RESEARCH ARTICLE

A Trial of Fire and Ice: Assessment of Control Techniques for *Pyrus calleryana* Invasion of Grasslands in Southwestern Ohio, USA

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ABSTRACT

Pyrus calleryana (Callery pear) is an invasive plant that threatens ecosystems in the eastern United States. We investigated the efficacy of various control techniques on *P. calleryana* invasion in grasslands. Treatments were applied to (a) *P. calleryana* stems that had experienced mowing annually for several years and were sprouting ($n = 100$ stems; "trees-sprouting") and (b) stems that had established ca. 10 years earlier, had never been cut, and were single-stemmed trees ($n = 40$ stems; "trees-intact"). In both experiments, existing stems were cut and randomly assigned one of the following treatments: cut only (control), burning, freezing, or herbicide, and in the trees-sprouting experiment there was also a negative control of monitoring existing sprouts. All trees in which the cut stumps were treated with herbicide were effectively killed, whereas stems in all other treatments, in both experiments, generated a vigorous sprout response. In the trees-sprouting experiment, there was a strong overall effect of treatments (RMANOVA; $p < 0.001$) and prescribed fire created a statistically significant increase in sprout number in relationship to the negative control (*post-hoc* test; $p = 0.036$). In the trees-intact experiment, there was vigorous sprouting in response to all treatments other than herbicide. Stump freezing resulted in a delay in sprout response; however, all frozen stems eventually sprouted. The ability of this species to sprout vigorously, even after experiencing frequent and intense ecological disturbance, creates the potential for a fundamental alteration of old-field succession in habitats where this species is present.

Keywords: Callery pear, prescribed fire, prairie restoration, ecological invasion

Biological invasion is a transformational process that may negatively influence biodiversity, alter nutrient cycling, shift patterns of succession, and drive changes in the composition of native plant communities (Ruesink et al. 1995, Webster et al. 2006, Hejda et al. 2009, Flory and Clay 2010, Vilá et al. 2011). The threat of invasive species may be accelerating due to climate change, and recent evidence suggests that invasive species continue to move into new habitats (Hejda et al. 2009, Chapman et al. 2012, NOAA 2021). A variety of factors contribute to the success of invasive species including predator escape, rapid evolution of competitive ability, prolonged phenology, and novel chemical constituents that may suppress potential competitors and alter soil conditions (Wolfe 2002, Callaway and Ridenour 2004, Batten et al. 2006, Lavergne and Molofsky 2007, McEwan et al. 2009). The potential long-term effects of invasive plants are relatively understudied; however, some work suggests that allelopathic chemicals released by invasive species could have legacy effects on soils (Corbin and D'Antonio 2012). Invasive species often have accelerated growth relative to native species and can proliferate rapidly in disturbed habitats via acquisition of available light, nutrients, and space (Luken and Goessling 1995, Baruch and Goldstein 1999) creating a unique physiognomy in some instances (Rowekamp et al. 2020).

Invasive species often have a successful and effective response to disturbance and this is particularly important for woody species that sprout in reaction to stem damage. An aggressive sprout response poses a challenge for ecological restoration because commonly used techniques such as fire and mowing can initiate sprouting in some woody invasive species, and rather than impede the success of these species, the management activity may facilitate the invasion process (DiTomaso et al. 2006). For example, Herrero et al. (2016) found that after a prescribed fire the sprouts from the invasive species were more viable than the native species. Bond and Midgley (2001) describe the

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Restoration Recap

- Callery pear (*Pyrus calleryana*) is a non-native invasive tree that is an increasingly difficult plant to manage during restoration of open habitats.
- We cut both large, and resprouting, *P. calleryana* and then treated the stumps with either nothing (control), herbicide, prescribed fire, or freezing using liquid nitrogen. The effectiveness of the treatments was assessed based on the number and size of sprouts that emerged from the treated stumps.
- Herbicide treated stumps did not sprout, creating nearly 100% mortality. Stumps treated with all other treatments sprouted vigorously. There was a delay in sprouting for some frozen stumps; however, these stumps ultimately sprouted. Fire seemingly promoted sprouting in some cases as indicated by an increased number of sprouts as compared to control or other treatments.
- Extremely vigorous sprouting by *P. calleryana* creates an awful challenge for restoring open habitats in eastern North America—herbicide use may be required until alternatives are developed.

concept of a "persistence niche" related to sprouting in which a species that deploys a set of ramets in response to disturbance can establish competitive primacy in a space much more rapidly than potential competitors. When light is abundant, these species will create long shoots (sprouts) and rapidly produce leaves to attain a greater plant height and avoid being shaded (Kikuzawa 1995). Woody invasive species that are able to access the persistence niche may have a particularly strong advantage in grasslands.

Pyrus calleryana is an invasive tree that has become an ecological threat in grasslands throughout much of the eastern and central United States (Culley and Hardiman 2007, Culley 2017). This species was intentionally introduced to the United States from its native range in Asia due to agricultural interest related to its resistance to fire blight (*Erwinia amylovora*; Bell et al. 2005, Culley 2017, Sapkota et al. 2021). This tree possesses a suite of traits that are advantageous from a horticultural perspective, including visually attractive spring flowering and fall color, along with physiological characteristics such as tolerance to heat, pollution, and drought, resulting in cultivars of this species becoming popular for plantings in residential areas (Society of Municipal Arborists 2004, Gerhold 2007, Culley et al. 2011, Hartshorn et al. 2022). The original cultivars had minimal reproductive capacity due to an inability to self-pollinate; however, flowering from root sprouts and the introduction of new cultivars released this species from this limitation leading to successful reproduction and dispersal (Culley and Hardiman 2009, Culley et al. 2011). The species originally invaded habitats in areas adjacent to residential plantings that had ample light and disturbed soils (Vincent 2005); however, *P. calleryana* is bird dispersed and is encroaching into natural areas (Culley 2017). Invasion by *P. calleryana* may be slowed by shady conditions, and previous work has indicated the potential for range limitation in regions that experience winters during which temperatures drop below –28°C (Society of Municipal Arborists 2004). This aspect of its biology may indicate a vulnerability to freezing that could slow the spread of *P. calleryana*.

Current treatment for invasive plants varies by species and ecosystem and is extremely expensive (Richardson 2022). Removal of invasive plants can be labor intensive, and common techniques include prescribed fire, herbicide treatment, and tree cutting or girdling (Hartman and McCarthy 2004, Loh and Daehler 2008). One particularly important component of the invasion biology of *P. calleryana* is its ability to sprout following stem damage. *Pyrus calleryana* can begin sprouting as soon as two weeks after damage (R. McEwan, University of Dayton, pers. obs.) and Warrix and Marshall (2018) found an average of 3.1 sprouts emerged from stems following cutting. Herbicide application following stem cutting has been reported to be an effective approach for eliminating sprouts in *P. calleryana* (Vogt et al. 2020); however, sprouting has been observed in some herbicide-treated trees (R. McEwan, University of Dayton, pers. obs.). *Pyrus calleryana* often invades grasslands where the habitat management techniques include prescribed fire and mowing, which initiated a vigorous sprout response (Just et al. 2017, Warrix and Marshall 2018). Advancing scientific understanding of sprout biology in *P. calleryana* is important for understanding the invasion ecology of this species, may yield insight into the role of the persistence niche in woody plant invasion in grasslands, and has practical implications for ecological restoration.

The overarching goals of this project were to advance understanding of sprout biology as a mechanism of persistence during ecological invasion of *P. calleryana* and test various control measures to assess their efficacy. Common methods used to control woody plant encroachment in grassland management were tested including fire, mowing, and herbicide application. Additionally, based on literature accounts that *P. calleryana* does not persist in particularly cold environments (Society of Municipal Arborists 2004), we tested a new post-cutting control method—stump freezing through application of liquid nitrogen. Although previously untested, liquid nitrogen is relatively inexpensive and operates by freezing, which has no residual ecosystem effects. These experiments focused on *P. calleryana* in two specific conditions: 1) cut and re-sprouting and 2) previously uncut. Control activities for *P. calleryana* (and other woody species) often involves clipping using

Figure 1. Examples of experimental treatments for *Pyrus calleryana* in restored grasslands near Dayton, Ohio, USA. The first treatment (left) consisted of a prescribed fire using a drip torch to ignite a 1-m² plot containing a single *P. calleryana* stump. The second treatment (right) consisted of pouring 0.5 L of liquid nitrogen on a *P. calleryana* stump.

cutting tools or power mowers. *P. calleryana* responds to cutting with aggressive sprouting, and we sought to test treatments on stems in this sprouting mode and contrast findings with outcomes from cutting and treating stems that were large and had never previously been cut. We had two research sites, one site (Stillwater Conservation Area, hereafter "trees-sprouting" site) where a grassland had been repeatedly mown with an established population of *P. calleryana* that was sprouting following each mowing event. The second site (Medlar Conservation Area; hereafter "trees-intact" site) had a population of *P. calleryana* that had begun establishing around 10 years prior to the beginning of the experiment, presumably from seed dispersal into the site, and these had never been cut or otherwise treated. In both sites, the stems were manually cut, then the root collars were randomly assigned a post-cutting treatment of either fire, freezing, herbicide, or a control of no follow-up treatment. We hypothesized (H_1) that cutting of the trees-sprouting stems would be damaging, as expressed by a reduction in the number and size of sprouts in relationship to the negative control. We further hypothesized (H_2) that fire, freezing and herbicide would each result in further damage to the stems with additional reductions as compared to the cut only treatment. In the trees-intact site we hypothesized (H_3) that post-cutting treatments would be damaging to the stems as expressed in a reduction in the total number of sprouts as compared to the cut-only treatments.

Methods

Pyrus calleryana's response to cutting and experimental treatment was assessed in two grasslands near Dayton, Ohio, USA. The first experiment took place at Stillwater Conservation Area (trees-sprouting) (39°50′24.8″ N 84°14′17.9″ W) which is owned and managed by the Five Rivers Metroparks. This site is a grassland that is undergoing restoration following around 50 years of use for row crop agriculture. Grassland restoration began approximately 10 years prior to the beginning of this experiment and the principle management technique used to keep the site open has been fall mowing with an industrial mower (colloquially known as a "bush hog"). Vegetation in the site is dominated by early successional old field forbs and grasses, and woody invasive species including *Lonicera maackii* (Amur honeysuckle), *Rosa multiflora* (multiflora rose) and a dense invasion of *Pyrus calleryana*. The site had been mowed approximately one year prior to the start of the experiment and *P. calleryana* was vigorously sprouting (mean # of sprouts = 2.65; Supplemental Material, Figure S1). In the field, we selected 100 sprouting *P. calleryana* and assigned each to one of five treatments (n = 20 each): no treatment (negative control), cut only (control), cut and burning, cut and freezing (0.5 L of liquid nitrogen application), and cut and 50% glyphosate herbicide applied to the cut stumps. Pretreatment data collected on each of these n = 100 stems included the number of sprouts, the vertical height of the tallest sprout, and basal diameter measurements of all sprouts (which were then summed for the individual). All sprouts were cut at the base using pruners. The fire treatment was accomplished by igniting a 1 m circular plot with a drip torch (Figure 1A). Experimental freezing consisted of placing a piece of metal piping around the root collar of each tree into which the liquid nitrogen was applied directly (Figure 1B). The temperature of each tree was taken afterwards with an infrared thermometer aimed on the stump after each pour to ensure it reached below −28°C. Treatments were applied in November of 2019. Following one full growing season, in the fall of 2020, trees were re-surveyed. The number of sprouts was counted, the maximum height of the tallest sprouts was measured, and measurements were taken of the basal diameter of each sprout (which was then summed for each individual). All sprouts were cut at ground level, materials were brought into the lab, dried at 70°C for at least 48 hours, and the final, dried, aboveground biomass was measured for each individual stump.

The second experiment took place in the Medlar Conservation Area (trees-intact) (39°36′09.4″ N 84°16′25.2″ W) near Miamisburg, Ohio, USA which is owned and managed by the Five Rivers Metroparks of Dayton, Ohio. This site was an agricultural field for roughly 50 years and had been converted to grassland for conservation purposes in 2015. Prior to the beginning of our experiment, the site had not been recently mowed nor treated, so in this site the trees were single-stemmed (mean height = 3.1 m; mean basal diameter = 6.42 cm; Supplemental Material, Figure S2). Treatment application began with cutting of all trees and then each was randomly assigned ($n = 10$) to one of four treatments: cut only (control), experimental burning, freezing, and herbicide. Due to conditions at the site, it was not possible to create a series of small prescribed fires as was done in the first experiment; therefore, we used a blow torch to heat each stump to 250°C to approximately mimic the maximum temperature that a woody plant may experience as a result of prescribed fire (Gibson et al. 1990, Graham and McCarthy 2006). In the fall of 2020, after one full growing season, all sprouts from *P. calleryana* individuals were counted, the maximum height of the tallest sprouts was measured, along with the basal diameter of each sprout (which was then summed for each individual). All sprouts were cut at ground level, materials were brought into the lab, dried at 70°C for at least 48 hours, and the final dried aboveground biomass was measured for each individual stump.

All statistical analyses were performed using R Statistical Software (v. 4.1.3; R Core Team 2022) and data visualization was accomplished using the ggplot2 package (Wickham 2016). For parameters that had before-and-after measurements (i.e., number of sprouts, height, sum of the basal diameter measurements in the stems-sprouting site) we conducted repeated measures analysis of variance (RMANOVA) using the lme4 package (Bates et al. 2015). When significant overall model effects were discovered, post-hoc analyses were performed to compare treatments using the emmeans library in R (Lenth et al. 2019) with contrasts based on the Kenward-Roger Degrees of Freedom Approximation. For parameters that could only be analyzed following the experiment (final dry mass in the trees-sprouting site and all of the parameters in the trees-intact site), we screened for assumptions and then used standard ANOVAs and post-hoc tests or the non-parametric Kruskal-Wallis test using the base functions in R. Non-parametric post-hoc comparisons were accomplished using the Dunn's Test (Dunn 1964) in the FSA package (Ogle et al. 2022) with the Benjamini and Hochberg (1995) adjustment. Note that our highly effective application of herbicide yielded results for many analyses with 0 values. We kept those values in the analysis as they are indicative of biological responses to the experimental treatment.

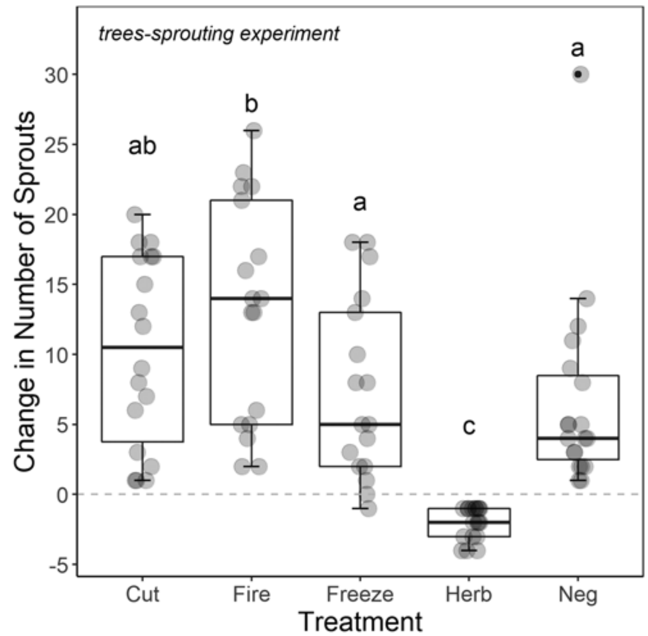

Figure 2. Change in the number of sprouts of *Pyrus calleryana* from individual stumps in a grassland near Dayton, Ohio, USA. Prior to the beginning of the experiment, these *P. calleryana* stems had experienced mowing from an industrial mower ("bush hog") annually for several years and were sprouting. In the negative control (Neg) these sprouts were not cut or treated. In all other treatments, these sprouts were counted, cut, and either no treatment was applied (Cut) or stumps were burned (Fire), frozen with liquid nitrogen (Freeze) or treated with herbicide (Herb). The centerline of the box plot represents the median change in number of sprouts from the pre-treatment survey to the final survey that occurred one year following the treatment applications. Repeated Measures Analysis of Variance indicated a highly significant effect of treatment ($p < 0.001$) and letters above the boxes represent statistically significant differences indicated by *post-hoc* pairwise comparisons (all $p \leq 0.05$).

Results

In the trees-sprouting site, all *P. calleryana* stems not treated with herbicide survived and generated additional sprouts over the course of the experiment (i.e., a positive change in the number of sprouts; Figure 2). Even so, the treatments did have a strong overall effect on the number of sprouts (RMANOVA result $p < 0.001$). The number of sprouts in the cut and fire treatments were statistically indistinguishable; however, stems that experienced the freeze treatments generated significantly fewer new sprouts than the fire treatment (Figure 2; emmeans pairwise contrast $p = 0.036$).

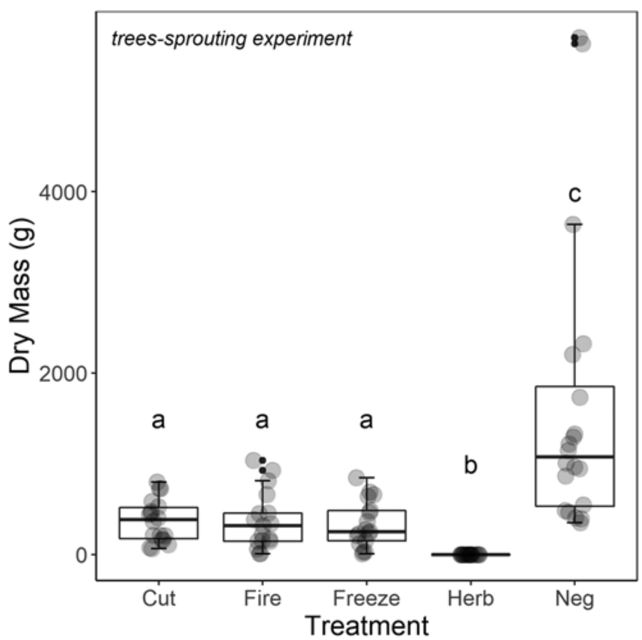

Figure 3. Final sprout dry mass of *Pyrus calleryana* from individual stumps in a grassland near Dayton, Ohio, USA. Prior to the beginning of the experiment, these *P. calleryana* stems had experienced mowing from an industrial mower ("bush hog") annually for several years and were sprouting. In the negative control (Neg) these sprouts were not cut or treated. In all other treatments, these sprouts were cut, and either no treatment was applied (Cut) or stumps were burned (Fire), frozen with liquid nitrogen (Freeze) or treated with herbicide (Herb). The centerline of the box plot is the median final dry biomass of above-ground materials of sprouts collected one year after treatment applications. Kruskal-Wallis rank sum test indicated highly significant overall treatment effect ($p < 0.001$) and letters above the boxes represent differences indicated by pairwise *post-hoc* comparisons (all $p < 0.001$).

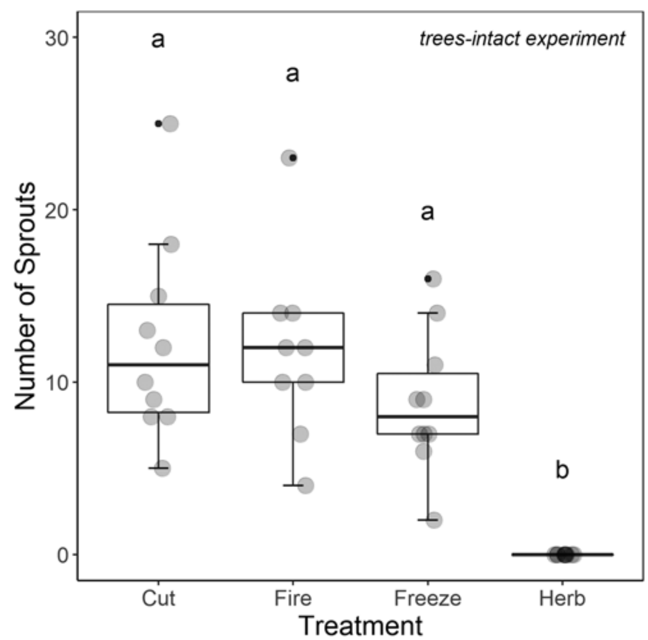

Figure 4. Total number of sprouts of *Pyrus calleryana* from individual stumps following various treatments in a grassland near Dayton, Ohio, USA. Prior to the beginning of the experiment, these *P. calleryana* stems had never been cut or treated and were medium-sized trees. In all treatments, trees were cut at the base and either no treatment was applied (Cut) or stumps were burned (Fire), frozen with liquid nitrogen (Freeze) or treated with herbicide (Herb). The centerline of the box plot is the median number of sprouts at the conclusion of the experiment, one year following treatment application. A Kruskal-Wallis test indicated a strong overall effect of treatment ($p < 0.001$) and letters represent statistically significant differences indicated by pairwise *post-hoc* comparisons (all $p < 0.001$).

The herbicide treatment resulted in mortality of all stems and a reduction in the number of sprouts that created statistically significant separation from the other treatments ($p < 0.001$ in all cases). Stems in the negative control exhibited a significantly greater number of sprouts than the herbicide treatment ($p = 0.04$), significantly fewer sprouts than the fire treatment ($p = 0.004$), and was indistinguishable from the freeze and cut-only treatments (Figure 2). At the conclusion of the experiment, stems that experienced fire generated significantly more sprouts than the negative control (Supplemental Material, Figure S3).

In the trees-sprouting experiment, sprout basal diameter, height and final biomass were generally reduced by all the treatments in relationship to the negative control. Over the course of the experiment, the change in maximum height was positive for the negative control, indicating ongoing sprout elongation, and near or below zero in all treatments, indicating that the stems were not able to regain the height they had attained prior to the initial cutting (Supplemental Material, Figure S4). A similar pattern was evident in basal diameter (Supplemental Material, Figure S5) and in final dry mass in which the negative control, which had not been cut or treated, was statistically separated from all treatments and the median biomass (1077 g) was nearly double the biomass of any of the other treatments (Figure 3). Taken together, these results indicate that, for all treatments besides herbicide, *P. calleryana* generated additional sprouts, that were thinner, shorter, and contained less overall biomass than the negative control.

In the trees-intact experiment, *P. calleryana* generated a strong sprout response in all treatments except the herbicide application (8–12 sprouts/treatment; Figure 4). There was a significant overall effect of treatments on final number of sprouts ($p < 0.001$) that was largely driven by the effectiveness of the herbicide treatment relative to the other methods (Figure 4). The median values for the number of sprouts in the cut-only, cut-fire, and cut-freeze treatments were relatively similar (approximately 10 sprouts/tree) and

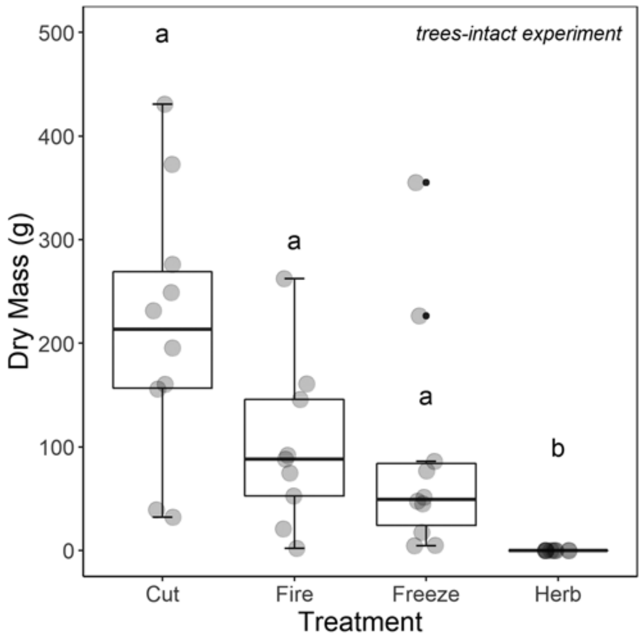

Figure 5. Total final dry mass of *Pyrus calleryana* sprouts from individual stumps following various treatments in a grassland near Dayton, Ohio, USA. Prior to the beginning of the experiment, these *P. calleryana* stems had never been cut or treated and were medium-sized trees. In all treatments, trees were cut at the base and either no treatment was applied (Cut) or stumps were burned (Fire), frozen with liquid nitrogen (Freeze) or treated with herbicide (Herb). The centerline of the box plot is the median final dry mass of aboveground materials one year following treatment applications. A Kruskal-Wallis test indicated a strong overall effect of treatment ($p < 0.001$) and letters represent statistically significant differences indicated by pairwise *post-hoc* comparisons (all $p < 0.001$).

statistically indistinguishable (Figure 4). Sprout height and basal diameter yielded similar patterns wherein the cut only treatment was not statistically distinguishable from the fire and freeze treatments and the herbicide treatment effectively killed the stems (Supplemental Material, Figures S6 and S7). In final sprout dry mass, the cut, burn, and freeze treatments were statistically indistinguishable; however, there was an apparent pattern where the fire treatment had lower biomass (median = 88 g) than the cut-only stems (median = 213.3 g) and the freeze treatments resulted in substantially reduced biomass (median = 49.4 g; Figure 5).

Discussion

Pyrus calleryana is a highly effective colonizer of grasslands in the eastern United States and is an important target for management in restoration projects seeking to maintain habitat openness. Our data support previous research indicating that this species has an extremely robust sprout response to stem damage (Warrix and Marshall 2018). In fact, cutting and herbicide application was the only effective means of removing *P. calleryana* from our site. Across both experiments, and all treatments, any stem not treated with herbicide sprouted, resulting in the generation of approximately ten sprouts for each individual, with some trees generating around 30 sprouts (refuting our H_1, H_2 and H_3). Visual observation suggests these sprouts were vigorous, and all indications are that this species physically expanded, and generated increased leaf area, in response to all treatments other than herbicide. Bond and Midgley (2001) suggest that for some species the ability to sprout may diminish as the trees increase in size; however, in our study, the trees-sprouting and trees-intact stems generated similar numbers of sprouts. Our data indicate complete mortality of *P. calleryana* with herbicide application, supporting the work of Vogt et al. (2020) who found nearly 100% mortality with four different herbicides.

Ecological restoration efforts that focus on maintaining grasslands through prescribed fire may facilitate the invasion of *P. calleryana.* Fire is a keystone ecological process in many systems and is a fundamental tool for controlling woody plant encroachment during ecological restoration (Curtis and Partch 1948, Packard 1988, Cramer and Hobbs 2007, Twidwell et al. 2013). As a restoration technique, fire is desirable because some grassland species are fire-adapted, the technique is applicable at larger scales, and there is a connection to historical land-use practices that may inspire volunteer interest (Packard and Mutel 2005). Even so, our data indicate that fire promotes a particularly strong *P. calleryana* sprout response. This finding supports work by Warrix and Marshall (2018) who report a substantial increase in the number of *P. calleryana* sprouts following fire in grassland experiment. One particularly challenging aspect of *P. calleryana* invasion is extremely sharp and stiff thorns which can penetrate the sole of a boot, and even a vehicle tire (R. McEwan, University of Dayton, pers. obs.), such that the physical presence of this species presents serious issues for land management activity in invaded sites. Coyle et al. (2021) found that one corollary benefit of prescribed fire may be weakening and dulling thorns on *P. calleryana* and, therefore, a combined treatment strategy of herbicide and fire may reduce the population size and also mitigate the problematic issue of thorns in areas where humans may be traversing the habitat.

Based on a report indicating that *P. calleryana* would not survive in climates with temperatures that fall below −28°C (Society of Municipal Arborists 2004), we used experimental applications of liquid nitrogen to assess the potential for extreme cold to kill stumps of this species. To our knowledge, this is the first-time freezing was used as an experimental treatment to control invasive species, and this approach offered the potential to provide insight into the sprout response of *P. calleryana*. Specifically, we hypothesized that freezing might disable the sprout response by damaging meristematic tissue. We considered the use of liquid nitrogen as analogous to spot treatment using herbicide, and while unusual, the practical application in the field was similarly complicated but with no potential for legacy or non-point effects. There was weak evidence suggesting the freezing was detrimental to sprout generation as compared to cut only and cut and fire treatments; however, all stems in both experiments survived stump freezing and generated a vigorous sprout response. Based on this sprout response, there is no evidence to support freezing as a control treatment for *P. calleryana*. Maloney et al. (2022) recently reported an extended phenology in *P. calleryana* including early leaf on, late leaf off, and tolerance to a frost event that suggested that this species may be biologically more tolerant of cold conditions than native species. While our experiment yielded no evidence of freeze vulnerability in this species, the use of freezing as an experimental control mechanism may be useful for other invasive species, particularly those with a home range characterized by mild winters. Further research is needed to explore the potentially unique effects of freezing on epicormic sprouting and as a treatment during ecological invasion.

The ability of *P. calleryana* to persist through sprouting in reaction to stem damage, in ecosystems in which disturbance processes are necessary to maintain openness, may be driving a foundational shift in the ecology of grasslands in the American Midwest. Grassland development on fertile soils in climates that are favorable to tree growth requires disturbance (such as fire) to impede woody plant establishment. Disturbance processes are likely to initiate a sprout response in *P. calleryana* that could facilitate, rather than impede, the invasion process. Disturbances that initiate sprouting in this species may have important ecosystem consequences as Woods et al. (2021) found soil biology was altered under sprouting *P. calleryana* when compared to non-sprouting stems. Overall, the sprout biology of *P. calleryana* seemingly creates a scenario where targeted herbicide application will be required during ecological restoration and to maintain an open canopy in these systems. Herbicide application was the only technique that was effective in eliminating sprouts from the research sites (Vogt et al. 2020), and evidence suggests that prescribed fire stimulates a sprout response (Warrix and Marshall 2018). Consequently, land managers seeking to use fire as a management technique may need to couple that practice with targeted cutting and herbicide application to prevent facilitating *P. calleryana* invasion. The flourishing of *P. calleryana* through sprouting, even in the face of relatively extreme (non-herbicide) treatments, indicates that commonly employed management techniques cannot prevent invasion where this species is present in the surrounding landscape. The ability of this species to both use long-distance dispersal to arrive in grasslands, and then access the persistence niche through aggressive sprouting in response to even relatively frequent and intense ecological disturbance creates the potential for a fundamental alteration of old-field succession in the eastern United States.

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Flowering branch of pear with corymbs of flowers. Source: Nicholson, G. 1884. *The Illustrated Dictionary of Gardening*, Div. VI (London, England: L. Upcott Gill), The Florida Center for Instructional Technology, College of Education, University of South Florida, fcit.usf.edu.