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A comparison of different chemical control application methods for managing *Elaeagnus pungens* in South Carolina

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Abstract

Several *Elaeagnus* species (autumn olive [*Elaeagnus umbellata* Thunb.], Russian olive [*Elaeagnus angustifolia* L.], and thorny olive [*Elaeagnus pungens* Thunb.]) are invasive in North America. *Elaeagnus pungens* is prevalent throughout much of the southeastern United States, commonly overtaking wooded and natural areas, bottomlands, and roadsides. While many management methods, including several herbicide treatments, have been evaluated, the efficacy of these methods can vary based on the size and density of the target plants. Further, personal communication with land managers revealed a lack of information that incorporated application effort, duration, and associated cost into treatment efficacy and usefulness. We evaluated three herbicide application methods using the free acid formulation of triclopyr in an *E. pungens*–infested forest in South Carolina, USA, to determine the effectiveness of each application method. We estimated pretreatment *E. pungens* biomass and destructively harvested all live material posttreatment to obtain actual biomass values. Foliar herbicide application was ineffective, but both cut stump and basal bark application nearly eliminated *E. pungens* in the treatment plots. The basal bark application took slightly more time to complete than cut stump treatments but was described as less physically demanding by applicators. Based on treatment efficacy and time required, the basal bark application method seems most prudent for controlling *E. pungens* in these areas. These results will help land managers more effectively use their resources for invasive woody plant control.

Introduction

An expansion in global trade and travel has increased the number of invasive species impacting natural and managed systems worldwide (Essl et al. 2020; Liebhold 2012; Seebens et al. 2017) and led to a drastic rise in global costs associated with invasive species management (Crystal-Ornelas et al. 2021). In the United States alone, invasive species costs ranged between US$18.2 billion and US$78.9 billion between 1970 and 2020 (Diagne et al. 2021; Zenni et al. 2021). Additionally, natural and managed systems can be negatively impacted, as native species are often outcompeted by unchecked invasive species populations, which can lead to a reduction in biodiversity and the alteration of entire trophic cascades (Beschta and Ripple 2009; Kimbro et al. 2009; Schmitz et al. 2000). Economic and ecological impacts associated with introduction of invasive species will only continue to escalate over time without significant regulatory intervention.

The southeastern United States, with its long growing season and warm, humid climate, is an ecologically diverse region with a rich forestry history, economy, and production potential (Carter et al. 2021; Napton et al. 2010). However, forests in this region are also impacted by many invasive plant species (Oswalt et al. 2015). Invasive plants are adept at establishing and flourishing in areas where management activities (e.g., logging, clearing, burning, fire suppression, and reforestation) and the indirect effects of climate change disrupt forest ecosystems (Holmes et al. 2009). Several invasive shrub species in the region are known to outcompete native flora and dominate the forest understory (Maynard-Bean et al. 2020); these species include Chinese privet (*Ligustrum sinense* Lour.), bush honeysuckles (*Lonicera* spp.); and silverberry or olives (*Elaeagnus* spp.).

Elaeagnus pungens (Thunb.), colloquially known as thorny olive, silverthorn, thorny elaeagnus, spiny oleaster, or silverberry, is a broadleaved evergreen shrub native to Japan and China (Figure 1). It was introduced as an ornamental species in 1830 and later promoted for wildlife (Davison 1942) and now occurs throughout the southeastern (and in parts of the northeastern) United States (Miller 2006). *Elaeagnus pungens* is a multistemmed, freely branched, dense shrub that can reach 7.5-m tall and 4.5-m wide; it can use other species to support branch growth and

Management Implications

Elaeagnus pungens (thorny olive) is an aggressive invasive shrub in North America that can take over natural areas and impact the ecology of the local environment. Material and labor costs associated with controlling this shrub can be high, and land managers need effective methods to reduce or eliminate *E. pungens* growth. Management of *E. pungens* can be uniquely challenging for several reasons. The thorns of the felled plant material or sprawling branches can puncture tires of equipment used in management activities, and cause injury to people working in these areas. The thick growth of particularly aggressive stands of *E. pungens* can result in a damp, shady forest floor and a lack of adequate fuel, precluding prescribed burning treatments. We evaluated three herbicide application methods using triclopyr as the free acid formulation (Trycera®): foliar, basal bark, and cut stump, in central South Carolina, USA, to determine the fastest, easiest management approach with maximum control efficacy. We prioritized treatment methods that could be applied with limited personnel (two to three applicators) and without motorized vehicles. We evaluated these factors to help land managers more effectively use their resources, limit the introduction of herbicides into the environment, and determine a reliably effective method to kill *E. pungens* plants. Basal bark and cut stump treatments were much more effective in reducing *E. pungens* biomass in our plots than the foliar treatment. Between basal bark and cut stump treatment methods, we recommend basal bark due to its relative ease of application compared with the cut stump application method and equal efficacy in terms of controlling *E. pungens*. This approach should be used as part of an integrated management strategy, and further studies should evaluate other management tactics to reduce seedling germination success and control the vigorous resprouting associated with *E. pungens* growth.

climb opportunistically (Serviss and Tumlison 2021; Figure 1A and 1F). Once established, this shrub produces copious, fast-growing branch "whips" that allow the plant to quickly increase in size and overtake neighboring vegetation (Figure 1A). Additionally, root suckering and prolific stem sprouts can lead to dense understory growth in a forested setting (Miller 2006). The stems produce thorns, and the leaves are tough and waxy with a dark green surface and an underside that is silvery with brown scales (Figure 1B, C, and E). In the southeastern United States, *E. pungens* benefits from an especially lengthy growing season that allows it to outcompete native plants (Riffe 2018). Specifically, *E. pungens* flowers and fruits for approximately 10 mo out of the year (Dirr 1990; Miller 2006). The fruit—fleshy red drupes—is readily consumed by birds and other animals that disperse it across large areas (Davison 1942), allowing *E. pungens* to quickly spread across the landscape (Figure 1C and 1D). *Elaeagnus pungens* readily grows in a variety of environmental conditions (open sun, forested settings, frequently flooded areas, disturbed sites, etc.) and is often a problem in fencerows, roadside margins, waste areas, and open woodlands.

Despite demonstrated deleterious ecological impacts, *Elaeagnus* spp. are still commonly sold in nurseries and online and are cultivated for hedges, screening, natural barriers, bank stabilization along highways, and landscape uses (Beaury et al. 2021; Fertakos et al. 2023). *Elaeagnus* spp. have been shown to reduce the abundance of native species, facilitate the establishment of other non-native plants, and cause long-lasting impacts on local soil characteristics and flora (Collette and Pither 2015; Katz et al. 2020). Their presence impacts soil microbial communities (Malinich et al. 2017) and alters stream biogeochemical cycles (Mineau et al. 2011). *Elaeagnus* spp. can be aggressive invaders in forests (Yates et al. 2004) and negatively impact native tree seedling and sapling abundance (Lázaro-Lobo et al. 2021). Even though birds feed on *Elaeagnus* fruit (Davison 1942), one study showed a decrease in cavity-nesting birds in areas invaded by *Elaeagnus*, presumably due to a lack of overstory trees (Fischer et al. 2012). Further, planting *Elaeagnus* in highway medians led to an increase in bird mortality by automobile strikes (Watts and Paxton 2000).

In his book *Manual of Woody Landscape Plants*, Dirr (1990) described *E. pungens* in its natural form as "a genuine horror" and went on to say, "Fast does not adequately describe the speed at which it grows." Because of *E. pungens*' prolific and hardy nature, employing a long-term, ecosystem-wide strategy prioritizing prevention, active monitoring, and prompt eradication would likely be more successful than site-specific, local control measures. However, ecosystem-wide strategies are not always feasible or possible. Several local control methods have been evaluated with varying efficacy. Prescribed fire can be an effective management tool to reduce seed viability and kill young *Elaeagnus* plants (Muscha et al. 2023), but established plants will typically resprout following a fire (Michielsen et al. 2017) or cutting (Corns and Schraa 1965).

Herbicides are a common, established, and often effective management tactic for invasive plants (Pile Knapp et al. 2023), and formulations with the active ingredient triclopyr are known for their efficacy on woody plant species (e.g., Bovey 1965; Bovey and Whisenant 1991; DiAllesandro 2012; Enloe et al. 2016, 2023), including *Elaeagnus* (Edgin and Ebinger 2001). Although most research on *Elaeagnus* management has occurred in the western United States and focused on *Elaeagnus* control in the context of rangeland management, a combination of cutting and stump treatment with triclopyr was shown to be effective for *Elaeagnus* management in former coal mines in the Appalachian region of the United States (Franke et al. 2018). However, relatively few studies have examined best management practices for forested lands in the southeastern U.S. We conducted informal interviews with land managers in the southeastern U.S. to determine the most common practices used to control woody understory growth in this region, whether motorized vehicles were used, and the number of personnel most often available, along with the operators' assessment of the tools at their disposal. We determined that many land managers lacked information that incorporated time, effort, and cost of application with treatment efficacy when controlling woody understory growth. Our objective was to determine an effective chemical management method for a dense *E. pungens* infestation in a southern hardwood-dominated forest. We prioritized methods that would be easily accepted and utilized by land managers. Using the active ingredient triclopyr in the free acid formulation, we tested foliar spray, basal bark, and cut stump application methods with the goal of quantifying local *Elaeagnus* control and ease of application.

Materials and Methods

Site Description

Our study was conducted on a 214-ha (529-acre) forested tract in Calhoun County, South Carolina, USA (33.63684, -80.70592). More than 26 ha (65 acres) of the understory in this area is dominated by *E. pungens* (voucher specimens are deposited in the Clemson University Herbarium, accessible

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Table 1. Site characteristics for each experimental block in the *Elaeagnus pungens* management study conducted in Calhoun County, South Carolina, USA.

Study location (Block)	1	2	3
Coordinates	33.63822, −80.70724	33.63936, −80.71324	33.64091, −80.70656
Soil series	Faceville fine sandy loam (Fine, kaolinitic, thermic Typic Kandiudults), 2–6% slopes	Ailey-Vaucluse complex (Fine-loamy, kaolinitic, thermic Fragic Kanhapludults), 6–15% slopes	Faceville fine sandy loam (Fine, kaolinitic, thermic Typic Kandiudults), 2–6% slopes
Species composition	Overstory: *Liquidambar styraciflua* Midstory: *Elaeagnus pungens* Understory: None	Overstory: *Ulmus alata*, *Liquidambar styraciflua*, *Pinus taeda*, *Quercus alba*, *Fraxinus* spp. Midstory: *Elaeagnus pungens*, *Ligustrum sinense*, *Acer negundo* L., *Morus rubra* L., *Celtis laevigata* Willd. Understory: *Elaeagnus pungens*, *Ligustrum sinense*, *Vitis rotundifolia* Michx., various native grasses	Overstory: *Quercus alba*, *Quercus falcata*, *Pinus taeda*, *Fagus grandifolia*, *Liquidambar styraciflua*, *Carya* spp. Midstory: *Cornus florida* L., *Elaeagnus pungens* Understory: *Vitis rotundifolia*, *Elaeagnus pungens*, *Smilax rotundifolia* L., various herbaceous species
Basal area (BA)	33.5–39.6 m^2 ha^{-1}	18.3–24.4 m^2 ha^{-1}	18.3–27.4 m^2 ha^{-1}
Average root collar diameter (rcd) of dominant overstory species	15.2–20.3 cm	35.6–51 cm	25.4–40.6 cm

Figure 1. Characteristics of *Elaeagnus pungens* in Calhoun County, South Carolina, USA: (A) dense, sprawling growth; (B) leaf surface is dark green and waxy; (C) leaf undersides are silver and reflective; (D) fruit is red drupes; (E) thorns 2.5–5 cm in length grow on branches; (F) growth is multistemmed and freely branched. Photos A, D, E, and F by MND; photos B and C by DRC.

as Molly Darr #1 [CLEMS0083037, CLEMS0083038, CLEMS0083039], Molly Darr #2 [CLEMS0083040, CLEMS0083041, CLEMS0083042, CLEMS0083043], and Molly Darr #3 [CLEMS0083044, CLEMS0083045]). The region's humid subcontinental climate has long, warm summers and mild winters with a mean maximum temperature from 2018 to 2023 of 37.3 C (99.2 F), a mean minimum temperature of 7.8 C (46.0 F), and an average annual precipitation of 110 cm (43 in.) (National Oceanic and Atmospheric Administration: =https://www.weather.gov/wrh/Climate?wfo=cae). Soils in these areas are classified as "southern Coastal Plain" and consist of Faceville fine sandy loam and Ailey-Vaucluse complex soil series (USDA-NRCS 2019; Table 1). The study site consisted of a hardwood-dominated riparian bottomland stand and an adjacent upland old-field sweetgum (*Liquidambar styraciflua* L.) stand. The overstory of the bottomland area was composed primarily of sweetgum, with winged elm (*Ulmus alata* Michx.), loblolly pine (*Pinus taeda* L.), white oak (*Quercus alba* L.), and ash (*Fraxinus* spp.) interspersed. The overstory of the upland area was a mixture of white oak, southern red oak (*Quercus falcata* Michx.), loblolly pine, American beech (*Fagus grandifolia* Ehrh.), hickory (*Carya* spp.), and sweetgum

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Table 2. Field application details for experimental treatments: foliar spray, cut stump, and basal bark.

Treatment	Foliar spray	Cut stump	Basal bark
Date applied	May 14, 2021	January 7, 2021	September 10, 2021
Temperature (C), relative humidity (%)	24 C, 35%	14 C, 79%	29 C, 76%
Dilution type[a]	Formulated product diluted in water	Formulated product undiluted	Formulated product diluted in petroleum-oil carrier
Application dilution (liters of Trycera® + liters of dilutant)[a]	0.3 L + 14.7 L H_2O	Undiluted	0.95 L + 2.85 L oil
Concentration (grams of triclopyr per liter of applied solution)	6.9 g L^{-1}	344 g L^{-1}	86.0g L^{-1}
Application duration	4 h	5 h	6 h

[a]Formulated product: Trycera®, 344 g ai triclopyr L^{-1}.

(Table 1). Treatment plots were assigned in a randomized complete block design and grouped into three 0.4-ha (1-acre) blocks, each at a separate geographic location on the study site (Zar 2010; Table 1). Each block contained sixteen 1-m^2 quadrats, and each quadrat within a block was randomly assigned one of three treatments (foliar spray, basal bark, and cut stump) or an untreated control (UTC). All 4 treatments had 4 replicates per block; therefore, each treatment had 12 replicates across the entire experiment.

Pretreatment Measurements

Pretreatment measurements were conducted to obtain a baseline measurement of *Elaeagnus* abundance and biomass to confirm that no preexisting differences occurred among treatment assignments. On March 11, 2020, we measured the total number of *E. pungens* plants, along with the basal circumference (cm) of every *E. pungens* plant within each 1-m^2 quadrat (16 quadrats per block, 48 total quadrats across 3 blocks). Basal stem circumference was measured at 15 cm (6 in.) aboveground level. Ideally, pretreatment measurements would have used direct measurements of biomass, as was performed for posttreatment measurements (see “Posttreatment measurements” section below). However, a true measurement of biomass requires destructive sampling, which could not be performed before treatment applications for this experiment. Instead, because basal stem diameter has a strong relationship with total aboveground biomass for many woody shrubs and trees (Reeves and Lenhart 1988; Telfer 1969) we employed a nondestructive sampling method to estimate pretreatment quadrat biomass by using basal stem circumference as an indicator of biomass. To verify that basal stem circumference was an accurate indicator of biomass for a species with such variable branching, we destructively sampled *E. pungens* plants outside our study locations to test this relationship. We cut down representative samples of all the circumference size classes we had collected in the baseline measurements (3 to 50 cm). Basal stem circumference of 45 plants was measured at 15 cm (6 in.) aboveground level, with 15 plants collected outside each study location (block). After the basal stem circumference of each individual plant was recorded, plants were cut, placed in paper bags, and transported to the laboratory, where they were dried at 65 C to a constant weight. We calculated the relationship between stem circumference and biomass using a power function regression analysis and observed a strong relationship between basal stem circumference and biomass ($y = 1.173x^{3.1079}$; $R^2 = 0.813$), suggesting that basal stem circumference is an adequate indicator of biomass for pretreatment quadrat comparisons.

Herbicide Treatments

We applied triclopyr herbicide using the free acid product formulation (Trycera®, 343.92 g ai L^{-1}, Helena Agri-Enterprises, Collierville, TN, USA) as foliar spray, basal bark, and cut stump application methods between January and September 2021 (Table 2). We used *E. pungens*’ annual cycle of growth initiation, timing of flowering (October to December), and fruiting (March to July) to determine the time of year that is most effective for each treatment in this environment (Dirr 1990; Ferrell et al. 2019; Miller 2006; Miller et al. 2013).

The foliar spray treatment was applied when *E. pungens* was actively growing new leaves, but the plant was not yet flowering. We used a 15-L backpack pump sprayer to apply the solution (Table 2) directly to the leaves and stems and attempted to spray to runoff. The basal bark application was made during fall, and the herbicide solution (25% Trycera®; Table 2) was applied to the lower 30 to 40 cm (12 to 16 in.) of every *E. pungens* stem using a 15-L backpack pump sprayer. For cut stump applications, stems were cut with hand clippers or a chain saw about 15 cm (6 in.) above ground level and treated directly per label directions. We used a 15-L backpack pump sprayer to apply the solution (100% Trycera®; Table 2) directly to the cut stump, covering the entire wood surface. No action was taken in the untreated control plots.

Posttreatment measurements

On May 16, 2022, the total biomass of surviving *E. pungens* plants was destructively sampled in each treatment plot. These posttreatment biomass measurements were taken the season following treatment application, 12, 8, and 16 mo after the foliar spray, basal bark, and cut stump treatments, respectively. Because treatments were administered at different times of year (as is necessary for each treatment to be effective), the time window between application and sampling was not equal among treatments (Ferrell et al. 2019; Miller et al. 2013). We ensured that plants in each treatment had a full overwintering cycle to respond to herbicide application and that the time allotted was adequate to show the desired effect (Shaner 2014). We prioritized sampling all treatments on the same day to produce measurements that are not biased by seasonality.

On the day of sampling, all living *E. pungens* plants within each quadrat were clipped 15 cm (6 in.) above ground level, including live foliage and woody material. Dead *E. pungens* material was left

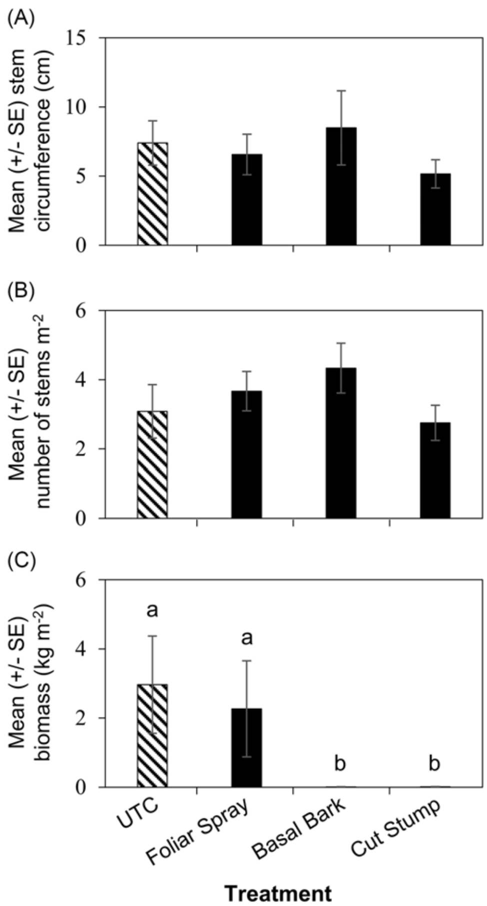

Figure 2. (A) Stem size pretreatment comparison from an *Elaeagnus pungens* management study in Calhoun County, South Carolina, USA: mean (±SE) stem circumference of *E. pungens* per 1-m^2 plot for each experimental treatment. (B) Stand density pretreatment comparison: mean (±SE) number of *E. pungens* stems per 1-m^2 plot for each experimental treatment. (C) Aboveground plant biomass posttreatment comparison: mean (±SE) *E. pungens* dry weight per 1-m^2 plot for each experimental treatment. *Elaeagnus pungens* biomass was significantly greater in the untreated control (UTC) and foliar spray treatment compared with the basal bark and cut stump application methods. Means sharing the same letter are not significantly different from each other.

in the field. Living plant material was identified by retention of leaves and woody tissue with living cambium. Dead material was colorless, brittle, and leafless. The freshly clipped *E. pungens* stems were bagged and transported to the Clemson University Forestry and Environmental Conservation shop room (Clemson, SC, USA) the following day, where the drying process began immediately. Once all bags were dried at 65 C to constant weight, the plant material was weighed to determine posttreatment biomass for each quadrat using the same process described earlier. All measurements for all treatments occurred on the same day.

Data Analysis

Statistical analyses were performed in SAS v. 9.4 using the PROC GLIMMIX procedure (SAS Institute Inc. 2023). All tests were performed using generalized linear models with treatment (UTC, foliar spray, basal bark, and cut stump) as the fixed-effect independent variables. For the pretreatment assessment, two response variables were tested, mean stem circumference per 1-m^2 quadrat and mean number of stems per 1-m^2 quadrat. For the posttreatment assessment, the response variable tested was mean biomass per 1-m^2 quadrat. The model included block (i.e., location) as a random effect and treatment as the fixed effect. Various distributions (Gaussian, Poisson, negative binomial, or lognormal) were examined for each response variable and selected based on optimal qualities: random spread in residual/ predicted plots, linear pattern in residual/ quantile plots, and low corrected Akaike information criterion values. A lognormal distribution was used for both pretreatment tests and the posttreatment test. Treatment effects within each model were considered significant at $P < 0.05$. Significant models were then analyzed by Tukey's honest significant difference to determine whether differences occurred among individual treatments, and significance was accepted at $P < 0.05$.

Results and Discussion

Before application of treatments, neither the mean basal circumference (cm) nor the mean number of *E. pungens* stems per 1 m^2 ($F(3, 42) = 1.29$; $P = 0.292$) was different among treatment plots ($F(3, 42) = 0.42$; $P = 0.738$) (Figure 2A and 2B), demonstrating that no preexisting bias existed among plots in terms of plant size or abundance before treatment applications. After treatment applications, biomass (kg m^{-2}) of *E. pungens* was significantly different among treatments ($F(3, 42) = 26.63$; $P < 0.001$). Both cut stump and basal bark treatments resulted in significantly lower *E. pungens* biomass (0.012 ± 0.004 kg m^{-2} and 0.006 ± 0.005 kg m^{-2}, respectively) compared with the foliar spray and untreated control (2.27 ± 1.39 kg m^{-2} and 2.97 ± 1.41 kg m^{-2}, respectively) (Figure 2C). The posttreatment biomass in the cut stump and basal bark treatments did not differ from each other, nor did those in the foliar spray and UTC treatments (Figure 2C).

Herbicides are used globally for vegetation management in forest ecosystems, and responsible use requires a constant refinement of application techniques to ensure the most efficient and effective management methods are being used (Little et al. 2006; Pile Knapp et al. 2023). One of our goals was to evaluate the usability of these application techniques from a land manager's perspective (Kettenring and Adams 2011). Natural resource land managers typically consider several different facets of invasive plant management techniques when determining which is most appropriate or useful for their specific situations (Kerr et al. 2016; Lindenmayer et al. 2015). In our study, we considered treatment effort, duration, and associated cost in addition to *E. pungens* mortality and related reduction in biomass to identify the optimal treatment method, and to that end, our study provided immediate and useful results for managers. These data could be included in a decision tree to help guide management activities in similar areas (e.g., Lindenmayer et al. 2015).

Each treatment method we evaluated had pros and cons. While foliar herbicide application is often one of the fastest and least physically demanding application methods, it was the least effective treatment method in our study (Table 2; Figure 2C). Foliar applications of triclopyr as the free acid formulation had the most immediate and dramatic visual effect, but the resulting superficial visual crown reduction was misleading. Upper foliage was killed within 5 mo of treatment (TLE, personal observation), and resprouting was evident around the plant base within 8 mo of treatment (TLE, personal observation). In many cases, the bottom half of the plant remained healthy, and growth continued normally. Both cut stump and basal bark application methods significantly impacted *E. pungens* mortality (Figure 2C). Cut stump application took less time but was more physically demanding than the basal bark application method and required three people to be on-site while both foliar spray and basal bark applications were completed with two people (TLE, personal observation; Table 2). The cut stump method required the applicators to cut through the base of the plant and drag the plant material out of the way to reach additional plants in other quadrats and move through the treatment area. This method left a great number of large, sprawling, dead *E. pungens* branches on the forest floor with intertwined sprouts, making physical navigation difficult. Further, the untreated tops of recently felled *E. pungens* may still hold viable seeds for a period of time posttreatment. Some studies have shown the use of triclopyr through cut stump applications yielded high percentages of resprouts in plants prone to root suckering (DiTomaso and Kyser 2007; Fogliatto et al. 2020). Anecdotally, more resprouting appeared to be present in quadrats treated with the cut stump method than those treated with basal bark applications, but more research is needed to determine sprouting potential for *E. pungens* while using this method. While the basal bark application method required a slightly longer application time than cut stump or foliar spray, basal spray application was equally effective and less physically demanding on the applicator than cut stump applications and could easily be performed by one person if necessary (TLE, personal observation; Table 2).

Herbicide application should be conducted in a manner that minimizes negative impacts to non-target flora and fauna. To do this requires a combination of empirical data (e.g., Gibson et al. 2019) and knowledge of how active ingredients work. Selective treatments with triclopyr instead of a broad-spectrum herbicide (e.g., glyphosate) were used to avoid non-target impacts to native flora. Other commonly used herbicides in forested settings (e.g., picloram) are soil active, and other non-target species may be injured through root absorption. Additionally, Trycera® carries an aquatic label allowing basal bark and cut stump applications in aquatic sites, making triclopyr a logical choice for this invasive species removal effort.

Recently, Yannelli et al. (2022) listed 15 emerging challenges and opportunities for vegetation science, one of which was halting forest degradation by targeted restoration in prioritized ecosystems. Accomplishing such a goal requires a thorough knowledge of methods to reduce or eliminate unwanted vegetation to facilitate the restoration of desired species. The details surrounding management costs (including finances, time, and labor) all factor into a land manager's decision-making process when determining when or whether to engage in management activities for invasive plants (Zhang et al. 2023). Although some may posit that straightforward studies like these which evaluate a single active ingredient on a single target species are too basic to have broader global applicability, we argue that these studies are crucial in the restoration of degraded forest ecosystems worldwide. Our study provides several essential details for land managers dealing with *Elaeagnus* spp. in temperate systems.

The use of *E. pungens* in ornamental, hedgerow, wildlife, and roadside plantings are the primary causes for its current widespread distribution in North America. Restricting its sale and use for landscape and roadside plantings would contribute positively to reducing its spread. As with any invasive flora, maintaining healthy natural landscapes through the cultivation of native plant communities and weed prevention and control is more effective than strictly attempting to control invasion. However, cost-effective management options are necessary for land reclamation and ecosystem restoration in invaded areas (Kimball et al. 2015; Meli et al. 2017). This study addressed a common management question and provided strong evidence for two effective application methods for *Elaeagnus* management in a forested setting. As many invasive shrubs in this region typically fill the same ecological niche and can be managed with similar techniques, our findings likely apply to other woody invasive species in North American natural areas (e.g., *Lonicera*, *Ligustrum*, *Rhamnus* spp.) for which triclopyr is already known to be an effective herbicide (Bisikwa et al. 2020; Delanoy and Archibold 2007; DiAllesandro 2012; Enloe et al. 2016, 2018; Harrington and Miller 2005; Hogan et al. 2024; Mervosh and Gumbart 2015). We advocate for additional research to further develop management techniques for *Elaeagnus* and other invasive woody flora, as this knowledge will directly and positively impact natural area restoration efforts worldwide.

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Competing interests. The authors declare no conflicts of interest.

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