Native Meadow Trial at the Hudson Valley Farm Hub

Botany Report for the First Four Seasons: 2017-2020

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March 2021

Photo courtesy of Oceans 8/Jon Bowermaster

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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 (seeding and mowing), nine person-hours/acre during the second year (weeding), three person-hours/acre during the third year (weeding), and seven person-hours/acre during the fourth year (mowing and weeding). (These values apply to the seeded meadows only and do not include the maintenance of the control plots, because those plots were only created for the purposes of our experiment.)

Although some of the seeded experimental plots were overrun by Crabgrass in the first year, the seeded wildflowers and native grasses asserted themselves in the second year, and by the third year, most seeded plots were composed of more than 80% cover (and several of more than 90% cover) native plants. While all but one seeded species did establish at least some seedlings during the first two years, only half of the originally seeded species really "took off"; these made up the bulk of the vegetation in the seeded meadows in the third and fourth year (2019 and 2020).

The seeded meadows produced very few flowers in the first year, but by the second year (2018), both seed mixes (flower-rich Mix A and grass-rich Mix B) resulted in a large amount of yellow flowers (Black-eyed Susan) in mid July. Mix A continued to provide flowers of diverse species into October, while flower abundance in Mix B declined rapidly at the end of July of the second year. In the third year (2019), yellow flowers again dominated the meadows in mid July, but they were not as abundant as in the second year. While the peak of yellow July flowers was higher in Mix B than in Mix A, it was again the only flush of flowers in Mix B in the third year. The peak of yellow in July was not as impressive in Mix A, but the meadows derived from this flower-rich seed mix did continue to provide abundant and diverse flowers through the end of September in the third year. The peaks of flower abundance in both, Mix A and Mix B, were lowest in the fourth year (2020, which was also the driest year!). The Black-eyed Susan flowers were most abundant in the first week of July (about a week earlier than in prior years) and Wild Bergamot flowers were most abundant in the second half of July (about three weeks earlier than in 2019).

From the insect research (Vispo et al. 2020; Allen 2019), we learned that the flower-rich Mix A resulted in meadows that attracted more butterflies, native bees, and perhaps hover flies, but parasitoid wasps, spiders, and lady beetles were, if anything, more in the fallow control.

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 several more 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 1,200 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

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 (A, B, C) of 100 x 200 feet, separated by 10 foot wide strips of mowed grass/clover.

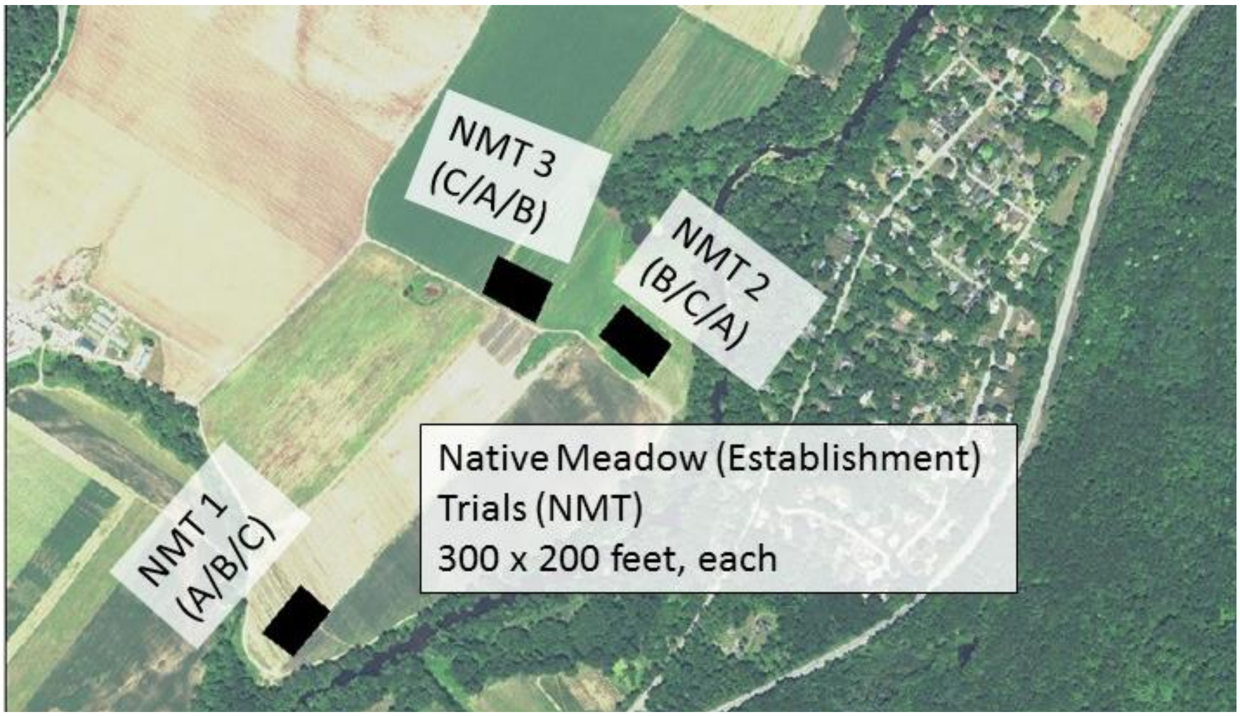

Figure 1: Map of Native Meadow Trial Areas at the Hudson Valley Farm Hub

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), we created two customized seed mixes for this trial. Meadow 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 Meadow 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/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 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	*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 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

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 Figure 17 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 2nd of the fourth year 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.

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 2017-2020. In addition, drone image were taken monthly July-Oct. in 2020.

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 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) 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, we documented the flower abundance in approximately two week intervals from June 25 to Nov 4 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, 2019 and 2020 (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 the entomology research report by Vispo et al. (2020, 2021). 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) 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.

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

Photographic Documentation of the Vegetation

Appendices 1.1 through 9.4 are the photographic documentation of each of the nine experimental plots during the first four years. Appendices 10.1 through 12.4 show side-by-side photographic comparisons during the first four years for all plots organized by treatment, while Appendices 13.1 through 15.4 show the same images organized by trial area. Appendix 16 contains a selection of the drone images from the trials taken between July and October of 2020.

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

Seeded Species (Seed Mix A): Figures 4a and b and figures 5a and b illustrate the results from the quantitative vegetation inventories in experimental plots seeded with Mix A during the first four years. Figures 4a and 4b show percent cover of *seeded* species and Figures 5a and 5b that of *wild-growing* species. Figures 6a and b and 7a and b show the same for experimental plots seeded with Mix B. Figures 8a and 8b illustrate percent cover by *wild-growing* plants in the control plots. Figures 4a, 5a, 6a, 7a, and 8a show the *average* composition of seeded and wild-growing species in each treatment across the three trial areas to illustrate the overall patterns. Figures 4b, 5b, 6b, 7b, and 8b show the same data for each experimental plot to illustrate the variation within treatments between the trial areas.

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 4a). While most individual species followed that trend of steady increase, 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. In contrast, Wild Bergamot increased disproportionally in the third and fourth year, reaching on average 40% cover in 2020 (while none of the other species reached 10% cover).

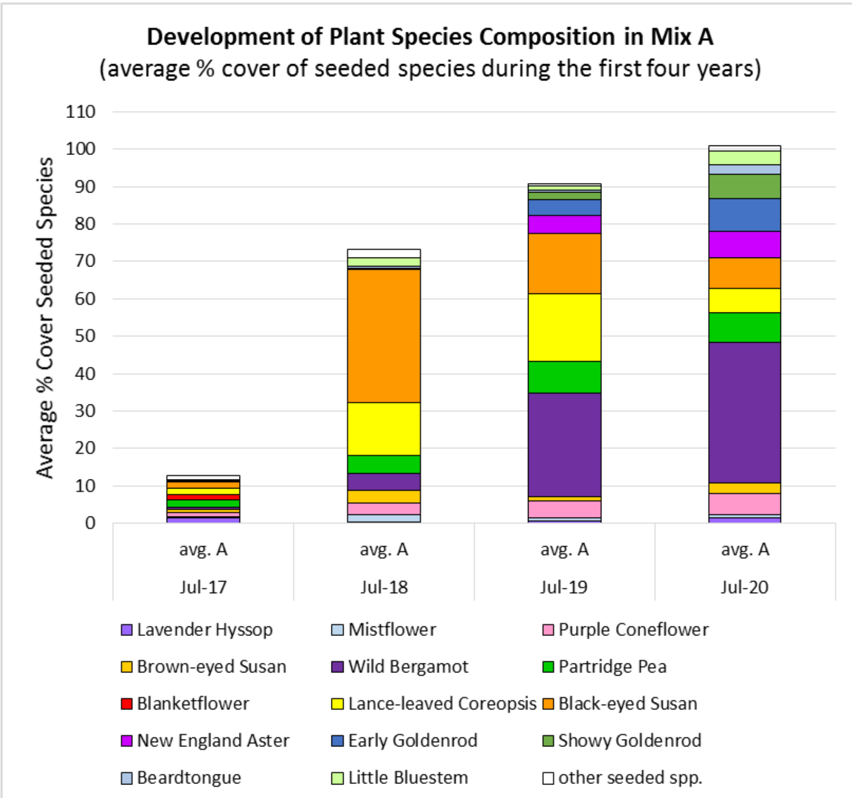

Figure 4a: Development of average vegetation composition (average % cover of seeded species only) in experimental plots seeded with Mix A during the first four years (2017-2020)

There was a marked difference in vegetation development during the first season between the trial areas. In trial area NMT1 (Fig. 1), both seeded plots (NMT1A and NMT1B) had better establishment of the seeded plants (reaching 44% and 26% cover respectively) by September 2017 than the same treatments in NMT2 and 3 (reaching at the most 15% and 5% cover, respectively). This might have been in part due to the different crop history of NMT1, which had been in mixed vegetables in 2015 and consequently seemed to have a different weed seed bank. NMT2 has the sandiest soil and lowest water holding capacity of the trial areas, and there might have been less germination success and higher seedling mortality due to the relative dryness in this trial area. NMT3A has the highest heterogeneity of soil conditions within any of the experimental plots, including a large area (approximately 20% of the plot) that often has standing water after rains, but also dries to a hard pan during dry periods. Germination of seeded plants was low in this intermittently-waterlogged area of NMT3A during the first year.

During the second season, the seeded plants "took off" in all experimental plots (including in the intermittently waterlogged area of NMT3A), reaching between 60% and 90% cover in July 2018 in those seeded with Mix A (Fig. 4b), and between 60% and 80% cover in those seeded with Mix B (Fig. 6b). The density of seeded plants in NMT1A compared to NMT2A and NMT3A remained somewhat higher, but the difference became much less striking (Fig. 4b). Although at the end of the 2017 season and into early 2018, NMT2A was densely covered with a mulch of Crabgrass stalks (App. 4.1 and 4.2), the seeded wildflowers eventually pushed through and reached almost the same density as in NMT3A (Fig. 4b). The initial difference in percent cover by seeded plants between the three experimental plots seeded with Mix B did not persist into the second season (Fig. 6b).

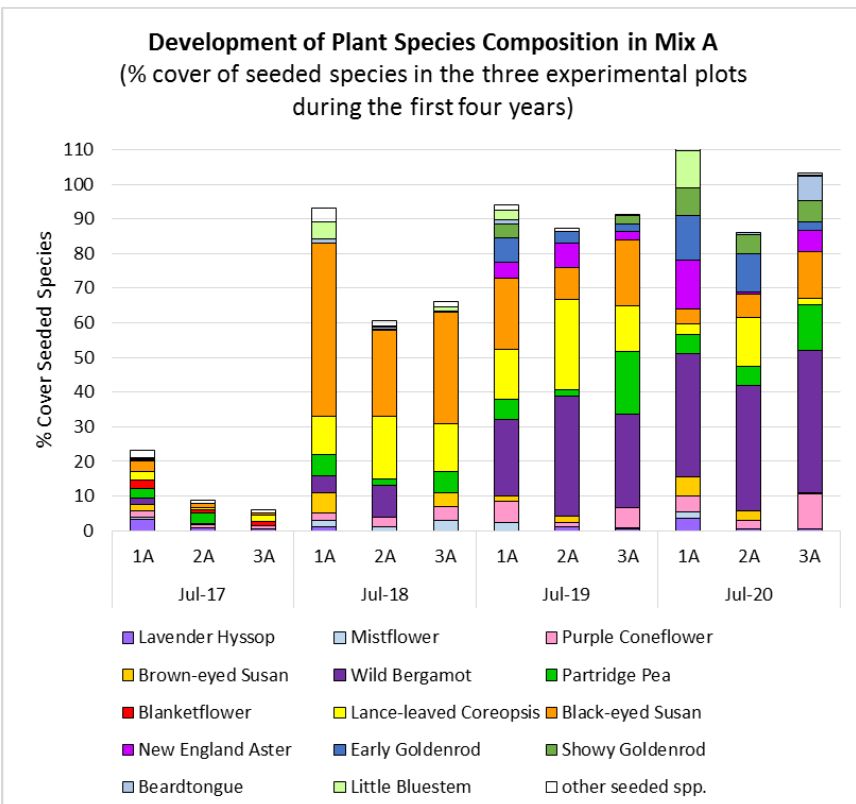

Figure 4b: Development of vegetation composition (seeded species only) in experimental plots seeded with Mix A during the first four years (2017-2020)

During the third season (2019), the seeded plants in the plots seeded with Mix A became more similar in their abundances (Fig. 4a). Black-eyed Susan, which had been the most common plant in all three plots in July 2018, diminished in abundance, to be partly replaced by Wild Bergamot, Partridge Pea, New England Aster, and a number of less common species. At the same time, the plots seeded with Mix A continued to diverge from each other in terms of their plant composition (Fig. 4b). For example, in July 2019, the different species of seeded plants were most evenly distributed in their abundance in NMT1A, with the two most abundant species covering around 20% each. In contrast, to species (Wild Bergamot and Lance-leaved Coreopsis) combined covered 60% of NMT2A, and three species (Wild Bergamot, Partridge Pea, and Black-eyed Susan) combined amounted to 70% cover in NMT3A.

During the fourth season (2020), the seeded plants continued to increase in in abundance, covering more than 100% of two of the plots (because of species layering). Black-eyed Susan and Lance-leaved Coreopsis decreased further, while late-flowering species, such as the asters and goldenrods, increased in all plots (Fig. 4b).

Obviously, the species in Mix A did not all establish evenly. Although, during 2017, we found young plants of 19 of the 22 seeded wildflowers and of Little Bluestem in at least one of the experimental plots, some species established themselves more quickly and abundantly. During the first season, these were Black-eyed Susan, Lance-leaved Coreopsis, Partridge Pea, Purple Coneflower, and Blanketflower (an annual, which had been added to the seed mixes as an afterthought) and, to a lesser degree, Mistflower, Wild Bergamot, Lavender Hyssop, and Phacelia (another annual, which also had been added to the seed mixes) (Fig. 4b).

In 2018, Lance-leaved Coreopsis and Black-eyed Susan became very common in the experimental plots that had been seeded with Mix A (Fig. 4b), but many other seeded species, such as Partridge Pea, Purple Coneflower, Brown-eyed Susan, Wild Bergamot, Lavender Hyssop, Mistflower, and—to a lesser degree--Dense Blazingstar, New England and Smooth Aster, Showy and Early Goldenrod, and Butterfly Milkweed also increased in abundance, and even a few individuals of Narrowleaf Mountainmint and Ohio Spiderwort, which had not been seen during the first season, began to appear. In 2019, Black-eyed Susan and Lance-leaved Coreopsis became less common, while most of the other species increased in cover. Roundhead and Slender Lespedeza, as well as Common Milkweed persisted through 2020 in very small numbers. The only seeded species that has not been detected at all during the first four seasons is Joe-Pye-Weed. Blanketflower and Phacelia, the two annual species which had been added to the seed mixes, flowered in the first season (2017) but did not reappear in subsequent years.

Wild-growing Species (Seed Mix A): As the seeded plants took up more space, the wild-growing plants in the experimental plots seeded with Mix A diminished, most drastically in the second year (Fig. 5a). They reached their lowest abundance in the third year. It remains to be seen if their slight increase in the fourth year is the beginning of a trend towards more wild-growing plants in the meadows in the future, or if the wild-growing plants will continue to remain few, possibly fluctuating somewhat from year to year.

The wild-growing plants were clearly more abundant in NMT2A and NMT3A than in NMT1A during the first season (Fig. 5b), with Crabgrass covering 85% and 65% of NMT2A and NMT3A at the end of the growing season, respectively (App. 10.1). Crabgrass was also the dominant wild-growing plant in all other experimental plots at the end of 2017. During the following two seasons, wild-growing plants declined markedly in all experimental plots that had been seeded with Mix A (reaching, at the most, 25% cover in 2018). They remained uncommon in NMT1A

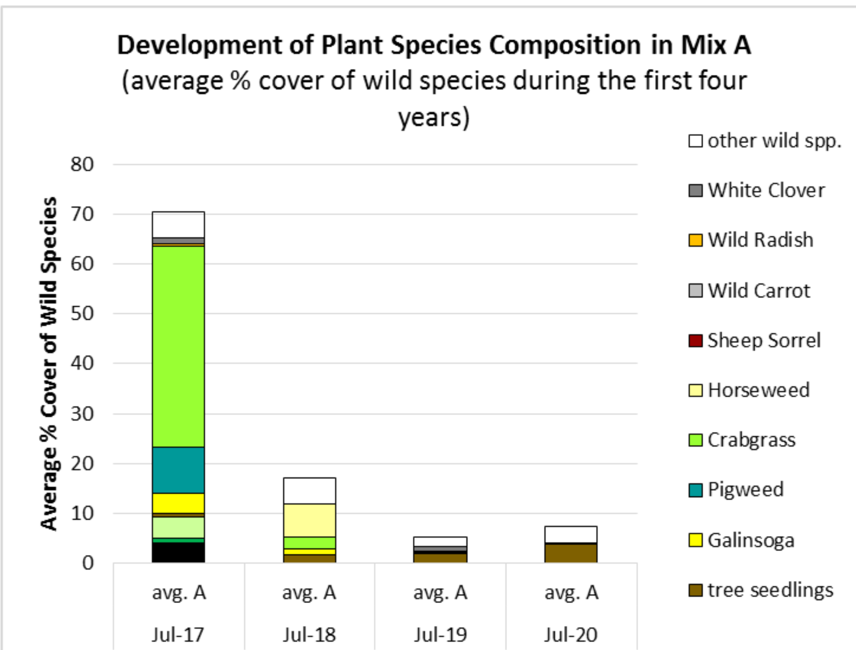

Figure 5a: Development of average vegetation composition (average % cover of wild-growing species only) in experimental plots seeded with Mix A during the first four years (2017-2020); the tree seedlings were mostly Cottonwood

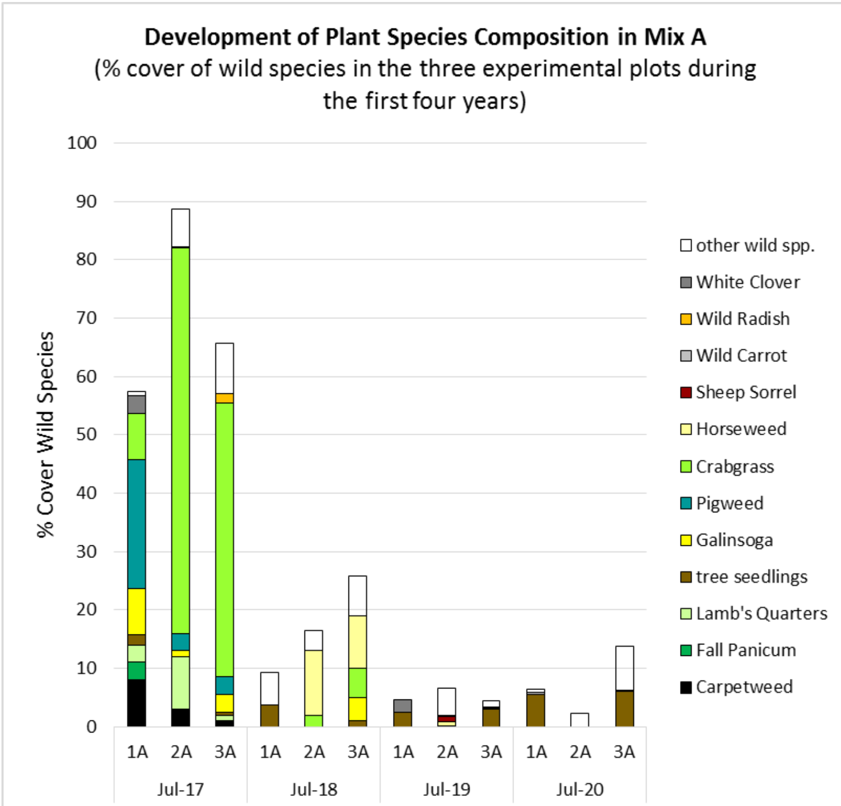

Figure 5b: Development of vegetation composition (wild-growing species only) in experimental plots seeded with Mix A during the first four years (2017-2020); the tree seedlings were mostly Cottonwood

and NMT2A, but increased a little to 14% cover in NMT3A in 2020. Young Cottonwood trees were the most common wild-growing plants in NMT1A and NMT3A starting in 2019.

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

Seeded Species (Seed Mix B): On average, in the plots seeded with Mix B, the native grasses asserted themselves during the third season (2019), at the expense of Black-eyed Susan and Lance-leaved Coreopsis, which nevertheless continued to be important components of the vegetation in these plots. By the fourth season (2020), native grasses had increased even more, and Lance-leaved Coreopsis and Purple Coneflower had become quite rare (Fig. 6a).

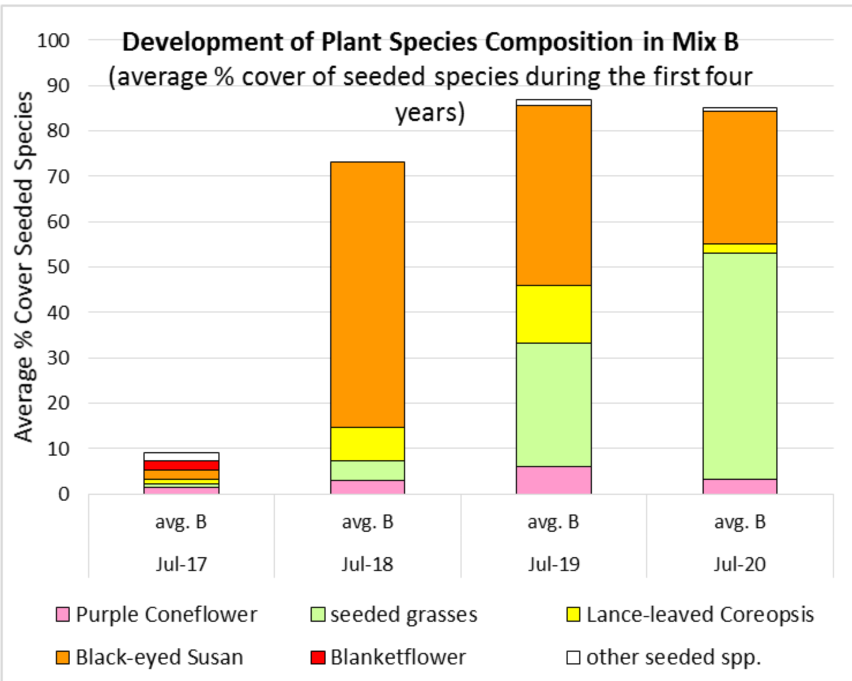

Figure 6a: Development of average vegetation composition (average % cover of seeded species only) in experimental plots seeded with Mix B during the first four years (2017-2020)

In NMTB2, the sandiest trial area, the grasses remained relatively uncommon and Black-eyed Susan remained abundant in the fourth season (2020; Fig. 6b).

In the experimental plots seeded with Mix B, the dominant species during the first season were Black-eyed Susan, Lance-leaved Coreopsis, and Blanketflower (Fig. 6b). The last did not persist into the second season. Of the native grasses, Little Bluestem and Canada Wildrye were most noticable in 2017. Native grasses steadily increased in abundance during the first four years. By 2019, all seeded native grass species were present, but Switchgrass, Indian Grass, Canada Wildrye, and Little Bluestem were the most abundant. Black-eyed Susan and Lance-leaved Coreopsis peaked in abundance in 2018 and became less (although they both remained prominent) in 2019. Purple Coneflower steadily increased during the first three years, although it never exceeded 10% cover and declined in all three experimental plots in the fourth year. Partridge Pea persisted in very low densities through 2018 and 2019, while Slender Lespedeza and Purple Prairie Clover were not observed during the first four seasons in any of the experimental plots seeded with Mix B.

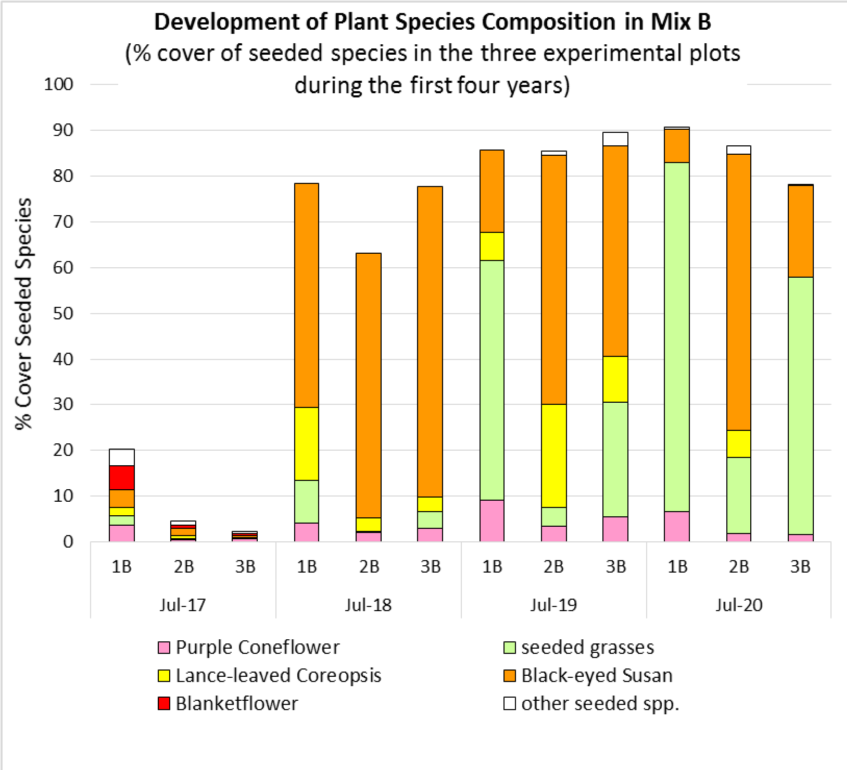

Figure 6b: Development of vegetation composition (seeded species only) in experimental plots seeded with Mix B during the first four years (2017-2020)

Wild-growing species (Seed Mix B): Wild-growing plants in the experimental plots seeded with Mix B followed a similar pattern to the one observed in Mix A. Wild-growing plants diminished substantially after the first season (Fig. 7a) and reached a low in the third year. However, they persisted at slightly higher overall densities than in the experimental plots seeded with Mix A (Fig. 5a).

During the first season, wild-growing plants were more abundant in NMT2B and NMT3B compared to NMT1B (Fig. 7b), similar to the pattern observed in the experimental plots seeded with Mix A (Fig. 5b), but this difference had also disappeared by 2019, when all of the plots seeded with Mix B hovered around 15% cover of wild-growing plants in mid-summer (Fig. 7b). Annual plants were the most common wild-growing plants in these plots during the first two seasons (Pigweed, Crabgrass, and Galinsoga in 2017, Horseweed in 2018). In 2019, the biennial Wild Carrot was the most common wild-growing plant in these plots, and in 2020 it was joined by a number of other wild species, including Hairy Chess and Black Bindweed (Fig. 7b).

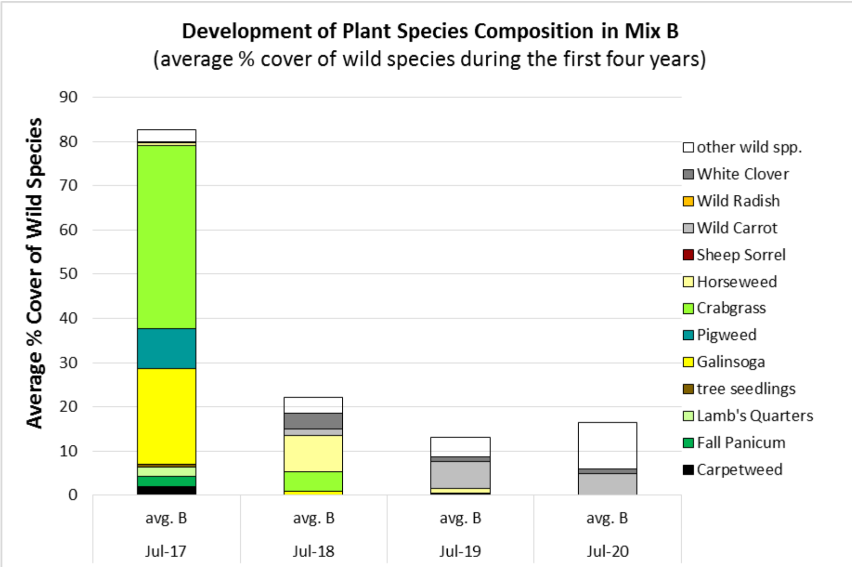

Figure 7a: Development of average vegetation composition (average % cover of wild-growing species only) in experimental plots seeded with Mix B during the first four years (2017-2020); the tree seedlings were mostly Cottonwood

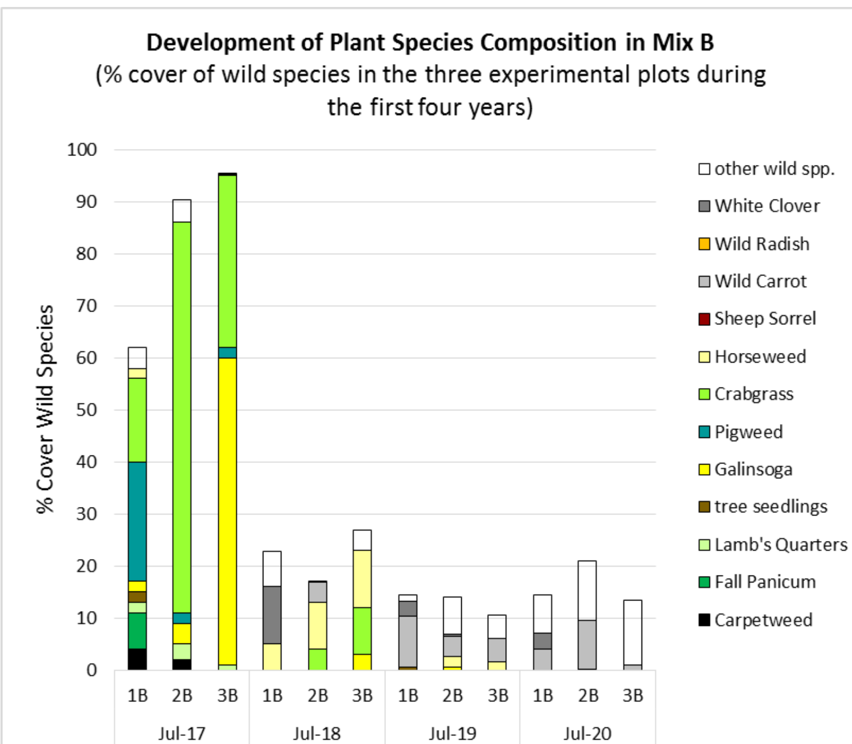

Figure 7b: Development of vegetation composition (wild-growing species only) in experimental plots seeded with Mix B during the first four years (2017-2020); the tree seedlings were mostly Cottonwood

Vegetation Development in Control Plots

Initially, the control plots were dominated by annual plants, such as Crabgrass and Galinsoga during the first season, and by Horseweed in 2018 and 2019 (Fig. 8a). In the fourth season, Horseweed had become noticably less and tree seedlings (mostly Cottonwood) were common. Cottonwood seedlings were already abundant in NMT1C in 2018 (Fig. 8b) and—after selective cutting of them in May 2019— they grew right back (to a height of 8 feet in one season!), and continued to increase in abundance in 2020 (Fig. 8b). The growing category of "other wild species" colonizing the fallow controls included Mugwort, Hairy Chess, Fleabane, Wood Sorrel, Vetch, and Canada Goldenrod.

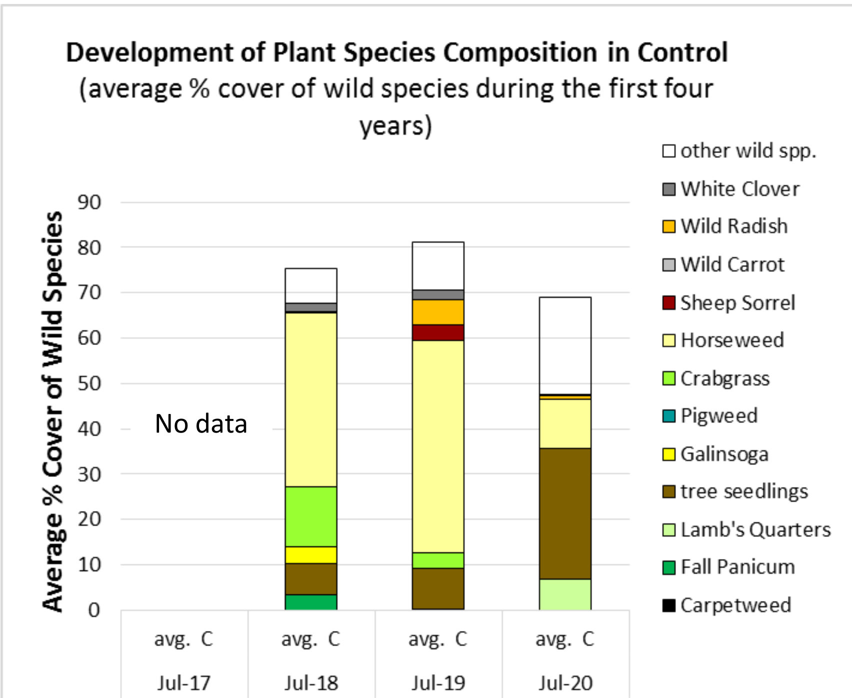

Figure 8a: Development of average vegetation composition in control plots (average % cover of wild-growing species) during the first four years (2017-2020); the tree seedlings were mostly Cottonwood

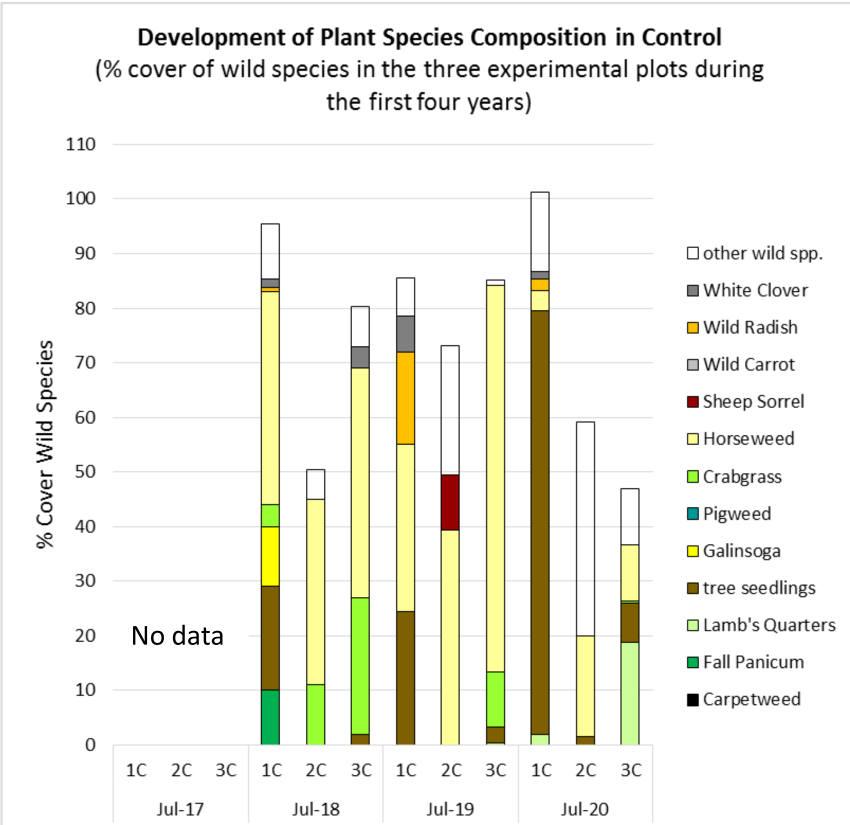

Figure 8b: Development of vegetation composition in control plots during the first four years (2017-2020); the tree seedlings were mostly Cottonwood

Comparison of Established Vegetation and Original Seed Mixes

It is also interesting to consider, how—after four years—the vegetation composition in the seeded meadows compares to the composition of the original seed mixes.

Seed Mix A vs. Established Vegetation: Figure 9 compares, for Seed Mix A, the species composition of the seeds planted in May 2017 and the average composition of the vegetation in those plots four years later (July 2020). Eight species (Wild Bergamot, Early Goldenrod, Black-eyed Susan, Partridge Pea, New England Aster, Showy Goldenrod, Lance-leaved Coreopsis, and Purple Coneflower), which made up 36% of the seeds are now composing 88% of the seeded vegetation. As shown in Fig. 5a, the wild-growing vegetation in these plots is on average less than 10%.

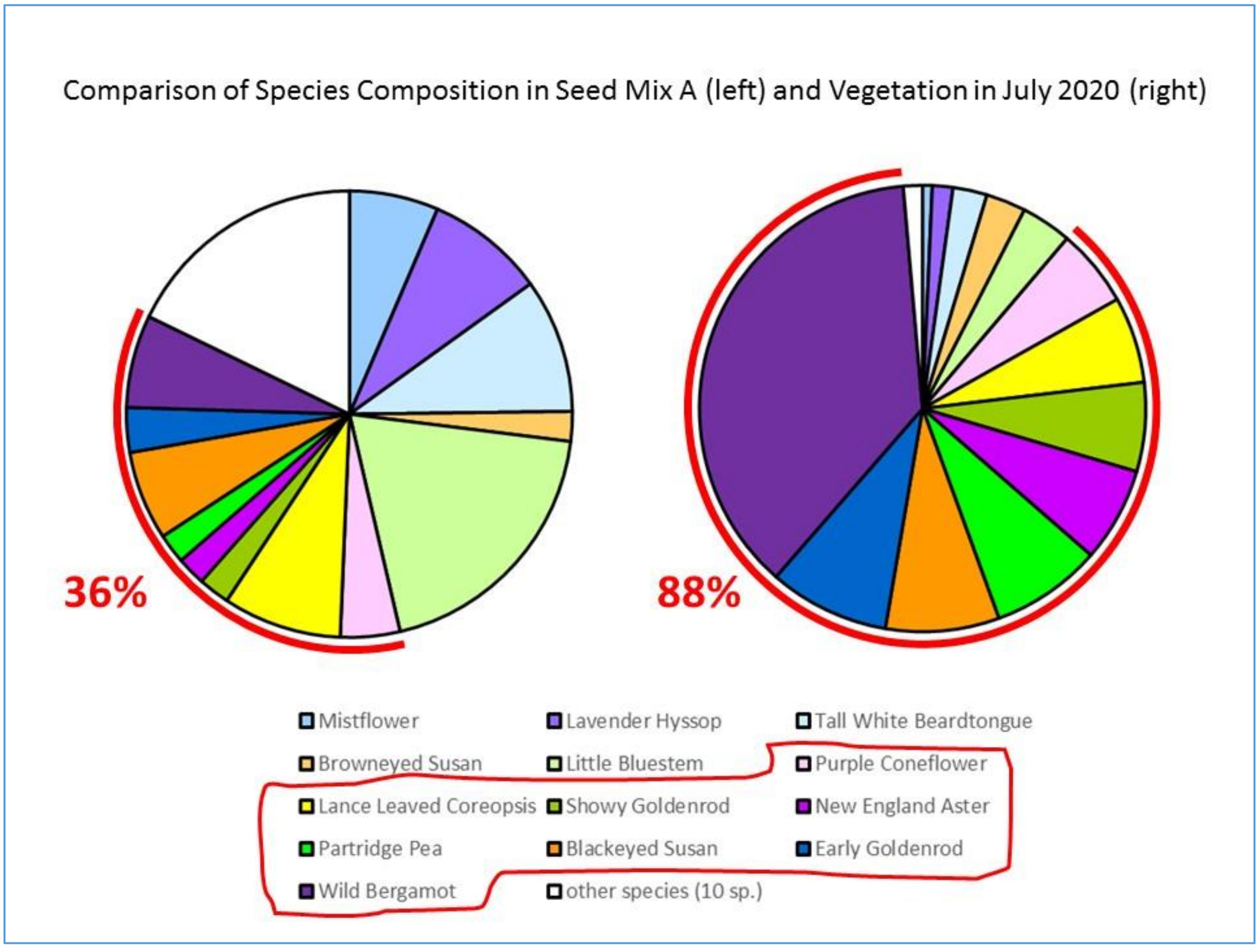

Figure 9: Comparison of the species composition in Seed Mix A (left) and the average composition of vegetation in the fourth year (July 2020; right) in the experimental plots seeded with Seed Mix A. The eight most successful species are highlighted in red.

Seed Mix B vs. Established Vegetation: Figure 10 illustrates that, although grass seeds made up 81% of Seed Mix B, even by the fourth year (July 2020) the seeded grasses made up on average only 50% of the seeded vegetation in the experimental plots seeded with Mix B. In contrast, Black-eyed Susan (6% of the seeds), made up 29% of the vegetation cover and 16% of the plots were still bare ground. Figure 10 also allows a closer look at the native grasses in Seed Mix B in comparison to their presence in the vegetation of the experimental plots seeded with Mix B in the fourth year (we use the October 2020 data for this comparison because grasses are notoriously difficult to distinguish early in the season, but by October they all have seed heads and are easily identified). Of the original eight native grass species in the seed mix, five (Switchgrass, Indiangrass, Big Bluestem, Canada Wild Rye, and Autumn Bentgrass) got established very well and now make up almost 100% of the grass vegetation. The smaller species, Little Bluestem and Purple Lovegrass, might have been crowded out by the taller species. Purpletop, although as tall as some of the others, just never really "took off".

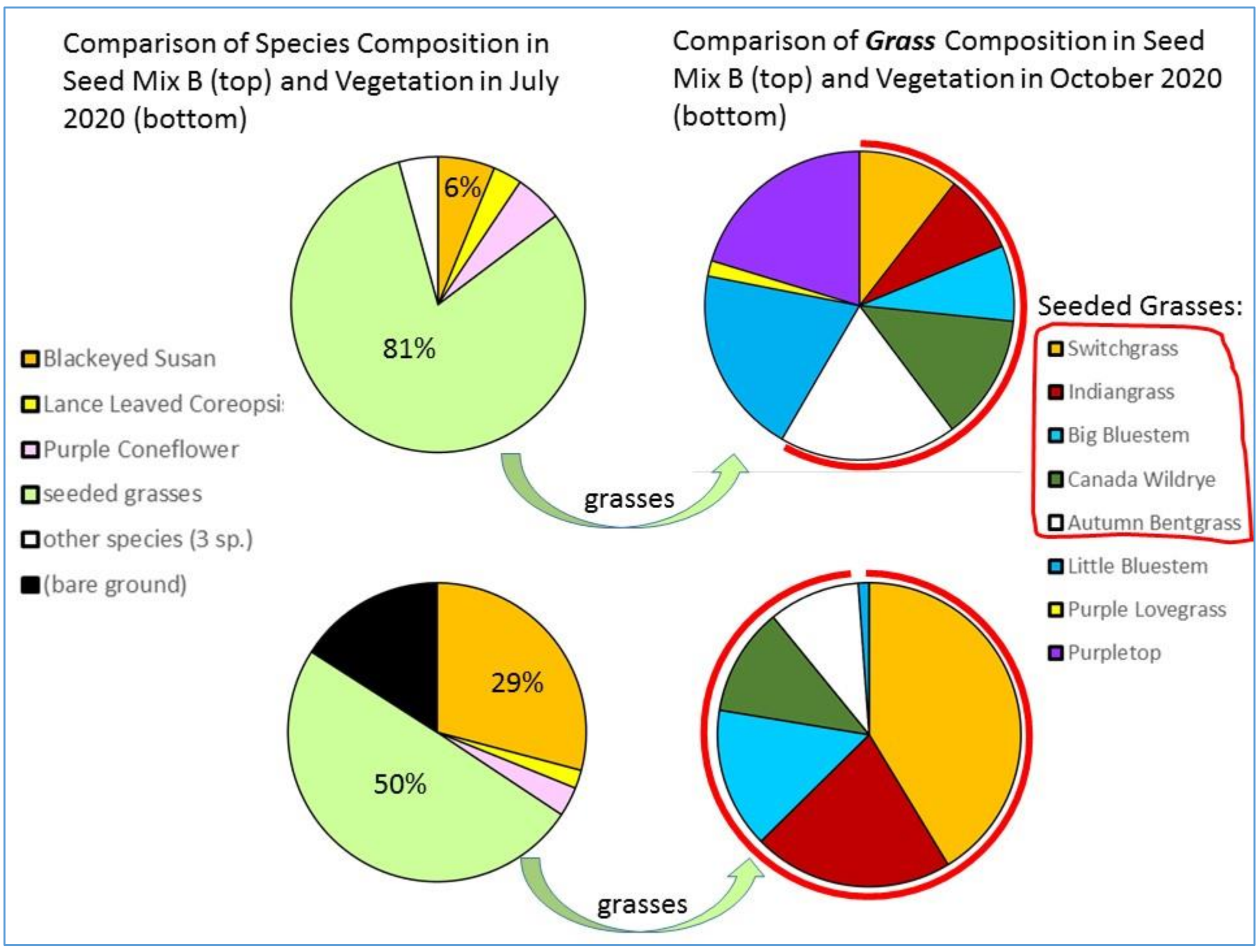

Figure 10: Comparison of the species composition in Seed Mix B (top left) and the average composition of vegetation in the fourth year (July 2020; bottom left) in the experimental plots seeded with Seed Mix B. The two pie charts on the right compare the composition of grass seeds (top right) and the average grass vegetation composition in the experimental plots seeded with Seed Mix B (bottom right; October 2020)

Flower Abundance and Diversity

In contrast to Figures 5 through 10, which describe the vegetation composition based on % cover each species contributes with all living plant material, the next set of graphs illustrates only the amount of flowers. Figures 11a through 11c show the average seasonal flower abundance of the most common flowers (all species with a flower abundance of at least 1% during any of the surveys) as well as the average total flower abundance in the experimental plots seeded with Mix A. Figures 12a through 12c show the equivalent data for the experimental plots seeded with Mix B, and Figures 13a through 13c for the control plots. *Note that, in order to illustrate the species-specific patterns, the vertical axes are not standardized across these figures.*

Flower Abundance in Wildflower-rich Experimental Plots (Seed Mix A)

We did not quantify the flower abundance in the first year, when it was minimal, because the meadows were kept mowed during the summer months to avoid seed set by wild-growing plants and to facilitate the establishment of seeded plants. During the second year (2018), the experimental plots seeded with Mix A had a high peak in overall flower abundance in early July, due to the abundant flowers of Black-eyed Susan (Fig. 11a). While Lance-leaved Coreopsis flowers had a small peak in June and suffused the Mix A plots with some light yellow, Black-eyed Susan flowers became very abundant in July and created a stunning visual display of a warm yellow (see App. 1.2 for NMT1A, App. 4.2 for NMT2A, and App. 7.2 for NMT3A). By early August, most of the Black-eyed Susan flowers had wilted, and Wild Bergamot was the most abundant flower, covering more area than Lance-leaved Coreopsis in June, but only 1/10th of the area covered by Black-eyed Susan in July.

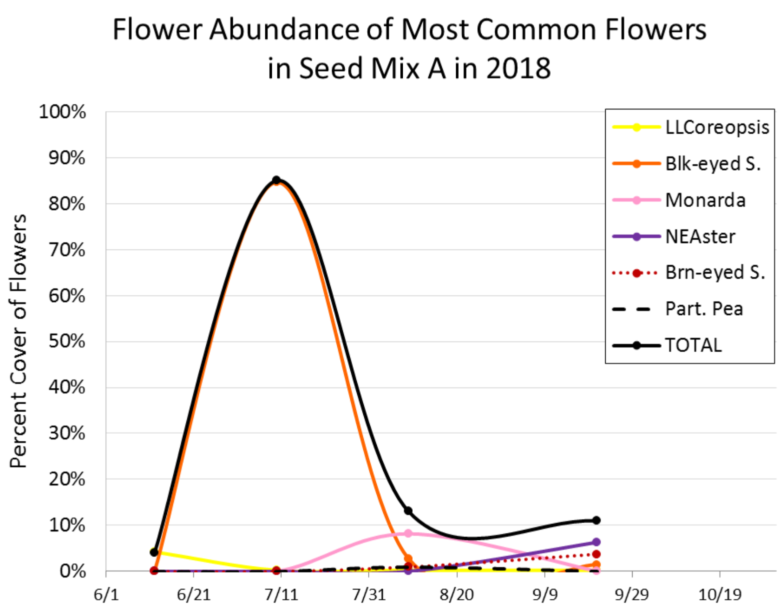

Figure 11a: Average total flower abundance and abundance of the most common flowers throughout 2018 in the three plots seeded with Mix A.

Although total flower abundance was substantially less in August compared to July, flower diversity was twice as high in August, with Wild Bergamot, Black-eyed Susan, Brown-eyed Susan, and Partridge Pea providing most flowers. By mid-September, total flower abundance increased again and the diversity of seeded plants in bloom continued to increase, as the remaining Black-eyed Susan flowers and the increasing Brown-eyed Susan flowers were joined by those of New England Aster and a number of less abundant flowers from seeded plants.

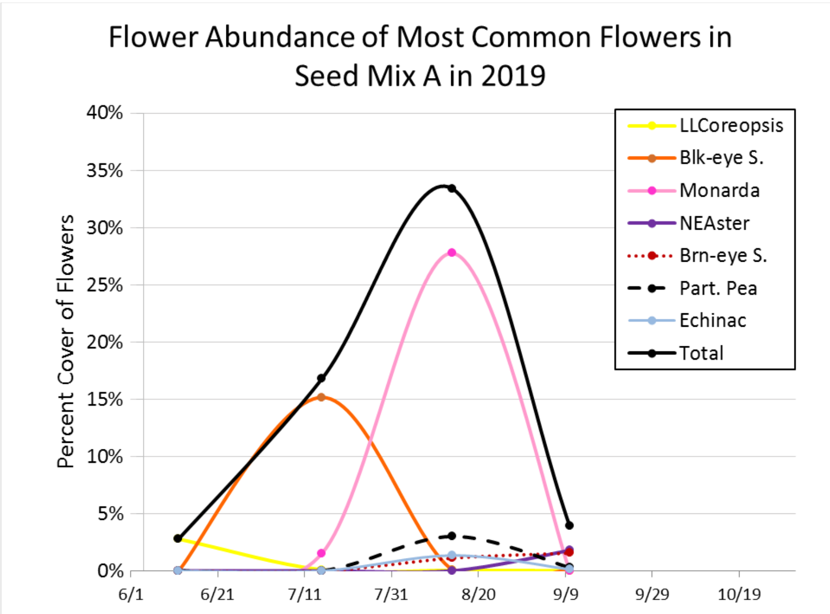

Figure 11b: Average total flower abundance and abundance of the most common flowers throughout 2019 in the three plots seeded with Mix A.

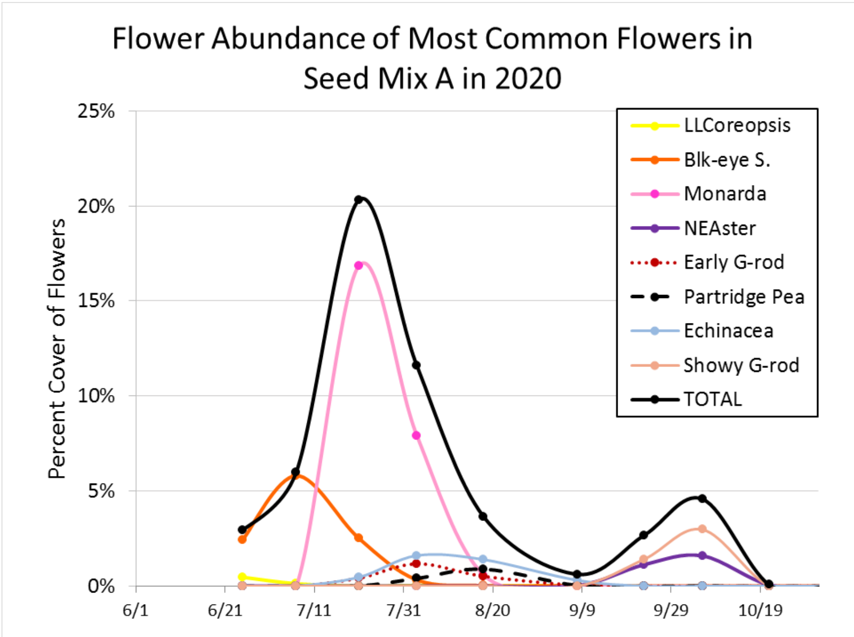

Figure 11c: Average total flower abundance and abundance of the most common flowers throughout 2020 in the three plots seeded with Mix A.

In 2019, total flower abundance in the Mix A plots was significantly less than the year before, peaked a month later, and flowers were distributed a little more evenly throughout the growing season (Fig. 11b). While Black-eyed Susan flowers still dominated the plots in July, their abundance was less than a quarter of that in the prior year. In turn, Wild Bergamot flowers tripled in abundance compared to the year before. While we did not quantify the flower abundance in late September, anecdotally we did observe another peak, composed mostly of New England Aster. Like in 2018, the number of seeded plants in bloom increased from month to month during the 2019 season.

In 2020, which had a very dry early summer, total flower abundance continued to decline (Fig. 11c). That year, we continued our sampling into the fall and documented the autumn flower peak we had observed, but not quantified in 2019. Earlier in the summer Black-eyed Susan and Wild Bergamot again created the two most noticeable flower peaks. However, in contrast to the prior year, Black-eyed Susan flower abundance peaked at least a week earlier and Wild Bergamot about three weeks earlier than in 2019.

Flower Abundance in Grass-rich Experimental Plots (Seed Mix B)

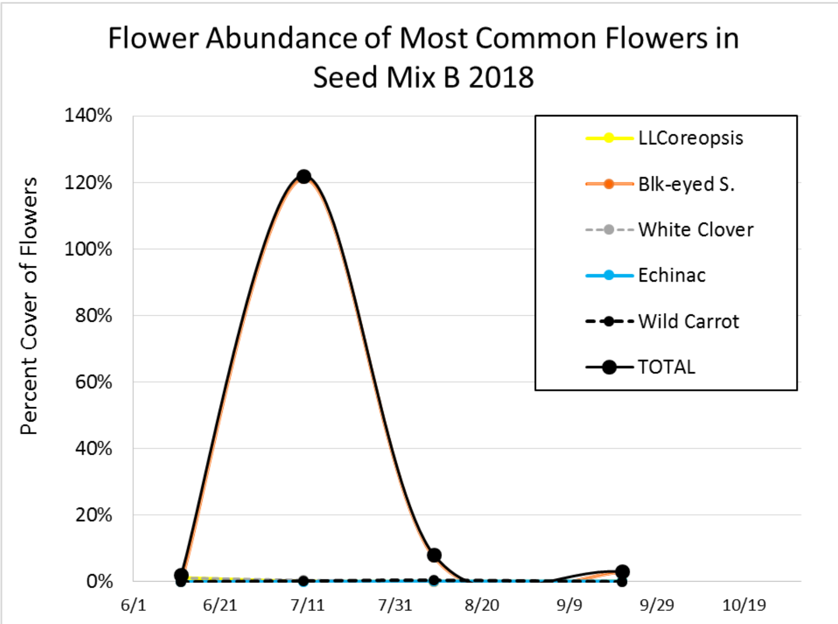

Figure 12a: Average total flower abundance and flower abundance of the most common flowers throughout 2018 in the three plots seeded with Mix B.

During the second year (2018), the experimental plots seeded with Mix B—similar to those seeded with Mix A—had a very high peak in flower abundance in early July almost exclusively composed of Black-eyed Susan (Fig. 12a). However, Mix B resulted in a much lower peak of Lance-leaved Coreopsis (barely reaching 1% cover) in June of the second year (2018), with only approximately a quarter of the flower abundance observed in Mix A at the same time (see App. 13.2, 14.2, and 15.2 for side-by-side comparisons of Mix A and B in NMT1, 2, and 3, respectively). This was to be expected, because the seeding rate for Lance-leaved Coreopsis in Mix B was less than half that in Mix A. White Clover (not seeded!) also contributed some flowers (just above 1%) in June in the experimental plots seeded with Mix B. In July, Seed Mix B was even more dominated than Mix A by the flowers of Black-eyed Susan. Also present were small amounts of flowers of Lance-leaved Coreopsis, as well as White Clover and Wild Carrot (the last two not seeded). In August, there were still some Black-eyed Susan flowers, accompanied by Wild Carrot. By September, there were very few flowers left in Mix B plots. As shown in Figure 12b, a similar pattern repeated itself in the Mix B plots in 2019, but—as in the Mix A plots—the July peak of Black-eyed Susan was markedly lower than the year before. The seeded Purple Coneflower (*Echinacea*) reached just above 1% flower cover in August, while White Clover did not reach 1% in flower cover at any point in 2019.

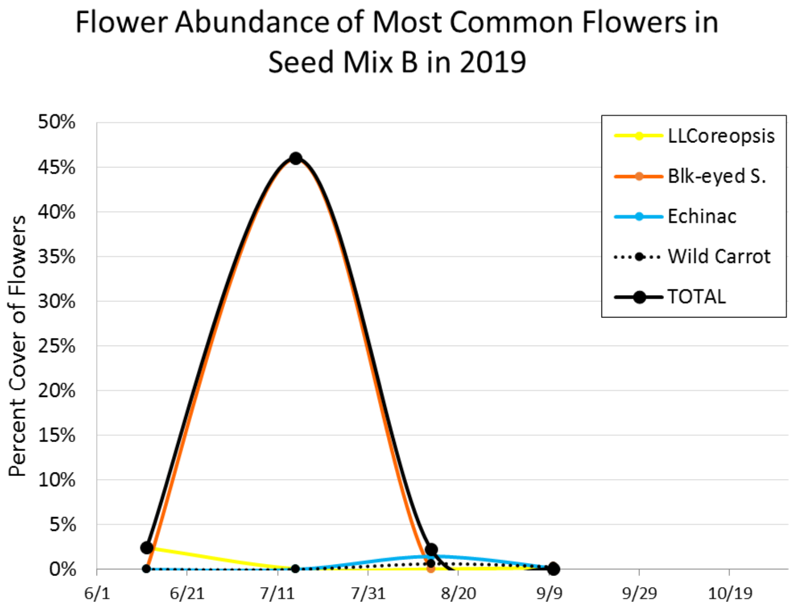

Figure 12b: Average total flower abundance and flower abundance of the most common flowers throughout 2019 in the three plots seeded with Mix B.

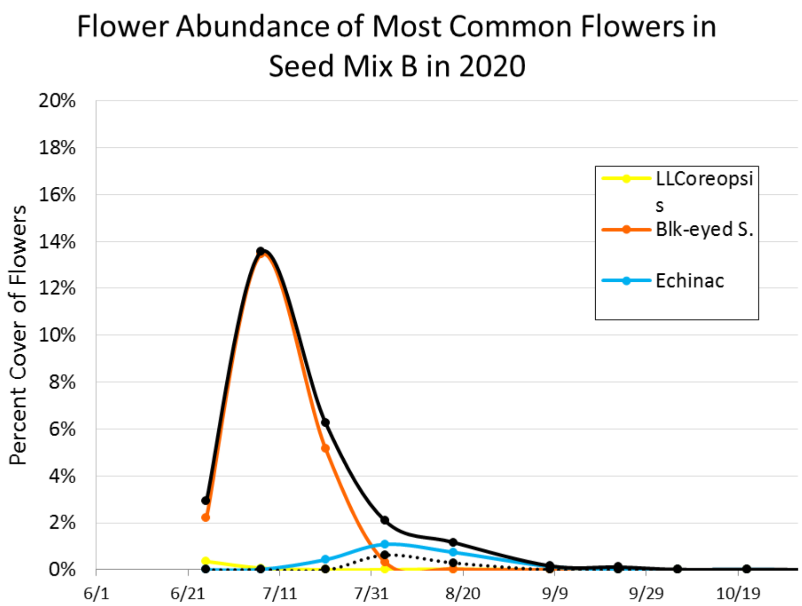

Figure 12c: Average total flower abundance and flower abundance of the most common flowers throughout 2020 in the three plots seeded with Mix B.

In 2020, total flower abundance in the experimental plots seeded with Mix B continued to decline and the peak in Black-eyed Susan was also a week earlier than in 2019.

Flower Abundance in Control Plots

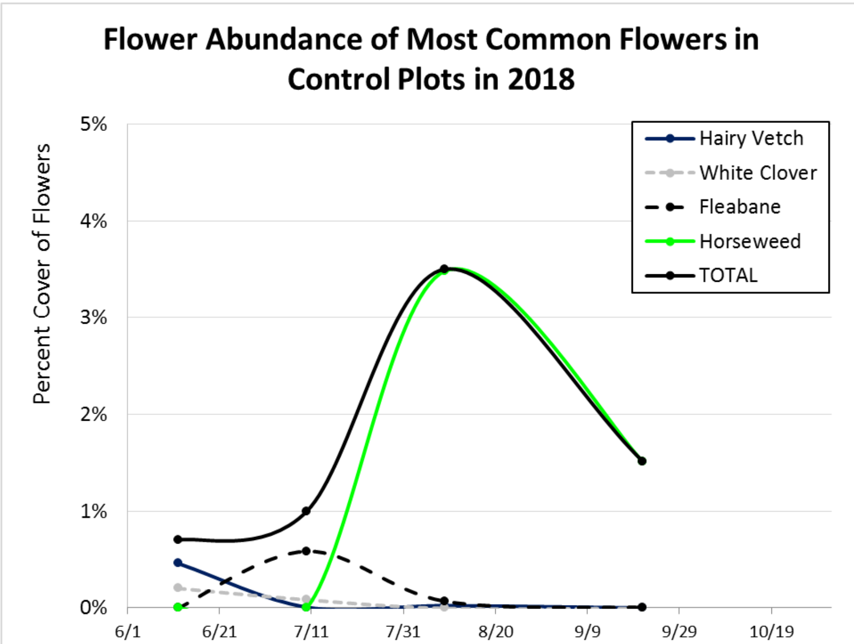

Figure 13a: Average total flower abundance and flower abundance of the most common flowers throughout 2018 in the three control plots.

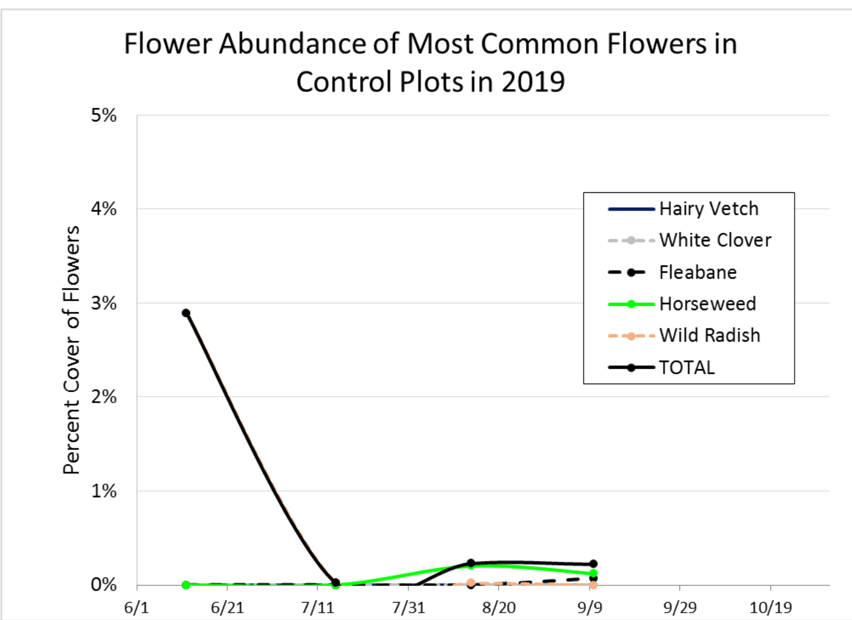

Figure 13b: Average total flower abundance and flower abundance of the most common flowers throughout 2019 in the three control plots. The early-season peak in total flower abundance is masking the identical peak of Wild Radish, which basically accounted for all the flowers observed in early June.

While the control plots had a higher diversity of wild-growing plants in bloom throughout 2019 and 2020 than the plots seeded with Mix A or B (Fig. 15), very few species reached a flower abundance of at least 1% cover. In 2018, Annual Fleabane reached it in July and Horseweed in August and September (Fig. 13a). In 2019, only Wild Radish flowers reached more than 1% cover in the control plots in June (Fig. 13b). This result was somewhat surprising, because Horseweed plants were very abundant in the control plots in both years (Figs. 8a & 8b) and flowered profusely. However, the individual flower heads of this species are very small and our sampling technique (based on our estimate of the number of flower heads in the samples) might have resulted in an underrepresentation of Horseweed flower abundance.

Total flower abundance in the control plots dropped below 1% cover during all our sampling dates in 2020 (Fig. 13c).

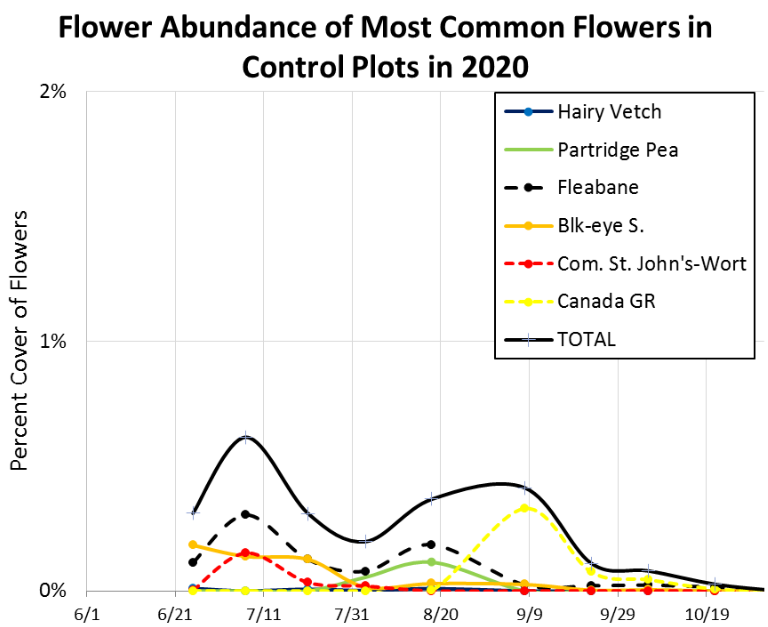

Figure 13c: Average total flower abundance and flower abundance of the most common flowers throughout 2020 in the three control plots.

Comparison of Total Flower Abundances

Figure 14 shows the average total flower abundance in the three treatments in 2018, 2019, and 2020 side by side *with the vertical axes standardized to allow for quick comparisons*. While Mix B had a higher peak of flowers in July during the second and third years (2018 & 2019) Mix A continued to produce flowers into the fall. Total flower abundance was highest in the second year in both treatments and dropped in both treatments in subsequent years. While flower abundance tended to be more evenly distributed over the growing season in Mix A from the beginning, in the fourth year (2020), Mix A also had for the first time a higher total flower abundance than Mix B. The control plots had a comparatively very low flower abundance throughout these years. (But see above comment about a possible underestimation of Horseweed flowers with the method we used to calculate flower abundance.)

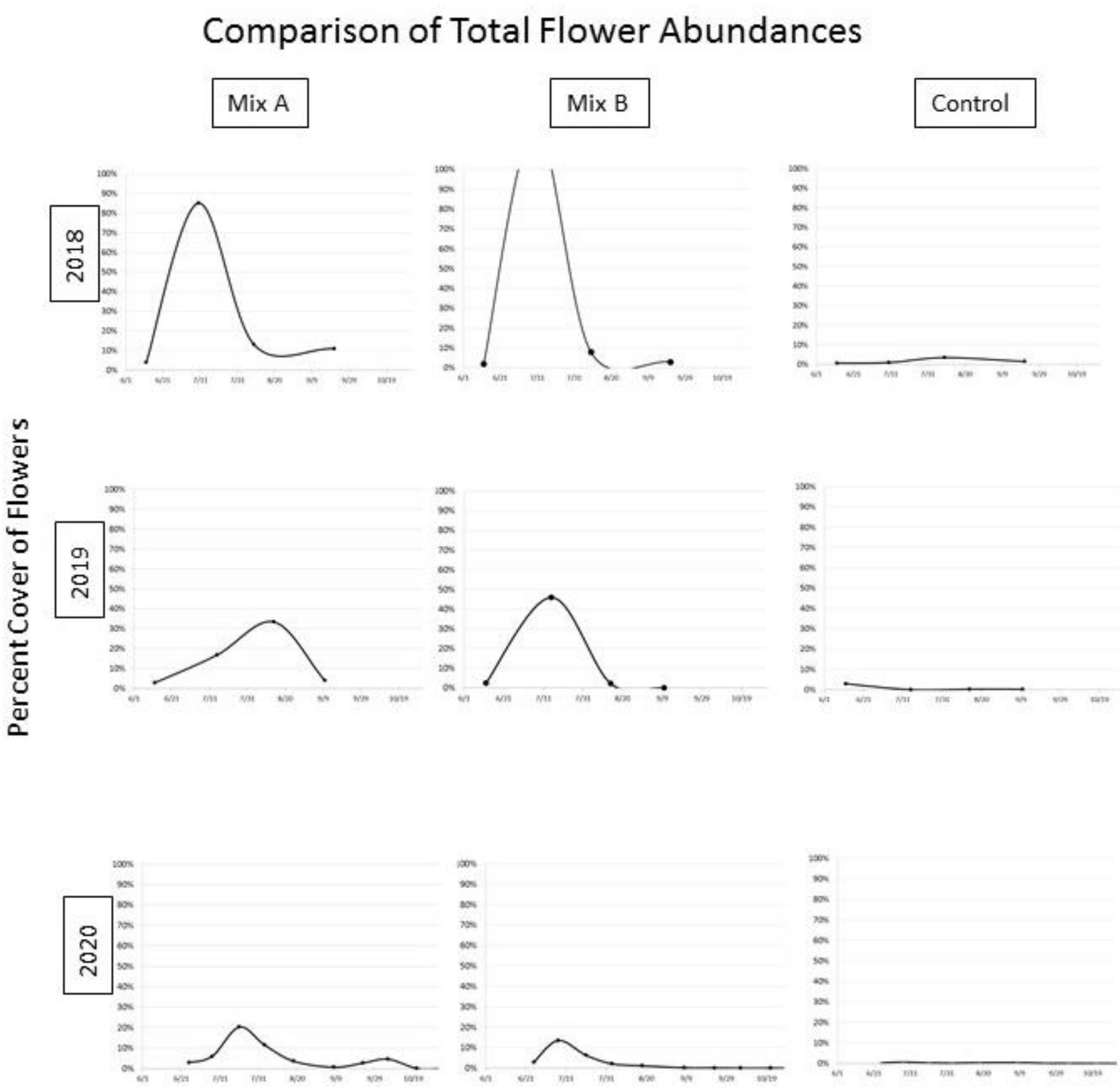

Figure 14: Average total flower abundance in the three treatments from 2018 – 2020. In contrast to Figures 11-13, which show the same data, here the vertical axes are standardized to allow for quick comparisons.

Flower Diversity

It is interesting to note in Fig. 15 how the diversity of wild-growing plants with insect-pollinated flowers, which we observed throughout each year in the three treatments, was quite similar during the first two years (2017/18), but diverged markedly in 2019, and even further in 2020. The diversity of wild-growing flowers in Mix B declined during the latter two years (as the seeded native grasses took up more and more space), while it soared in the control plots, which—even in the fourth year—continue to have open ground and space for new plants to colonize. It is also interesting how this increase in flower diversity in the control plots (Fig. 15) has not been reflected in an increase in flower abundance (Fig. 14). As expected, the diversity of seeded plants in bloom throughout the years was consistently higher in Mix A than in Mix B or the control plots. However, after an increase from 7 to 13 species during the first two years, the diversity of seeded plants in bloom in Mix A did not increase further and hovered between 13 and 15 species in 2019 and 2020. Note that a couple of species seeded in neighboring experimental plots in 2017 found their way into control plots and contributed to the flower diversity in 2019 and 2020. Overall flower diversity seems to be still increasing in the control plots, while it might have plateaued in Mix A and is even declining in Mix B.

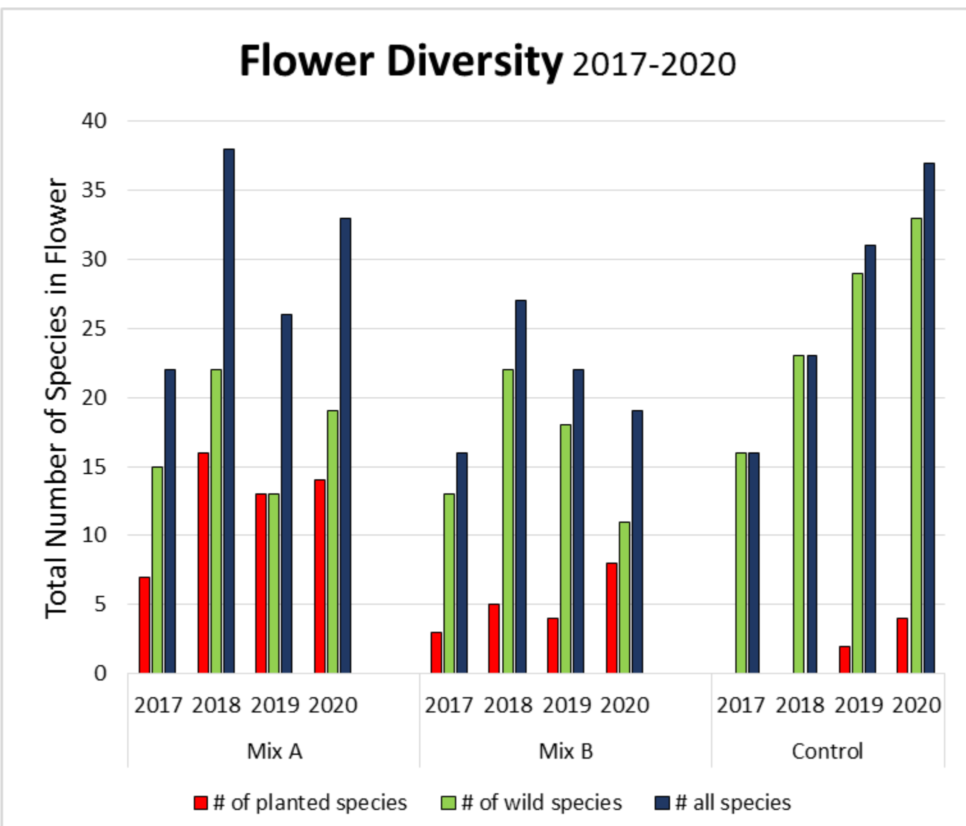

Figure 15: Total number of insect-pollinated plants in flower in each treatment over the first four years.

Invertebrate Monitoring

The results from the invertebrate monitoring in the native meadow trials are summarized in the entomology reports by Vispo (2018) and Vispo et al. (2020, 2021). The results from the monitoring of flower visiting insects are presented in Allen (2019), Vispo (2018), and Vispo et al. (2020).

Soil Conditions

The soil samples taken in spring of 2017 (before the plots were seeded) and in spring of the second and third year (2018 and 2019) 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, but worst in experimental plot NMT2A. Root pathology was very variable across the experimental plots, with NMT2A ranking worst and NMT1A pretty good. Water holding capacity was ranked high in trial areas NMT1 and 3, but only intermediate in NMT2 (worst in NMT2A and B).

Figure 15 illustrates the differences in soil texture between the experimental plots in 2017. Trial area NMT2 has the sandiest soils (classified as sandy loam to loamy sand), while NMT3 has the siltiest (classified as sandy loam, loam, and silt loam). The soils of trial area NMT1 are intermediate in their soil texture (classified as sandy loam and loam).

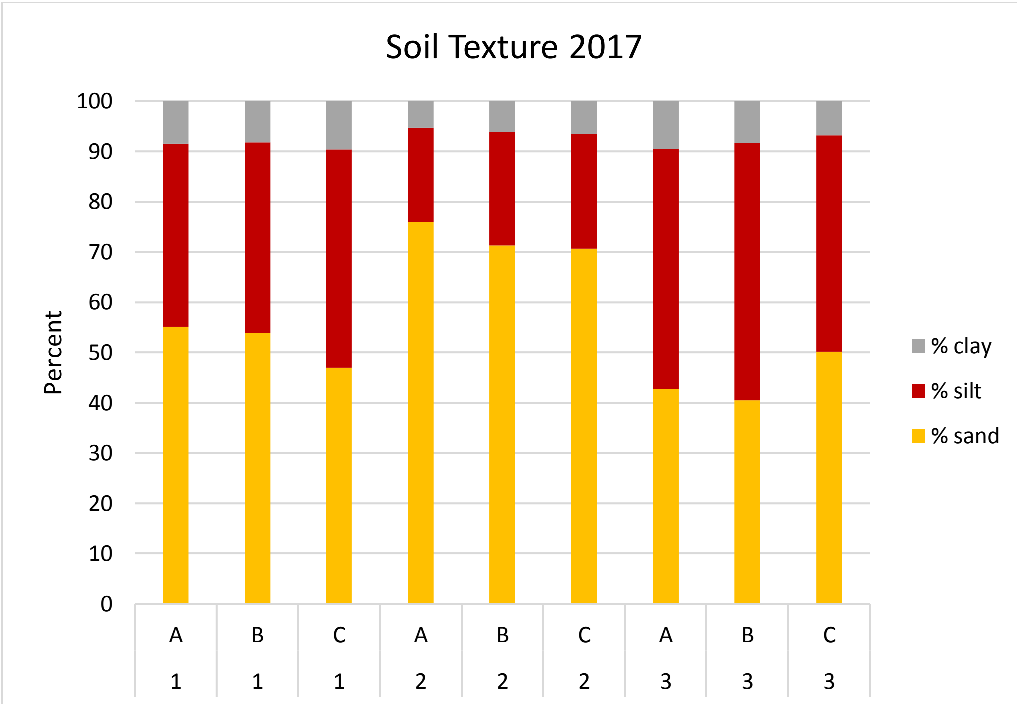

Figure 14: Soil texture of the experimental plots according to the 2017 soil samples (please note that A1, B1, C1, etc. refers to experimental plots NMT1A, NMT1B, NMT1C, etc., respectively).

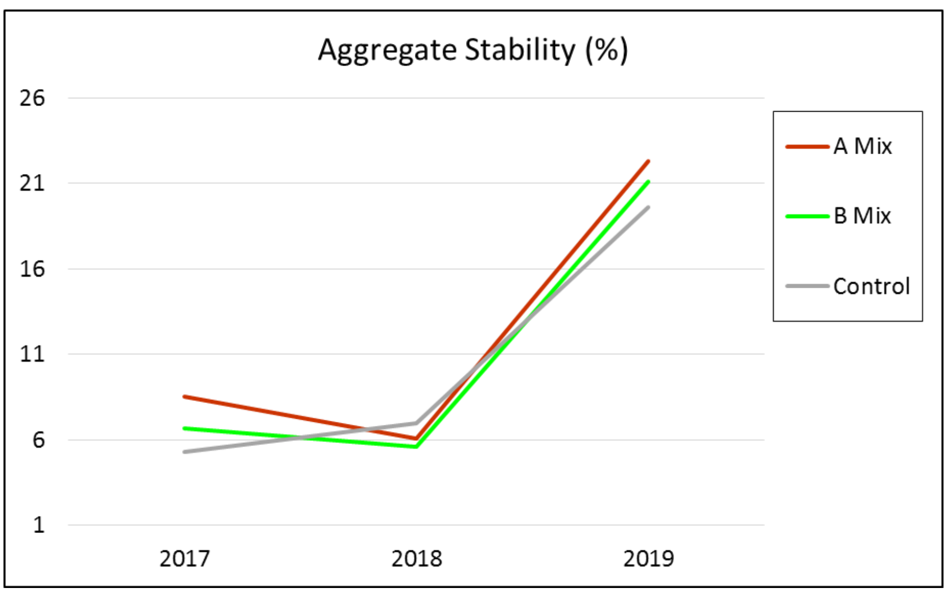

Figure 15: Comparison of average aggregate stability in the three treatments over the first three years.

The 2018 and 2019 test results showed no consistent trends over time or between treatments in some variables, such as water holding capacity, soil respiration, and root pathogens. Other variables changed in all treatments over time. For example, the somewhat excessive phosphorous values in 2017 became less and were evaluated as ideal across the experimental plots in 2018 and 2019. Potassium showed a similar trend of diminishing values across all experimental plots. On the other hand, aggregate stability, while not changing much between May 2017 and May 2018, had increased markedly in all three treatments by May 2019 (Fig. 14)

While some of the soil variables changed over time across treatments, most did not show any consistent differences in the development of the soils due to experimental treatments (Mix A, Mix B, or control) between 2017 and 2019. However, organic matter might be an exception. While percent organic matter increased in all treatments between 2017 and 2018, the 2019 data might indicate the beginning of a trend for a differentiation between the treatments (Fig. 15), with organic matter continuing to increase in the experimental plots seeded with Mix A and Mix B, but decreasing in the control plots. Time will tell, whether these 2019 data are part of an overarching trend towards faster accumulation of organic matter in the seeded plots.

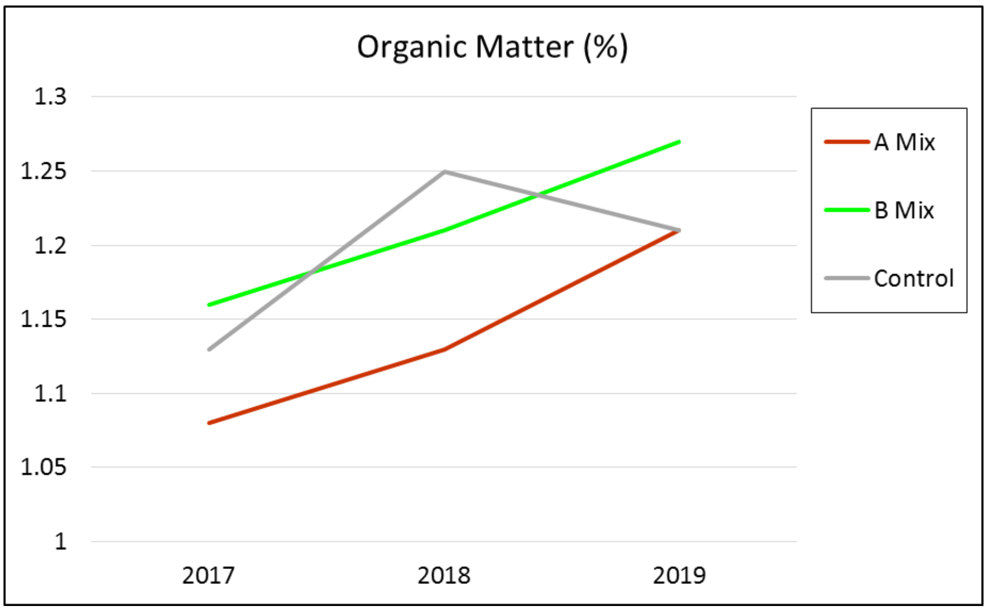

Figure 16: Development of Percent Organic Matter in the three treatments over the first three years.

Labor and Equipment

Starting with the site preparation in early Spring 2017, Table 3 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).

Table 3: 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, *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, 2021	Mowing	0.7	Rotary Mower
	June-Sept	Selective Weeding/ Cutting	6.8	by hand; Clippers, Loppers, String Trimmer (Mugwort)

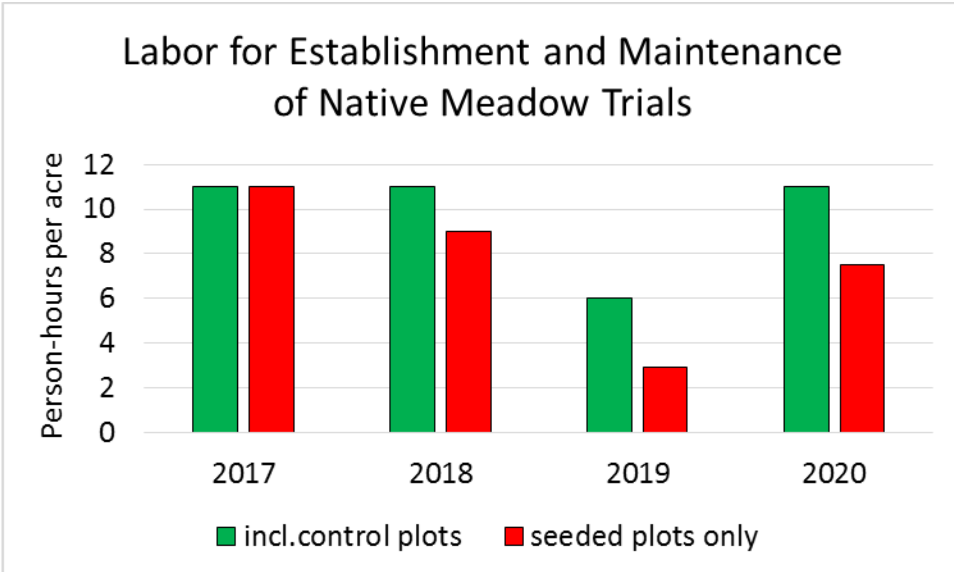

Figure 17: A summary of the labor applied to the establishment and maintenance of the native meadow trials during the first four years. The green bars represent the labor applied across all treatments, including the control plots. The red bars represent the labor applied only in the seeded native meadows.

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 ranged from 3 to 9 person-hours per acre per year.

The more diverse seed mix (Mix A) resulted in a more diverse set of flowers and the presence of flowers over a longer period (June through October) compared to Mix B. In the third and fourth year, Mix A also had a higher flower abundance than Mix B. However, in contrast to the fallow control, the diversity of flowers in Mix A might have peaked in the second year, while the diversity of flowers in the fallow control has been steadily increasing over all four years. The flower abundance in the fallow control remains very low compared to the seeded meadows.

While the insect monitoring shows preference of certain insect groups (including butterflies, bumblebees and some other native bees, as well as Honey Bees) for the diverse seeded meadows, others (including wasps, most of which are considered of benefit to the crops), did not seem to be attracted to the seeded meadows. Beneficial wasps, as well as certain pest insects (Tarnished Plant Bugs, weevils, and flea beetles) were more common in the fallow control plots. In addition, some pests (such as leafhoppers and aphids) were more widely distributed, occurring in high numbers in both native meadows and the control.

We have not yet fully explored our data to determine the relationship between flower abundance and the abundance of different insects. In the future, we hope to learn if there is any evidence for one-on-one relationships between plant and insect species. It will also be interesting to see, if--and to what degree—more flowers translates into more insects. Is there a point where the insect populations seems "saturated" by flowers?

ACKNOWLEDGEMENTS

I thank Kelly Gill of the Xerces Society for her advice and patience in answering all my questions; the farmers at the Farm Hub for all their help with the preparation, establishment, and management of the test plots; Erin Allen, Brenna Bushey, Dylan Cipkowski, Jackie Edgett, Molly Fava, Kenny Fowler, Julia Meyer, Nellie Ostow, Stephanie Ripsom, Ellen Scheid, Rosa Villegas, Conrad Vispo, and Otter Vispo for help with the management as well as for their assistance with the data collecting and analyzing; and Anne Bloomfield for helping coordinate it all.

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