

Native Meadow Trial at the Hudson Valley Farm Hub

Botany Report for the First Five Seasons: 2017-2021

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Contents

SUMMARY	3
INTRODUCTION & OBJECTIVE OF TRIAL	5
METHODS	6
<i>Experimental Design</i>	<i>6</i>
<i>Soil Types</i>	<i>6</i>
<i>Crop History</i>	<i>6</i>
<i>Site Preparation</i>	<i>7</i>
<i>Seed Mixes and Seeding</i>	<i>7</i>
<i>Management</i>	<i>11</i>
<i>Monitoring Methods</i>	<i>12</i>
MONITORING RESULTS AND DISCUSSION	13
<i>Vegetation Development</i>	<i>13</i>
Vegetation Development in Wildflower-rich Experimental Plots (Seed Mix A)	13
Vegetation Development in Grass-rich Experimental Plots (Seed Mix B)	15
Vegetation Development in Control Plots	17
Variation in Vegetation Between Trial Plots	19
Plant Diversity	20
Evaluation of Plant Species Performance	21
Flower Abundance and Diversity	23
<i>Invertebrate Monitoring</i>	<i>27</i>
<i>Soil Conditions</i>	<i>28</i>
<i>Weather</i>	<i>29</i>
<i>Labor and Equipment</i>	<i>29</i>
CONCLUSIONS	31
ACKNOWLEDGEMENTS	32
REFERENCES	32

SUMMARY

In 2017, a 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 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 of meadows derived from two different seed mixes and spontaneously establishing themselves in fallow fields
- assess the value of these seed mixes for supporting insect biodiversity and beneficial invertebrates.

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 1 and 9 person-hours per acre and year (mowing and weeding) since then.

By the third year, native plants covered on average more than 80% of the seeded plots (Figures 4 & 6). While all but one seeded species did establish at least some seedlings during the first two years, the following seeded species were most successful: Black-eyed Susan and Lance-leaved Coreopsis (Seed Mix A & B), Wild Bergamot, Early Goldenrod, New England Aster, and Little Bluestem (Seed Mix A) and Big Bluestem, Indiangrass, Canada Wild Rye, and Switchgrass (Seed Mix B). While these common species dominated the vegetation in the seeded meadows since the second year, their relative proportions evolved and seem to continue to evolve (Figures 5 & 7).

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 mostly in the wildflower-rich meadows (Mix A) and fallow controls (Figure 9).

The diversity of *all* plants and that of *native* plants was on average significantly higher in the wildflower-rich meadows (Mix A) than in the grass-rich meadows (Mix B) or the fallow control). The diversity of *all* plants in seeded meadows (wildflower-rich and grass-rich) seemed to decrease over time, but this decrease was not considered statistically significant. The diversity of *native* plants remained more or less constant in the seeded meadows over time. The diversity of *all* plants and of *native* plants increased significantly over time in the fallow control (Figure 11).

Total flower abundance peaked in 2018 in both the wildflower-rich and grass-rich meadows and has declined every year since (Figures 14 & 16). However, with maturation of the wildflower-rich meadows, their flower availability became more evenly spread across the seasons (Figure 15). Flower abundance in the fallow control plots remained consistently below that of the seeded meadows during the first five years (Figure 17).

The number of plant species found in bloom increased markedly in the seeded meadows (both, wildflower-rich and grass-rich) from the first to the second year of seeding, but seemed to have plateaued since. In contrast, the number of plant species in bloom in the fallow control plots has been increasing steadily from year to year (Figure 18).

We plan to continue the monitoring of the vegetation composition, flower abundance, and insect communities, as well as any management action, in the native meadows for at least another five years and to maintain them as a well-documented demonstration sites of seeded native meadows in the mid Hudson Valley. This will also allow us to assess the “longevity” of such meadows. Few studies have followed the long-term ecology of wildflower meadows in the Northeast.

INTRODUCTION & OBJECTIVE OF TRIAL

The Hudson Valley Farm Hub is a non-profit, organic farm located on 1,500 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 corn fields that had 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 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?
- Which 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?
- How do soil conditions evolve in the native meadow trial plots compared to neighboring hayfields and tilled soil?

The native meadow trial plots are intended to serve as well-documented demonstration areas and inspiration for other farmers. 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.

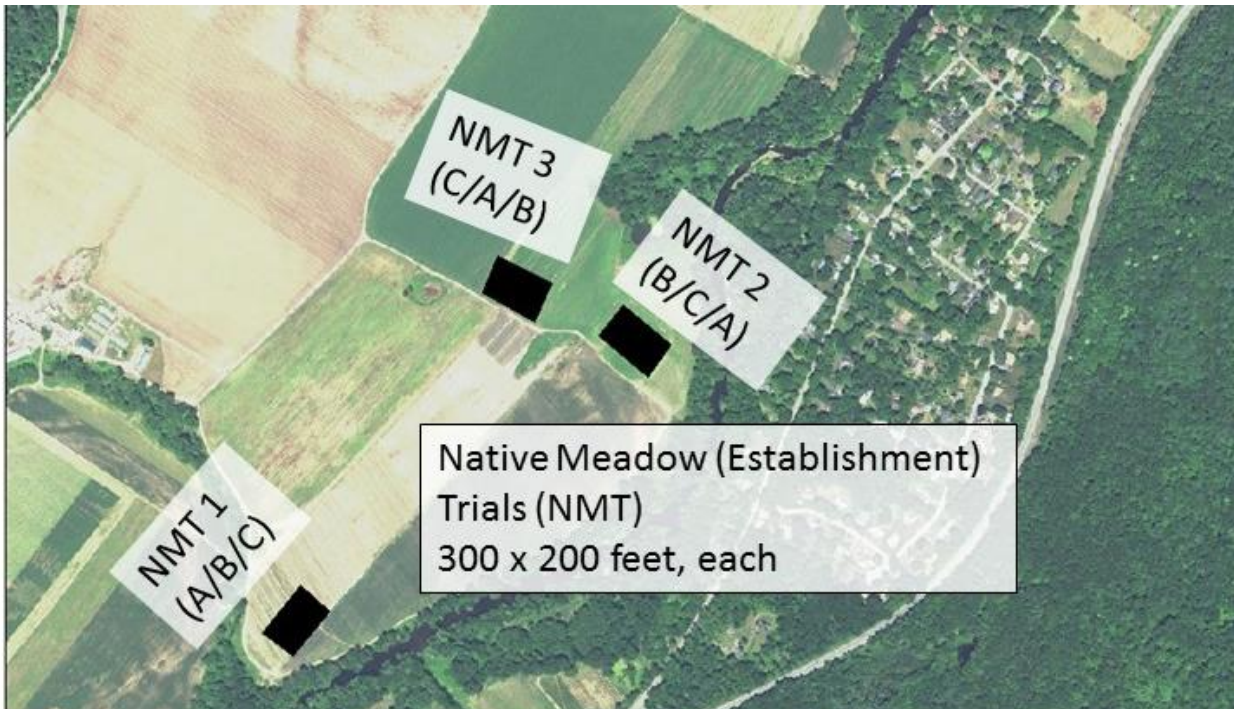


Figure 1: Map of Native Meadow Trial Areas at the Hudson Valley Farm Hub

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) is 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 3 and Figure 3) has a variety of native bunch grasses, but also contains 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. For comparative purposes, these were cut and weeded on the same schedule as the seeded trial areas.

Table 1: Species list for Seed Mix A, which is rich in wild flowers. 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/ft ²)	Final Mix Total pounds (lb) for 1.5 acres	Supplier
Blackeyed Susan	<i>Rudbeckia hirta</i>	6.5%	0.19	Ernst Seeds
Browneyed Susan	<i>Rudbeckia triloba</i>	2.2%	0.18	Ernst Seeds
Butterfly Milkweed	<i>Asclepias tuberosa</i>	1.1%	0.73	Ernst Seeds
Common Milkweed	<i>Asclepias syriaca</i>	1.1%	0.73	Ernst Seeds
Dense Blazingstar	<i>Liatris spicata</i>	1.1%	0.51	Ernst Seeds
Early Goldenrod	<i>Solidago juncea</i>	3.2%	0.06	Ernst Seeds
Joe Pye Weed	<i>Eupatorium purpureum</i>	1.0%	0.07	Prairie Moon
Lance Leaved Coreopsis	<i>Coreopsis lanceolata</i>	8.6%	1.84	Ernst Seeds
Lavender Hyssop	<i>Agastache foeniculum</i>	8.6%	0.27	Ernst Seeds
Little Bluestem	<i>Schizachyrium scoparium</i>	19.4%	4.59	Ernst Seeds
Mistflower	<i>Eupatorium coelestinum</i>	6.5%	0.20	Ernst Seeds
Narrowleaf Mountainmint	<i>Pycnanthemum tenuifolium</i>	3.8%	0.03	Prairie Moon
New England Aster	<i>Aster novae-angliae</i>	2.1%	0.09	Ernst Seeds
Ohio Spiderwort	<i>Tradescantia ohiensis</i>	2.2%	0.81	Prairie Nursery
Partridge Pea	<i>Chamaecrista fasciculata</i>	2.2%	1.57	Ernst Seeds
Purple Coneflower	<i>Echinacea purpurea</i>	4.3%	1.76	Ernst Seeds
Purple Prairie Clover	<i>Dalea purpurea</i>	2.2%	1.27	Ernst Seeds
Roundhead Lespedeza	<i>Lespedeza capitata</i>	1.1%	0.19	Prairie Moon
Showy Goldenrod	<i>Solidago speciosa</i>	2.3%	0.08	Ernst Seeds
Slender Lespedeza (added)	<i>Lespedeza virginiana</i>	2.1%	1.27	Ernst Seeds
Smooth Blue Aster	<i>Aster laevis</i>	2.1%	0.10	Ernst Seeds
Tall White Beardtongue	<i>Penstemon digitalis</i>	9.7%	0.25	Pinelands Nursery
Wild Bergamot	<i>Monarda fistulosa</i>	6.7%	0.25	Pinelands Nursery
	TOTALS:	100.0%	17.04 lbs	

Table 2: Species list of Seed Mix B, which is rich in grasses; 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	<i>Agrostis perennans</i>	15.0%	0.09	Ernst Seeds
Big Bluestem	<i>Andropogon gerardii</i>	6.4%	2.12	Ernst Seeds
Blackeyed Susan	<i>Rudbeckia hirta</i>	6.3%	0.19	Ernst Seeds
Canada Wildrye	<i>Elymus canadensis</i>	10.7%	4.47	Ernst Seeds
Indiangrass	<i>Sorghastrum nutans</i>	6.7%	1.82	Ernst Seeds
Lance Leaved Coreopsis	<i>Coreopsis lanceolata</i>	3.2%	0.69	Ernst Seeds
Little Bluestem	<i>Schizachyrium scoparium</i>	16.0%	3.82	Ernst Seeds
Partridge Pea	<i>Chamaecrista fasciculata</i>	1.1%	0.78	Ernst Seeds
Purple Coneflower	<i>Echinacea purpurea</i>	5.3%	2.20	Ernst Seeds
Purple Lovegrass	<i>Eragrostis spectabilis</i>	1.3%	0.06	Prairie Moon
Purple Prairie Clover	<i>Dalea purpurea</i>	2.1%	1.27	Ernst Seeds
Purpletop	<i>Tridens flavus</i>	16.4%	1.69	Ernst Seeds
Slender Lespedeza	<i>Lespedeza virginiana</i>	1.1%	0.65	Ernst Seeds
Switchgrass	<i>Panicum virgatum</i>	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 Wildrye, Indiangrass; second row: Lance-leaved Coreopsis, Little Bluestem, Partridge Pea, Purple Coneflower, Purple Lovegrass; third row: Purple Prairie Clover, Purpletop, Slender Lespedeza, Switchgrass).

Management

The meadows were established and managed with techniques and a level of effort realistic for a farm context. 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, but we consciously decided against it, because then the trial would not have served its purpose as a 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 necessary 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 was left standing into the winter.

Second Season (2018): By Spring of the second year, the native perennials had established dense stands and were not threatened by competition for light by early-season annual weeds any more. 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 19 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.

Fourth Season (2020): 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.

Fifth Season (2021): 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.

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 2017-2021. In addition, drone image were taken monthly July-Oct. in 2020 and June-Sept. in 2021.

Quantitative Vegetation Inventories: Twice a year (July & September/early October), we documented the vegetation in ten evenly-spaced samples along two transects in each of the nine experimental plots. In ten square-shaped samples of one square foot, we recorded the percent cover and maximum height of each plant species present. 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 mm²). 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) and four times in 2018 (June 12, July 10, Aug. 9, Sept. 21) and 2019 (June 12, July 15, Aug. 14, Sept. 10) to represent the duration of the flowering period. In 2020 and 2021, we documented the flower abundance in approximately two week intervals from May/June to the beginning of November to capture its variation on a finer time scale and for a longer period than in prior years.

Invertebrate Monitoring

We documented the presence and abundance of invertebrates in the experimental plots three times in 2017 (May, Aug., Oct.) and four times in 2018-2021 (in June, July, Aug., and Sept.). In each of the nine plots, insects were sampled over a 24-hour period with a variety of traps. For a detailed description of the insect monitoring methods, please see Vispo et al. (2020). In addition to the general insect monitoring, flower-visiting insects were documented in the nine experimental plots every two weeks from June through September 2018 with standardized visual surveys conducted by Erin Allen as part of her graduate work at SUNY Albany (Allen 2019).

Soil Conditions

Three composite soil samples (composed of 10 samples each) were taken from each of the nine experimental plots annually in the spring (May 2, 2017; May 7, 2018; May 22, 2019; June 1, 2021) and analyzed at the Cornell Soil Health Lab for their chemical, physical, and biological characteristics. Due to Covid-19, no soil samples were taken in 2020.

Weather

The Hudson Valley Farm Hub has a weather station that has been in operation since July 2017 and can be accessed remotely at <https://www.rainwise.net/weather/FarmHub>.

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 5 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.

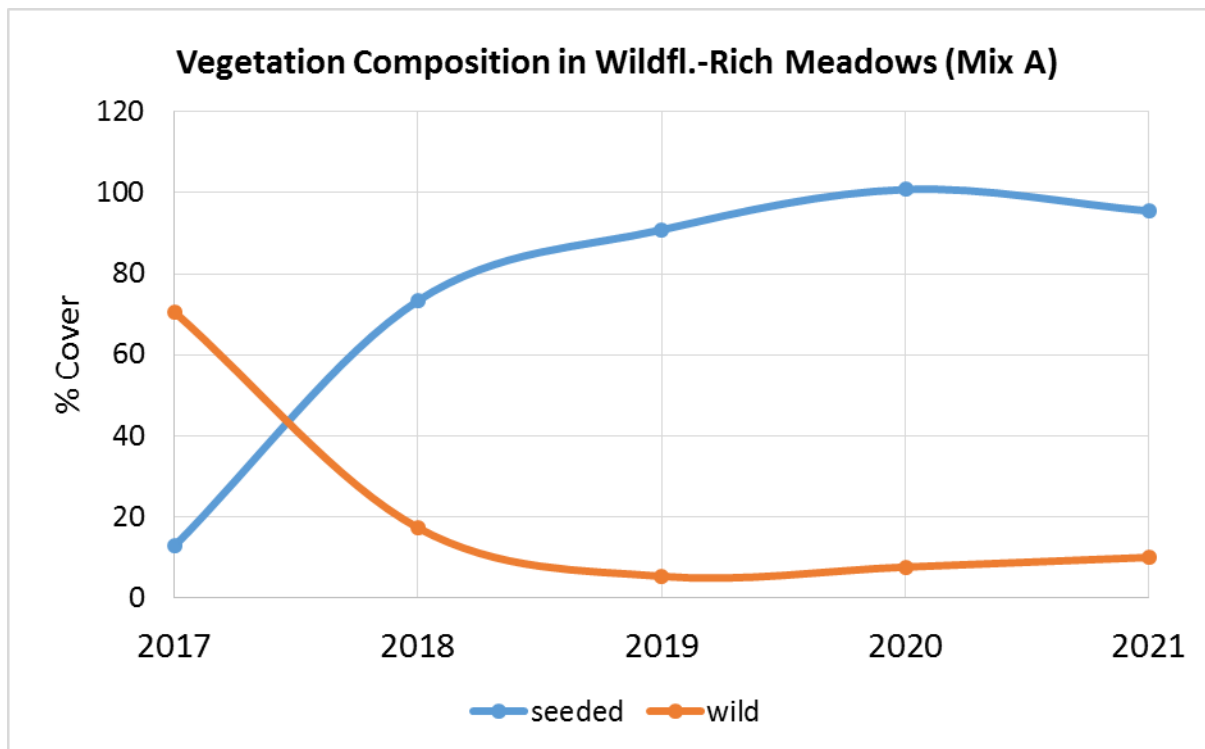


Figure 4: Development of average vegetation composition (average % cover of seeded vs. wild-growing species) over the years in experimental plots seeded with Mix A.

The seeded plants quickly established themselves in the wildflower-rich treatments (Mix A) and by the second season (2018) covered on average more than 70% of the ground. Their average percent cover peaked in 2020 and declined somewhat in 2021. Wild-growing plants (Crabgrass, Pigweed, and Galinsoga) dominated the vegetation in the wildflower-rich meadows in the first season. In the second season, 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. However, two perennial wild-growing plant species, Cottonwood and Mugwort, began to establish themselves in 2018 and have slowly, but steadily increased in abundance in the wildflower-rich meadows, in spite of our efforts to control their spread.

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

Over the first four years, the experimental plots seeded with Mix A, showed on average a steady increase in the percent cover by seeded species (Figure 5). However, the relative proportions of seeded 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. In the fifth year, total cover of seeded species began to decline, but cover by Early Goldenrod, New England Aster, and Little Bluestem continued to increase.

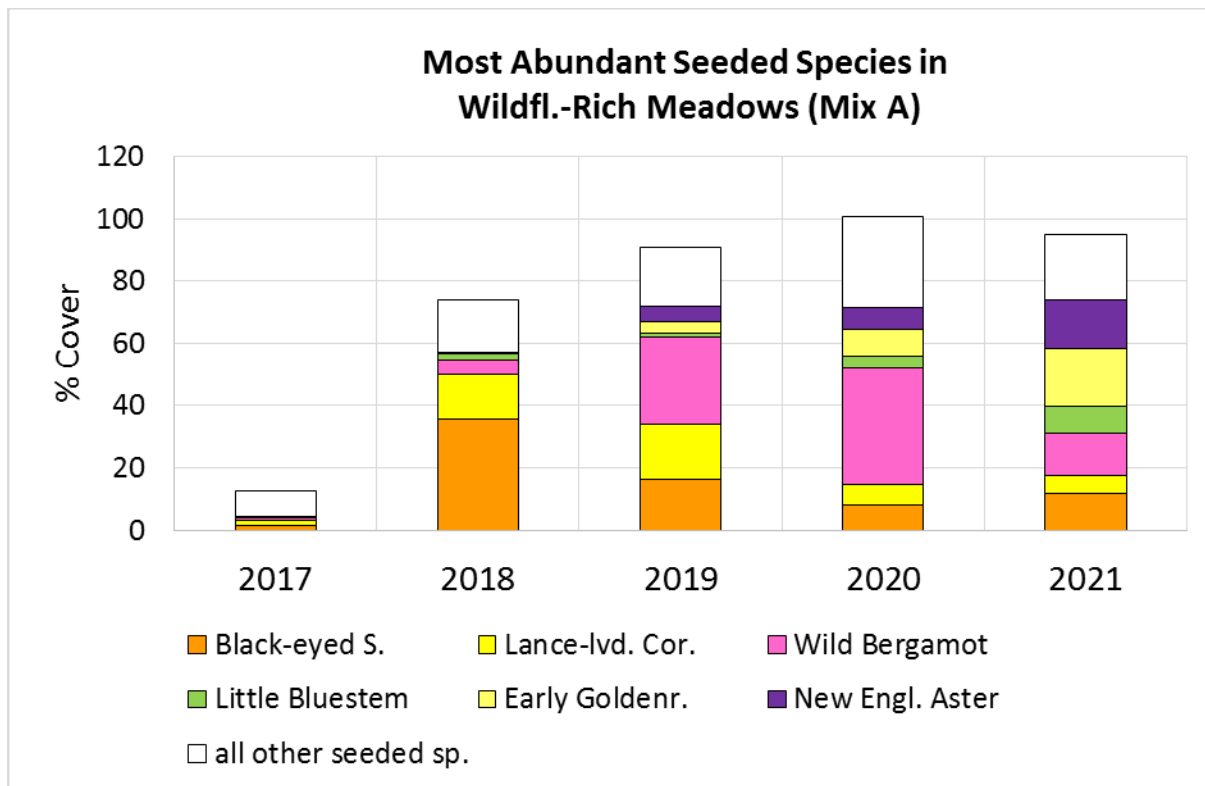


Figure 5: Development of average vegetation composition (average % cover of seeded species only) over the years in experimental plots seeded with Mix A.

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

Figures 6 and 7 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.

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 as in the wildflower-rich meadows (Mix A; Figure 4). In fact, between 2019 and 2020 there was no increase (and potentially even a slight decrease), but by 2021, the abundance of seeded plants in the grass-rich meadows continued to increase (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 season (Crabgrass, Pigweed, and Galinsoga). In the second season, Horseweed was the most common wild-growing plant in the grass-rich meadows. In subsequent years, these annual plants did not get replaced by wild-growing perennials to the same degree as in the wildflower-rich meadows. Wild-growing plants had declined substantially by 2021 and were only half as abundant in the grass-rich meadows compared to the wildflower-rich meadows.

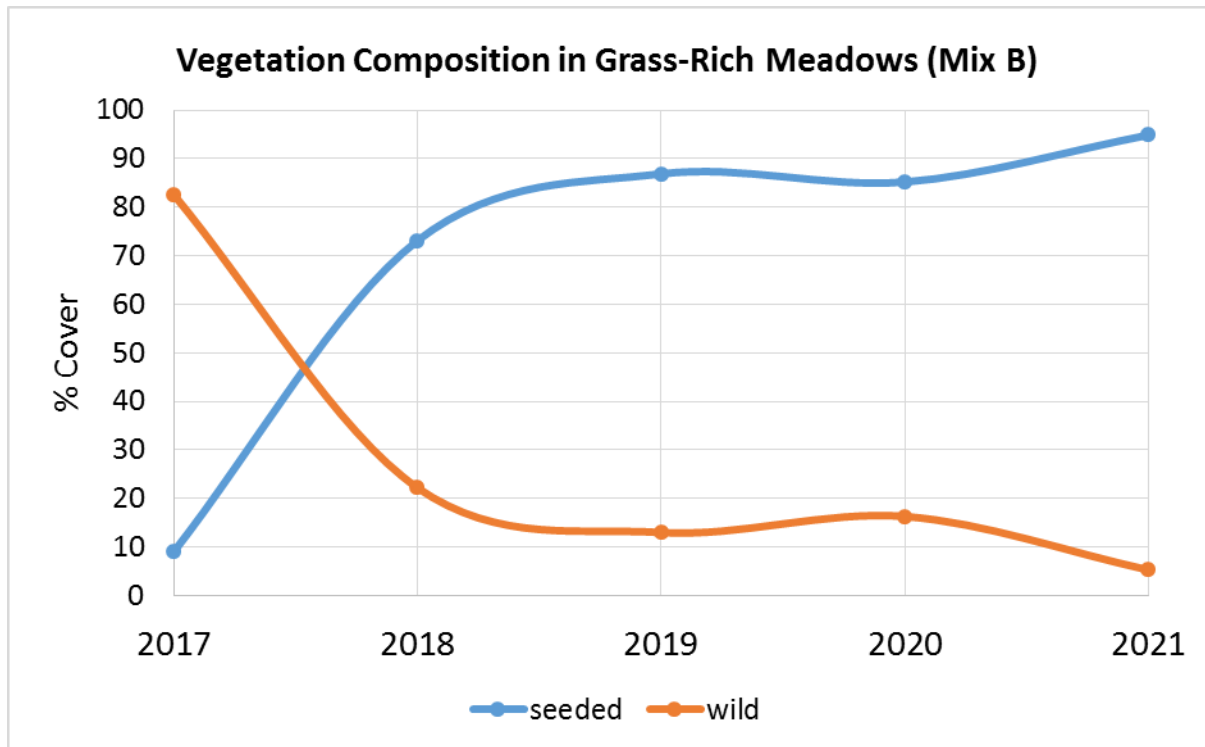


Figure 6: Development of average vegetation composition (average % cover of seeded vs. wild-growing species) over the years in experimental plots seeded with Mix B.

Figure 7 shows the contribution of the most abundant species to the *seeded* vegetation in the grass-rich treatments (Mix B) over time.

Over the first five years, the experimental plots seeded with Mix B, showed on average a general increase in the percent cover by seeded species (Figure 7). The “dip” or stagnation in 2020 might be attributable to the dry summer that year (Table 4). Like 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 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 (mostly Switchgrass, Big Bluestem, Indiangrass, and Canada Wildrye) increased steadily over the years.

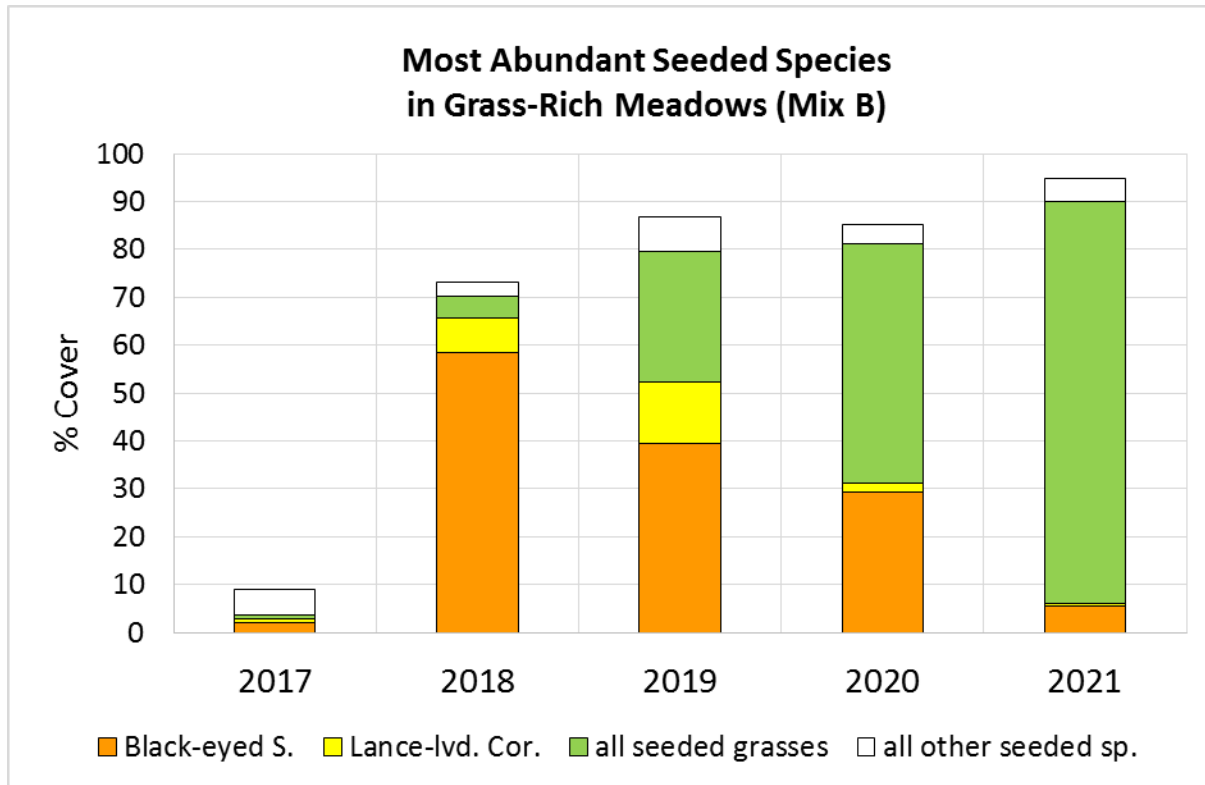


Figure 7: Development of average vegetation composition (average % cover of seeded species only) over the years in experimental plots seeded with Mix B.

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.

Similar to the seeded plots, wild-growing plants quickly covered most of the ground in the control plots (more than 70% by 2018; Figure 8). In contrast to the seeded meadows, where the seeded plants quickly replaced the wild-growing plants, the latter remained abundant in the control plots. However—after the first wave of colonization—the wild-growing plants did not increase markedly in abundance. Instead, they hovered around 80% cover for the last four years. This means that—on average—20% of the ground in the control plots remained bare after five years of fallow.

As in the seeded plots, the control plots were dominated by annual weeds, such as Crabgrass, Galinsoga, and Pigweed, in the first year (observed, but not sampled in 2017). They were successively replaced by Horseweed in 2018 and 2019 (Figure 9). In the fourth season, Horseweed had become noticeably less and been partially replaced by Cottonwood. The category of “other wild species”, which contributed more than 50% of the vegetation of the fallow controls in 2021 included Mugwort, Hairy Chess, Fleabane, Wood Sorrel, Vetch, and Tall Goldenrod.

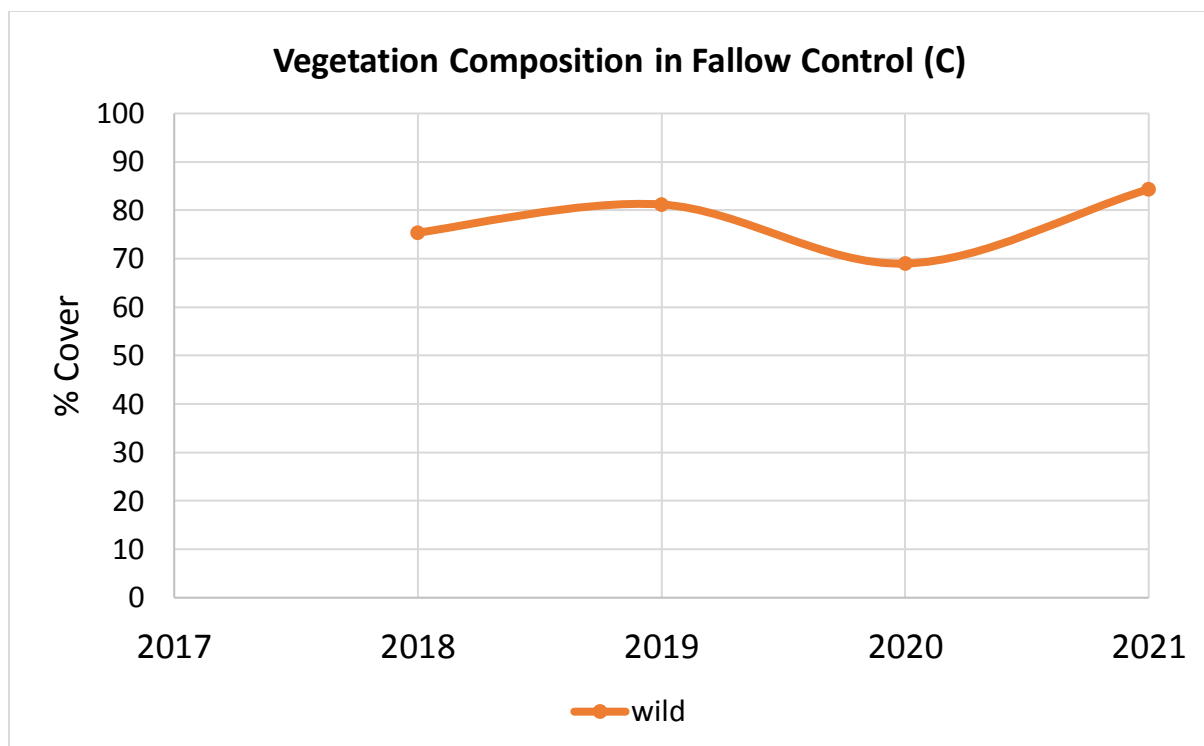


Figure 8: Development of average vegetation composition (average % cover of wild-growing species) over the years in control plots.

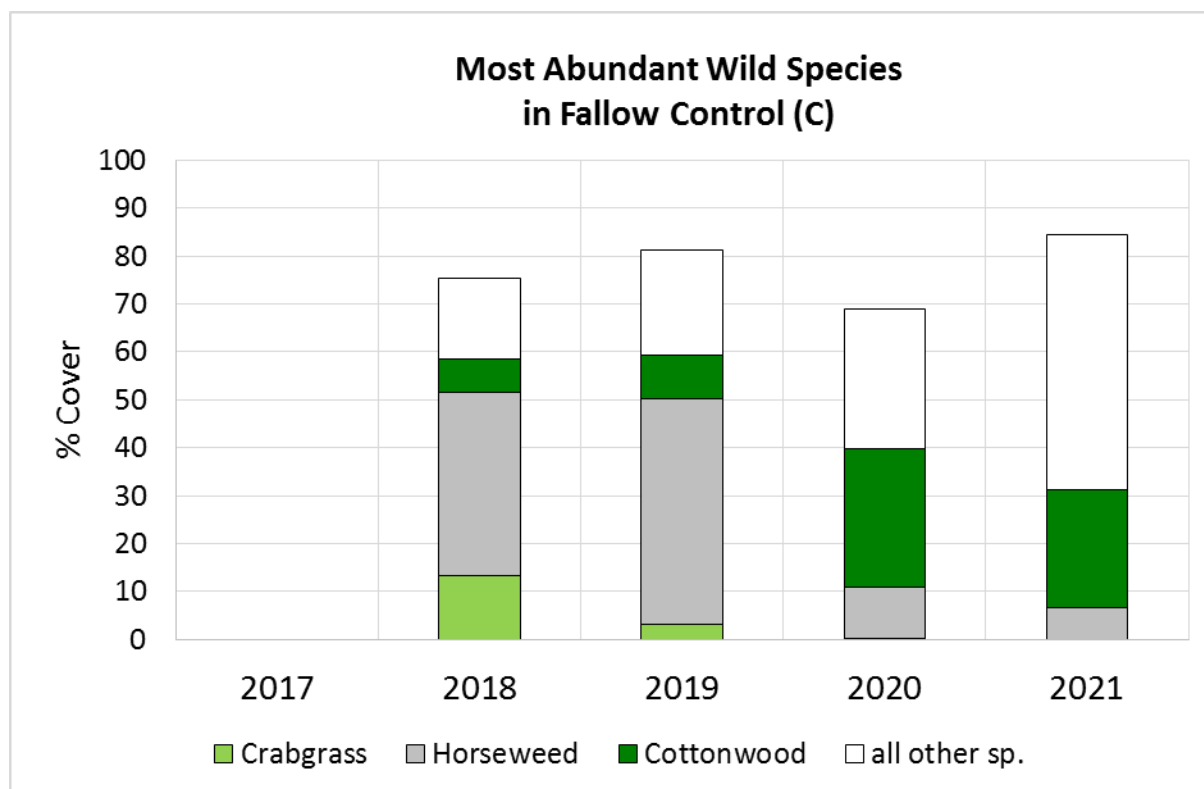


Figure 9: Development of average vegetation composition (average % cover of wild species only) over the years in fallow control plots.

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 10 illustrates this with a collage of drone images of the nine plots taken in July 2020.

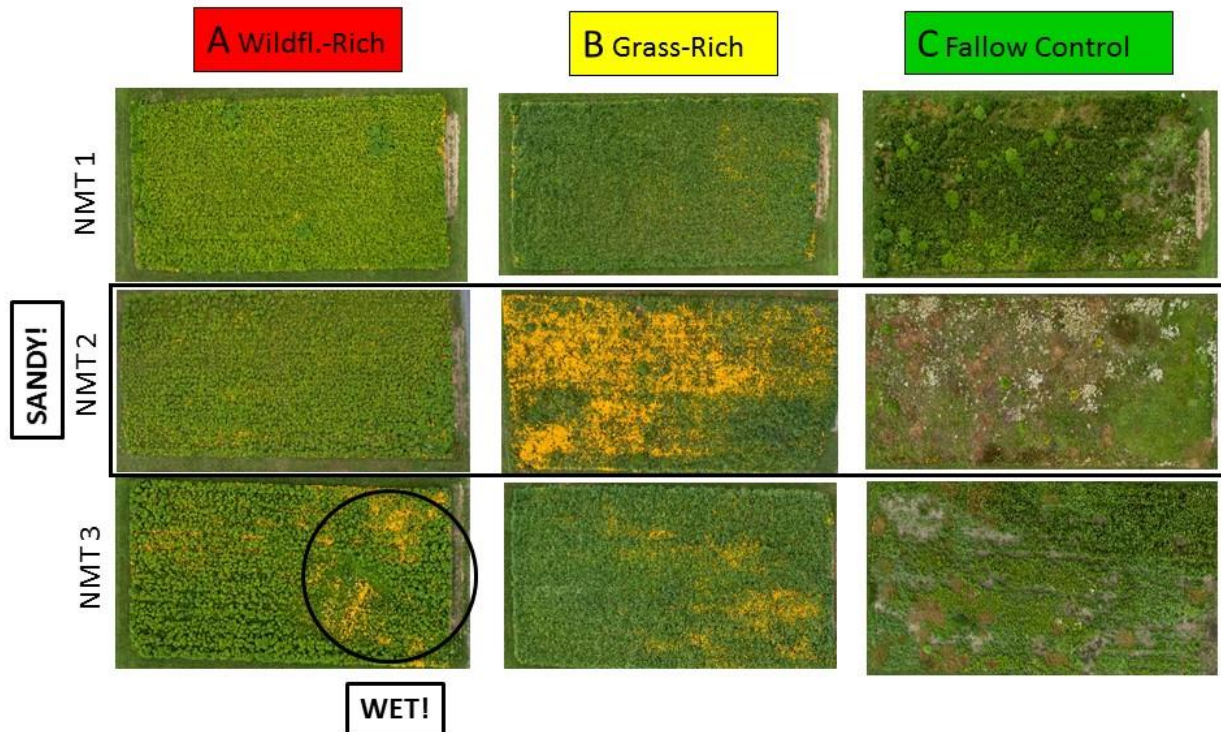


Figure 10: Collage of drone images (taken in July 2020 by Oceans 8/Jon Bowermaster) picturing the nine experimental plots of each trial location (NMT1, NMT2, and NMT3; side by side) and of each treatment (A: wildflower-rich, B: grass-rich; and C: fallow control; below each other)

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 soil, the native grasses took longer to establish at NMT2 and Black-eyed Susan (yellow signature in the central plot in Figure 10) remained common longer here than in the grass-rich plots at NMT1 and 2. 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 10).

Within plot variation is most striking in the wildflower-rich plot at NMT3 (bottom left plot in Figure 10), where a puddle of standing water forms after each significant rain event. The seeded plants were slower to establish in this wet spot, but now have formed a community that is quite distinct from that in the adjacent well-drained soil. The seeded plants that are more common in the wet spot are Beardtongue, Partridge Pea, and Blazing Star.

Plant Diversity

Figure 11 shows the patterns of plant diversity in the seeded meadows and fallow control plots over time.

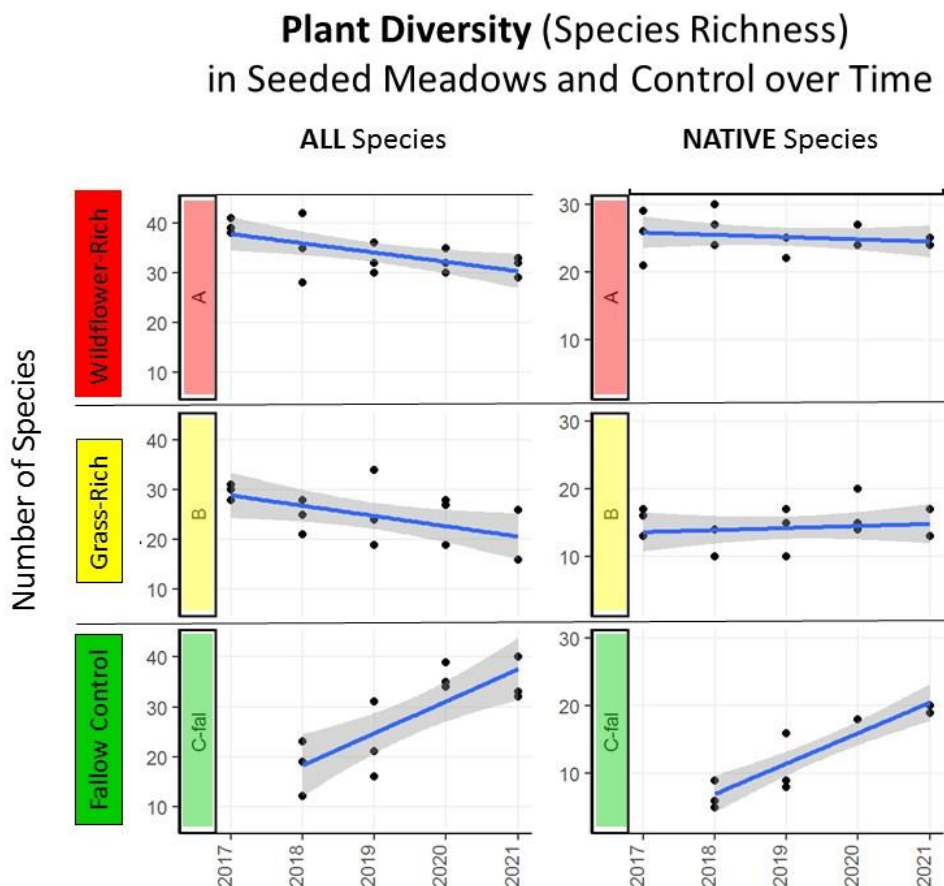


Figure 11: Plant Diversity (measured as species richness) in seeded meadows and control plots over time.

Plant diversity is depicted as species richness (number of species) in Figure 11, but Shannon and Simpson Indices followed very similar patterns. The diversity of *all* plants (left column in Figure 11) and that of *native* plants (right column in Figure 11) was on average significantly higher in the wildflower-rich meadows (Mix A; top row in Figure 11) than in the grass-rich meadows (Mix B) or the fallow control (General Linear Model; $p < .001$). The diversity of *all* plants in seeded meadows (wildflower-rich and grass-rich) seemed to decrease over time, but this decrease was not considered statistically significant. The diversity of *native* plants remained more or less

constant in the seeded meadows over time. The diversity of all plants and of native plants increased significantly over time in the fallow control (General Linear Model; $p < .001$).

Evaluation of Plant Species Performance

In order to evaluate the performance of individual species in our seed mixes over time, we compared the expected % cover for each species (based on its proportion of seeds in the seed mix; % of mix by volume in Tables 1 and 2) with the % cover observed in 2018, 2019, and 2020. If all species had gotten established equally well, one would expect their % cover to be the same as their proportion of seeds.

Figure 12 indicates with orange/blue bars the species that are more/less abundant in the vegetation of the wildflower-rich meadows in July of each year than expected from their proportion of seeds in Seed Mix A (Table 1). The numbers on the x-axis indicate the difference (in % cover). For example, in 2018, Black-eyed Susan (whose seeds made up 6.5 % of Seed Mix A), contributed on average 41.5% to the plant cover in the wildflower-rich meadows, which is 35% more than expected. In 2019, its contribution was 16.5%, which is only 10% more than expected, and by 2020, the % cover of Black-eyed Susan in the wildflower-rich meadows was very close to the expected 6.5%.

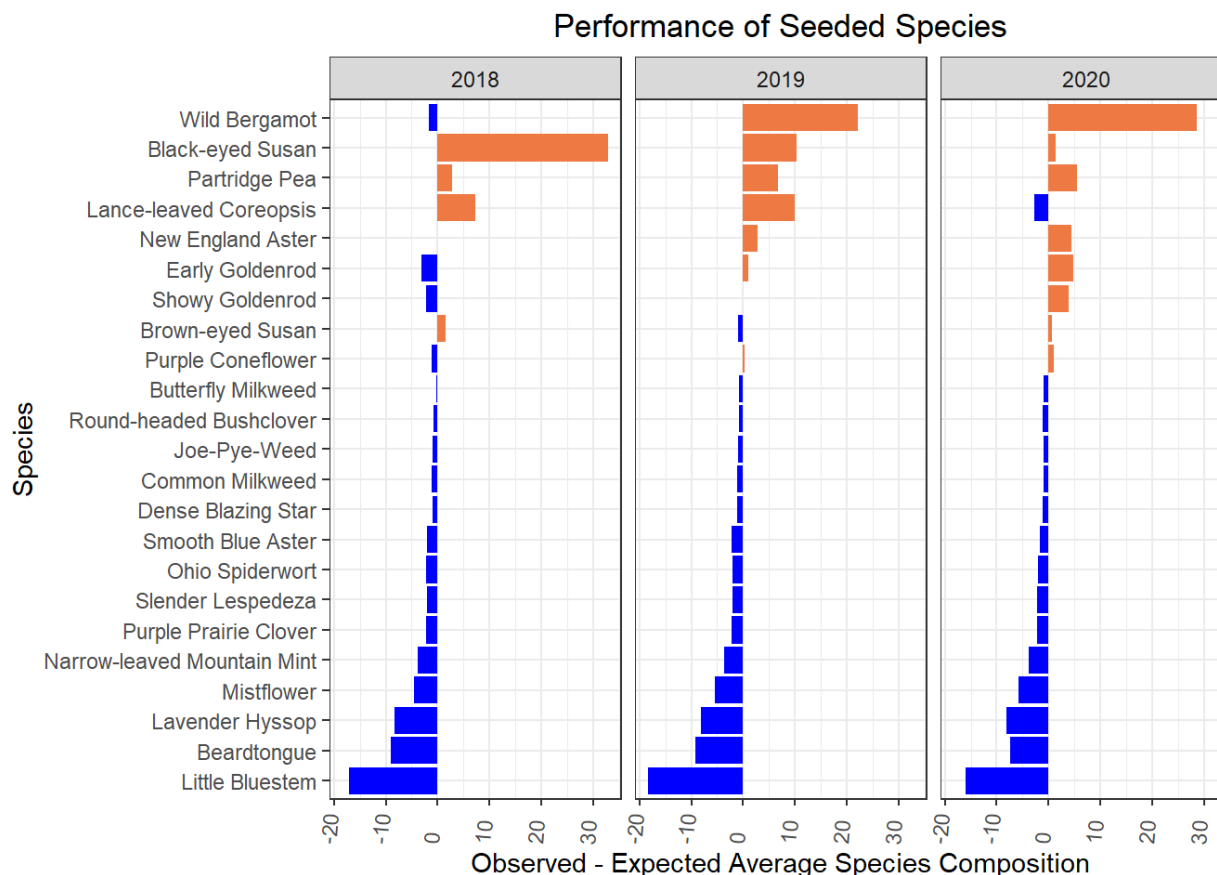


Figure 12: By-species comparison of observed abundance in the vegetation (% cover) in wildflower-rich meadows vs. their expected abundance based on their number of seeds in Seed Mix A (% seed by volume; Table 1). Orange/blue bars indicate species that are more/less abundant than expected.

In addition to the species already highlighted as making up most of the vegetation in the wildflower-rich meadows (Mix A; Figure 5), Figure 12 shows that Partridge Pea, Showy Goldenrod, Purple Coneflower,

and—in some years—Brown-eyed Susan were more abundant in the vegetation than expected from their amount of seeds in the seed mix during the early years after seeding. Note that Little Bluestem, although still much less represented in the vegetation than expected from its proportion of seeds, seems to be increasing in abundance and has become one of the most common seeded plants in the wildflower-rich seed mix in 2021 (Figure 5). As already discussed above, there is also a clear evolution in the composition of plants in the wildflower-rich meadows over time.

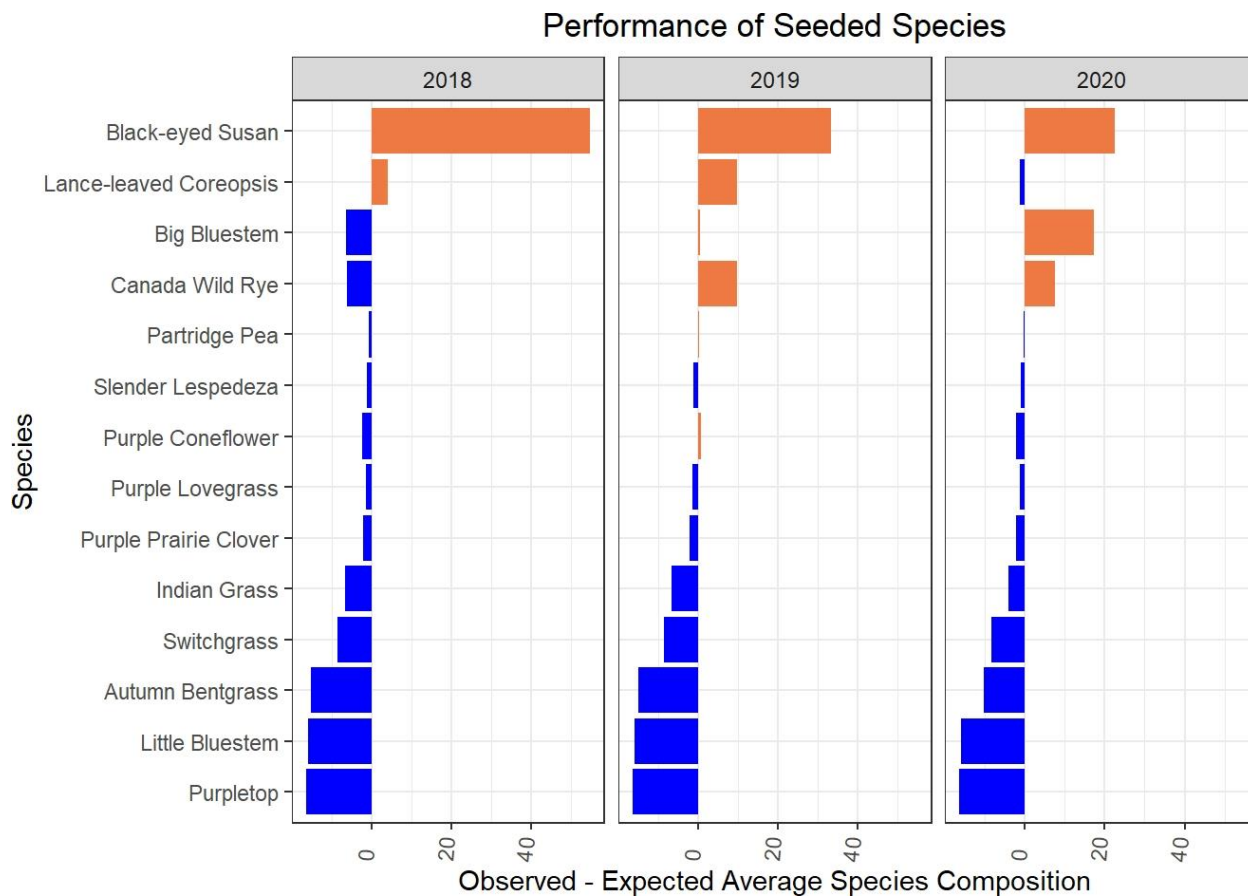


Figure 13: By-species comparison of observed abundance in the vegetation (% cover) in grass-rich meadows vs. their expected abundance based on their number of seeds in Seed Mix B (% seed by volume; Table 2). Orange/blue bars indicate species that are more/less abundant than expected.

Figure 13 indicates with orange/blue bars the species that are more/less abundant in the vegetation of the grass-rich meadows in July of each year than expected from their proportion of seeds in Seed Mix B (Table 2). As already discussed above, Black-eyed Susan and Lance-leaved Coreopsis got established quickly and made up the bulk of the vegetation in early years of the grass-rich meadows. Their contribution to the vegetation during the first couple of years was disproportionate to their amount of seeds in Seed Mix B (Figure 13). Partridge Pea and Purple Coneflower contributed briefly (in 2019) to the vegetation at approximately the abundance expected from their amount of seeds in Seed Mix B, but have declined again since. A detailed species-specific evaluation of the success of the seeded grasses is hampered by the difficulty of distinguishing the different grasses in the field when they are not reproductive. While, according to Figure 13, Big Bluestem and Canada Wild Rye seem to be disproportionately successful in the grass-rich meadows, Switchgrass and Indiangrass are also quite

common, and easily confused with Big Bluestem at certain stages. Therefore, the data presented on the grasses in Figure 13 should be taken with a grain of salt.

Flower Abundance and Diversity

Flower Abundance: In contrast to Figures 5 through 9, 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 14, 16, and 17 show the average total abundance of flowers (all species) across the season and years in the three treatments.

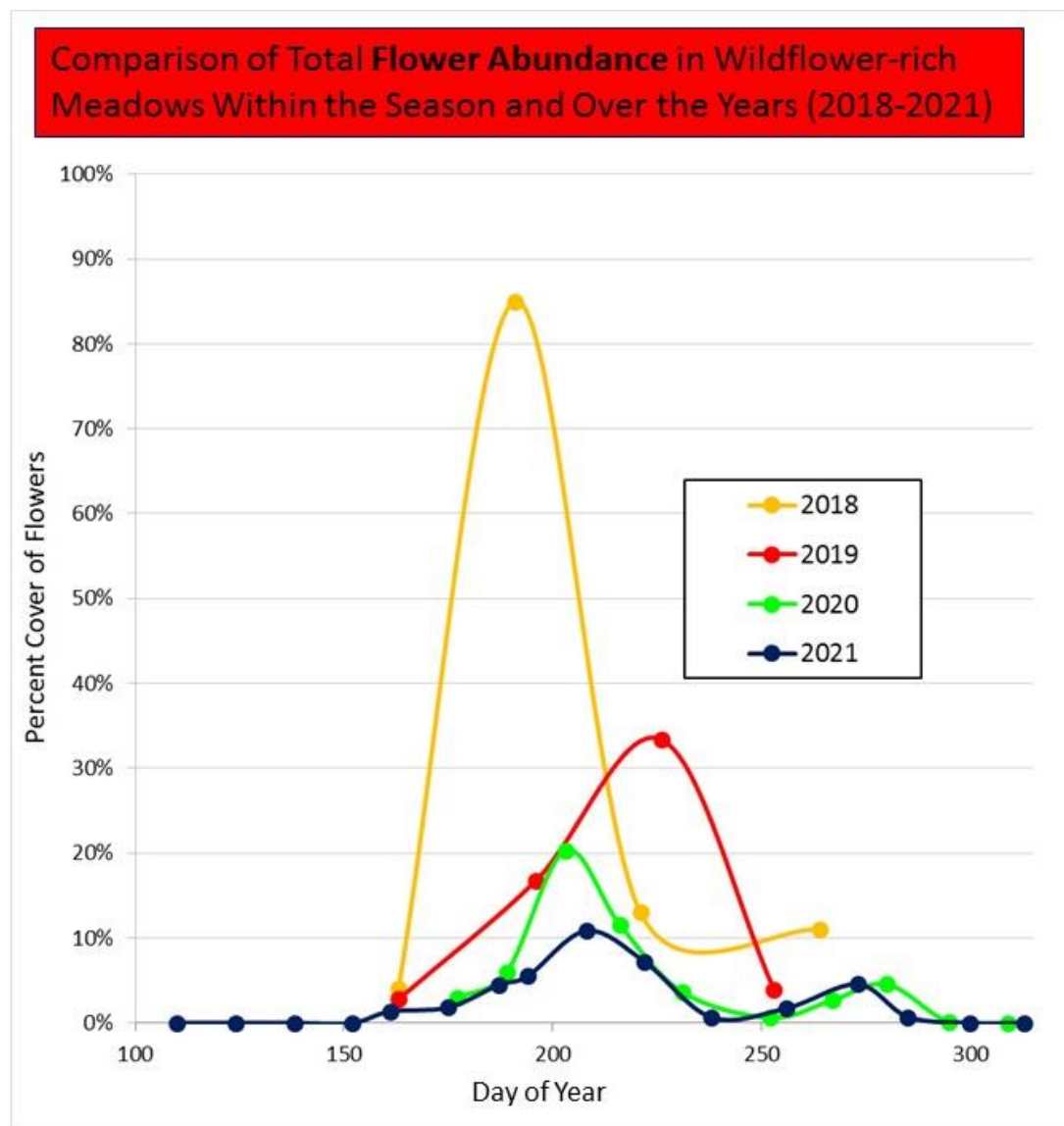


Figure 14: Comparison of Total Flower Abundance in wildflower-rich meadows within the seasons and over the years

Total flower abundance in the wildflower-rich meadows was highest in 2018, the year after seeding (Figure 14). Flower abundance peaked early in the season, mostly due to a profuse blooming of Black-eyed Susan and, to a much lesser extent, Lance-leaved Coreopsis. Total flower abundance in the wildflower-rich meadows has decreased every year since then. At the same time, flower abundance became more evenly distributed throughout the season.

Figure 15 shows the blooming sequence of the species with the most abundant flowers in the wildflower-rich meadows in 2021 starting with Beardtongue and Lance-leaved Coreopsis, followed by Black-eyed Susan, Wild Bergamot and Early Goldenrod, Purple Coneflower, Early Goldenrod, Purple Coneflower, Early

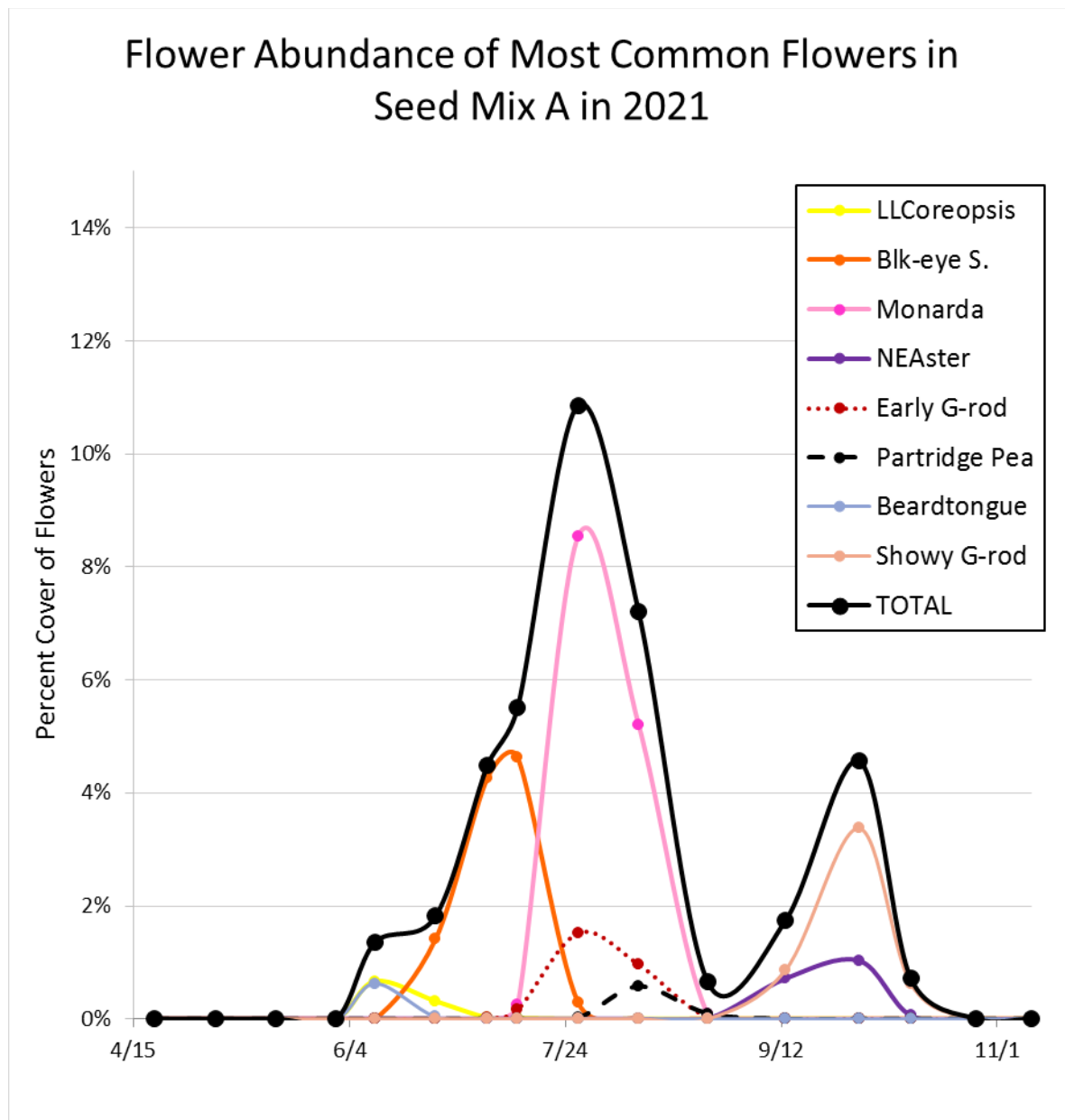


Figure 15: Seasonal blooming sequence for most abundant flowers in the wildflower-rich meadows (Mix A) in 2021.

Goldenrod, Partridge Pea, and culminating in New England Aster and Showy Goldenrod. We have observed that this sequence of flowering follows the same order each year, but the actual dates of peak flower abundance of each species can vary by up to three weeks. For example, Wild Bergamot flower abundance peaked on July 27 (in 2021), July 21 (in 2020), and August 14 (in 2019). The very early peak in 2020 coincided with an unusually dry summer and it seemed as if the flowers just dried up and were abandoned before they would have reached their peak in a wetter year.

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-

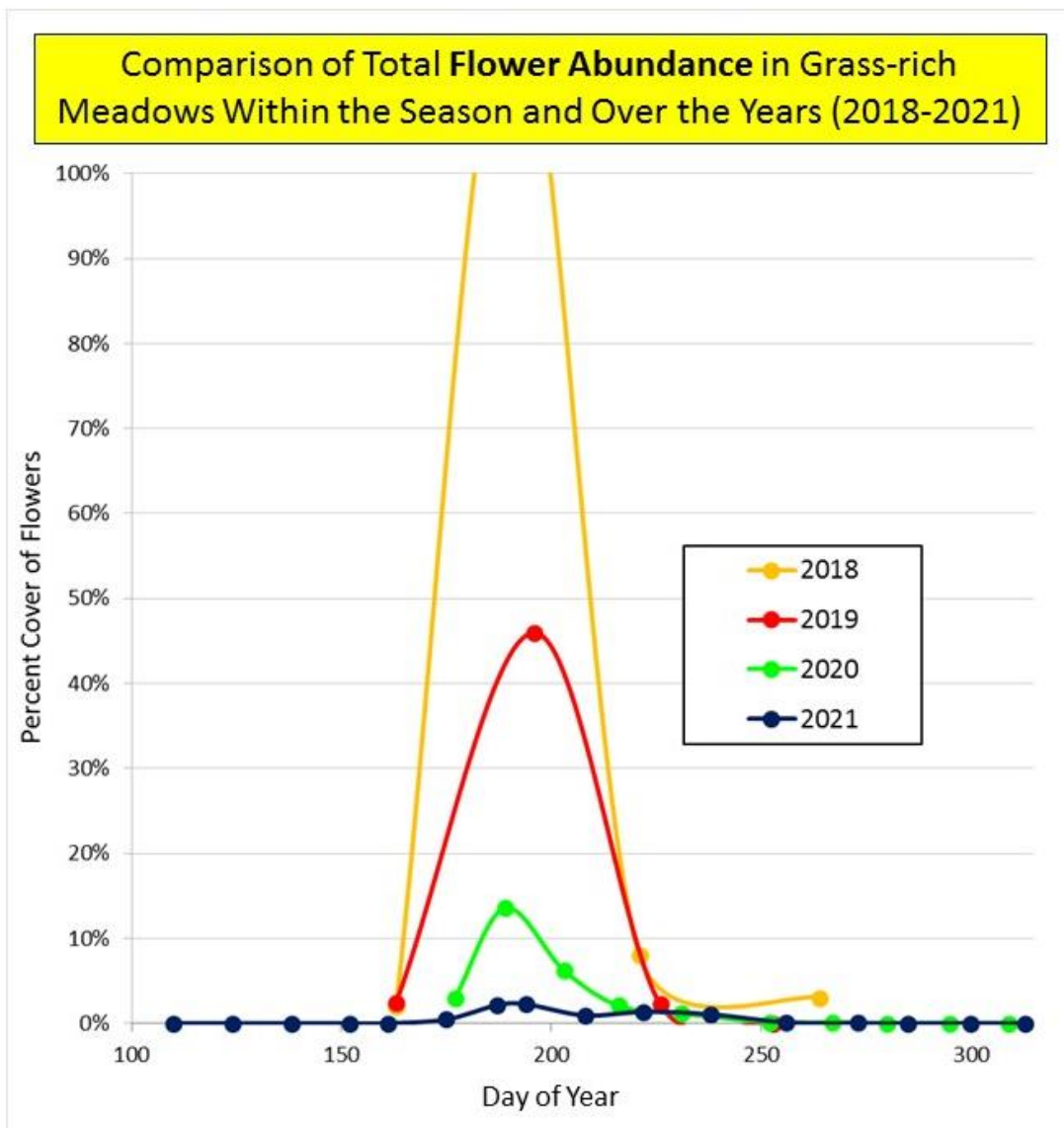


Figure 16: Comparison of Total Flower Abundance in grass-rich meadows within the seasons and over the years

eyed Susan) and a steady decrease since then (Figure 16). However, in the grass-rich meadows, the drop in overall flower abundance over the years is not balanced by a longer availability of flowers across the seasons.

The total flower abundance in the fallow control was significantly lower than that in the seeded meadows (both wildflower-rich and grass-rich) in all years (Figure 17).

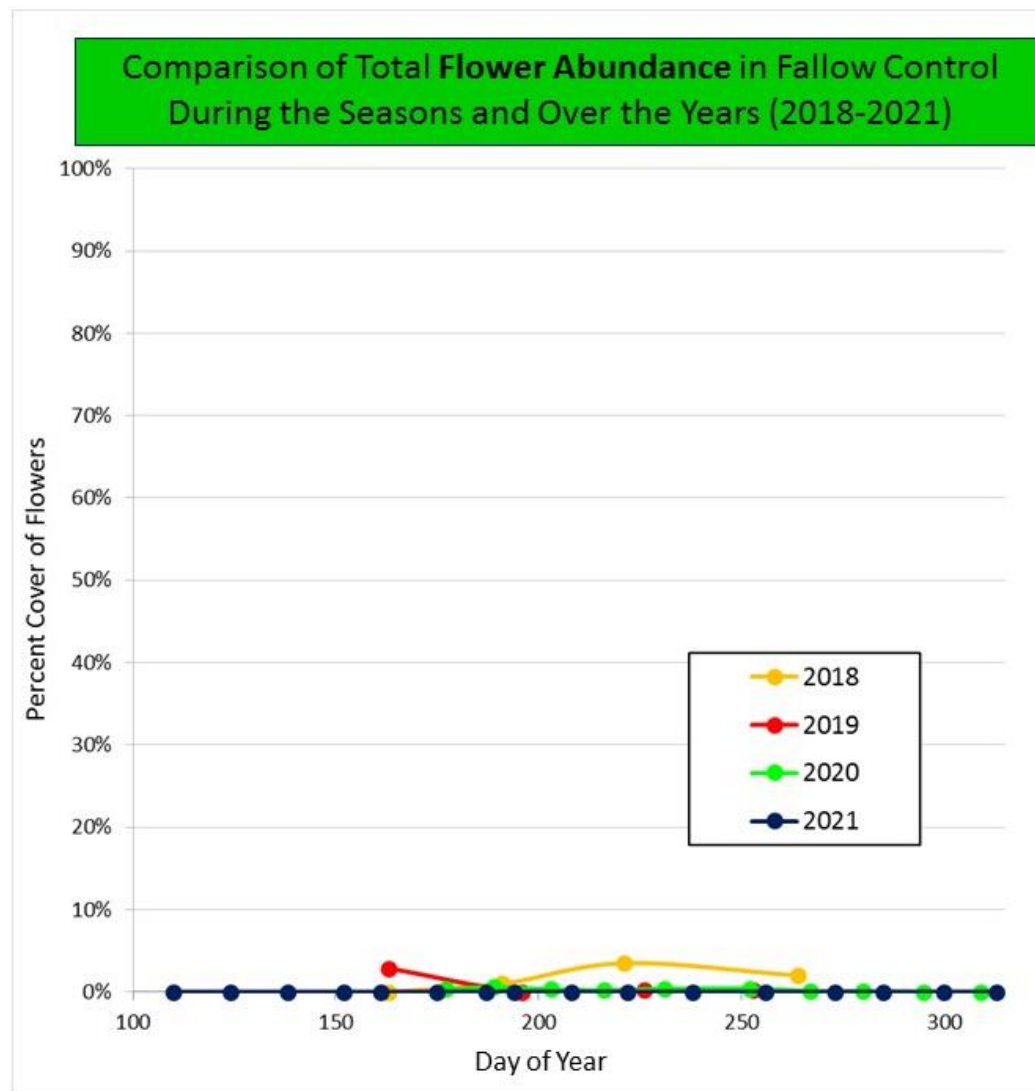


Figure 17: Comparison of Total Flower Abundance in fallow control within the seasons and over the years

Flower Diversity: Figure 18 compares the number of plant species (native and non-native) found in bloom in each of the treatments over the years. The number of plant species found in bloom increased markedly in the seeded meadows (both, wildflower-rich and grass-rich) from the first to the second year of seeding, but seemed to have plateaued since. This is true of both the number of all plant species as well as the number of native species in bloom. While the number of native species in bloom was fluctuating around a mean of 25 in the wildflower-rich meadows

during the last four years, it was significantly lower (a mean of 12) in the grass-rich meadows. In contrast, the number of native plant species in bloom in the fallow control plots has been increasing steadily from year to year and in 2021 was the same (27) as in the wildflower-rich seeded meadows. The total number of plant species in bloom in the fallow controls had far exceeded that in the wildflower-rich meadows in 2021. However, it is important to remember that these numbers refer only to the diversity of flowers, not their abundance (see Figures 14 to 17 above)

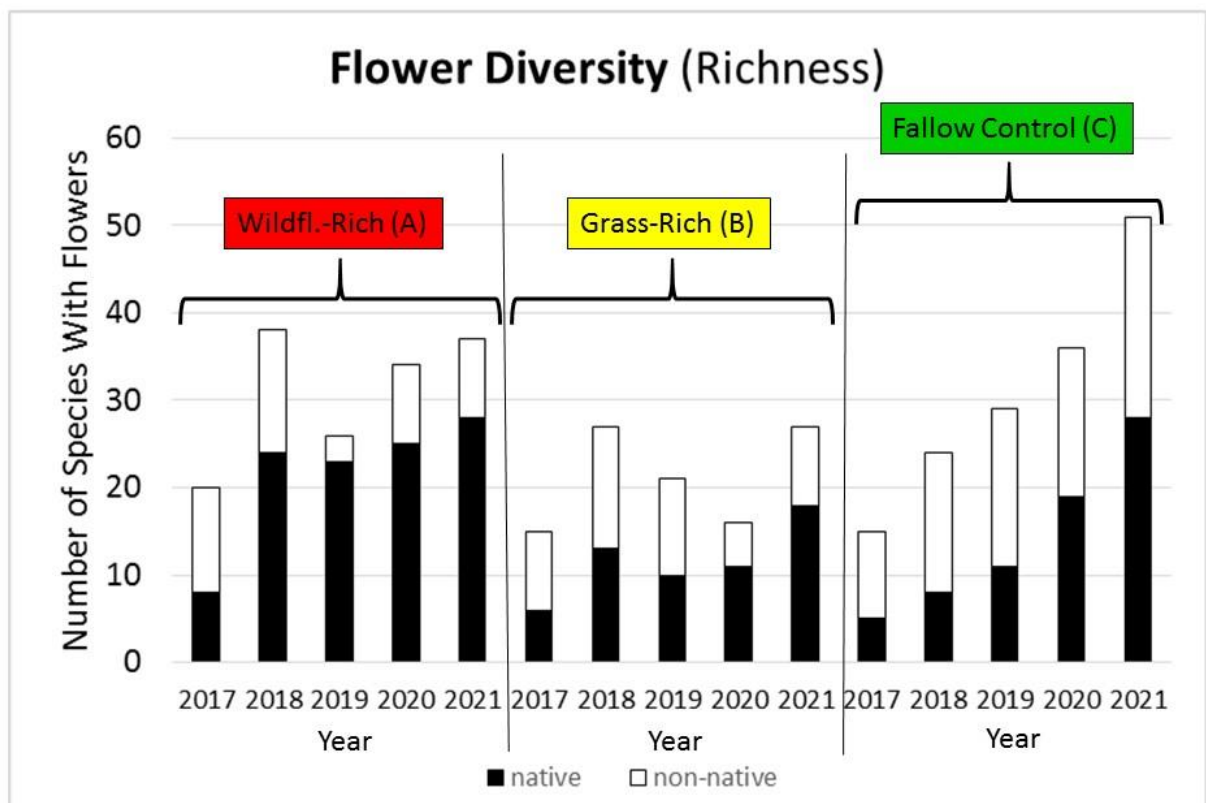


Figure 18: Comparison of Flower Diversity (Species Richness) in the three treatments over the years.

Invertebrate Monitoring

The results from the invertebrate monitoring in the native meadow trials are summarized in the entomology reports Vispo et al. (2020), Vispo (2021), and Vispo et al. (2022). The results from the monitoring of flower visiting insects are presented in Allen (2019) and Vispo et al. (2020).

Soil Conditions

The soil samples taken in spring of 2017 (before the plots were seeded) and in spring of 2018, 2019, and 2021 were analyzed by the Cornell Soil Health Lab. As part of the Soil Health Lab report, the values for the different soil variables were ranked by comparing them to a comprehensive database of agricultural soils throughout the US and beyond.

For the 2017 (pre-seeding) soil samples, this ranking indicated a good pH range and high-to-excessive phosphorous values in all experimental plots. Potassium was ranked perfect for trial areas NMT1 and NMT3, but low for NMT2. Organic matter, active soil carbon, soil protein, subsurface hardness and even surface hardness were ranked low in all trial areas. Aggregate stability also ranked very low overall, only experimental plot NMT2A ranked slightly better. Soil respiration ranked overall low. Root pathology was very variable across the experimental plots. Water holding capacity was ranked high in trial areas NMT1 and 3, but only intermediate in NMT2.

Table 3 summarizes the development of soil health in the experimental plots over time.

Table 3: Summary of the development of soil health and other characteristics in the experimental plots over time, based on samples taken in 2017 (pre-seeding), 2018, 2019, and 2021.

Soil Health and Other Characteristics

	Effect (General Linear Model)			Statistically Significant Differences
	Treatment	Site	Year	
Overall Soil Health Score	no	no	yes (p=.01)	increase over time
Active Carbon	no	no	yes (p<.001)	increase over time
% Sand	no	yes (p<.001)	no	higher in NMT2 than NMT1 and NMT3
Water Holding Capacity	no	no	no	
Aggregate Stability	no	no	no	
Organic Matter	no	no	no	
Soil Respiration	no	no	no	
pH	no	no	no	
Phosphorous	no	no	yes (p<.001)	decrease over time
Potassium	no	yes (p=.01)	no	higher in NMT1 than NMT2
Magnesium	no	no	no	
Iron	no	no	no	
Manganese	no	no	no	
Zinc	no	no	no	

The treatments (wildflower-rich meadow, grass-rich meadow, or fallow control) did not have any statistically significant effect on any of the soil characteristics. The sites (trial locations NMT1, NMT2, and NMT3) were significantly different in their soil texture. As mentioned before, NMT2 was significantly sandier than NMT1 and NMT3. In addition, potassium was significantly higher in NMT1 than in NMT2. Across all treatments and trial locations, there was a significant

decrease in phosphorous over the years, which is not surprising because all the plots had been rated as having high to excess amounts of this element in 2017. There was also a significant increase in active carbon across all treatments and trial locations over time. This translated into a significant increase in the overall soil health score (Moebius-Clune et al. 2017) across all treatments and trial locations over time.

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. (°F)	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

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 Native Meadow Trials in chronological order, specifies the equipment used, and the time spent (in person-hours per acre).

Figure 19 illustrates the total amount of labor (person hours per acre) applied to the establishment and maintenance of the seeded native meadows (red bars) and of the entire trial (green bars; including seeded native meadows as well as the control plots) 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 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.

Table 5: List of Management Activities in the Native Meadow Trials; the labor calculation only applies to the seeded experimental plots, excluding any management of the control plots

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, <i>Rumex</i> 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, 2020	Mowing	0.7	Rotary Mower
	June-Sept	Selective Weeding/ Cutting	6.8	by hand; Clippers, Loppers, String Trimmer (Mugwort)
2021	March 26, 2021	Mowing	0.7	Rotary Mower
		no weeding in seeded plots		

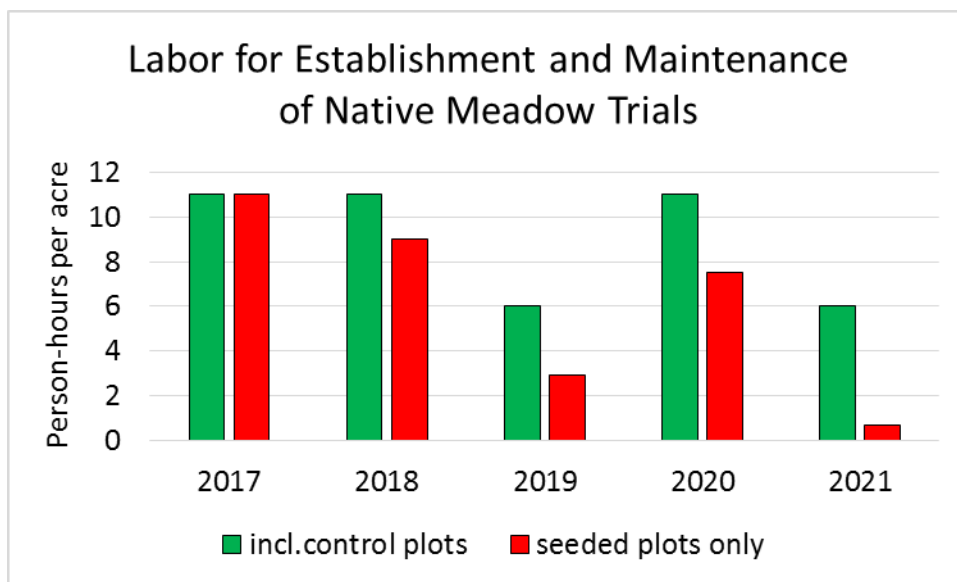


Figure 19: A summary of the labor applied to the establishment and maintenance of the native meadow trials during the first four years. The green bars represent the labor applied across all treatments, including the control plots. The red bars represent the labor applied only in the seeded native meadows.

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 ranged from 1 to 9 person-hours per acre per year.

The more diverse seed mix (Mix A) resulted in a more diverse vegetation compared to Seed Mix B. The vegetation derived from both seed mixes continued to evolve for the first five years. A small set of species quickly dominated both types of meadows (wildflower-rich and grass-rich), but the relative proportion of the dominant species changed over time and seems to continue to change. We are looking forward to seeing if they will ever reach a resemblance of an equilibrium.

The more diverse seed mix (Mix A) also resulted in a more diverse set of flowers, a higher flower abundance (from year three onward), and the presence of flowers over a longer period (June through October) compared to Mix B.

However, in contrast to the fallow control, the diversity of flowers in Mix A (and Mix B) might have peaked in the second year, while the diversity of flowers in the fallow control has been steadily increasing over the first five years. The flower abundance in the fallow control remained very low throughout the first five years compared to the seeded meadows.

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