Mowing Effects on Woody Stem Density and Woody and Herbaceous Vegetation Heights Along Mississippi Highway Right-of-Ways

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Abstract

Roadside right-of-ways (ROWs) undergo regular disturbances such as mowing, maintenance, wrecks, and road developments, which affect soils, groundwater, surface hydrology, and the composition of vegetation. Roadside ROWs provide and support an environment for diverse plant communities, but management practices have reduced native grasses, wildflowers, and woody plants. Woody plants are not desirable for traffic safety, maintenance, and visibility along road ROWs. Therefore, the objectives of this study were to investigate effects of roadside mowing frequency on native and nonnative herbaceous and woody plant vertical height coverage and native and nonnative woody stem density within plant communities along highway ROWs. We subdivided 10 research plots, systematically situated along Highway 25 in Oktibbeha and Winston counties, Mississippi, to receive 1) four or more mowings annually, 2) one mowing during fall, and 3) one mowing during fall with supplemental native wildflower seeding. We differentiated upland plots on the basis of soil drainage in upward hills. Riparian (lowland) areas were influenced by overbank inundations from streams and drainages, and were typically spanned by bridges or box culverts. We used line transects to sample vegetation. We detected 277 plant species, including native and nonnative forbs, legumes, grasses, rushes, sedges, and woody perennials (vines, shrubs, and trees). Nonnative grasses exhibited the greatest percent coverage (>90%) in all treatments. Woody plants, including vines, trees, and shrubs, comprised <8% coverage throughout the study. Percent coverage of all vegetation in different height categories differed between upland and riparian elevations ($F_{1,59} = 4.65, P = 0.04$), seasons ($F_{1,59} = 12.78, P = 0.01$), and between years ($F_{1,59} = 4.91, P = 0.03$), but did not differ in height categories among treatments. Of the <8% coverage of woody plants, woody vines comprised most (>68%) of the stem counts, whereas 24% were trees and <8% were shrubs. Woody stem density did not differ among treatments or seasons, but between elevations ($F_{1,59} = 3.34, P = 0.07$) and during the 2-y study ($F_{1,59} = 3.21, P = 0.08$) as the trend was in the predicted direction ($\alpha = 0.05$). Thickets of woody vines and low-lying trees and shrubs along the roadside ROWs did not compromise height requirements needed for roadside visibility and safety. At least one mowing per year would be needed to control tree and shrub species for visibility along roadside ROWs. We concluded that a 2-y mowing regimen was no different from mowing once annually and/or more than three times annually in the plant communities in east-central Mississippi. However, one mowing/y retained agronomic plant coverage, which is useful for erosion control and soil stabilization during roadside maintenance. Proactive management implementations can include native plantings, selective herbicide use to decrease nonnatives, continual mowing from roadside edge to 10 m, and only one mowing in late fall with an extension of the boundary to reach beyond 10 m from the roadside edge to suppress invasion of woody plants. Adopting this less-frequent mowing regimen could reduce long-term maintenance costs for Mississippi highways.

Keywords: native plants; nonnative plants; east-central Mississippi; woody stem density; plant communities; reduced mowing; roadside right-of-ways (ROWs).

Received: May 21, 2018; Accepted: November 12, 2018; Published Online Early: December 2018; Published: June 2019 Citation: Entsminger ED, Jones JC, Guyton JW, Leopold BD, Strickland BK. 2019. Mowing effects on woody stem density and woody and herbaceous vegetation heights along Mississippi highway right-of-ways. Journal of Fish and Wildlife Management 10(1):19–37; e1944-687X. https://doi.org/10.3996/052018-JFWM-043

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Roadside right-of-ways (ROWS) can provide and support an environment for plant communities, but management practices have reduced native grasses, wildflowers, and woody plant species (Hill and Horner 2005; Noordijk et al. 2009; Willard et al. 2010; Yager et al. 2011; Wiggin and Meyerson 2018). Plant communities along roadside ROWs can be very diverse depending on type of road, width, slope, and adjacent land uses (Forman et al. 2003; Li et al. 2008). Roadside ROWs are described as the land area directly adjacent to the roadway and maintained by transportation agencies. Numerous studies have focused on effects of intensive mowing on plant heights and woody species densities along roadside ROWs (Webb et al. 1983; Olander et al. 1998; Milchunas et al. 2000; Bradford 2013; Entsminger 2014; Gardiner et al. 2018). Management of ROWs designed to enhance native plant communities often must not compromise soil stability, safety considerations, fire prevention measures, and visibility (Forman and Deblinger 2000; Huisjer and Cleverenger 2006; Young and Claassen 2007; Armstrong et al. 2017). Factors for roadside vegetation are safety, economics, erosion prevention, environmental stewardship, public relations, legal compliance, aesthetics, and transportation sustainability according to the 2011 American Association of State Highway and Transportation Officials Guidelines for Vegetation Management (AASHTO 2011). Specific factors of safety include vegetation height, density of woody plants, and motorist visibility for avoidance of wildlife along roadsides, such as white-tailed deer Odocoileus virginianus, American black bear Ursus americanus, coyotes Canis latrans, raccoons Procyon lotor, and various fox species (Michael and Kosten 1981; Louisiana Department of Transportation and Development 2000; Hewitt 2011; McKee and Cochran 2012; Fulbright and Ortega-Santos 2013). Visibility can be improved with frequent mowings and even a reduced mowing regimen during certain times of the year (Guyton et al. 2014; Entsminger et al. 2017).

Faunal benefits are available with proper ROW management. Proactive management of ROW vegetation can enhance establishment of native plant communities and improve their ecological function and structure for native wildlife (Arner 1959; Harper-Lore and Wilson 2000; Arner and Jones 2009; Rohinke and Cummins 2014; Cubie 2016; Armstrong et al. 2017). Concerns exist pertaining to enhancement of roadside ROW environments, such as potentially increased large mammals’ density and presence at the roadside, resulting in increased wildlife–vehicle collisions (Michael and Kosten 1981; Dixon et al. 1984; McKee and Cochran 2012; Normandeau Associates Inc. 2012). However, Normandeau Associates Inc. (2012) conducted a literature review and a survey of 24 states in the United States, and found that many studies confirmed that frequent mowing along roadsides results in regrowth of the fresh new vegetation, which attracts white-tailed deer to the roadsides. Their results indicated that deer–vehicle collision rates are not correlated to any form of mowing regimen (e.g., reduced mowing or typical frequent mowings per year [Normandeau Associates Inc. 2012]). Establishment of woody plant coverage may not always be desirable for traffic safety and visibility along road ROWs; however, establishment of certain woody plants has been reported to favor various wildlife species on ROWs (Roach and Kirkpatrick 1985). Woody plants along highway ROWs can support a variety of wildlife species (e.g., songbirds, rabbits, white-tailed deer, Eastern wild turkeys Meleagris gallopavo, and quail) and their habitat needs (Hartley et al. 1984; Johnson 2000; Folck and Kick-Raack 2005; Rohinke and Cummins 2014; Cubie 2016). However, visibility and traffic safety should take precedence over wildlife habitat. There is a need to investigate approaches for effective management options that mutually benefit agencies, motorists, and native fauna and flora and the resultant plant and animal communities along roadways.

Frequent mowings and intensive herbicide applications along ROWs can directly affect native plant communities through reduction of species diversity, plant growth, flowering, preventing their successful reproduction, and seed maturation periods (Mader 1984; Ewing et al. 2005; Hill and Horner 2005; Jones et al. 2007; Yager et al. 2011; Armstrong et al. 2017; Gardiner et al. 2018). Many fauna (i.e., large and small mammals, songbirds, waterfowl, insects, and spiders) that use roadside ROWs, roads, and railroad areas are negatively affected, with reduction of food resources and loss of shelter, nesting, denning, and escape cover (Godt et al. 1997; Forman and Alexander 1998; Spellerberg 1998; Van der Grift 1999; Forman et al. 2003; Normandeau Associates Inc. 2012). Because of the ecological impact of roads and roadside maintenance to plants and wildlife, transportation agencies and others are exploring alternatives, which have gained more attention in recent years.

Roadwork and associated disturbances to ROWs and adjacent vegetation communities can often alter plants along roadsides (Lamont et al. 1994; Angold 1997; Spellerberg 1998). With time, direct and indirect impacts
of roadside management can cause ROWs to become more susceptible to invasions of nonnative and invasive plants (Forman and Alexander 1998; Greenfield et al. 2005; Andrews et al. 2015; National Invasive Species Council 2016). Road maintenance and ROW management spread nonnative invasive plants by providing environments that are suitable for colonization (Wilcox 1989; Parendes and Jones 2000; Gelbard and Belnap 2003; Hansen and Clevevger 2005; Miller et al. 2015). This is only logical as spreading perennial nonnatives are seeded in ROW construction because of limited suitabili- ty and seed availability of dense-forming natives. When soil disturbances occur, nonnative grasses and legumes are among the most common groups that colonize roadside ROWs (Yager et al. 2011; Miller et al. 2015). In general, Simberloff et al. (2012) stated that nonnative invasive species were 40 times more problematic and costly than native species in natural environments. Other negative impacts of mowing on native species along roadsides include changes in adjacent ecosystems through modification of plant communities, changes in wetland hydrology, degradation of water quality, and dispersal of invasive nonnative species (Forman and Deblinger 2000; Mortensen et al. 2009; Yager et al. 2011; Miller et al. 2015; National Invasive Species Council 2016). Native and nonnative herbaceous vegetation can become established after soil disturbances, which reset ecological succession stages (Huijser and Clevevger 2006; Willard et al. 2010). Under conditions in which there is a lack of disturbances (i.e., prescribed burning, herbicide, disking, or mowing), plant communities go through successional growth stages (Miller and Miller 1999; Hamrick et al. 2007; Iglay et al. 2010; Miller et al. 2015; Gardiner et al. 2018; Scholtz et al. 2018). With time, woody plant species become denser and well established without disturbance that sets back succession (De Steven 1991; Myster 1993; Hodge and Harmer 1996; Hopwood et al. 2015).

Cadenasso and Pickett (2001) determined that dense woody vegetation along forest edges and near roadside ROWs serves as a barrier to slow invasion by plant species with wind-borne seeds from fields, forests, and other local sites. In Mississippi, Yager et al. (2011) reported that an increased percent coverage and density of woody vegetation along forest edges were associated with decreased seed dispersal and reduced establishment rates of invasive cogongrass Imperata cylindrica on ROWs and in adjacent forests. Native plant communities along roadsides can decrease the diversity and spread of invasive plants, reduce erosion, lessen maintenance costs, and protect water quality and wetlands (Forman and Alexander 1998; Welker and Green 2003; Yager et al. 2011; Normandeau Associates Inc. 2012; Green 2016; Wigginton and Meyerson 2018). Native plants within ROWs also create habitat for early successional wildlife species including small mammals, songbirds, herpeto-fauna, and insects (Bugg et al. 1997; Forman and Alexander 1998; Tallamy 2009; Hopwood 2010; Rohinke and Cummins 2014; Andrews et al. 2015; Cubie 2016). Although increasing native plant coverage along highway ROWs cannot completely mitigate the negative impacts to wildlife and native flora caused by roadways, the modifications in management approaches of ROWs can lessen the effects of erosion, water quality, and wetlands.

Specifically along Mississippi’s roadways, Wright (2006) determined that mowing crews must mow to a height of 15 cm and use spot treatments and selective herbicides to help control nonnative plants overall for better motorists’ visibility. Many other studies recommend frequent mowing at a height of 15.24 to 30.48 cm for visibility and safety, specifically 9.14 m from the roadside edge and near intersections (Ode 1972; Schwarzmeyer 1972; Anderson 1996; Barras et al. 2000; Wright 2006; Kutschbach-Brohl et al. 2010). Brown and Sawyer (2012) stated that raising the height of the mowers, conducting fewer mowings, and using narrower mowers could reduce disturbances, benefit native perennial wildflower species vs. annuals, and help reduce maintenance expenditures along roadside ROWs. Many studies have also found that reduced mowing combined with native plant seeding can enhance roadsides by establishing native plant communities without decreasing roadside visibility (Anderson 1996; Barras et al. 2000; Kutschbach-Brohl et al. 2010; Entsminger 2014; Guyton et al. 2014; Entsminger et al. 2018). Studies found that roadside ROW treatment regimens that include native plantings, selective herbicides to decrease nonnative grasses, and one fall mowing to reduce woody plant height could lead to lesser maintenance costs over time (Russell et al. 2005; Normandeau Associates Inc. 2012; Entsminger 2014; Hopwood et al. 2016; Armstrong et al. 2017; Entsminger et al. 2017, 2018).

Annual mowing in late fall is one low-maintenance approach that can improve native plant communities along roadsides (Entsminger 2014; Guyton et al. 2014; Armstrong et al. 2017; Entsminger et al. 2017, 2018). Reduced mowing frequencies during the growing season can result in lesser costs. The annual fall mowing can be done after seed maturation in native plants and after nesting seasons for ground-nesting birds and other wildlife (Jones et al. 2007; Arner and Jones 2009; Normandeau Associates Inc. 2012; Hopwood et al. 2015, 2016; Cubie 2016). This approach also increases availability of pollen and nectar-producing plants that provide food sources for songbirds, small mammals, and pollinating insects (Anderson 1996; Andrews et al. 2015; Hopwood et al. 2015, 2016; Dickson and Wigley 2017). Recently published research also showed an increase of native grasses and wildflower species along roadsides with a reduced mowing regimen (Entsminger et al. 2017; Wigginton and Meyerson 2018). Reduced mowing also has the potential to create attractive prairie environments along roadways by increasing native prairie grasses and wildflowers (Entsminger et al. 2018).

Therefore, the objectives of this study were to: 1) investigate influences of three mowing regimens on the community structure within vertical height coverage of native and nonnative herbaceous and woody plants along a state highway ROW in east-central Mississippi, and 2) investigate influences of three mowing regimens on the community structure of native and nonnative
woody plant stem density along a state highway ROW in east-central Mississippi. Our first approach was to compare three height categories (≤ 0.46 m; > 0.46 to ≤ 0.91 m; and > 0.91 m) for percent coverage of native and nonnative herbaceous and woody plant species among treatments (control: four or more mowings per year; treatment 1: one mowing in late-fall [reduced mowed]; and treatment 2: one mowing in late fall with native supplemental seeds [reduced mowed–seeded]) and to compare upland vs. riparian ROW study sites. Our second approach was to compare native and nonnative woody plant species’ stem densities among different treatments and to compare upland vs. riparian ROW study sites. Our first hypothesis stated that there would be no significant differences in percent coverage of vertical heights ≤ 0.46 m, > 0.46 to ≤ 0.91 m, and > 0.91 m of herbaceous and woody vegetation among the three treatments and in upland vs. riparian sites. Our second hypothesis stated that there would be no significant differences in stem densities of woody plants within vine, shrub, and tree growth forms among treatments and in upland vs. riparian sites. Information on plant community conditions under different mowing regimens can provide new approaches to enhance floristic diversity and roadside aesthetics, while resulting in lower rates of roadside maintenance and associated costs of vegetation management.

**Study site**

Our study was conducted on roadside ROWs along a 48.28-km stretch of Highway 25 beginning at the intersection of Highways 12 and 25, western edge of Starkville, Mississippi (Okolona County), and continuing south 4.5 km into Winston County, in east-central Mississippi (Figure 1). The average distance between each of the 10 research plots was 2.7 km. Plots were regionally located within the Interior Flatwoods in east-central Mississippi (33°12′N, 88°54′W; township 15–18N, range 13–14E; Leidolf et al. 2002; Edwards 2009; Kushla and Oldham 2017). Soil formation and plant communities were influenced by the mild humid subtropical climatic region of North America, with temperate winters (0–15°C) and long hot summers (21–38°C; Leidolf et al. 2002; Posner 2012; Kushla and Oldham 2017; Brown 2019). Annual mean temperature for the region is 16.67°C, whereas high temperatures exceed 32°C more than 100 d each year, with temperatures routinely exceeding 38°C (Brown 2019). Normal precipitation ranges from 127 to 165 cm across the state from north to south (Brown 2019). Our 48.28-km-long study area was crossed by third- to fourth-order streams differentiating upland and riparian plots (Figure 1). Upland areas had well-drained soils, whereas riparian areas were influenced by overbank inundations by streams and drainage ditches that were typically spanned by bridges or box culverts.

Previous highway ROW management in Mississippi consisted of multiple mowings during the growing season (more than three times per season) and selective herbicide applications such as imazapyr, triclopyr, sulfosulfuron, metsulfuron-methyl, and glyphosate Roundup® (among other herbicides depending on the target species, vegetation composition, and geographic location) to control encroaching woody vegetation and nonnative invasive plant species (e.g., johnsongrass *Sorghum halepense*, kudzu *Pueraria montana*, and cogongrass; D. Thompson, Mississippi Department of Transportation, Roadside Development Manager, personal communication). Before study initiation, the area ROW plant communities were predominately comprised of nonnative grasses including field brome *Bromus arvensis*, soft brome *Bromus hordeaceus*, Bermuda grass *Cynodon dactylon*, Italian ryegrass *Lolium perenne*, dallisgrass *Paspalum dilatatum*, bahiagrass *Paspalum notatum*, Vasey’s grass *Paspalum urvillei*, tall fescue *Schedonorus arundinaceus*, yellow foxtail *Setaria pumila*, green foxtail *Setaria viridis*, johnsongrass, and nonnative legumes, such as Japanese clover *Kummerowia striata*, sericea lespedeza *Lespedeza cuneata*, low hop field clover *Trifolium campestre*, crimson clover *Trifolium incarnatum*, white clover *Trifolium repens*, bird vetch *Vicia cracca*, and garden vetch *Vicia sativa*. The specific roadways where sites were collected were all public-access ROW and had similar traffic patterns with side roads and intersections throughout. The landscape adjacent to the ROW was comprised of primarily forests and pine plantations, with a limited number of pastures and fallow fields, with a mix of hilly and flatland topography.

**Methods**

We compared plant community characteristics along ROWs managed with different mowing regimens from 2010 to 2012. Along the highway ROW study area, we randomly selected and identified 10 plots consisting of five upland and five riparian plots (Figure 2). Study plots were 30.48 × 30.48 m in size, adjacent to the road, and line transect sampling was perpendicular to the road (Figure 2). In relation to the roadway, plots were located on the west side of Highway 25. Each study plot had a varied distance (mean = 15.33 m) from the edge of the road pavement due to the diverse width of the landscape aspect conditions and roadway characteristics of the roadside ROW overall. Similar to the study of Li et al. (2008), we used a randomized complete block design by dividing each of the 10 plots into three equal subplots (10.16 × 30.48 m each; Figure 2). We randomly assigned each of the 30 subplots one of three treatments: 1) annual mowing during November (treatment 1), 2) annual mowing during November with supplemental native wildflower seed mixture (treatment 2), and 3) mowing four or more times annually in May, July, September, and November (control). We mowed treatment 2 in late November to reduce vegetation height before seeding. We broadcasted the seed mixture onto mowed vegetation using a hand broadcasting methodology and a Scott’s® Company easy handheld broadcast seed spreader. The wildflower seed mixture included black-eyed susan *Rudbeckia hirta*, 2.24 kg/ha; dense
blazing star *Liatris spicata*, 11.21 kg/ha; and lanceleaf tickseed *Coreopsis lanceolata*, 11.21 kg/ha (Native American Seed 2019). Germination percentage rates of *R. hirta* were 86–99%, *L. spicata* were 74–80%, and *C. lanceolata* were 85–93% (Native American Seed 2019).

We measured the height and percent coverage of each herbaceous and woody species along a 30.48-m-long line transect in the middle of each subplot during summer 2010 and 2011 (July to September) and spring 2011 and 2012 (March to June). We separated the vegetation into three vertical height categories, 0.46 to 0.91 m, of herbaceous and woody vegetation to measure composition and to address vegetation heights of different growth forms (herbaceous forbs, legumes, grasses, grasslike species, etc.) and woody plants over growing seasons due to line-of-sight visibility issues associated with highway safety. Different heights are also important ecologically from the standpoint of vertical structure for wildlife. This segregation of heights addressed which herbaceous and woody species could potentially be visibility barriers for motorists. Woody plant density was counted in a belt transect 0.5 × 30.48 m to the right of each line transect to determine abundance (stems/ha; Figure 2; Hays et al. 1981; Buckland et al. 2007). Line and belt transects were <5 m from subplot edges to avoid potential edge effects, whereas line initiation and ends were marked using a Garmin E-Trex HCx Vista global positioning system GPS handheld unit to establish the same start and end points for future counts. We identified plants to species to document species richness, whereas we grouped growth forms and status categories by native and nonnative herbaceous and woody plants (i.e., trees, shrubs, and woody vines; Hays et al. 1981; Buckland et al. 2007). We grouped data by season (fall vs. spring) because of expected vegetation coverage differences within treatment plots between seasons (e.g., taller plants in fall than in spring, and certain species emerge during specific growing times).

We used mixed-effects models, univariate repeated-measures analysis of variance (ANOVA; PROC MIXED) in SAS (SAS Institute Inc. 2013; Ott and Longnecker 2015), to test hypotheses of differences in height characteristics and woody plant stem densities among treatments,
elevations, and years. We classified treatment, elevation, year, and interactions as fixed effects, whereas we classified elevation with year as random effect. We used the term elevation of upland vs. lowland as a categorical variable, not the actual elevation. We designated year as the repeated measure. We used Akaike’s information criterion corrected (AICc) for smaller sample sizes to compare autoregressive, compound symmetry, and unstructured covariance structures for each response variable using restricted maximum likelihood (Gutzwiller and Riffell 2007). We designated top model structures (i.e., best covariance structure and inclusion or exclusion of random effect) as models with ΔAICc ≤ 2 to the next best model (Burnham and Anderson 2002). We used Fisher’s least significant difference for pairwise comparisons of significant effects (Meier 2006). Level of significance for all tests was α = 0.05 (Ott and Longnecker 2015).

Results

Percent coverage of height categories

We identified 277 plant species (forbs, grasses, legumes, rushes, sedges, trees, shrubs, and woody vines) along the roadside ROWs. Native species within different categories were forbs 111, grasses 21, legumes 4, rushes 8, sedges 15, shrubs 7, trees 24, and vines 21. Nonnative species counts included 23 forbs, 18 grasses, 12 legumes, 1 sedge, and 3 vines. Nine species could not be identified; therefore their status classification was unknown. For further reference on the specific 277 plant species, see appendix A table A.1 in Entsminger (2014). We recorded the greatest plant species richness in the riparian plots, with >106 species, with an average of 82.3 species (SE ± 5.0) among all riparian plots. On all study plots, coverage of nonnative grasses averaged 88.6% (SE ± 3.0%), followed by nonnative legumes, with an average of 31.9% (SE ± 3.5%). Seven agronomic grasses, such as field brome, Bermuda grass, bahiagrass, Vasey’s grass, tall fescue, yellow foxtail, and johnsongrass, dominated the nonnative grass coverage. Native and nonnative forbs averaged >22% coverage collectively, whereas other herbaceous plants averaged <2% coverage. Percent coverage was >100% because of species overlap along each line transect (Figure 3).

Woody plant species, including vines, trees, and shrubs, comprised <8% coverage throughout the study. Of the woody plant species detected, native and nonnative woody vines were dominant. The greatest coverage of native woody vines was on upland elevations during fall seasons, with an average percent coverage of 12.0% (SE ± 4.1%), whereas the least percent coverage was nonnative vines during the fall season with an average coverage of 2.1% (SE ± 1.0%). The dominant native and nonnative woody vines included sawtooth blackberry Rubus argutus, field blackberry Rubus flagellaris, southern dewberry Rubus trivialis, Japanese honeysuckle Lonicera japonica, purple passionflower Passiflora incarnata, greenbriers Smilax spp., trumpet creeper Campsis radicans, eastern poison ivy Toxicodendron radicans, Chinese wisteria Wisteria sinensis, summer grapevine Vitis aestivalis, and muscadine grapevine Vitis rotundifolia. In the reduced mowed–seeded subplots, mean percent coverage of native forbs increased from 1.5 to 4.2% during the study, and there was a slight change in ground coverage of nonnative forbs from 1.8 to 2.2%. Additionally, in the reduced mowed–seeded plot treatments, mean percent coverage of nonnative grasses decreased from 39.5 to 25.2%, whereas native grass coverage increased from 1.1 to 5.3% during the study. Height measurements ranged from 0.3 cm to 2.4 m, with an average plant height of 1.0 m in frequently mowed areas compared with an average height of 1.0 m in areas mowed only once annually. Percent coverage of herbaceous and woody vegetation in the three height categories differed significantly between upland and riparian elevations (F1,59 > 4.65, P < 0.04) and between years (F1,59 > 4.91, P ≤ 0.03; Figure 3; Table 1). However, the herbaceous and woody vegetation percent coverage did not differ in height category among treatments (Table 1).
During fall seasons, percent coverage of herbaceous and woody plants among the three height categories did not differ among treatments, but differed between years ($F_{1,59} > 8.39, P < 0.01$; Figure 3; Table 1). Percent coverage of herbaceous and woody vegetation in the $\leq 0.46$ m and $> 0.46$ to $\leq 0.91$ m height categories did not differ between riparian and upland elevations during fall seasons (Figure 3; Table 1). The trend was in the predicted direction ($\alpha = 0.05$) among elevations in the $> 0.91$ m height category ($F_{1,59} = 3.41, P = 0.07$). Although a significant difference between years and elevations in the $> 0.46$ to $\leq 0.91$ m height category ($F_{1,59} = 3.71, P = 0.06$) during fall seasons did not occur, the trend was in the predicted direction ($\alpha = 0.05$; Table 1). Likewise, we did not observe differences among years, elevations, and treatments interactions in the $> 0.46$ to $\leq 0.91$ m height category ($F_{1,59} = 2.76, P = 0.07$) during fall seasons, but the trend was in the predicted direction ($\alpha = 0.05$; Table 1).

During spring seasons, percent coverage of herbaceous and woody plants in the three height categories did not differ among treatments; however, percent coverage in the $> 0.46$ to $\leq 0.91$ m ($F_{1,59} = 18.03, P < 0.001$) and $> 0.91$ m ($F_{1,59} = 4.91, P = 0.03$) height categories differed among years (Table 1). We did not detect differences in percent coverage in the $\leq 0.46$ m height category among study years (Table 1). However, we detected differences in

### Table 1. Test statistics for comparisons of mean percent coverage of all vegetation (herbaceous and woody) within different height categories between years, treatments, elevations, and interactions during fall and spring seasons 2010–2012 along Highway 25 right-of-way in Oktibbeha and Winston counties, Mississippi. Summary metrics include $F$-values and $P$-values significant at $\alpha = 0.05$.

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<th>Source</th>
<th>$df$</th>
<th>$F$</th>
<th>$P &gt; F$</th>
<th>$F$</th>
<th>$P &gt; F$</th>
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<td>Year $^a$</td>
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<tr>
<td><strong>Spring seasons 2011–2012 mean percent coverage of vegetation within specified height category</strong></td>
<td></td>
<td></td>
<td></td>
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<td>Year $^a$</td>
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<td>0.001$^*$</td>
<td>4.91</td>
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<td>TRT</td>
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<td>0.06</td>
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<tr>
<td>Elevation $^b$</td>
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<td>0.064$^*$</td>
<td>19.19</td>
<td>0.001$^*$</td>
<td>4.65</td>
<td>0.036$^*$</td>
</tr>
<tr>
<td>Year × TRT</td>
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<td>Year × elevation</td>
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<td>Total</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

TRT = treatments: mowed, reduced mowed, reduced mowed–seeded.

$^a$ Denotes significant differences at $\alpha = 0.05$.

$^b$ Denotes a trend toward $\alpha = 0.05$.

$^c$ Over the 2-y study period 2010–2012.

$^d$ Upland vs. lowland (riparian) elevations.
percent coverage of all three height categories ($F_{1,59} > 3.60, P \leq 0.06$) among upland and riparian elevations in spring seasons as the trend was in the predicted direction ($\alpha = 0.05$; Table 1). We also detected interactions among years and elevations of percent coverage in the $> 0.46$ to $\leq 0.91$ m height category during spring seasons ($F_{1,59} = 19.17, P \leq 0.001$; Table 1). Differences in percent coverage among three height categories was greatest during spring, whereas riparian elevations exhibited the greatest herbaceous and woody plant coverage mainly in the $\leq 0.46$ m height category (Figure 3).

**Woody plant stem densities**

Stem densities of native and nonnative woody plants ranged from a mean of 7,771.78 (SE $\pm 1,981.90$) stems/ha in year 1 to 10,025.23 (SE $\pm 2,031.12$) stems/ha in year 2 in all study plots. Woody vines comprised most (>68%) of stem densities, whereas 24% were trees and <8% were shrubs. Of the woody plants detected in the study, 91% were native species and 9% were nonnative species. The average stem density of all woody plants was greater in upland elevations during fall seasons, which ranged from 1,276.18 (SE $\pm 340.81$) stems/ha to 10,209.00 (SE $\pm 1,974.91$) stems/ha (Figure 4). In spring seasons, we recorded greatest woody stem densities in riparian elevations, with a range of 1,726.47 (SE $\pm 517.45$) stems/ha to 10,880.00 (SE $\pm 1,987.92$) stems/ha (Figure 4). Although no difference between upland and riparian elevations ($F_{1,59} = 3.34, P = 0.07$) and the 2-y study ($F_{1,59} = 3.21, P = 0.08$) occurred, the trend was in the predicted direction ($\alpha = 0.05$; Table 2). We detected no differences among treatments in woody stem densities (Table 2).

During fall seasons, stem densities of native/nonnative combined, nonnative, and native woody plants did not differ among years or treatments, but the trend was in the predicted direction in elevations ($F_{1,59} = 3.34, P = 0.07$; Table 2). Trends were discovered among elevations, but no statistical interactions among years or treatments during fall occurred (Table 2). During spring, woody plant stem densities of native/nonnative combined, native, and nonnative did not differ among treatments or elevations (Figure 4; Table 2). Although there was no difference between years ($F_{1,59} = 3.21, P = 0.08$) detected, the trend was in the predicted direction (Figure 4; Table 2). Woody plant stem density did not differ among years, treatments, or elevations when data were combined with fall and spring seasons ($F_{1,59} = 3.34, P = 0.07$; Figure 4; Table 2). No interactions among treatments or elevations occurred, but we determined trends among years during spring (Table 2). Overall, woody stem densities did not differ among treatments or seasons, but showed trends among years ($P = 0.08$) and elevations ($P = 0.07$) at $\alpha \leq 0.05$ (Table 2). Stem densities of trees and shrubs did not increase from year 1 to year 2; however, stem densities of woody vines increased greater than two-fold from year 1 to year 2 (Figure 5).

![Figure 4](http://meridian.allenpress.com/jfwm/article-pdf/10/1/19/2461548/052018-jfwm-043.pdf)

**Figure 4.** Mean woody plant stem densities of native and nonnative species between treatments (mowed, reduced mowed, and reduced mowed–seeded) and upland vs. lowland (riparian) elevations along the Highway 25 right-of-way in Oktibbeha and Winston counties, Mississippi during fall and spring seasons 2010–2012 with standard error bars variability of the means. Note: The majority (>90%) of the woody plant stem densities in the roadside plots were native species, showing statistical differences in natives vs. nonnatives among the treatments, elevations, seasons, and years.

**Discussion**

Overall, our results supported our first hypothesis: no differences among the three treatments for the herbaceous and woody vegetation. There were, however, differences among the percent coverage within vertical height categories. These results supported our second hypothesis of no differences among the three treatments within stem densities of woody plants. One mowing per year maintained height of the agronomic grass coverage, which is beneficial for erosion control and ground cover, but did not increase native plant species or coverage. In this study, height measurements ranged from 0.3 cm to 2.4 m, with an average plant height of 1.0 m in frequently mowed areas compared with an average height of 1.0 m in areas mowed once annually. Many of the plant species used on roadsides today require extensive maintenance such as mowing, which results in increased budget costs (Bradford 2013). These maintenance costs may add up to millions of dollars each year (Bradford 2013).

Due to cost considerations, mowing only once annually is recommended, since the average height of vegetation was similar across all mowing regimens and reduced-mowed treatments. Throughout the United States, studies have shown cost savings outcomes with a reduced mowing regimen (Heine 1990; Dana et al. 1996; Entsminger 2014; Guyton et al. 2014). During 2009 to 2013, cost estimates for Mississippi Department of Transportation were approximately $100/ha ($40/acre) per mowing (D. Thompson, Mississippi Department of Transportation, Roadside Development Manager, personal communication). However, with only one mowing/
costs projections could be reduced to around $25/ha ($10/acre), a savings up to 75% annually (Entsminger 2014). Dana et al. (1996) also mentioned that programs in Texas and Minnesota reduced their mowing frequency and had an annual cost savings of 35%. These benefits can be accomplished at no additional costs to taxpayers and could result in up to 75% cost savings/y for vegetation management in Mississippi. Our findings were similar to other research that focused on plants that dominated roadside ROWs with high productivity in riparian sites, especially during high rainfall periods of spring (Bush and Van Auken 1989; Burke and Grime 1996; Greenfield et al. 2005; Huijser and Clevenger 2006). Upland and riparian elevations and the seasons of sampling produced the greatest influences on vegetation height and percent coverage in this study. Likewise, Gruchy et al. (2006) also reported the greatest diversity of vegetation in the reduced-mowed treatments, with an increase in forbs, grasses, and woody plants, as opposed to the frequently mowed treatments. As these results indicated, the reduced mowed and reduced mowed–seeded subplots were similar, with no statistical differences. This could have been the result of broadcasting wildflower seeds into existing agronomic and nonnative grass coverage, which may have negatively influenced germination and poor establishment of seeded wildflowers in the reduced mowed–seeded subplots. The late sowing time frame in March could

<table>
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<th>Source</th>
<th>Combined native/ nonnative woody stem density</th>
<th>Nonnative woody stem density</th>
<th>Native woody stem density</th>
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<tr>
<td></td>
<td>(stems/ha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>P &gt; F</td>
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<tr>
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<tr>
<td>Residuals</td>
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</tr>
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<td>Total</td>
<td>59</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TRT = treatments: mowed, reduced mowed, reduced mowed–seeded. † Denotes a trend toward P < 0.05.

Spring seasons 2011–2012 woody plant stem density (stems/ha)

| Year   | 3.18      | 0.081†                       | 0.01                      | 0.910                     | 3.21         | 0.080†      |
| TRT    | 0.66      | 0.522                        | 0.31                      | 0.732                     | 0.55         | 0.583       |
| Elevation | 1.963    | 0.168                        | 0.42                      | 0.521                     | 2.32         | 0.134       |
| Year × TRT | 2.033    | 0.719                        | 0.06                      | 0.945                     | 0.35         | 0.706       |
| Year × elevation | 1.800   | 0.376                        | 0.04                      | 0.850                     | 0.88         | 0.353       |
| Elevation × TRT | 2.033    | 0.721                        | 1.10                      | 0.342                     | 0.53         | 0.591       |
| Year × elevation × TRT | 2.011 | 0.895                        | 0.38                      | 0.689                     | 0.19         | 0.830       |
| Model  | 1.080      | 0.640                        | 0.38                      | 0.959                     | 0.88         | 0.569       |
| Residuals  | 48       |                               |                           |                           |             |             |
| Total   | 59        |                               |                           |                           |             |             |

TRT = treatments: mowed, reduced mowed, reduced mowed–seeded. † Denotes a trend toward P < 0.05.

Over the 2-y study period 2010–2012.

Upland vs. lowland (riparian) elevations.

Figure 5. Mean stem densities (stems/ha) with standard error bars of the means of the 10 most common woody plant species during fall 2010 through spring 2012 along the Highway 25 right-of-way in Oktibbeha and Winston counties, Mississippi. (** Indicate nonnative, whereas all the other dominant woody species listed are native). Note: Figure shows the 10 most common woody plant species in the roadside plots and their stem density changes from year 1 to year 2.
have also been a significant factor in the delay or lack of supplemental seed growth in seeded subplots during the 2-yr study period. The hand-sowed seeding process was a similar technique that Mississippi Department of Transposition and other agencies would likely use to sow ROWs after a disturbance or maintenance of the ROW. Leaf litter from densely mowed vegetation might have acted as mulch, preventing germinating seedlings of wildflowers from contact with bare mineral soil, reducing overall seed establishment (Arner 1959; Arner et al. 1976; Bush and Van Auken 1989; Greenfield et al. 2005). The seed used had germination percentage rates of 86–99% for R. hirta, 74–80% for L. spicata, and 85–93% for C. lanceolata (Native American Seed 2019), but recorded approximately 10% success establishment rate from each seed. Additionally, Burke and Grime (1996) also reported low establishment: <10% success rates of seeding native wildflowers into a dominant nonnative agronomic grass coverage during the first growing season after seeding. However, other research indicated that greater native plant establishment occurs in areas that have received site preparation through herbicide control of agronomic plants and soil scarification (Arner 1959; Arner et al. 1976; Bush and Van Auken 1989; Greenfield et al. 2005). To improve upon future research, herbicide application and soil scarification may improve seed germination on the basis of literature review findings (Arner et al. 1976; Greenfield et al. 2005; Wright 2006; Jones et al. 2007; Armstrong et al. 2017; Wigginton and Meyerson 2018).

Height differences in herbaceous and woody plants were found among years, seasons, and elevations. Likewise, Barras et al. (2000) described differences among vegetation composition between mowed and unmowed plot treatments and discovered that native vegetation heights were greater in unmowed plots, whereas mowed plots had a lesser percentage of woody plants. They also stated that a single mowing in late fall produced vegetation height conditions similar to those of frequently mowed subplots (Barras et al. 2000), which were very comparable with results found in this study. Lack of detection of differences in herbaceous and woody plant height characteristics among treatments in this study may have resulted from drought conditions during 2010 and 2011. However, the riparian site conditions may have been associated with greater stem densities of woody plants and greater coverage of vegetation within the ≤ 0.46 m and > 0.46 to ≤ 0.91 m heights. No differences were detected in woody plant stem densities and height characteristics among mowing treatments, but differences were detected among upland and riparian elevations. Similar findings associated with elevation differences have been reported by Alexander et al. (2009), who found that vegetation heights decreased significantly as elevation increased. Other studies reported that intensive mowing regimens were related to reduced plant species diversity and decreases in plant species richness (Collins et al. 1998; Gardiner et al. 2018). They also discovered that mowing prevented woody plant species from becoming established (Collins et al. 1998; Gardiner et al. 2018), which supports the recommendation to mow once annually to set back height of vegetation growth and succession on woody plants. Without repeated mowing or prescribed burning, at least one mowing per year would be needed to control early successional tree and shrub species such as winged elm Ulmus alata, loblolly pine Pinus taeda, sweetgum Liquidambar styraciflua, eastern red cedar Juniperus virginiana, and green ash Fraxinus pennsylvanica along the roadsides in Mississippi (Arner et al. 1976; Arner 1979; Hamrick et al. 2007; Arner and Jones 2009; Entsminger 2014; Miller et al. 2015; Scholtz et al. 2018). Similarly, in this study, woody vine stem densities increased almost two-fold, whereas shrub and tree stem densities remained relatively constant (Figure 5) in the reduced mowed and reduced mowed–seeded treatments over the 2-yr study period.

The reduced mowed regimens in this study also led to a greater number of native woody vines detected in each plot. On the basis of these woody stem density results, the most abundant woody plants detected were woody vine species (Figure 5), which are precocious in growth form because of the absence of vertical structures and included greenbriers, raspberries, blackberries, dewberries, purple passionflower, Chinese wisteria, trumpet creeper, Japanese honeysuckle, poison ivy, and grapevines. Forman and McDonald (2007) stated that the advantages of increasing roadside woody vegetation far outweigh the disadvantages. They found that roadside ROWs tailored to the type of vegetation in the different situations along highways was key to success (Forman and McDonald 2007). Furthermore, many studies found that thickets of woody vines and low-lying trees and shrubs along ROWs provide good cover for pollinators, songbirds, small mammals, and other wildlife without compromising height requirements of vegetation related to roadside visibility and safety (Entsminger 2014; Guyton et al. 2014; Hopwood et al. 2015, 2016; Cubie 2016). Although our study did not investigate wildlife usage, other studies found that roadside ROWs can provide areas where native vegetation can colonize and survive, and increase habitat quality for native fauna including pollinating and nonpollinating insects, small mammals, herpetofauna, and songbirds (Svedarsky et al. 2002; Jones et al. 2007; Tallamy 2009; Andrews et al. 2015; Hopwood et al. 2015, 2016; Armstrong et al. 2017). Mowing modifications in lowlands, wetlands, riparian areas, and those areas associated with bridge crossings could also allow safe passage of wildlife beneath bridges by providing food and cover plants. Reduced mowing in these specific lowland areas could also create greater food plant abundance and cover for insects, large and small mammals, and many other wildlife species (Van der Grift 1999; Transportation Research Board and National Research Council 2005; McKee and Cochran 2012; Hopwood 2013; Cubie 2016; Hopwood et al. 2016). For example, a study in Western Europe discovered that sections of highways in the Netherlands mowed twice a year resulted in the greatest species diversity and density of native plants for pollinating insects (Bak et al. 1998).

Rather than repeated mowing and broad-spectrum herbicide use, research shows that an alternative management of ROWs by using native plants, selective herbicide use to decrease nonnative grasses, and one fall mowing to remove woody plant height is highly effective, while reducing annual maintenance costs by
upward of 75% (Russell et al. 2005; Hopwood 2010; Normandean Associates Inc. 2012; Entsminger 2014; Hopwood et al. 2016; Armstrong et al. 2017; Wigginton and Meyerson 2018). Meeting the many requirements of managing roadways can be challenging, such as meeting the needs of plant species while providing sufficient soil fertility and preventing erosion (Bradford 2013). Other challenges are managing wildlife (particularly white-tailed deer) and having good visibility for motorists. An abundance of woody shrubs and trees on roadside ROWs could result in limbs or trees falling onto the road surface and impeding motorists’ visibility at intersections; however, mowing once per year in late fall reduces the plant height, especially at >10 m from roadside berms, without compromising visibility. Reduced mowing is beneficial to the upper safe zones of the ROWs combined with a more frequent mowing regimen within 4.58 to 9.15 m of the roadside for visibility, to reduce vegetation encroachment, and prevent fire hazards on roadways (Johnson 2000; Hill and Horner 2005; Transportation Research Board and National Research Council 2005; Harper 2008; Willard et al. 2010). Brown and Sawyer (2012) suggested mowing once in midsummer and once in late fall, permitting warm-season and cool-season grasses to produce seeds, while still preventing the growth of woody plants. One way to enhance native species richness is with alternative mowing practices to allow native wildflowers and grasses to produce seeds and flourish. The prime benefits gained with reduced mowing along roadside ROWs are wildlife and landscape connectivity, driver safety and experience, and water and pollutant improvements in nearby water bodies, yet many ancillary benefits are identified (Forman and McDonald 2007). Finally, it is recommended that only one mowing be conducted after mid-October each year for Mississippi’s roadside ROWs, specifically for the outer zones (start at 9.15 m from the roadside edge and mow to the forest line). Research efforts that consider and explore other appropriate management strategies for roadside maintenance and landscape design. Washington, D.C.: U.S. Department of Transportation and the Federal Highway Administration (FWHA), Report No. FHWA-HEP-16-059.


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Mowing Effects Along Mississippi Right-of-Ways E.D. Entsminger et al.


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Data A1. Raw data (height) from over 276 plant species that were collected along a 48.28-km stretch of roadside right-of-ways in east-central Mississippi from 2010 to 2012. The data are categorized by a unique identification field with elevation (lowland, upland), site location number (1, 2, 3, 4, and 5), treatments (mow = mowing, no-mow = no mowing, and seeded = no mowing with seeding), and season/year (fall 2010, spring 2011,...), elevation (upland, lowland), season/year (fall 2010, spring 2011,...), season (fall, spring), year (2010, 2011, 2012), sites (lowland 1, lowland 2,...,upland 1, upland 2,...), treatments (mow, no-mow, and seeded), and status (native, nonnative, unknown status)/veg type (vegetation type = forb, grass, legume,...)/height of vegetation (<18-in., 18–36-in., >36-in. height category) are displayed for an overall value of percent coverage within each height category.

Data A2. Raw data (stem counts and densities in hectares) from over 1,942 woody plant species that were collected along a 48.28-km stretch of roadside right-of-ways in east-central Mississippi from 2010 to 2012. The data are categorized by season/year (fall 2010, spring 2011,...), elevation (low = lowland, up = upland), site location number (1, 2, 3, 4, and 5), TRT = treatments (mow = mowing, no mow = no mowing, and seed = no mowing with seeding), native woody stem counts, nonnative woody stem counts, total woody stem counts, total stems/ha, total stems/m², native total stems/ha, and nonnative total stems/ha. These values are displayed for an overall value of woody stem counts within each category.

Data A3. Raw data (stem count) from over 1,942 woody plant species that were collected along a 48.28-km stretch of roadside right-of-ways in east-central Mississippi from 2010 to 2012. The data are categorized by site/elevation (lowland 1, lowland 2,..., upland 1, upland 2,...), status/vegetation type/height (n= native, nn= nonnative, un= unknown status), vegetation type (forb, grass, legume,...), and the height of vegetation (<18-in., 18–36-in., >36-in. height category,...), scientific names, and percent coverage. These values are displayed for an overall value of woody stem counts within the each category.

Data A4. Raw data (vegetation percent coverage within each status and height category) from over 276 plants that were collected along a 48.28-km stretch of roadside right-of-ways in east-central Mississippi from 2010 to 2012. The data are categorized by a unique identification field, with elevation (low = lowland, up = upland), site location number (1, 2, 3, 4, and 5), treatments (mow = mowing, nmow = no mowing, and seed = no mowing with seeding), and season/year (f10 = fall 2010, sp11 = spring 2011,...). The status (n = native, nn = nonnative, un = unknown status), vegetation type (forb, grass, legume,...), and the height of vegetation (<18-in., 18–36-in., >36-in. height category) are displayed for an overall value of percent coverage.


Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S17 (2.61 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/3.


Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S18 (2.3 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/4.


Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S19 (1.48 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/5.


Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S21 (1.35 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/7.


Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S22 (633 KB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/7.


Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S23 (5.91 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/8.


Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S25 (1.59 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/10.


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Found at DOI: https://doi.org/10.3996/052018-JFWM-043.S27 (5.36 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/12.

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Found at DOI: https://doi.org/10.3996/052018-JFWM-043.530 (3.15 MB PDF); archived in Dryad Digital Repository: https://doi.org/10.5061/dryad.960dh/19.

Acknowledgments

We thank Mississippi State University (MSU) and the Mississippi Department of Transportation (MDOT) for funding this project. Thanks to the visionary input and support of D. Thompson and C. Smith at MDOT. Thanks to the assistance in the Department of Wildlife, Fisheries, and Aquaculture, College of Forest Resources, Forest and Wildlife Research Center (FWRC) at MSU, county mowing personnel, wildlife field technicians, and graduate and undergraduate students. Special thanks go to R.B. Iglay at MSU for his help with long hours of statistical analysis. E.D. Entsminger gives glory to God, Jesus his Lord and Savior, and the Holy Spirit who kept him going in the easy and difficult times of life with this research. We thank J.E. Silvius at Cedarville University, and S.W. Westlake and W.D. Jones at MSU for their review and comments that improved earlier versions of this manuscript. Finally, we also thank all the many anonymous peer reviewers and the Associate Editor who provided comments and editorial assistance that improved earlier versions of this manuscript. This publication is a contribution of the Forest and Wildlife Research Center, Mississippi State University.

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