Incorporation of Pollinator Plantings to Enhance Ecosystem Functions and Durability of Transportation Right-of-Way Infrastructure

Final Report
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The Transportation Infrastructure Durability Center (TIDC) is the 2018 US DOT Region 1 (New England) University Transportation Center (UTC) located at the University of Maine Advanced Structures and Composites Center. TIDC's research focuses on efforts to improve the durability and extend the life of transportation infrastructure in New England and beyond through an integrated collaboration of universities, state DOTs, and industry. The TIDC is comprised of six New England universities, the University of Maine (lead), the University of Connecticut, the University of Massachusetts Lowell, the University of Rhode Island, the University of Vermont, and Western New England University.

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List of Key Terms

Cultivar – A plant population developed for commercial production of seed or other planting material. Cultivars are generally selected for broad adaptation and high yields of planting material. They may also be selected for ornamental value or agricultural utility.

Ecotype – a naturally occurring seed-propagated plant population below the species level. Within the region of origin an ecotype population is presumed to be better adapted than a cultivar.

Forb – an herbaceous plant that is not a grass, sedge or rush. Similar to "wildflower".

Native – a species that is believed to have arrived in the region of interest without human intervention.

Naturalized – a species that occurs outside of cultivation but is known or assumed to have been deliberately introduced to the region of interest. Some naturalized species are invasive, but most are not.

FHWA – Federal Highway Administration

DOT – Department of Transportation

RIDOT – Rhode Island Department of Transportation

Abstract

Monarch butterflies, ground-nesting bees and many other crucial pollinators depend on early succession grassland habitats for survival. In New England these habitats have been disappearing as agricultural lands are developed or allowed to mature into forest. Many of our native pollinator species are threatened or endangered. Highway clear zones and rights-of-way have become a primary source of early succession habitat. The linear nature of highways also facilitates connections and migration of pollinators between other sources of early succession habitat such as pollinator meadows, agricultural lands and natural areas. However, highway rights-of-way have not traditionally been managed as pollinator habitat. Limited access highways in New England and the Northeast were modeled after the parkways of the early 20th century, with their manicured lawns and carefully pruned ornamental plantings. In the intervening years landscape management intensity has decreased but mowed turfgrass remains the default ground cover.

Establishment of pollinator plantings poses a challenge for managers of rights-of-way. Departments of transportation and the landscape installation companies they contract with are experienced at establishing cool-season turfgrasses using hydroseeding, and at establishing perennial forbs from container-grown transplants. However, they have little experience establishing native grasses and forbs from seed, and the lengthy pre- and post-seeding maintenance protocols recommended to minimize weed intrusion do not fit with existing project timelines. Selection of plant materials is also an issue as existing recommendations for roadside wildflower plantings come from outside of New England, and contain species or ecotypes that are not native in New England or not well adapted to New England soils and climate. Existing resources on establishment of pollinator plantings in New England are intended for homeowners, farmers or managers of natural areas and assume a very different set of management resources than what is available for highway rights-of-way. Finally, most of the available resources on roadside use of native plants do not include information on the pollinator benefits of the recommended species.

This project addressed these knowledge gaps through three inter-connected tasks. A seed mix of regionally native grasses and insect-pollinated forbs was established using five different methods and then monitored for three years to identify effects of establishment method on the species composition of the resulting plant community. Twenty-six insect-pollinated forb species that are native to Rhode Island and have potential for use in roadside pollinator habitat were transplanted into the roadside environment and data were collected over two years on survival and growth. Existing lists of native species, of pollinator species, and of species suitable for the roadside environment were reviewed and combined to identify native woody plants that could be used in landscape plantings in highway rights-of-way to support pollinators during seasons when native forbs are not in flower. The project determined that broadcast seeding into plantable soil was the best method for establishing native forbs on roadsides, identified twelve species that are good candidates for inclusion in pollinator-friendly seed mixes for roadsides in Rhode Island and 14 species that should not be used, and created a guide to pollinator-friendly native woody plants for use by landscape architects in New England.

Chapter 1: Introduction and Background

1.1 Project Motivation

Public interest in landscaping with native plants has been increasing for decades. In 1987 Congress began requiring that states use at least 1% of a project's landscaping budget for planting wildflowers whenever federal funds were used (USDOT-FHWA 2025). In the 1994 President Clinton issued an executive memorandum recommending the use of regionally native plants for landscaping on all federally owned lands and grounds and in all federally-funded projects; this was reinforced by the 1999 executive order on invasive species management (USDOT-FHWA 2025). Wide-spread news coverage of honeybee colony collapse disorder beginning in 2007 and of the 2014 petition to list monarch butterflies as threatened under the Endangered Species Act resulted in greatly increased public awareness of pollinators and the need to protect them. In 2014 President Obama issued a presidential memorandum directing federal agencies to take additional steps to improve habitat for pollinators (USDOT-FHWA 2025). Many native bee species are specialists, able to pollinate only specific native forbs. Monarch butterflies and many other butterflies and moths require native species as larval hosts. Thus pollinator habitat is naturally connected to native plants, and FHWA and state DOTs responded to the presidential memorandum by increasing the use of native plants on roadsides and by implementing integrated vegetation management practices to protect pollinators in highway rights-of-way (USDOT-FHWA 2025).

In New England pollinator conservation efforts have focused on protecting the 400 species of bees native to the region. Most of the species native to New England nest in or on the ground and require undisturbed bare soil in addition to grassland or shrubland habitats (Odanaka et al. 2018). Farms and landscapes are generally managed in ways that favor dense stands of perennial vegetation with limited bare soil, or in ways that favor annual vegetation with frequent soil disturbance. In contrast, mowed areas of highway rights-of-way are dominated by a mixture of clump-forming grasses, rosette-forming forbs, and low-density patches of species that spread via rhizomes (Brown and Sawyer 2012). Small patches of bare soil are abundant, and soil disturbance is rare. Highway rights-of-way provide abundant nesting habitat for ground-nesting bees but lack foraging habitat. This project was motivated by a desire to help RIDOT improve foraging habitat for native pollinators while complying with the guidance of the FHWA to increase the use of native plants in landscaping.

1.2 Research, Objectives, and Tasks

This was an applied field research project. Most of the research was conducted in a 1.5 mile stretch of the median of Interstate 95 in West Greenwich, Rhode Island in collaboration with RIDOT. The research focused on identification of native insect-pollinated species adapted to the roadside environment in southern New England, and development of a BMP for establishment of pollinator plantings from seed under roadside conditions. The project was designed to address three objectives:

1. Evaluate regionally native insect pollinated wildflower species for adaptation to the conditions of the occasionally mowed roadside environment.

2. Evaluate the effectiveness of different methods of establishing pollinator meadows from seed in the roadside environment.
3. Survey the existing roadside vegetation community to evaluate usefulness to pollinators and to identify additional pollinator plant species which are adapted to the roadside environment and could be encouraged through management practices.

These objectives were addressed through four tasks. The fieldwork for each objective was classified as a task; data analysis and creation of the final deliverables (peer-reviewed papers, graduate theses, materials for DOT use) was the fourth and final task.

The guidance from the project funder included a requirement that projects include public involvement and education. Objective 3 was originally envisioned as a series of vegetation surveys on parcels where RIDOT had plans to build. The surveys would be organized by the project team and the actual surveying would be done by citizen scientists recruited through local organizations active in botany and preservation of native plants. Unfortunately RIDOT leadership decided that they were not comfortable with giving community members access to the sites. The objective was shifted to a plan to involve URI students in collaboration with RIDOT landscape architects and the RIDOT communications staff to design a pollinator garden in an area bordered by a highway off-ramp and a city street, and to create educational signage for the garden. This plan also had to be abandoned as RIDOT priorities shifted; the objective finally settled on a literature review to identify native woody plants which were suited to roadside use and offered pollen, nectar, or larval food sources for pollinators.

1.3 Report Overview

The three objectives are combined throughout this report. Chapter 2 includes the methodology used for all three objectives. Chapter 3 presents the results and draws them together into conclusions and recommendations.

Chapter 2: Methodology

2.1 Evaluation of Regionally Native Wildflower Species for Ability to Survive Roadside Conditions

Literature sources including the Native Plant Trust's Go Botany database and plant lists for establishment of pollinator gardens were reviewed and 43 forb species were selected as being native to Rhode Island, suited to upland meadow habitats, insect pollinated, and having a mature height of 3 feet or less (list is in Appendix). Ecotype seed was obtained for 33 of the species; seed was purchased from Ernst Conservation Seeds (Pennsylvania), Prairie Moon Nursery (Minnesota), and the Wild Seed Project (Maine). Seeds were imbibed in glass petri dishes on moistened germination paper; species requiring stratification were stored at 40°F in a refrigerator for the stratification period indicated by the seed supplier or according to Deno (1993). Seeds were germinated on a heat mat set to 75°F under ambient light on a bench in the laboratory. Once seeds were germinated they were transferred to plug trays filled with a peat-based potting mix and maintained in the greenhouse until large enough to transplant into the field plots.

Transplant production was successful for 23 species. The other 10 species either failed to germinate or had poor germination such that fewer than 32 transplants were available. Plugs of three additional species were purchased from Prairie Moon Nursery for a total of 26 species in the roadside field test. Once seedlings reached transplantable size they were moved outdoors to a sheltered location until being transplanted into the field plots. Nineteen species were transplanted in 2022. An additional seven species were added in 2023.

The four field plots were located approximately 30 ft from the edge of the pavement and at least 700 feet apart on a north-south axis. Prior to transplanting existing vegetation was killed with glyphosate herbicide, soil was tilled to a depth of 4 inches and any large stones were removed. No soil amendments or fertilizer were used. Plots were 20 ft x 40 ft with 19 rows each 20 ft long. Rows within a plot were spaced 18 inches apart; plants within a row were spaced either 18 inches apart or 30 inches apart. Each plot received 12 transplants for most species but some species had 8 plants per plot due to limited supply. Plants were transplanted in June 2022 or June 2023. All plots were hand watered immediately after transplanting and as needed for the first month. No irrigation was provided after establishment.

Data were collected on winter survival in May 2023 and May 2024, and on survival and plant height and width in June – September of 2023 and 2024. Drought and weed pressure limited plant growth in 2022 and made it impossible to evaluate summer survival separately from overwintering survival. Data were analyzed using non-parametric statistics due to a non-normal distribution that could not be corrected through transformation.

2.2 Evaluation of Different Methods of Establishing Pollinator Meadows from Seed in the Roadside Environment

In this objective a single seed mix was used to compare the long-term effects of five different establishment methods. The seed mix was sourced from Ernst Conservation Seeds and is detailed in the Appendix. All plots were seeded at a rate of 30 lbs pure live seed per acre. Plot preparation and seeding were done by RIDOT Maintenance staff together with the project team to ensure that RIDOT had the equipment and capacity to use the methods being evaluated. All materials met RIDOT specifications. Plots were 20 ft x 40 ft and were located 20 ft from the edge of the pavement. The experimental design consisted of four replications (blocks) with each treatment occurring once in each replication. Within a block treatment plots were separated by at least 20 ft of undisturbed roadside. Blocks were at least 700 ft apart on a north-south axis along the roadway. All plots were seeded October 13, 2021. No fertilizer or soil amendments were used. After establishment RIDOT Maintenance mowed plots once per year in the late fall. The area around the plots was mowed on the normal schedule.

The establishment methods were as follows:

No-till (NT): Existing vegetation was mowed as low as possible with a tractor-mounted flail mower. Seed was planted using a no-till native grass drill (Truax Flex-II) pulled behind a tractor.

No-till plus glyphosate (NT-G): Existing vegetation was treated with glyphosate herbicide at label rate using a backpack sprayer equipped with a 4-foot spray boom. Two weeks after herbicide application the vegetation was mowed and seed was planted as for NT.

Plantable Soil plus hydromulch (PS-H): Existing vegetation was dug out to a depth of 4 inches to remove all crowns and rhizomes. Plantable soil purchased from a local landscape supply company was spread to return the plot to level. Seed was broadcast by hand and raked to ensure shallow incorporation. Following seeding the plot was mulched with paper-based hydromulch using a hydroseeder (Kincaid Agitator 900) to prevent erosion.

Plantable Soil (PS): Prepared and seeded as for PS-H but following seeding the plot was driven over with a tracked vehicle to press seed into the soil and create divots to trap rainwater and prevent erosion.

Compost plus Hydromulch (CH): Existing vegetation was mowed as low as possible with a tractor-mounted flail mower. Locally-sourced yardwaste compost was spread to a depth of 1 inch over the entire plot. Seed was then broadcast and raked, and hydromulch was applied as for PS-H.

Plant population diversity surveys were conducted monthly during the growing season in 2022, 2023 and 2024. Two quadrats (1.2 m x 1.2 m) were installed in each plot in May 2022. Quadrat locations were selected by dividing each plot into two 6m by 6m sections and randomly placing a quadrat in each section. Plants were identified to species when possible and flowering status and total percent coverage of quadrat area were recorded. In addition to the detailed quadrat surveys, in 2023 and 2024 lists were created each month of all species flowering in each plot. Soil samples were collected October 8th, 2024, using a soil probe. Within plots, soil cores were taken at each corner and in the center of the plot until one cup of soil was collected. Control soil cores were taken at least 10 feet downslope (southeast) of each plot within each of the four blocks. Soil cores from each area were then combined into a composite sample for analysis. Soil samples were tested for organic matter, nutrient composition, pH, and textural class by the Soil Nutrient Analysis Laboratory at the University of Connecticut.

Establishment metrics (forb, grass, insect-pollinated forb richness, bare ground percentage, and total species) were analyzed using repeated-measures mixed-effects models and Tukey HSD pairwise comparisons with a 95% confidence interval in JMP Pro 17 (JMP Statistical Discovery LLC, Cary, NC). The experimental unit was the treatment plot with 4 replications per treatment.

Soil parameters Mg lb A, Fe ppm, Zn ppm, S ppm, Pb ppm. and organic matter percentage all underwent log transformations while Ca lb A, P lb A, Mn ppm and cation-exchange capacity (CEC) data underwent bestNormalize( ) transformations, as this works best when using R for analysis. Two parameters, B ppm and Cu ppm were analyzed using a nonparametric Kruskal-Wallis test. Soil pH, buffer pH, K lb A, sand %, silt %, and clay % did not require transformations. One-way ANOVA and Tukey HSD means separation were conducted using JMP Pro 17 to identify differences in soil parameters and amount of bare ground between treatments. Bare ground percentages were averaged between the two quadrats to create one value per plot.

2.3 Identification of Additional Pollinator Plant Species Adapted to the Roadside Environment

This objective was addressed through a literature review. The Go Botany database was used to generate a list of all woody plants native to Rhode Island. The pollinator resources provided by each species was then evaluated using databases and publications from the Xerces Society, the Missouri Botanical Garden, and Cooperative Extension. Species which provided few or no food resources to pollinators were removed from the list and the remaining species were evaluated for suitability to roadside environments using the USDA Plants Database, lists of native plants for roadside use published by the FHWA, and lists created through previous collaborations between University of Rhode Island faculty and RIDOT. Species that were not suited to the roadside environment were removed. The final list was annotated with information that landscape architects use when developing planting plans, including plant type (tree, shrub, vine, groundcover), mature height and width, bloom time, specific requirements for light, fertility and moisture levels, tolerances or sensitivities to stresses, specific benefits to pollinators, and availability of named cultivars. A picture of each species was also included. The annotated list was converted to a format that can be published either as a formatted PDF/print handbook or as a searchable web database.

Chapter 3: Results and Discussion

3.1 Evaluation of Regionally Native Wildflower Species for Ability to Survive Roadside Conditions

Transplants were evaluated for survival in May 2023, September 2023, early June 2024, and September 2024. The May 2023 data reflects both survival over the 2022 growing season and winter survival. Plants that failed to survive were replaced with new greenhouse-grown transplants in June 2023. No new transplants were added in 2024.

Location Effects: There were no significant differences in soil texture or fertility between the four planting blocks, so differences in survival between blocks were most likely due to differences in microclimate (especially drainage and sun exposure) resulting from topography. Blocks 1 and 2 were on a 2.5% slope facing southwest while Blocks 3 and 4 were on a 2% slope facing northeast. Blocks 1 and 4 were near the tops of their respective slopes, with blocks 2 and 3 lower on the slopes. Precipitation was only 58% of normal between May and October of 2022. May 2023 transplant survival was significantly (Wilcoxon test $P < 0.001$) lower on the southwest slope than on the northeast slope. Differences between blocks on the same slope were not significant. Precipitation was 140% of normal during the summer of 2023 and location had no significant effect on survival (table 1). Location had a slight effect on survival over the winter of 2023-24 with Block 2 having a higher survival rate than the other blocks. Location was again significant in the summer of 2024. Survival was highest in block 2 and lowest in Block 1. The 2024 growing season started out with above-average rainfall but ended with drought conditions.

Table 1. Effect of location on transplant survival. Blocks 1 and 2 were on a slope facing southwest while blocks 3 and 4 were on a slope facing northeast. Blocks 1 and 4 were near the tops of their respective slopes while blocks 2 and 3 were mid-slope. P-values are from the Kruskal-Wallis Chi-square test.

Block	Year 1	Summer 2023	Winter 23-24	Summer 2024
1	10%	68%	71%	31%
2	12%	81%	93%	81%
3	72%	83%	79%	48%
4	63%	85%	80%	68%
P-VALUE	<.001	0.33	0.11	0.001

Species Performance: There were significant differences in year 1 survival (Chi-square test $P = <0.001$) between species as well as between locations. *Penstemon digitalis* and *Symphyotrichum pilosum* had the best survival at 78% and 71%, respectively. Both species had surviving plants in all four blocks in May 2023. Other species with survival in all four blocks included *Achillea millefolium* (42%) and *Euthamia graminifolia* (52%). These four species are strongly recommended for inclusion in seed mixes as they can withstand even hot, dry conditions. *Pycnanthemum tenuifolium* and *Solidago nemoralis* performed as well as *Penstemon digitalis* and *Symphyotrichum pilosum* in blocks 3 and 4 (100% survival) but could not tolerate the harsher conditions of Blocks 1 and 2. Other species with good performance on the northeast slope were *Solidago bicolor* and *Symphyotrichum lateriflorum.*

Top performers in the wetter conditions of years 2 and 3 were *Lespedeza capitata*, *Pycnanthemum muticum*, *Pycnanthemum tenuifolium*, *Penstemon digitalis*, and *Solidago odora*. *Oligoneuron rigidum* and *Tradescantia ohiensis* showed potential in block 2 and block 4, respectively, but were not planted into other blocks. *Solidago bicolor* continued strong through the summer of 2023 but declined over the winter and the summer of 2024. *Symphyotrichum pilosum* averaged 31% survival from June 2023 through September 2024. *Euthamia graminifolia* averaged 27% survival and *Achillea millefolium* averaged 39% survival.

Several species were clearly not suited to the roadside environment. These included *Aquilegia canadensis*, *Antennaria neglecta*, *Blephilia ciliata*, *Monarda fistulosa* and *Cirsium discolor*. Many others showed greater than 50% survival in at least one block but also failed completely in one or more blocks. These species could be useful in seed mixes intended to be planted over large areas, but should be carefully matched to the micro-climate when used for smaller plantings.

Table 2. Survival data for June 2022 through May 2023

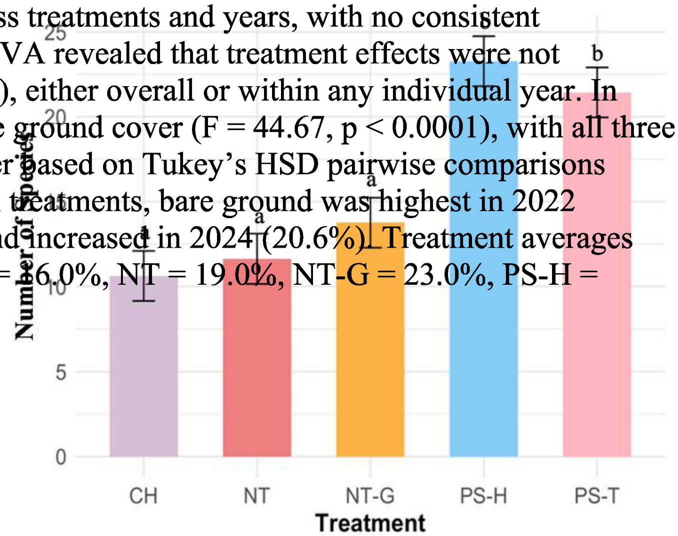
Species	**Year 1 (All Blocks)**	**Year 1 (Northeast Slope)**
Aquilegia canadensis	15%	29%
Achillea millefolium	42%	75%
Antennaria neglecta	19%	38%
Antennaria plantaginifolia	42%	59%
Asclepias tuberosa	25%	46%
Asclepias verticillata	31%	58%
Cirsium discolor	19%	38%
Euthamia graminifolia	52%	88%
Lespedeza capitata	38%	50%
Penstemon digitalis	78%	100%
Penstemon hirsutus	25%	50%
Pycnanthemum tenuifolium	50%	100%
Solidago bicolor	50%	94%
Symphyotrichum lateriflorum	42%	79%
Solidago nemoralis	52%	100%
Symphyotrichum novae-angliae	25%	51%
Symphyotrichum pilosum	71%	100%
Zizia aptera	33%	67%

Table 3. Survival data for 2023 and 2024. Seasonal data shows the percentage of the plants present at the beginning of the season that were still alive at the end of the season. Years 2 & 3 combined gives total survival.

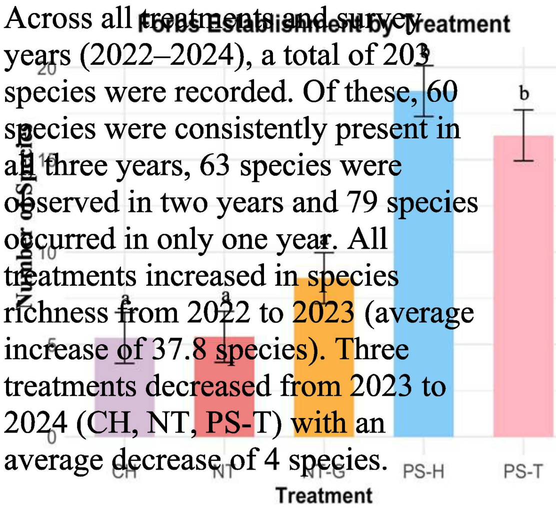
Species	**Summer 2023**	**Winter 2023-24**	**Summer 2024**	**Years 2 & 3 combined**
Aquilegia canadensis	75%	50%	0%	0%
Anaphalis margaritaceae	42%	79%	42%	20%
Achillea millefolium	50%	100%	50%	39%
Antennaria neglecta	20%	0%		0%
Antennaria plantaginifolia	92%	76%	62%	42%
Asclepias tuberosa	64%	59%	82%	23%
Asclepias verticillata	81%	98%	66%	48%
Blephilia ciliata	41%	0%		0%
Cirsium discolor	92%	62%	8%	4%
Euthamia graminifolia	89%	68%	40%	27%
Lespedeza capitata	100%	98%	87%	84%
Lupinus perennis	88%	100%	72%	56%
Monarda fistulosa	45%	41%	25%	8%
Oligoneuron rigidum	91%	100%	100%	91%
Penstemon digitalis	91%	100%	85%	81%
Penstemon hirsutus	90%	81%	53%	44%
Pycnanthemum muticum	100%	100%	92%	92%
Pycnanthemum tenuifolium	100%	100%	79%	79%
Solidago bicolor	91%	57%	38%	22%
Symphyotrichum laeve	80%	88%	71%	50%
Symphyotrichum lateriflorum	62%	100%	36%	35%
Solidago nemoralis	98%	89%	50%	41%
Symphyotrichum novae-angliae	86%	62%	42%	28%
Solidago odora	100%	100%	84%	84%
Symphyotrichum pilosum	77%	76%	45%	31%
Tradescantia ohiensis	100%	100%	88%	88%
Zizia aptera	100%	95%	64%	62%

3.2 Evaluation of Different Methods of Establishing Pollinator Meadows from Seed in the Roadside Environment

Bare ground percentages varied across treatments and years, with no consistent directional trend. A repeated measures ANOVA revealed that treatment effects were not statistically significant (F = 1.16, p = 0.3561), either overall or within any individual year. In contrast, year had a significant effect on bare ground cover (F = 44.67, p < 0.0001), with all three years differing significantly from one another based on Tukey's HSD pairwise comparisons (2022 > 2024 > 2023). On average across all treatments, bare ground was highest in 2022 (31.6%), dropped sharply in 2023 (4.1%), and increased in 2024 (20.6%). Treatment averages across the three years were as follows: C-H = 16.0%, NT = 19.0%, NT-G = 23.0%, PS-H = 24.0%, and PS-T = 24.0%. Establishment method had a significant effect on total species richness (F = 15.88, p < 0.0001). Counts were highest in treatments PS-H (23.3 species) and PS-T (21.4 species), and lowest in treatment CH (10.6 species) (Figure 3). Tukey-adjusted pairwise comparisons showed that PS-H and PS-T each averaged significantly more species than CH, NT, and NT-G (p ≤ 0.0057 for all). No significant differences were detected among CH, NT, and NT-G treatments (p ≥ 0.56), nor between PS-T and PS-H (p = 0.8984).



Across all treatments and survey years (2022–2024), a total of 203 species were recorded. Of these, 60 species were consistently present in all three years, 63 species were observed in two years and 79 species occurred in only one year. All treatments increased in species richness from 2022 to 2023 (average increase of 37.8 species). Three treatments decreased from 2023 to 2024 (CH, NT, PS-T) with an average decrease of 4 species.



Treatment NT-G maintained species richness at 74 species. Treatment PS-H slightly increased species richness from 2023 to 2024 by 2 species (Figure 2).

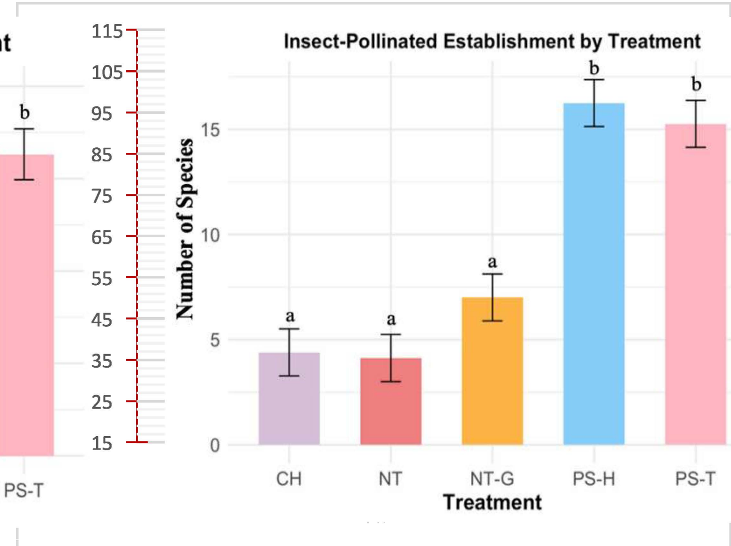


Figure 2. Annual species richness (mean ± comparison-wise SE) across five seeding treatments from 2022 to 2024.

Treatment type significantly influenced forb species richness (p < 0.0001). Least square means estimates indicated the highest richness in the PS-H (18.7 forb species) and PS-T (16.3 forb species) treatments. The lowest richness estimates were observed in the CH (5.3 forb species) and NT (5.4 forb species) treatments (Figure 5). Tukey HSD pairwise comparisons confirmed that forb richness in PS-H and PS-T was significantly greater than in CH, NT, and NT-G (p < 0.0001 for all relevant comparisons). No significant differences were found between CH and NT (p = 0.3343), or NT and NT-G (p = 0.3546). PS-H and PS-T did not differ significantly from one another ($p = 0.6252$). Establishment treatments had a significant effect on insect-pollinated forb species richness ($p = 0.0001$). PS-H and PS-T yielded the highest least squares means estimates (16.2 and 15.3 insect-pollinated forbs, respectively), while CH and NT showed the lowest values (4.4 and 4.1, respectively) (Figure 5). Tukey pairwise comparisons indicated that PS-H and PS-T were significantly higher in richness than CH, NT, and NT-G ($p < 0.0001$ for all comparisons) CH, NT, and NT-G did not differ significantly from one another ($p > 0.32$ in all cases), and the difference between PS-H and PS-T was not statistically significant ($p = 0.9632$).

Findings indicate that soil preparation methods involving screened loam and broadcast seeding were more effective in supporting a diverse assemblage of forbs within the three-year period following establishment. Treatments involving plantable soil (PS-T, PS-H) outperformed other establishment methods in nearly all categories of interest, including species richness, forb richness, and insect-pollinated richness. Treatment PS-H facilitated the germination of 24 out of 26 seed mix species, while PS-T supported 20 out of 26. Hydromulching and tracking after seeding had similar effects. These findings suggest that establishing native plantings on a cleared, plantable soil seedbed is the most effective approach for maximizing total species richness and supporting insect-pollinated forb diversity.

Notably, a sharp increase in total species richness was observed between 2022 and 2023 (Figure 2), which may be partially explained by the prevalence of perennial species in the seed mix that did not germinate or become detectable until their second growing season. Establishment may also have been influenced by the timing of rainfall, with below-normal precipitation in the first growing season following establishment. These environmental limitations underscore the importance of life history traits (e.g., annual, biennial, perennial) in interpreting temporal patterns of establishment.

Functional group analysis revealed that forb richness was highest in treatments involving imported soil (Figure 3), though other treatments that reduced competition, such as compost mulching (CH) and herbicide application (NT-G), also supported forb establishment. This suggests that competition reduction, rather than the specific method used, is a key factor in successful forb recruitment. Treatments CH, NT, and NT-G were significantly less successful than the plantable soil treatments. Treatments NT and NT-G showed a higher proportion of grasses to forbs (when compared to plantable soil treatments) within the plant community. The lack of statistically significant differences between these two treatments suggests that failure of forbs to establish successfully was a result of seed drilling, rather than competition from existing vegetation. Drill-seeding methods have been shown to preferentially favor warm-season grasses due to uniform seed placement, increased light interception by dense grass canopies, and the inability to accommodate small-seeded species with shallow seeding depths (Grygiel et al., 2009; Yurkonis et al., 2010a, 2010b).

No till techniques have been shown to improve seed-to-soil contact and suppress emergence from the weed seed bank via both residue cover and lack of disturbance. However, emerging research indicates that the benefits of no-till drilling may be more nuanced and highly context dependent. While some studies demonstrate that drill seeding can improve establishment of native warm-season grasses due to enhanced soil contact and structured seed placement (Yurkonis et al. 2010a) its efficacy for small-seeded forbs remains inconsistent (Applestein et al.

2018). For example, Larson et al. found that dormant-season broadcast seeding yielded higher perennial forb cover in northern tallgrass prairie sites, suggesting that broadcast methods may be more suitable for achieving diverse forb establishment in certain climates or soil types (Larson et al. 2011).

Differences in seed morphology and germination requirements necessitate tailored delivery strategies (Shaw et al. 2020). Forbs, particularly those requiring shallow seeding or cold stratification, may not benefit equally from uniform row planting. Bellangue et al. (2024) found that cold stratification and high seeding rates significantly improved native forb establishment in pasture systems, with the highest rate tested (56 kg/ha) yielding nearly three times more forb establishment than the lowest. Although no-till methods like drilling are commonly used to suppress invasive species and improve seed placement, they may hinder forb diversity when seed mixes are not calibrated to account for forb-specific ecological needs (Yurkonis et al. 2010b; Shaw et al. 2020). This misalignment between seeding method, mix composition, and species traits—especially forbs—likely explains the discrepancy between literature expectations and field results observed in the NT and NT-G treatments.

A total of 26 native and naturalized species were included in the original seed mix, selected for their compatibility with low-fertility, upland roadside environments and low height at maturity. Of these, 25 species were recorded in at least one treatment plot over the course of the study. *Geum canadense* (White Avens) was the only species from the seed mix not observed in any plot during any year. The absence of *G. canadense* across all plots may be attributed to low seed viability, poor competitive ability, or unsuitable site conditions for germination. Its absence from plots with high overall seed mix success (PS-H, PS-T) suggests that site preparation alone does not account for its failure to establish.

A substantial proportion of the species observed in treatments plots from 2022 – 2024 were not included in the original seed mix, suggesting strong recruitment from the surrounding landscape (see Appendix 1). Of particular interest is the prevalence of ruderal and early successional species among the non-seeded plant species, many of which are commonly associated with roadside and edge habitats throughout coastal New England. Brown and Sawyer (2012) found similar patterns in their survey of Rhode Island highway verges, where species composition was dominated by disturbance-tolerant grasses and forbs, with nearly half of all species (45%) being native to Rhode Island. This study found similar species, including *Rumex acetosella, Plantago lanceolata, Digitaria sp.,* and *Trifolium repens* – which were also found on the roadside in the 2012 study. *Trifolium repens* (White Clover) and *Trifolium pratense* (Red Clover) were almost exclusively found in PS-H and PS-T treatments, suggesting they originated from the imported plantable soils' seedbank, whereas a large collection of early colonizing plants (e.g. *Ambrosia atemisiifolia, Daucis carota, Erigeron annuus, Rumex acetosella, Digitaria spp.*) were found across all treatments and likely represent a larger body of persistent or sitewide seedbank already present prior to the study. This phenomenon - termed "passive recruitment" - has been noted in other studies where topsoil transfer or soil amendment introduced desirable species not originally sown (Prach & Pyšek 2001; Gerrits et al., 2023). While such outcomes can enrich plant community composition and increase habitat heterogeneity, they also introduce variability and potential unpredictability in restoration outcomes.

The origin of the plantable soil, including its land-use history and local floristic composition, likely influences the character of the soil seedbank. In this study, the inclusion of native or regionally adapted seedbank species appears to have augmented total species richness and enhanced the ecological function of treated plots. These findings suggest that plantable soil can serve a dual purpose in restoration: improving soil structure while simultaneously acting as a reservoir for ecologically compatible species. However, future restoration projects employing this method should also consider potential risks, including the inadvertent introduction of invasive or undesired species. Strategic sourcing and screening of plantable soil may allow for maximization of these benefits while minimizing ecological risk. Miao et al. (2016) documented that the inclusion of seed-rich topsoil significantly increased plant species richness and seed density in degraded sandy grasslands. In Australian grasslands, Munro et al. (2024) found that relocating topsoil reduced weed seed banks and boosted native seedling survival. The unexpected emergence of legumes such as *Trifolium arvense*, *T. pratense*, and *T. repens* (clovers) in the treatment plots, likely introduced through a remnant seed bank in the imported plantable soil, contributed to an increase in early-stage biodiversity. These nitrogen-fixing species may have enhanced soil fertility and supported broader plant establishment. Their dense ground cover also provided erosion control and soil stabilization during the critical establishment period. These outcomes collectively suggest that careful sourcing and screening of plantable soil are critical steps in enhancing both structural and floristic recovery in restoration settings.

3.3 Identification of Additional Pollinator Plant Species Adapted to the Roadside Environment

A team of three URI undergraduate students in Plant Sciences and Landscape Architecture researched the 546 broadleaf woody plants in the Go Botany database and identified 168 species with potential for use in roadside pollinator plantings. Most of the species (159) are native to New England while nine are widely naturalized but not invasive. Pollinator plantings often focus on herbaceous forbs because they grow quickly and are attractive to insects over a long period of time. However, woody plants offer a very concentrated food source to pollinators over a short period of time. Many of our native woody plants flower in the spring, before the majority of herbaceous species. This makes them an essential food resource when bees are rearing their young and building their colonies. Other native woody plants flower in July and August. These species are an important supply of pollen and nectar in dry years. Woody plants generally root much more deeply than herbaceous plants, making them less sensitive to short-duration droughts.

Approximately 50% of the species on the plant list are readily available in the nursery trade. The other species were included in the annotated list for two reasons. First, many of the species occur naturally in unmowed areas of highway rights-of-way. Increasing awareness of the pollinator value of these species among DOT landscape architects and maintenance staff can guide decisions about management of naturally-occurring plants. Second, some of the species that are not currently available could be good candidates for propagation and adoption as the public becomes more interested in landscaping with native plants. As large-volume purchasers DOTs can help to steer the nursery industry in new directions.

"Pollinator-Friendly Woody Plants for Roadside Use" is available through University of Rhode Island Cooperative Extension. It was developed for use by landscape architects working for DOTs in New England but can also be useful to anyone looking for low-maintenance native trees or shrubs that benefit pollinators.

Chapter 4: Conclusions and Recommendations

This three-year applied study allowed us to draw several conclusions which will hopefully have a beneficial effect on management of highway rights-of-way in New England. The core conclusions are summarized and elaborated on below.

- Seed mixes for pollinator plantings should seek to maximize the number of forb species.
- Areas of new construction where plantable soil will be applied should be prioritized for seed establishment of pollinator plantings.
- Native trees and shrubs that support pollinators are available and should be used in landscape plantings
- Naturally-occurring native species that support pollinators should be encouraged and protected in unmowed sections of rights-of-way.

Seed mixes: Location and micro-climate had a significant effect on the survival of transplanted forb species. Twenty-six species were tested; a few performed well across all years and locations and a few completely failed to survive but most of the species showed mixed results. A diverse seed mix maximizes the likelihood that every microclimate will be suitable for a subset of the species in the mix. Management practices that allow for natural re-seeding of pollinator plantings will allow the adapted species to spread within each planting and enhance the ability of the planting to recover following natural stress events such as droughts.

Lespedeza capitata is particularly recommended for inclusion in seed mixes. It is a native legume which showed strong survival and can increase soil fertility in addition to benefiting pollinators.

Plantable soil: Seeding into freshly spread plantable soil resulted in the best establishment of the species in the seed mix. The plantable soil also contributed a significant number of insect-pollinated forbs from the soil seedbank, particularly legumes. The use of a no-till drill to renovate existing roadside grassland was not effective as forb establishment was low. Surface application of yardwaste compost successfully reduced competition from the soil seedbank but it created an ideal habitat for meadow voles (*Microtus pennsylvanicus*) which preyed on seedlings of many of the species in the seed mix, reducing establishment. Application of compost over much larger areas would likely decrease the intensity of predation, but the cost of compost would become a limiting factor. Future research should evaluate additional methods of renovating existing grasslands to determine the minimum amount of soil disturbance required for good establishment of broadcast seed. Adjustments to the seed mix and/or the seeding rate could increase forb establishment following no-till planting.

Native trees and shrubs: Many native trees and shrubs are important sources of pollen during the spring, while others provide pollen and nectar during the often dry months of late summer. Pollinator plantings should include woody plants wherever it is safe to do so. Use of a diverse array of species will increase benefits to pollinators through overlapping bloom times.

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Appendices

Species considered for evaluation under roadside conditions, including seed sources and results.

Scientific Name	Common Name	Source	Results
Achillea millefolium L. var. lanulosa	Western yarrow or Woolly yarrow	Ernst Conservation Seed	Successful on roadside
Anaphalis margaritacea (L.) Benth.	western pearly everlasting	Wild Seed Project	Successful on roadside
Anemone canadensis	Canada windflower	Ernst Conservation Seed	Seed did not germinate
Anemone virginiana	Tall thimbleweed	Wild Seed Project	Seed did not germinate
Antennaria neglecta	Field pussytoes	Landscape plugs from Prairie Moon Nursery	Not successful on roadside
Antennaria parlinii Fernald ssp. Parlinii	Parlin's pussytoes		Seed not available
Antennaria plantaginifolia	Plantain-leaved pussytoes	Landscape plugs from Prairie Moon Nursery	Successful on roadside
Aquilegia canadensis L.	Eastern Columbine	Ernst Conservation Seed	Not successful on roadside
Asclepias syriaca	Common Milkweed	Ernst Conservation Seed	Seed failed to germinate
Asclepias tuberosa L.	Butterfly milk weed	Ernst Conservation Seed	Successful on roadside
Asclepias verticillata	Whorled milkweed	Prairie Moon Nursery	Successful on roadside
Baptisia tinctoria	Small yellow false indigo	Prairie Moon Nursery	Seed did not germinate
Cirsium discolor	Pasture Thistle	Prairie Moon Nursery	Not successful on roadside
Erigeron philadelphicus	Fleabane daisy		Seed not available
Erigeron pulchellus	Robin’s Plantain	Prairie Moon Nursery	Seed failed to germinate
Eurybia divaricata (L.) G.L. Nesom	White Wood Aster, PA Ecotype	Ernst Conservation Seed	Seed failed to germinate
Eurybia macrophylla (L.) Cass. (Aster macrophylla)	large-leaved wood-aster	Ernst Conservation Seed	Not used

Euthamia graminifolia	flat-top goldentop	Ernst Conservation Seed	Successful on roadside
Fragaria virginiana	Wild strawberry	Wild Seed Project	Poor germination – did not use
Helenium autumnale	fall sneezeweed	Ernst Conservation Seed	Seed failed to germinate
Hypoxis hirsuta (L.) Coville	common star-grass		Seed not available
Lespedeza capitata	Roundhead Lespedeza	Ernst Conservation Seed	Successful on roadside
Liatris novae-angliae (L. scariosa (L.) Willd. var. novae-angliae Lunell)	New England blazing star		Seed not available
Linum virginianum L.	woodland yellow flax		Seed not available
Lupinus perennis L.	sundial lupine	Ernst Conservation Seed	Successful on roadside
Mentha canadensis (Mentha arvensis ssp. Canadensis)	American wild mint		Seed not available
Monarda fistulosa L.	Wild Bergamot	Ernst Conservation Seed	Not successful on roadside
Packera aurea (L.) A. & D. Löve	golden ragwort	Prairie Moon Nursery	Seed failed to germinate
Penstemon digitalis	Foxglove beardtongue	Wild Seed Project	Successful on roadside
Penstemon hirsutus	Hairy beardtongue	Ernst Conservation Seed	Successful on roadside
Prunella vulgaris L. subspecies lanceolata	common selfheal, heal-all		Ecotype seed not available
Pycanthemum virginianum	Virginia mountain mint	Wild Seed Project	Seed failed to germinate
Pycnanthemum tenuifolium Schrad.	Narrowleaf Mountainmint PA ecotype	Ernst Conservation Seed	Successful on roadside
Solidago odora	Licorice Scented Goldenrod, PA Ecotype	Ernst Conservation Seed	Successful on roadside
Solidago bicolor	White Goldenrod PA Ecotype	Ernst Conservation Seed	Successful on roadside
Solidago nemoralis	Gray Goldenrod, PA Ecotype	Ernst Conservation Seed	Successful on roadside
Symphyotrichum lanceolatum (Willd.) G.L. Nesom ssp. lanceolatum var. lanceolatum	white panicle aster	Prairie Moon Nursery	Not used
Symphyotrichum lateriflorum	Calico Aster	Ernst Conservation	Successful on

		Seed	roadside
Symphyotrichum novae-angliae	New England Aster	Ernst Conservation Seed	Successful on roadside
Symphyotrichum pilosum	Heath Aster	Ernst Conservation Seed	Successful on roadside
Zizia aptera (Gray) Fern.	heart-leaved golden Alexanders	Wild Seed Project	Successful on roadside
Zizia aurea	Common Golden Alexanders	Ernst Conservation Seed	Seed did not germinate

Composition of the seed mix used for the establishment method study. All seed was obtained from Ernst Conservation Seeds except for *Schizachyrium scoparium* which was produced at the University of Rhode Island.

Scientific name	Common Name	Ecotype
Asclepias syriaca	Common Milkweed	PA Ecotype
Asclepias tuberosa	Butterfly Milkweed	-
Chamaecrista fasciculata	Partridge Pea	PA Ecotype
Desmodium canadense	Showy Tick-Trefoil	PA Ecotype
Desmodium paniculatum	Panicled Tick-trefoil	PA Ecotype
Elymus virginicus	Virginia Wildrye	PA Ecotype
Eragrostis spectabilis (RI Ecotype)	Purple Lovegrass	RI Ecotype
Festuca rubra	Red Fescue	-
Geum canadense	White Avens	PA Ecotype
Lespedeza capitata	Round-headed Bushclover	RI Ecotype
Monarda fistulosa	Wild Bergamot	PA Ecotype
Oenothera fruticosa	Sundrops	-
Panicum virgatum	Switchgrass	NY Ecotype
Pycnanthemum tenuifolium	Narrowleaf Mountain Mint	-
Rudbeckia hirta	Black-eyed Susan	-
Sisyrinchium angustifolium	Blue-eyed Grass	-
Schizachyrium scoparium (RI Ecotype)	Little Bluestem	RI Ecotype
Solidago bicolor	Silverrod	PA Ecotype
Solidago juncea	Early Goldenrod	PA Ecotype
Solidago nemoralis	Gray Goldenrod	PA Ecotype
Symphyotrichum lateriflorum	Calico Aster	-

Symphyotrichum novae-angliae	New England Aster	-
Symphyotrichum pilosum	Frost Aster	PA Ecotype
Tradscantia ohiensis	Ohio Spiderwort	PA Ecotype
Tridens flavus	Purpletop Tridens	-
Zizia aurea	Golden Alexanders	PA Ecotype

List of all species observed in the establishment plot study along with the years in which each species was observed and the total number of times it was observed within the sampling quadrats.

Species	Years Observed	Occurrences
Acalypha rhomboidea	2022, 2023, 2024	26
Acalypha virginica	2022, 2023	9
Achillea millefolium	2022, 2023, 2024	78
Agrostis capillaris	2022, 2023, 2024	346
Ambrosia artemisiifolia	2022, 2023, 2024	62
Ampelopsis brevipedunculata	2022	2
Amphicarpaea bracteata	2023, 2024	7
Andropogon virginicus	2022, 2023, 2024	75
Anthoxanthum odoratum	2022, 2023, 2024	47
Aristida oligantha	2022	3
Artemisia vulgaris	2023, 2024	28
Asclepias syriaca	2022, 2023, 2024	13
Asclepias tuberosa	2022, 2023, 2024	31
Baccharis halimifolia	2024	5
Barbarea vulgaris	2023, 2024	6
Bidens frondosa	2022	2
Calamagrostis arundinacea	2022	1
Calamagrostis canadensis	2022	1
Cardamine pensylvanica	2022	1
Carex pensylvanica	2024	1
Carex scoparia	2023, 2024	3
Carex vulpinoidea	2023, 2024	22
Celastrus orbiculatus	2022	1
Centaurea stoebe	2023, 2024	44
Cerastium fontanum	2022, 2023, 2024	65
Chamaecrista fasciculata	2022, 2023, 2024	131
Chenopodium album	2023, 2024	9
Comptonia peregrina	2023, 2024	10
Cyperus esculentus	2022	1
Cyperus strigosus	2023, 2024	4
Dactylis glomerata	2023, 2024	10
Daucus carota	2024	6

Desmodium canadense	2022, 2023, 2024	56
Desmodium paniculatum	2023, 2024	22
Desmodium varians	2022	1
Dichanthelium clandestinum	2024	2
Dichanthelium oligosanthes	2022, 2023, 2024	7
Dichanthelium sphaerocarpon	2022	1
Dichanthelium spp.	2022, 2023, 2024	287
Digitaria ischaemum	2023, 2024	6
Digitaria sanguinalis	2023, 2024	3
Digitaria spp. complex	2022, 2023, 2024	244
Diodia teres	2022, 2023, 2024	26
Distichlis spicata	2023, 2024	5
Elaeagnus umbellata	2023, 2024	18
Elymus repens	2022, 2023, 2024	14
Elymus virginicus	2022, 2023, 2024	251
Eragrostis spectabilis	2022, 2023, 2024	52
Erechtites hieraciifolius	2023, 2024	11
Erigeron annuus	2022, 2023, 2024	19
Erigeron canadensis	2022, 2023, 2024	136
Erigeron strigosus	2023, 2024	18
Euphorbia maculata	2023, 2024	5
Eurybia spectabilis	2022	1
Euthamia graminifolia	2023, 2024	16
Festuca rubra	2022, 2023, 2024	596
Fragaria virginiana	2024	1
Fraxinus pennsylvanica	2024	2
Galium tinctorium	2024	3
Geranium maculata	2022	1
Hieracium caespitosum	2023, 2024	2
Hieracium paniculatum	2024	1
Holcus lanatus	2024	1
Houstonia caerulea	2023, 2024	10
Hypericum gentianoides	2022, 2023, 2024	51
Hypericum hypericoides	2024	1
Hypericum mutilum	2023, 2024	13
Hypericum perforatum	2022, 2023, 2024	86
Hypochaeris radicata	2022, 2023, 2024	197
Ilex verticillata	2023, 2024	4
Imperata cylindrica	2024	2
Juncus effusus	2024	14
Juncus tenuis	2022, 2023, 2024	160
Juniperus spp.	2024	2
Lactuca biennis	2024	1
Lactuca virosa	2023, 2024	2
Leontodon hispidus	2024	27

Lepidium virginicum	2024	2
Lespedeza bicolor	2024	3
Lespedeza capitata	2022, 2023, 2024	73
Lespedeza cuneata	2023, 2024	12
Lespedeza hirta	2023, 2024	4
Lespedeza spp.	2023, 2024	2
Lespedeza virginica	2023, 2024	8
Leucanthemum vulgare	2023, 2024	5
Linaria vulgaris	2023, 2024	14
Lotus corniculatus	2022, 2023, 2024	99
Lotus tenuis	2024	2
Luzula multiflora	2024	1
Lysimachia quadrifolia	2023, 2024	2
Medicago lupulina	2022, 2023, 2024	48
Melilotus albus	2023, 2024	24
Melilotus officinalis	2024	1
Mollugo verticillata	2024	1
Monarda fistulosa	2022, 2023, 2024	117
Myosotis verna	2024	1
Mysotis spp.	2024	1
Nuttallanthus canadensis	2022, 2023, 2024	70
Oenothera biennis	2022, 2023, 2024	48
Oenothera fruticosa	2023, 2024	9
Oxalis stricta	2022, 2023, 2024	96
Panicum capillare	2024	1
Panicum dichotomiflorum	2022, 2023, 2024	20
Panicum virgatum	2022, 2023, 2024	339
Paspalum setaceum	2024	5
Paspalum spp. complex	2022, 2023, 2024	64
Paspalum urvillei	2024	1
Persicaria bicornis	2023, 2024	23
Persicaria maculosa	2023, 2024	35
Phalaris arundinacea	2023, 2024	2
Phytolacca americana	2022	1
Pinus spp.	2023	1
Pinus sylvestris	2023	2
Plantago aristata	2022, 2023, 2024	7
Plantago lanceolata	2022, 2023, 2024	77
Plantago major	2022	10
Poa bulbosa	2022	2
Poa pratense	2022, 2023, 2024	38
Polygala polygama	2023, 2024	11
Potentilla argentea	2022, 2023, 2024	17
Potentilla canadense	2023	28
Potentilla norvegica	2022	2

Potentilla simplex	2022, 2023,2024	56
Prunella vulgaris	2022	1
Prunus serotina	2023, 2024	12
Pseudognaphalium obtusifolium	2022, 2023	20
Pycnanthemum tenuifolium	2023, 2024	40
Pycnanthemum virginianum	2022	4
Ranunculus spp.	2022	1
Rhus copallinum	2023, 2024	10
Rhus glabra	2023	1
Robinia pseudoacacia	2023, 2024	23
Rorippa sylvestris	2022	2
Rubus flagellaris	2023, 2024	10
Rubus hispidus	2022, 2023, 2024	18
Rudbeckia hirta	2022, 2023, 2024	331
Rumex acetocella	2022, 2023, 2024	362
Sassafras spp.	2024	1
Schizachyrium scoparium	2023, 2024	50
Schoenoplectus americanus	2022	1
Scleranthus annuus	2022, 2023	7
Securigera varia	2022, 2023, 2024	100
Setaria faberi	2022	1
Setaria pumila	2022, 2023, 2024	45
Setaria viridis	2022, 2023	9
Silene latifolia	2022, 2023, 2024	12
Sisyrinchium angustifolium	2023, 2024	7
Sisyrinchium atlanticum	2022	2
Solanum carolinense	2022, 2023, 2024	46
Solidago altissima	2022	2
Solidago bicolor	2022, 2023, 2024	12
Solidago canadensis	2023	1
Solidago juncea	2023, 2024	75
Solidago nemoralis	2022, 2023, 2024	83
Solidago odora	2023	1
Solidago rugosa	2023, 2024	50
Solidago spp.	2022, 2023, 2024	21
Spergula arvensis	2023, 2024	10
Spergularia rubra	2022, 2023	3
Spiranthes vernalis	2023, 2024	2
Stellaria graminea	2022	1
Stellaria spp.	2022	1
Strophostyles helvola	2022	2
Strophostyles umbellata	2022	1
Symphyotrichum laeve	2022	1
Symphyotrichum lanceolatum	2023, 2024	10
Symphyotrichum lateriflorum	2022, 2023, 2024	13

Symphyotrichum novae-angliae	2022, 2023, 2024	43
Symphyotrichum novi-belgii	2023, 2024	16
Symphyotrichum pilosum	2023, 2024	70
Symphyotrichum racemosum	2023	9
Symphyotrichum spp.	2022	1
Thlaspi arvense	2022	1
Toxicodendron radicans	2023, 2024	8
Tradescantia ohiensis	2024	1
Tridens flavus	2022, 2023, 2024	86
Trifolium arvense	2022, 2023, 2024	54
Trifolium aureum	2022	1
Trifolium campestre	2022, 2023, 2024	11
Trifolium pratense	2022, 2023, 2024	102
Trifolium repens	2022, 2023, 2024	155
Verbascum thapsus	2023, 2024	8
Verbena bracteata	2023, 2024	3
Verbena hastata	2023, 2024	4
Veronica arvensis	2023, 2024	8
Veronica officinalis	2024	2
Veronica peregrina	2022	1
Veronica serpyllifolia	2022	1
Vicia cracca	2022, 2023, 2024	45
Vicia hassei	2022	2
Vicia sativa	2022	5
Vicia tetrasperma	2022, 2023, 2024	16
Viola spp.	2022	1
Vitis aestivalis	2022	3
Vitis cinerea	2022	1
Vitis labrusca	2023, 2024	8
Vitis vinifera	2022	1
Xanthium strumarium	2022	3
Zizia aptera	2023, 2024	8
Zizia aurea	2023, 2024	50