Forest Ecology and Management 550 (2023) 121517

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Review

Invasive plant management in eastern North American Forests: A systematic review

Lauren S. Pile Knapp [a,*], David R. Coyle [b], Daniel C. Dey [a], Jacob S. Fraser [a], Todd Hutchinson [c], Michael A. Jenkins [d], Christel C. Kern [e], Benjamin O. Knapp [f], Dacoda Maddox [a], Cornelia Pinchot [c], G. Geoff Wang [b]

[a] USDA Forest Service, Northern Research Station, Columbia, MO 65211, USA
[b] Clemson University, Forestry and Environmental Conservation, Clemson, SC 29634, USA
[c] USDA Forest Service, Northern Research Station, Delaware, OH 43015, USA
[d] Purdue University, Department of Forestry and Natural Resources and Hardwood Tree Improvement and Regeneration Center, West Lafayette, IN 47907, USA
[e] USDA Forest Service, Northern Research Station, Rhinelander, WI 54501, USA
[f] University of Missouri, School of Natural Resources, Columbia, MO 65211, USA

ARTICLE INFO

Keywords:
Herbicide
Prescribed fire
Mastication
Regeneration
Silviculture
Ground flora

ABSTRACT

Invasive plants can significantly impact the diversity of understory ground flora and forest regeneration in eastern North America. However, managing invasive plants has resulted in positive, negative, or neutral effects on key ecosystem components depending on treatment type, duration, and intensity. Management may also result in short-term control, but legacy effects from prior land use or secondary invasions may hamper desired long-term outcomes. We conducted a systematic review of the invasive plant management literature for eastern North American forests to examine treatment outcomes for invasive and native plants, tree regeneration, and secondary invasions. Our review included 165 articles with few papers published in the 1980s but the number of papers increasing through time thereafter. A variety of control methods were used, including herbicide applications, prescribed burning, torching, girdling, clipping, mastication, soil amendments, flooding, enrichment plantings, and biocontrol, as well as combinations of these treatments. Species included some of the most common forest invaders, such as the privets (*Ligustrum* spp.), honeysuckles (*Lonicera* spp.), autumn olive (*Elaeagnus umbellata*), buckthorns (*Rhamnus cathartica* and *Frangula alnus*), garlic mustard (*Alliaria petiolata*), Japanese stiltgrass (*Microstegium vimineum*), cogongrass (*Imperata cylindrica*), tree-of-heaven (*Ailanthus altissima*), and Chinese tallow (*Triadica sebifera*). The literature also included recent invaders in eastern North America, such as Callery pear (*Pyrus calleryana*) and fig buttercup (*Ficaria verna*). Findings suggest that invasive plant control efficacy is highly variable and context dependent. Information on long-term effects is limited because most studies reported on findings occurring within a few years of treatment. However, long-term success may be limited without additional management (e.g., enrichment plantings, artificial tree regeneration, re-establishing historic fire regimes, reducing herbivore densities) that ameliorates impacts from past land-use, disturbance history, or other factors. We suggest that future studies and the development of control tactics consider comprehensive approaches to building resilience in forest communities where invasive plants are only one aspect of the forest management continuum.

1. Introduction

Pathogen, plant, and insect invasions change essential resources, stand structure, and trophic interactions within forest ecosystems. Reducing the impacts of species invasions is a major priority for many public agencies across the eastern North America (Environment Canada 2004, Northeastern Area Association of State Foresters 2011, USDA Forest Service 2013). At a national level, science priorities have been proposed to inform forest management of best practices to reduce the impact of invasive species. These priorities include compiling accessible invasive species databases, building decision models, and advancing technology in forest operations to detect and reduce invasive species

* Corresponding author.
E-mail address: lauren.pile@usda.gov (L.S. Pile Knapp).

https://doi.org/10.1016/j.foreco.2023.121517
Received 31 July 2023; Received in revised form 18 October 2023; Accepted 19 October 2023
0378-1127/Published by Elsevier B.V.

spread (Chornesky et al. 2005, Zhang et al. 2023). Bridging science and management to combat invasive species is critical. Invasive species management is complicated by forests that are degraded by cumulative effects of settlement, fragmentation, fire suppression, natural resource exploitation, and the unintended consequences of past management practices (Webster et al. 2018). Unfortunately, as forest communities have continued to deviate from their historical structure, composition, and function, greater effort will be required to maintain key ecological processes that provide resilience to emerging stressors (Johnstone et al. 2016), and one of the first steps in that process is managing nonnative, invasive plants ('invasive plants' hereafter).

Forests in eastern North America are among the most heavily affected by invasive plants on the continent (Oswalt et al. 2015), representing a significant threat to the future of these ecologically, culturally, and economically important resources (Shifley et al. 2014, Dey et al. 2019). Negative impacts of invasive plants include not only the loss of biodiversity, forest products, and other goods and services, but also the associated management costs. For example, the Wisconsin Department of Natural Resources estimates that woody invasive plants such as buckthorns (*Rhamnus cathartica* L. and *Frangula alnus* Mill.) and bush honeysuckles (*Lonicera* spp.) dampen the growth and survival of native trees, threatening the viability of the $28 billion a year forest industry that supports 66,000 jobs (Wisconsin Department of Natural Resources 2019). In 2015, the state of Wisconsin spent $8.4 million on invasive species management (Olden and Tamayo 2014). As a result, the Wisconsin Council on Forestry (2009) determined that "invasive exotic [non-native] species may present the greatest threat" to forest sustainability and therefore developed a practical guide for forestry professionals to stop or slow the expansion of invasive species.

Invasion ecology research has grown over the past several decades, but science-based management recommendations often fall short of practitioner's needs (Esler et al. 2010, Funk et al. 2020). Applied science for the management of invasive plants has generally lagged behind basic biological and ecological research and mathematical models to predict invasion and spread (Funk et al. 2020, Zhang et al. 2023). Further, most studies report only short-term effects on the invader (Kettenring and Adams 2011). This results in poorly understood and often compounding effects of invasive plants and invasive plant management on other ecosystem properties, including direct and indirect effects on native plant species.

Invasive species and climate change are two of the most pressing anthropogenic forces threatening biodiversity today (US Global Change Research Program 2017). Climate change will further challenge the effective management of invasive species (Beaury et al. 2020), as it is generally expected that climate change will favor invasive plants over native plants (Catford and Jones 2019, Turbelin and Catford 2021). Several invasive plants in eastern North America are predicted to expand in range with climate warming (Dukes et al. 2009, Bradley et al. 2010, Wang et al. 2011, Beans et al. 2012, Allen and Bradley 2016), having the potential to impact climate mitigation strategies if not included in scenario planning. Furthermore, compounding threats from climate change, pests, and disease create novel ecosystems where there is no management analog.

Although many invasive plants in eastern North America are beyond eradication due to their abundance and large geographic distribution, managing their impact on ecosystem function is important. In addition to losses in biodiversity, invasive plants can compete with native trees for water, nutrients, and light, leading to reduced growth and vigor (Hartman and McCarthy 2007). Stressed trees are more susceptible to both primary and secondary insects and pathogens. For example, garlic mustard [*Alliaria petiolata* (M. Bieb.) Cavara & Grande] has been shown to compete more effectively for soil nutrients and water than oak (*Quercus* spp.) seedlings, suggesting it could reduce oak reproduction and regeneration success (Meekins and McCarthy 1999). Cogongrass [*Imperata cylindrica* (L.) P. Beauv.] reduces fine root biomass of loblolly pine (*Pinus taeda* L.), leading to increased bark beetle susceptibility (Trautwig et al. 2016). Further, invasive trees, like fast growing native trees, use more water per unit leaf area than slow growing native species, resulting in greater competition for water in invaded forest stands (Cavaleri et al. 2014). With increases in the abundance, distribution, and diversity of nonnative pests and diseases, trees stressed from invasive plant colonization could lead to novel cycles of native forest replacement.

The restoration of native plant communities and the promotion of tree regeneration is often a desired outcome of invasive plant control, yet there is conflicting evidence regarding effects of invasive plant control treatments on native plant response (Kettenring and Adams 2011). Due to its roots in agricultural pest management, early invasive plant management often failed to report on or explicitly monitor outcomes for resident plants (Pearson and Ortega 2009). Secondary invasions (i.e., an increase in the abundance of non-target invasive plants) and reinvasions can further challenge management efforts and may require extensive resources to achieve control.

As the diversity and abundance of invasive plants increases across the landscape, managers are increasingly seeking effective management methods to reduce their dominance and impacts. Our objectives for this review were to 1) evaluate invasive plants management strategies in eastern North American forests, and 2) evaluate outcomes on native plants and trees from invasive plant management tactics. To meet our objectives, we performed a systematic review of the scientific literature for studies that experimentally evaluated invasive plant management strategies in eastern North American forests.

Specifically, our systematic review addressed the following questions:

1. What are common treatment types and emerging control tactics for managing invasive plants?
2. What are the responses of invasive plant functional groups and native plants to invasive plant control?
3. What are the complexities that challenge invasive plant research and management?

2. Methods

We defined an invasive plant as a species that is nonnative to its region, has overcome biogeographical dispersal barriers through human assistance, has sustaining self-replacing populations (often at large numbers), and can spread over long distances (Hui and Richardson 2017). For the systematic review, we used a search term string in Google Scholar and Web of Science including the words exotic* OR alien* OR invas* AND plant OR tree AND manage* AND forest* AND North America AND east*. Using Web of Science, we were further able to refine the search to only peer-reviewed articles, proceedings, and reviews with listings under the disciplines of ecology, plant sciences, environmental sciences, and forestry. This resulted in 9,384 records on August 12, 2019, for Web of Science. In Google Scholar, because the search string resulted in 129,000 results on July 25, 2019, we limited the search to the first 100 pages of 10 records. Theses and dissertations were included in the systematic review when peer-reviewed publications of the same research could not be located. Papers were selected that explicitly tested invasive plant management, restricted to forested conditions in eastern North America. For example, studies testing management under controlled environments (e.g., greenhouse) were not included as they do not represent conditions encountered by land managers. In some cases, studies were included even if the treatments were not explicitly used for invasive control; for example, prescribed fire studies were included if they reported effects on invasive species even if the objectives for burning were not solely for that purpose. We also identified papers through a backwards approach by assessing references in the papers identified from the above method. Sometimes this led to the inclusion of papers that occurred outside of our geographic range but that tested management approaches on invasive plants common to eastern North

America (e.g., DiTomaso and Kyser 2007). Additionally, authors shared relevant papers from their geographies or specialty area that may have not been identified through other means. New paper alerts were also established using the above criteria in Web of Science and Google Scholar. Papers were screened initially by abstract and then comprehensively to meet the study objectives.

The papers selected through systematic review were then summarized by length of study duration, invasive plant control technique, invasive plant functional group, and geographic region (eastern Canada, Northeast US, Mid-Atlantic US, Midwest US, or Southeast US) of the study area. We tabulated information on the type of control tactics used and the invasive plant species by functional group (functional group defined by USDA Plants Database, https://plants.usda.gov). We also recorded site information including forest type and soil texture, as well as disturbance history for each study. When multiple invasive plants or other metrics including forest or disturbance type were provided, each was tabulated individually, resulting some papers being counted more than once. Secondary invasions were tallied for controlled, experimental studies that had pre- and post-treatment plot data that examined plant community response for management that was targeted to invasive plants (e.g., effects foliar herbicide on invasive shrubs). Positive secondary invasion response was considered an increase from pre- to post-treatment from a known invasive plant (e.g., garlic mustard) or when responses were categorized as 'exotic' or 'non-native', but specific species were not provided. As overabundant white-tailed deer (*Odocoileus virginianus*) are a substantial driver of plant community structure and composition and forest regeneration potential in many regions of eastern North America (Nuttle et al. 2014, Royo and Carson 2022, Miller et al. 2023), we tallied the number of papers that reported an influence of white-tailed deer on site characteristics or study results and the number of papers that experimentally controlled for white-tailed deer herbivory. Then, the experimental findings were synthesized to address our specific research questions. Finally, knowledge gaps and areas for future research were identified. We estimated the geographic range of species using spatial records of occurrence for the eastern United States from the EDDMapS database (Wallace and Bargeron 2014) and the USDA Forest Service Forest Inventory and Analysis (FIA) database (Burrill et al. 2021).

3. Results

3.1. Summary of the systematic review papers

The systematic review resulted in 165 papers identified for inclusion in our study, including invasive ferns, forbs, grasses, subshrubs, shrubs, trees, and vines that are highly abundant, pervasive, transformative, and well-distributed across the eastern North American landscape (Figs. 1a and 1b; **Supplemental Interactive Maps**; **Supplemental Spreadsheet**). We report outcomes by invasive functional groups because the methods for their control and impact on the plant community were likely to be similar within a functional group. Invasive shrubs had a high number of detections across eastern North America and were also the most common functional group experimentally managed in the systematic review (Fig. 2). Bush honeysuckle was the most common species across all studies (Fig. 3). The invasive grass, Japanese stiltgrass (*Microstegium vimineum* [Trin.] A. Camus), and the invasive forb, garlic mustard, were also common for control studies. The earliest paper was published in 1985 with few papers published annually until the early 2000 s (Fig. 4). Beginning around 2005, invasive shrubs was the most frequently reported functional group per year. Herbicide was the most common control method evaluated, and clipping and manual removal treatments were also often used. Regionally, most studies occurred in the Midwest and Southeast US (Fig. 5). Mixed hardwood forests were the most common forest type followed by oak-hickory forests, planted pine

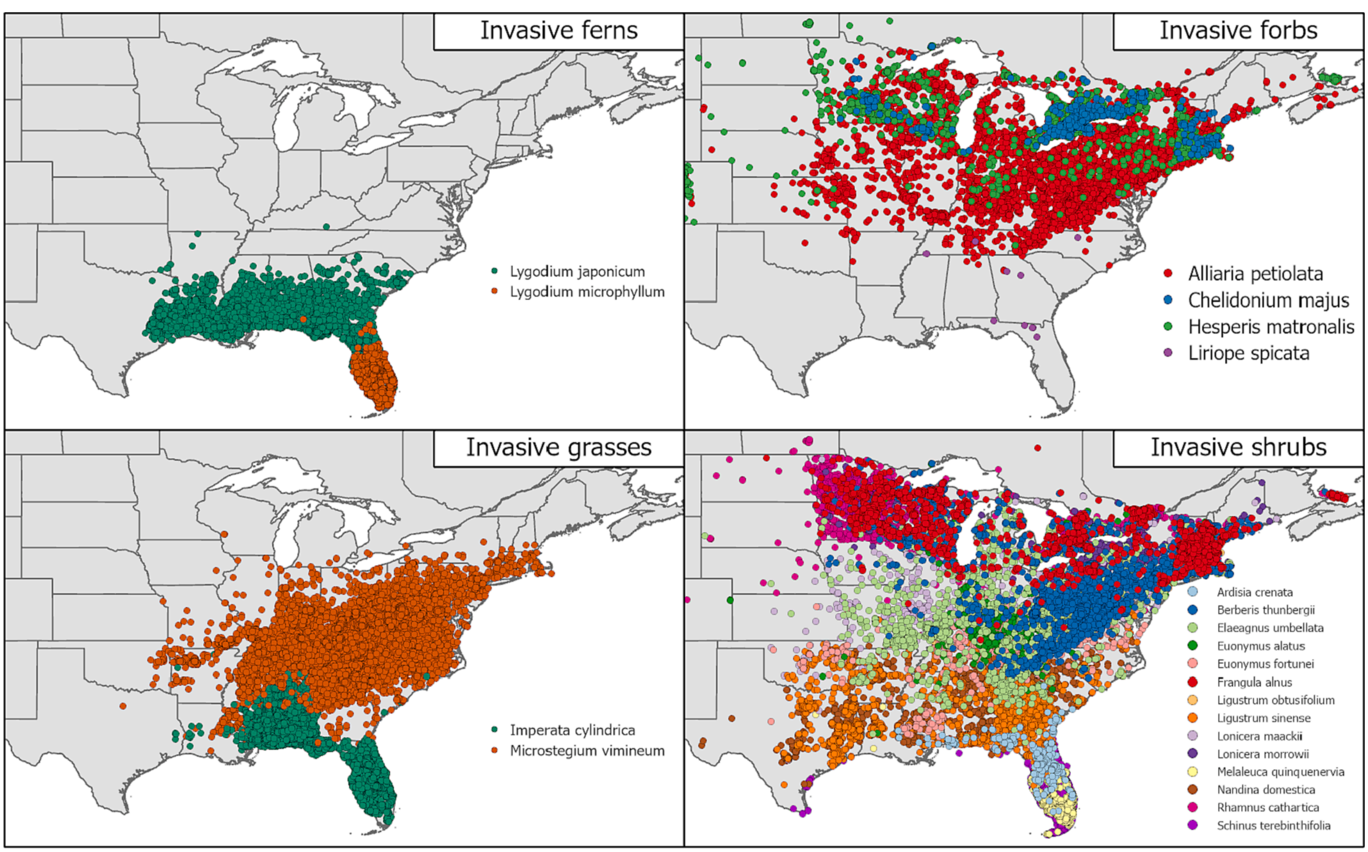

Fig. 1a. Map of study invasive ferns (n = 44,689), forbs (n = 68,553), grasses (n = 106,552), and shrubs (n = 162,147) based on recorded FIA and EDDMaps locations in eastern North America.

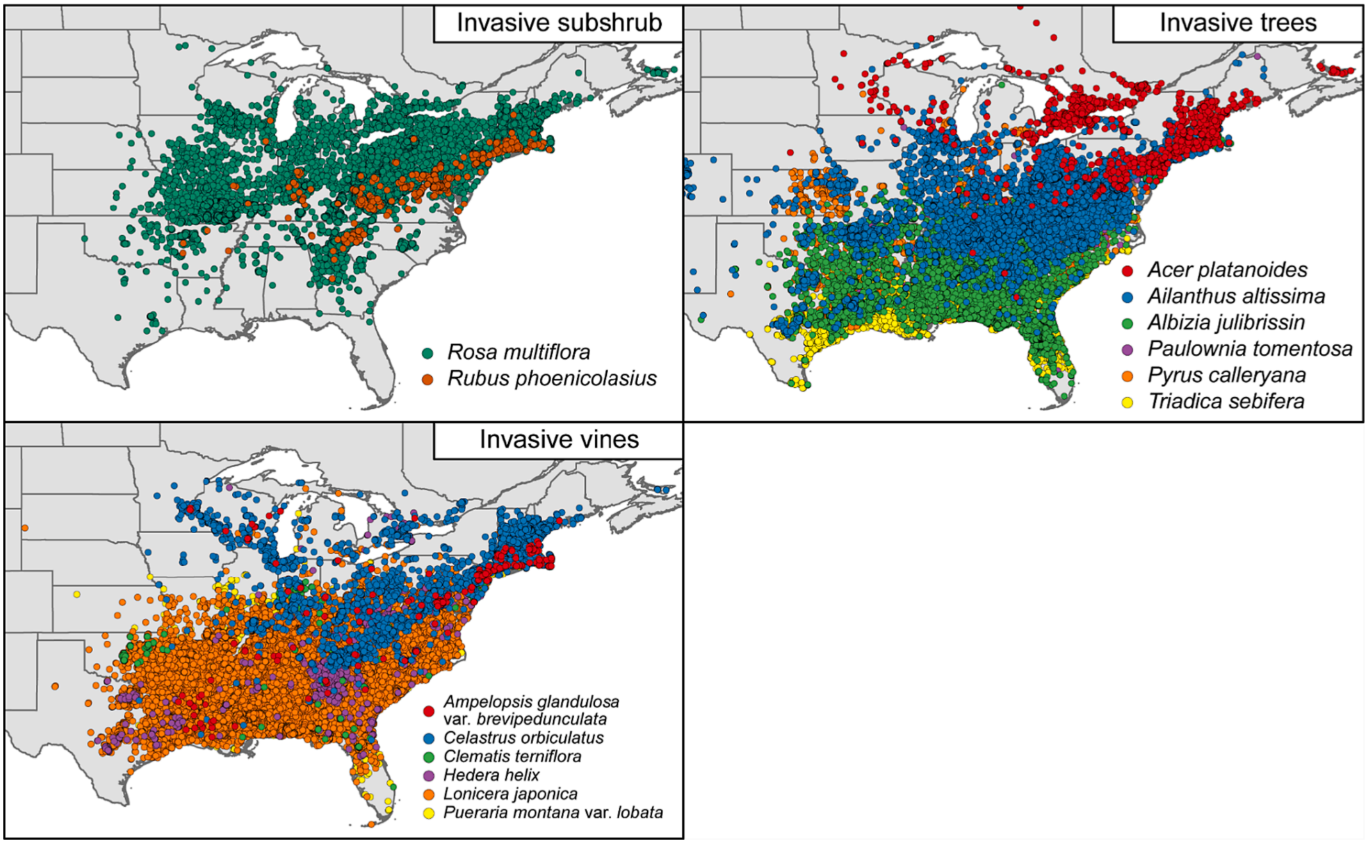

Fig. 1b. Map of study invasive subshrubs (n = 45,839), trees (n = 90,719), and vines (n = 121,587) based on recorded FIA and EDDMaps locations in eastern North America.

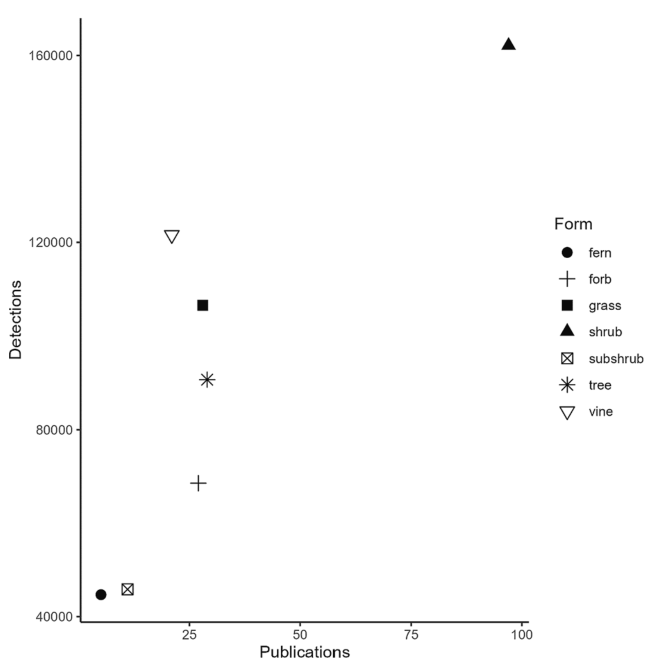

Fig. 2. The number of FIA and EDDMaps detections in eastern North America by the number of invasive plant management publications found through systematic review group by invasive functional group.

forests, bottomland hardwood forests, floodplain/riparian forests, and dry-mesic upland oak forests. Silt loams and sandy loams were commonly reported as the soil texture associated with a study site. Historic logging or secondary forests were the most reported disturbances characterizing the site condition. Studies also attributed past agricultural land-use, anthropogenic habitats (roadsides, urban, etc.), prescribed burning, grazing, fire suppression, flooding, and recent harvest as drivers of site invasibility. Most studies (57 %) reported treatment outcomes within the first 3 years of monitoring (Fig. 6).

3.2. Overview of common treatment types

To be effective over the long-term, reductions in the abundance of invasive plants must exceed new colonization and recruitment. When compared to a 'do nothing' approach, most management options for the control of invasive plants resulted in a reduction of the invader, at least in the short-term. The general exceptions were that only topkill of invasive plants, including mechanical clipping or cutting, single prescribed fire, or mulching of woody invasive species without follow up treatments, often resulted in greater densities following treatment than pre-treatment (Pavlovic et al. 2016, Warrix and Marshall 2018).

Chemical Control – Of the papers evaluated in our systematic review, 106 (64 %) evaluated the use of herbicides. The use of herbicides was often the most successful approach to initial reductions in invader abundance. However, chemical formulation, application method, rate, season, applicator experience and motivation, chemical adjuvants, and other factors all influenced treatment outcomes (Miller 1985, Enloe et al. 2015, Mervosh and Gumbart 2015, Enloe and Lauer 2016, Enloe et al. 2016, Enloe et al. 2018b, Young et al. 2020, Rivera et al. 2022). In our review, common herbicides used for invasive plant control included glyphosate, triclopyr, imazapyr, metsulfuron, 2,4-D, picloram, and dicamba (Fig. 7). Common herbicide applications included directed foliar (applied to leaves), basal bark (applied to the lower portion of young woody stems), cut stem injections (applied to downward incision cuts of woody stems), tree injection [primarily using EZ-Ject® (ArborSystems,

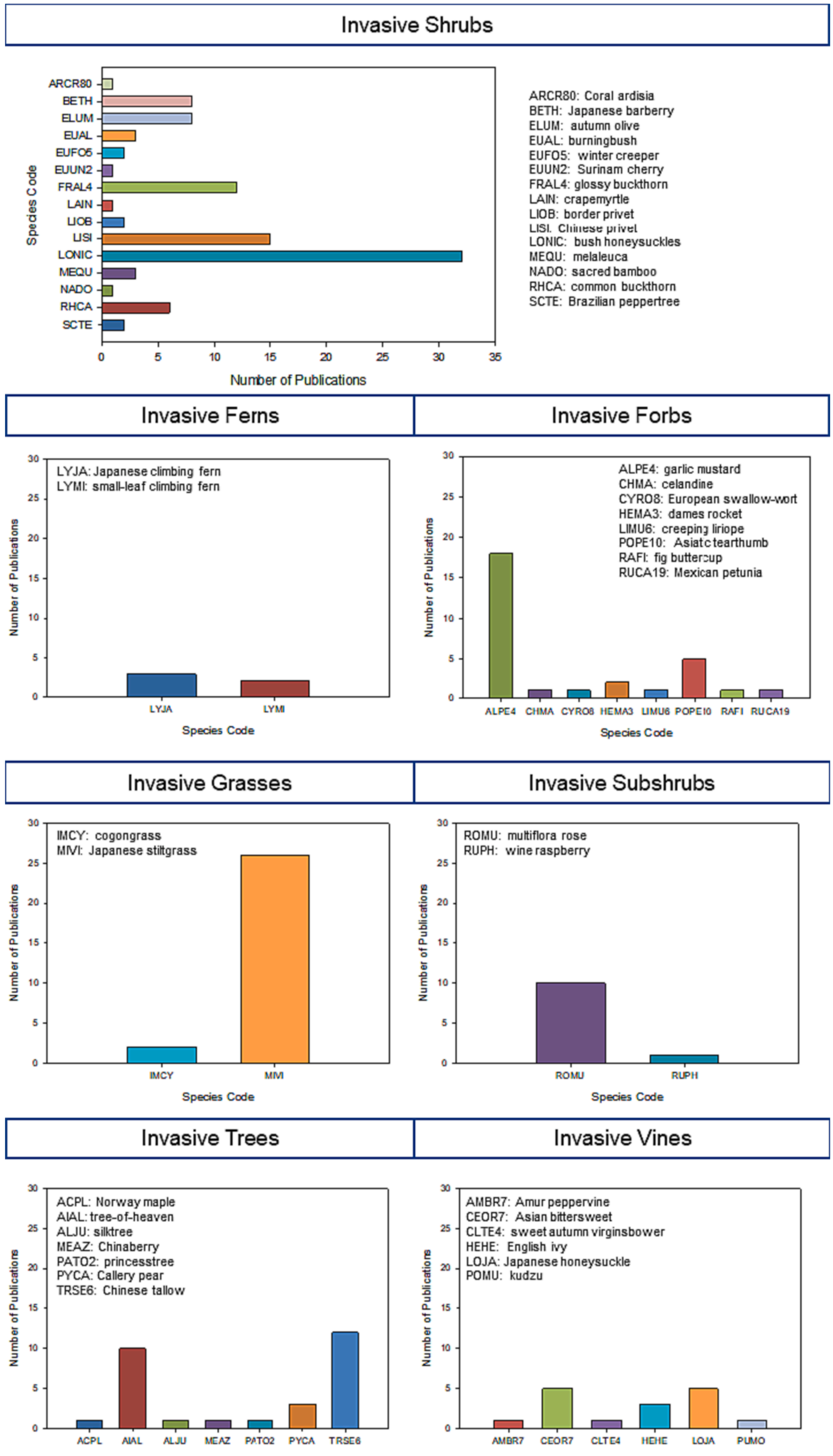

Fig. 3. Number of invasive plant species tabulated across publications (n = 165) by functional group that were identified through systematic review.

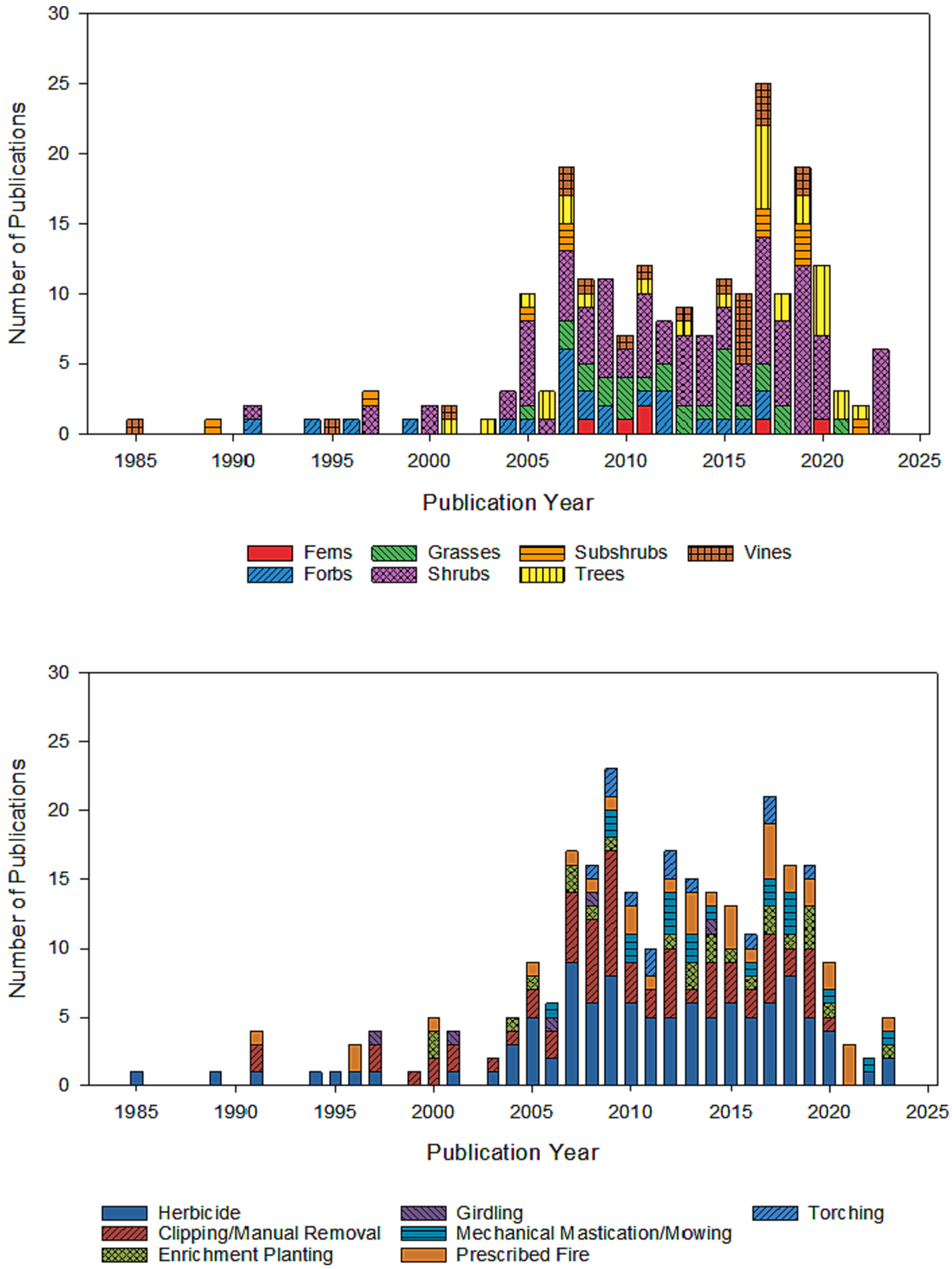

Fig. 4. Number of publications (n = 165) by year that report on outcomes for an invasive species categorized by functional habit group (top panel) and the number of publications per year by the common invasive plant management tactics (bottom panel) indentified through systematic review.

Omaha, NE) whereby shells of herbicide are jammed through the bark into the interior bark] and cut stump (applied directly to the surface or outer circumference of fresh cut stems) treatments [for detailed information on herbicide applications, see Miller et al. (2010)] (Fig. 7). Many papers evaluated the efficacy of herbicide application at different phenological stages or seasons as an important consideration for control and non-target impacts, and these are detailed below by invasive plant functional group. For example, Judge et al. (2005) compared the phenological timing of different post-emergent herbicides for the growing-season control of Japanese stiltgrass and found no difference in effectiveness among application timings. Broadcast herbicide treatments evaluated in our systematic review included those that used aircrafts and gasoline-powered backpack mist blowers. Broadcast applications are typically non-selective, depending on the herbicide, and are often used when infestations of woody invasives are dense and have unique phenology that results in them being photosynthetically active when native plants species are dormant. For example, Leahy et al. (2018) documented the effects of aerial glyphosate applications for the late-growing season control of bush honeysuckle. However, some herbicides are highly selectively for certain species (e.g., imazamox for Chinese tallow) or functional groups (e.g., grass-specific herbicides) reducing the risk to non-target species. Broadcast applications are also traditionally used in planted forest management for site preparation, often to control aggressive native and invasive plants.

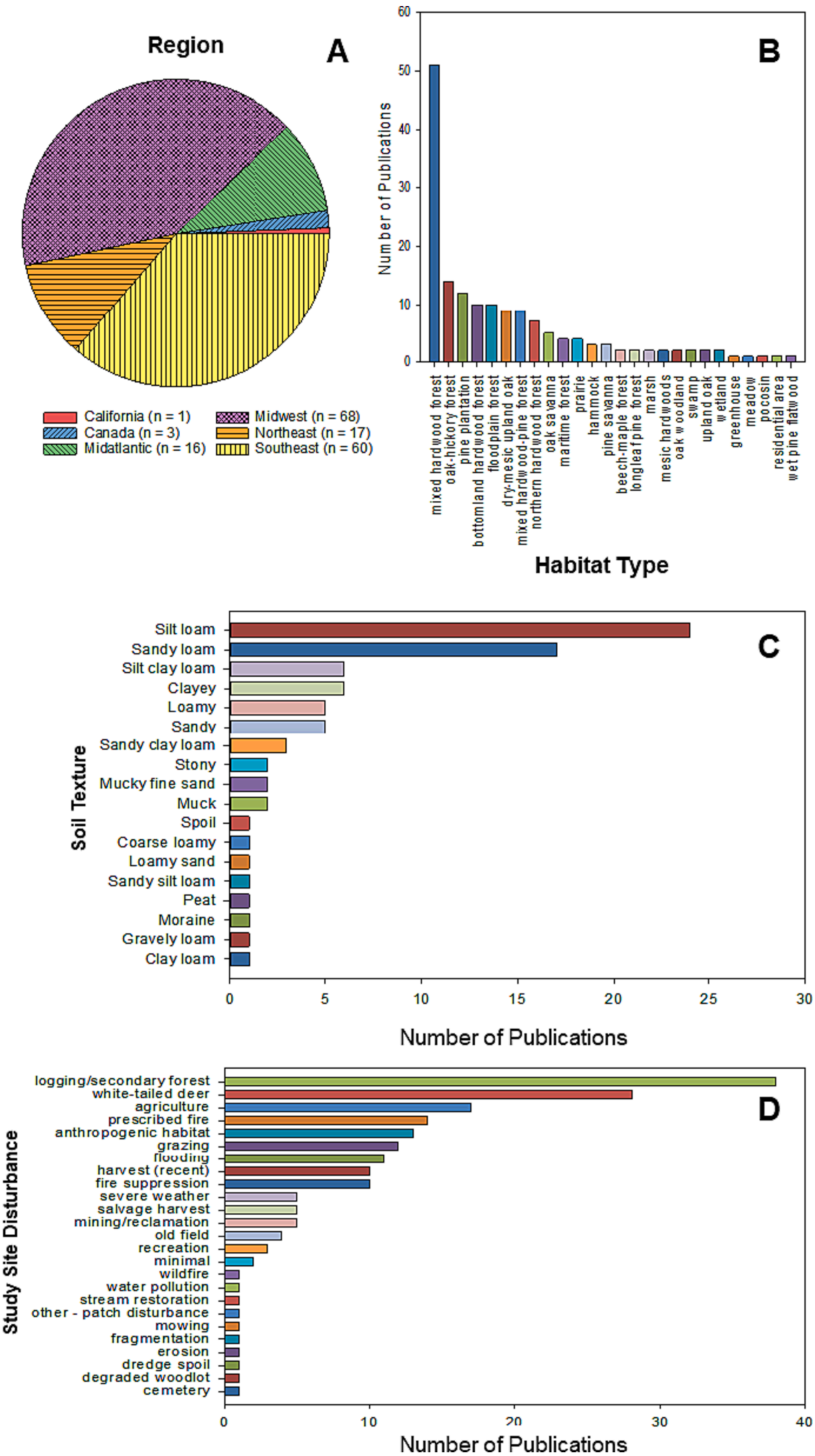

Fig. 5. Characteristics of the study sites evaluated through systematic review. Study region (A), habitat types (B), soil textures (C), and study site disturbance (D) reported in the papers identified (n = 165).

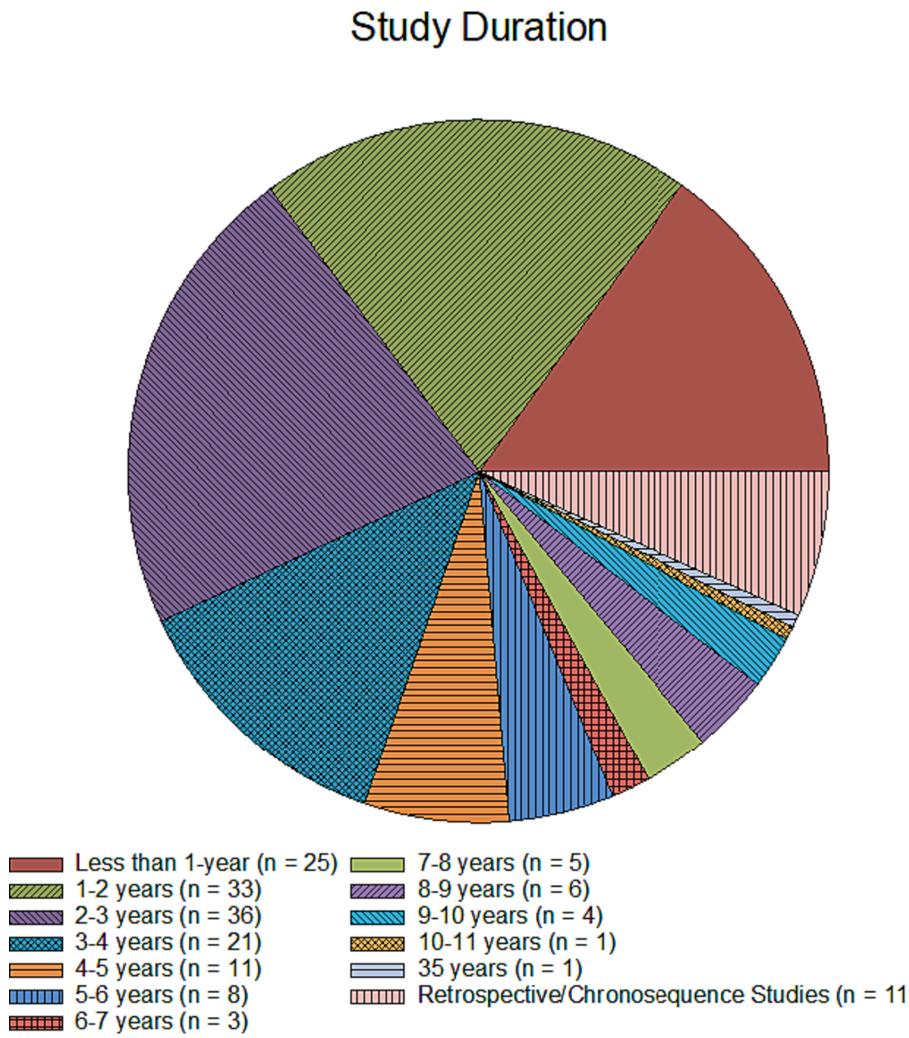

Fig. 6. Study duration reported for the papers (n = 165) selected through systematic review. Of the papers evaluated, 57 % of studies occurred within the first 3 years and 69 % occurred within the first 4 years.

Manual and Mechanical Non-Chemical Control – Of the papers evaluated in our systematic review, 97 (59 %) evaluated manual or mechanical means for the control of invasive plants. Manual methods are often time-consuming, laborious, and expensive when contracted; however, they are often utilized when the use of herbicides is not appropriate or allowed. Manual methods included stem girdling, clipping, and full removal including below-ground roots and tissues (i.e., uprooting). Mechanical treatments often include mowing or mulching (mastication). In our systematic review, push mowers or string trimmers were evaluated to reductions in invasive grasses and forestry mowers, brush chippers, and mulching machines were common for invasive shrubs and trees. Mechanical treatments can also be designed to target susceptible stages in plant phenology, such as prior to seed set or when total nonstructural carbohydrate (TNC) concentrations in roots are at their lowest. For example, Shelton (2012) found that mowing any time after midsummer can reduce the abundance and seed production of Japanese stiltgrass but that mowing even later into the growing season may have an additive effect. Mechanical treatments can also be used in combination with other treatment methods, such as following mechanical treatments with herbicide to target regrowth. For both manual and mechanical treatments, the lack of complete removal of below-ground tissues and resulting aggressive regrowth and resprouting can complicate control objectives when not followed with additional control. For example, Anfang et al. (2020) found that the increased light provided by the removal of common buckthorn in a simulated mowing experiment benefited its own regeneration. However, Frank et al. (2018) found that deeper, more aggressive application (1.5 cm below soil surface) of a mulching (mastication) head (Bull Hog®; Fecon Inc., Lebanon, OH, US) resulted in lower rates of resprouting than shallower applications that resulted in less damage to meristematic tissue in the root collar.

Control with Fire – Of the papers evaluated in our systematic review, 34 (21 %) evaluated the influence of prescribed fire, while 13 (8 %) evaluated the direct effects of torching on invasive plants. As fire both influences and is influenced by plant structure and composition, its relationship with invasive plants is complex (Mandle et al. 2011). As the prevailing fire regime can drive structure and composition, communities with more frequent fire return intervals have surface fuels that can promote fire spread, reducing the probability of invasion and establishment (Fan et al. 2021). For example, longleaf pine (*Pinus palustris* Mill.) ecosystems maintained with frequent fire are some of the least invaded habitats in the eastern US. The maintenance of the historic disturbance regime likely impedes invasive plant establishment when fire frequency is sufficient to increase mortality or disrupt reproduction and spread (Simberloff 2001, Just et al. 2017). However, when present, fire may drive the spread of cogongrass in longleaf pine forests and intensify grass invasion-fire cycles (Yager et al. 2010, Tomat-Kelly et al. 2021). The re-establishment of pre-invasion fire regimes may be an effective control strategy for invasive woody plants by promoting past ecological processes (Brooks et al. 2004). The manipulation of fine fuels

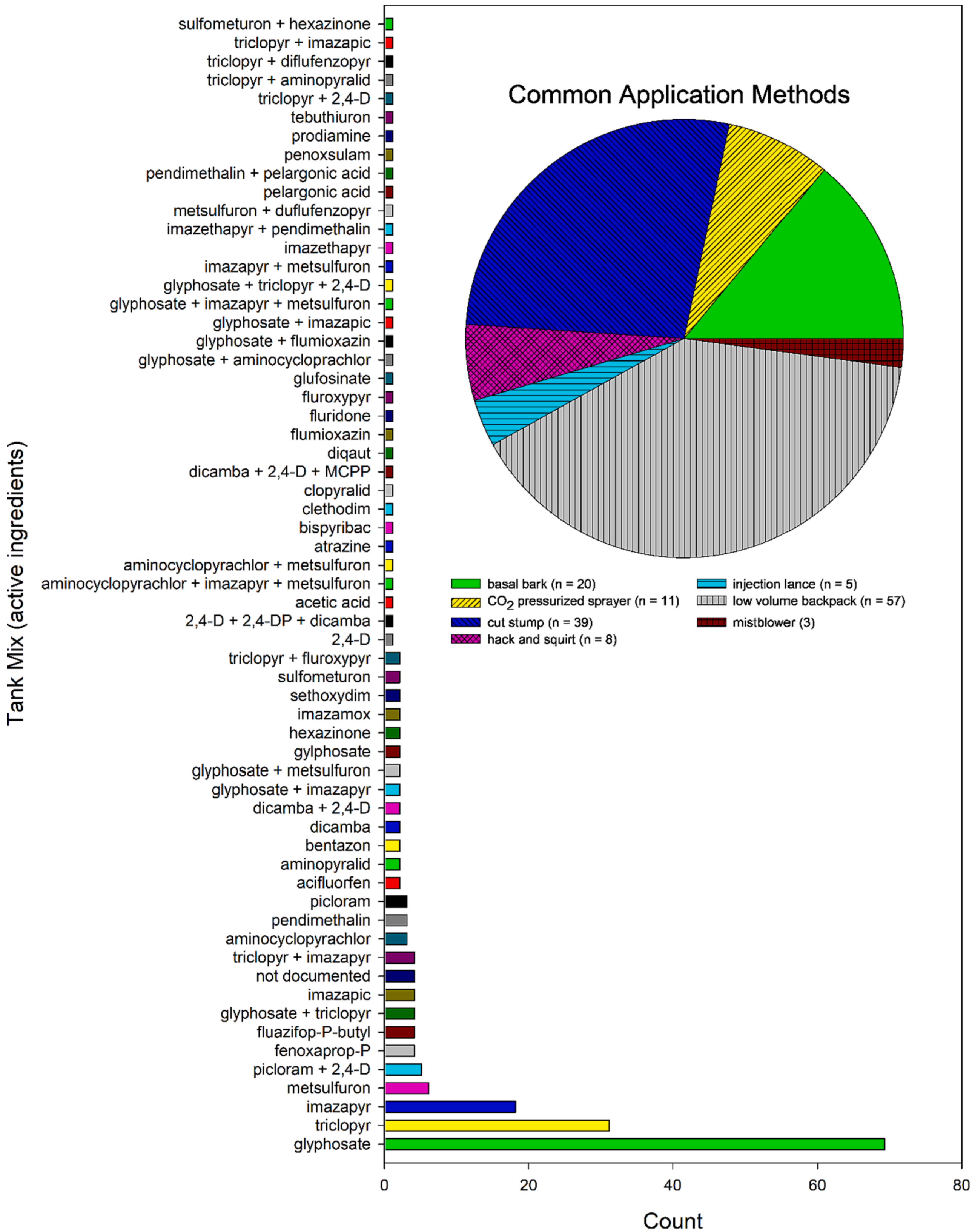

Fig. 7. Evaluation of herbicide control for the papers selected through systematic review including the count of tank mix active ingredients (bar chart) and common application methods (pie chart).

to increase fuel loading and continuity to promote the management of prescribed surface fires and increase available burn days may be necessary for sites with dense invasive plant infestations, especially tall shrubs or coarse woody debris, that limits the production of vegetation at the ground level (Mandle et al. 2011). For example, because Chinese tallow leaves rapidly decompose, ultimately reducing fuel continuity, Pile et al. (2017b) tested mastication of Chinese tallow to increase surface fuels prior to prescribed fire. Conversely, reducing invasive grass abundance before burning may increase the survival of native trees by reducing fire intensity (Flory et al. 2015). Further, prescribed fire seasonality and frequency can be manipulated based on invasive plant phenology, size, and age to reproduction. Burning during the growing season, when stems are physiologically active, is often recommended for controlling invasive woody plants because of its negative impact on belowground TNC stores (Grace 1998, Richburg et al. 2004). Prescribed burning also disproportionally affects juveniles or seedlings of invasive shrubs and trees (Muscha et al. 2023) more than mature plants due to the bark accumulation and height with age. Short fire return intervals may increase flushes of new seedlings and small saplings whereas longer return intervals can promote the growth of saplings into larger trees (Fan et al. 2021) thereby reducing the probability of topkill and increasing the number of individuals that are reproductive. When used in combination with other management actions (e.g., hand-felling, mastication, herbicide) to reduce mature, fruit-bearing invasive trees and shrubs, prescribed fire may be helpful in limiting populations at juvenile stages and subsequently, reducing seed bank potential through time (Pile et al. 2017b, Rebbeck et al. 2019). In contrast to prescribed burning, direct torching (or flaming) is used to control individual stems or small populations of invasive plants, especially when the use of chemical herbicides is not feasible or desired. Species responses that were evaluated with direct torching included Japanese stiltgrass, Japanese barberry, and glossy buckthorn (Flory and Lewis 2009, Ward and Williams 2011, Lee et al. 2017, Ward et al. 2017, Link et al. 2019).

Enrichment Seeding or Planting – Of the papers evaluated in our systematic review, 23 (14 %) reported the response of native species that were seeded or planted to enhance restoration outcomes or to competitively displace invasive plants. Following invasive plant removal or control, enrichment planting of native species may be necessary to reestablish a diverse native plant community, including ground flora and woody shrubs and trees. Planting native vegetation may decrease the invasibility of sites by occupying growing space and resources that would otherwise be available for invasive species, though most studies of this type have occurred in grassland systems (Schuster et al. 2018). Establishing functionally diverse native plant communities that include species with traits similar to invasive plants may further increase invasion resistance [a strategy termed “limiting similarity” (Shea and Chesson 2002, Funk et al. 2008)]. The early establishment of fast growing native species may also limit plant invasion by outcompeting invasive plants (Byun et al. 2018). Most studies evaluating the ability of seeding and planting to reduce invasive reestablishment in forests have used herbaceous plants. Herbaceous species may be effective at reducing invasion due to their ability to establish and spread more quickly than woody plants (Schuster et al. 2018). The use of planted native woody species to reduce reinvasion by invasive woody plants has been understudied in forests (Schuster et al. 2018) but may be an opportunity to limit functional similarity or infill niche space the invasive plant would occupy without direct competition for growing space. Further, incorporating the reintroduction of functionally extinct or marginalized, sometimes called “iconic” foundational tree species, such as American elm (*Ulmus americana* L.) and American chestnut (*Castanea dentata* [Marshall] Borkh.) into ecosystem restoration strategies may improve ecosystem function and functional redundancy (Ellison et al. 2005, Jacobs et al. 2013, Looney et al. 2015, Flower et al. 2017, Knight et al. 2017). Both American elm and American chestnut are highly competitive and fast-growing (Wang et al. 2013, Marks 2017).

3.3. Emerging control tactics

Biological Control – Of the papers evaluated in our systematic review, 11 (7 %) reported the efficacy of field-tested biological control agents for invasive plants. The release of biocontrol agents may be controversial for introducing novelty to an ecosystem, but they may also reduce or prevent an undesirable shift in forest species composition (Dudney et al. 2018). Although biological control has been around for quite some time, few species are available for general management. Several field-assessed biological controls report successful outcomes for invasive plant control, with other biological controls in development. For example, two biological control agents, a flea beetle (*Bikasha collaris* [Baly]) and a defoliating moth (*Gadirtha fusca* Pogue), have been developed for Chinese tallow (Wang et al. 2012, Wheeler et al. 2017, Wheeler et al. 2018) but have not been released outside of experimentation. Several released biological control agents have been evaluated for old world climbing fern (Lake et al. 2014b, Smith et al. 2014). Biological controls released in melaleuca-dominated stands in Florida resulted in declines in invader density and basal area (Rayamajhi et al. 2007) with concomitant increases in native plant diversity (Rayamajhi et al. 2009). The air potato leaf beetle (*Lilioceris cheni* Gressitt and Kimoto) has been found to have high host-specificity for the air potato vine (*Dioscorea bulbifera* L.) representing one of the best cost-effective control strategies for this highly aggressive vine in Florida’s natural areas (Gakpetor 2019, Kraus et al. 2022). Additionally, experimental field tests for the native mycoherbicide, *Verticillium nonalfalfae* Inderbitzin et al. have demonstrated promising control of tree-of-heaven with no negative effects observed to native species (Harris et al. 2013, Brooks et al. 2020, Pile Knapp et al. 2022). Similarly, rose rosette disease, native to North America, has been studied for the control of multiflora rose (*Rosa multiflora* Thunb.) (Epstein et al. 1997). *Chondrostereum purpureum* (Pers. ex Fr.) Pousar, is a naturally occurring fungal plant pathogen that resulted in over 90 % mortality when applied to girdled European buckthorn in the early-summer (Au and Tuchscherer 2014). Further, field and greenhouse studies have successfully documented reductions in fecundity and growth for mile-a-minute weed by *Rhinoncomimus latipes* Korotvaev, a host-specific Asian weevil (Hough-Goldstein et al. 2008), and the greatest benefit occurred when restoration efforts included the weevil, native plantings or seeding (Cutting and Hough-Goldstein 2013), and herbicide (Lake et al. 2014a). Integrated approaches to invasive plant management that include biological controls along with other treatments are promising and for some invasive plants, these combinations may offer the greatest opportunity for suppressing large-scale invasions.

Soil Amendments & Flooding – Several studies were novel in testing the use of soil amendments or flooding to control invasive plants. It has been hypothesized that amending the soil may increase the competitiveness of desirable species over invasive plants. For example, high levels of phosphorous additions for short periods reduce the competitiveness of cogongrass in longleaf pine savannas by favoring native legumes (Brewer and Cralle 2003). Organic carbon has been shown to increase microbial uptake and N immobilization, causing direct chemical inhibition through the sorption of allelopathic compounds that consequently affects the growth and competitive relationship of native and invasive plants (Adams et al. 2013). Only a few studies have investigated carbon applications to manipulate plant community response for the control of invasive plants. To limit the negative effects of allelochemicals associated with garlic mustard, Cipollini et al. (2008) tested the response of transplanted jewelweed (*Impatiens capensis* Meerb.) to activated carbon additions with garlic mustard removal. Although the mechanisms were not well-understood, activated carbon was beneficial to jewelweed when in the presence of garlic mustard but not when it was removed. This reduced inhibitory effect has been reported as an example of the ‘novel weapons hypothesis’ for garlic mustard as well as other invasive plants (Callaway and Ridenour 2004). Similarly, a study from prairie communities found that the addition of biochar increased the growth of blue bluestem (*Andropogon gerardii* Vitman) but did not affect invasive sericea lespedeza (*Lespedeza cuneata* [Dum. Cours.] G. Don) or their competitive interactions (Adams et al. 2013). Increasing soil carbon with mulch created from European buckthorn, either through tilling or surface application, did not reduce reinvasion or soil N availability (Iannone et al. 2013). Further, flooding has been suggested to reduce the abundance of some invasive plants, but short-term flooding was not an effective strategy for controlling Chinese privet (Conner 1994, Brown and Pezeshki 2000).

Targeted Herbivory – Increasingly, there has been interest in using domesticated browsers or grazers to meet land management objectives, including for the control of invasive plants (Hart 2001, Marchetto et al. 2021). Targeted herbivory (also referred to as prescribed herbivory or managed browsing) can be defined as a land management technique that incorporates the seasonality, frequency, and intensity of an herbivory event to meet land management objectives (Beebe 2021). It is an interdisciplinary approach that combines plant ecology, livestock nutrition, and foraging behavior (Bailey et al. 2019). Targeted herbivory further differs from natural or uncontrolled herbivory in that its duration, frequency, and intensity are controlled while its effects are closely monitored. Goats (*Capra hircus* L.) are the most commonly used herbivore for invasive plant control in eastern North America because they are considered intermediate feeders (Hackmann and Spain 2010), consuming a wide variety of food sources but constituting a large proportion of their diet from woody species (Papachristou et al. 2005, Manousidis et al. 2016). For example, targeted browsing by goats may be an effective option for reducing multiflora rose (Luginbuhl et al. 1998, Luginbuhl et al. 2000, Bowden et al. 2022), English ivy (*Hedera helix* L.) (Ingham and Borman 2010), and invasive shrubs (Rathfon et al. 2021, Mundahl and Walsh 2022). However, similar to mastication or prescribed fire, effectiveness of control is improved by follow-up treatments of herbicides or mechanical removal (Rathfon et al. 2021). Further, repeated targeted browsing treatments are more effective at reducing invader abundance than single browse events (Ingham and Borman 2010, Rathfon et al. 2021, Mundahl and Walsh 2022). Utilizing targeted herbivory for invasive plant control may increase concerns for invasive seed dispersal through endozoochory. Although seeds greater than > 4 mm in length have limited survival following digestion (Marchetto et al. 2020), however, fleshy fruited invasive plants such the honeysuckles have seeds that are smaller than 4 mm (Munger 2005).

3.4. Outcomes for invasive plant functional groups

There are several biological and ecological commonalities among the invasive plants in our systematic review (Tables 1-5). For example, many are bird or wind dispersed. The forbs and shrubs are characterized by a high number of species that are intermediate to shade tolerant, while the invasive trees are more commonly intolerant to intermediate shade tolerance. Several of the invasive shrubs are evergreen or have traits that extend their leaf phenology in the growing season by leafing out early, senescing late, or both. Additionally, several invasive shrubs and vines have variable leaf persistence depending on climate and site conditions. Many species have reproductive traits beyond seeds or spores, such as rhizomes, tubers, and tillers or sprouting from stumps, roots, or nodes. However, information on seed banking, an important consideration for long-term control, lacks across the invasive plant

Table 1
Life history characteristics of invasive forbs.

Species	Life Cycle	Pollination	Germination	Vegetative reproduction	Flowers	Seed Set	Dispersal	Seed Bank	Habitat affinity
garlic mustard *Alliaria petiolata* (M. Bieb.) Cavara & Grande	Biennial, occasional winter annual	Open and self-pollinating	Early spring, requires cold stratification	None	April-June (second season)	June-November	Ballistics, humans, deer	Minimal, but a small percentage < 6 years	Establish prior to canopy leaf out
celandine *Chelidonium majus* L.	Biennial or perennial	self-fertilization			May-August				Intermediate to shade tolerant
European swallow-wort *Cynanchum rossicum* (Kleopow) Borhidi	Perennial	Open and self-pollinating	Early September	Early literature suggests rhizomatous, can regenerate from root crowns	May-July	September-November	Wind		Shade intolerant to tolerant
dames rocket *Hesperis matronalis* L.	Biennial or perennial			None	Spring	Summer			Intermediate shade tolerance
creeping liriope *Liriope spicata* (Thunb.) Lour.	Perennial								
Asiatic tearthumb *Polygonum perfoliatum* L.	Annual, but may be considered a perennial	Self-fertilization, occasional outcrossing	Early April, requires moisture and cold stratification	None	June-July	September-November	Water, birds, mammals, ants, logging equipment	<4 years	Shade intolerant, moist
fig buttercup *Ranunculus ficaria* L.	Perennial			Tubers, bulbils	March-May		Water		Shade intolerant to intermediate, moist
Mexican petunia *Ruellia caerulea* Morong	Perennial	Open and self-pollinating		rhizomes	June-October, or throughout the year		Ballistics, animals		Intermediate shade tolerance, moist sites but can withstand drought

Table 2
Life history characteristics of invasive grasses.

Species	Life Cycle	Pollination	Germination	Vegetative Reproduction	Flowers	Seed Set	Seed production (viability)	Dispersal	Seed Bank	Establishment requirement
cogongrass *Imperata cylindrica* (L.) P. Beauv.	Perennial	Outcross (wind) and clonal	Do not require stratification, germinate within 1–4 weeks after ripening	Rhizomes (expansion and fragment) and seed	February-June (year-round in Florida)	May-June	Highly variable (0–100 %)	Wind (24 km)	1 year	Open, disturbed areas
Japanese stiltgrass *Microstegium vimineum* (Trin.) A. Camus	Annual	Self and cross (wind)	March-June	Seed, tillers and stolons	September-October	October-December	100–1,000 seeds per tiller (33–90 %)	Water and animals (including humans). Limited dispersal without dispersing agents. Wind.	<1 year to 5 years	Exposed mineral soil/disturbed soil/reduced litter

functional groups. For invasive shrubs, trees and vines, age to reproductive maturity is also vague or lacking, which is an important factor in establishing treatment regimens to maintain populations at immature life stages. Improvements in our basic understanding of plant invasive biology could significantly aid management as well as models for predicting invasive plant distribution, spread, and response to management.

Ferns – Management outcomes were reported for two species of invasive climbing ferns (5 publications, 3 % of the total publications) that are highly problematic in the southeastern US, including small-leaf climbing fern (*Lygodium microphyllum* [Cav.] R. Br.) and Japanese climbing fern (*Lygodium japonicum* [Thunb] Sw.) (Fig. 1a). Both *Lygodium* species have a climbing habit with small-leaf climbing fern expanding in Florida and Japanese climbing fern expanding across the southeastern US. Both species smother and displace native vegetation, with small-leaf climbing fern capable of forming rachis mats up to a meter thick (Lott et al. 2003). Climbing ferns are rhizomatous and reproduce sexually by wind dispersed spores (Clewell 1985, Pemberton and Ferriter 1998, Ferriter 2001). The invasive vine, narrow swordfern (*Nephrolepis cordifolia* [L.] C Presl), is an aggressive invader in southeastern forests but was not in our original search as limited research is available for this species. Of the five papers that tested control tactics, four evaluated chemical control, one evaluated mechanical removal, and two evaluated prescribed fire in combination with herbicide. **Herbicide can control invasive ferns, but the active ingredient used may be important and long-term management is necessary as fern regrowth can trellis up dead vines.** Dietz et al. (2020) reported the reduction in invasive fern coverage to increase with treatment intensity, with significant reductions only following four or more foliar treatments of glyphosate in a 6-year period. Two papers tested the effects of chemical formulation on control, with both papers reporting the greatest control from glyphosate when compared to imazapyr or metsulfuron-methyl alone or in combination (Minogue et al. 2010, Bohn et al. 2011). Further, considerable invasive fern regrowth was observed in the second year, particularly when using imazapyr or metsulfuron-methyl (Bohn et al. 2011). No treatment of herbicide or burning and herbicide resulted in complete elimination (Stocker et al. 2008, Hutchinson and Langeland 2010).

Forbs – The invasive forb literature (25 publications, 15 % of the total publications) was dominated by publications investigating control tactics for garlic mustard (Fig. 3), along with seven other less common invasive forb species (Table 1). Most of the invasive forbs occur in areas outside of the southeastern US (Fig. 1a), although Mexican petunia is present in limited distribution and abundance in that region. Several invasive forbs have characteristics that complicate management planning, including capacity for vegetative reproduction and uncertainty in seedbank longevity (Table 1). **Management of invasive forbs will require treatments that reduce seed production, persistent seed banks, and underground stems through consideration of the species phenology and the life stage of the population.** Of the studies identified through systematic review, herbicide, mowing, or clipping were the most common control tactics, followed by prescribed fire and native revegetation. Some of the earliest invasive plant management research was led by Victoria Nuzzo, who investigated the effects of herbicide and fire on garlic mustard in the 1990s (Nuzzo 1991, Nuzzo 1994, Nuzzo 1996, Nuzzo et al. 1996). Nuzzo (1991) noted that a reduction in abundance following treatment in one year can have a cascading effect on subsequent populations in following years. However, this is not universally true in the literature. Even with complete removal of flowering garlic mustard individuals, complete eradication of even small populations is difficult due to a persistent seedbank (Drayton and Primack 1999). One-time control treatments may not only fail to reduce invasive populations but also stimulate increases in invader abundance (Murphy et al. 2007), especially with stage-structured and density-dependent invasive forbs (Pardini et al. 2008). Incipient populations are more susceptible to local eradication, but exhausting the seedbank

Table 3
Life history characteristics of invasive shrubs.

Species	Leaf persistence	Breeding and pollination	Germination	Reproductive maturity	Vegetative reproduction	Flowers	Seed Set	Dispersal	Seed Bank	Habitat affinity
coral ardisia *Ardisia crenata* Sims	Evergreen									Shade tolerant
Japanese barberry *Berberis thunbergii* DC.	Deciduous, extended leaf phenology	Open-pollinated, bees	Spring; morphophysiological dormancy, requires cold stratification		Sprouts from root crown, rhizomes and layering	Late winter (March)-spring	Summer-fall	Gravity, birds (low priority fruit)	Minimal < 1 year	Shade intolerant to shade tolerant
autumn olive *Elaeagnus umbellata* Thunb.	Deciduous, extended leaf phenology	Open-pollinated, insects	Cold stratification enhances germination but is not required	3–5 years	Sprouts from root crown	April-May	August-September	Birds, mammals		Intermediate shade tolerant, nitrogen fixer
burningbush *Euonymus alatus* [Thunb.] Siebold	Deciduous				Sprouts from root crown	April-July	September-October	Birds		Shade intolerant to shade tolerant
winter creeper *Euonymus fortunei* [Turcz.] Hand.-Maz	Evergreen	Perfect flowers	May require cold stratification		Produces long shoots and roots at nodes that can form independent plants	June-July	Fall	Birds and other animals		Shade intolerant to shade tolerant, may vary by cultivar
Surinam cherry *Eugenia uniflora* L.	Evergreen					Spring				
glossy buckthorn *Frangula alnus* Mill.	Deciduous	Perfect flowers	Fresh seeds germinate readily	“Early”	Sprouts from root crown	Throughout the growing season	Throughout the growing season	Birds, mammals, gravity, water	2 + years	Shade intolerant, moist sites
crapemyrtle *Lagerstroemia indica* L.	Deciduous		Fresh seeds germinate readily			May-fall				
privets *Ligustrum sinense* Lour. *Ligustrum obtusifolium* Siebold & Zucc	*L. sinense*: evergreen but variable; *L. obtusifolium*: deciduous		Germination may be enhanced through digestion		Sprouts from root crown and root suckers	March-May	September-November	Birds and other animals	Minimal < 1 year	Intermediate to shade tolerant, *L. sinense*: tolerant of short-term flooding
bush honeysuckles *Lonicera* spp.	Deciduous, extended leaf phenology	Perfect flowers; bees	Variable depending on species	3–8 years	Sprouts from root crown but may also produce root suckers and layer	Spring	Late summer-early fall	Gravity, birds	Minimal < 1 year but requires additional research	Intermediate to shade tolerant
melaleuca *Melaleuca quinquenervia* [Cav.] S.F. Blake	Evergreen	Perfect flowers, honeybees and other insects	Enhanced when soils are moist		Sprouts from root crown, root sprouting is unclear	2–5 times per year	Continuous and episodically	Gravity, wind, water	Seed stored in canopy; minimal soil seed banking	Shade intolerant; tolerates flooding and drought
sacred bamboo *Nandina domestica* Thunb.	Evergreen		Occurs the fall following seed set	<1 year to several years	May have rhizomes; sprouts from roots	May-June	Late winter	Birds, mammals, water	>1 year	Shade intolerant to shade tolerant
common buckthorn *Rhamnus cathartica* L.	Deciduous, extended leaf phenology	Dioecious	Does not require scarification or stratification; must be extracted from fruit	5–20 years	Sprouts from root crown; seedlings will not sprout	Appear with leaves, early spring	Fall	Gravity, birds, animals, water	2–6 years	Shade tolerant
Brazilian peppertree *Schinus terebinthifolius* Raddi	Evergreen	Synchronous; dioecious; insects	Exocarp inhibits germination	2–3 years	Sprouts from root crown and root suckers	October, 10 % flowering again in April-May	December-March	Humans, birds, mammals, reptiles, water	<1 year	Shade intolerant; tolerates flooding

Table 4
Life history characteristics of invasive trees.

Species	Leaf persistence	Breeding and pollination	Germination	Reproductive maturity	Vegetative reproduction	Flowers	Seed Set	Dispersal	Seed Bank	Habitat affinity
Norway maple *Acer platanoides* L.	Deciduous, extended leaf phenology	Dioecious, insect pollinated	Spring, requires cold stratification		Stump sprouting	April-June	Fall	Wind		Shade tolerant to very shade tolerant
tree-of-heaven *Ailanthus altissima* [Mill.] Swingle	Deciduous	Dioecious, insect pollinated	Stratification improves germination		Stump and root sprouting	April-June	Fall	Wind	>5 years	Moderately shade tolerant
silktree *Albizia julibrissin* Durazz	Deciduous	Monoecious or andromonecious, insect pollinated	Requires scarification	"Early"	Stump and root sprouting	May-August	August-November	Gravity, wind, water, animals	>5 years, requires investigation	Nitrogen-fixer
Chinaberry *Melia azedarach* L.	Deciduous	Perfect flowers, insect pollinated	Short period of physiological dormancy	May begin flowering in the seedling stage	Stump and root sprouting	March-May	September-October	Animals, gravity, water	>1 year	Shade intolerant, requires investigation
princesstree *Paulownia tomentosa* [Thunb.] Siebold & Zucc. Ex Steud.	Deciduous	Insect pollinated	Requires light for germination	3–10 years	Stump and root sprouting	July-August	September-October	Wind	2–3 years	Shade intolerant
Callery pear *Pyrus calleryana* Decne.	Deciduous			3 years	Stump sprouting	early spring	Spring-summer	Birds	11 years	Shade intolerant
Chinese tallow *Triadica sebifera* [L.] Small	Deciduous	Imperfect flowers, wind and insect pollinated, requires investigation	Digestion improves germination	3 years	Stump and root sprouting	April-June	August-January	Water, birds	>1 year	Moderately shade tolerant

requires extensive effort by annual removal of flowering individuals (Drayton and Primack 1999, Pardini et al. 2009), especially prior to fruit initiation (Chapman et al. 2012). However, prior to fruit development, targeting stages of flowering phenology (e.g., prior to flowering vs. some percentage of the population in flower) does not appear to increase invasive forb control (Frey and Schmit 2017). Invasive forbs that remain green during the dormant-season provide treatment opportunities with minimal impact on native species; however, for species that are stage-structured, limiting treatments to the dormant season may only target a single life stage. Further, low soil temperatures may limit herbicide effectiveness. Minimum thresholds to maximize treatment effectiveness of glyphosate applications include soil temperatures above 4.6℃ with air temperatures at or slightly below freezing (Frey et al. 2007).

Effectiveness of prescribed burning for the control of invasive forbs can vary with characteristics of the fire regime, fire behavior, and the abundance of the invasive forb population. Established and abundant invasive forbs may limit prescribed burning as a management option due to low flammability and discontinuous surface fuels. Nuzzo (1991) described difficulty in implementing prescribed fire in both the spring and fall due to the abundance of green garlic mustard plants. However, in fire-maintained natural communities where garlic mustard establishment is limited, on-going prescribed burning may reduce invasion (Nuzzo 1991). Garlic mustard response to fire may vary by the amount of litter present and consumed, the season in which the prescribed fire is applied, the length of the fire return interval, and climatic conditions (Nuzzo et al. 1996, Schwartz and Heim 1996). Within the first growing season, a single fire may decrease invasive forb abundance, but without subsequent fire or other control, invasive forb populations may increase in abundance. In contrast, repeated fire may reduce opportunities for establishment and reproduction. Incomplete burns that do not consume the leaf litter surrounding established invasive plants may not damage belowground vegetative structures. However, the germination of seeds might be enhanced on bare mineral soil created following prescribed fire. Even with repeated fire, a fire free interval may allow for propagules of surviving individuals to germinate and rapidly expand without other interventions (Nuzzo et al. 1996).

Grasses – The invasive grass management literature (28 publications, 17 % of the total publications) is limited to two aggressive species in forested communities, Japanese stiltgrass and cogongrass. Although both invasive grasses thrive with high light and disturbance, they differ in their life history traits and environmental tolerances (Table 2). **Consideration for the life histories of invasive grasses will help determine their response to control tactics.** Drought may limit the reproductive capacity of Japanese stiltgrass whereas cogongrass is more widely adaptable to a range in soil moisture availability. For example, late season drought may greatly diminish or eliminate the seed production of Japanese stiltgrass (Gibson et al. 2002) and at low levels of full sunlight, it will allocate more biomass to leaves than flower production. Japanese stiltgrass is an annual C_4 grass that spreads vegetatively through tillering (Cheplick 2010) and stolons (Hunt and Zaremba 1992); it has limited spread without a dispersal agent, and the vegetative shoots do not survive through the next growing season. Although tolerant to shade, vegetative production of Japanese stiltgrass is favored by increased available sunlight, which results in greater reproductive success through carbon gain (Gibson et al. 2002). Cogongrass is less tolerant of shade than Japanese stiltgrass, perennial, easily wind dispersed, and primarily expands from asexual reproduction by rhizomes with regeneration capacity linked to developmental characteristics including stem age. Only older rhizomes can sprout and produce roots, and sprouting readily follows disturbance (Ayeni and Duke 1985).

Research has confirmed that post-emergent herbicides, hand removal, and clipping or mowing are effective for reducing invasive grass abundance when applied prior to seed set in the mid to late-growing season (Judge et al. 2005, Judge et al. 2008, Flory and Clay 2009, Shelton 2012, Hall et al. 2014, Brooke et al. 2015). Herbicides are generally more effective than hand pulling or clipping, but direct

Table 5
Life history characteristics of invasive vines.

Species	Leaf persistence	Breeding and pollination	Germination	Reproductive maturity	Vegetative reproduction	Flowers	Seed Set	Dispersal	Seed Bank	Habitat affinity
Amur peppervine *Ampelopsis brevipedunculata* [Maxim.] Trautv.	Deciduous; slow to leaf out	Perfect, cross and may be insect pollinated	High germination rate, readily germinates following disturbance		May produce 'sucker shoots' or sprout from root crown	Midsummer	Fall	Birds, deer, small animals, maybe water		Intolerant to tolerant of partial shade
Asian bittersweet *Celastrus orbiculatus* Thunb.	Deciduous					Spring	Winter	Animals and humans for decorative purposes		Shade tolerant with high germination under an intact canopy
sweet autumn virginsbower *Clematis terniflora DC.*	Deciduous to evergreen depending on conditions					Summer to fall		Wind		Intolerant to tolerant of partial shade
English ivy *Hedera helix* L.	Evergreen, leaves are long-lived (3–4 years)	Bisexual and cross pollinated by a variety of insects	Cold weather may prevent seed viability; rapidly germinates	Two distinctive vegetative phases: juvenile (ground cover) and adult (climbing)	Sprouts from stem fragments and cut stumps and adventitious roots	Variable: summer to fall	Variable: fall to winter	Birds	Limited and short-lived	Tolerant of a wide range of light conditions; stress tolerant
Japanese honeysuckle *Lonicera japonica* Thunb.	Deciduous or evergreen depending on conditions	pollinated by insects and hummingbirds	Requires cold stratification	Open-grown plants: 3 years; shade-grown 5 years; peaks at 4–6 years then rapidly declines	Sprouts from root crown and layers; adventitious roots form at the nodes of trailing stems	March-October	Late summer to late fall	Birds and small mammals	Anecdotal evidence suggests low seed bank potential	Intolerant to somewhat shade tolerant
kudzu *Pueraria montana* var. *lobata* [Willd.] Maesen & S.M. Almeida ex Sanjappa & Predeep	Deciduous. Semi-woody perennial. Diurnal pattern in leaflet orientation		Will not germinate until seedcoats are water permeable	3 years	Large and deep taproot. Roots along nodes where new root crowns can form	July-September	Fall; Infrequent, may be more reliant on asexual reproduction		Potential to seed bank	Intolerant

torching, clipping and torching, or repeated vinegar (acetic acid) treatments may also reduce abundance (Ward and Mervosh 2012). Control and herbicide type may be important for native plant response to invasive grass management. For example, although pre-emergent herbicides may reduce Japanese stiltgrass abundance, they may also limit the potential for restoring the native plant community (Flory and Clay 2009, Flory 2010). Grass-selective herbicides, such as Fenoxaprop-p-ethyl, may be more effective at reducing invasive grass abundance and increasing native species than non-selective chemical herbicides, such as glyphosate (Pomp et al. 2010). Both glyphosate and imazapic were found to be effective at reducing Japanese stiltgrass coverage one year following treatment, but neither herbicide treatment increased the coverage of other species (Brooke et al. 2015). However, because glyphosate lacks soil activity it may be a better option for control when coupled with native enrichment seeding, as reported by Enloe et al. (2013) in longleaf pine communities invaded by cogongrass. Further, although managers have reported concerns regarding glyphosate resistance in cogongrass populations, Enloe et al. (2018a) confirmed glyphosate's efficacy across populations, but environmental conditions (i.e., drought, shade) or faulty application may impact control efficacy.

Invasive grasses will alter fuel conditions, and cogongrass can increase fire intensity, subsequently altering fire regimes and community response (Lippincott 2000, Emery et al. 2011, Flory et al. 2015). Conversely, research also suggests that invasion by Japanese stiltgrass will reduce fire intensity, with lower flame lengths, shorter residence times, and smaller burned areas (Salemme and Fraterrigo 2021). **The contrasting life history characteristics between Japanese stiltgrass and cogongrass indicate the response of the species' to prescribed fire will vary based on their adaptions to the prevailing fire regimes.** For example, cogongrass is highly adapted to frequent fire regimes (Howard 2005). The timing and sequence of prescribed fires in relation to invasive grass presence and abundance are important. When invasive grasses are not present, but propagules are available, prescribed fire may facilitate establishment through the exposure of bare ground (Glasgow and Matlack 2007). However, when Japanese stiltgrass is present, fall prescribed fires are effective in reducing population abundance (Flory and Lewis 2009, Emery et al. 2013). When compared to prescribed burning, post-emergent herbicides may have longer-lasting reductions in invasive grass abundance (Emery et al. 2013). Prescribed fire followed by an application of glyphosate can result in short-term reductions in cogongrass, but burning alone is not effective at reducing cogongrass abundance or increasing native species richness (Enloe et al. 2013).

Several other factors can have interactive effects with prescribed burning on invasive grasses. For example, sites with agricultural land use legacies (and thus depauperate seedbanks) may experience greater increases in Japanese stiltgrass abundance in response to forest thinning and burning due to a lack of native competition (Brewer et al. 2015). Soil moisture may also influence the response of invasive grasses to prescribed fire. For example, burning facilitated the invasion of Japanese stiltgrass more on wet sites than dry sites (Wagner and Fraterrigo 2015). Studies have also found the abundance of invasive grass to affect native tree response to prescribed burning. In communities highly invaded by Japanese stiltgrass, Flory et al. (2015) and Salemme and Fraterrigo (2021) reported increased mortality of tree seedlings due to the compounding effects of invasion and prescribed fire. Successional dynamics may also play an important role in the abundance of Japanese stiltgrass. For example, in experimentally seeded field plots (5.25 m^2 plots), Japanese stiltgrass comprised 60 % of the herbaceous plant biomass in 4 years, but by 8 years was nearly absent, even with prescribed burning occurring in year 7 (Flory et al. 2017). The reduction in Japanese stiltgrass facilitated the dominance of native trees in plots that did not receive fire and by herbaceous species where fire did occur, thereby suggesting that invader dominance may decline through time with natural successional dynamics (Flory et al. 2017).

Shrubs – Invasive shrubs of different species occupy a wide distribution in eastern North America (Fig. 1a). **Invasive shrubs are the invasive functional group most problematic to the sustainability of forests in eastern North America, because they are often shade tolerant and bird dispersed.** Our literature search resulted in 79 publications (48 % of the total publications) of invasive shrub control and included 14 shrub species (Fig. 3; Table 3). Many of the invasive shrubs are evergreen or have extended leaf phenology, whereby they assimilate carbon prior to overstory canopy leaf expansion and after canopy senescence (Fridley 2012). Most have some degree of shade tolerance, or their leaf phenology may allow them to invade intact deciduous forests, and many can persist by sprouting from their root crowns. Some invasive shrubs have viable seed in the soil seed bank for longer than 1 year, but generally, information on seed banking is sparse or requires additional investigation. Similarly, age to reproduction is documented for several species but missing for others and would improve management planning for invasive shrub populations.

Full mechanical removal, which includes removing below-ground structures, is highly effective but one of the most labor intensive options for shrub control (Love and Anderson 2009). Mechanical topkill is only effective for reducing stem densities in the short-term, as invasive shrubs are aggressive resprouters (Schweitzer and Dey 2020). However, mulching can aid in the transformation of large and dense invasive shrub layers into populations that are more easily targeted with foliar herbicide following regrowth. Mulching of stems and subsequent mulch additions to the forest floor have not been found to be effective in reducing shrub reinvasion (Anfang et al. 2020). However, tilling or mulching of the root collar may reduce sprouting and prolong the time before reinvasion (Iannone et al. 2013, Frank et al. 2018). The response following topkill depends on site conditions and the intensity or frequency of the treatments (Loeb et al. 2010). **Repeated clipping of invasive woody plants under a native overstory may offer an additional strategy for control when herbicide is limited or not permitted.** The seasonality of control will also impact residual growth; for example, initial clipping of bush honeysuckle had no significant effect in the first year but after repeated clipping, shaded, forest interior populations were reduced to 30 % of their original densities when compared to open-grown populations that retained 91 % of their original density (Luken and Mattimiro 1991). Total nonstructural carbohydrates (TNC), which support regrowth following topkill, are replenished within the first growing season following dormant-season clipping (Richburg 2005). For growing season treated invasive shrubs, however, TNC concentrations remain depleted for longer, which reduced subsequent biomass and height of regrowth compared to dormant-season applications (Richburg 2005, Love and Anderson 2009).

Herbicides are highly effective at reducing shrub densities within the first growing season (Hartman and McCarthy 2004, Miller 2005, Rathfon and Ruble 2007, Hutchinson et al. 2011, Byrd et al. 2012, Sullivan 2013). However, the efficacy of herbicides is dependent on other environmental factors, including soil moisture, where drier soils result in greater control (Dornbos and Pruim 2012). Mechanical removal in combination with herbicides (e.g., cut stump) are more effective at reducing sprouting and regrowth than mechanical or chemical treatments alone (McDonnell et al. 2005, Pergams and Norton 2006, Schulz et al. 2012, Sullivan 2013, Enloe et al. 2018b). For example, a single treatment of winter girdling or cutting did not affect glossy buckthorn, but stump cutting followed immediately with glyphosate application resulted in over 90 % mortality after the first growing season (Reinartz 1997). Further, cutting near ground level in the early growing season when TNC concentrations are at their lowest and following up with a diluted concentration of foliar herbicide might be just as effective as cut-stump herbicide applications (Schultz et al. 2009). Low volume foliar herbicide applications are reported to have a wide range of control on different shrub sizes but the efficacy of herbicide application is improved when it is dictated by plant size (Rathfon and Ruble 2007, Ward and Williams 2013). For example, it is ineffective to treat large shrubs with foliar backpack applications when cut stump or basal bark treatments are more practical. Similarly, cut stump applications are impractical for small individuals (Rathfon and Ruble 2007, Schweitzer and Dey 2020). However, backpack mistblowers or aerial applications might be effective for applying foliar herbicide when the height of invasive shrubs is too tall for traditional backpack options and invasive shrubs have extended leaf phenology (e.g., bush honeysuckles) or evergreenness (e.g., Chinese privet) allowing for treatment when most native species are dormant (Vaughn 2013, Caplan et al. 2018, Leahy et al. 2018). Of the chemicals studied to control invasive shrubs, glyphosate is often reported as the most effective for inducing mortality and reducing resprouting, especially when considering impacts from chemicals that have residual soil activity (Miller 2005, Pergams and Norton 2006, Vaughn 2013, Ward and Williams 2013, Mervosh and Gumbart 2015, Enloe et al. 2018b). Basal bark applications with triclopyr in both dormant and growing seasons are also highly effective (Enloe et al. 2016, Kleiman et al. 2018, Baker 2019). Repeated herbicide treatments may be necessary to prevent regrowth from aggressive sprouting. For example, Japanese barberry (*Berberis thunbergii* DC.) recovered to 81 % of its pre-treatment levels 5-years following a single treatment (Ward et al. 2013). Nagel et al. (2008) reported significant reductions in glossy buckthorn seedling and stump sprout density two years post-treatment with a 5 % glyphosate application, but only following an initial 20 % glyphosate stump treatment the year prior. The season of herbicide application may affect the efficacy of control. For example, spring and fall foliar applications of glyphosate and triclopyr were more effective at controlling Chinese privet than summer applications (Harrington and Miller 2005) but fall treatments may be more effective than spring treatments (Enloe et al. 2018b). Additionally, low herbicide application rates might be just as effective as higher dosages. For example, a rate of 1.7 kg ae/ha of glyphosate was no different than application rates up to 6.7 kg ae/ha for controlling Chinese privet and rates less than 1.7 kg ae/ha may also be as effective (Harrington and Miller 2005).

The effectiveness of prescribed fire to control invasive shrubs is likely limited and may require treatment prior to burning. In addition to invasive shrubs changing the flammability and continuity of surface fuels, using fire to control invasive shrubs in bottomlands may further be impacted by difficulties to ignite surface fires and short fire windows (Cash and Anderson 2020). Single prescribed fires reduce the density of invasive shrubs in the short-term, but due to their capacity to resprout, repeated fire or other follow-up treatments are necessary (Schweitzer and Dey 2020). In an observational study, repeated prescribed fire and invasive shrub mechanical removal reduced the abundance of buckthorns in a woodland undergoing restoration in northeastern Illinois, US (Laatsch and Anderson 2000). Research has suggested that autumn-olive seeds are capable of surviving fire temperatures as high as 500℃ (Emery et al. 2011), but the heat-tolerance of other invasive shrub seeds has not been studied [but see Muscha et al. (2023) for information on Russian olive (*Elaeagnus angustifolia* L.)]. Further, the flammability and ignitability of some invasive plants have been studied, but generally, information is still lacking. Dependent on the ecosystem, in the dormant season Chinese privet leaves are just as flammable as yaupon holly (*Ilex vomitoria* Sol. ex Aiton) (Tiller et al. 2020), a native species with high ignitability that is often regarded as a live surface fuel in southern pine ecosystems. Directed flame or torching may provide control when chemical options or prescribed fire is limited. Direct torching reduces shrub clump size initially, but retreatment may be necessary for long-term control (Ward et al. 2009, Ward and Williams 2011). Although herbicide is more effective than direct torching following an initial reduction in clump size by prescribed fire or mowing, torching was nearly three times more effective than no additional treatment (Ward et al. 2009). The effectiveness of follow up treatments also depends on the size for the shrub. Smaller shrubs (average crown height and crown diameter > 120 cm) had greater mortality with any follow up treatment, but larger shrubs responded more to herbicide than direct torching (Ward et al. 2010).

Subshrubs – Multiflora rose and wine raspberry (*Rubus phoenicolasius* Maxim.) were the only subshrubs (10 publications, 6 % of the total publications), plants with a perennial base with annual, herbaceous shoots, included in our review (Fig. 3). **Management for invasive subshrubs was often combined with other invasive shrubs and vines, so specific outcomes for this group and species were difficult to discern**. Direct control tactics are also limited to outcomes for multiflora rose. Management practices utilizing periodic prescribed fire and vegetation management, including invasive plant treatments for species excluding multiflora rose, may increase the abundance of multiflora rose through time (Laatsch and Anderson 2000, Gharehaghaji et al. 2019). Topkill during the growing season will reduce TNC reserves but without repeated treatment, multiflora rose will replenish reserves by the end of the next growing season (Richburg 2005). Further, spring applications of herbicide may be more effective than fall treatments (Derr 1989). The susceptibility of multiflora rose to spring herbicide treatments may be attributed to its nonstructural carbohydrate trends during early leaf stages prior to flowering (Fick et al. 1983).

Trees – Our literature search resulted in 26 publications (16 % of the total publications) documenting invasive tree control, including seven tree species (Table 4). **Unlike the invasive shrubs, invasive trees were more commonly early-successional species that are shade intolerant to moderately shade tolerant and deciduous, and most are capable of root sprouting in addition to stump sprouting.** When noted, most become reproductively mature within a few years of life and have persistent seed banks. Several are also wind dispersed.

Mechanical removal or topkill, including mastication or mulching without follow up treatments, often results in higher stem densities than prior to treatment (Burch and Zedaker 2003). For example, tree-of-heaven is able to capitalize following topkill by producing prolific root suckers and stump sprouts (Meloche and Murphy 2006). **Removal of mature, overstory invasive trees is important for reducing the invasive seed and seedling bank; however, the removal of seedlings may provide opportunities for the recruitment of more invasive seedlings.** For instance, the removal of Norway maple (*Acer platanoides* L.) trees reduced future Norway maple seedling density while increasing the abundance of native sugar maple (*A. saccharum*) seedlings (Webb et al. (2001). However, when Norway maple seedlings where removed, Norway maple seedlings increased following treatment but not those of sugar maple. Mulching of invasive trees and subsequent mulch residuals have been tested as a method to reduce invasive tree densities and reinvasion. For example, mulch depths of 15 cm may reduce Chinese tallow seedling survival, but to achieve those depths, mulching a dense, closed canopy Chinese tallow forest would be required and would impact the establishment and growth of native plants (Donahue et al. 2006). A study designed on the phenological TNC trends of Chinese tallow found reductions in abundance when spring applications of mastication were followed by foliar herbicide targeting new growth (Pile et al. 2017b), leading to increased cover and diversity of native ground flora (Pile et al. 2018).

Herbicides are effective for reducing invasive tree stem densities and resprouting, although some chemical formulations and application types are more effective than others (Burch and Zedaker 2003, Vogt et al. 2020). Control of tree-of-heaven was greatest when triclopyr and picloram were combined, but of the seven herbicide treatment combinations evaluated, all achieved greater than 79 % mortality 1-year following treatment (Burch and Zedaker 2003). Cut stump and basal bark treatments can be highly effective for controlling invasive trees and reducing resprouting (Enloe et al. 2015). However, these methods might be challenged by dense thorny thickets (e.g., Callery pear, *Pyrus calleryana* Decne.) (Vogt et al. 2020), similar to the constraints imposed by managing invasive shrubs. Cut stump applications of glyphosate are effective for controlling treated tree-of-heaven stems (Meloche and Murphy 2006), but applications of triclopyr or imazapyr may be more effective at reducing residual sprouting (DiTomaso and Kyser 2007). Foliar applications were more consistent at controlling Callery pear when compared to other application types (Vogt et al. 2020). However, EZ-Ject® applications of glyphosate were less effective than other herbicide/control methods for reducing resprouting (Bowker and Stringer 2011). Imazapyr was documented as the most effective for controlling Chinese tallow when compared to triclopyr and glyphosate when applied as a 'hack and squirt' treatment (Gresham 2010). Imazapyr and triclopyr are also generally effective for basal bark treatments, but injection treatments with triclopyr (Eck and McGill 2007) and other assessments of triclopyr suggest that it has inconsistent control (Enloe et al. 2015). Basal bark treatments of aminocyclopyrachlor or fluroxypyr and foliar treatments of aminocyclopyrachlor are demonstrated as being highly effective for controlling Chinese tallow, including reducing resprouting (Enloe et al. 2015). Imazapyr has been shown to kill off-target tree-of-heaven and native species through root grafting, which may be an important consideration when managing mixed-species patches (Lewis and McCarthy 2008).

A single prescribed fire is not effective for controlling invasive trees (Warrix and Marshall 2018), but prescribed fire combined with other treatments has been found to be effective (Pile et al. 2017b, Rebbeck et al. 2019). **The response of invasive trees to prescribed fire is dependent on the species and the size of the individual.** As trees grow from seedlings to saplings to mature trees, their tolerance to fire increases with size through the protection of the meristem with thicker bark, regardless of any evolutionary adaptation to fire-frequent ecosystems (Shearman et al. 2018, Rosell 2019). Limited research exists on the role of frequent fire in managing invasive trees. Shorter fire return intervals may reduce invasive tree abundance through topkill and mortality, however, intervals that are too long may facilitate colonization as larger trees are able to persist and provide additional seeds or sprouts (Pile et al. 2017a, Yang et al. 2019). This is especially concerning as topkill often results in greater stem densities, and the age to fruit-bearing can be as short as 3-years for some species. For example, exposed Callery pear seeds, fruits, and 1-year-old seedlings may be killed by prescribed fires, but older individuals resprout and become multi-stemmed following topkill from fire (Warrix and Marshall 2018). Limited research exists on the flammability and ignitability of invasive tree wood and litter. However, during the growing season, the wood of Chinese tallow has high ignitability and combustibility, which may allow for masticated Chinese tallow mulch to serve as an adequate surface fuel for growing season prescribed fire (Pile et al. 2017b, Tiller et al. 2020).

Vines – Our literature search resulted in 16 publications (10 % of the total publications) documenting invasive vine control, including six species (Table 5**;** Fig. 3). There was a high number of detections of invasive vines across eastern North America but markedly fewer studies than invasive shrubs (Fig. 2). **Invasive vines are notoriously difficult to control because they can become very dense and are often difficult to treat with herbicides.** Additionally, invasive vines often resprout from stumps and roots following topkill (Mervosh and Gumbart 2015, Pavlovic et al. 2016). Further, some vines can sprout from aerial stems (Melzer et al. 2011, Pavlovic et al. 2016). Targeting a particular season of application for clipping or mechanical removal may result in greater control than others. For example, summer clipping of Asian bittersweet produces fewer sprouts than either spring or fall clipping (Mervosh and Gumbart 2015). Chemical herbicides are generally effective for treating invasive vines (Mervosh and Gumbart 2015, Farmer et al. 2016, Pavlovic et al. 2016, Weese and Barnes 2017). However, glyphosate was not as effective as other chemicals for the control of kudzu (Miller 1985) but was effective for other invasive vines (Thomas 1993, McCormick and Hartwig 1995, Farmer et al. 2016, Weese and Barnes 2017). Preemergent herbicides were found to be more effective than post-emergent herbicides for the treatment of mile-a-minute (McCormick and Hartwig 1995). Herbicide and herbicide plus mechanical removal were more effective than mechanical treatments alone for Japanese honeysuckle, but Asian bittersweet required a combination of chemical and mechanical control (Farmer et al. 2016). One paper suggests that for the control of invasive vines, cut stump herbicide applications may be more effective than basal bark treatments, and spring treatments may be more effective than fall treatments (Mervosh and Gumbart 2015). Treatment of Japanese honeysuckle during the dormant season with chemical herbicides is effective for control while minimizing impacts on other flora (Weese and Barnes 2017). Also, regrowth following treatments is site dependent. For example, although herbicide and summer clipping treatments were effective for reducing Asian bittersweet coverage, second-year regrowth was greater on moraine soils than sandy soils (Pavlovic et al. 2016). Limited research exists on the direct control of invasive vines with fire. However, single prescribed burns and burning and cutting are not an effective control treatment for Asian bittersweet as resprouting can sustainably increase stem densities (Pavlovic et al. 2016).

3.5. Native plant response to invasive plant management

Of the papers evaluated in our systematic review, 94 (57 %) reported some outcome for native plants from invasive plant management. The implications of treatment effects on native species will depend on management objectives and desired outcomes. For example, no decline in native species richness and abundance may be acceptable when treatments are expected to minimize non-target impacts, such as targeted applications of herbicide or when non-targeted impacts are being mitigated through dormant season broadcast applications. In multiple studies, glyphosate application during the dormant season effectively reduced the abundance of adult-stage garlic mustard with minimal impacts on native flora (Nuzzo 1994, Nuzzo 1996, Frey et al. 2007, Hochstedler et al. 2007). However, in restoration frameworks, where invasive plant control is anticipated to increase native species abundance and coverage, many studies have documented no change in the coverage, abundance, or richness of native ground cover with invasive plant control (Frappier et al. 2004, Vidra et al. 2007, Karlovitz 2008, Stocker et al. 2008, Swab et al. 2008, Hanula et al. 2009, Minogue et al. 2010, Chess 2011, Vaughn 2013, Christopher et al. 2014, Cutway 2017, Gharehaghaji et al. 2019). This lack of a positive response by native species may occur even with repeated invasive plant treatment, which may be attributed to a variety of factors including effects of site history, depauperate seed bank, or lack of favorable conditions for germination and growth. In a study by Cutway (2017), although mechanical removal reduced nonnative cover, subsequent increases in native richness and abundance did not follow even after eight years of continued management. These results are similar to Hochstedler et al. (2007), who observed no differences in community richness or diversity between treated and control conditions after five years of consecutive dormant-season herbicide treatments. Further, even with annual growing-season removal of dames rocket (*Hesperis matronalis* L.) over a three year period, significant increases in neither native richness nor diversity occurred (Pavlovic et al. 2009). However, one study reported no change in species richness but positive changes in other diversity metrics (Shannon's or evenness) following invasive plant treatment (Hanula et al. 2009).

Some studies have identified increases in species richness following treatment (Bohn et al. 2011, Thompson and Poindexter 2011, Shields et al. 2015, Maynard-Bean and Kaye 2019), but often these trends were short-lived with reinvasion impacting initial gains (McDonnell et al. 2005, Frey et al. 2007, Hochstedler et al. 2007, Slaughter et al. 2007, Herold et al. 2011, Mattingly et al. 2016, Hopfensperger et al. 2019). For example, annual hand removal increased native species richness after three years but rapid reinvasion of Japanese stiltgrass erased gains in the fourth year following no management (DeMeester and Richter 2010). Although chemical control is easier, manual removal of invasive plants may have additional, unforeseen benefits for restoration. In several cases, hand-pulling or other soil disturbances expose bare mineral thereby creating favorable conditions for germination (Biggerstaff and Beck 2007, Flory and Clay 2009, Flory 2010). Manual removal plus native seeding was found to be more successful at controlling English ivy while promoting native species than herbicide (glyphosate) plus native seeding, which was successful at control but diminished any seeding effect (Biggerstaff and Beck 2007). Mulching and hand felling followed by herbicide of Chinese privet had positive outcomes for native plants, especially ruderals, but these communities were compositionally different than reference plots representing desired future conditions (Hudson et al. 2014). Increases in ground flora richness and coverage were reported 8 years following herbicide control on bush honeysuckle, but these increases were likely confounded by mortality in overstory ash (*Fraxinus* spp.) from the invasive emerald ash borer (*Agrilus planipennis* Fairmaire) (Boyce 2015). Runkle et al. (2007) reported no differences after the first growing season following invasive shrub removal but higher ground flora richness and cover and greater tree seedling densities by eight years after treatment. This result was attributed to lower densities and shorter heights of bush honeysuckle following treatment under a closed canopy, thus allowing for native plants and tree seedlings to benefit from the competitive release from bush honeysuckle (Runkle et al. 2007).

Invasive plant control can result in undesirable reductions in native plant richness and abundance, especially when treatments are not highly selective. For example, mowing of Japanese stiltgrass at ground-level prior to seed set can decrease Japanese stiltgrass abundance but can also negatively impact the resident native ground flora (Nestory 2016). The control of invasive shrubs may also result in reductions of native shrubs, especially when treatments are not highly selective (Love and Anderson 2009). Even with efforts to mitigate non-target impacts, dormant-season broadcast applications of foliar herbicide can adversely affect forbs and graminoids or shift community composition to non-herbicide sensitive species (Vaughn 2013, Leahy et al. 2018). More targeted approaches may also reduce native plants, for example, reductions in native plant richness and diversity have been reported one year following herbicide or hand removal with herbicide of garlic mustard (Shartell et al. 2012).

4. Discussion

4.1. Complexities of invasive plant management

Invasive plant management in eastern North America is highly variable, both in its application and outcome. As expected, invasive plant control can reduce invader abundance, at least in the short-term but treatment efficacy and subsequent impact on native plants is inconsistent and is impacted by many biotic and abiotic factors. Common invasive plant management strategies 1) highlighted the efficacy of herbicides for controlling individuals and populations, 2) demonstrated the need for strategic timing and application for mechanical control to reduce vigor or reproduction, 3) highlighted the need for more research on the re-establishment of fire in fire-dependent ecosystems and fire's role in controlling invasive plants and reducing community invasibility, and 4) demonstrated the benefit of using enrichment plantings to improve restoration outcomes for native plants. Control tactics such as biological control agents (when they become widely available for use) and targeted herbivory show promise for reducing invader impacts. This is especially true when biological control or targeted herbivory are combined with other treatments, while soil amendments and flooding as control strategies were less successful at demonstrating reductions in the competitiveness of invasive plants but they are also not well-tested. Regardless of the invasive plant functional group, many studies stressed the need for repeated treatment over the long-term and to strategize treatment type and frequency based on age structure, phenological susceptibility, and community characteristics. The response of native plants following invasive plant management was highly variable and inconsistent, confounded by past land use, changes to disturbance regimes, and a multitude of other factors that are still not well understood.

Inconsistencies in methodology and design challenge the ability to generalize results across studies. The use of different response variables (e.g., change in plant coverage or richness) can limit direct comparison or complicate interpretation. For example, a reduction in invasive shrub coverage may occur across different treatment strategies, but the effect on shrub density may be very different (Love and Anderson 2009). An accurate assessment of invasive shrubs is complicated by their growth strategy and how their abundance is measured. Ward et al. (2009 and 2010) used the average of an individual shrub (clump) crown height and crown diameter to assign a clump size. Control was then assessed by a reduction in clump size. Further, many studies of efficacy report outcomes only for treated stems, not accounting for reinvasion, secondary invasions, or community-level response, and reports were often only months to 1–2 years following treatment. For example, most herbicides are highly effective in killing woody stems of targeted invasive plants, but subsequent monitoring of reestablishment and regrowth is needed. Studies that only report increases in richness without species lists or other descriptive information do not provide enough evidence to know if increases were due to colonization by non-native plants or weedy native plants, further limiting the ability to make inferences about treatment effects on native plants. Additionally, several studies reported different outcomes for some native plant groups (e.g., evergreen forbs or sedges and native shrubs), depending on the control tactic used (e.g., broadcast applications of herbicide or mulching). Without studies that investigate the effects on species-specific or species group response to invasive plant control, managers will not be able to accurately evaluate tradeoffs when considering different management strategies.

Although important to the literature, many published studies were observational case or retrospectives studies with either inadequate or a complete lack of controls. These studies often do not collect pre-treatment data, instead using nearby areas as references to evaluate or compare desired future conditions of community composition and structure. Although not always explicitly mentioned, experimental units were often established in areas of high invasive plant density and anthropogenic disturbance, resulting in relatively high variability across sites. This was typified by non-significant results when controls were statistically compared to *Ailanthus* wilt inoculation treatments (Pile Knapp et al. 2022) or a lack of response by herbaceous cover and species richness to garlic mustard control (Frappier et al. 2004) which was attributed to low statistical power from high variability in response variables. While this may not diminish the efficacy of the treatments, it highlights the complexities of applied plant invasion science.

Most studies with short-term results reported reductions in invasive plant abundance following management, but these short-term results can be contradicted with longer-term monitoring. For example, reductions in garlic mustard were reported in all treatment types after one month but increases in juveniles occurred one-year following several treatment types (Shartell et al. 2012). However, some long-term studies or chronosequences, using space-for-time substitution, have reported effective reduction in invasive plants and increases in native plant metrics, especially when management is prescribed over long time frames, guided by managers on the ground, and varied to include treatments such as invasive plant control, revegetation, and prescribed fire (Larkin et al. 2014, Wragg et al. 2021).

Based on our survey of the literature, we offer some key considerations for invasive plant management:

- **Effective invasive plant control requires repeated treatments, representing an investment of resources to maintain control.** Our review highlights that different techniques and approaches can have varying levels of success and that reductions in invasive plant abundance and diversity are greatest when treatments are 1) applied repeatedly (Aulakh et al. 2014, Dietz et al. 2020, Young et al. 2020) and 2) incorporated within larger restoration or resilience objectives (Murphy et al. 2007). Long-term planning strategies should include prescriptions for repeated treatment and monitoring using adaptive management approaches that allocate resources based on treatment intensity and invasion severity. Often, initial treatments are the most resource consumptive, with follow up treatments requiring fewer resources as invasive plant populations are reduced. However, without long-term approaches to invasive plant control, initial gains are quickly lost to reinvasion and secondary invasions. In addition to a need for long-term investment in the management of invasive plants, funding and prioritization of long-term invasive plant management research is greatly needed.

- **Site and environmental conditions can influence treatment outcomes.** Site conditions, such as environmental factors including soil type and moisture content, or legacy effects of past land use or disturbance, can influence invasive plant responses to herbicide or prescribed fire (Dornbos and Pruim 2012, Pavlovic et al. 2016). For example, Swab et al. (2008) reported that both bush honeysuckle abundance and native species metrics increased with increasing elevation within a floodplain, and subsequently, the removal of bush honeysuckle was not important for driving native plant richness and abundance. Contrary to expectations, Fuselier et al. (2017) reported lower diversity and richness of native ferns in bush honeysuckle managed plots, when compared to unmanaged plots, likely due to differences in site conditions or legacy effects. Better understanding of how these background factors affect invasive and native plants response to specific treatments is critical for explaining contradictory results across studies and refining management prescriptions. Unfortunately, most studies did not evaluate the influence of site or environmental factors on treatment outcomes, and this should be a consideration for research moving forward.
- **Secondary invasions are likely to occur.** Literature reviews and data syntheses suggest that secondary invasions are pervasive when community responses to management are documented (Reid et al. 2009, Kettenring and Adams 2011, Abella 2014, Pearson et al. 2016). In our study, 42 % of the articles that monitored community outcomes (24 of 57 studies) reported secondary invasions by nontarget invaders following treatment. For example, the removal of bush honeysuckle resulted in invasion by tree-of-heaven (Love and Anderson 2009) and garlic mustard (Boyce 2015). However, Boyce (2015) reported that the increases in garlic mustard were short-lived, reflecting that some secondary invasions may be transitory. Mulching of bush honeysuckle and subsequent mulch deposition was associated with secondary invasions by garlic mustard (Frank et al. 2018) and Japanese stiltgrass was commonly reported to invade or increase in abundance following the removal of other invasive plants (Osland et al. 2009, Chess 2011, Vaughn 2013, Lake et al. 2014a, Frey and Schmit 2017). Disturbance from invasive plant control may drive the establishment and growth of other invasive plants by freeing up resources and reducing competition for other invaders. For example, secondary invasions from Brazilian peppertree (*Schinus terebinthifolia* G. Raddi) and Japanese climbing fern were recorded with declines in melaleuca (*Melaleuca* spp.) due to biological control (Rayamajhi et al. 2009). Unfortunately, invasive plant treatments applied at short intervals may favor secondary invasions rather than development of native plants. For example, in a Japanese stiltgrass removal experiment, season-long hand removal increased the relative cover of other invasive plants by 51 % when compared to treatments that occurred once (Judge et al. 2008). Following reductions in the coverage of dame's rocket from annual removal, significant increases in multiflora rose and burning bush were recorded with no increases in native diversity or richness (Pavlovic et al. 2009). Control techniques that created gaps in bush honeysuckle thickets were found to increase the density of native, primarily ruderal, species but also led to increases in garlic mustard (Luken et al. 1997). Tradeoffs between aggressively managing invasive plants and allowing native plants to respond and recover without facilitating secondary invasions will need to be considered.
- **Scale of treatment application has important implications for invasive plant and native plant community outcomes**. The efficacy of a treatment is directly related to its impact and the intent of the treatment will depend on management objectives. For example, chemical herbicides are typically applied to an individual with the intent to kill all vegetative tissue, likely increasing the probability of mortality and reducing abundance. Prescribed fire is applied at stand or landscape scales, resulting in inherent variability in severity that may affect invasive plants positively or negatively depending on fire intensity and behavior, and population size and life stage. Mechanical removal, often achieved through cutting or mastication, results in top-kill but leaves below-ground reproductive structures, reducing invader abundance in the short-term but leading to long-term increases without additional management. Treatment combinations may be one of the most effective tools for managing invasive plants. Approaches that integrate applications based on seasonality or scale of impact may have greater success than those that are not thoughtful in their treatment approach. For example, broadcast applications of prescribed burning or mastication that reduce woody invasive stem densities to a more manageable size may allow for easier, targeted follow up applications of foliar herbicide or direct torching (Ward et al. 2009, Ward et al. 2010, Byrd et al. 2012, Pile et al. 2017b). Stem cutting with follow up applications of herbicide to target regrowth may also be more practical for volunteer groups, but the results may not be as efficacious as cut-stump treatments (Schulz et al. 2012).
- **Removing invasive plants does not always equal success for the native plant community**. Unfortunately, across invasive plant functional groups, management of the plant invader does not always lead to an increase in the abundance and diversity of native flora. Similar to control efficacy, native plant response depends on site and environmental conditions including legacy effects from historic land use, seed and reproductive organ availability, and favorable conditions for germination and growth. Further, improvement in data collection and experimental design could greatly improve our understanding in the variability of native plant response across conditions and treatments.
- **Enrichment planting of the native community may be required.** Many studies failed to achieve restoration outcomes without additional efforts to seed, establish, or promote native species. Sites with a long history of invasion may have a diminished or inhibited native seed bank (Collier et al. 2002, Bauer and Reynolds 2016). Further, the removal of the invasive plant may facilitate competition from the same or other invasive plants (D'Antonio and Meyerson 2002). Investment in enrichment planting strategies will require consideration of the species' ability to germinate (if required), establish, grow, and compete on a given site, within the prevailing disturbance regime and with the resident invasive plants. Further, successful establishment will be influenced by the type of cultural practices employed (e.g., planting plugs vs broadcast seeding). Finally, although native plants may become well-established after treatment, reinvasion may still occur without additional management. For example, failed germination of seeded native plants impeded restoration success in floodplain forests invaded by Mexican petunia (*Ruellia simplex* C. Wright), and although native plugs had adequate survival, they did not prevent reinvasion (Smith et al. 2016). Three initial applications of glyphosate within a calendar year (April, October, November) can reduce the abundance of cogongrass and increase native species richness in three years, but the greatest gains in native species richness occurred when a native seed mix containing 15 species were seeded upon initial glyphosate treatment with reseeding in the following dormant season (Enloe et al. 2013). Further, seeding was ineffective without herbicide to control the cogongrass population (Enloe et al. 2013). Transplanting live plants into Japanese stiltgrass populations can increase native richness and manual removal of Japanese stiltgrass can improve native plant

performance, but suppression of the invader by natives is not likely to occur within two years (Moyer and Brewer 2018). One study documented increases in native species richness through time when invasive shrub control was combined with native seeding (Hopfensperger et al. 2019). However, results like these can be highly variable and dependent on site characteristics (Wragg et al. 2021). For example, Murphy (2005) reported suppressed populations of garlic mustard with transplanted bloodroot (*Sanguinaria canadensis* L.). However, even with chemical control and native enrichment plantings, reductions in the invasive Mexican petunia did not occur in the floodplain forests of Florida (Smith et al. 2016). Invasive shrub control or removal can increase the survival and fecundity of planted or seeded ground flora (Gould and Gorchov 2000, Cipollini et al. 2009), the growth and expansion of native giant cane (Osland et al. 2009), and the growth of native tree reproduction (Lanzer et al. 2017). Complex interactions with drought, microenvironmental conditions, handling, and native species identity may limit the success of native tree enrichment plantings even after invasive shrub control (Hartman and McCarthy 2004). For example, Link et al. (2019), found no differences in first-year survival or growth of native tree species planted in densely infested Japanese barberry forest understories compared to control plots, this outcome was attributed to nurse effects of the barberry by increasing soil moisture through shading.

- **Identifying and documenting the extent and severity of invasive plants is a common problem for most land managers and natural resource agencies**. Although not explicitly reviewed, limited resources and multiple priorities can make allocating resources to invasive plant surveys challenging ultimately impacting invasive plant control. Effective invasive plant control requires efficient detection and strategic consideration of the spatial distribution and abundance of current populations, dispersal mechanisms, and other species-specific traits. Further, considerations include the degree of management effort to constrain populations for the long-term and the overall management objectives for the area. In the past decade, significant advances have been made in the remote detection of invasive plants. Many invasive plants are distinct in their cover, morphology, and/or seasonality making detection based on spectral signatures, or textural or phenological differences possible (Bradley 2014). These advancements in detection allow for spatially explicit guidance for effective control of invasive plant populations across large landownerships by prioritizing management action (Shaw 2005). However, remote surveys are still a highly underutilized tool for identifying invasion and modeling risk (Bradley 2014). Further, invasive species that have the potential to alter disturbance regimes and fundamentally change the structure and function of ecosystems (i.e., 'transformative invasive species') should be prioritized over other nonnative species (Gaertner et al. 2014). Functional eradication has been suggested for managing invasions by suppressing invader populations in priority locations below levels that cause unacceptable ecological effects (Green and Grosholz 2020). For large and abundant invasive plant populations, prioritizing life-stage and remote, satellite populations may be the most effective way to reduce or suppress invasive plant impact across landscapes. For example, mother trees or shrubs of dioecious woody invasive plants should be a priority to reduce spread. Female, seed-bearing tree-of-heaven have seed displays in the dormant season that are unique in color, quantity and arrangement when compared to native trees, allowing for aerial detection from helicopters (Rebbeck et al. 2015). Further, the size of an individual may also complicate control. Smaller individuals are more likely to survive treatments because they are often inconspicuous in other vegetation and missed when growing among larger invasive plants (Rathfon and Ruble 2007) or dense, large and extensive populations (Love and Anderson 2009). Once identified and prioritized, landscape planning and stand-level silvicultural prescriptions should include resident and emerging invasive plants as a holistic component of natural resource management.
- **The influence of white-tailed deer should not be overlooked**. Across the studies we examined, 28 reported that white-tailed deer had a substantial ecological role shaping the study site's plant community or influenced invasive plant treatment outcomes. Of those 28 papers, 7 papers experimentally controlled for herbivory from white-tailed deer. Deer herbivory can impede natural forest regeneration following invasive plant treatment (Maynard-Bean and Kaye 2019) and may have a greater negative effect on the survival and growth of underplanted tree seedlings than invasive plants (Owings et al. 2017). Interactive effects have been documented with invasive plant control and white-tailed deer exclusions (Gorchov et al. 2021). For example, Haffey and Gorchov (2019) found that the exclusion of deer and removal of bush honeysuckle resulted in greater cover of tree seedlings, vines, and spring perennials, and a tendency for greater native species richness. Further, Ward et al. (2017) reported that neither fencing nor invasive shrub control alone restored plant communities; however, when present in the seedbank, recovery of native shrubs and forbs occurred with increasing control intensity with deer exclusion. Further, native tree seedling survival and biomass was greatest when Japanese stiltgrass was controlled and deer were removed (Johnson et al. 2015). However, invasive vines might also benefit from the competitive release from invasive shrub removal and deer exclusion (Ward et al. 2013, Ward et al. 2017). White-tailed deer may also keep the abundance of ground flora low even when invasive shrubs are removed, but removal may still result in increases in native plant coverage (Christopher et al. 2014). Research has also shown that the selective browsing of native plants by deer reinforces the dominance of herbaceous invasive species (Knight et al. 2009). In fact, based on population modeling with long-term exclosure data, Kalisz et al. (2014) predicted that garlic mustard was declining towards local extinction with the exclusion of deer herbivory in a Pennsylvania hardwood forest. In a long-term exclosure study in the Great Smoky Mountain National Park, Webster et al. (2008) found that native woody vegetation overtopped and shaded out Japanese stiltgrass after 10 years. Periodic drought knocked back the stiltgrass, but consumption by deer prevented any seedlings from taking advantage outside the deer exclosure. A long-term observational study by Gharehaghaji et al. (2019) noted the benefit of invasive plant management when coupled with active deer herd reductions. Treatment method may also be important to managing native species response in areas with abundant deer herds. Basal bark treatments, which leave standing dead stems, may protect the establishment and growth of native flora from herbivory better than cut stump methods (Cipollini et al. 2009). In addition to white-tailed deer, populations of invasive hogs may also hamper invasive plant control, restoration efforts, and influence the outcomes of experimental treatments (Vaughn 2013).

5. Management considerations

Through silviculture, forest managers manipulate stand structure, composition, and growing conditions to address a wide range of objectives. Considering forest stand dynamics is a fundamental part of silvicultural prescriptions, although the explicit inclusion of invasive species in silvicultural concepts is less common. Research on manipulating competitive relationships, and the role of initial plant community composition in facilitating native plants and reducing competition by suppressing invasive plants is critically needed (Lang et al. 2017, Young et al. 2017, Weidlich et al. 2020). By incorporating knowledge of life history traits, life cycles, and ecophysiology along with other general characteristics of the targeted invasive plants and the environmental conditions that facilitate their establishment and growth into silvicultural frameworks, better ecological and economic outcomes are achieved at both the stand and landscape scale. This approach reframes the management of invasive plants as part of the silvicultural system rather than something separate, and it seeks to reduce the dominance of invasive plants by facilitating the growth of native species. Including invasive plant management in silvicultural prescriptions requires planning throughout a stand's rotation, incorporating a long-term perspective that is needed to address reinvasion and secondary invasions. It is time to reframe silvicultural systems to explicitly consider invasive plants, as eradication of many invaders is no longer feasible at large scales but can occur within management units. Successional trajectories and stand dynamics that include invasive plants are understudied, but several studies have suggested that invasive plants may decline in dominance through stand development (Flory et al. 2017, Link et al. 2019, Pile et al. 2019). Research is needed to further our understanding on how to manage forest structure or density to affect light availability for invasive plant control. Research on manipulating stand structures and maintaining low levels of invader abundance should also be conducted in combination with prescribed burning to achieve management goals such as restoring open and diverse woodlands. Unfortunately, heavily invaded communities can reach an alternative stable state where factors that typically drive forest successional processes no longer function (Miller-Adamany et al. 2019). More studies are needed to understand the comparative growth dynamics of invasive and native species and the successional trajectories of invaded forests.

Sitzia (2014) made a call to silviculturists of the European Union to help share and improve the scientific knowledge on invasive plant management. This information-gathering through applied invasive plant research is also required in eastern North America. Basic silvicultural tenets, including managing competing vegetation by modifying the light environment, native artificial regeneration, and tending and release treatments, will need to consider novel species compositions. Unfortunately, as indicated by the disturbance characteristics identified by studies in our systematic reviews, silvicultural practices commonly facilitate invasive plants' presence and abundance. Skid trails and haul roads used in harvesting are often conduits for invasive plant dispersal (Buckley et al. 2003). Harvest-created canopy gaps release advanced regeneration of the invasive shrubs that may have otherwise been outcompeted by native flora (Burnham and Lee 2010). However, timber management activities coupled with invasive plant management can lead to positive outcomes for native tree reproduction and native ground flora. For example, timber harvest and Japanese stiltgrass control increased the survival of northern red oak (*Quercus rubra* L.) seedlings in southern Indiana, US (Johnson et al. 2015). When invasive plants are present, taking a slower approach to opening the canopy and manipulating the light environment may be required. A study in oak forests in West Virginia, US suggested that silvicultural activities that limit canopy openings to < 15 % of the management unit can deter invasive plant establishment and encourage the maintenance of native plant communities (Huebner et al. 2018). Treating invasive populations through chemical, mechanical, or with prescribed burning before overstory thinning or harvesting operations may help reduce invader abundance and improve native tree and flora outcomes. Lee et al. (2017) found that treating glossy buckthorn (*Rhamnus frangula* L.) two years prior to harvest activity reduced buckthorn height and density while resulting in positive increases in eastern white pine (*Pinus strobus* L.) seedling density and height. Increasing herbaceous fuels may also help to promote frequent surface fire regimes and increase competition with invasive plants. Additionally, post-harvest release treatments may allow native woody species an opportunity to grow above invasive species. For example, by removing competing vegetation, including invasive shrubs, eastern white pine saplings increased in height and diameter growth (Lanzer et al. 2017). Although these treatments will not eliminate invasive plants, they may accelerate native forest stand dynamic processes by reducing invasive plant impacts on tree recruitment and growth.

Forest management into the future will need to include strategies for invasive plant control, for species already on the landscape and those that may come through increased globalization and climate warming. Climate-smart forestry practices, such as focusing on forest densities and compositions that are resistant or resilient to climate change should also include invasive plants in their management approach. Unfortunately, there is a lack of information on climate resilient strategies that encompass invasive plant control, greatly diminishing proactive management that is already challenged by limited funding and resources (Beaury et al. 2020). Further, impacts from invasive insects and diseases in association with climate change will further impact forest successional processes and provide opportunities for the establishment of invasive plants.

6. Conclusion

Research on invasive plant management in forested ecosystems of eastern North American has been growing for several decades. While there are commonalities and recommendations that can be made based on the available literature, the science of invasive plant management could be improved by standardizing methodology, improving data reporting, and providing resources for long-term monitoring. Our review may have missed some species or papers on the topic of invasive plant management, and we recognize the need for focused reviews on topics such as native plant response, species or functional group management and ecology, biological control, or other control techniques. We hope this review initiates that conversion. This review also highlights that information on basic biology is missing for many species and that understanding a species' biology is important for determining its management. We found that management with herbicide typically results in some level of short-term control. However, research is needed to develop herbicide prescriptions and to provide alternatives when herbicides are not available. Some plant invasions may be a short-term response to disturbance and that their presence might decline with forest succession. Long-term monitoring or space-for-time studies are needed to shed light on this question. Native herbivores (i.e., white-tailed deer) and domesticated livestock may hamper control efforts or provide a method of control when combined with other treatments, and further evaluation of both is warranted. Enrichment seeding and planting may be helpful in reducing the impact of reinvasion and secondary invasions, but enrichment is not always successful at securing desired species. Research is needed to develop protocols for enrichment seeding or planting to establish native species while reducing invader abundance. Plant invasions will continue to challenge natural area management and actively managed forest lands; however, scientists and managers working together may offer the best approach to reducing the impact and spread of invasive plants in the forests of eastern North America.

CRediT authorship contribution statement

Lauren S. Pile Knapp: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft, Visualization. **David R. Coyle:** Conceptualization, Writing – original draft, Writing – review & editing. **Daniel C. Dey:** Conceptualization, Methodology, Writing – review & editing. **Jacob S. Fraser:** Methodology, Data curation, Visualization, Writing – review & editing. **Todd Hutchinson:** Conceptualization, Writing – original draft, Writing – review & editing. **Michael A. Jenkins:** Conceptualization, Writing – original draft, Writing – review & editing. **Christel C. Kern:** Conceptualization, Writing – original draft, Writing – review & editing. **Benjamin O. Knapp:** Conceptualization, Methodology, Writing – review & editing. **Dacoda Maddox:** Data curation, Writing – review & editing. **Cornelia Pinchot:** Conceptualization, Writing – original draft, Writing – review & editing. **G. Geoff Wang:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We would like to sincerely thank the two anonymous reviewers for their thoughtful comments and feedback. We would also like to thank Drs. Steve Shifley and Frank Thompson who inspired the concept of this paper on one of our regular coffee walks. Additionally, our retired colleagues Drs. Joanne Rebbeck and Greg Wheeler who imparted their wisdom during early conversations on this project. Funding for this project, in part, provided by the USDA Forest Service, Northern Research Station.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2023.121517.

References

Abella, S.R., 2014. Effectiveness of exotic plant treatments on National Park Service lands in the United States. Invasive Plant Science and Management 7, 147–163.
Adams, M.M., Benjamin, T.J., Emery, N.C., Brouder, S.J., Gibson, K.D., 2013. The effect of biochar on native and invasive prairie plant species. Invasive Plant Science and Management 6, 197–207.
Allen, J.M., Bradley, B.A., 2016. Out of the weeds? Reduced plant invasion risk with climate change in the continental United States. Biological Conservation 203, 306–312.
Anfang, C., Schuster, M.J., Wragg, P.D., Reich, P.B., 2020. Increased light availability due to forestry mowing of invasive European buckthorn promotes its regeneration. Restoration Ecology 28, 475–482.
Au, R.C.F., Tuchscherer, K., 2014. Efficacy of biological and chemical herbicides on non-native buckthorn during three seasonal periods. Natural Areas Journal 34 (92–98), 97.
Aulakh, J.S., Enloe, S.F., Loewenstein, N.J., Price, A.J., Wehtje, G., Miller, J.H., 2014. Pushing toward cogongrass (Imperata cylindrica) patch eradication: the influence of herbicide treatment and application timing on cogongrass rhizome elimination. Invasive Plant Science and Management 7, 398–407.
Ayeni, A.O., Duke, W.B., 1985. The influence of rhizome features on subsequent regenerative capacity in speargrass (Imperata cylindrica (L.) Beauv.). Agriculture, Ecosystems & Environment 13, 309–317.
Bailey, D.W., Mosley, J.C., Estell, R.E., Cibils, A.F., Horney, M., Hendrickson, J.R., Walker, J.W., Launchbaugh, K.L., Burritt, E.A., 2019. Synthesis Paper: Targeted livestock grazing: Prescription for healthy rangelands. Rangeland Ecology & Management 72, 865–877.
Baker, K., 2019. Controlling Lonicera maackii (Amur honeysuckle): basal bark and prescribed fire efficacy and impacts. Northern Illinois University.
Bauer, J.T., Reynolds, H.L., 2016. Restoring native understory to a woodland invaded by *Euonymus fortunei*: multiple factors affect success. Restoration Ecology 24, 45–52.
Beans, C.M., Kilkenny, F.F., Galloway, L.F., 2012. Climate suitability and human influences combined explain the range expansion of an invasive horticultural plant. Biological Invasions 14, 2067–2078.
Beaury, E.M., Fusco, E.J., Jackson, M.R., Laginhas, B.B., Morelli, T.L., Allen, J.M., Pasquarella, V.J., Bradley, B.A., 2020. Incorporating climate change into invasive species management: insights from managers. Biological Invasions 22, 233–252.
Beebe, G.R., 2021. Smoke, goats, and oaks: The effects of targeted goat browsing and prescribed fire on woody regeneration and ground flora in Ozark woodlands. University of Missouri, Columbia, MO.
Biggerstaff, M.S., Beck, C.W., 2007. Effects of method of English ivy removal and seed addition on regeneration of vegetation in a southeastern piedmont forest. The American Midland Naturalist 158 (206–220), 215.
Bohn, K.K., Minogue, P.J., Pieterson, E.C., 2011. Control of invasive Japanese climbing fern (Lygodium japonicum) and response of native ground cover during restoration of a disturbed longleaf pine ecosystem. Ecological Restoration 29, 346–356.
Bowden, R.D., Caylor, A., Hemmelgarn, G., Kresse, M., Martin, A., Althouse, M., 2022. Prescribed browsing by goats shows promise in controlling multiflora rose in a deciduous forest at the Erie National Wildlife Refuge in northwestern Pennsylvania. Natural Areas Journal 42 (196–205), 110.
Bowker, D., Stringer, J., 2011. Efficacy of herbicide treatments for controlling residual sprouting of tree-of-heaven. In: Fei, S., Lhotka, J.M., Stringer, J., Gottschalk, K.W., Miller, G.W. (Eds.), 17th Central Hardwood Forest Conference. USDA Forest Servive, Northern Research Station, Lexington, KY, pp. 128–133.
Boyce, R.L., 2015. Recovery of native plant communities in southwest Ohio after *Lonicera maackii* removal. The Journal of the Torrey Botanical Society 142, 193–204.
Bradley, B.A., 2014. Remote detection of invasive plants: a review of spectral, textural and phenological approaches. Biological Invasions 16, 1411–1425.
Bradley, B.A., Wilcove, D.S., Oppenheimer, M., 2010. Climate change increases risk of plant invasion in the eastern United States. Biological Invasions 12, 1855–1872.
Brewer, J.S., Abbott, M.J., Moyer, S.A., 2015. Effects of oak-hickory woodland restoration treatments on native groundcover vegetation and the invasive grass, *Microstegium vimineum*. Ecological Restoration 33, 256–265.
Brewer, J.S., Cralle, S.P., 2003. Phosphorus addition reduces invasion of a longleaf pine savanna (Southeastern USA) by a non-indigenous grass (Imperata cylindrica). Plant Ecology 167, 237–245.
Brooke, J.M., Basinger, P.S., Nanney, J.S., Harper, C.A., 2015. Effectiveness of three postemergence herbicides in controlling an invasive annual grass, *Microstegium vimineum*. Journal of the Southeastern Association of Fish and Wildlife Agencies 2, 262–267.
Brooks, M.L., D'Antonio, C.M., Richardson, D.M., Grace, J.B., Keeley, J.E., DiTomaso, J. M., Hobbs, R.J., Pellant, M., Pyke, D., 2004. Effects of invasive alien plants on fire regimes. Bioscience 54, 677–688.
Brooks, R.K., Wickert, K.L., Baudoin, A., Kasson, M.T., Salom, S., 2020. Field-inoculated *Ailanthus altissima* stands reveal the biological control potential of *Verticillium nonalfalfae* in the mid-Atlantic region of the United States. Biological Control 148, 104298.
Brown, C.E., Pezeshki, S.R., 2000. A study on waterlogging as a potential tool to control *Ligustrum sinense* populations in western Tennessee. Wetlands 20, 429–437.
Buckley, D.S., Crow, T.R., Nauertz, E.A., Schulz, K.E., 2003. Influence of skid trails and haul roads on understory plant richness and composition in managed forest landscapes in Upper Michigan, USA. Forest Ecology and Management 175, 509–520.
Burch, P.L., Zedaker, S.M., 2003. Removing the invasive tree *Ailanthus altissima* and restoring natural cover. Journal of Arboriculture 29, 18.
Burnham, K.M., Lee, T.D., 2010. Canopy gaps facilitate establishment, growth, and reproduction of invasive *Frangula alnus* in a *Tsuga canadensis* dominated forest. Biological Invasions 12, 1509–1520.
Burrill, E. A., A. M. DiTommaso, J. A. Turner, S. A. Pugh, J. Menlove, G. Christiansen, C. J. Perry, and B. L. Conkling. 2021. The Forest Inventory and Analysis Database: database description and user guide version 9.0.1 for Phase 2. Page 1026. U.S. Department of Agriculture, Forest Service.
Byrd, S.M., Cavender, N.D., Peugh, C.M., Bauman, J.M., 2012. Sustainable landscapes: evaluating strategies for controlling autumn olive (Elaeagnus umbellata) on reclaimed surface mineland at the wilds conservation center in southeastern Ohio. Journal of the American Society of Mining and Reclamation 193, 1.
Byun, C., de Blois, S., Brisson, J., 2018. Management of invasive plants through ecological resistance. Biological Invasions 20, 13–27.
Callaway, R.M., Ridenour, W.M., 2004. Novel weapons: invasive success and the evolution of increased competitive ability. Frontiers in Ecology and the Environment 2, 436–443.
Environment Canada. 2004. An Invasive Alien Species Strategy for Canada. Page 46. Environment Canada., Ottawa - Canada.
Caplan, J.S., Whitehead, R.D., Gover, A.E., Grabosky, J.C., 2018. Extended leaf phenology presents an opportunity for herbicidal control of invasive forest shrubs. Weed Research 58, 244–249.
Cash, J.S., Anderson, C.J., 2020. Feasibility of igniting prescribed fires in bottomland hardwood forests. Journal of Forestry.
Catford, J.A., Jones, L.P., 2019. Grassland invasion in a changing climate. In: Gibson, D. J., Newman, J.A. (Eds.), Grasslands and Climate Change. Cambridge University Press, Cambridge, UK, pp. 149–171.
Cavaleri, M.A., Ostertag, R., Cordell, S., Sack, L., 2014. Native trees show conservative water use relative to invasive trees: results from a removal experiment in a Hawaiian wet forest. Conservation. Physiology 2.
Chapman, J.I., Cantino, P.D., McCarthy, B.C., 2012. Seed production in garlic mustard (Alliaria petiolata) prevented by some methods of manual removal. Natural Areas Journal 32, 305–315.
Cheplick, G.P., 2010. Limits to local spatial spread in a highly invasive annual grass (Microstegium vimineum). Biological Invasions 12, 1759–1771.
Chess, P., 2011. Effect of invasive species removal on the understory of an urban forest. North Carolina State University, Raleigh, NC.
Chornesky, E.A., Bartuska, A.M., Aplet, G.H., Britton, K.O., Cummings-Carlson, J., Davis, F.W., Eskow, J., Gordon, D.R., Gottschalk, K.W., Haack, R.A., Hansen, A.J., Mack, R.N., Rahel, F.J., Shannon, M.A., Wainger, L.A., Wigley, T.B., 2005. Science priorities for reducing the threat of invasive species to sustainable forestry. Bioscience 55, 335–348.
Christopher, C.C., Matter, S.F., Cameron, G.N., 2014. Individual and interactive effects of Amur honeysuckle (Lonicera maackii) and white-tailed deer (Odocoileus virginianus) on herbs in a deciduous forest in the eastern United States. Biological Invasions 16, 2247–2261.
Cipollini, K., Ames, E., Cipollini, D., 2009. Amur honeysuckle (Lonicera maackii) management method impacts restoration of understory plants in the presence of white-tailed deer (Odocoileus virginiana). Invasive Plant Science and Management 2, 45–54.
Cipollini, K.A., McClain, G.Y., Cipollini, D., 2008. Separating above- and belowground effects of *Alliaria petiolata* and *Lonicera maackii* on the performance of *Impatiens capensis*. The American Midland Naturalist 160 (117–128), 112.

Clewell, A.F., 1985. Guide to the vascular plants of the Florida panhandle. University Presses of Florida, Florida State University.
Collier, M.H., Vankat, J.L., Hughes, M.R., 2002. Diminished plant richness and abundance below *Lonicera maackii*, an invasive shrub. The American Midland Naturalist 147 (60–71), 12.
Conner, W.H., 1994. The effect of salinity and waterlogging on growth and survival of baldcypress and Chinese tallow seedlings. Journal of Coastal Research 10, 1045–1049.
Cutting, K.J., Hough-Goldstein, J., 2013. Integration of biological control and native seeding to restore invaded plant communities. Restoration Ecology 21, 648–655.
Cutway, H.B., 2017. Effects of long-term manual invasive plant removal on forest understory composition. Natural Areas Journal 37 (530–539), 510.
D'Antonio, C., Meyerson, L.A., 2002. Exotic plant species as problems and solutions in ecological restoration: A synthesis. Restoration Ecology 10, 703–713.
DeMeester, J. E., and D. d. Richter. 2010. Restoring restoration: removal of the invasive plant *Microstegium vimineum* from a North Carolina wetland. Biological Invasions **12**: 781-793.
Derr, J.F., 1989. Multiflora rose (Rosa multiflora) control with metsulfuron. Weed Technology 3, 381–384.
Dey, D.C., Knapp, B.O., Battaglia, M.A., Deal, R.L., Hart, J.L., O'Hara, K.L., Schweitzer, C. J., Schuler, T.M., 2019. Barriers to natural regeneration in temperate forests across the USA. New Forests 50, 11–40.
Dietz, S.L., Anderson, C.T., Sowell, D.R., Gundy, R.L., King, L.E., 2020. The effects of treatment and management history on the control of old world climbing fern (Lygodium microphyllum), Brazilian pepper (Schinus terebinthifolia) and punktree (Melaleuca quinquenervia). Invasive Plant Science and. Management:1–28.
DiTomaso, J.M., Kyser, G.B., 2007. Control of *Ailanthus altissima* using stem herbicide application techniques. Arboriculture and Urban Forestry 33, 55.
Donahue, C., Rogers, W.E., Siemann, E., 2006. Restoring an invaded prairie by mulching live Sapium sebiferum (Chinese tallow trees): effects of mulch on Sapium seed germination. Natural Areas Journal 26, 244–253.
Dornbos, D.L., Pruim, R., 2012. Moist soils reduce the effectiveness of glyphosate on cut stumps of buckthorn. Natural Areas Journal 32 (240–246), 247.
Drayton, B., Primack, R.B., 1999. Experimental extinction of garlic mustard (Alliaria petiolata) populations: implications for weed science and conservation biology. Biological Invasions 1, 159–167.
Dudney, J., Hobbs, R.J., Heilmayr, R., Battles, J.J., Suding, K.N., 2018. Navigating novelty and risk in resilience management. Trends in Ecology & Evolution 33, 863–873.
Dukes, J.S., Pontius, J., Orwig, D., Garnas, J.R., Rodgers, V.L., Brazee, N., Cooke, B., Theoharides, K.A., Stange, E.E., Harrington, R., Ehrenfeld, J., Gurevitch, J., Lerdau, M., Stinson, K., Wick, R., Ayres, M., 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict?This article is one of a selection of papers from NE Forests 2100: A Synthesis of Climate Change Impacts on Forests of the Northeastern US and Eastern Canada. Canadian Journal of Forest Research 39, 231–248.
Eck, W. E., and D. W. McGill. 2007. Testing the efficacy of triclopyr and imazapyr using two application methods for controlling tree-of-heaven along a West Virginia highway. Pages 163-168 *in* Proceedings of the 15th Central Hardwood Forest Conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Knoxville, TN.
Ellison, A.M., Bank, M.S., Clinton, B.D., Colburn, E.A., Elliott, K., Ford, C.R., Foster, D.R., Kloeppel, B.D., Knoepp, J.D., Lovett, G.M., Mohan, J., Orwig, D.A., Rodenhouse, N. L., Sobczak, W.V., Stinson, K.A., Stone, J.K., Swan, C.M., Thompson, J., Von Holle, B., Webster, J.R., 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 3, 479–486.
Emery, S.M., Uwimbabazi, J., Flory, S.L., 2011. Fire intensity effects on seed germination of native and invasive Eastern deciduous forest understory plants. Forest Ecology and Management 261, 1401–1408.
Emery, S.M., Luke Flory, S., Clay, K., Robb, J.R., Winters, B., 2013. Demographic responses of the invasive annual grass *Microstegium vimineum* to prescribed fires and herbicide. Forest Ecology and Management 308, 207–213.
Enloe, S.F., Lauer, D.K., 2016. Seasonal variation in Macartney rose (Rosa bracteata) response to herbicide treatment. Weed Technology 30, 758–764.
Enloe, S.F., Loewenstein, N.J., Held, D.W., Eckhardt, L., Lauer, D.K., 2013. Impacts of prescribed fire, glyphosate, and seeding on cogongrass, species richness, and species diversity in longleaf pine. Invasive Plant Science and Management 6 (536–544), 539.
Enloe, S.F., Loewenstein, N.J., Streett, D., Lauer, D.K., 2015. Herbicide treatment and application method influence root sprouting in Chinese tallowtree (Triadica sebifera). Invasive Plant Science and Management 8, 160–168.
Enloe, S.F., O'Sullivan, S.E., Loewenstein, N.J., Brantley, E.F., Lauer, D.K., 2016. Triclopyr application timing and concentration influence low-volume basal bark efficacy on Chinese privet (Ligustrum sinense). Invasive Plant Science and Management 9, 235–241.
Enloe, S.F., Lucardi, R.D., Loewenstein, N.J., Lauer, D.K., 2018a. Response of twelve Florida cogongrass (Imperato cylindrica) populations to herbicide treatment. Invasive Plant Science and Management 11, 82–88.
Enloe, S.F., O'Sullivan, S.E., Loewenstein, N.J., Brantley, E., Lauer, D.K., 2018b. The influence of treatment timing and shrub size on Chinese privet (Ligustrum sinense) control with cut stump herbicide treatments in the southeastern United States. Invasive Plant Science and Management 11, 49–55.
Epstein, A.H., Hill, J.H., Nutter, F.W., 1997. Augmentation of rose rosette disease for biocontrol of multiflora rose (Rosa multiflora). Weed Science 45, 172–178.
Esler, K.J., Prozesky, H., Sharma, G.P., McGeoch, M., 2010. How wide is the "knowing-doing" gap in invasion biology? Biological Invasions 12, 4065–4075.
Fan, Z., Yang, S., Cheng, N., Liu, X., Song, A., Dong, L., 2021. Invasibility of fire-managed ecosystems to the Chinese tallow tree (Triadica sebifera) in the lower Gulf Coastal Plain, USA: Mechanisms and key factors at the landscape level. Forest Ecology and Management 479, 118539.
Farmer, S., Jennifer Rhode, W., Horton, J.L., Clarke, H.D., 2016. Southern Appalachian urban forest response to three invasive plant removal treatments. Management of Biological Invasions 7, 329–342.
Ferriter, A., 2001. *Lygodium* management plan for Florida: a report from the Florida Exotic Pest Plant Council's *Lygodium* task force. Florida Exotic Pest Plant Council.
Fick, W. H., H. L. Stites, P. D. Ohlenbusch, and G. L. Kilgore. 1983. Nonstructural carbohydrate reserves and control of multiflora rose. Pages 91-98 *in* Proceedings of the North Central Weed Conference.
Flory, S.L., 2010. Management of *Microstegium vimineum* invasions and recovery of resident plant communities. Restoration Ecology 18, 103–112.
Flory, S.L., Bauer, J., Phillips, R.P., Clay, K., 2017. Effects of a non-native grass invasion decline over time. Journal of Ecology 105, 1475–1484.
Flory, S.L., Clay, K., 2009. Invasive plant removal method determines native plant community responses. Journal of Applied Ecology 46, 434–442.
Flory, S.L., Clay, K., Emery, S.M., Robb, J.R., Winters, B., 2015. Fire and non-native grass invasion interact to suppress tree regeneration in temperate deciduous forests. Journal of Applied Ecology 52, 992–1000.
Flory, S.L., Lewis, J., 2009. Nonchemical methods for managing Japanese stiltgrass (Microstegium vimineum). Invasive Plant Science and Management 2, 301–308.
Flower, C. E., C. C. Pinchot, and J. M. Slavicek. 2017. Restoring ecosystem resilience to urban forests using Dutch elm disease-tolerant American elm trees. Pages 141-142 *in* Proceedings of the American Elm Restoration Workshop 2016. US Department of Agriculture, Forest Service, Northern Research Station, Lewis Center, OH.
Frank, G.S., Saunders, M.R., Jenkins, M.A., 2018. Short-term vegetation responses to invasive shrub control techniques for Amur honeysuckle (Lonicera maackii [Rupr.] Herder). Forests 9, 607.
Frappier, B., Eckert, R.T., Lee, T.D., 2004. Experimental Removal of the non-indigenous shrub Rhamnus frangula (glossy buckthorn): effects on native herbs and woody seedlings. Northeastern Naturalist 11, 333–343.
Frey, M.N., Schmit, J.P., 2017. Early-season treatment of fig buttercup (Ranunculus ficaria). Invasive Plant Science and Management 10, 191–200.
Frey, M.N., Herms, C.P., Cardina, J., 2007. Cold weather application of glyphosate for garlic mustard (Alliaria petiolata) control. Weed Technology 21, 656–660.
Fridley, J.D., 2012. Extended leaf phenology and the autumn niche in deciduous forest invasions. Nature 485, 359.
Funk, J.L., Cleland, E.E., Suding, K.N., Zavaleta, E.S., 2008. Restoration through reassembly: plant traits and invasion resistance. Trends in Ecology & Evolution 23, 695–703.
Funk, J.L., Parker, I.M., Matzek, V., Flory, S.L., Aschehoug, E.T., D'Antonio, C.M., Dawson, W., Thomson, D.M., Valliere, J., 2020. Keys to enhancing the value of invasion ecology research for management. Biological Invasions 22, 2431–2445.
Fuselier, L.C., Carreiro, M., Nason, L., 2017. Invasive species management impacts on native and nonnative ferns in an urban forest spore bank. Castanea 83 (28–37), 10.
Gaertner, M., Biggs, R., Te Beest, M., Hui, C., Molofsky, J., Richardson, D.M., 2014. Invasive plants as drivers of regime shifts: identifying high-priority invaders that alter feedback relationships. Diversity and Distributions 20, 733–744.
Gakpetor, G., 2019. The cost effectiveness of biological control of air potato vine using air potato beetle; A biocontrol agent in Florida. Florida Agricultural and Mechanical University.
Gharehaghaji, M., Kobal, S., Reklau, R., Minor, E.S., 2019. Management slows down invasion by non-native plants but does not prevent community change over 35 years in urban forests of the Midwestern USA. Forest Ecology and Management 448, 424–431.
Gibson, D.J., Spyreas, G., Benedict, J., 2002. Life history of Microstegium vimineum (Poaceae), an invasive grass in southern Illinois. The Journal of the Torrey Botanical Society 129, 207–219.
Glasgow, L.S., Matlack, G.R., 2007. The effects of prescribed burning and canopy openness on establishment of two non-native plant species in a deciduous forest, southeast Ohio, USA. Forest Ecology and Management 238, 319–329.
Gorchov, D.L., Blossey, B., Averill, K.M., Dávalos, A., Heberling, J.M., Jenkins, M.A., Kalisz, S., McShea, W.J., Morrison, J.A., Nuzzo, V., Webster, C.R., Waller, D.M., 2021. Differential and interacting impacts of invasive plants and white-tailed deer in eastern U.S. forests. Biological Invasions 23, 2711–2727.
Gould, A.M.A., Gorchov, D.L., 2000. Effects of the exotic invasive shrub *Lonicera maackii* on the survival and fecundity of three species of native annuals. The American Midland Naturalist 144, 36–50.
Grace, J.B., 1998. Can prescribed fire save the endangered coastal prairie ecosystem from Chinese tallow invasion? Endangered Species Update 15, 70–76.
Green, S.J., Grosholz, E.D., 2020. Functional eradication as a framework for invasive species control. Frontiers in Ecology and the Environment **N/a**.
Gresham, C.A., 2010. Efficacy of'hack and squirt'application of imazapyr, triclopyr, and glyphosate to control the invasive tree species Chinese tallowtree. General Technical Report-Southern Research Station, USDA Forest Service:121–122.
Hackmann, T.J., Spain, J.N., 2010. Invited review: Ruminant ecology and evolution: Perspectives useful to ruminant livestock research and production. Journal of Dairy Science 93, 1320–1334.
Haffey, C.M., Gorchov, D.L., 2019. The effects of deer and an invasive shrub, *Lonicera maackii*, on forest understory plant composition. Écoscience 26, 237–247.
Hall, K.R., Spooner, J., Richardson, R.J., Hoyle, S.T., Frederick, D.J., 2014. Postemergence control of *Microstegium vimineum* on riparian restoration sites with

aquatic-use registered herbicides. JAWRA Journal of the American Water Resources Association 50, 533–542.
Hanula, J.L., Horn, S., Taylor, J.W., 2009. Chinese privet (Ligustrum sinense) removal and its effect on native plant communities of riparian forests. Invasive Plant Science and Management 2, 292–300.
Harrington, T.B., Miller, J.H., 2005. Effects of application rate, timing, and formulation of glyphosate and triclopyr on control of Chinese privet (Ligustrum sinense). Weed Technology 19, 47–54.
Harris, P.T., Cannon, G.H., Smith, N.E., Muth, N.Z., 2013. Assessment of plant community restoration following Tree-of-Heaven (Ailanthus altissima) control by Verticillium albo-atrum. Biological Invasions 15, 1887–1893.
Hart, S.P., 2001. Recent perspectives in using goats for vegetation management in the USA. Journal of Dairy Science 84, E170–E176.
Hartman, K.M., McCarthy, B.C., 2004. Restoration of a forest understory after the removal of an invasive shrub, Amur honeysuckle (Lonicera maackii). Restoration Ecology 12, 154–165.
Hartman, K.M., McCarthy, B.C., 2007. A dendro-ecological study of forest overstorey productivity following the invasion of the non-indigenous shrub *Lonicera maackii*. Applied Vegetation Science 10, 3–14.
Herold, J., Anderson, M.R., Bauer, J.T., Borowicz, V., Anderson, R.C., 2011. Comparison of the effect of early and late removal of second-year garlic mustard (Alliaria petiolata) on first-year plants and deciduous forest spring and summer dominant herbaceous groundlayer species in central Illinois, USA. Ecological Restoration 29, 225–233.
Hochstedler, W.W., Slaughter, B.S., Gorchov, D.L., Saunders, L.P., Stevens, M.H.H., 2007. Forest floor plant community response to experimental control of the invasive biennial, Alliaria petiolata (garlic mustard). The Journal of the Torrey Botanical Society 134 (155–165), 111.
Hopfensperger, K.N., Boyce, R.L., Schenk, D., 2019. Potential Reinvasion of *Lonicera maackii* after Urban Riparian Forest Restoration. Ecological Restoration 37, 25–33.
Hough-Goldstein, J., Schiff, M., Lake, E., Butterworth, B., 2008. Impact of the biological control agent Rhinoncomimus latipes (Coleoptera: Curculionidae) on mile-a-minute weed, Persicaria perfoliata, in field cages. Biological Control 46, 417–423.
Howard, J. L. 2005. *Imperata brasiliensis, I. cylindrica*. Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.fed.us/database/feis/plants/graminoid/impspp/all.html.
Hudson, J.R., Hanula, J.L., Horn, S., 2014. Impacts of removing Chinese privet from riparian forests on plant communities and tree growth five years later. Forest Ecology and Management 324, 101–108.
Huebner, C.D., Regula, A.E., McGill, D.W., 2018. Germination, survival, and early growth of three invasive plants in response to five forest management regimes common to US northeastern deciduous forests. Forest Ecology and Management 425, 100–118.
Hui, C., Richardson, D.M., 2017. Invasion Dynamics. Oxford University Press, New York, NY.
Hunt, D.M., Zaremba, R.E., 1992. The northeastward spread of Microstegium vimineum (Poaceae) into New York and adjacent states. Rhodora 94, 167–170.
Hutchinson, J.T., Langeland, K.A., 2010. Monitoring of applied management techniques to control old world climbing fern (Lygodium microphyllum) in disturbed habitat. Florida Scientist 73, 262–273.
Hutchinson, J.T., Langeland, K.A., Meisenburg, M., 2011. Field trials for herbicide control of coral ardisia (Ardisia crenata) in natural areas of North-Central Florida. Invasive Plant Science and Management 4, 234–238.
Iannone, B.V., Umek, L.G., Heneghan, L., Wise, D.H., 2013. Amending soil with mulched European buckthorn (Rhamnus cathartica) does not reduce reinvasion. Ecological Restoration 31, 264–273.
Ingham, C.S., Borman, M.M., 2010. English ivy (Hedera spp., Araliaceae) response to goat browsing. Invasive Plant Science and Management 3, 178–181.
Jacobs, D.F., Dalgleish, H.J., Nelson, C.D., 2013. A conceptual framework for restoration of threatened plants: the effective model of American chestnut (Castanea dentata) reintroduction. New Phytologist 197, 378–393.
Johnson, D.J., Flory, S.L., Shelton, A., Huebner, C., Clay, K., 2015. Interactive effects of a non-native invasive grass *Microstegium vimineum* and herbivore exclusion on experimental tree regeneration under differing forest management. Journal of Applied Ecology 52, 210–219.
Johnstone, J.F., Allen, C.D., Franklin, J.F., Frelich, L.E., Harvey, B.J., Higuera, P.E., Mack, M.C., Meentemeyer, R.K., Metz, M.R., Perry, G.L., Schoennagel, T., Turner, M.G., 2016. Changing disturbance regimes, ecological memory, and forest resilience. Frontiers in Ecology and the Environment 14, 369–378.
Judge, C.A., Neal, J.C., Derr, J.F., 2005. Response of Japanese stiltgrass (Microstegium vimineum) to application timing, rate, and frequency of postemergence herbicides. Weed Technology 19, 912–917.
Judge, C.A., Neal, J.C., Shear, T.H., 2008. Japanese stiltgrass (Microstegium vimineum) management for restoration of native plant communities. Invasive Plant Science and Management 1, 111–119.
Just, M.G., Hohmann, M.G., Hoffmann, W.A., 2017. Invasibility of a fire-maintained savanna–wetland gradient by non-native, woody plant species. Forest Ecology and Management 405, 229–237.
Kalisz, S., R. B. Spigler, and C. C. Horvitz. 2014. In a long-term experimental demography study, excluding ungulates reversed invader's explosive population growth rate and restored natives. Proceedings of the National Academy of Sciences **111**:4501-4506.
Karlovitz, C., 2008. Effects of aboveground removal of buckthorn on the surrounding plant community. Carthage College, Kenosha, WI.
Kettenring, K.M., Adams, C.R., 2011. Lessons learned from invasive plant control experiments: a systematic review and meta-analysis. Journal of Applied Ecology 48, 970–979.
Kleiman, L.R., Kleiman, B.P., Kleiman, S., 2018. Successful control of Lonicera maackii (Amur honeysuckle) with basal bark herbicide. Ecological Restoration 36, 267–269.
Knight, T.M., Dunn, J.L., Smith, L.A., Davis, J., Kalisz, S., 2009. Deer facilitate invasive plant success in a Pennsylvania forest understory. Natural Areas Journal 29 (110–116), 117.
Knight, K. S., L. M. Haugen, C. C. Pinchot, P. G. Schaberg, and J. M. Slavicek. 2017. American elm (*Ulmus americana*) in restoration plantings: a review. Pages 133-140 *in* Proceedings of the American Elm Restoration Workshop 2016. US Department of Agriculture, Forest Service, Northern Research Station, Lewis Center, OH.
Kraus, E.C., Murray, R., Kelm, C., Poffenberger, R., Rohrig, E., Fairbanks, K., 2022. Advancements in mass rearing the air potato beetle *Lilioceris cheni*. Insects 13, 65.
Laatsch, J.R., Anderson, R.C., 2000. An evaluation of oak woodland management in northeastern Illinois, USA. Natural Areas Journal 20, 211–220.
Lake, E.C., Hough-Goldstein, J., D'Amico, V., 2014a. Integrating management techniques to restore sites Invaded by mile-a-minute weed, *Persicaria perfoliata*. Restoration Ecology 22, 127–133.
Lake, E.C., Smith, M.C., Pratt, P.D., Boughton, A.J., Pemberton, R.W., 2014b. Dispersal and establishment of new populations of the biological control agent Floracarus Perrepae (Acariformes eriophyidae) on old world climbing fern, Lygoduim microphyllum (Polypodiales: Lygodiaceae). The Florida Entomologist 97, 827–829.
Lang, M., Hanslin, H.M., Kollmann, J., Wagner, T., 2017. Suppression of an invasive legume by a native grass — High impact of priority effects. Basic and Applied Ecology 22, 20–27.
Lanzer, N.B., Lee, T.D., Ducey, M.J., Eisenhaure, S.E., 2017. Sapling white pine (Pinus strobus L.) exhibits growth response following selective release from competition with glossy buckthorn (Frangula alnus P. Mill) and associated vegetation. Forest Ecology and Management 404, 280–288.
Larkin, D.J., Steffen, J.F., Gentile, R.M., Zirbel, C.R., 2014. Ecosystem changes following restoration of a buckthorn-invaded woodland. Restoration Ecology 22, 89–97.
Leahy, M.J., Vining, I.W., Villwock, J.L., Wesselschmidt III, R.O., Schuhmann, A.N., Vogel, J.A., Shieh, D.Y., Maginel III, C.J., 2018. Short-term efficacy and nontarget effects of aerial glyphosate applications for controlling Lonicera maackii (Amur honeysuckle) in oak-hickory forests of Eastern Missouri, U.S.A. Restoration Ecology 26, 686–693.
Lee, T.D., Eisenhaure, S.E., Gaudreau, I.P., 2017. Pre-logging treatment of invasive glossy buckthorn (Frangula alnus Mill.) promotes regeneration of eastern white pine (Pinus strobus L.). Forests 8, 16.
Lewis, K., McCarthy, B., 2008. Nontarget tree mortality after tree-of-heaven (Ailanthus altissima) injection with imazapyr. Northern Journal of Applied Forestry 25, 66–72.
Link, A.F., Johnson, L.M.K., Utz, R.M., 2019. To manage or not? Successful native tree seedling restoration despite a dense, invasive shrub, Berberis thunbergii. Plant Ecology 220, 577–593.
Lippincott, C.L., 2000. Effects of Imperata cylindrica (L.) Beauv. (Cogongrass) invasion on fire regime in Florida Sandhill (USA). Natural Areas Journal 20, 140–149.
Loeb, R.E., Germeraad, J., Treece, T., Wakefield, D., Ward, S., 2010. Effects of 1-year vs. annual treatment of Amur honeysuckle (Lonicera maackii) in forests. Invasive Plant Science and Management 3, 334–339.
Looney, C.E., D'Amato, A.W., Palik, B.J., Slesak, R.A., 2015. Overstory treatment and planting season affect survival of replacement tree species in emerald ash borer threatened *Fraxinus nigra* forests in Minnesota, USA. Canadian Journal of Forest Research 45, 1728–1738.
Lott, M.S., Volin, J.C., Pemberton, R.W., Austin, D.F., 2003. The reproductive biology of the invasive ferns Lygodium microphyllum and L. japonicum (Schizaeaceae): implications for invasive potential. American Journal of Botany 90, 1144–1152.
Love, J.P., Anderson, J.T., 2009. Seasonal effects of four control methods on the invasive Morrow's honeysuckle (Lonicera morrowii) and initial responses of understory plants in a southwestern Pennsylvania old field. Restoration Ecology 17, 549–559.
Luginbuhl, J., Green Jr, J., Poore, M., Conrad, A., 2000. Use of goats to manage vegetation in cattle pastures in the Appalachian region of North Carolina. Sheep & Goat Research Journal 16, 124–135.
Luginbuhl, J.M., Harvey, T.E., Green, J.T., Poore, M.H., Mueller, J.P., 1998. Use of goats as biological agents for the renovation of pastures in the Appalachian region of the United States. Agroforestry Systems 44, 241–252.
Luken, J.O., Kuddes, L.M., Tholemeier, T.C., 1997. Response of understory species to gap formation and soil disturbance in *Lonicera maackii* thickets. Restoration Ecology 5, 229–235.
Luken, J.O., Mattimiro, D.T., 1991. Habitat-specific resilience of the invasive shrub Amur honeysuckle (Lonicera maackii) during repeated clipping. Ecological Applications 1, 104–109.
Mandle, L., Bufford, J.L., Schmidt, I.B., Daehler, C.C., 2011. Woody exotic plant invasions and fire: reciprocal impacts and consequences for native ecosystems. Biological Invasions 13, 1815–1827.
Manousidis, T., Kyriazopoulos, A.P., Parissi, Z.M., Abraham, E.M., Korakis, G., Abas, Z., 2016. Grazing behavior, forage selection and diet composition of goats in a Mediterranean woody rangeland. Small Ruminant Research 145, 142–153.
Marchetto, K.M., Heuschele, D.J., Larkin, D.J., Wolf, T.M., 2020. Goat digestion leads to low survival and viability of common buckthorn (Rhamnus cathartica) seeds. Natural Areas Journal 40 (150–154), 155.
Marchetto, K.M., Wolf, T.M., Larkin, D.J., 2021. The effectiveness of using targeted grazing for vegetation management: a meta-analysis. Restoration Ecology 29, e13422.
Marks, C. O. 2017. The ecological role of American elm (*Ulmus americana* L.) in floodplain forests of northeastern North America. Pages 74-98 *in* Proceedings of the

American Elm Restoration Workshop 2016. US Department of Agriculture, Forest Service, Northern Research Station, Lewis Center, OH.
Mattingly, K.Z., McEwan, R.W., Paratley, R.D., Bray, S.R., Lempke, J.R., Arthur, M.A., 2016. Recovery of forest floor diversity after removal of the nonnative, invasive plant *Euonymus fortunei*. The Journal of the Torrey Botanical Society 143 (103–116), 114.
Maynard-Bean, E., Kaye, M., 2019. Invasive shrub removal benefits native plants in an eastern deciduous forest of North America. Invasive Plant Science and Management 12, 3–10.
McCormick, L.H., Hartwig, N.L., 1995. Control of the noxious weed mile-a-minute (Polygonum perfoliatum) in reforestation. Northern Journal of Applied Forestry 12, 127–132.
McDonnell, A.L., Mounteer, A.M., Owen, H.R., Todd, B.L., 2005. Influence of stem cutting and glyphosate treatment of *Lonicera maackii*, an exotic invasive species, on stem regrowth and native species richness. Transactions of the Illinois State Academy of Science 98, 1–17.
Meekins, J.F., McCarthy, B.C., 1999. Competitive ability of Alliaria petiolata (Garlic Mustard, Brassicaceae), an invasive, nonindigenous forest herb. International Journal of Plant Sciences 160, 743–752.
Meloche, C., Murphy, S.D., 2006. Managing tree-of-heaven (Ailanthus altissima) in parks and protected areas: a case study of Rondeau Provincial Park (Ontario, Canada). Environmental Management 37, 764–772.
Melzer, B., Seidel, R., Steinbrecher, T., Speck, T., 2011. Structure, attachment properties, and ecological importance of the attachment system of English ivy (Hedera helix). Journal of Experimental Botany 63, 191–201.
Mervosh, T.L., Gumbart, D., 2015. Cutting and herbicide treatments for control of Oriental bittersweet, pale swallow-wort and Morrow's honeysuckle. Natural Areas Journal 35, 256–265.
Miller, J.H., 1985. Testing herbicides for kudzu eradication on a Piedmont site. Southern Journal of Applied Forestry 9, 128–132.
Miller, J.H., 2005. Chinese privet control with herbicide foliar sprays. Wildland Weeds 8, 4–7.
Miller, J. H., S. T. Manning, and S. F. Enloe. 2010. A management guide for invasive plants in southern forests. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.
Miller, K.M., Perles, S.J., Schmit, J.P., Matthews, E.R., Weed, A.S., Comiskey, J.A., Marshall, M.R., Nelson, P., Fisichelli, N.A., 2023. Overabundant deer and invasive plants drive widespread regeneration debt in eastern United States national parks. Ecological Applications 33, e2837.
Miller-Adamany, A., Baumann, D., Thomsen, M., 2019. Facilitating natural succession in a heavily invaded ecosystem. Forest Ecology and Management 444, 235–243.
Minogue, P.J., Bohn, K.K., Osiecka, A., Lauer, D.K., 2010. Japanese climbing fern (Lygodium japonicum) management in Florida's Apalachicola bottomland hardwood forests. Invasive Plant Science and Management 3, 246–252.
Moyer, S.A., Brewer, J.S., 2018. Competitive responses and effects of the invasive grass *Microstegium vimineum* during oak woodland restoration. Natural Areas Journal 38 (139–147), 139.
Mundahl, N.D., Walsh, R., 2022. Bark-stripping of common buckthorn by goats during managed browsing on bur oak savannas. Biological Invasions 24, 481–493.
Munger, G. T. 2005. *Lonicera* spp. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).
Murphy, S.D., 2005. Concurrent management of an exotic species and initial restoration efforts in forests. Restoration Ecology 13, 584–593.
Murphy, S.D., Flanagan, J., Noll, K., Wilson, D., Duncan, B., 2007. How incomplete exotic species management can make matters worse: experiments in forest restoration in Ontario, Canada. Ecological Restoration 25, 85–93.
Muscha, J.M., Vermeire, L.T., Angerer, J.P., 2023. Fire reduces Russian olive seed germination and seedling survival with increasing fuel load. Restoration Ecology 31, e13904.
Nagel, L.M., Corace III, R.G., Storer, A.J., 2008. An experimental approach to testing the efficacy of management treatments for glossy buckthorn at Seney National Wildlife Refuge, Upper Michigan. Ecological Restoration 26, 136–142.
Nestory, S., 2016. Biological and mechanical control of Japanese stiltgrass (Microstegium vimineum). University of Delaware.
Northeastern Area Association of State Foresters. 2011. Statewide Forest Resource Assessments and Strategies in the Northeast and Midwest: a Regional Summary. Page 47 *in* U. F. Service, editor., Newtown Square, PA.
Nuttle, T., Ristau, T.E., Royo, A.A., 2014. Long-term biological legacies of herbivore density in a landscape-scale experiment: forest understoreys reflect past deer density treatments for at least 20 years. Journal of Ecology 102, 221–228.
Nuzzo, V.A., 1991. Experimental control of garlic mustard [Alliaria petiolata (Bieb.) Cavara & Grande] in northern Illinois using fire, herbicide, and cutting. Natural Areas Journal 11, 158–167.
Nuzzo, V.A., 1994. Response of garlic mustard (Alliaria petiolata Bieb. [Cavara and Grande]) to summer herbicide treatment. Natural Areas Journal 14, 309–310.
Nuzzo, V.A., 1996. Impact of dormant season herbicide treatment on the alien herb garlic mustard (Alliaria petiolata [Bieb.] Cavara and Grande) and groundlayer vegetation. Transactions of the Illinois State Academy of Science 89, 25–36.
Nuzzo, V.A., McClain, W., Strole, T., 1996. Fire impact on groundlayer flora in a sand forest 1990–1994. The American Midland Naturalist 136, 207–221.
Olden, J.D., Tamayo, M., 2014. Incentivizing the public to support invasive species management: Eurasian milfoil reduces lakefront property values. PLoS One1 9, e110458.
Osland, M.J., Pahl, J.W., Richardson, C.J., 2009. Native bamboo [Arundinaria gigantea (Walter) Muhl., Poaceae] establishment and growth after the removal of an invasive non-native shrub (Ligustrum sinense Lour., Oleaceae): implications for restoration. Castanea 74.
Oswalt, C.M., Fei, S., Guo, Q., Iannone III, B.V., Oswalt, S.N., Pijanowski, B.C., Potter, K. M., 2015. A subcontinental view of forest plant invasions. NeoBiota 24, 49–54.
Owings, C. F., D. F. Jacobs, J. M. Shields, M. R. Saunders, and M. A. Jenkins. 2017. Individual and interactive effects of white-tailed deer and an exotic shrub on artificial and natural regeneration in mixed hardwood forests. AoB PLANTS **9**.
Papachristou, T.G., Dziba, L.E., Provenza, F.D., 2005. Foraging ecology of goats and sheep on wooded rangelands. Small Ruminant Research 59, 141–156.
Pardini, E.A., Teller, B.J., Knight, T.M., 2008. Consequences of density dependence for management of a stage-structured invasive plant (Alliaria petiolata). The American Midland Naturalist 160 (310–322), 313.
Pardini, E.A., Drake, J.M., Chase, J.M., Knight, T.M., 2009. Complex population dynamics and control of the invasive biennial Alliaria petiolata (garlic mustard). Ecological Applications 19, 387–397.
Pavlovic, N.B., Leicht-Young, S.A., Frohnapple, K.J., Grundel, R., 2009. Effect of removal of Hesperis matronalis (Dame's Rocket) on species cover of forest understory vegetation in NW Indiana. The American Midland Naturalist 161 (165–176), 112.
Pavlovic, N.B., Leicht-Young, S.A., Grundel, R., 2016. Oriental bittersweet (Celastrus orbiculatus): Spreading by fire. Forest Ecology and Management 364, 183–194.
Pearson, D., Ortega, Y., 2009. Managing invasive plants in natural areas: moving beyond weed control. In: Kingely, R.V. (Ed.), Weeds: Management. Economic Impacts and Biology. Nova Science, New York, pp. 1–21.
Pearson, D.E., Ortega, Y.K., Runyon, J.B., Butler, J.L., 2016. Secondary invasion: The bane of weed management. Biological Conservation 197, 8–17.
Pemberton, R.W., Ferriter, A.P., 1998. Old World climbing fern (Lygodium microphyllum), a dangerous invasive weed in Florida. American Fern. Journal: 165–175.
Pergams, O.R.W., Norton, J.E., 2006. Treating a single stem can kill the whole shrub: a scientific assessment of buckthorn control methods. Natural Areas Journal 26 (300–309), 310.
Pile, L. S., G. G. Wang, J. L. Walker, and P. A. Layton. 2018. Plant community response to the management of an invasive tree. Pages 33-40 *in* J. E. Kirschman, editor. Proceedings of the 19th Biennial Southern Silvicultural Research Conference. USDA Forest Service, Southern Research Station, Asheville, NC.
Pile Knapp, L.S., Rebbeck, J., Hutchinson, T., Fraser, J., Pinchot, C.C., 2022. Controlling an invasive tree with a native fungus: inoculating Ailanthus altissima (tree-of-heaven) with Verticillium nonalfalfae in highly disturbed Appalachian forests of Ohio. Journal of Forestry.
Pile, L.S., Wang, G.G., Knapp, B.O., Walker, J.L., Stambaugh, M.C., 2017a. Chinese tallow (Triadica sebifera) invasion in maritime forests: the role of anthropogenic disturbance and its management implication. Forest Ecology and Management 398, 10–24.
Pile, L.S., Wang, G.G., Waldrop, T.A., Walker, J.L., Bridges, W.C., Layton, P.A., 2017b. Managing an established tree invader: developing control methods for Chinese tallow (Triadica sebifera) in maritime forests. Journal of Forestry 115, 522–529.
Pile, L.S., Vickers, L., Stambaugh, M., Norman, C., Wang, G.G., 2019. The tortoise and the hare: A race between native tree species and the invasive Chinese tallow. Forest Ecology and Management 445, 110–121.
Pomp, J., D. McGill, W. Grafton, R. Chandran, and R. Richardson. 2010. Effects of mechanical and chemical control on Microstegium vimineum and its associates in central West Virginia.*in* Proceedings of the 14th biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.
Rathfon, R., and K. Ruble. 2007. Herbicide treatments for controlling invasive bush honeysuckle in a mature hardwood forest in West-Central Indiana. Pages 187-197 [CD-ROM]. Department of Agriculture, Forest Service, Southern Research Station.
Rathfon, R.A., Greenler, S.M., Jenkins, M.A., 2021. Effects of prescribed grazing by goats on non-native invasive shrubs and native plant species in a mixed-hardwood forest. Restoration Ecology 29, e13361.
Rayamajhi, M.B., Van, T.K., Pratt, P.D., Center, T.D., Tipping, P.W., 2007. *Melaleuca quinquenervia* dominated forests in Florida: analyses of natural-enemy impacts on stand dynamics. Plant Ecology 192, 119–132.
Rayamajhi, M.B., Pratt, P.D., Center, T.D., Tipping, P.W., Van, T.K., 2009. Decline in exotic tree density facilitates increased plant diversity: the experience from *Melaleuca quinquenervia* invaded wetlands. Wetlands Ecology and Management 17, 455–467.
Rebbeck, J., Kloss, A., Bowden, M., Coon, C., Hutchinson, T.F., Iverson, L., Guess, G., 2015. Aerial detection of seed-bearing female *Ailanthus altissima*: A cost-effective method to map an invasive tree in forested landscapes. Forest Science 61, 1068–1078.
Rebbeck, J., Hutchinson, T.F., Iverson, L.R., 2019. Effects of prescribed fire and stem-injection herbicide on *Ailanthus altissima* demographics and survival. Forest Ecology and Management 439, 122–131.
Reid, A.M., Morin, L., Downey, P.O., French, K., Virtue, J.G., 2009. Does invasive plant management aid the restoration of natural ecosystems? Biological Conservation 142, 2342–2349.
Reinartz, J.A., 1997. Controllng glossy buckthorn (Rhamnus frangula L.) with winter herbicide treatments of cut stumps. Natural Areas Journal 17, 38–41.
Richburg, J.A., 2005. Timing treatments to the phenology of root carbohydrate reserves to control woody invasive plants. University of Massachusetts Amherst.
Richburg, J.A., Patterson III, W.A., Ohman, M., 2004. Fire management options for controlling woody invasive plants in the Northeastern and Mid-Atlantic US. Joint Fire Science Program Northeast Barrens Fuel Demonstration Project.

Rivera, B.J., Meilan, R., Scharf, M.E., Karve, R.A., Jenkins, M.A., 2022. The effect of a novel herbicide adjuvant in treating Amur honeysuckle (Lonicera maackii). Invasive Plant Science and Management 15, 81–88.
Rosell, J.A., 2019. Bark in Woody Plants: Understanding the Diversity of a Multifunctional Structure. Integrative and Comparative Biology 59, 535–547.
Royo, A.A., Carson, W.P., 2022. Stasis in forest regeneration following deer exclusion and understory gap creation: A 10-year experiment. Ecological Applications 32, e2569.
Runkle, J.R., DiSalvo, A., Graham-Gibson, Y., Dorning, M., 2007. Vegetation release eight years after removal of Lonicera maackii in West-Central Ohio. The Ohio Journal of Science 107, 125–129.
Salemme, R.K., Fraterrigo, J.M., 2021. Grass invasion reduces the resilience of tree regeneration to fire in the Central Hardwoods Region. Forest Ecology and Management 491, 119202.
Schultz, K.E., Vaughn, A., Remelius, E., 2009. Physiologically based control of invasive Asiatic shrub honeysuckle. Transactions of the Illinois State Academy of Science 102, 21–32.
Schulz, K.E., Wright, J., Ashbaker, S., 2012. Comparison of invasive shrub honeysuckle eradication tactics for amateurs: stump treatment versus regrowth spraying of *Lonicera maackii*. Restoration Ecology 20, 788–793.
Schuster, M.J., Wragg, P.D., Reich, P.B., 2018. Using revegetation to suppress invasive plants in grasslands and forests. Journal of Applied Ecology 55, 2362–2373.
Schwartz, M.W., Heim, J.R., 1996. Effects of a prescribed fire on degraded forest vegetation. Natural Areas Journal 16, 184–191.
Schweitzer, C. J., and D. C. Dey. 2020. Testing five treatments to control *Lonicera* and promote natural hardwood reproduction in north Alabama. Pages 295-301 *in* Proceedings of the 20th Biennial Southern Silvicultural Research Conference. USDA Forest Service, Southern Research Station, Asheville, NC.
Shartell, L.M., Nagel, L.M., Storer, A.J., 2012. Efficacy of treatments against garlic mustard (Alliaria petiolata) and effects on forest understory plant diversity. Forests 3, 605–613.
Shaw, D.R., 2005. Translation of remote sensing data into weed management decisions. Weed Science 53, 264–273.
Shea, K., Chesson, P., 2002. Community ecology theory as a framework for biological invasions. Trends in Ecology & Evolution 17, 170–176.
Shearman, T.M., Wang, G.G., Ma, P.T., Guan, S., 2018. Patterns of bark growth for juvenile trees of six common hardwood species in the eastern United States and the implications to fire-tolerance. Trees 32, 519–524.
Shelton, A.L., 2012. Mowing any time after midsummer can manage Japanese stiltgrass. Invasive Plant Science and Management 5, 209–216.
Shields, J.M., Saunders, M.R., Gibson, K.D., Zollner, P.A., Dunning, J.B., Jenkins, M.A., 2015. Short-term response of native flora to the removal of non-native shrubs in mixed-hardwood forests of Indiana, USA. Forests 6, 1878–1896.
Shifley, S.R., Moser, W.K., Nowak, D.J., Miles, P.D., Butler, B.J., Aguilar, F.X., DeSantis, R.D., Greenfield, E.J., 2014. Five anthropogenic factors that will radically alter forest conditions and management needs in the northern United States. Forest Science 60, 914–925.
Simberloff, D., 2001. Biological invasions—how are they affecting us, and what can we do about them? Western North American Naturalist 61, 308.
Sitzia, T., 2014. A call to silviculturists for a new field of science: The forestry of invasive alien species. The Forestry Chronicle 90, 486–488.
Slaughter, B.S., Hochstedler, W.W., Gorchov, D.L., Carlson, A.M., 2007. Response of Alliaria petiolata (garlic mustard) to five years of fall herbicide application in a southern Ohio deciduous forest. The Journal of the Torrey Botanical Society 134, 18–26.
Smith, M.C., Lake, E.C., Pratt, P.D., Boughton, A.J., Pemberton, R.W., 2014. Current status of the biological control agent Neomusotima conspurcatalis (Lepidoptera: Crambidae), on Lygodium microphyllum (Polypodiales: Lygodiaceae) in Florida. Florida Entomologist 97 (817–820), 814.
Smith, A.M., Reinhardt Adams, C., Wiese, C., Wilson, S.B., 2016. Re-vegetation with native species does not control the invasive *Ruellia simplex* in a floodplain forest in Florida, USA. Applied Vegetation Science 19, 20–30.
Stocker, R.K., Miller, R.E., Black, D.W., Ferriter, A.P., Thayer, D.D., 2008. Using fire and herbicide to control *Lygodium microphyllum* and effects on a pine flatwoods plant community in South Florida. Natural Areas Journal 28 (144–154), 111.
Sullivan, R.L., 2013. The mapping of nonnative plants leads to a herbicide trial of autumn olive in Lake Raleigh Woods Nature Preserve. North Carolina State University, Raleigh, NC.
Swab, R.M., Zhang, L., Mitsch, W.J., 2008. Effect of hydrologic restoration and *Lonicera maackii* removal on herbaceous understory vegetation in a bottomland hardwood forest. Restoration Ecology 16, 453–463.
Thomas, L.K., 1993. Chemical grubbing for control of exotic wisteria. Castanea 58, 209–213.
Thompson, R.L., Poindexter, D.B., 2011. Species richness after *Lonicera maackii* removal from an old cemetery macroplot on Dead Horse Knob, Madison County, Kentucky. Phytoneuron 50, 1–16.
Tiller, M. B., B. P. Oswald, A. Frantzen, I.-K. Hung, S. Jerez, and Y. Weng. 2020. Spatial and seasonal flammability comparisons of native and exotic plants in the post oak savannah, blackland prairie, and pineywoods ecoregions of Texas. Pages 79-85 *in* Proceedings of the 20th Biennial Southern Silvicultural Research Conference. USDA Forest Service, Southern Research Station, Asheville, NC.
Tomat-Kelly, G., Dillon, W.W., Flory, S.L., 2021. Invasive grass fuel loads suppress native species by increasing fire intensity and soil heating. Journal of Applied Ecology 58, 2220–2230.
Trautwig, A.N., Eckhardt, L.G., Loewenstein, N.J., Hoeksema, J.D., Carter, E.A., Nadel, R. L., 2016. Cogongrass (Imperata cylindrica) affects above- and belowground processes in commercial loblolly pine (Pinus taeda) stands. Forest Science 63, 10–16.
Turbelin, A., and J. A. Catford. 2021. Chapter 25 - Invasive plants and climate change. Pages 515-539 *in* T. M. Letcher, editor. Climate Change (Third Edition). Elsevier.
US Global Change Research Program, 2017. Fourth National Climate Assessment: Impacts, Risks, and Adaptation in the United States. Summary Findings and Overview, US Global Change Research Program.
USDA Forest Service, 2013. Forest Service National Strategic Framework for Invasive Species Management. USDA Forest Service, Washington, DC.
Vaughn, K., 2013. Evaluation of dormant-season herbicide treatment methods for Chinese privet at Congaree National Park. Clemson University, Clemson, SC.
Vidra, R.L., Shear, T.H., Stucky, J.M., 2007. Effects of vegetation removal on native understory recovery in an exotic-rich urban forest. The Journal of the Torrey Botanical Society 134, 410–419.
Vogt, J.T., Coyle, D.R., Jenkins, D., Barnes, C., Crowe, C., Horn, S., Bates, C., Roesch, F. A., 2020. Efficacy of five herbicide treatments for control of Pyrus calleryana. Invasive Plant Science and Management 13, 252–257.
Wagner, S.A., Fraterrigo, J.M., 2015. Positive feedbacks between fire and non-native grass invasion in temperate deciduous forests. Forest Ecology and Management 354, 170–176.
Wallace, R.D., Bargeron, C.T., 2014. Identifying invasive species in real time: early detection and distribution mapping system (EDDMapS) and other mapping tools. Invasive Species and Global Climate change:219–231.
Wang, G. G., B. O. Knapp, S. L. Clark, and B. T. Mudder. 2013. The silvics of *Castanea dentata* (Marsh.) Borkh., American chestnut, Fagaceae (beech family). Gen. Tech. Rep. SRS-GTR-173. Asheville, NC: US Department of Agriculture Forest Service, Southern Research Station. 18 p. **173**:1-18.
Wang, H.H., Grant, W.E., Swannack, T.M., Gan, J., Rogers, W.E., Koralewski, T.E., Miller, J.H., Taylor, J.W., 2011. Predicted range expansion of Chinese tallow tree (Triadica sebifera) in forestlands of the southern United States. Diversity and Distributions 17, 552–565.
Wang, Y., Zhu, L., Gu, X., Wheeler, G.S., Purcell, M., Ding, J., 2012. Pre-release assessment of Gadirtha inexacta, a proposed biological control agent of Chinese tallow (Triadica sebifera) in the United States. Biological Control 63, 304–309.
Ward, J.S., Mervosh, T.L., 2012. Nonchemical and herbicide treatments for management of Japanese stiltgrass (Microstegium vimineum). Invasive Plant Science and Management 5, 9–19.
Ward, J., Williams, S., 2011. Controlling an invasive shrub, Japanese barberry (Berberis thunbergii DC), using directed heating with propane torches. Natural Areas Journal 31, 156–162.
Ward, J.S., Williams, S.C., Worthley, T.E., 2013. Comparing effectiveness and impacts of Japanese barberry (Berberis thunbergii) control treatments and herbivory on plant communities. Invasive Plant Science and Management 6, 459–469.
Ward, J.S., Williams, S.C., 2013. Treating Japanese barberry (Berberis thunbergii) during the dormant season. In: *In* 18th Central Hardwood Conference. USDA Forest Service, Northern Research Station, Morgantown, WV, pp. 182–191.
Ward, J.S., Worthley, T.E., Williams, S.C., 2009. Controlling Japanese barberry (Berberis thunbergii DC) in southern New England, USA. Forest Ecology and Management 257, 561–566.
Ward, J.S., Williams, S.C., Worthley, T.E., 2010. Effectiveness of two-stage control strategies for Japanese barberry (Berberis thunbergii) varies by initial clump size. Invasive Plant Science and Management 3 (60–69), 10.
Ward, J.S., Williams, S.C., Linske, M.A., 2017. Independent effects of invasive shrubs and deer herbivory on plant community dynamics. Forests 8, 2.
Warrix, A.R., Marshall, J.M., 2018. Callery pear (Pyrus calleryana) response to fire in a managed prairie ecosystem. Invasive Plant Science and Management 11, 27–32.
Webb, S.L., Pendergast, T.H., Dwyer, M.E., 2001. Response of native and exotic maple seedling banks to removal of the exotic, invasive Norway maple (Acer platanoides). The Journal of the Torrey Botanical Society 128, 141–149.
Webster, C.R., Rock, J.H., Froese, R.E., Jenkins, M.A., 2008. Drought–herbivory interaction disrupts competitive displacement of native plants by Microstegium vimineum, 10-year results. Oecologia 157, 497–508.
Webster, C.R., Dickinson, Y.L., Burton, J.I., Frelich, L.E., Jenkins, M.A., Kern, C.C., Raymond, P., Saunders, M.R., Walters, M.B., Willis, J.L., 2018. Promoting and maintaining diversity in contemporary hardwood forests: Confronting contemporary drivers of change and the loss of ecological memory. Forest Ecology and Management 421, 98–108.
Weese, Z., Barnes, T.G., 2017. Efficacy of dormant season herbicide application on control of Japanese honeysuckle (Lonicera japonica) in Kentucky. Natural Areas Journal 37 (286–293), 288.
Weidlich, E.W.A., Flórido, F.G., Sorrini, T.B., Brancalion, P.H.S., 2020. Controlling invasive plant species in ecological restoration: A global review. Journal of Applied Ecology 57, 1806–1817.
Wheeler, G.S., Steininger, M.S., Wright, S., 2017. Quarantine host range of Bikasha collaris, a potential biological control agent of Chinese tallowtree (Triadica sebifera) in North America. Entomologia Experimentalis Et Applicata 163, 184–196.
Wheeler, G.S., Jones, E., Dyer, K., Silverson, N., Wright, S.A., 2018. Quarantine host range and natural history of Gadirtha fusca, a potential biological control agent of Chinese tallowtree (Triadica sebifera) in North America. Entomologia Experimentalis Et Applicata 166, 894–906.
Wisconsin Council on Forestry. 2009. Wisconsin's Forestry Best Management practices for invasive species. Page 81 *in* W. D. o. N. Resources, editor., Madison, WI.
Wisconsin Department of Natural Resources. 2019. State-wide invasive species strategic plan.*in* B. o. S. Services, editor., Madison, WI.

Wragg, P.D., Schuster, M.J., Roth, A.M., Bockenstedt, P., Frelich, L.E., Reich, P.B., 2021. Revegetation to slow buckthorn reinvasion: Strengths and limits of evaluating management techniques retrospectively. Restoration Ecology 29, e13290.

Yager, L.Y., Miller, D.L., Jones, J., 2010. Susceptibility of longleaf pine forest associations in south Mississippi to invasion by cogongrass [Imperata cylindrica (L.) Beauv.]. Natural Areas Journal 30.

Yang, S.Y., Fan, Z.F., Liu, X., Ezell, A.W., Spetich, M.A., Saucier, S.K., Gray, S., Hereford, S.G., 2019. Effects of prescribed fire, site factors, and seed sources on the spread of invasive Triadica sebifera in a fire-managed coastal landscape in southeastern Mississippi. Forests, USA, p. 10.

Young, C.C., Bell, J.C., Morrison, L.W., 2020. Long-term treatment leads to reduction of tree-of-heaven (Ailanthus altissima) populations in the Buffalo National River. Invasive Plant Science and Management 13, 276–281.

Young, T.P., Stuble, K.L., Balachowski, J.A., Werner, C.M., 2017. Using priority effects to manipulate competitive relationships in restoration. Restoration Ecology 25, S114–S123.

Zhang, B., Zhai, L., Ervin, G.N., Coyle, D.R., 2023. Effective and timely use of models to inform on-the-ground management of invasive plants. Biological Invasions 25, 2089–2102.