led to many days spent afield hunting, fishing, trapping, hiking, and exploring. Driven to make his passion for the outdoors into a career, he completed his Bachelor of Science degree in Wildlife and Fisheries Science at the University of Tennessee in 2014. Wade went on to work as a wildlife technician at Oak Ridge National Laboratory for 1.5 years before returning to the University of Tennessee to complete his Master of Science degree.