Native Meadow Trial at the Hudson Valley Farm Hub

Botany Report for the First Nine Seasons: 2017-2025

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Photo courtesy of Oceans 8/Jon Bowermaster

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SUMMARY

In 2017, a long-term trial was initiated in three trial areas totaling 4.5 acres of former corn fields to

- document the establishment and maintenance of native meadows without the use of herbicides
- describe the performance (their ability to establish and persist) of 22 insect-pollinated wildflowers and 8 grasses native to northeastern North America seeded into farmland in the mid Hudson region
- monitor the development of the plant composition and flower abundance over the years in three different kinds of meadows: (1) derived from a wildflower-rich seed mix, (2) from a grass-rich seed mix, and (3) spontaneously established in fallow fields
- assess the value of the three kinds of meadows for supporting insect biodiversity and beneficial invertebrates over the years
- evaluate the soil health and soil life implications of the three kinds of meadows over the years.

The meadows were successfully established and required approximately 11 person-hours of labor per acre during the first year (site preparation, seeding, and mowing), and between 3 and 9 person-hours per acre and year (mowing and weeding) during the next three years. Since 2021, they were mowed once in very early spring. Initially the mowing was done with a rotary mower (which required on average less than one person-hour per acre), but since 2024 a flail mower had to be used to cut the dense Cottonwood regrowth, which took on average a little less than two person-hours per acre.

By the third year, native plants covered on average more than 80% of the seeded plots (Figures 4 & 6). All but one seeded species (Joe-Pye-weed) did establish at least some seedlings during the first two years. Black-eyed Susan and Lance-leaved Coreopsis (Seed Mix A & B); Wild Bergamot, Early Goldenrod, Showy Goldenrod, New England Aster, and Little Bluestem (Seed Mix A); and Big Bluestem, Indiangrass, Canada Wild Rye, and Switchgrass (Seed Mix B) were the most common species during the first nine years. However, their relative proportions evolved over time and continue to evolve In the wildflower-rich meadows (Figure 5a), while they seem to have stabilized in the grass-rich meadows (Figure 7b). Some of the initially common species had become quite rare by 2025.

Wild-growing, annual plants diminished quickly over the first three years, but the native Cottonwood and non-native Mugwort are the two wild-growing perennial species which have established themselves and continued to be present in the ninth year, mostly in the wildflower-rich meadows (Mix A; Figure 5c) and fallow controls (Figure 9).

The total number of plant species changed significantly over the years in all treatments (Figure 11; p<0.0001). It decreased over time in both types of seeded meadows and after nine years was higher in the wildflower-rich meadow than in grass-rich meadows. In contrast, the plant

species richness in the fallow control plots increased continuously during the first years, peaked in 2021, and seems to have stabilized since then at a slightly higher average than that in the wildflower-rich meadows. The species richness of *seeded* plants was consistently and significantly ($p<.0001$) higher in the wildflower-rich meadows (Mix A) than in the grass-rich meadows (Mix B; $p=0.0005$) and the fallow controls ($p<0.0001$) during the first nine years. However, during that same period, the richness of *seeded* plants decreased slightly in the wildflower-rich meadows and markedly in the grass-rich meadows, while it increased in the fallow controls.

Total flower abundance peaked in 2018 in both the wildflower-rich and grass-rich meadows and has generally declined since (Figure 12). However, some fluctuation in the total flower abundance in wildflower-rich meadows since 2023 might indicate it stabilizing at a low level. Since 2020 and 2022, there were consistently less flowers in the grass-rich meadows than in the wildflower-rich meadows and fallow controls, respectively. Flower abundance in the fallow control plots remained below that of the seeded meadows during eight of the first nine years (Figure 12). Flower abundance in the fallow controls peaked in 2018 (at a very low level!), dropped sharply for a few years after that and has generally increased again since 2022.

With maturation of the wildflower-rich meadows over the last nine years, peak flower abundance moved from earlier to later in the season (Figures 15.1-3).

The number of plant species found in bloom quickly peaked in the seeded meadows (both, wildflower-rich and grass-rich) in the second year (2018). Since then, it has decreased quickly (2018-2019) and then more gradually (2021-2025) in the wildflower-rich meadows, and quite continuously in the grass-rich meadows. In contrast, the number of plant species in bloom in the fallow control plots peaked three years later (in 2021), but has declined since then to about the same level as in the wildflower-rich meadows (Figure 18).

During the first nine years of the trial (2017-2025), the overall soil health score increased significantly over time (ANOVA; $p<0.0001$; Figure 19), although there was some year-to-year variability, including an apparent drop in soil health score between 2023 and 2025. However, during the course of the experiment, we did not find a statistically significant difference in soil health between the treatments (wildflower-rich meadow, grass-rich meadow, or fallow control) or trial areas.

We plan to continue the monitoring of the vegetation composition and flower abundance, as well as any management action, in the native meadows during their 10th year (2026). Few studies have followed the long-term ecology of seeded wildflower meadows in the Northeast. Together with the Hudson Valley Farm Hub and the other researchers in the Applied Farmscape Ecology Research Collaborative, future plans for these meadows will be determined during the course of 2026.

INTRODUCTION & OBJECTIVE OF TRIAL

The Hudson Valley Farm Hub is a non-profit, organic farm located on 1,600 acres of prime farmland in the floodplain of the Esopus Creek, between the Catskills and the Hudson River. It strives to contribute to a resilient food system for the Hudson Valley and is committed to strengthening the synergies between farming and wild nature. The Farm Hub is a production farm that also serves as a resource for education, demonstration, and research.

One area of research is the establishment and monitoring of on-farm habitats to support beneficial invertebrates and other wildlife. In 2017, we established a native meadow trial on former, conventionally managed corn and vegetable fields that had become part of an organically-certified farm and been taken out of tillage because of their exposure to infrequent but severe flooding.

Our overall objective for the native meadow trial is to understand what seed mixes and management regimes can produce good herbaceous habitat for beneficial insects and other wildlife at the Farm Hub.

Specifically, we hope to learn and document (in this report) the following:

- What does it take (in terms of equipment, labor, and cost of seeds) to establish permanent meadows composed mostly of native grasses and wildflowers on former cornfields? Is that possible without the use of herbicides and with techniques that are potentially practical to other farmers?
- Which plant species seem most suitable as components of permanent meadows here at the Farm Hub and so, perhaps, elsewhere in the region? What is the composition and abundance of flowers produced by these meadows across the season and over the years?
- How do soil conditions evolve in the native meadow trial plots compared to neighboring hayfields and tilled soil?

In addition, the trial serves as a basis for other researchers to address the following questions:

- Which above-ground invertebrates are attracted to the experimental plots of the native meadow trial? What is the balance between beneficials and pests?
- The ultimate agroecological question is: What is the net effect of such wildflower plantings on crop production?
- What role might these native meadows play for birds?
- What is the impact of perennial meadows on soil macroinvertebrates, bacterial/fungal communities, and overall soil health?

The native meadow trial plots are intended to serve as well-documented demonstration areas and inspiration for other farmers and land managers. They will also help inform future management decisions at the Farm Hub itself, as it explores opportunities for conservation biological control, pollinator conservation, and options for productive permanent cover of flood-prone fields.

METHODS

Experimental Design

The Native Meadow Trial consists of three rectangular trial areas of 320 x 200 feet (NMT1, NMT2, and NMT3; Figure 1), each of which has been subdivided into three experimental plots (Treatment A, B, C) of 100 x 200 feet, separated by 10 foot wide strips of mowed grass/clover.

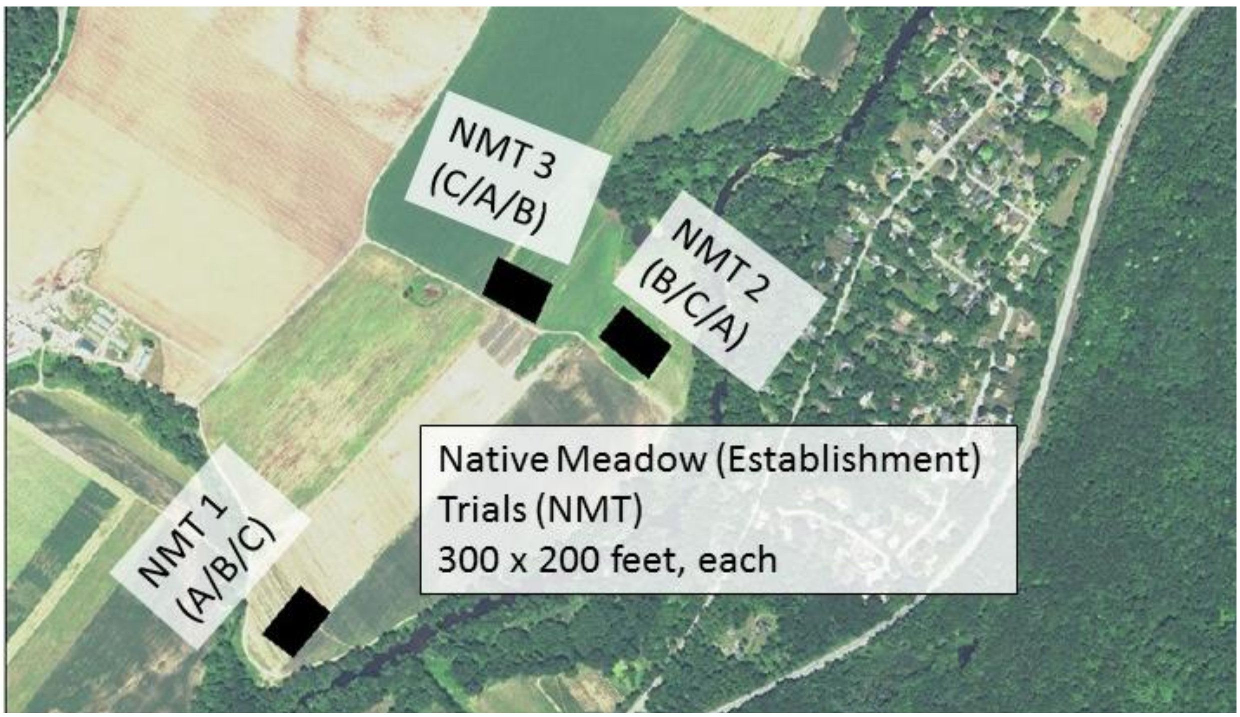

Figure 1: Map of Native Meadow Trial Areas at the Hudson Valley Farm Hub

Treatment A was seeded with wildflower-rich Seed Mix A (see below), Treatment B with grass-rich Seed Mix B (see below), and Treatment C served as a control which did not receive any seeds, but was otherwise treated the same as A and B.

Soil Types

The trial areas were located on different soil types. NMT1 is on Tioga fine sandy loam, NMT2 on Suncook loamy fine sand, and NMT3 on Unadilla silt loam. The soil characteristics are described in more detail in the results section below.

Crop History

All three trial areas were planted in Sweet Corn (preceded and followed by Rye) in 2013. In 2014, they all had a cover crop of Crimson Clover. In 2015, NMT1 was planted in mixed vegetables while NMTs 2 and 3 were in Wheat, all followed by Rye. In 2016, all three trial areas were planted in Rye, followed by Oat—in preparation for the seeding with native meadow seed mixes the following year.

Site Preparation

The decision to dedicate these particular areas to the native meadow trial was only made in the summer of 2016, when they were all in Rye. We decided to plan for a spring 2017 seeding, realizing that this would not allow for the recommended year-long site preparation. The trial areas were seeded with Oat in fall 2016, which was expected to winter-kill and leave bare soil for seeding the following spring. Although the Oat was winter-killed, the Rye volunteered in most of the experimental areas in early spring 2017. Therefore, the experimental areas were harrowed three times in the spring of 2017 with a Perfecta II Harrow with S-tines equipped with duck feet in order to uproot the rye and to prepare a weed-free seedbed for the native meadow mixes. Each harrowing pass over the entire 4.5 acre trial area took 2 hours. According to Jean-Paul Courtens (then one of the farmers at the Farm Hub), disking would have accomplished the same; however a Perfecta Harrow with points (rather than duck feet) would not have been effective at uprooting the Rye.

Seed Mixes and Seeding

With the help of Kelly Gill (Xerces Society/NRCS), we created two customized seed mixes for this trial. Wildflower-rich Seed Mix A (see Table 2 and Figure 2) was—at the time—considered an ideal (but expensive) pollinator mix, rich in wildflowers native to North America, most of them native to the Northeast (including 22 species intended to provide ample flower resources to pollinators throughout the seasons) and with one species of native bunch grass (Little Bluestem).

The cheaper grass-rich Seed Mix B (see Table 2 and Figure 3) had a variety of native bunch grasses, but also contained six native wildflowers, which likewise were selected to provide floral resources throughout the seasons.

The seeds were sourced from three different suppliers, as indicated in Tables 2 and 3. Please also refer to these tables for scientific names of the plant species referred to in the text by common names. In addition to the perennial species listed as “official” components of the seed mixes, seeds from annual Blanketflower (*Gaillardia* sp.) and Phacelia (*Phacelia tanacetifolia*), which had been left over from annual insectary seedings elsewhere on the farm, were added to both seed mixes (approximately 1 lb of each species to each seed mix).

On May 19, 2017, we used a Great Plains No-till Seeder to seed experimental plots A and B in each of the three trial areas with Meadow Mix A and Meadow Mix B, respectively. For unknown reasons, we did not quite accomplish the recommended seeding rates, and seeds were left over after the first pass of the seeder. To correct this, the leftover seeds were broadcast by hand on May 25th (before the next rain, to maximize soil seed contact and minimize the danger of the seeds getting blown away by the wind) to approximate the recommended seeding rates. Seeds of each species in the seed mixes were seeded on May 19th into pots in the greenhouse to serve as a reference. This enabled us to photographically document seedling morphology and to monitor seed germination, both in the greenhouse and in the field.

Experimental plot C in each of the three trial areas was left fallow as a control and developed a plant community from the seed bank in the soil and from naturally dispersed seeds. These fallows were mowed and weeded on the same schedule as the seeded trial areas for the first three years. Subsequently, they received additional weeding to reduce the density of seeded species that had dispersed into the fallow control plots from neighboring plots.

*Table 1: Species list for wildflower-rich Seed Mix A. Seeds from annual Blanketflower (*Gaillardia *sp.) and Phacelia (Phacelia tanacetifolia) were added to this mix, approximately 1 lb each.*

Native Meadow Mix A				
Common Name	**Scientific Name**	**Percent of mix by volume (seed/ft2)**	**Final Mix Total pounds (lb) for 1.5 acres**	**Supplier**
Blackeyed Susan	Rudbeckia hirta	6.5%	0.19	Ernst Seeds
Browneyed Susan	Rudbeckia triloba	2.2%	0.18	Ernst Seeds
Butterfly Milkweed	Asclepias tuberosa	1.1%	0.73	Ernst Seeds
Common Milkweed	Asclepias syriaca	1.1%	0.73	Ernst Seeds
Dense Blazingstar	Liatris spicata	1.1%	0.51	Ernst Seeds
Early Goldenrod	Solidago juncea	3.2%	0.06	Ernst Seeds
Joe Pye Weed	Eupatorium purpureum	1.0%	0.07	Prairie Moon
Lance Leaved Coreopsis	Coreopsis lanceolata	8.6%	1.84	Ernst Seeds
Lavender Hyssop	Agastache foeniculum	8.6%	0.27	Ernst Seeds
Little Bluestem	Schizachyrium scoparium	19.4%	4.59	Ernst Seeds
Mistflower	Eupatorium coelestinum	6.5%	0.20	Ernst Seeds
Narrowleaf Mountainmint	Pycnanthemum tenuifolium	3.8%	0.03	Prairie Moon
New England Aster	Aster novae-angliae	2.1%	0.09	Ernst Seeds
Ohio Spiderwort	Tradescantia ohiensis	2.2%	0.81	Prairie Nursery
Partridge Pea	Chamaecrista fasciculata	2.2%	1.57	Ernst Seeds
Purple Coneflower	Echinacea purpurea	4.3%	1.76	Ernst Seeds
Purple Prairie Clover	Dalea purpurea	2.2%	1.27	Ernst Seeds
Roundhead Lespedeza	Lespedeza capitata	1.1%	0.19	Prairie Moon
Showy Goldenrod	Solidago speciosa	2.3%	0.08	Ernst Seeds
Slender Lespedeza (added)	Lespedeza virginiana	2.1%	1.27	Ernst Seeds
Smooth Blue Aster	Aster laevis	2.1%	0.10	Ernst Seeds
Tall White Beardtongue	Penstemon digitalis	9.7%	0.25	Pinelands Nursery
Wild Bergamot	Monarda fistulosa	6.7%	0.25	Pinelands Nursery
	TOTALS:	100.0%	17.04 lbs	

*Table 2: Species list for grass-rich Seed Mix B. Seeds from annual Blanketflower (*Gaillardia *sp.) and Phacelia (Phacelia tanacetifolia) were added to this mix, approximately 1 lb each.*

Native Meadow Mix B				
Common Name	**Scientific Name**	**Percent of mix by volume (seed/ft2)**	**Final Mix Total pounds (lb) for 1.5 acres**	Supplier
Autumn Bentgrass	*Agrostis perennans*	15.0%	0.09	Ernst Seeds
Big Bluestem	*Andropogon geradii*	6.4%	2.12	Ernst Seeds
Blackeyed Susan	*Rudbeckia hirta*	6.3%	0.19	Ernst Seeds
Canada Wildrye	*Elymus canadensis*	10.7%	4.47	Ernst Seeds
Indiangrass	*Sorghastrum nutans*	6.7%	1.82	Ernst Seeds
Lance Leaved Coreopsis	*Coreopsis lanceolata*	3.2%	0.69	Ernst Seeds
Little Bluestem	*Schizachyrium scoparium*	16.0%	3.82	Ernst Seeds
Partridge Pea	*Chamaecrista fasciculata*	1.1%	0.78	Ernst Seeds
Purple Coneflower	*Echinacea purpurea*	5.3%	2.20	Ernst Seeds
Purple Lovegrass	*Eragrostis spectablis*	1.3%	0.06	Prairie Moon
Purple Prairie Clover	*Dalea purpurea*	2.1%	1.27	Ernst Seeds
Purpletop	*Tridens flavus*	16.4%	1.69	Ernst Seeds
Slender Lespedeza	*Lespedeza virginiana*	1.1%	0.65	Ernst Seeds
Switchgrass	*Panicum virgatum*	8.5%	1.57	Ernst Seeds
	TOTALS:	**100.00%**	**21.42 lbs**	

Figure 2: Images of plants included in Seed Mix A (first row: Lavender Hyssop, Dense Blazingstar, Black-eyed Susan, Smooth Blue Aster, Purple Prairie Clover, New England Aster; second row: Little Bluestem, Early Goldenrod, Brown-eyed Susan, Tall White Beardtongue, Round-headed Lespedeza, Ohio Spiderwort; third row: Mistflower, Joe-Pye-Weed, Butterfly Milkweed, Showy Goldenrod, Partridge Pea, Purple Coneflower; fourth row: Narrow-leaved Mountain-mint, Lance-leaved Coreopsis, Common Milkweed, Wild Bergamot, Slender Lespedeza); Pictures were copied from on-line seed catalogues, mostly by Prairie Moon

Figure 3: Images of plants included in Seed Mix B (first row: Autumn Bentgrass, Big Bluestem, Black-eyed Susan, Canada Wild Rye, Indiangrass; second row: Lance-leaved Coreopsis, Little Bluestem, Partridge Pea, Purple Coneflower, Purple Lovegrass; third row: Purple Prairie Clover, Purpletop, Slender Lespedeza, Switchgrass); Pictures were copied from on-line seed catalogues, mostly by Prairie Moon.

Management

We attempted to establish and manage these plots with minimum labor so as to make them as practical as possible for farmers. This required some hard decisions where creating a "perfect" native meadow that would pass muster as a landscaping project, might have been possible with more effort. However, we generally decided against pursuing such perfection, because then the trial would not have served as a valid demonstration project for farmers.

First Season (2017): All experimental plots (those seeded with Mixes A & B, as well as the control plots) were mowed to approximately 6-7 inches height three times during the first season. This was intented to reduce shading of the slow-growing seedlings of the perennial native plants by the fast-growing annual weeds that had germinated from the seed bank and to limit the production of new weed seeds. The mowing was done on:

- 6-10 July 2017: with flail mower (6 hours total for 4.5 acres)
- 26/28 July 2017: with flail mower (6 hours total for 4.5 acres)
- 15/16 Aug 2017: with rotary mower (3 hours total for 4.5 acres)

No management occurred during the rest of the season and the vegetation (mostly composed of crabgrass) and was left standing into the winter.

Second Season (2018): By Spring of the second year, the native perennials had established dense stands, with the plants growing through the thatch of crabgrass that had covered the ground through the winter. The seeded perennials were not threatened by competition for light by early-season annual weeds any more and therefore we did not mow the entire experimental plots that year. However, the perennial and non-native Red Clover, Hairy Vetch, Mugwort, Curly and Broad-leaved Dock, and Wild Carrot were growing vigorously in the experimental plots, and were reduced by selective weeding/string trimming in all nine experimental plots, including the control plots (50 hours total for 4.5 acres between 25 May and 15 June 2018; please see Table 5 and Figure 22 below for an estimate of the labor required to maintain just the seeded meadows, vs. the entire experimental design). During the summer, we noticed young Cottonwood trees colonizing some of the experimental plots, most densely in NMT1C, and to a lesser degree in NMT1A, NMT3A, and NMT3C. Because five of the nine experimental plots had basically no colonization with Cottonwood, we decided to try to selectively pull out/cut the Cottonwood in those plots where it was getting common the following spring. Thus, the vegetation was again left standing into the winter in all experimental plots.

Third Season (2019): On May 6th of the third year, we selectively cut (and pulled where still possible) the young Cottonwood trees (20 person hours total; most of them applied to NMT1 C). No other selective weeding was necessary that spring. In late summer, we selectively cut most (but did not get to all) Mugwort patches that had persisted in the experimental plots. This took 7 person hours total. Once more, the vegetation was left standing into the winter in all experimental plots. The young Cottonwood trees had regrown to a height of up to 8 feet by the end of the season.

<u>Fourth Season (2020):</u> Because we had been unable to control the growth and spread of young Cottonwood trees manually, all the experimental plots were mowed on March 2, 2020 with a rotary mower (3 person hours total). Unfortunately, this mowing resulted in the spread of seeds across experimental plots, and subsequent vigorous growth of seeded native plants in the control plots. Before each insect sampling event, we eliminated—as much as possible—the flowers of seeded plants (mostly Black-eyed Susan and Partridge Pea) from the control plots. This took approximately a total of 20 person hours (6 in July, 10 in August, and 4 in September). In addition to the Cottonwood trees, which—after having been mowed to stubbles in the spring—grew again up to a height of 8 feet during the fourth season, we felt it necessary to discourage the Mugwort in the experimental plots. Between June 17 and September 18, we spent a total of 34 person hours with pulling/cutting this species. The vegetation was left standing into the winter in all experimental plots.

<u>Fifth Season (2021):</u> All experimental plots were mowed on March 26, 2021 with a rotary mower (3 person hours total). We did not do any selective weeding in the seeded meadows, but spent a total of 27 hours throughout the season removing flowers from the control plots and digging up seeded plants that had dispersed into the control plots.

<u>Sixth Season (2022):</u> All experimental plots were mowed on March 23, 2022 with a rotary mower (3 person hours total). We did not do any selective weeding in the seeded meadows, but spent a total of 23 hours throughout the season removing flowers from the control plots and digging up seeded plants that had dispersed into the control plots.

<u>Seventh Season (2023):</u> All experimental plots were mowed on March 27, 2023 with a rotary mower (3 person hours total). We did not do any selective weeding in the seeded meadows, but spent a total of 25 hours throughout the season removing flowers and digging up plants of species that had been seeded into wildflower-rich plots and had dispersed into neighboring control plots (most time was spent on NMT2 control).

<u>Eighth Season (2024):</u> All experimental plots were mowed between March 15-22, 2024 with a 10-foot flail mower (approximately 12 person hours total). We did not do any selective weeding in the seeded meadows or control plots this year. In spite of our earlier efforts to remove seeded plants that had dispersed into neighboring plots, they had become too abundant to remove within the scope of this project. As in prior years, this “cross-contamination” with seeded plants was most notable in the control plots, but it also became evident this season, that some of the native grasses seeded into the grass-rich plots had established themselves in adjacent wildflower-rich plots.

<u>Ninth Season (2025):</u> All experimental plots were mowed April 1st, 2025 with a 10-foot flail mower (approximately 8 person hours total). As in the prior year, we did not do any selective weeding in the seeded meadows or control plots this year.

Monitoring Methods

Vegetation Development

Photographic Documentation: We documented the development of the vegetation in all nine experimental plots with a series of images taken from standard locations on the ground at monthly intervals during the growing seasons and less frequently in the off-seasons 2017-2025. In addition, drone image were taken monthly July-Oct. in 2020, June-Sept. in 2021, and May-Oct. from 2022 to 2025 (see Appendix).

Quantitative Vegetation Inventories: Twice a year (July & September/early October), we documented the vegetation in ten evenly-spaced nested samples along two transects in each of the nine experimental plots. In ten square-shaped samples of one ft^2, we recorded the (absolute) percent cover (visual estimate of the portion of the ground covered) and maximum height of each plant species present. Thus, the total percent cover of all species present could add to less than 100%, if the vegetation did not cover all of the ground. It could also add to more than 100%, if the vegetation was layered, with different species covering the same area of ground at different heights. In ten larger circular samples of 3 feet radius (which included the square samples), we recorded the presence of all plant species and ranked their relative abundance from 1-4.

Flower Abundance

We quantitatively documented the seasonal flower abundance by species. In each experimental plot, we counted or estimated the number of open flowers or flower clusters of each species in ten circular, three-foot radius samples spaced evenly along two transects. Species-specific flower abundances in each sample were calculated by multiplying the number of flowers or inflorescences by their average size (=flower or inflorescence area in mm^2). We then extrapolated this value to the average % cover of each flower species within each experimental plot. Flower abundance was monitored twice in 2017 (Aug 10 and Sept 8; the newly seeded plants were slow to produce flowers in the first year, therefore, we only began documenting flower abundance later in the summer), four times in 2018 (June 12, July 10, Aug. 9, Sept. 21) and 2019 (June 12, July 15, Aug. 14, Sept. 10), and five times in 2022 (June 7, July 7, Aug. 2, Sept. 2, Sept. 20) to represent the main flowering period and to coincide with the insect sampling. In 2020, 2021, and since 2023, we documented the flower abundance in approximately two to three week intervals from May/June to late October/beginning of November in order to document its variation on a finer time scale and for a longer period.

Soil Conditions

Three composite soil samples (composed of 10 samples each) were taken from each of the nine experimental plots annually or every two years in the spring (May 2, 2017; May 7, 2018; May 22, 2019; June 1, 2021; and May 30, 2023; May 28, 2025) and analyzed at the Cornell Soil Health Lab for their chemical, physical, and biological characteristics.

Rooting Depth—A preliminary Exploration

On July 3, 2024, we conducted a brief exercise in NMT2 to explore the rooting depth of several native grass and wildflower species. We dug up one or two examples of five seeded wildflowers, three seeded grasses, and a cottonwood plant, and measured the depth of their roots.

Weather

The Hudson Valley Farm Hub has a weather station that can be accessed remotely at newa.cornell.edu (choose "Hurley, NY" as the station).

Labor and Equipment

We kept records of all management actions to document the labor and equipment used to establish and maintain these wildflower meadows.

MONITORING RESULTS AND DISCUSSION

Vegetation Development

Vegetation Development in Wildflower-rich Experimental Plots (Seed Mix A)

Figures 4 and 5a/b illustrate the average vegetation development over the years in experimental plots seeded with wildflower-rich Seed Mix A. Figure 4 compares percent cover of seeded vs. wild-growing species.

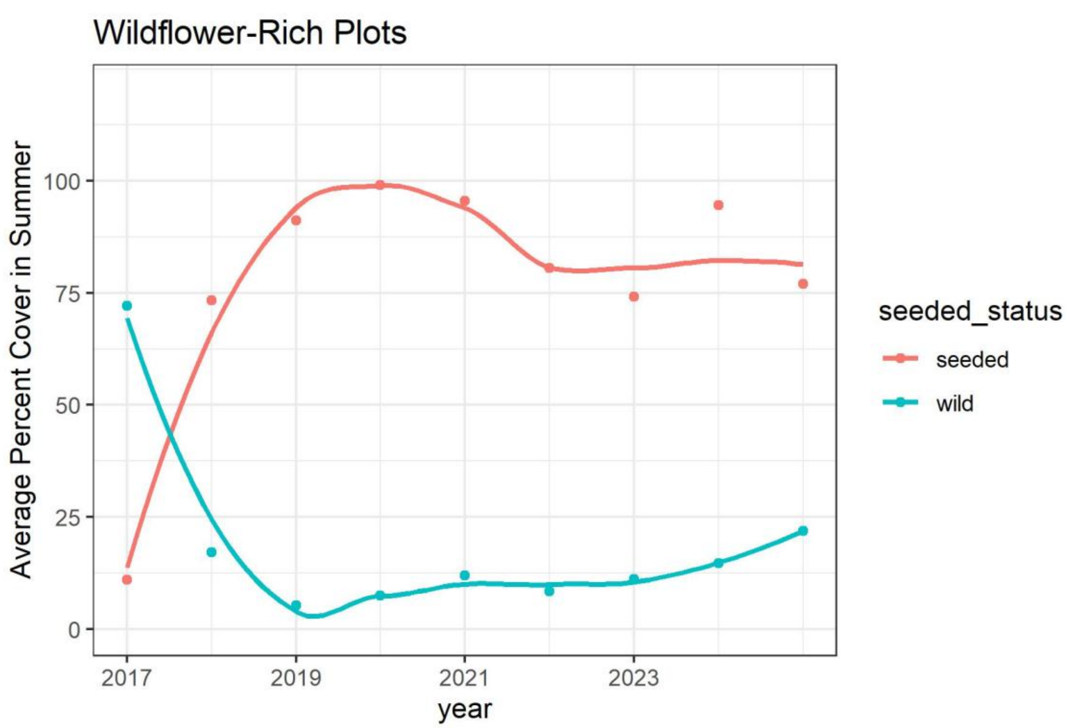

Figure 4: Development of average vegetation composition (average % cover of seeded vs. wild-growing species) over the years in experimental plots seeded with Mix A.

The seeded plants quickly established themselves in the wildflower-rich treatments (Mix A) and by the second season (2018) covered on average 73% of the ground. Their average percent cover peaked at 99% in 2020, and has been fluctuating between 75% and 95% since 2021. Wild-growing plants (Crabgrass, Pigweed, and Galinsoga) dominated the vegetation in the wildflower-rich meadows in the first season (Figure 5c). In the second season, the native Horseweed was the most common wild-growing plant in these meadows, but the annual wild-growing plants quickly declined as the seeded perennials got established. Since 2019, young trees of the native Cottonwood have been a noticeable component of the wildflower-rich meadows. In spite of the annual early-spring mowing, which coppices the established Cottonwood plants, their abundance has increased slowly to an average of 13% cover by 2025. More recently, Mugwort has also increased in abundance to 6% in 2025.

Figure 5a shows the contribution of the most abundant species to the seeded vegetation in the wildflower-rich treatments (Mix A) over time.

Of the 22 seeded species, nine made up at least 80% of the vegetation since 2018 (Figure 5a). However, the relative proportions of these nine species evolved over the years. Black-eyed Susan reached its maximum percent cover in the second year and has been declining since, Lance-leaved Coreopsis reached its (smaller) maximum percent cover in the third year and has significantly declined since, and Wild Bergamot peaked in the fourth year and has declined since. The native grass Little Bluestem had a first peak at 8% cover in the fifth year (2021), decreased substantially in 2022, but since then has increased again to 11% in 2025. Similarly, Partridge Pea had a first peak at 9% in 2021, with a subsequent decline to 4% in 2023 and a rebound to 10% in 2025. New England Aster has remained quite stable at just below 20% from 2021 to 2024, but declined to 10% in 2025. Early Goldenrod peaked at 25% in 2024, but declined to 17% in 2025. Similarly, Showy Goldenrod had steadily increased to 19% in 2024, but then declined to 15% in 2025.

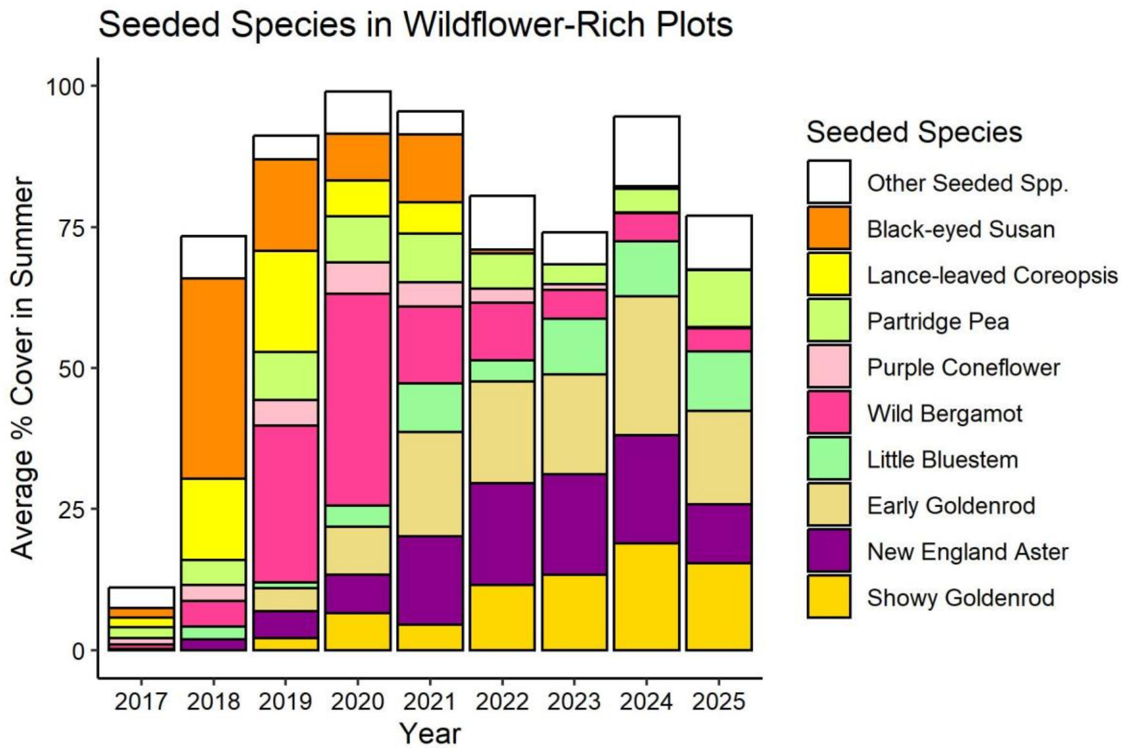

Figure 5a: Development of average vegetation composition (average % cover of seeded species only) over the years in experimental plots seeded with Mix A

Please see Figure 10b below to illustrate the plot-by-plot variation in common seeded species in the wildflower-rich plots.

It is interesting to note that the category "other seeded species" was highest in the eighth year (2024), which indicates that not only did some formerly common species diminish significantly over the years, while others quickly became common (as described above). In addition, a group of initially uncommon seeded species were becoming more prominent only eight years after seeding. These included Beardtongue, Ohio Spiderwort, Smooth Blue Aster, Round-headed Bush-clover, and Slender Lespedeza, which were largely responsible for the increase in the "other seeded species" category observed in 2024 (Figure 5b). Note, how that category had decreased again by 2025. Finally, there was also a group of seeded species that persisted at low densities without much change through the first nine years (for example, Narrow-leaved Mountain Mint, Mistflower, Butterfly Milkweed), which are also included in the "other seeded species" category in Figure 5a.

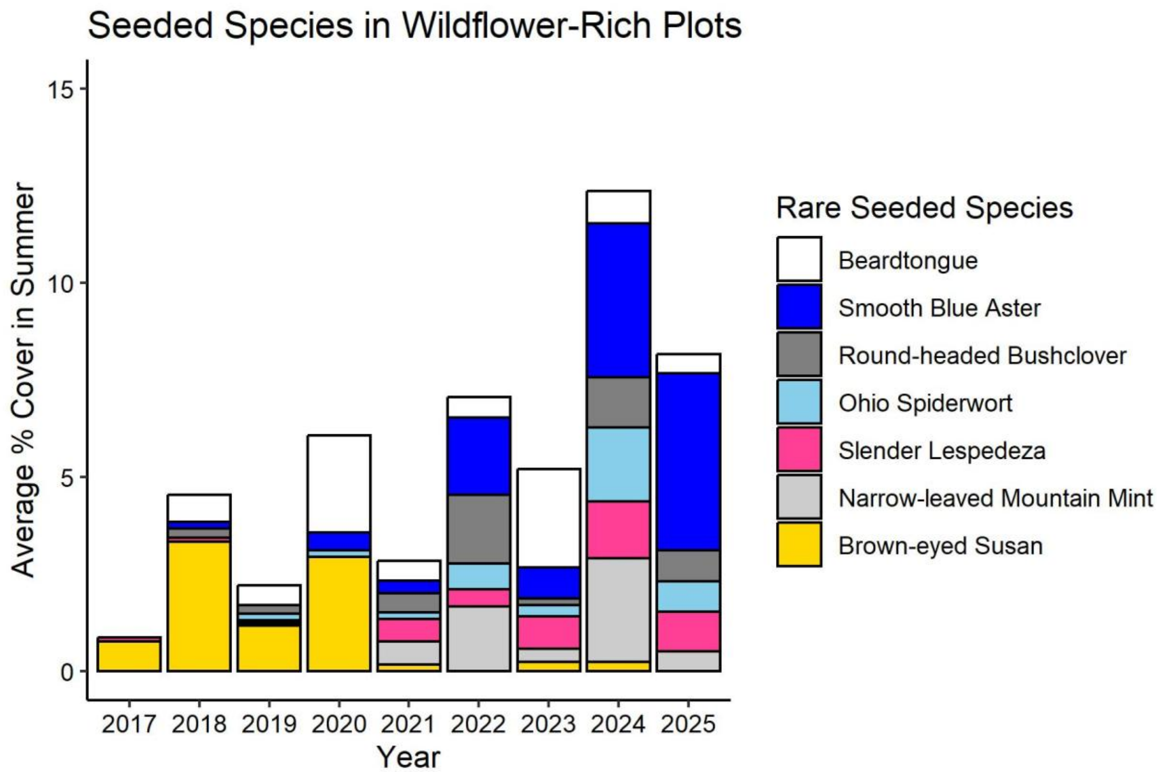

Figure 5b: Development of average vegetation composition (average % cover of rare seeded species only) over the years in experimental plots seeded with Mix A. These are most of the species in the "other seeded species" category in Figure 5a.

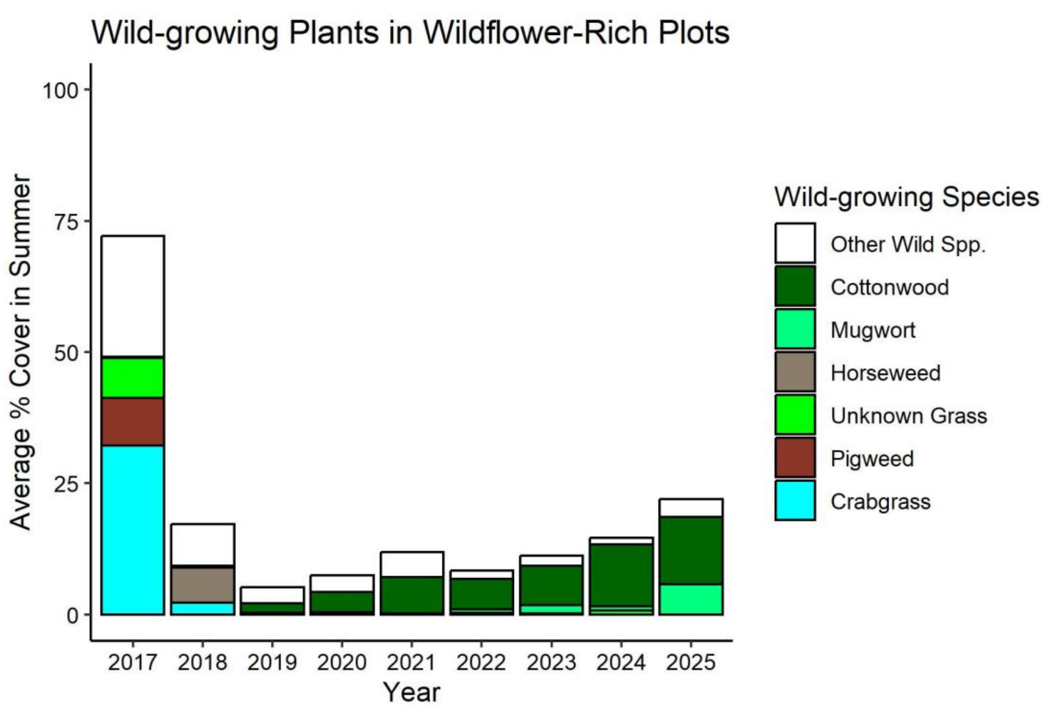

Figure 5c: Development of average vegetation composition (average % cover of wild-growing species only) over the years in experimental plots seeded with Mix A.

Vegetation Development in Grass-rich Experimental Plots (Seed Mix B)

Figures 6 and 7a/b illustrate the average vegetation development over the years in experimental plots seeded with grass-rich Seed Mix B. Figure 6 compares percent cover of seeded vs. wild-growing species.

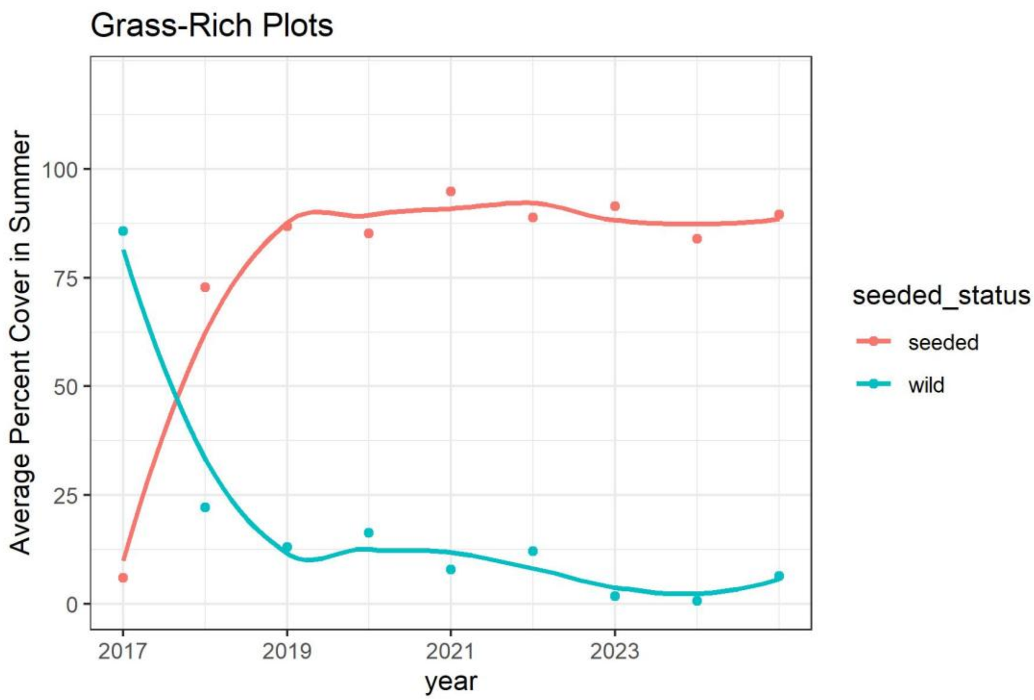

Figure 6: Development of average vegetation composition (average % cover of seeded vs. wild-growing species) over the years in experimental plots seeded with Mix B.

Similar to the situation in the wildflower-rich treatment (Figure 4), the seeded plants quickly established themselves in the grass-rich meadows (Mix B) and by the second season (2018) covered on average more than 70% of the ground (Figure 6). However, their increase in subsequent years was not as steep, and their fluctuation in total abundance was not as pronounced as in the wildflower-rich meadows (Mix A; Figure 4). Instead, the grass-rich meadows have hovered around just below 90% summer cover of seeded plants since 2019 (Figure 6).

The same species of wild-growing plants as in the wildflower-rich meadows dominated the vegetation in the grass-rich meadows in the first (Crabgrass, Pigweed, and Galinsoga) and second (Horseweed) season (Figure 7c). However, in contrast to the wild-flower rich plots, Cottonwood did not get established in the grass-rich meadows (see drone images in Figs. 9a and 9b, below). Instead, Mugwort had become established in a few widely-spaced clusters, mostly on the plot edges, and continues to persist at low density in the grass-rich meadows. Some of these clusters happened to be included in our vegetation samples in 2022 and 2025, but not in the years between. These apparent spikes in Mugwort are an artifact of sampling and do not represent an actual fluctuation in Mugwort abundance in the grass-rich meadows. The continued presence of Mugwort (at approximately 6% cover in 2025) in the grass-rich meadows is confirmed by the drone images (Figs. 9a and 9b).

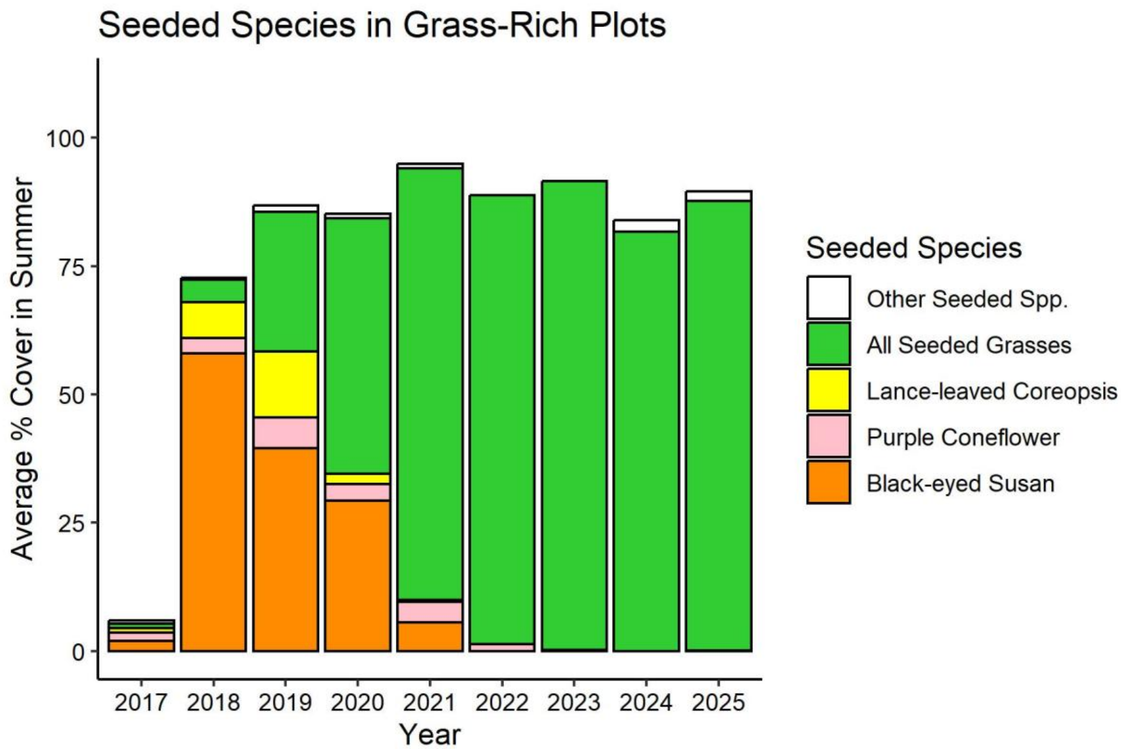

Figure 7a: Development of average vegetation composition (average % cover of seeded species in July) over the years in experimental plots seeded with Mix B.

Figure 7a shows the contribution of the most abundant species to the *seeded* vegetation in the grass-rich treatments (Mix B) in summer over time. Over the first five years, the experimental plots seeded with the grass-rich Mix B, showed on average a general increase in the percent cover by seeded species (Figure 6 and 7a). As in the wildflower-rich meadows, the relative proportions of seeded species in the grass-rich meadows evolved over the years. Black-eyed Susan reached its maximum percent cover in the second year and has been steadily declining since. Lance-leaved Coreopsis reached its (smaller) maximum percent cover in the third year and has almost disappeared since. In contrast, the percent cover of seeded native grasses (combined in a single category in Figure 7a, because of the difficulty to distinguish individual species in their non-reproductive phase during the July vegetation surveys) increased steadily and substantially until the fifth year (2021) and has since hovered around 90%.

Figure 7b shows the composition of seeded vegetation in the grass-rich plots in autumn, when the species of native grasses can easily be distinguished. Of the eight grass species originally seeded, Canada Wild Rye and Indian Grass peaked in abundance in 2020 (at 12% and 22% cover, respectively) and have almost disappeared since then. For the last four years, the grass-rich plots were increasingly dominated by Switchgrass and Big Bluestem. By 2025 these two species provided on average 60% and 39% autumn cover, respectively.

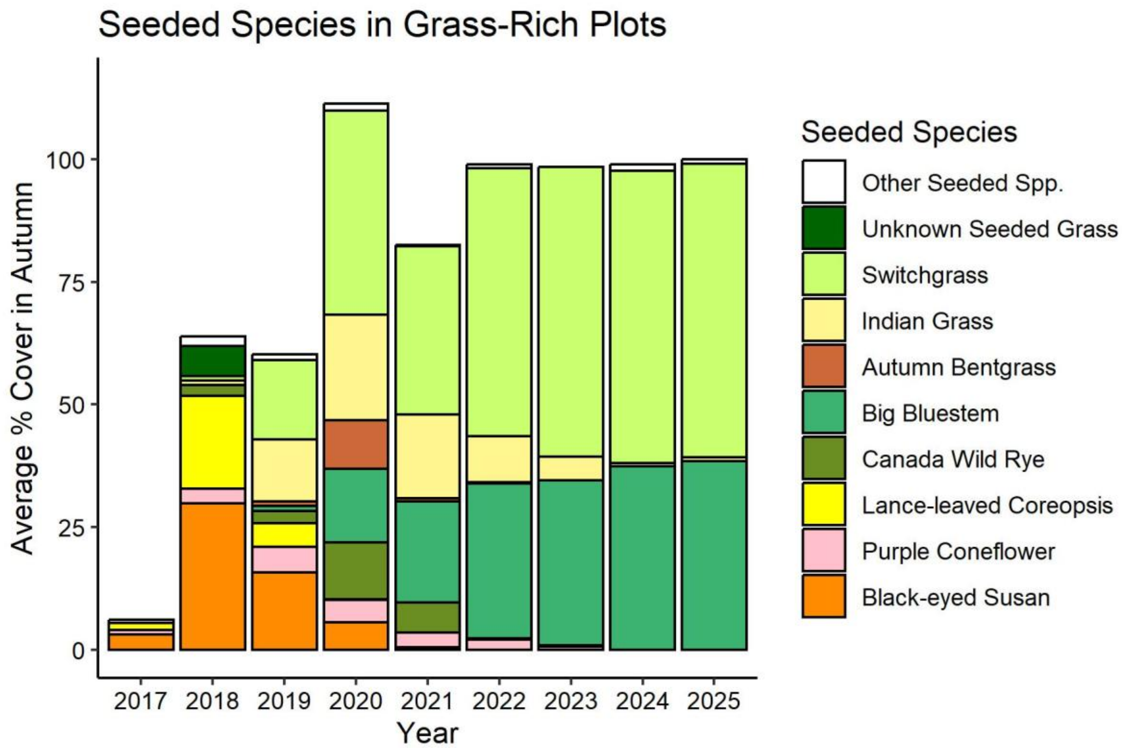

Figure 7b: Development of average vegetation composition (average % cover of seeded species in September) over the years in experimental plots seeded with Mix B.

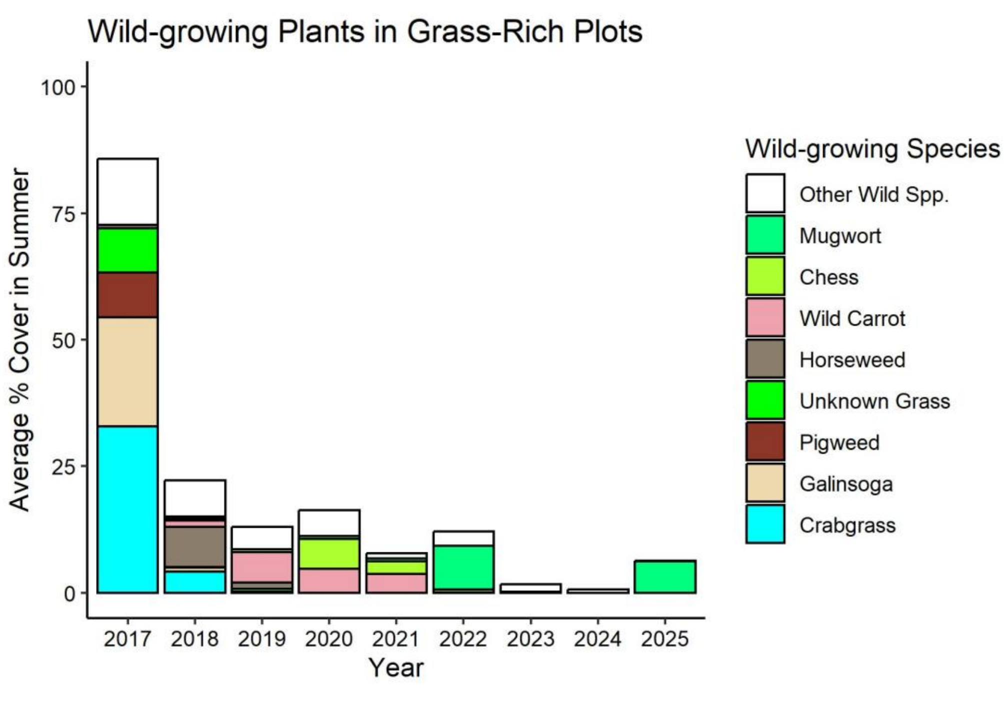

Figure 7c: Development of average vegetation composition (average % cover of wild-growing species in July) over the years in experimental plots seeded with Mix B.

Vegetation Development in Control Plots

Figures 8 and 9 illustrate the average vegetation development over the years in the control plots. Figure 8 shows percent cover of all wild-growing species as well as percent cover of seeded species that had dispersed into the control plots from neighboring wildflower-rich or grass-rich plots. Some of these seeded plants persisted in the control plots in spite of our efforts through 2023 to weed them out. By 2025, they covered on average 13% of the area in these plots.

Wild-growing, non-seeded plants quickly covered most of the ground in the control plots (more than 70% by 2018; Figure 8). After a dip during the dry year 2020, they continued to increase at a slower rate and with some year-to-year fluctuation. During the last five years, their summer cover fluctuated between 80% and 99%. Seeded plants (which were seeded in neighboring plots, but wild-growing in the control plots) increased from 0.2% in 2019, when they were first noticed in the control plots, to an average of 13% in 2025. Bare ground slowly diminished over the years, but into the seventh year of the fallow (2023), more than 10% of the ground in the control plots remained without vegetation.

As in the seeded plots, the control plots were initially dominated by annual weeds, such as Crabgrass, Galinsoga, and Pigweed (observed, but not sampled in 2017). These were successively replaced by Horseweed in 2018 and 2019 (Figure 9). By the autumn of 2019, Cottonwood had become well established in two of the fallow controls (NMT1 and NMT3; visible clearly in the eastern half of the control plot in the drone images in Fig. 9b, below) and covered on average almost a third of the ground in the three control plots since 2020. A year later, Mugwort became very noticable and has since steadily increased to 38% cover in 2025 (visible as light green patches in the control plot in the drone images in Fig. 9a, below). In addition, Partridge Pea, which had been seeded in neighboring plots, and accidentally dispersed into the controls, as well as the non-seeded, but native Tall Goldenrod were the most abundant wild-growing species in the control plots in 2025 (7% and 12% cover, respectively). The category of "other species", which contributed 19% of the vegetation in the fallow controls in 2025 included 34 species, such as the native Evening Primrose, Common Yellow Wood Sorrel, and Wrinkle-leaved Goldenrod, the non-native Wild Carrot and Chess, and the invasive Purple Loosestrive and Japanese Stiltgrass. It also included seeded species dispersed from neighboring plots, most notably Switchgrass, Black-eyed Susan, New England Aster, and Wild Bergamot. Finally, this category included a couple of species that were seeded in neighboring plots, but also occur wild in the surrounding landscape and whose origin in the control plots is uncertain: Common Milkweed and Early Goldenrod.

Please see Figure 10b below to illustrate the plot-by-plot variation in species composition between the control plots over the years.

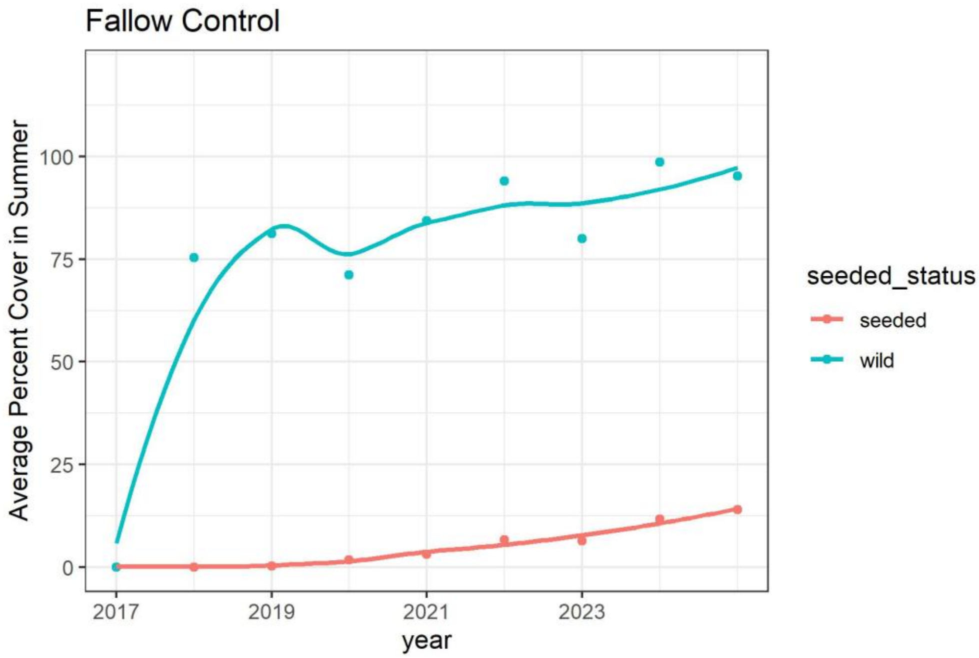

Figure 8: Development of average vegetation composition (average % cover of seeded vs. wild-growing species) over the years in in control plots. "Seeded" species had not been seeded in the control plots, but dispersed from neighboring seeded plots into the controls during the 2020 spring mowing, when the mowing direction accidentally promoted some "cross-contamination" between the plots.

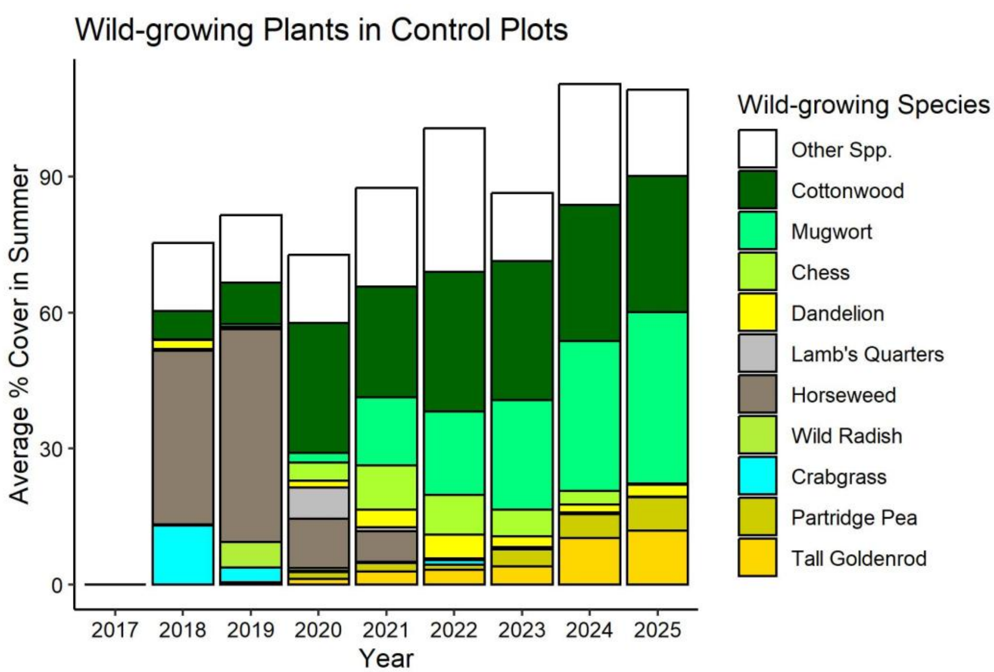

Figure 9: Development of average vegetation composition (average % cover in July) over the years in fallow control plots. Note that in the control plots, which were not seeded, wild-growing species included some that had been seeded in neighboring plots and dispersed into the control plots, such as Partridge Pea and less abundant species included in the category of "other species."

Figure 9a: Drone images of three experimental plots at trial location NMT2 (sandy soils) taken in autumn (2020-2025): grass-rich (left, west), control (center), and wildflower-rich (right, east). Images courtesy of Jon Bowermaster/Oceans8.

Figure 9b: *Drone images of three experimental plots at trial location NMT3 taken in early summer (2020-2025): control (left, west), wildflower-rich (center), and grass-rich (right, east). Images courtesy of Jon Bowermaster/Oceans8.*

Variation in Vegetation Between Trial Plots

Up to now, we have presented the plant composition data based on averages across the three plots in each treatment (wildflower-rich meadows, Seed Mix A; grass-rich meadows, Seed Mix B; and fallow controls). It is important to be aware of the fact, that there is quite a bit of variation in the vegetation between our three trial locations and—sometimes even within a single plot. Figure 10a illustrates this with a collage of drone images of the nine plots taken in July 2020. Figure 10b quantifies the variation in the abundance of the most common plant species between plots in the same treatments (wildflower-rich and control) over the years.

As mentioned above, NMT1 is located on Tioga fine sandy loam, NMT2 on Suncook loamy fine sand, and NMT3 on Unadilla silt loam. NMT2 had significantly sandier soils than the other two trial locations and this seem to be a big factor in explaining the obvious differences especially in the vegetation of the grass-rich meadow and the fallow control at the NMT2 location compared to corresponding treatments at the other two locations. On the sandy NMT2 soils, the native grasses took longer to establish, and Black-eyed Susan (yellow signature in the central plot in Figure 10a) remained common longer here than in the grass-rich plots at NMT1 and 3. Similarly, the sandy soil of the fallow control at NMT2 did not facilitate the colonization by Cottonwood in contrast to the fallow controls at NMT1 and 3, where Cottonwood has become common (dark green signature in the top right and bottom right plot pictured in Figure 10a). Instead, a group of 23 "other wild-growing species" (including, most abundantly, Common Milkweed, Wild Carrot, Evening Primrose, Purple Loosestrife, Common Wood Sorrel, Wrinkle-leaved Goldenrod, Japanese Stiltgrass) covered most of the ground (72%) in the sandy fallow control at NMT2 in summer 2024 (Figure 10b, below). Since then, due to increasing Mugwort, other wild-growing species have declined in NMT2.

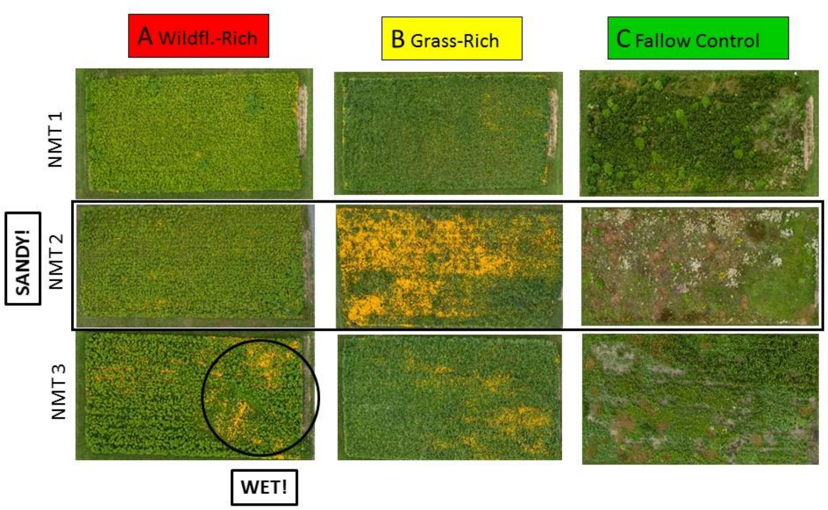

Figure 10a: Collage of drone images (taken in July 2020 by Oceans 8/Jon Bowermaster) picturing the nine experimental plots of each trial location (NMT1, NMT2, and NMT3; side by side) and of each treatment (A: wildflower-rich, B: grass-rich; and C: fallow control; below each other)

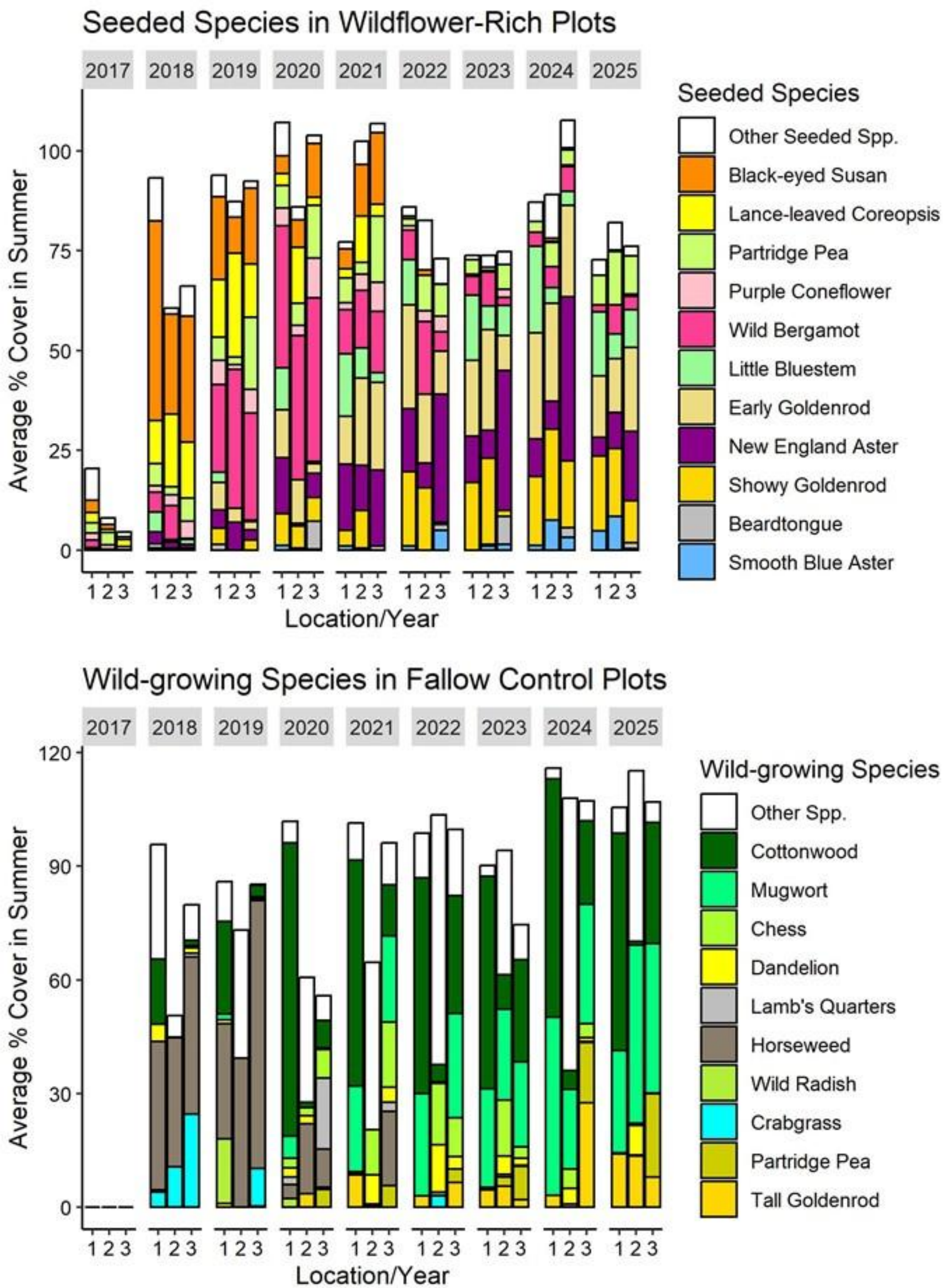

Figure 10b: Illustration of the variation in the seeded vegetation in the wildflower-rich plots (above) and in the wild-growing vegetation in the fallow control plots (below) over the years.

Within plot variation is most striking in the wildflower-rich plot at NMT3 (bottom left plot in Figure 10a), where a puddle of standing water forms after each significant rain event. The seeded plants were slower to establish in this wet spot, but then have formed a community that is somewhat distinct from that in the well-drained soil within the same plot. This is where Beardtongue persists in the highest density, but also where Cottonwood has successfully colonized.

Plant Diversity

Figure 11 shows the patterns of plant species richness in the seeded meadows and fallow control plots over time (2017-2025).

Based on the statistical analysis of the data from 2017-2024, the total number of plant species changed significantly over the years in all treatments (Figure 11; $p<0.0001$). It decreased over time in both types of seeded meadows and after eight years was qualitatively but not statistically significantly higher in the wildflower-rich meadow than in grass-rich meadows. In contrast, the plant species richness in the fallow control plots increased continuously during the first years, peaked in 2021, and seems to have stabilized since then at a slightly higher average than that in the wildflower-rich meadows. However, there is a very large variation in species numbers between the three fallow control plots. The sandy plot in NMT2 continues to have almost twice as many plant species as the fallow control plots at the other two locations.

The species richness of *seeded* plants was consistently and significantly ($p<.0001$) higher in the wildflower-rich meadows (Mix A) than in the grass-rich meadows (Mix B; $p=0.0005$) and the fallow controls ($p<0.0001$) over the first nine years. However, during that same period, the richness of *seeded* plants decreased slightly in the wildflower-rich meadows and markedly in the grass-rich meadows, while it increased in the fallow controls. The latter was due to seeded species dispersing into the non-seeded fallow controls from neighboring seeded experimental plots.

The species richness of *wild-growing native* plants showed a slight decrease from 2017-2024 in the wildflower-rich meadows ($p=0.003$) and a greater decrease in the grass-rich meadows ($p<0.0001$). There was no statistically significant difference in the average richness of wild-growing native plants between the two seeded meadow treatments 2017-2024. In contrast, wild-growing native plant richness quickly increased during the first years in the fallow controls, but hovered around an average of 20 species since 2021. Since the second year after seeding, the richness of wild-growing native plants has been significantly higher in the fallow controls than in the wildflower-rich ($p=0.0005$) and grass-rich ($p<0.0001$) meadows. This suggests that the seeding of native plants both in the wildflower-rich and grass-rich meadows did not facilitate the establishment of wild-growing native plants.

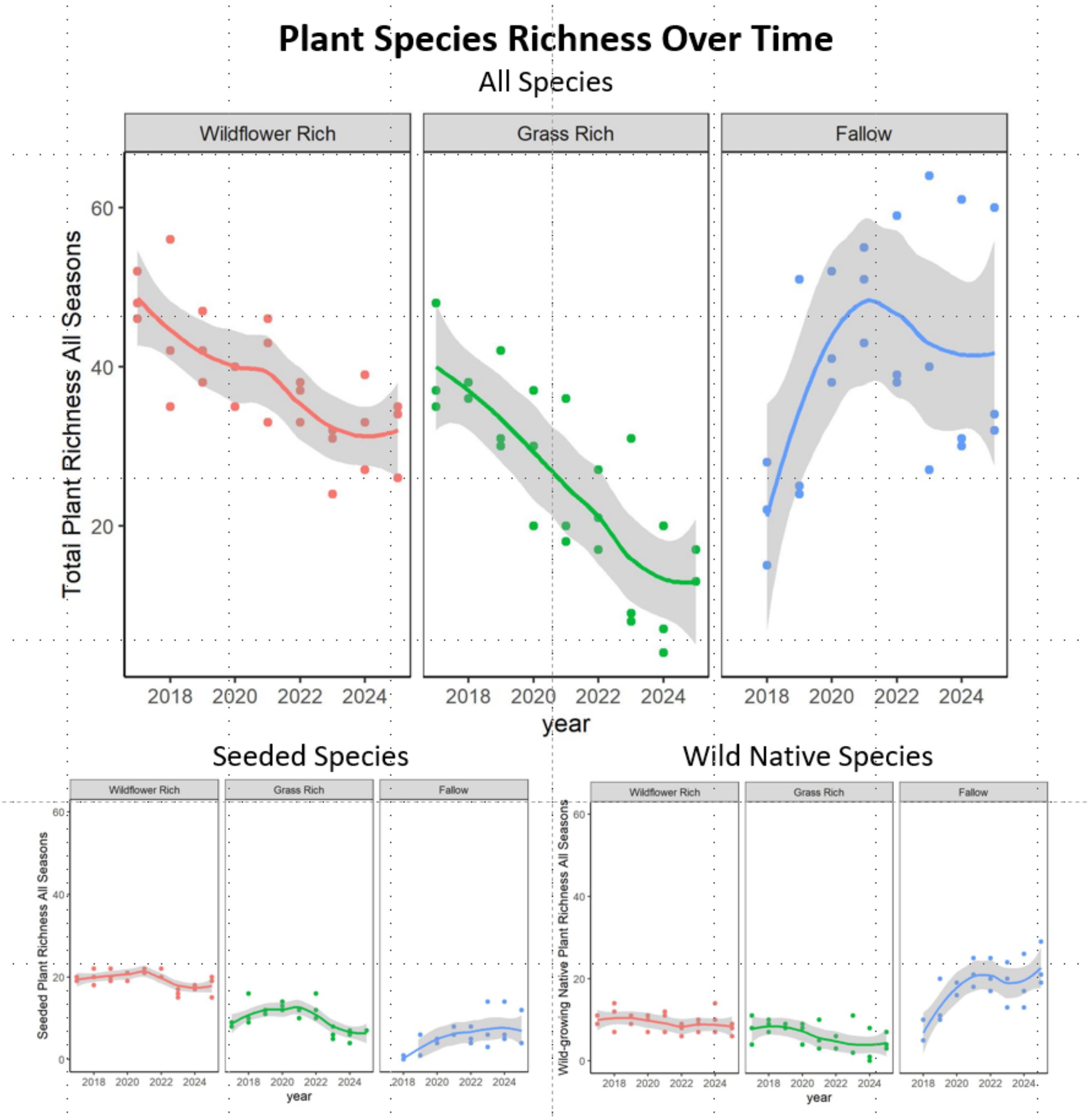

Figure 11: Plant Diversity (measured as species richness) in seeded meadows and control plots over time.

Flower Abundance and Diversity

Flower Abundance: In contrast to Figures 5 through 9 and 10b, which describe the vegetation composition based on the % cover each species contributes with all living plant material, the next set of graphs illustrates only the amount of flowers. Figures 12 and 13 show the development of average core-season (June-Sept., when most species of insects are active) flower abundance in the three treatments over the years.

Figure 12 illustrates the change over time in core-season (June-Sept.) flower abundance of the common species (which had at least 1% flower cover during one of the years) in the three treatments. Core-season flower abundance generally declined in the wildflower-rich and grass-rich meadows from a peak in 2018, which was almost exclusively due to the abundant flowers of Black-eyed Susan. Interestingly, the trend of declining flower abundance was interrupted in 2025, when flower abundance in the wildflower-rich meadows increased again. However, since 2022 the grass-rich meadows had almost no flowers anymore, because Black-eyed Susan did not persist in these meadows. The fallow control plots had comparatively few flowers throughout the first nine years (note the difference in scale of the y-axes), and their abundance also peaked in 2018 and decreased for the following three years. However--in contrast to the seeded plots--flower abundance in the fallow control plots has been increasing again from 2022-2024, followed by a slight dip in 2025.

It is important to note that these core-season flower abundances do not adequately reflect the flowers contributed by late-fall flowering species, such as New England Aster and Showy Goldenrod. Please see Figures 15.1-3 for a more detailed representation of the flower abundances of common species across the entire flowering season in some years.

Figure 13 illustrates the change over time in core-season flower abundance of the rarer species (which had up to 1% flower cover during one of the years) in the three treatments. The flower abundance of these rarer species in the grass-rich meadows peaked in 2019, and has significantly decreased since. The pattern in the wildflower-rich meadows is not as clear. The flower abundance of several of the rarer species peaked at different times during the nine years. Flowers of Ohio Spiderwort were most abundant in year eight (2024) and Partridge Pea, which had an early peak in flower abundance in 2019 and almost disappeared, suddenly had a burst of flowers again in 2025. Similarly, the flower abundance of rare species in the fallow controls shows some species that flowered in the early years and have since almost disappeared (for example, Galinsoga, Fleabane, and Wild Radish), some that have continued to flower at low densities (for example, Partridge Pea), some that peaked late (for example, Wild Carrot and Wild Bergamot in 2024), and Tall Goldenrod, which had a relatively high flower abundance in 2025. Note that, due to the dispersal of some seeded species (for example, Partridge Pea and Wild Bergamot) from neighboring plots into the control plots, their flower abundance was somewhat inflated in 2019 and from 2022-2024, when these seeded species flowered most profusely in the control plots.

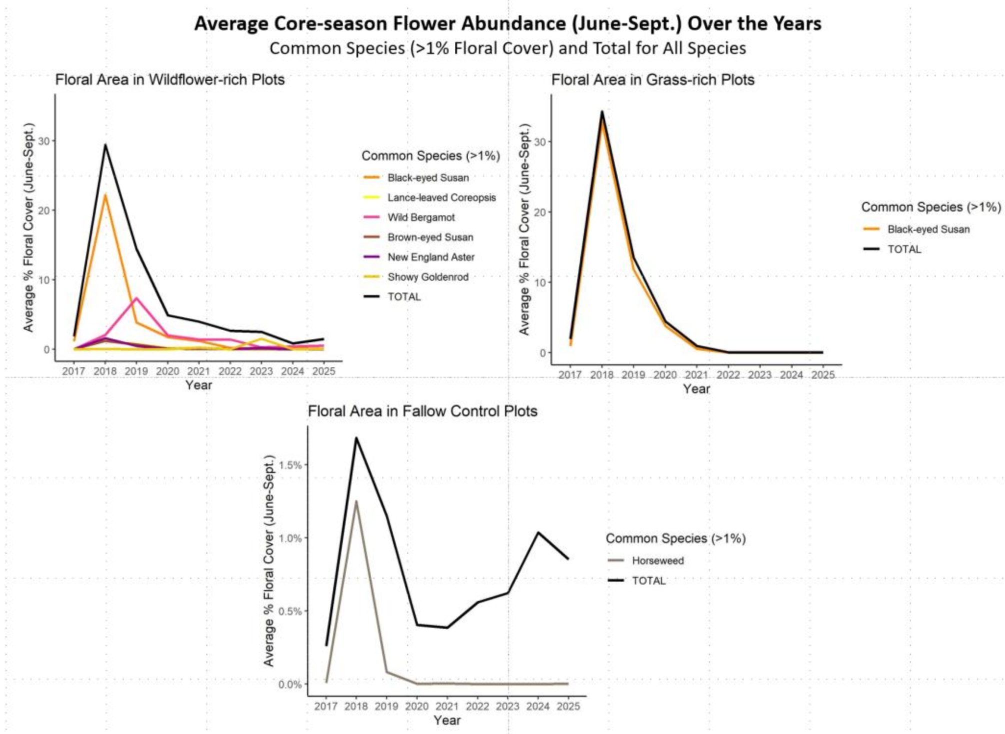

Figure 12: Average Core-season Flower Abundance (June-Sept.) of the common flower species (>1% cover at any year) and of all species over the years in the three treatments. Please note the marked difference in the scale of the y-axis between the graphs for the seeded plots and that of the fallow control plots.

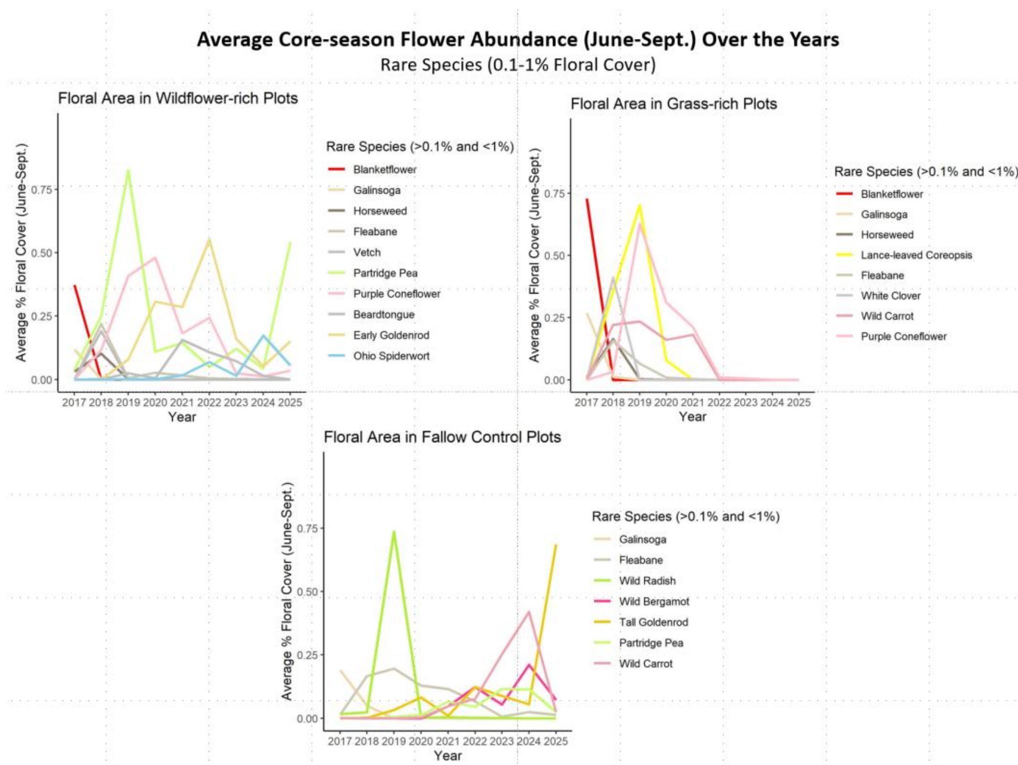

Figure 13: Average Core-season Flower Abundance (June-Sept.) of the rare flower species (<1% cover at any year) over the years in the three treatments.

Figures 14, 16, and 17 show the average total abundance of flowers (all species) across the season and years in the three treatments. Please note the variability in the scales of the y-axes in these figures.

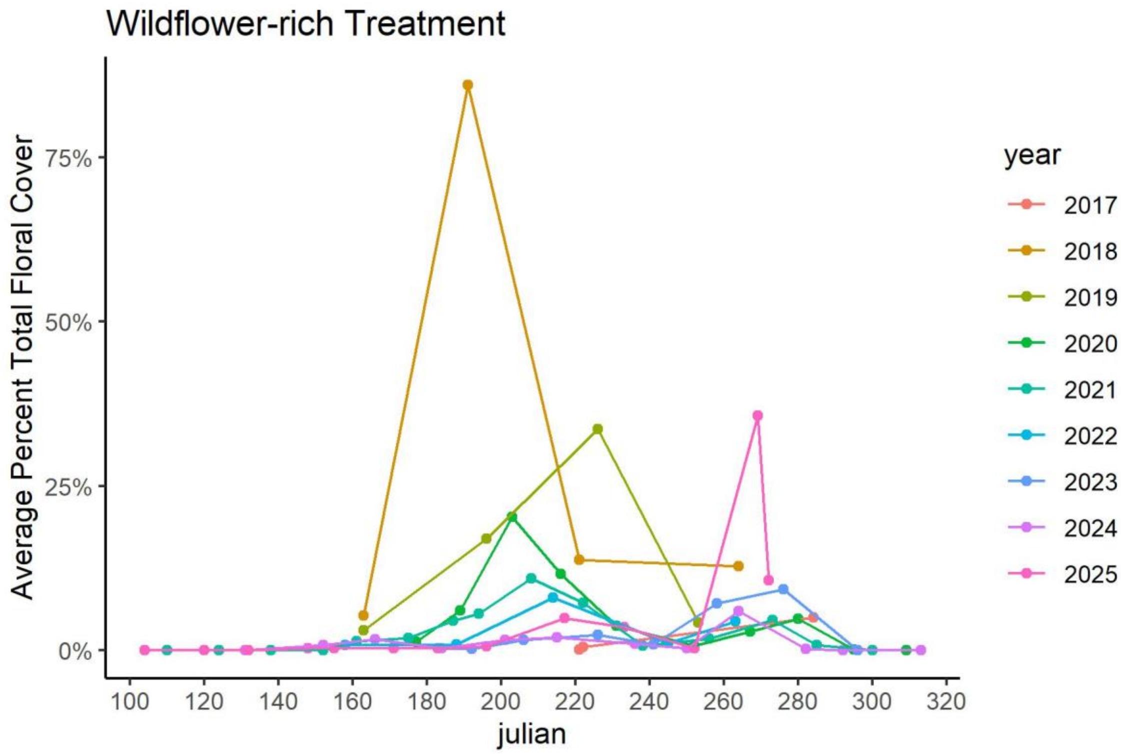

Figure 14: Comparison of Average Total Flower Abundance (sum of all species) in wildflower-rich meadows within the seasons and over the years. To help interpret the x-axis, Julian day 180 corresponds to June 19, 240 to Aug. 28, and 300 to Oct. 27.

Total flower abundance in the wildflower-rich meadows peaked at 86% floral cover during the July 10 sampling in 2018, the year after seeding (Figure 14). This early summer peak was mostly due to a profuse blooming of Black-eyed Susan and, to a much lesser extent, Lance-leaved Coreopsis. Total core-season flower abundance in the wildflower-rich meadows has decreased almost every year since then (Figure 12).

Figures 15.1-3 show total flower abundance and the abundance of the most common flower species across the seasons for each of the nine years since establishment of the wildflower-rich meadows. When interpreting these charts, be aware that the sampling frequency for the flower abundance and length of sampling season varied from year to year. There is also a difference in the scale of the y-axes across the years. Initially, flower abundance in the wildflower-rich meadows peaked in mid summer, but these mid-summer peaks (documented between July 21 and August 14 since 2019) dropped from 37% (2019) to 2% (2024) floral cover and mostly represented the flowers of Wild Bergamot and—especially in 2022—Early Goldenrod. Since then, we documented a second, smaller autumn peak mostly representing New England Aster and Showy Goldenrod. Since 2023, the highest flower abundance was observed in the autumn.

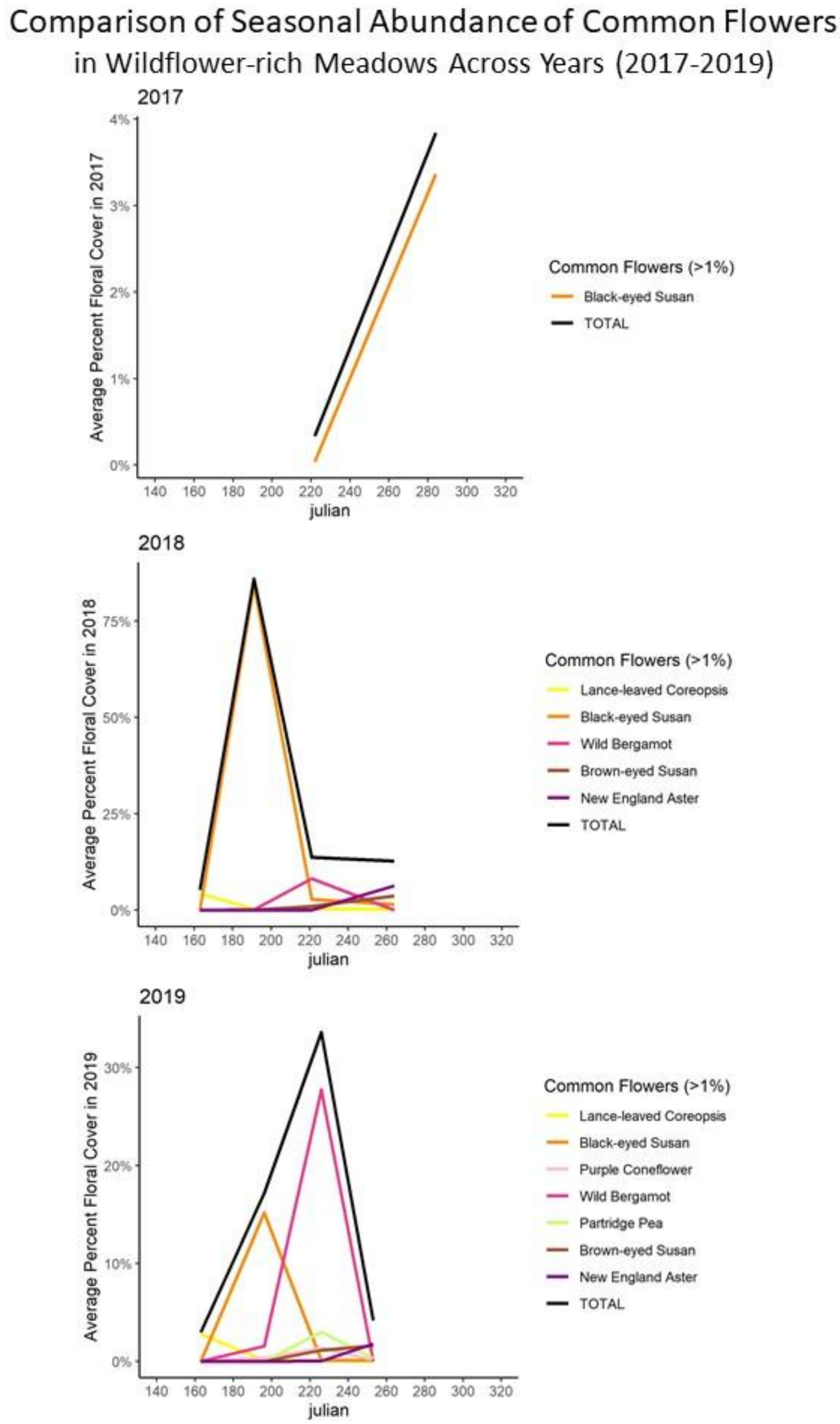

Figure 15.1: Seasonal blooming sequence for the most abundant flowers in the wildflower-rich meadows (Mix A) across the years 2017-2019. Please note that the sampling frequency and length of sampling season varied from year to year. There is also a difference in the scale of the y-axes across the years. To help interpret the x-axis, Julian day 180 corresponds to June 19, 240 to Aug. 28, and 300 to Oct. 27.

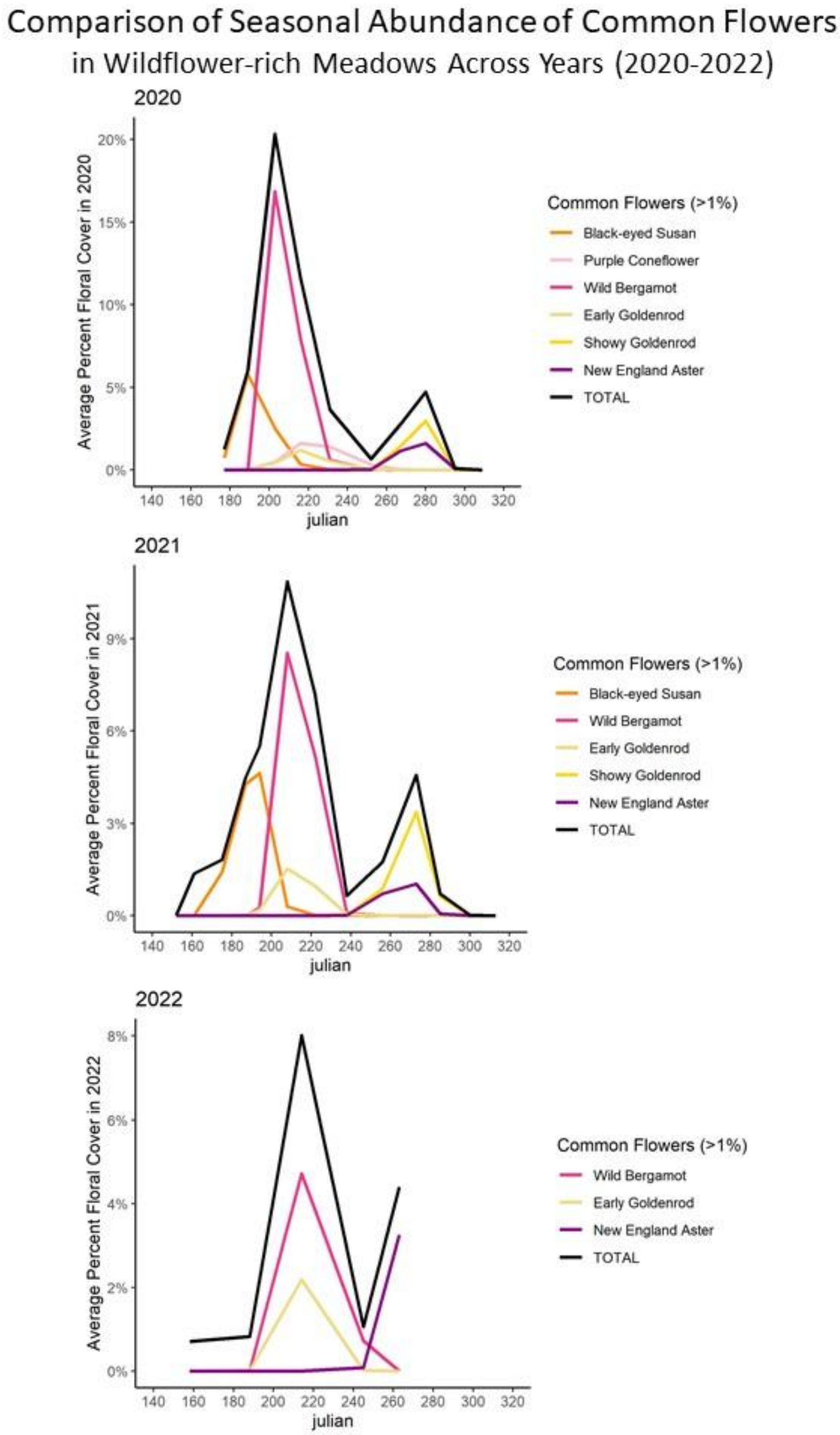

Figure 15.2: Seasonal blooming sequence for the most abundant flowers in the wildflower-rich meadows (Mix A) across the years 2020-2022. Please note that the sampling frequency and length of sampling season varied from year to year. There is also a difference in the scale of the y-axes across the years. To help interpret the x-axis, Julian day 180 corresponds to June 19, 240 to Aug. 28, and 300 to Oct. 27.

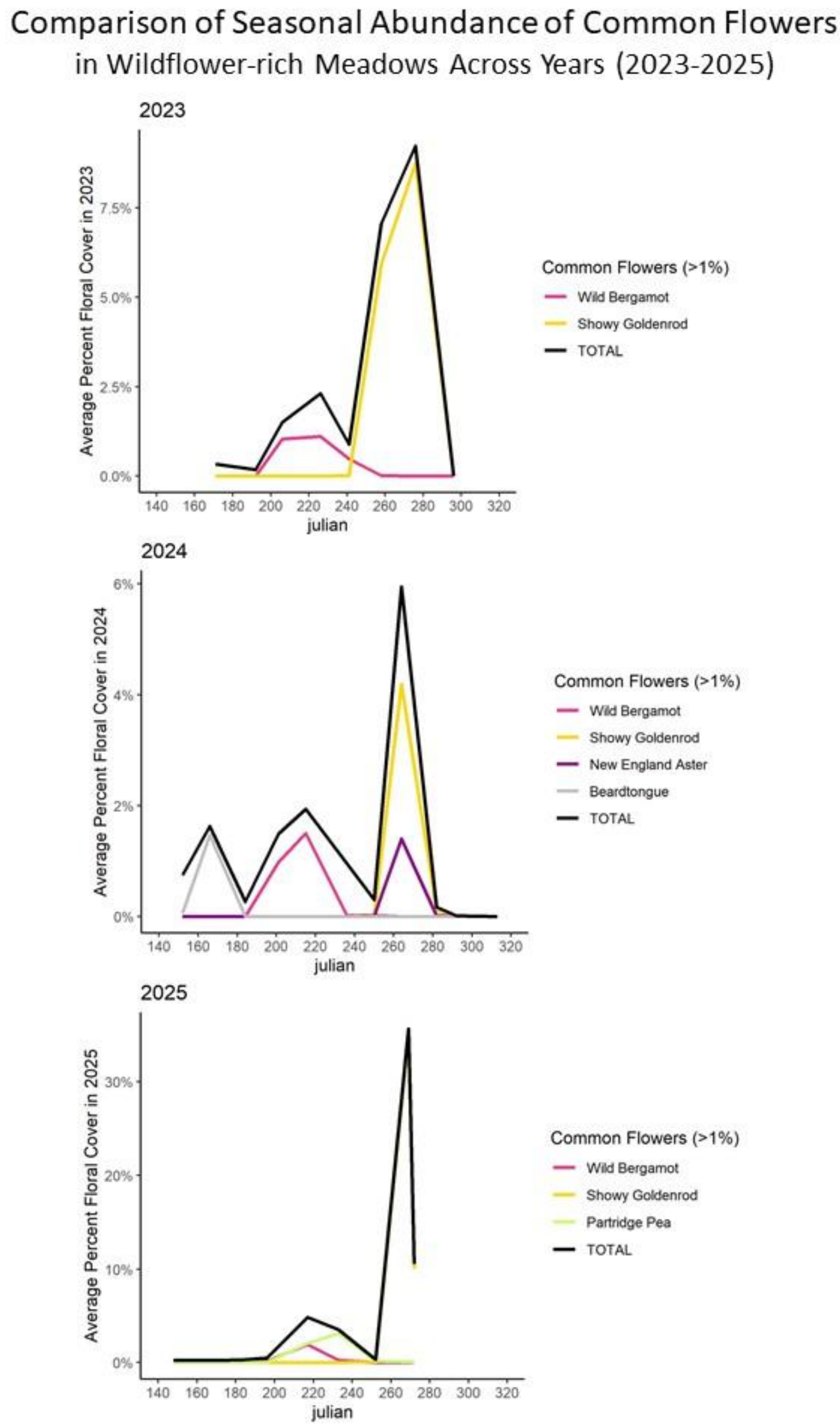

Figure 15.3: Seasonal blooming sequence for the most abundant flowers in the wildflower-rich meadows (Mix A) across the years 2023-2025. Please note that the sampling frequency and length of sampling season varied from year to year. There is also a difference in the scale of the y-axes across the years. To help interpret the x-axis, Julian day 180 corresponds to June 19, 240 to Aug. 28, and 300 to Oct. 27.

In 2023 and 2025 this peak in autumn flowers was composed almost exclusively of Showy Goldenrod, while in 2024, it was composed of both, Showy Goldenrod and New England Aster flowers. A smaller mid-summer peak, mostly composed of Wild Bergamot persisted during the last three years. Interestingly, in 2024, we documented another small, early-season peak in flower abundance composed largely of Ohio Spiderwort and Beardtongue. This early-season peak was not evident in 2025, when Partridge Pea contributed to the mid-summer peak again with an abundance of flowers not seen since 2019.

Note how the autumn peak in flower abundance in 2024 and 2025 (both years had a very dry late summer/autumn; Table 4) occurred approximately ten days earlier than during the other years when flower abundance was sampled into the autumn.

Similarly, we have observed that the timing of peak flower abundance of individual species in mid-summer can also vary by up to three weeks. For example, Wild Bergamot flower abundance peaked on July 21 (in 2020), July 27 (2021), August 2 (2022), and August 14 (in 2019). The very early peak in 2020 occurred during the dryest year in our study (Table 4), and it seemed as if the flowers just dried up and were abandoned before they would have reached their (presumably higher) peak in a wetter year.

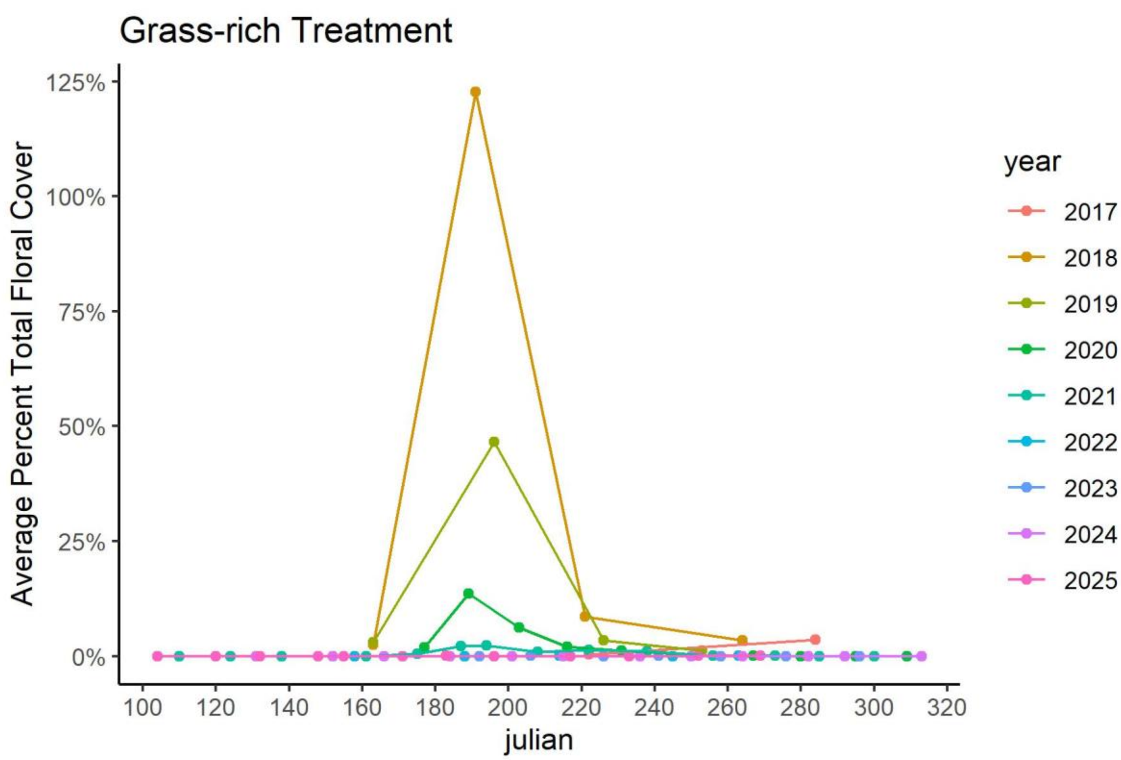

Figure 16: Comparison of Total Flower Abundance (sum of all species) in grass-rich meadows within the seasons and over the years. To help interpret the x-axis, Julian day 180 corresponds to June 19, 240 to Aug. 28, and 300 to Oct. 27.

The total flower abundance in the grass-rich meadows follows a similar pattern of maximum flower abundance the year after seeding (2018; also mostly due to profuse blooming of Black-eyed Susan) and a steady decrease since then (Figure 16). In contrast to the wildflower-rich meadows, we did not observe a spreading of flower availability across the seasons in the grass-rich meadows, due to their lack of late-season flowering species, such as goldenrods and asters.

The total flower abundance in the fallow control was significantly lower than that in the wildflower-rich seeded meadows throughout the season in all years. It surpassed the flower abundance in the grass-rich seeded meadows every year since 2022 (Figure 17; note the change in scale of the y-axis compared to Figures 14 and 16). In most years, peak flower abundance occurred in the fallow controls during the first week of August. Since 2024, a second peak was observed at the end of September, reflecting the flowers of Tall Goldenrod, a wild-growing native species which seems to be increasing in the control plots (Figure 9).

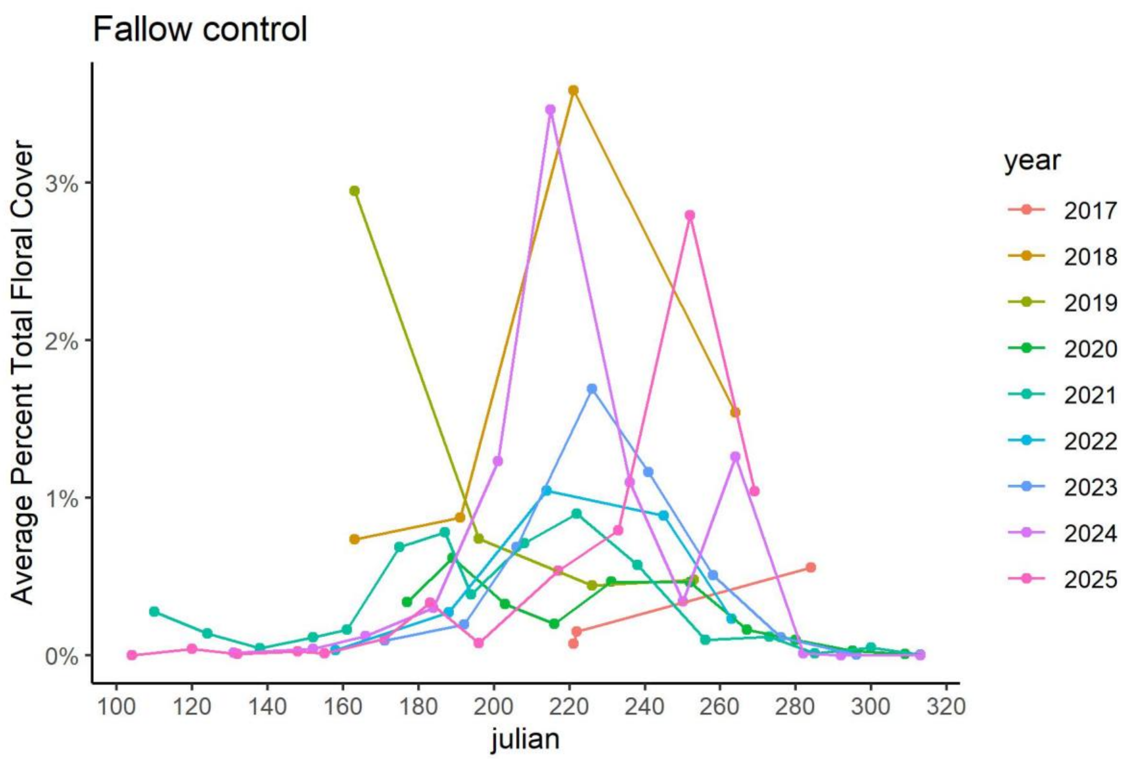

Figure 17: Comparison of Total Flower Abundance (sum of all species) in fallow control within the seasons and over the years

<u>Flower Diversity</u>: Figure 18 compares the number of insect-pollinated plant species (seeded native, wild native, and non-native) found in bloom during the core-season (June-Sept.) in each of the treatments over the years. The total number of plant species found in bloom quickly peaked in the seeded meadows (both, wildflower-rich and grass-rich) in the second year (2018).

Since then, it has decreased quickly (2018-2019) and then more gradually (2021-2025) in the wildflower-rich meadows, and quite continuously in the grass-rich meadows. In contrast, the number of plant species in bloom in the fallow control plots peaked three years later (in 2021), but has declined since then to about the same level as in the wildflower-rich meadows.

The decline in flower *diversity* in the wildflower-rich meadows since 2018 has been relatively slow compared to the rapid decline in flower *abundance* since then (Figure 12). The pattern is different in the grass-rich meadows were both the *diversity* and *abundance* of insect-pollinated flowers (Figure 12) have decreased rapidly since their peak in 2018. The *diversity* of insect-pollinated flowers in the fallow controls has briefly exceeded that in the wildflower-rich meadows in 2020 and 2021, but since then has become quite similar to that of the wildflower-rich meadows. The continuous decline of flower diversity in the fallow controls since 2021 is largely due to a decline in wild-growing native flower species. The diversity of flowers from seeded species that had dispersed into the control plots from neighboring plots, has been quite stable since 2022. As described above, flower *abundance* in the fallow controls remained below that in the wildflower-rich meadows during most years in the study period (Figures 12).

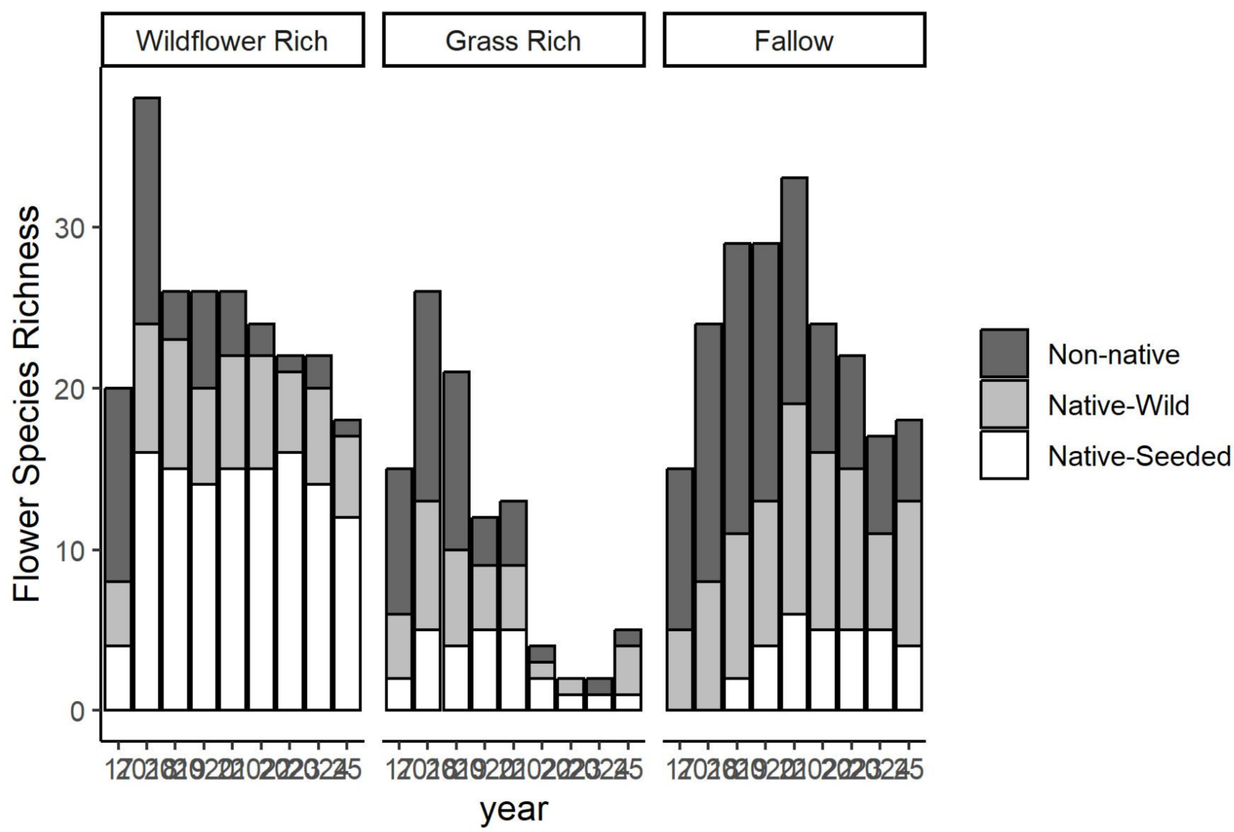

Figure 18: Comparison of Flower Diversity (Species Richness) in the three treatments over the years.

Soil Conditions

The soil samples taken in spring of 2017 (before the plots were seeded) and in spring of 2018, 2019, 2021, 2023, and 2025 were analyzed by the Cornell Soil Health Lab. As part of the Soil Health Lab report, the values for the different soil variables were scored by comparing them to a comprehensive database of agricultural soils throughout the US and beyond and—based on the average of these scores—each sample was assigned a score for overall soil health (http://www.css.cornell.edu/extension/soil-health/manual.pdf).

For the 2017 (pre-seeding) soil samples, this ranking indicated a good pH range (6.4-6.7) and high-to-excessive phosphorous values (18-32 ppm) in all experimental plots. Potassium was ranked perfect for trial areas NMT1 and NMT3 (76-106 ppm), but low for NMT2 (45-70 ppm). Organic matter (1-1.4%), active soil carbon (153-251 ppm) soil protein (2.8-3.7 mg/g dry weight), subsurface hardness (429-563 psi) and even surface hardness (190-283 psi) were ranked low in all trial areas. Aggregate stability (3.5-8 %) also ranked very low overall, only experimental plot NMT2A ranked slightly better (17%). Soil respiration ranked overall low (0.31-0.42 mg CO_2/g dry weight) Root pathology was very variable across the experimental plots. Water holding capacity was ranked high in trial areas NMT1 and 3 (0.21-0.28 g/g) but only intermediate in NMT2 (0.12-0.18 g/g).

During the first nine years of the trial (2017-2025), the overall soil health score generally increased significantly over time (ANOVA; $p<0.0001$; Figure 19), but there was no statistically significant difference in soil health between the treatments (wildflower-rich meadow, grass-rich meadow, or fallow control) or trial areas. That said, the soil health score did decrease in seven of the nine plots between 2023 and 2025. Time will tell, whether this was part of the year-to-

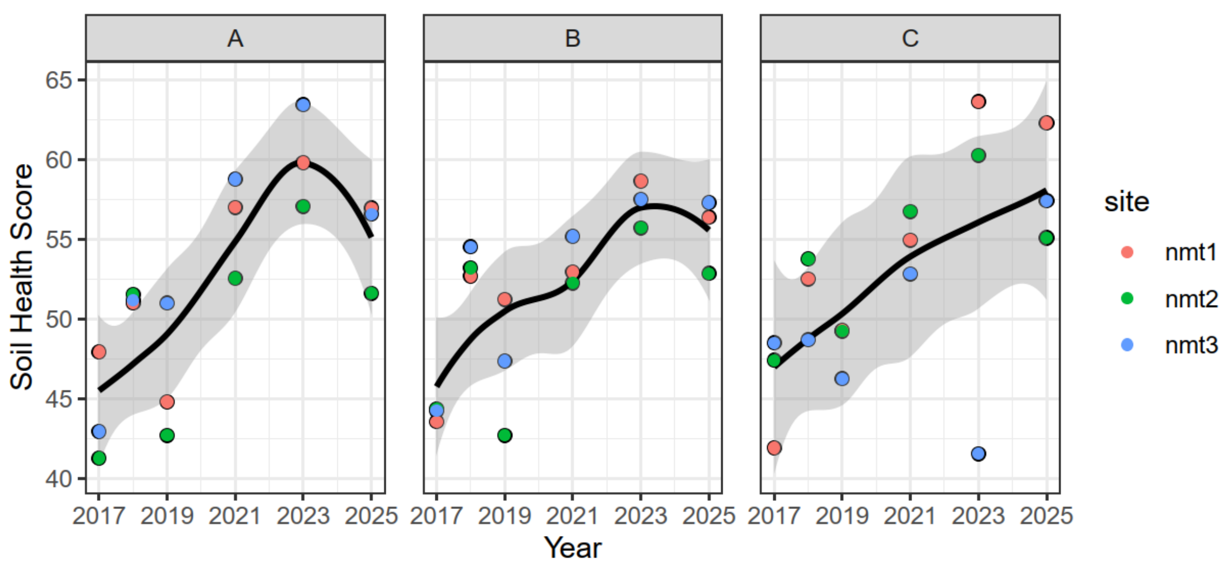

Figure 19: Overall Soil Health Scores by treatment (A=wildflower-rich, B=grass-rich, C=control) and site over the first nine years of the trial.

year variability (note how the soil health score was also low across all samples in 2019) and the trend towards higher soil health scores continues in the future, or whether the soil health in the trial areas is approaching its "ceiling."

Because many of the soil variables are strongly correlated with each other, the data were subjected to principal component analysis (PCA) to obtain composite variables. Figure 20 shows a biplot of the first two principal components PC1 and PC2, which together account for 56% of the variation in the soil variables. The plot illustrates that % sand is inversely related to pH, water-holding capacity, organic matter, soil respiration, and active carbon. Aggregate stability is inversely related to the concentrations of Zn, Mn, P, and Fe.

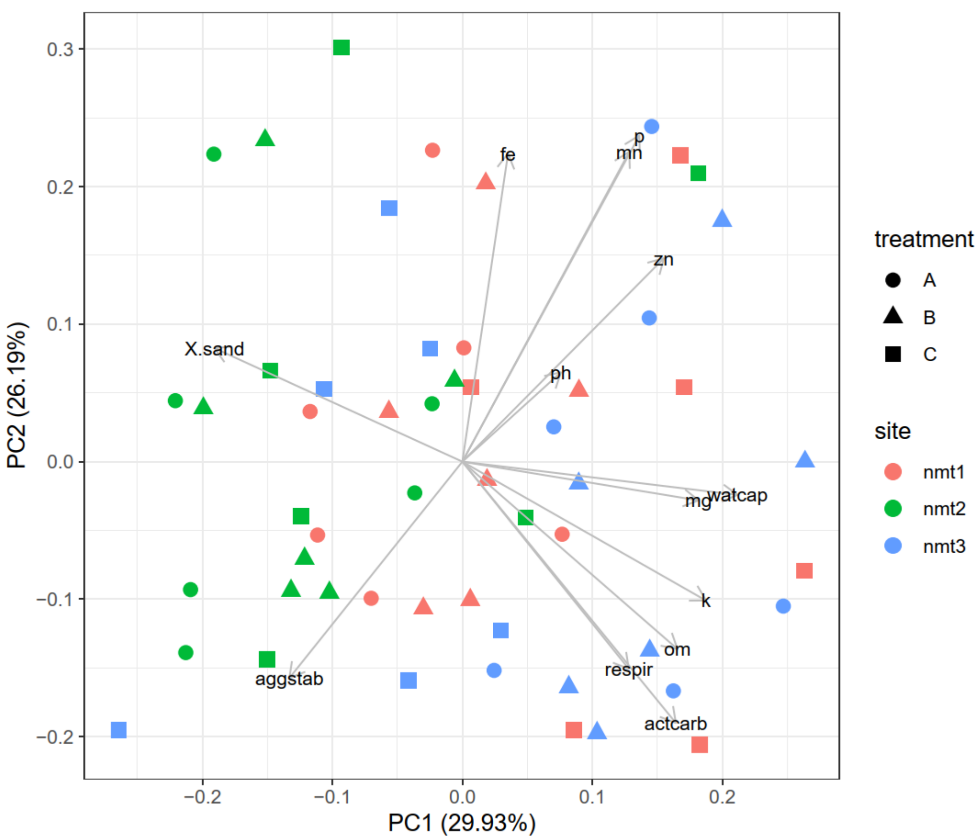

Figure 20: Principal components biplot showing the direction of loadings for individual soil variables

PC1 and PC2 showed no statistically significant difference between treatments (ANOVA). However, PC1 and PC2 were significantly different between trial locations (ANOVA; ($p<0.001$) and $p<0.05$, respectively). While PC1 did not significantly change with time, PC2 did show a significant decrease over time ($p<0.0001$; Figure 21). This suggests an increase over time of aggregate stability, water-holding capacity, organic matter, soil respiration, active carbon, and the concentrations of Mg and K (all of which load negatively on PC2) and a decrease in pH, Fe, P, Mn, Zn, and percent sand (all of which load positively on PC2).

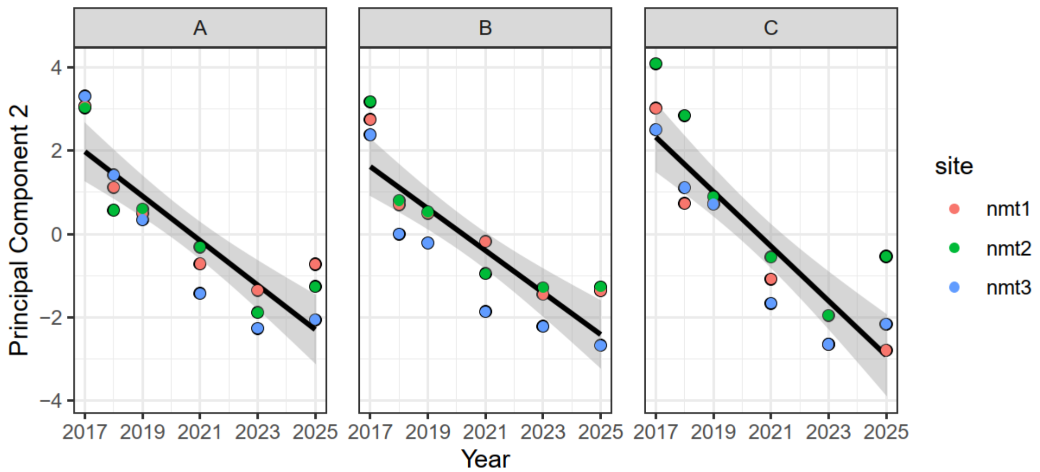

Figure 21: Principal component 2 scores by treatment (A=wildflower-rich, B=grass-rich, C=control) and site over the first nine years of the trial.

Rooting Depth—A preliminary exploration

Table 3 shows the approximate rooting depth of plants (one or two individuals of each species) dug up from the NMT2 trial area on July 3, 2024, eight years after seeding.

Table 3: Rooting depth of some species in the native meadow trial

		Root Depth
Cottonwood	*Populus tremuloides*	>> 14"
Big Bluestem	*Andropogon gerardi*	12"
Indian Grass	*Sorghastrum nutans*	12"
Little Bluestem	*Schizachyrium scoparium*	6"
Round-headed Bush-clover	*Lespedeza capitata*	10"
Early Goldenrod	*Solidago juncea*	8"
Showy Goldenrod	*Solidago speciosa*	5"
Brown-eyed Susan	*Rudbeckia triloba*	4"
Wild Bergamot	*Monarda fistulosa*	4"
Partridge Pea	*Chamaecrista fasciculata*	4"

The wild-growing Cottonwood plants had established the deepest roots. The roots of the tall native grasses reached to about 12” depth, while those of Little Bluestem remained relatively shallow. Of the seeded wildflowers, Round-headed Bush-clover had the deepest roots.

Weather

Table 4 summarizes the mean annual temperature and total rainfall during the years of the native meadow trial at the Hudson Valley Farm Hub.

Table 4: Summary of weather data at the Hudson Valley Farm Hub during the years of the native meadow trial.

Year	Avg. Temp. (^oF)	Total Rainfall (inches)	Comment
2018	50.3	63.72	late spring, very wet overall (dry spell in May)
2019	49.6	44.34	overall dry, with wet May/June
2020	51.5	40.4	early spring, overall very dry
2021	51.5	49.5	overall average, some very dry (April, June) and very wet (May, July, August) months
2022*	50.3	47.3	rain just below average, but May-August were quite dry
2023*	52.5	61.69	very mild winter, but growing season temperatures not particularly high; quite wet April-Sept., with a dry spell in May
2024*	52.7	49.75	drought in late summer and autumn
2025*	50.9	53.35	very wet May and very dry August
* some data for these years had to be estimated from nearby stations due to equipment problems			

The second year of the trial was very wet, which probably contributed to the good establishment of the seeded plants in that year. 2020 was a hot and dry summer, which might have somewhat impacted the flower abundance and timing, with Black-eyed Susan flower abundance peaking two weeks earlier in 2020 than in 2019 and 2021, and Wild Bergamot peaking three weeks earlier in 2020 than in 2019, and one week earlier than in 2021.

Labor and Equipment

Starting with the site preparation in early Spring 2017, Table 5 lists the management actions taken to date in the seeded native meadows in chronological order, specifies the equipment used, and the time spent (in person-hours per acre). This excludes any weeding of seeded plants that had spread into the control plots (which was done for our research, but would not be a management action required by a farmer maintaining seeded meadows).

Figure 22 illustrates the total amount of labor (person hours per acre) applied to the establishment and maintenance of the seeded native meadows over the years. The establishment of a native meadows required most labor in the first (site preparation, seeding, repeated mowing of annual weeds germinating from the seed bank) and second year (selective weeding/weed-whacking of non-native perennial plants which, if left unchecked, could have outcompeted the seeded native plants). In the third year, we chose to take a relatively relaxed approach to weeding/weed-whacking of non-native perennial plants, because the seeded

Table 5: List of Management Activities in the Native Meadow Trials; the labor calculation only applies to the seeded experimental plots, excluding any additional weeding in the control plots (which was only done for experimental purposes).

Labor over time in **SEEDED PLOTS** only!				
Year	**Timing**	**Action**	**Labor (person hrs/acre)**	**Equipment** (species targeted)
2017	April to mid May	1st Harrowing	0.5	Perfecta II Harrow with S-tines equipped
	April to mid May	2nd Harrowing	0.5	Perfecta II Harrow with S-tines equipped
	April to mid May	3rd Harrowing	0.5	Perfecta II Harrow with S-tines equipped
	May 19	Seeding	5.0	Great Plains No Till Seeder
	May 25	Seeding	1.0	by hand
	July 6-10	Mowing	1.3	Flail Mower
	July 26-28	Mowing	1.3	Flail Mower
	Aug. 15/16	Mowing	0.7	Rotary Mower
2018	late May to mid Jun	Selective Weeding/ Mowing	9.0	String Trimmer; by hand (Red Clover, Hairy Vetch, Wild Carrot, *Rumex* sp.)
2019	May	Selective Weeding/ Cutting	1.0	by hand; Clippers; String Trimmer (Cottonwood)
	Aug/Sept.	Selective Weeding/ Cutting	1.9	by hand; Clippers (Mugwort)
2020	March 2	Mowing	0.7	Rotary Mower
	June-Sept	Selective Weeding/ Cutting	6.8	by hand; Clippers, Loppers, String Trimmer (Mugwort)
2021	March 26	Mowing	0.7	Rotary Mower
2022	March 23	Mowing	0.7	Rotary Mower
2023	March 27	Mowing	0.7	Rotary Mower
2024	March 15-22	Mowing	2.0	Flail Mower (needed to cut the Cottonwood stems)
2025	April 1	Mowing	1.8	Flail Mower (needed to cut the Cottonwood stems)

plants seemed to have gotten established well. By the fourth year, it became obvious that Mugwort was spreading in the seeded meadows and we applied some labor to try to control its spread. However, given the fact that this trial is meant to demonstrate what farmers can expect seeded wildflower meadows on former farm fields to look like when managed at an intensity that is realistic for a farmer, we did not attempt to completely eradicate the Mugwort. Since the fifth year, we have not done any weeding in the seeded plots.

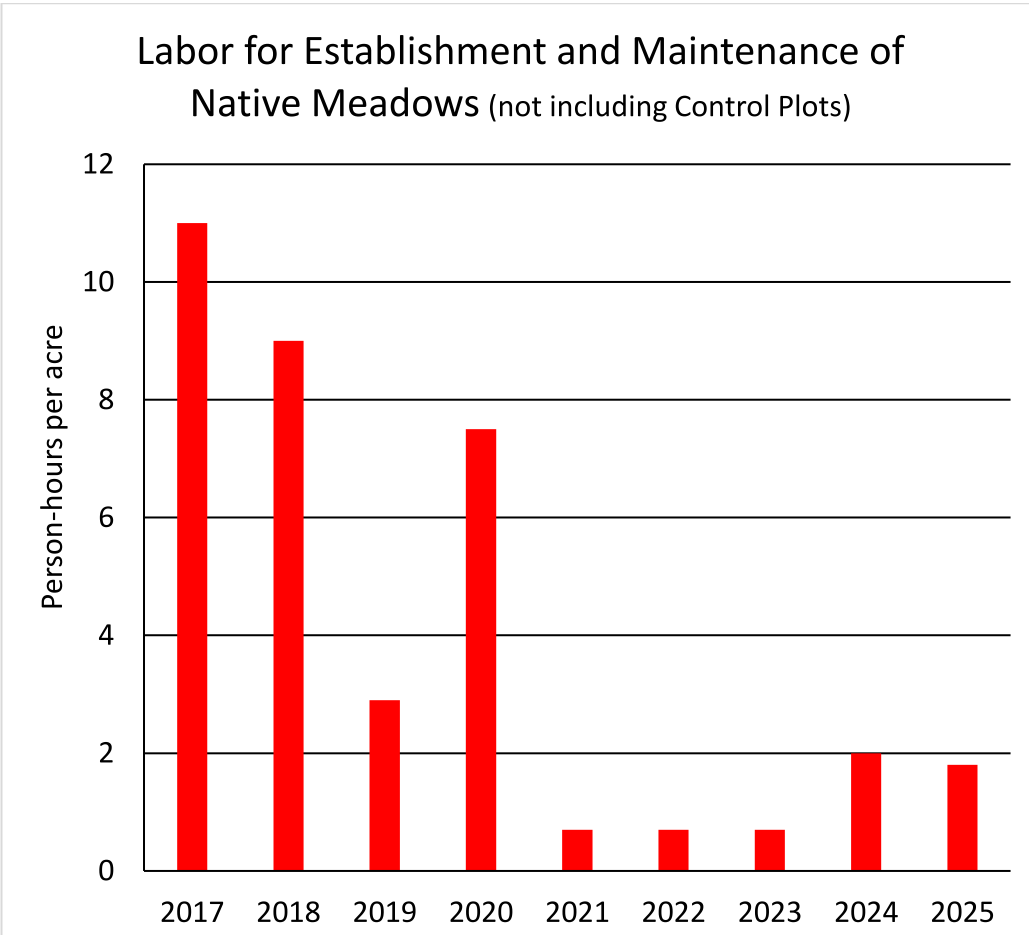

Figure 22: A summary of the labor applied to the establishment and maintenance of the seeded native meadows during the first nine years.

CONCLUSIONS

We successfully established two types of native meadows (plus a fallow field control) in three 1.5-acre trial areas on former corn fields at the Hudson Valley Farm Hub. This was accomplished without the use of herbicides, but required repeated shallow harrowing to prepare a weed-free seed bed. After the initial effort of 11 person-hours per acre for soil preparation, seeding, and mowing in the first year, the maintenance effort for the seeded meadows until the fourth year ranged from 3 to 9 person-hours per acre per year. Since the fifth year, when we discontinued selective weeding, the seeded meadows have required very little maintenance, which took the form of an annual early spring mowing.

By the ninth year of the trial, the wildflower-rich meadows maintain a reasonable diversity of native plants and have not been overrun by invasive species, in spite of minimal management since the fifth year. Flower abundance has declined markedly over the years, but seems to be stabilizing at a level that might be sustainable in the long-term. The early-summer flower burst in 2018 caused by an abundance of short-lived Black-eyed Susan, while pleasing to our eyes, was clearly a transitory state of the seeded meadow as it developed into a more mature and diverse plant community. The biggest challenge in maintaining these wildflower-rich meadows are the Cottonwood trees that have seeded into them from the nearby floodplain forest. Annual early spring mowing with a flail mower effectively keeps them in a coppiced stage, but—every year—by the end of the season, the Cottonwood plants have grown to eight feet height, again (see Appendix 1.5-9).

The grass-rich meadows, originally seeded with eight native grasses and six native wildflowers, have become dominated by two native grasses: Switchgrass and Big Bluestem, which form a very dense and tall (seven feet high) vegetation by the end of the season. Overwintering birds feed on the grass seeds and seek shelter in these meadows, but during the growing season, we have not observed much bird activity in them. They also don't provide any resources for flower-visiting insects.

The control plots developed along very different trajectories. Two of them quickly became dominated by Cottonwood and Mugwort (see control plot at NMT3, Fig. 9b), while the one on the sandiest soil maintains a diverse plant community (see control plot at NMT2, Fig. 9a).

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