Effects of Mid-rotation Management on the Spread of Invasive Sericea Lespedeza in Working Pine Forests

William B. Lewis[1], *Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30602*

Allison Colter, *Wildlife Resources Division, Georgia Department of Natural Resources, Richmond Hill, GA 31324*

Daniel U. Greene, *Weyerhaeuser Company, Environmental Research South, Columbus, MS 39701*

William Gulsby, *College of Forestry, Wildlife and Environment, Auburn University, Auburn, AL 36849*

Tina Johannsen, *Wildlife Resources Division, Georgia Department of Natural Resources, Social Circle, GA 30025*

Kent Keene, *Congressional Sportsmen's Foundation, Washington, DC 20003*

James A. Martin, *Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30602*

Abstract: Relatively little research has focused on the spread of sericea lespedeza (*Lespedeza cuneata*) in working pine forests of the southeastern United States despite sericea being one of the most prominent forest invaders of this region. Timber thinning is commonly used to meet forestry and wildlife habitat objectives within these forests, with thinning intensity being objective-dependent. Higher-intensity thinning may facilitate the spread of sericea or other forest invaders due to effects such as increased availability of understory sunlight and understory disturbance, though the degree to which this effect could be mitigated by common management practices is unclear. We compared the probability of sericea occurrence along transects in loblolly pine (*Pinus taeda*) stands in central Georgia treated with early growing season prescribed fire, herbicide application, and differing levels of thinning intensity to assess the effects of common mid-rotation silvicultural practices on sericea spread. We found that sericea was generally uncommon and never a major component of the understory vegetation in our study area. We found no indication that thinning intensity affected sericea spread, potentially due to the historical lack of sericea planting or invasion in the study areas. When present, sericea was reduced in the first growing season post-treatment by early growing season burns and broadcast herbicide (metsulfuron-methyl and imazapyr) application, but only the herbicide mixture provided multi-year control. While sericea is a problematic invasive species in Southeastern forests, our results suggest that timber thinning intensity and common management actions are unlikely to promote sericea spread in working pine forests.

Key words: herbicide application, invasive species, *Lespedeza cuneata*, mid-rotation timber thinning, prescribed fire

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Invasive exotic species are one of the greatest threats facing working pine forests of the southeastern U.S. (hereinafter, Southeast). Planted pines comprise over 16.8 million ha across the Southeast, most of which is composed of shortleaf (*Pinus echinata*) and loblolly (*P. taeda*) pine (Oswalt et al. 2019). Besides negative effects on biodiversity and ecological processes, invasive species can reduce timber productivity through direct mortality, modify nutrient availability, and reduce growth of regenerating seedlings (Skulman et al. 2004, Lázaro-Lobo et al. 2021, Mayfield et al. 2021). Invasive species occur over 7.7 million ha of the Southeast and are spreading at a rate of over 59,000 ha per yr (Miller et al. 2013). The economic impacts of these invasions have been conservatively reported at US$17.31 billion over the past 60 yr, with most of these costs associated with the loss of natural resources (Fantle-Lepczyk et al. 2022). Natural resource managers in the Southeast therefore require accurate knowledge about any factors which could facilitate or impede the spread of invasive species in working lands of this region.

Sericea lespedeza (*Lespedeza cuneata*; hereafter sericea) is one of the most aggressive invasive plant species in the southern and central U.S. (Miller et al. 2013, Oswalt et al. 2015). Sericea can invade disturbed and remnant plant communities, displacing native vegetation through shading and allelopathic chemicals (Adams et al. 1973, Brandon et al. 2004). Introduction of sericea can cause native grass and forb species richness to decline by almost 70% and biomass to decline by over 90% (Eddy and Moore 1998), though the magnitude of effects can be scale-dependent (McMillan et al. 2023). Many species of insects avoid sericea, and colonization can reduce the invertebrate richness of an area by over 60% (Bugg and Dutcher 1989, Eddy and Moore 1998). Furthermore, sericea is a

1. E-mail: wbl31675@uga.edu

poor food provider for socio-economically important wildlife species such as white-tailed deer (*Odocoileus virginianus*) and northern bobwhite (*Colinus virginianus*; Newlon et al. 1964, McKinney et al. 2023). Northern bobwhite are largely incapable of digesting the hard shell of sericea seeds, such that birds quickly starve when fed sericea (Newlon et al. 1964, Baldwin Blocksome 2006).

Many methods have been proposed to impede the spread of sericea, though results are often inconsistent. Herbicide application can be effective at reducing sericea cover, at least at local scales; however, effectiveness can differ based on active ingredients used and the timing of application in relation to seasonal changes in sericea physiology (e.g., Bradley and Masters 2007, Brooke et al. 2015, Brooke and Harper 2016, Turner et al. 2023). Prescribed burns have yielded mixed results as a method to reduce sericea coverage (Cummings et al. 2007, Wong et al. 2012, Alexander et al. 2021, Sherrill et al. 2022). Fires may destroy above-ground biomass and reduce the competitive ability of remaining plants (Alexander et al. 2021) but can scarify seeds and promote germination (Wong et al. 2012). Inconsistencies among studies could be explained by variations in the timing, intensity, and application of treatments, though the effectiveness of management strategies is also affected by site characteristics such as climate, vegetation communities, and other disturbances such as cattle grazing (Eisworth and Johnson 2002, Nyamai et al. 2011). Most studies researching methods of sericea control have occurred in the Great Plains or old-field areas of the eastern U.S. (Kroger et al. 2002, Farris and Murray 2009, Turner et al. 2023), but the degree to which these strategies may be applicable to other regions and vegetation types is uncertain.

Relatively little work has examined the spread and control of sericea in the working pine forests of the Southeast. These pine forests are generally thinned at mid-rotation to reduce competition. However, proper thinning also reduces canopy cover and allows for greater sunlight penetration and increased understory plant diversity (Peitz et al. 2001). In stands managed for a variety of commercially and culturally important species such as the northern bobwhite, white-tailed deer, and gopher tortoise (*Gopherus polyphemus*), mid-rotation thinning is often combined with prescribed burns and herbicide application to promote and maintain early-successional understory vegetation conditions which provide habitat for these species (Burke et al. 2008, Mixon et al. 2009, Greene et al. 2016, Greene et al. 2019).

The intensity of mid-rotation timber thinning depends on specific management objectives, as managing for bobwhite or deer often requires greater thinning intensity than is financially optimal for timber production (Huang 2009, Davis et al. 2017). Greater intensity thinning is associated with increased understory sunlight, potentially facilitating the proliferation of sericea or other invasive species compared to lower intensity thinning (Ghazoul 2004, Rebbeck et al. 2017, Bekris et al. 2021). Timber thinning may also promote invasive species through understory disturbance (Moreira et al. 2013) and can facilitate the spread of sericea to uninvaded stands if operational machinery travels from sericea-rich areas without proper cleaning (Eddy et al. 2003). Furthermore, implementing prescribed burns in thinned stands could further facilitate sericea spread. Most prescribed fires in the southeastern U.S. occur in the late-winter or early spring (Cummins et al. 2023), potentially scarifying sericea seeds and promoting sericea spread (Wong et al. 2012, Alexander et al. 2021). Only one study of which we are aware has investigated the effects of timber thinning and management actions on sericea spread. Pitman (2006) found that sericea showed little response to timber harvest in stands of longleaf pine (*P. palustris*) in Louisiana; however, this study investigated responses to harvest at previously planted sericea plots. Study plots used by Pitman (2006) were also exposed to a single harvest intensity, prescribed fire, and mechanical disking, potentially confounding the effects of each treatment on facilitating or impeding the spread of sericea.

Currently, little is known about the capacity for timber thinning operations to facilitate the spread of sericea under more natural conditions without sericea plantings, especially for working loblolly forests in the Southeast. Furthermore, no studies of which we are aware have rigorously investigated how the intensity of timber thinning may interact with common wildlife management practices to affect sericea invasions. The objectives of our study were to assess the potentially interacting effects of mid-rotation timber thinning intensity, early growing season prescribed fire, and herbicide application on the distribution and establishment of sericea in working pine forests of the Southeast. We predicted that sericea cover would increase over time post-thinning, particularly in stands of greater thinning intensity. We further predicted that early growing season fire would lead to short-term reductions in sericea due to destruction of above-ground biomass, but only herbicide application would affect long-term sericea cover reductions post-thinning.

Methods

Study Area

Our study was conducted among five loblolly pine forests (hereinafter, stands) in Greene and Hancock counties of the Piedmont region of central Georgia. Stand sizes ranged from 36–53 ha and were 13–21 yr old before thinning was initiated. Four of the five stands were primarily on moderately eroded Lloyd gravelly loam and Cataula-Cecil complex soils, though two stands were also composed of either Cecil gravelly sandy loam or Pacolet sandy loam soils (USDA NRCS 2019). The fifth stand was composed largely of Alley-Vaucluse-Lucy complex, Fuquay loamy sand, Lakeland sand, and Vaucluse-Norfolk complex soils (USDA NRCS 2019). Site index was relatively uniform across stands, ranging from 24–25 m with a base age of 25 yr (Colter 2019).

Experimental Design and Treatment Implementation

We used a split-plot design to test for effects of timber thinning, fire, and herbicide application on sericea cover. Each stand was divided into three roughly even-sized plots of 12–18 ha which were randomly assigned to one of three experimental treatments: thinning to 9.2, 13.8, or 18.4 basal area (m^2 ha^{-1}). Timber thinning occurred between April and July of 2017. We do not possess data on sericea coverage at plots prior to thinning, but instead draw conclusions by comparing changes in sericea coverage over time across a range of thinning intensities. Experimental units were also randomly assigned to treatment levels within stands to minimize the effects of any potential spatial biases in pre-thinning sericea distribution. Sericea occurrence was low immediately after thinning (see Results), suggesting that sericea coverage was likely low prior to manipulations. We note that the objective of our study was to assess the potential for timber thinning practices to facilitate invasion by sericea into Southeastern pine forests, rather than to assess control methods in established sericea areas, thereby necessitating study plots with low initial sericea coverage. Furthermore, assessing our objective required applying treatments in a manner typically undertaken by forest managers in the Southeast, rather than specifically optimized to control sericea.

Study plots were further subdivided into two subplots of 6–9 ha and randomly assigned to either a prescribed fire or no fire treatment. Prescribed burns were implemented on fire subplots on a 2-yr burn rotation. Burns were conducted in 2018 and 2020 during March–April to mimic the timing of most prescribed fires used for promoting herbaceous vegetation communities in the Southeast (Cummins et al. 2023). Burning occurred on days with temperatures between 17–28 C, 33–59% relative humidity, and ≤6 km h^{-1} wind speeds. Flame height of prescribed burns varied from 0.3–0.6 m with an average rate of spread of 20–40 m $hour^{-1}$ (Colter 2019, Keene et al. 2021).

Starting in fall 2019, subplots were subdivided again into two sub-subplots of 3–5 ha and randomly assigned to either an herbicide treatment or no herbicide treatment. The most frequently applied herbicide mixture to control non-pine vegetation in pine plantations in the Southeast is imazapyr (Arsenal® AC, BASF Corporation, Research Triangle Park, North Carolina) + metsulfuron methyl (Escort® XP, Bayer CropScience, Cary, North Carolina) which is applied to >30,000 ha annually (Shepard et al. 2004). On working forest lands, this mixture is often used during site preparation, herbaceous weed control, and conifer release. Mixture rates vary depending on the amount and composition of competing vegetation (e.g., Miller 1990, Jones and Chamberlain 2004, Shepard et al. 2004, Iglay et al. 2014). In September 2019, we applied a broadcast herbicide treatment via skidder using a mixture of 0.59 L of Arsenal® AC (imazapyr;), 0.03 L of Escort® XP (metsulfuron methyl), and 0.38 L of RRSI Sunset® (methylated seed oil concentrate; Red River Specialties, Inc., Shreveport, Louisiana) per 114 L tank applied to 0.4 ha. Imazapyr is a broad-spectrum herbicide commonly used by forest managers to control woody brush at mid-rotation, although it is also labeled to control a variety of herbaceous species. Metsulfuron methyl is a pre- and post-emergent herbicide commonly mixed with imazapyr to broaden the control of broadleaf weeds and several annual grasses. Methylated seed oil is used as a spray adjuvant to maximize the performance of post-emergent herbicides. Arsenal® AC is listed for control of members of the *Lespedeza* genus while Escort® XP is specifically listed for control of sericea. Our application rates are roughly equivalent to manufacturer specifications for control of sericea with Escort® XP but below manufacture specifications for control of *Lespedeza* with Arsenal® AC; however, application rates were in line with common application rates for control of non-pine vegetation at mid-rotation in the region. Our study design led to four different treatments at the sub-subplot level: Control (no fire or herbicide), Fire (fire but no herbicide), Herbicide (herbicide but no fire), and Mix (both fire and herbicide).

Vegetation Measurements

We conducted vegetation surveys from July–August annually during 2017–2021 along 20 m line transects established in each subplot. We used a stratified random design to choose transect locations by overlaying a 50 × 50 m grid over the subplot and randomly selecting 10 cells for transect establishment. This design led to an average of 5 transects per sub-subplot (range 3–7). Transects were oriented perpendicular to harvest rows of the pine stands. We assessed the cover of understory plant species by measuring the horizontal cover of each understory plant (<2 m in height) as in Canfield (1941). We placed a tape measure 0.5 m high along the transect and measured the horizontal width of intersection between each understory plant and the tape measure. We then summed the coverage of all sericea plants and divided by the transect length to calculate the total percentage cover of sericea for each survey. Plots were thinned to three different average basal area levels, but we also assessed the basal area at each transect to account for potential heterogeneity within plots. We used a 10-factor wedge prism to measure basal area at the midpoint of each line transect in 2017. We used basal area as a measure of the local thinning intensity at each transect.

Statistical Analysis

Due to the low cover of sericea in the study area (see Results), we used logistic regression to model the presence or absence of sericea on vegetation surveys. We modelled the probability of sericea occurrence ($P_{i,t}$) at transect i in year t based on local thinning intensity (TI_i), fire treatment ($F_{i,t}$), herbicide treatment ($H_{i,t}$), and the interaction between fire and herbicide ($F_{i,t}H_{i,t}$) as follows:

$$\text{logit}(P_{i,t}) = \text{b}_{0,i}^{(transect)} + \beta_1 TI_t + \beta_2 F_{i,t} + \beta_3 F_{i,t} TI_t + \beta_4 H_{i,t} + \beta_5 H_{i,t} TI_t + \beta_6 F_{i,t} H_{i,t} + \beta_7 F_{i,t} H_{i,t} TI_t + \beta_8 R_{i,t} + \beta_Y t$$

We incorporated a temporal effect for fire and herbicide treatments because the prescribed burns began in 2018, and herbicide application began after the 2019 vegetation surveys. Transects in the fire treatment therefore started in the control treatment in 2017 before switching to the fire treatment in 2018–2021. Similarly, transects could stay in the control treatment from 2017–2019 before switching to the herbicide treatment for 2020–2021, or could switch from the control treatment to the fire treatment in 2018 and then from the fire treatment to the mix treatment from 2020–2021. Prescribed burns were initiated on a 2-yr rotation while herbicide application only occurred in the fall of 2019. Under both treatments, the vegetation response could differ between the first growing season post-treatment (treatment year) and second growing season post-treatment (recovery year). With only one application of herbicides in late 2019, we were unable to estimate separate recovery effects for each treatment. We therefore assumed that the effect of the recovery year ($R_{i,t}$) would be similar between fire and herbicide treatments. We estimated separate effects for each year 2018–2021 ($\beta_Y t$), with 2017 corresponding to the intercept, to account for differences in weather or other environmental conditions between years which could affect sericea growth. We also incorporated interaction effects between thinning intensity, fire, and herbicide application.

To account for repeat surveys at the same transects across years, we estimated separate intercepts for each transect ($\text{b}_{0,i}^{(transect)}$). Because transects were nested within subplots in the experimental design, we modeled the transect-specific intercepts as arising from a Normal distribution with a subplot-specific mean ($\text{b}_{0,k}^{(subplot)}$):

$$\text{b}_{0,i}^{(transect)} \sim Norm\ (\text{b}_{0,k}^{(subplot)}, \sigma^{(subplot)})$$

with the subscript k denoting the subplot associated with transect i. We used a similar framework to nest subplots within plots ($\text{b}_{0,m}^{(plot)}$, $\sigma^{(plot)}$) and plots within stands ($\text{b}_{0,n}^{(stand)}$, $\sigma^{(stand)}$).

We fit our model in a Bayesian framework with Markov chain Monte Carlo (MCMC) simulations in the NIMBLE package (de Valpine et al. 2017) in R (R Core Team 2020). We incorporated vague Normal and Uniform priors on all parameters. Posterior distributions were estimated using three MCMC chains of 50,000 iterations and a burn-in period of 3000 iterations. We assessed model convergence through the Gelman-Rubin statistic and visual inspection of MCMC chains. We present posterior medians and 95% credible intervals (CrI) of the posterior samples for logit-scale β parameters in the Results.

Results

We detected sericea on 192 (13.9%) of the 1377 vegetation surveys performed during 2017–2021. During the first year (2017), sericea was detected at all stands but only 30 of 50 subplots, averaging detection on 10% of surveys per subplot (range 0–40%). By 2021, sericea was detected at all stands and subplots with sericea detected on 28% of surveys per subplot on average (range 0–80%). Though occurrence of sericea was highly variable across subplots, most of this variation was explained by stand-level differences in sericea coverage (see below). Sericea was not a dominant member of the understory vegetation community in our study area when present. The total cover of sericea at occupied sites averaged 2.3% (SD = 3.3%) and never exceeded 23% for any vegetation survey.

The probability of sericea occurrence on vegetation surveys varied by stand, year, and treatment. The probability of occurrence was generally higher in one of the stands dominated by moderately-eroded Lloyd gravelly loam and Cataula-Cecil complex soils (back-transformed estimate of $\text{b}_{0,1}^{(stand)}$: 0.18, 95% CrI 0.06–0.46) than in the other stands (average back-transformed estimate of $\text{b}_{0,2:5}^{(stand)}$: 0.05, 95% CrI 0.02–0.11), though uncertainty was high. Probability of occurrence increased during 2018 (1.45; 0.78–2.13) and 2021 (2.15; 1.39–2.92) but declined during 2020 (-1.81; -3.41– -0.55, Figure 1). After controlling for effects of stand and year, we found that both herbicide application (-2.04; -3.22– -0.95) and prescribed fire (-0.98; -1.80– -0.16) significantly decreased the probability of occurrence of sericea (Figure 2). The probability of occurrence increased in the recovery year (0.97; 0.06–1.88, i.e., second growing season after treatment) for both treatments; however, recovery-year occurrence probability was equivalent between control and fire treatments but lower in any herbicide treatment (herbicide only or mix, Figure 2). We did not detect an effect of thinning intensity (-0.19; -0.59–0.19) or any interaction among thinning intensity and any of the treatments (herbicide: 0.01, CrI -0.72–0.69; fire: 0.14, -0.37–0.64; fire and herbicide: -0.16, -1.19–0.88). We also did not detect an interaction between herbicide application and prescribed fire (0.94; -0.32–2.20) on sericea occurrence.

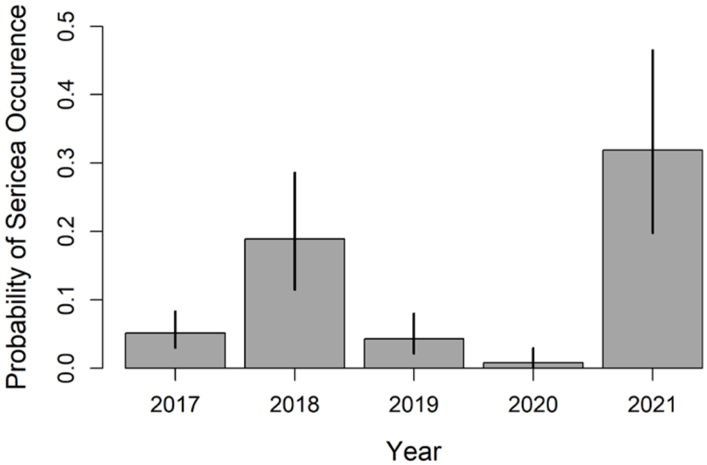

Figure 1. Model-predicted probability of occurrence of sericea lespedeza (*Lespedeza cuneata*) at vegetation survey transects at five pine stands thinned mid-rotation in central Georgia, 2017–2018. Predictions were generated under the control treatment (no prescribed fire or herbicide application) at the mean thinning intensity across transects (16.8 m^2 ha^{-1} basal area). Means and 95% credible intervals are shown.

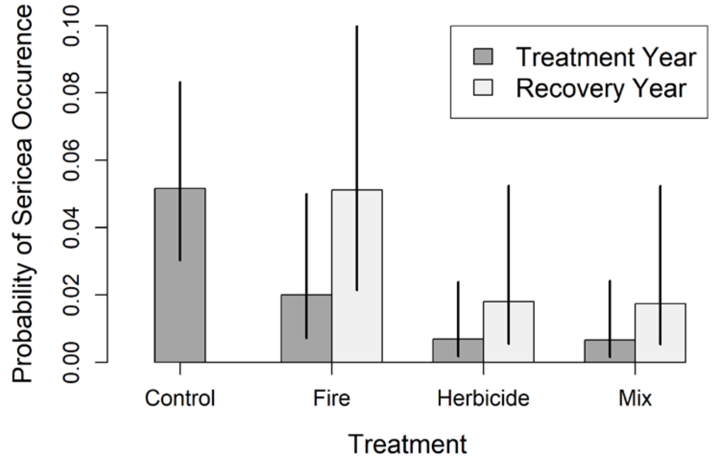

Figure 2. Model-predicted probability of occurrence of sericea lespedeza (*Lespedeza cuneata*) at pine stands in central Georgia in relation to four management treatments: neither prescribed fire nor herbicide application (Control), prescribed fire (Fire), herbicide application (Herbicide), or both prescribed fire and herbicide application (Mix). Predictions were generated for 2017 at the mean thinning intensity across transects (16.8 m^2 ha^{-1} basal area). Means and 95% credible intervals are shown. Prescribed fire and herbicide application were implemented with a treatment year (first growing season since treatment, dark gray) and recovery year (second growing season since treatment, light gray).

Discussion

We found little indication that mid-rotation timber thinning promoted the spread of sericea into working pine stands. Sericea was a generally uncommon member of the understory vegetation community post-thinning, and we found no relationship between thinning intensity and sericea occurrence. An effect of timber thinning could have been masked if sericea coverage varied widely pre-thinning, such that we were unable to detect the effect without comparing pre-and-post thinning data. This explanation seems unlikely, as sericea only constituted a minor component of the understory vegetation across all stands regardless of thinning intensity, even several years post-thinning. The negligible effect of thinning intensity on sericea spread observed in our study is similar to Pitman (2006), who found that sericea does not rapidly spread through managed pine forest following timber thinning.

The lack of response by sericea to different thinning intensities may reflect the history of the study area. In the Southeast, sericea is most common and persistent in areas where it has historically been planted, such as roadsides and reclaimed mines (Lemke et al. 2013, Miller et al. 2013). In contrast, our study sites have never, to our knowledge, been seeded with sericea, and it was likely introduced by animals or equipment. Furthermore, herbicides were applied at all stands prior to tree planting before the study began. This lack of a colonization foothold may have prevented sericea from responding more to variation in thinning intensity.

In contrast to the results for timber thinning intensity, we found strong negative and persistent effects of herbicide application on occurrence of sericea. We cannot definitively separate the effects of the two herbicides through our study design; however, metsulfuron-methyl has frequently been found to be effective or moderately effective at controlling sericea (Bradley and Masters 2007, Brooke et al. 2017), including for multiple growing seasons post-treatment (Kroger et al. 2002). Sericea occurrence increased only slightly in the second growing season post-spraying, and remained below control levels, suggesting that the herbicide mixture may effectively reduce sericea coverage post-disturbance for at least 2 yr in our study system. Forest managers in the Southeast commonly apply an Arsenal® AC and Escort® XP mixture following mid-rotation thinning to reduce non-pine woody vegetation and increase coverage of understory herbaceous vegetation important to a variety of wildlife species. Our results suggest that this treatment can also provide the added benefit of impeding any potential spread of sericea into pine forests post-thinning.

Early growing season burning had a more complicated effect on sericea occurrence than did herbicide application. Though sericea coverage was initially decreased in the months after burning, early growing season burns were not able to generate sustained sericea suppression beyond the growing season following the burn. This lack of sustained fire effect may be attributable to the timing of the burns. Burning may scarify seeds and stimulate germination in the spring (Wong et al. 2012), though we note that early growing season burning did not increase sericea coverage above control levels in our study. Prescribed burns later in the growing season can achieve effective control by reducing seed production and survival during the non-growing season (Alexander et al. 2021), however, these are unlikely to be an effective strategy for slowing sericea invasions in the Southeast because prescribed burns in this region are generally preformed during the late winter and early spring (Cummins et al. 2023). Our results suggest that herbicide application is likely to be more effective than early growing season burns for impeding potential sericea invasions into loblolly pine stands post-thinning, though the long-term effects of these management actions on sericea are unknown.

We also found that the probability of sericea occurrence varied over time, independent of treatment effects. These fluctuations are likely attributed to changing environmental conditions rather than a long-term response to timber thinning or initial thinning intensity. The probability of occurrence was greatest during the last year of the study (2021); however, the year before had the least probability of occurrence with almost no cover of sericea. This region of central Georgia experienced moderate-to-severe drought from the late summer through early winter of 2019 (NOAA NCEI 2023). Severe drought may have reduced the seed yield of sericea during 2019 (Hoveland et al. 1971), thereby leading to low coverage the following year. Our study area then experienced wetter conditions in 2020, which could have led to the substantial increase in sericea occurrence by 2021.

Though we found generally low sericea occurrence at our study sites, our results should not be taken to mean that sericea is not a problematic invasive species in the Southeast. Sericea is one of the worst invasive species in southeastern forests and is spreading at a rate of 3076 ha per yr (Miller et al. 2013, Oswalt et al. 2015). Instead, our results and those of Pitman (2006) suggest that varying the intensity of timber thinning may do little to further facilitate the spread of sericea regardless of whether stands are already invaded by sericea or not. Furthermore, any potential invasions can be reduced, but not completely eradicated, through application of an herbicide mixture that is frequently used in the Southeast for conifer release and herbaceous weed control. Our results show that three commonly applied management actions, mid-rotation thinning, early growing season prescribed burns, and herbicide application, are unlikely to facilitate invasions of sericea into working pine forest of Georgia.

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Literature Cited

Adams, W. E., H. D. Morris, J. Giddens, R. N. Dawson, and G. W. Langdale. 1973. Tillage and fertilization of corn grown on Lespedeza sod. Agronomy Journal 65:653–655.

Alexander, J. A., et al. 2021. Effects of prescribed fire timing on vigor of the invasive forb sericea lespedeza (*Lespedeza cuneata*), total forage biomass accumulation, plant-community composition, and native fauna on tallgrass prairie in the Kansas Flint Hills. Translational Animal Science 5:1–6.

Baldwin Blocksome, C. E. 2006. Sericea lespedeza (*Lespedeza cuneata*): Seed dispersal, monitoring, and effect on species richness. Doctoral dissertation, Kansas State University, Manhattan.

Bekris, Y., J. S. Prevéy, L. C. Brodie, and C. A. Harrington. 2021. Effects of variable-density thinning on non-native understory plants in coniferous forests of the Pacific Northwest. Forest Ecology and Management 502:119699.

Bradley, K. and R. A. Masters. 2007. Influence of selected pasture herbicides and application timings on sericea lespedeza control. Forage and Grazinglands 5:1–6.

Brandon, A. L., D. J. Gibson, and B. A. Middleton. 2004. Mechanisms for dominance in an early successional old field by the invasive non-native *Lespedeza cuneata* (Dum. Cours.) G. Don. Biological Invasions 6:483–493.

Brooke, J. M. and C. A. Harper. 2016. Herbicides are effective for reducing dense native warm-season grass and controlling a common native species, sericea lespedeza. Journal of the Southeastern Association of Fish and Wildlife Agencies 3:178–184.

_____, et al. 2015. Habitat manipulation influences northern bobwhite resource selection on a reclaimed surface mine. Journal of Wildlife Management 79:1264–1276.

_____, et al. 2017. Northern bobwhite breeding season ecology on a reclaimed surface mine. Journal of Wildlife Management 81:73–85.

Bugg, R. L. and J. D. Dutcher. 1989. Warm-season cover crops for pecan orchards: Horticultural and entomological implications. Biological Agriculture and Horticulture 6:123–148.

Burke, J. D., M. J. Chamberlain, and J. P. Geaghan. 2008. Effects of understory vegetation management on brood habitat for northern bobwhites. Journal of Wildlife Management 72:1361–1368.

Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39:388–394.

Colter, A. G. 2019. Northern bobwhite habitat condition response to mid-rotation loblolly pine management. Master's thesis, University of Georgia, Athens.

Cummings, D. C., S. D. Fuhlendorf, and D. M. Engle. 2007. Is altering grazing selectivity of invasive forage species with patch burning more effective than herbicide treatments? Rangeland Ecology and Management 60:253–260.

Cummins, K., et al. 2023. The Southeastern U.S. prescribed fire permit database: Hot spots and hot moments in prescribed fire across the Southeastern U.S.A. Fire 6:372.

Davis, P. B., I. A. Munn, J. E. Henderson, and B. K. Strickland. 2017. Economic tradeoffs of managing for timber production or wildlife habitat. Journal of Wildlife Management 81:1363–1371.

de Valpine, P., D. Turek, C. J. Paciorek, C. Anderson-Bergman, D. T. Lang, and R. Bodik. 2017. Programming with models: Writing statistical algorithms for general model structures with NIMBLE. Journal of Computational and Graphical Statistics 26:403–413.

Eddy, T. A., J. Davidson, and B. Obermeyer. 2003. Invasion dynamics and biological control prospects for sericea lespedeza. Great Plains Research 13:217–230.

______ and C. M. Moore. 1998. Effects of sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Don) invasion on oak savannas in Kansas. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 86:57–62.

Eiswerth, M. E. and W. S. Johnson. 2002. Managing nonindigenous invasive species: Insights from dynamic analysis. Environmental and Resource Economics 23:319–342.

Fantle-Lepczyk, J. E., et al. 2022. Economic costs of biological invasions in the United States. Science of the Total Environment 806:151318.

Farris, R. L. and D. S. Murray. 2009. Control of seedling sericea lespedeza (*Lespedeza cuneata*) with herbicides. Invasive Plant Science and Management 2:337–344.

Ghazoul, J. 2004. Alien abduction: Disruption of native plant-pollinator interactions by invasive species. Biotropica 36:156–164.

Greene, R. E., R. B. Iglay, K. O. Evans, D. A. Miller, T. B. Wigley, and S. K. Riffell. 2016. A meta-analysis of biodiversity responses to management of southeastern pine forests-opportunities for open pine conservation. Forest Ecology and Management 360:30–39.

______, ______, ______, T. B. Wigley, and D. A. Miller. 2019. Estimating capacity of managed pine forests in the southeastern U.S. to provide open pine woodland condition and gopher tortoise habitat. Forest Ecology and Management 432:200–208.

Hoveland, C. S., G. A. Buchanan, and E. D. Donnelly. 1971. Establishment of sericea lespedeza. Weed Science 19:21–24.

Huang, C. H. 2009. Economics of northern bobwhite and timber management in the southeastern United States. Journal of Wildlife Management 73:1355–1361.

Iglay, R. B., B. D. Leopold, and D. A. Miller. 2014. Vegetation responses to fire and herbicide in intensively managed, mid-rotation pine. Forest Ecology and Management 328:69–78.

Jones, J. D. J. and M. J. Chamberlain. 2004. Efficacy of herbicides and fire to improve vegetative conditions for northern bobwhites in mature pine forests. Wildlife Society Bulletin 32:1077–1084.

Keene, K. A., et al. 2021. Short-term effects of loblolly pine thinning intensity on coverage of preferred white-tailed deer forage plants. Canadian Journal of Forest Research 51:604–610.

Kroger, C. H., J. F. Stritzke, and D. C. Cummings. 2002. Control of sericea lespedeza (*Lespedeza cuneata*) with triclopyr, fluroxypyr, and metsulfuron. Weed Technology 16:893–900.

Lázaro-Lobo, A., R. D. Lucardi, C. Ramirez-Reyes, and G. N. Ervin. 2021. Region-wide assessment of fine-scale associations between invasive plants and forest regeneration. Forest Ecology and Management 483:118930.

Lemke, D., C. J. Schweitzer, I. A. Tazisong, Y. Wang, and J. A. Brown. 2013. Invasion of a mined landscape: What habitat characteristics are influencing the occurrence of invasive plants? International Journal of Mining, Reclamation and Environment 27:275–293.

Mayfield, A. E., et al. 2021. Impacts of invasive species in terrestrial and aquatic systems in the United States. Pages 5–40 *in* T. M. Poland, T. Patel-Weynand, D. M. Finch, C. F. Miniat, D. C. Hayes, and V. M. Lopez, editors. Invasive species in forests and rangelands of the United States: A comprehensive science synthesis for the United States forest sector. Springer, New York, New York.

McKinney, C. M., et al. 2023. Forage quantity and protein concentration changes across a forest-savanna gradient with management implications for white-tailed deer. Forest Ecology and Management 538:120987.

McMillan, N. A., S. D. Fuhlendorf, C. A. Davis, R. G. Hamilton, L. K. Neumann, and S. M. Cady. 2023. A plea for scale, and why it matters for invasive species management, biodiversity and conservation. Journal of Applied Ecology:1468–1480.

Miller, J. H. 1990. Directed foliar sprays of forestry herbicides for loblolly pine release. Southern Journal of Applied Forestry 14:199–206.

______, D. Lemke, and J. Coulston. 2013. The invasion of southern forests by nonnative plants: Current and future occupation, with impacts, management strategies, and mitigation approaches. Pages 397–456 *in* D. N. Wear and J. G. Greis, editors. The Southern Forest Futures Project: Technical Report. U.S. Forest Service General Technical Report SRS-178. Southern Research Station, Asheville, North Carolina.

Mixon, M. R., S. Demarais, P. D. Jones, and B. J. Rude. 2009. Deer forage response to herbicide and fire in mid-rotation pine plantations. Journal of Wildlife Management 73:663–668.

Moreira, F., et al. 2013. Occurrence of native and exotic invasive trees in burned pine and eucalypt plantations: Implications for post-fire forest conversion. Ecological Engineering 58:296–302.

National Oceanic and Atmospheric Administration, National Centers for Environmental Information (NOAA NCEI). 2023. Historical Palmer Drought Indices. <https://www.ncei.noaa.gov/access/monitoring/historical-palmers/>. Accessed on 15 June 2023.

Newlon, C. F., T. S. Baskett, R. P. Breitenbach, and J. A. Stanford. 1964. Sustaining values of emergency foods for bobwhites. Journal of Wildlife Management 28:532–542.

Nyamai, P. A., T. S. Prather, and J. M. Wallace. 2011. Evaluating restoration methods across a range of plant communities dominated by invasive annual grasses to native perennial grasses. Invasive Plant Science and Management 4:306–316.

Oswalt, C. M., et al. 2015. A subcontinental view of forest plant invasions. NeoBiota 24:49–54.

Oswalt, S. N., W. B. Smith, P. D. Miles, and S. A. Pugh. 2019. Forest resources of the United States, 2017: A technical document supporting the Forest Service 2020 RPA assessment. USDA Forest Service General Technical Report WO-97, Washington, D.C.

Peitz, D. G., M. G. Shelton, and P. A. Tappe. 2001. Forage production after thinning a natural loblolly pine-hardwood stand to different basal areas. Wildlife Society Bulletin 29:697–705.

Pitman, W. D. 2006. Stand characteristics of sericea lespedeza on the Louisiana Coastal Plain. Agriculture, Ecosystems and Environment 115:295–298.

R Core Team. 2020. R: A language and environment for statistical computing. Version 4.1.1. R Foundation for Statistical Computing, Vienna, Austria.

Rebbeck, J., T. Hutchinson, L. Iverson, D. Yaussy, and T. Fox. 2017. Distribution and demographics of *Ailanthus altissima* in an oak forest landscape managed with timber harvesting and prescribed fire. Forest Ecology and Management 401:233–241.

Shepard, J. P., J. Creighton, and H. Duzan. 2004. Forestry herbicides in the United States: An overview. Wildlife Society Bulletin 32:1020–1027.

Sherrill, C. W., S. D. Fuhlendorf, L. E. Goodman, R. D. Elmore, and R. G. Hamilton. 2022. Managing an invasive species while simultaneously conserving native plant diversity. Rangeland Ecology and Management 80:87–95.

Skulman, B. W., J. D. Mattice, M. D. Cain, and E. E. Gbur. 2004. Evidence for allelopathic interference of Japanese honeysuckle (*Lonicera japonica*) to loblolly and shortleaf pine regeneration. Weed Science 52:433–439.

Turner, M. A., et al. 2023. Sericea lespedeza control with postemergence and preemergence herbicide applications in fields managed for northern bobwhite. Wildlife Society Bulletin 47:e1442.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 2019. Web Soil Survey. <https://websoilsurvey.nrcs.usda.gov/app/>. Accessed on 15 May 2023.

Wong, B. M., G. R. Houseman, S. E. Hinman, and B. L. Foster. 2012. Targeting vulnerable life-stages of sericea lespedeza (*Lespedeza cuneata*) with prescribed burns. Invasive Plant Science and Management 5:487–493.