Final Report

Seed Mix Experiments and Analysis of Native Seed Supply for the Pollinator Habitat Initiative

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Executive Summary

We examined the relationship between seed mix design, native seed supply, and delivery of ecosystem services by the Conservation Reserve Program, using the CP-42 Pollinator Initiative in Iowa from 2015 to 2019 as a test case. Iowa farmers enrolled over 237,000 acres into this program over a short time, an achievement that is noticeable on the Iowan landscape.

We sought to document the challenges in providing appropriate seed for farmers enrolling in the CP-42 program between 2015 and 2017. **Despite a large spike in demand for native seed due to this program, pollinator seed mixes maintained many basic minimum objectives.** Overall seeding rate of 40 seeds per square foot, and a 3:1 ratio of forbs to grasses was achieved. The minimum distribution of early, mid- and late-flowering forb species was attained, at least nominally, and seed mixes averaged an impressive 33 species. Prices paid by farmers for seed rose just 30.1% at peak implementation in 2017. This price rise was low compared to the 97% increase in price of a standard benchmark mix assembled in 2015.

While these facts could be taken as evidence of success, they were achieved by substituting long-lived species of high conservation value with short-lived and common species, and seeds from distant origins that are potentially maladapted to site conditions. To attain early-flowering species in the mix, species were included that rarely established from seed. Critical shortages of native seed, and subsequent imports from outside the region, contributed to the widespread introduction of Palmer amaranth. **Market adaptations to high demand likely compromised the delivery of expected ecosystem services from the CRP program.** A meeting of midwestern native seed producers, buyers and regulators at the University of Northern Iowa produced several strategies and policy recommendations to improve the quality of native plant materials for the CRP program.

Evaluation of the effectiveness of the CRP program to meet program objectives is hampered by the lack of common methodology and data analysis. Seed mix specifications can be compared based on cost-effectiveness, when effectiveness is appropriately defined in multifunctional terms. **We developed a flexible template for vegetation sampling and data analysis that can be broadly applied in grassland habitats, to quantify cost-effectiveness and other performance metrics associated with seed-based revegetation projects**.

Technical specifications for seed mix design and establishment methods form the basis for delivering desired ecosystem services for the CRP program, but little research exists to explicitly test and compare various strategies. In a replicated, randomized trial, we compared two specialized seed mixes addressing general habitat and soil erosion (CP-25) and pollinator habitat (CP-42) with a seed mix designed on ecological restoration principles: high functional group diversity, balanced seeding density of grasses and forbs, and adapted to the site's soil conditions. **In a published study, the seed mix designed on ecological restoration principles produced a plant community that was more broadly functional at excluding weeds, providing ground cover, and supporting pollinators than either of the specialized mixes.** We initiated a second experiment at a new site to attempt to replicate these results, adding a planting time treatment that shows promise for further improving measures of cost effectiveness in eastern Iowa.

Ultimately, the success of a given CRP program must be measured on the ground, but resources for monitoring and evaluation are limited. Over two years, we recruited, trained and managed a 9-person research crew to conduct high-intensity surveys of vegetation, bees and butterflies on a random sample (N=45) of three-year-old sites in eastern Iowa for which the original seed mix data could be obtained. In the process we developed training modules and procedures which could be applied to other locations. Analysis of this large dataset is ongoing. **Preliminary results indicate high variability in vegetation outcomes compared to the seed mixes, with half of sites dominated by weeds, and a small number of planting failures. On average, establishment was 2.9% of initial seeding rate. In restoration ecology terms, this would be a poor outcome.** Crucial data on each site's planted seed mix and seed cost were not readily available. However, should these data gaps be filled, they could be combined with vegetation monitoring to evaluate measures of cost effectiveness for the program. Anecdotally, farmers and landowners were generally enthusiastic about their enrollment in CP-42, and curious about our findings. Each landowner received a report with quantitative findings.

Research and Policy recommendations

1) Native Seed Market:
    a) Investigate means to include seed supply chain considerations and strategic communication in the roll-out and administration of new CRP programs.
    b) Improve procedures to retain planted (in addition to planned) seed mix and price information at the contract level.
    c) Consider how seed specification policies affect competitive seed markets at the regional level; identify policies that maintain high quality native plant materials and reduce risk of weed seed introduction.

2) Seed mix design strategy and planting specifications:
    a) Test multifunctional vs. specialized seed mix strategies using controlled field experiments; validate in multiple locations
    b) Test methods for reducing seeding rates and improving establishment, e.g. dormant season vs. growing season plantings, nurse crops to guard against loss from extreme weather; diversionary seed to reduce predation

3) Monitoring and evaluation should be built in to CRP program by creating capacity for a monitoring program
    a) Monitor a sample of CRP plantings throughout their contracts to detect potential issues
    b) Pair establishment outcomes with the seed plan, seed mix, and implementation and management records to better understand where the barriers to success are. This allows decision makers to distinguish the appropriate level for improvement, whether it be seed mix design strategy, seed mix specifications, actual seed mix planted, implementation practices, site factors, or management practices

Introduction

The Conservation Reserve Program (CRP) strives to deliver particular ecosystem services in a cost-effective manner, and earn the support of local users. While we know that the technical knowledge and experience of NRCS field offices and contractors is important for the successful implementation of individual contracts, this is only one component of the process. The success of any given CRP program hinges, in part, on the general seed mix specifications, the performance of the resulting plant community, and the ability of the native seed industry to meet the demand for appropriate seed in the time frame of the program.

Our project was designed to examine the relationship between seed mix design, native seed supply, and delivery of ecosystem services of the resulting plant communities. We used the CP-42 Pollinator Initiative in Iowa as a test case. We sought to understand a) the cost-effectiveness of using specialized seed mixes versus a multiple-benefits seed mix design, b) the successes and failures of the native seed industry to supply appropriate seed for the CP-42 program between 2015 and 2017, and c) the vegetation and pollinator outcomes in a sample of even-aged CP-42 fields in eastern Iowa.

Unsurprisingly, these are challenging questions. On the seed mix design side, one approach is to document the vegetation of existing contracts and make correlations with the seed mix (retrospective surveys). However, the many uncontrolled variables such as soil type, site preparation, weather immediately pre- and post-planting, and a myriad other variables make it difficult to draw inferences. Any test of the cost-effectiveness of seed mixes requires the ability to control those variables, and to alter the seeding rates systematically. Few such tests exist, especially for seed mixes relevant to CRP programs. Moreover, results of experimental plantings take 3-4 years to obtain, and then must be repeated at different sites and years.

On the seed supply side of the question, the success of the native seed industry in supplying CRP seed can only be quantified by sampling of the seed mixes actually planted over the life cycle of a program (as opposed to the plans provided by NRCS field offices). The geographically-dispersed private companies who supply native seed to farmers, and the other partners in the supply chain (seed testing labs, brokers, regulators, large buyers) are not coordinated, nor do they have a uniform or objective perception of how the system works.

Finally, there is little capacity within the NRCS or FSA to measure vegetation outcomes of a particular conservation practice, so the relationship between program specifications and ecosystem service outcomes has so far remained murky—based on casual observation or low-resolution, rapid assessments. To compound matters, it is not easy to link vegetation data to the original seed mix that was planted, or cost paid for the seed. Thus, the cost-effectiveness information we seek is difficult to obtain on several levels.

Section 1 of this report details native seed market dynamics between 2014 and 2018, during the “CP-42 boom,” and documents the multi-level consequences for seeding quality. We draw individual seed mix costs from FSA contract data. We also report the insights gained from a series of interviews with native seed stakeholders, and a one-day conference attended by 46 members of the native seed supply chain from several midwestern states, held here at UNI in March 2019 (Appendix 2).

Section 2 summarizes results from a published, four-year experiment testing three seed mix designs and two mowing treatments. We also introduce a flexible template for analyzing cost effectiveness that can be used by others outside our region, in other habitats. Any revegetation project (including CRP plantings) with a known seed mix and monitoring data that uses quadrats to measure density-based metrics like flowers and stems per square meter could be assessed using this template.

Section 3 summarizes first year results from a new experiment at UNI. The study described in Section 2 can be applied to conservation practices in the upper Midwest utilizing native plants to achieve multiple objectives. Before making broad recommendations, however, the experiment should be replicated on at least one more site. Because soil type, annual weather, and cropping history can influence restoration outcomes, trials must be repeated to assess the robustness of ecological outcomes. In addition to summarizing results from the first year of this experiment, planted in Fall 2018, we report preliminary findings on a a new treatment, seeding time. This additional treatment provides insights and potential improvements in cost effectiveness, of planting in the dormant season.

Section 4 describes our project to characterize vegetation patterns, and subsequent use by bees and butterflies, in 45 CRP pollinator plantings throughout eastern Iowa. We provide summary statistics for all 45 plantings that we sampled in 2018 and 2019, analysis of the 2018 data for site establishment, and a comparison of the species richness and abundance of the original seed mixes versus the subsequent plant community. Data analysis of the vegetation, bee and butterfly dataset across 2 years and 45 sites is ongoing through at least summer 2020; we anticipate at least two manuscripts for publication over the next two years.

Section 1: Native seed market dynamics during rapid implementation of a popular CRP practice

As part of our first objective, we assessed the native seed market dynamics during the CP-42 program. Our aims were to 1) characterize seed cost changes during the program, and 2) assess seed mixes and how they changed in response to the program and the market.

Methods

Representative seed mix costs and changes in native seed prices

In order to characterize changes in the cost of native seed as a popular CRP practice was implemented at large scale, we tracked market-wide seed costs for individual species and representative seed mixes. We compiled cost data for 160 species native to grasslands in the US corn belt (primarily corresponding to the Central and Western Corn Belt Plains EPA Level III Ecoregions (US Environmental Protection Agency 2013)). These species are inclusive of the majority of those used in most corn belt CRP plantings that specify the use of native vegetation, and also reflect typical species used in other ecosystem restoration projects with biodiversity conservation goals. We obtained cost information for these species by requesting price quotes from 4 to 7 native seed growers based in the Upper Midwest (MN, IA, WI) in 2015-2018. We obtained price quotes for a more limited selection of 79 species in 2015. Timing of price quote collection varied, but were typically sent January to April of each year. Availability of price data for species varied over time, but we were able to collect price data for 140 to 145 species each year.

We applied the seed cost data from 2015-2018 to a series of representative seed mixes to quantify how the cost of seed for a typical CRP seed mix changed over time. These mixes were static in species composition, and the changes in price reflect changes in cost for individual species. To determine seed mix costs, we used the lowest quoted price ($ per oz) for each species each year (modeling the typical preference for minimizing planting costs when possible) to multiply by the specified amount of seed needed for 1 acre, then summed the seed cost of all species. We also calculated the proportion of total seed mix cost that different plant functional groups made up. We assessed three different seed mixes: 1) an “Economy mix” – 21 species at a 3:1 grass-to-forb seeding ratio (based on seed numbers); 2) a “Pollinator mix” – 38 species at a 1:3 grass-to-forb seeding ratio; and 3) a “Diversity mix” – 71 species at a 1:1 grass-to-forb seeding ratio. The Economy mix was designed to resemble a seed mix that met the specifications for USDA’s Rare and Declining Habitat Conservation Practice (CP25), the Pollinator mix was designed to resemble a seed mix that met the specifications for USDA’s Pollinator Habitat Conservation Practice (CP42), and the Diversity mix was designed to resemble a seed mix used for ecosystem restoration (based on remnant prairies in northeastern Iowa). In addition to plotting seed mix costs over time, we also assessed changes among individual species. We tracked 60 forb species that had consistently available price data and calculated the change in price ($ per oz) from the beginnings of the CP-42 program in 2015 to the peak of implementation in 2017.

Price and composition of planted CP-42 seed mixes

While our approach to tracking the price of a static seed mix over time can give a clear picture of how seed prices changed for the important species on the market, landowners or seed companies often opt to substitute expensive species for cheaper ones to keep costs down. To take this behavior into account and assess the actual costs of seed mixes planted over the course of the CP-42 program, we used cost-share data from the USDA Farm Service Agency on CP-42 contracts (*n*= 920) in Iowa that were planted 2014-2018. To estimate the cost per acre for IA CP-42 seed mixes, we multiplied the per contract reported cost share for seeding (50% for the CP-42 program; Farm Service Agency 2013)) by 2, then divided by the total acres of the contract. We tracked cost per acre from beginning to end of program and compared changes in planted seed mix costs over time, and to the costs of the static, representative seed mixes.

We also wanted to characterize the species composition of real seed mixes planted as part of the CP-42 program, how they were eventually planted and managed, and describe how they changed as the program became popular. In order to obtain seed mixes that were planted as part of the Pollinator Habitat Initiative, we surveyed landowners in eastern Iowa. We needed to gather actual seed mixes from landowners because seed mixes planted are not always readily accessible at individual FSA county offices, and NRCS typically files only a seeding plan produced by NRCS conservationists (which does not necessarily match the seed mix planted). We sent customized letters to 800 farmers in 16 Iowa counties (within 60 min driving distance) who had participated in the CP-42 program from 2014-2018, requested a copy of the seed mixes they planted as part of the program, and asked a series of questions about the size, number, time planted, and management of CP-42 plantings they owned (Appendix 1). We followed up with an additional email if we received no response. From the 390 respondents, we received 113 seed mixes (as opposed to planting plans), and we were able to build a dataset of 83 CP-42 plantings with management and seeding time data associated with them. Of the sites with management and seeding time data, 79 had an associated seed mix with enough legible information to calculate seeding density for each species seeded. Seeding density is necessary to assess plant establishment rates on a per-species basis.

Many seed mixes contained information on seed origin, and we wanted to assess how the suitability of seed sourcing changed during the CP-42 program. In order to quantify changes in seed sourcing, we used the origin data from seed mixes to estimate an approximate distance of each seed source from the site it was planted (*n*=40). We assumed that origin data on seed mixes reported the state where seeds were produced, though the geographic source of the foundation seed for these supplies may have been different. In order to calculate this seed source distance, we used QGIS to generate polygon centroid points from each US state, then calculated the distance from each centroid to a point located at Cedar Falls, IA using the distance matrix function in QGIS. We used Cedar Falls as the reference point because the seed mixes we assessed were generally associated with sites within a ~70km radius of the town. Seed lots with a "Canada" origin were a special case, and we did not use centroids from a country polygon as we did with US states. Rather, we chose Manitoba as a reference point to measure distance due to its location (in part) within the Tallgrass Prairie Ecoregion and the presence of active native seed vendors in the province.

Native Seed Stakeholder Meeting

While seed mix and species price data work well to quantitatively inform native seed market dynamics, we also wanted to describe the dynamics more fully by incorporating qualitative reporting. In particular, we wanted to understand how stakeholders in the native seed supply chain perceived the roll-out and implementation of the CP-42 program, and how it affected them. To this end we organized a Native Seed Stakeholders meeting in February 2019. A detailed description of the meeting structure and goals is outlined in Appendix 2.

Data Analysis

To analyze seed mixes, we needed to standardize the highly variable types of seed mixes that we received. Very few seed mixes included direct seeding density information for individual species—most had a combination of species percent of mix, species PLS pounds per acre seeding rate, overall seeding rate, total PLS pounds seeded per species, or acres seeded. We used the dplyr package in R (v. 3.6.1, R Core Team 2019) to create a script that standardized the seeding rate information by incorporating multiple sources of seed mix information in an Excel spreadsheet to calculate seeding density by number of seeds (Supplement 1). We used the standardized data to tabulate summary statistics about the seed mixes planted. We summarized average seeding rate, average grass to forb ratio, average number of species planted, composition of planted species, and origin of seeds. We also analyzed site data associated with seed mixes, and calculated summary statistics on season of seeding and frequency of establishment mowing.

As part of our seed mix origin summary, we classified seed origins on a spectrum of source appropriateness. We generally followed recommendations based on Bower (2014) that consider a seed source to be appropriate for a given site when the seed origin and planting site fall within the same US Bureau of Land Management Seed Transfer Zone and EPA Level III Ecoregion. We classified seed origins as: 1) Appropriate Source based on whether a significant portion of the state of origin fell a) within the *same* BLM Seed Transfer zones and b) the *same* EPA Level III Ecoregion as the seed mixes we analyzed from sites in eastern IA; 2) Moderately Appropriate Source when a significant portion of the state of origin fell a) within the *same* BLM Seed Transfer zones and b) an *adjacent* EPA Level III Ecoregion as planting sites, 3) Inappropriate Source when a significant portion of the state of origin fell a) within an *adjacent* BLM Seed Transfer zones and b) *adjacent* and/or *same* EPA Level III Ecoregion as planting sites; 4) Highly Inappropriate Source when a significant portion of the state of origin fell *outside* either an adjacent BLM Seed Transfer zone or EPA Level III Ecoregion. See Supplement 2 for maps.

In order to understand how seed mixes changed over the course of the CP-42 program, we used linear regression models to test whether key metrics of seed mix quality were associated with time since program initiation (i.e. planting date). We used R to test two linear models using fixed effects. The first model assessed all 81 seed mixes and included seed mix floristic quality as response variable, and time since program initiation as predictor variable. The second model assessed the 42 seed mixes with seed source data, and used seed source distance as response variable and time since program initiation as predictor variable. We defined the floristic quality variable as the weighted mean Iowa Coefficient of Conservatism (CoC) of each seed mix, using sown species' CoC and weighted by number of seeds sown of each species. See Spyreas (2019) for a discussion of how other authors have used CoC to assess vegetation quality. We defined the seed source variable as the weighted mean distance of each seed mix to the planting source, using each sown species source distance weighted by number of seeds sown of each species.

Results and Discussion

The CP-42 practice enjoyed a high level of popularity that coincided with substantial changes in native seed market dynamics. Over the course of the CP-42 program, acres planted in Iowa spiked rapidly as the program rolled out, with relatively few acres added in the initial years of the program to adding nearly 175,000 acres in one year by 2017 (Fig. 1). We found that the price of native seeds following this large surge in demand increased substantially. When comparing seed mix prices over the duration of the CP-42 program, we found that a representative CP-42 pollinator seed mix with a 1:3 grass to forb seeding ratio increased in price by 97% ($375.25 to $739.98) during peak implementation in 2017, while a typical ecosystem restoration diversity mix increased 77% ($298.48 to $536.93), and a representative CP-25 economy mix with a 3:1 grass/forb ratio increased 45% ($131.43 to $206.93) (Fig. 2). Breaking the costs of each mix down into plant functional groups, we found that the cost of forb seed overwhelmingly drove the price increases. Comparing peak prices to those in 2015, forb seed cost increases ranged from 102% in the pollinator mix to 126% in the economy mix, while grass seed cost increases were much smaller, ranging from 15% in the economy mix to 32% in the pollinator mix.

Our results from tracking seed costs of individual species over time showed that price increases to individual species were quite volatile. Many important species used regularly in native vegetation projects increased in price to an extreme degree—for example *Solidago rigida* increased in cost by 490%, *Echinacea pallida* increased 486%, and *Ratibida pinnata* increased by 357%. Other species, including easy-to-produce annuals such as *Rudbeckia hirta* and *Chamaecrista fasciculata* increased in price more modestly, by 20.5% and 79.4% respectively. Some species even decreased in price, such as *Amorpha canescens* (-20.0%) and *Lespedeza capitata* (-41.7%).

Results from our analysis of CP-42 planting costs across all Iowa differed from those expected by seed prices and representative seed mix costs. We found that the average cost of CP-42 seed mixes planted in Iowa increased 30.1%, from $230.08 ± 6.19 SE during early program implementation in 2014 to $299.49 ± 3.33 SE at its peak in 2017 (Fig. 3). Compared to the static mix we tracked prices for, the actual seed mixes planted increased in cost much more modestly with the static mix increasing in price 60% more than the actual seed mixes planted. This mismatch in response suggests that during peak implementation, seed mix design was not driven by biological considerations such as ensuring that long-lived or ecologically conservative plants were well represented, but was driven primarily by keeping costs down (while maintaining adherence to minimum practice standards). By substituting expensive species with cheaper ones, costs can be controlled at the expense of seed mix quality.

Species composition of actual seed mixes planted during CP-42 generally reflected a reliance on a core set of native species from varied seed sources. We found that on average, CP-42 seed mixes were sown at an overall rate of 41.94 ± 0.41SE seeds /ft^2, and that each mix included 33.65 ± 0.79 SE species. Nearly 75% of all seeds sown among mixes comprised 20 species, though overall we found 132 species in seed mixes. Twenty percent of all seeds sown among mixes were from two species, *Schizachyrium scoparium* and *Rudbeckia hirta* (Table 1). We found that several species (*S. scoparium, Bouteloua curtipendula,* *Dalea purpurea*) were present in practically all seed mixes (>~95%), with *R. hirta and A. gerardii* found in all but one of the mixes (Table 2). The species that were most frequently planted in seed mixes were not necessarily the most abundantly planted, and many species were added in very small, amounts. For example, *Euphorbia corollata* and *Allium canadense* were both frequently planted (found in 55-56% of seed mixes) but the amount of seeds planted was very low (0.036-0.041% of seeds).

Seed sourcing for species included in the mixes was not always reported in seed mixes, and nearly half of seed mixes did not include source of origin information (Table 3). When seed mixes reported source information, roughly half asserted that all seed origin was of "Iowa" source, while the others included seed origin for each individual species. When comparing the composition of seed source by seeds planted among all mixes (those with origin reported), most seeds planted (78.88%) could be considered from an appropriate source. There was a minor component (2.2%) of seeds from a moderately appropriate seed source. We found that nearly 20% of seeds planted originated from geographic origins considered ecologically inappropriate. In particular, approximately 13% of seeds originated from highly inappropriate sources. Typically, these sources came from states or provinces that share little ecological resemblance to Iowa (e.g. Oregon, Pennsylvania). The remaining 6.0% of seeds originated from less problematic, but nonetheless inappropriate sources.

Overall, management and seeding time of seed mixes we assessed were quite uniform. The seed mixes we assessed were overwhelmingly planted during the growing season; 86.7% were planted from April to July (Table 4). Of those sites, over half were planted in the spring (April-May) with about a third planted during the summer (Jun-Jul). The sites planted in the dormant season were mostly planted in November and December, but a handful were "frost seeded" (Smith et al., 2010), i.e. they were planted in February and March. Once planted, nearly all the sites (95.2%) we assessed reported being mowed at least once during establishment (Table 6). The plurality of sites were mowed once or twice (42.2%), 40.9% were reported mowed three to four times, and 12% were reported mowed more than 4 times.

Seed mix quality declined during the rapid implementation of the CP-42 practice. We found that the weighted mean floristic quality index of seed mixes was negatively associated with time (R^2=0.157, $p <$ 0.001), indicating that seed mixes at the start of the CP-42 program had greater floristic quality than those towards the end of the project (Fig. 4). Generally, greater floristic quality indicates a plant community with higher biodiversity value (Spyreas, 2019) and stands with low floristic quality are usually made up of early successional species that can be found in practically any naturalized area. When translated to seed mix design, lowered floristic quality means that much of what is being planted as a seed mix may have established passively without seeding at all, and thus precludes creating a stand with conservation value for specialist wildlife that using a seed mix with higher floristic quality may have created. We also found that the weighted mean seed source distance of seed mixes was positively associated with time (R^2=0.306, $p < 0.01$), indicating that seed mixes at the start of the CP-42 program were comprised of seed sources closer to the planting site than mixes planted towards the end (Fig. 5).

Native Seed Stakeholder Meeting Outcomes

The native seed stakeholder meeting and the interviews leading up to it captured a wide variety of information about industry experiences, agency perspectives, and regulator concerns. Stakeholders perceived that native seed supply affects program success. In the case of the Pollinator Habitat Initiative, meeting participants noted that success was impacted in four ways: 1) prices spiked for high demand species (forbs), 2) substitutions resulted in seed mixes with poor outcomes, 3) seed mixes included more seed from outside the region, 4) a new weed (Palmer amaranth) was introduced to Iowa. To address these challenges, stakeholders identified four recommendations (see Appendix 2 for more details).

First, agencies should implement new programs more gradually. Stakeholders noted that this could be achieved by: 1) stabilizing the number of acres planted per year, 2) allowing use of cover crops to postpone planting during high demand years.

Second, the planning process of native revegetation projects should be improved. Specifically, 1) enabling direct communication between seed suppliers and conservation planners, 2) encouraging use of the NRCS seed calculator, and 3) ensuring that “what’s planned is what’s planted” were actions identified that could be taken to improve the planning process.

Third, quality assurance for native seed should be improved. Stakeholders identified four actions to achieve this: 1) evaluate and close loopholes in seed mix design, 2) increase consistency in seed testing and labeling requirements, 3) support research into native seed testing methods and variability, 4) improve establishment and avoid weed introductions.

Fourth, outcomes-based practices should be developed. In particular, 1) using science to inform policy, 2) incorporating monitoring into practice guidelines, and 3) supporting research into seed mix design, planting practices, and establishment were actions identified that could be taken to improve agency practices.

Section 2: Verifying and improving establishment management and seed mix design specifications

Our second objective was to verify and improve seed mix design and management specifications. Our aims were 1) evaluate establishment and ecosystem service provision for a typical CP-42 and two other CRP mixes, and 2) compare performance among mixes used for pollinator and other wildlife habitat of differing specifications. We carried out a field experiment to achieve our aims. Our field study tested whether prairie reconstructions installed at post-agricultural sites can effectively provide three ecosystem services commonly targeted by CRP (erosion control, weed resistance, and pollinator resources) and assessed whether seed mix design and first year mowing influence the degree of service enhancement or cost-effectiveness. An extensive account of methodology and results used can be found in Meissen et al. 2019 (Appendix 3).

Methods

Study Site and Experimental Design

We conducted a field experiment at the Iowa State University Northeast Research and Demonstration Farm near Nashua, Iowa. Soil composition is primarily poorly drained Clyde clay loams (Natural Resources Conservation Service 2016) and the land was used for corn and soybean production prior to site establishment in 2015. At planting time, the harrowed seedbed was loose, with small clods. To stabilize the soil as prairie seedlings established, we seeded a nurse crop of oats at a rate of 16 lb/acre.

We established plots with three different seed mixes: (1) the “Economy mix” – 21 species at a 3:1 grass-to-forb seeding ratio (assessed on the basis of seed numbers); (2) the “Pollinator mix” – 38 species at a 1:3 grass-to-forb seeding ratio; and (3) the “Diversity mix” – 71 species at a 1:1 grass-to-forb seeding ratio. The Economy mix was designed to resemble a seed mix that met the specifications for USDA’s Rare and Declining Habitat Conservation Practice (CP25). The Pollinator mix was designed to resemble a seed mix that met the specifications for USDA’s Pollinator Habitat Conservation Practice (CP42). The Diversity mix was designed to resemble a remnant prairie of matching geographic and soil conditions on site (i.e. species included in the mix would be expected to exist on mesic prairie remnants in the Iowan Surface ecoregion (US Environmental Protection Agency 2013) and were commercially available). The costs of the Economy, Pollinator, and Diversity mixes in 2015 were $130, $365, and $291 per acre respectively. We planted all mixes at an overall seeding rate of 40 seeds/ft^2

We established 36 research plots using a split-plot design with two spatial blocks. Eighteen plots (20ft × 28ft each) were established in each block. This resulted in an overall experimental design of 3 seed mixes × 2 mowing treatments × 3 replicates × 2 blocks = 36 research plots (Fig. S1). We drill-seeded the research plots in April 2015 and applied a first year mowing treatment to half of the plots of each seed mix. When the vegetation height exceeded 20 in, we mowed it to a height of 4.5 in using a riding type rotary mower. We mowed the plots four times in 2015 (June 16, July 23, August 13, November 4) but did not mow in 2016, 2017, or 2018.

Data Collection and Data Analysis

In each year of the study (2015-2018), we measured stem density of planted species in August (September for first year sampling). We assessed the stem density of planted species in five, 1ft^2 quadrats in each plot. In each quadrat, we identified and counted all stems (ramets) >4 in in height of each planted species. We measured canopy cover of native plants, annual weeds, perennial weeds, and bare ground in the same quadrats used to assess stem density and species richness. We visually estimated cover for these classes to the nearest 5%. We also recorded the number of inflorescences and floral richness (number of planted species that produced inflorescences) of species rooted in the quadrat. We report inflorescence number as the total number of native planted inflorescences produced from 2016 to 2018 and floral richness as the total number of native planted species that produced inflorescences from 2016 to 2018.

We used stem density, cover, floral richness, and inflorescence production to assess the ecosystem services (erosion control, weed resistance, and pollinator resources) provided by each seed mix. Cost-effectiveness was calculated as the cost of the seed mixture (per plot) divided by the variable of interest (i.e., the number of 1K native stems produced in 2018 or the number of 1K inflorescences produced between 2016 and 2018) per plot.

We analyzed stem density, species richness, and cover using repeated measures ANOVA, with seed mix and mowing as fixed factors, year as the repeated measure, and plot nested within block as a random factor. We analyzed the total cumulative number of inflorescences produced by 2018 (2016 – 2018) and cost-effectiveness using two-way ANOVA with seed mix and mowing as fixed factors and plot nested within block as a random factor. To meet the assumptions of normality and homoscedasticity of residual variance, grass stem density, forb stem density, and annual weed cover were cube-root transformed, perennial weed cover was log(y+0.1) transformed, bare ground cover was square root(y+0.1) transformed, cumulative inflorescence production was log transformed, and the cost of producing one thousand native stems was 1/square root transformed. Within year post-hoc comparisons of significant treatment effects were made using one-way ANOVA and Tukey HSD tests. All data were analyzed in R (v. 3.5.1, R Core Team 2018).

Data Visualization

To assess multifunctionality, we scored each seed mix on its ability to achieve the three ecosystem services examined in this study. To assess quality of pollinator habitat, we used inflorescence production (total inflorescences produced, 2016 – 2018) and floral richness (total species that produced inflorescences, 2016 – 2018). To assess weed resistance, we used weed cover-1 (in 2018) and bare ground cover-1 (in 2018). To assess erosion control, we used percent native cover (in 2018) and native stem density (in 2018). We used native cover as our proxy for erosion control, rather than total cover, because weeds are generally viewed as undesirable in prairie reconstructions, because the root systems of weeds are not as expansive as the root systems of prairie plants, and because any noxious weeds would need to be removed from reconstructions, thereby negating their value for erosion control. The seed mix with the highest value for each variable was scored as a 1.0 and the other seed mixes were scored as a relative proportion of that total (i.e., highest possible multifunctionality score = 6.0). For clarity, we presented each seed mix's multifunctionality score as a percentage out of 100. We depicted the relative values of each seed mix as a 'multifunctionality flower', in which each of the six traits was represented as a petal (see Asbjorsen et al. (2014) for comparable analysis).

Cost Effectiveness Template

To ensure our work can apply more broadly to regions outside of the Upper Midwest, we developed our overall sampling design and method of analysis to be generalizable for use in other regions and habitats. Typically, researchers use data collection methods and data organization/ analysis techniques that are unique to specific studies or sites. This specificity can allow the deployment of powerful inferential tools. While the study specific approach is necessary in design and data collection methods, data organization and analysis techniques can be more generalized. This generalizability allows the creation of a flexible template for analyzing cost-effectiveness and other performance metrics associated with seed-based revegation projects (e.g. establishment success). Any revegetation project (including CRP plantings) with known seed mix, cost, and monitoring data that uses a sampling method similar to the one described above (using quadrats to measure density based metrics like flowers and stems per unit area) could be assessed by modifying the method. While a template provides a repeatable means of data analysis within the framework of quadrat-based vegetation study, a valid sampling design must still be developed individually based on desired objectives (e.g. the number of quadrats and sites may need to change based on site size and desired statistical power of the study).

To create a template that can be used to assess cost effectiveness, we developed a script and database system using freely available statistical programming software (R) and a widely used data entry/storage system (Microsoft Excel). The assessment template (Supplement 3) consists of three parts: 1) measurement and study design spreadsheets, 2) spreadsheet keys to hold and link seed mix composition, seed cost, and species trait information to measurement data, and 3) an R script that combines the spreadsheet data to calculate measures of cost effectiveness. Investigators seeking to utilize this template need vegetation data (stem and/or flower density), pure live seeding (PLS) densities for all species planted, and cost data either for each species planted or for the seed mix as a whole. As such, this tool cannot accommodate studies using untested bulk or hand harvested seed (though hand harvested or bulk seed with a reliable seed test could be utilized).

The first component, the measurement and design spreadsheets, consists of raw measurement data spreadsheets in an Excel workbook (measure.xlsx). This raw field data is separated into individual sheets based on the measures recorded in a vegetation survey (sheets “ramet” and “flower” as presented in the template) and formatted for ease of data entry and data validation for plant community ecology; that is, variables (e.g. species) take rows and observations (e.g. quadrats) take columns. Because the R script does not use row/column position information from the spreadsheet to make calculations, the order of species and rows is unimportant. This allows new species to be added easily to the dataset as they are observed over time. Each column must have a unique identifier (“sid”) and contain the number of individuals observed in each quadrat. Columns must also have a site identifier (“ID”), which is associated with all the quadrats at each site. We present a template with 10 quadrats per site, though the spreadsheet could be modified to increase this amount for larger sites. Lastly, columns must have a value to mark the year the observation was taken. The measurement spreadsheet as presented is set up to accept stem density and inflorescence density, but other density based metrics could be substituted in the template if desired.

The study design data (sheet “design” in the “measure.xlsx” workbook) holds information related to each observation, such as the site where observed, seed mix planted, and the year observed. Each observation takes a row, and each observation attribute variable takes a column. The data associated with observations (“sid”) in this table (“ID” and “Year”) should match those in the measurement spreadsheets. The column “AssessmentYear” must contain the year to be used as a reference for any cost effectiveness assessments (vegetation data must exist for this year), and the column “SampleArea” must contain the total area sampled per site.

The second component of the template is an Excel workbook (“key.xlsx”) that contains information about species traits, composition of seed mixes used, and cost of seed mixes. The “species” spreadsheet contains a list of plant species codes, species taxonomic information, and various functional trait data. Template users working with tallgrass prairie reconstruction data should find all species of interest in this spreadsheet, since it is based on species lists found in key restoration texts (Packard and Mutel, 2005). Users applying the template in other regions or habitats may need to add additional species and trait data to this spreadsheet. The “mix” spreadsheet defines the seed mix or mixes used in sites of interest, with data expressed in seeds sown per square foot. Names of seed mixes in this spreadsheet must match the seed mix names used in the “design” spreadsheet of the “measure.xlsx” Excel workbook.

The template accepts two kinds of cost data for seed mixes based on how much information is known about the seed mix. Some organizations doing prairie reconstruction make yearly bulk purchases of seed of many individual species, from which multiple different seed mixes are created and planted. The template accommodates this seed mix design strategy by incorporating costs for individual species in the “sppcost” spreadsheet, where plant species (codes) take rows and cost of each species (in USD ($) per ounce) take columns. The template requires mix names in the “sppcost” spreadsheet to exactly match those named in the sheet “design” of the “measure.xlsx” workbook. In many circumstances, seed mixes are purchased pre-mixed and cost information is known only for the mix as a whole, and not for individual species that make up the mix. The template accommodates the assessment of these kinds of seed mixes by incorporating overall cost in the “mixcost” spreadsheet, where each seed mix takes rows and mix cost (USD ($) per acre) takes a single column. If seed mixes are assigned cost information both with individual species cost data and overall cost data, the overall cost data will be calculated using the sum of the individual species costs from the “sppcost” spreadsheet, and will override input found in the “mixcost” spreadsheet.

The third component consists of an R script (“data-template.R”) which is used in conjunction with the measurement data and key tables to calculate measures of cost effectiveness. The script provides a repeatable and standardized way of summarizing the complex multivariate data that results from analyzing seed mix costs and vegetation outcomes. As output, the script creates a table (“costeffectivenesssummary.csv”) with cost effectiveness metrics (cost per thousand stems & flowers; stems/flowers produced per dollar) for each site included in the measurement spreadsheets. Specific descriptions of the operations of the script are found as comments within the code. To run the script, users must ensure that the “tidyverse” package is installed in R, and that the supplemental files (“measure.xlsx”, “key.xlsx”, and “data-template.R”) are located in the working directory of R.

Results and Discussion

Stem Density

Native grass and native forb stem density differed between seed mixes. Grass stem density was higher in the Economy and Diversity mixes than in the Pollinator mix (Fig. 6B), while forb stem density was higher in the Diversity and Pollinator mixes than in the Economy mix in most years (Fig. 6C). Grass and forb stem density were higher in mowed plots than in plots that were not mowed; however, this effect was weaker for forbs than for grasses, and became less pronounced with time (Fig. 6E, F). Forb and grass stem density changed with time and were generally lower in earlier years (2015 and 2016) than in later years (2017 and 2018; Fig. 6B, C, E, F).

Cover

Cover of native plants, annual weeds, perennial weeds, and bare ground differed between seed mixes (term for perennial weeds was marginally significant, $p = 0.096$). Native plant cover was consistently higher in the Economy and Diversity mixes than in the Pollinator mix (Fig. 7A), annual weed cover was higher in the Pollinator mix than in the Economy and Diversity mixes in 2017 (Fig. 7B), perennial weed cover was higher in the Pollinator mix than in the Economy and Diversity mixes in 2017 and 2018 (Fig. 7C), and bare ground cover was higher in the Pollinator mix than in the Economy and Diversity mixes every year (Fig. 7D). First year management influenced cover of native plants and annual weeds, but this effect became less pronounced with time. More specifically, native plant cover was higher and annual weed cover was lower in mowed plots than in plots that were not mowed in 2016, but this effect was no longer significant in 2017 and 2018 (Fig. 7E, F). In general, cover of native plants and perennial weeds increased with time, while cover of annual weeds and bare ground decreased with time (Fig. 7A-H).

Inflorescence Production and Floral Richness

Cumulative inflorescence production over the three years (2016 – 2018) differed between seed mixes. The Pollinator mix produced more inflorescences than the Diversity mix and the Diversity mix produced more inflorescences than the Economy mix (Fig. 8). First year management affected inflorescence production, but the effect of this treatment differed between seed mixes. In particular, mowing increased inflorescence production in the Pollinator and Diversity mixes but decreased inflorescence production in the Economy mix (Fig. 8).

In total, seven planted forb species flowered in the Economy mix, 13 planted forb species flowered in the Pollinator mix, and 16 planted forb species flowered in the Diversity mix (Table 6). Species accounting for a high percentage of total inflorescence production include: Ratibida pinnata (47.85%) and Heliopsis helianthoides (37.83%) in the Economy mix; Ratibida pinnata (50.71%) and Rudbeckia hirta (36.14%) in the Pollinator mix; and Ratibida pinnata (30.62%), Heliopsis helianthoides (20.01%), Rudbeckia hirta (14.70%), and Desmodium canadense (9.85%) in the Diversity mix (Table 6).

Cost-effectiveness

Seed mix design and mowing both influenced cost-effectiveness once prairies established (fourth growing season). The cost of producing one thousand native stems differed between seed mixes ($p < 0.0001$); specifically, the Economy mix was the most cost-effective seed mix and the Pollinator mix was the least cost-effective seed mix for producing stems (Table 7). On the other hand, the cost of producing inflorescences was 21% lower in the Pollinator mix than in the Economy mix (Table 7); however, this difference was not significant due to high variability in the Pollinator mix. The cost of producing one thousand inflorescences differed between mowing treatments, but the effect of mowing on cost-effectiveness differed between seed mixes ($p = 0.0003$). In particular, mowing increased cost-effectiveness (in the Diversity and Pollinator mixes, but decreased cost-effectiveness in the Economy mix (Table 7).

Multifunctionality (i.e., the ability to concurrently provide erosion control, weed resistance, and pollinator resources) was highest in the Diversity mix (multifunctionality score = 89%), followed by the Economy (multifunctionality score = 75%) and Pollinator (multifunctionality score = 54%) mixes (Fig. 9). Our results suggest that the Economy mix would effectively provide erosion control and weed resistance, but not pollinator resources. Our results suggest that the Pollinator mix would effectively provide pollinator resources, but not erosion control or weed resistance. Our results also suggest that the Diversity mix would effectively provide all three ecosystem services. Further, a multifunctionality score of 89% suggests that the Diversity mix would provide erosion control and pollinator resources in a comparable manner to seed mixes designed to achieve these specific ecological outcomes.

Conclusions and Recommendations

In this study, we showed that a site-customized, high-diversity, grass:forb balanced seed mix can produce a plant community that is both multifunctional (i.e., provides erosion control, weed resistance, and pollinator resources) and cost-effective. Although the 1:1 Diversity mix would meet the necessary criteria of several conservation practices, including CP25, cost-share for seed is typically extremely limited under these conservation practices. Because land and resources for conservation are always limited, we recommend consolidating many conservation practices into one practice focused on whole ecosystem restoration of native tallgrass prairie.

We also showed that establishment management using first year repeated mowing can accelerate ecosystem service provision. While the benefits of mowing on floral resources and stem density faded over time, failure to mow stands during establishment resulted in a “lost year” with respect to pollinator and stand density value. For CRP contracts that typically last 10-15 years, this could represent up to 10% less conservation value over the contract lifetime. Ultimately, our research indicates that first season mowing should be encouraged as part of managing CRP plantings consisting of tallgrass prairie vegetation. Based on our surveys of CRP landowners in Iowa, first year mowing is already an adopted practice, and indicates that current recommendations for establishment management are in line with scientifically based best practices.

Section 3: Improving outcome predictability, multifunctionality and cost-effectiveness in prairie reconstruction

The present study can be applied to conservation practices in the upper Midwest utilizing native plants to achieve multiple objectives. Before making broad recommendations, however, the experiment should be replicated on at least one more site. Because soil type, annual weather, and cropping history can influence restoration outcomes, trials must be repeated to assess the robustness of ecological outcomes.

Additionally, there are other important management choices that may influence establishment success and cost effectiveness of CRP plantings. Timing of seeding is an important determinant of early grassland reconstruction performance (Larson et al., 2011), with dormant season seeding often resulting in greater cover of native forbs. For CRP programs with wildlife habitat goals, and particularly pollinator habitat goals, increasing the abundance of diverse plant functional groups at a site by optimizing seeding time may significantly increase ecosystem service provision at no additional cost. Our surveys of CRP landowners in Iowa indicated that the vast majority of those who planted stands of CP-42 pollinator habitat seeded during the growing season (Table 5) rather than the dormant season. This mismatch in actual vs. optimal seeding time, given the program objectives. may show an area where significant gains in cost effectiveness may be realized. Although the opportunity to boost services at no additional cost exists, there have been no studies investigating establishment success and cost effectiveness of fall vs. spring planting within the context of common CRP practice objectives.

In order to build on results from Sections 1-2, we aimed to 1) validate the conclusions of our seed mix experiment (see Section 2) at a different location to strengthen the scientific basis for making practice recommendations and (2) evaluate dormant vs. growing season seeding on stand establishment, cost-effectiveness, and functionality for common CRP practices.

Methods

Study Site and Experimental Design

We initiated a new field experiment in farmland owned by the University of Northern Iowa in Cedar Falls, Iowa in 2018-2019. Soil composition matched those at the previous experiment site in Nashua, Iowa but the land was used for corn production immediately prior to site establishment, rather than soybeans). Other aspects of experiment implementation replicated those at Nashua. One important difference in site preparation resulted from the addition of dormant and growing season seeding treatments. At Nashua, the tillage and harrowing occurred in April 2015 prior to planting, but did site preparation in November 2018, prior to planting the dormant season treatments. Thus, while the method of tillage remained comparable, the timing was not held constant between experimental replications.

We established 72 research plots using a split-plot design with two spatial blocks. Thirty six plots (20ft × 28ft each) were established in each block. This resulted in an overall experimental design of 3 seed mixes × 2 mowing treatments × 2 seeding time treatments x 3 replicates × 2 blocks = 72 research plots (Fig. 10). We drill-seeded the research plots on November 15, 2018 for the dormant seeding treatment and April 30, 2019 for the growing season treatment and applied a first year mowing treatment to half of the plots of each seed mix. When the vegetation height exceeded 20 in, we mowed it to a height of 4.5 in using a riding type rotary mower. We mowed the plots four times in 2019 (June 12, July 11, August 8, October 28).

Data Collection and Data Analysis

Data collection and data analysis followed the protocol described in Meissen et al. (2019). One exception to the data collection protocol related to the cover types recorded. Much of the annual weed cover was taller than the observation height of 1m in 2019, so we recorded an additional cover estimate for annual weeds that created a canopy above the observation height (i.e. giant ragweed). Further, we recorded unplanted perennial native species as an additional category for this study, since we found an abundance of potentially desirable native vegetation regenerating from the recently farmed land. The abundance of unplanted native species was likely due to the adjacency of our experiment site to a naturalized hedgerow habitat, which is atypical of most post-agricultural prairie reconstructions. Species in this category were made up mostly of *Solidago altissima*, *Symphyotrichum pilosum*, *Geum* spp. and *Potentilla* spp. Native annual and biennial species (e.g. *Ambrosia trifida*, *Conyza canadensis*) were still categorized as annual/biennial weeds. Because very few plots flowered, we were unable to analyze cost effectiveness of floral resource production using the same cost per 1k flowers metric that we used in the previous experiment (division by zero for many values creates data gaps). Instead, we used number of flowers produced per dollar spent, which can utilize zeroes in data more effectively. To preserve consistency, we assessed cost effectiveness for stem production using an analogous metric (stems produced per dollar spent).

We analyzed stem density, inflorescence production, cost-effectiveness, species richness, and cover using ANOVA, with seed mix, mowing, and season of planting as fixed factors, and plot nested within block as a random factor. To meet the assumptions of normality and homoscedasticity of residual variance, native stems produced per dollar, native cover, and stem density measures were square-root transformed. Perennial weed cover, unplanted native cover, inflorescences produced per dollar, and inflorescence production were log(y+0.1) transformed. Within-year post-hoc comparisons of significant treatment effects were made using one-way ANOVA and Tukey HSD tests. All data were analyzed in R (v. 3.6.1, R Core Team 2018).

First Year Results and Discussion

Stem Density

In general, stem density of planted native species responded as expected based on previous experiment results. Stem density ranged from an average of around 10 stems/m^2 in the unmowed pollinator mix planted in spring to over 70 stems/m^2 in the mowed economy mix planted in the fall. For most species, the stem densities we found among treatments were comparable to those we found at our previous experiment. However, two species responded much more positively in the present study compared to the previous experiment (*Sporobolus compositus* and *Elymus canadensis)* and as such increased the overall stem densities by significant amounts. Both seed mix (F = 14.02, $p < 0.001$) and mowing (F = 8.45, $p < 0.001$) influenced overall planted native stem density, though season of planting was not influential. Similar to our previous experiment, mowing increased native stem density, and the pollinator mix had the fewest stems. However, our first year results showed that the diversity mix did not perform the best overall as it did in the previous experiment, rather the economy mix performed best in the present study.

Testing the response of functional groups individually to time of planting revealed important effects. Planting in the dormant season led to better establishment of cool season grasses and sedges (F = 24.09, $p < 0.0001$) (though a significant interaction term with seed mix suggests this result was driven by the importance of planting season in the economy mix), spring forbs (F = 10.31, $p < 0.01$), and fall forbs (F = 17.71, $p < 0.001$). Planting during the growing season resulted in better establishment from warm season grasses (F = 7.65, $p < 0.01$) and legumes (F = 6.05, $p < 0.05$). Summer forbs responded no differently when planted in the dormant or growing season.

Most functional groups responded less strongly to mowing than they did to seeding time. After the first year, we found that mowing led to better establishment of warm season grasses (F = 23.58, $p < 0.0001$), and summer forbs (F = 5.60, $p < 0.05$) but did not impact other functional groups. These findings suggest that the benefits from mowing are primarily derived from improving establishment of warm season grasses and summer forbs.

Cover

Canopy cover across all plant types was primarily affected by mowing; seed mix and planting season affected cover to a lesser extent. Canopy cover of planted native species was higher in mowed treatments compared to unmowed treatments (F = 28.02, $p < 0.0001$) and higher in dormant plantings compared to growing season plantings (F = 11.64, $p < 0.01$). We found only marginal evidence that seed mix influenced native cover in the first year (F = 3.24, $p = 0.054$) and we found a significant interaction between the effects of planting season and seed mix, driven largely by dormant-planted pollinator and dormant-planted economy plots that produced more cover than other treatments. Both mowing and seed mix influenced unplanted native cover. Mowing increased unplanted native cover (F = 8.20, $p < 0.01$) but only slightly- from 1.9% in unmowed plots to 4.3% in mowed plots. Among seed mixes, we found more unplanted native cover in the pollinator mix compared to economy mix (F = 3.76, $p < 0.05$).

Of the treatments we tested, mowing was the only important determinant of weed cover. Canopy cover among different types of weeds varied significantly between mowing treatments, where perennial weed cover made up a very small amount of total cover (0.5% to 1.8% canopy cover) and combined annual weed cover made up a significant portion (31% to 56% canopy cover). Mowing completely removed annual weed (i.e. giant ragweed) cover over 1m tall (F = 108.19, p < 0.0001), but it increased shorter (< 1m) annual weed cover (F = 67.90, $p < 0.001$). The net impact of mowing on annual weeds was a reduction in canopy cover. Surprisingly, mowing also increased perennial weed cover (F = 13.93, $p < 0.001$), though there is little biological significance of an approximately 1% increase in canopy cover.

Mowing decreased bare ground (F = 88.70, p < 0.0001), though it was the dominant cover type among all treatments. Bare ground cover ranged from 51.9% in mowed plots to 77.3% in unmowed plots. We found marginal evidence that plots planted in fall had less bare ground than those planted in the spring (F = 3.67, p = 0.065).

Inflorescence production

In general, few plants flowered in first year plots, though some treatments did provide floral resources. Dormant season planting increased floral resources provided in the first year (F = 18.42, p < 0.001), though the significant interaction effect of seed mix and planting season and follow up contrasts show that the importance of planting season in the pollinator mix drove this result. We found marginal evidence that mowing increased inflorescence production in the first year (F = 3.34, p = 0.077). Among seed mixes, the pollinator mix produced the most inflorescences (F= 6.44, p < 0.01).

Cost-effectiveness

Both mowing and seed mix influenced cost effectiveness of stem production. Mowing increased the number of stems produced per dollar (F = 7.68, p < 0.01). We found that the number of stems produced per dollar was predicted by mix (F = 44.49, p < 0.0001), where cost effectiveness was highest in the economy mix, and lowest in the pollinator mix. Cost-effectiveness for the diversity mix was intermediate.

Planting season and seed mix influenced cost effectiveness in floral resource production, though we found that these effects also interact. Compared to planting during the growing season, planting in the dormant season increased the number of flowers produced per dollar (F = 17.81, p < 0.001). Seed mix predicted flowers produced per dollar (F = 5.61, p < 0.001), where the pollinator mix was more cost effective than either the diversity mix or economy mix. We did not find any difference in cost effectiveness between the diversity and economy mix. Post-hoc testing showed that the importance of planting season in determining cost effectiveness. A positive response from pollinator mix drove the interaction between seed mix and planting season. Thus, we urge caution in extending the predictive relationship between floral resources cost effectiveness and planting season for non-pollinator seed mixes.

Conclusions and Recommendations

After an initial growing season, we observed several results that validate the findings of our previous experiment. We found general correspondence among studies when comparing the effect of seed mix and mowing. In both studies, mowing and seed mix design influenced stem density with pollinator mixes having fewest stems, and grass-dominated mixes having most stems overall. Cost effectiveness (and to a lesser extent inflorescence production) in the present study was influenced by seed mix and increased by mowing much like it was in the previous experiment. However, other than a shared increase in native cover, the effect of mowing on canopy cover types was often divergent among the present study and the general trends observed in the previous experiment. Because we did not directly measure canopy cover in the first year of the previous experiment, it is difficult to make valid comparisons using year one data. While continuation of this study is needed to fully validate our previous experiment, initial results are encouraging that the overall importance of seed mix design and mowing to cost-effectiveness and establishment success holds true in different locations in different years. Our recommendations based on the previous experiment remain the same, though additional years of data collection are needed to to fully verify our results.

The increase in establishment and floral resources that resulted from dormant season planting suggests that encouraging farmers to use dormant seeding (November-March) may represent a no-cost strategy to increase cost effectiveness for provision of some ecosystem services. The majority of benefits from dormant season planting were derived from the increased success of forbs, both in promoting early flowering, and in the establishment of spring and fall forbs. Because the abundance and availability (both spatially and temporally) of floral resources is a key aim of the CP-42 practice, our results show that dormant season pollinator plantings may be more cost effective and provide higher quality ecological benefits than those planted during the growing season. By improving the seedling establishment of forbs and spreading out the planting times across the year, policymakers may eventually be able to reduce seeding rates and thus soften the impact of new CRP programs on native seed markets. Diversifying planting time could also spread out the work load of NRCS technical staff and improve service and oversight. Additional years of data collection are needed to confirm our early results.

Section 4: Evaluating Success of CP-42 pollinator plantings

Our final objective was to assess whether fields planted as part of the Pollinator Habitat Initiative were aims were achieving key ecological objectives. We aimed to 1) characterize vegetation outcomes for forbs on a random sample of three-year-old CP-42 plantings in eastern Iowa by comparing vegetation to the initial seed mix and program objectives,2) Quantify the cost per thousand forb stems for a subset of sites where seed mix cost was available, and 3)characterize butterfly and bee species richness and abundance on a subset of the vegetation sites. While we did not originally set out to directly measure pollinator metrics, subsequent collaboration with bee and butterfly experts allowed us to assess pollinator usage in tandem with vegetation surveys.

Methods

Study Site Selection

We chose to evaluate a random sample of CP-42 sites within 60 minute travel radius of Cedar Falls, IA, to facilitate data collection. After obtaining contact information through USDA-FSA in Fall 2017, we sent customized letters to over 800 farmers in 16 Iowa counties, who had participated in the CP-42 program from 2011-2018. We requested a copy of the seed mixes they planted as part of the program, and asked a series of questions about the size, number, time planted, and management of CP-42 plantings they owned (Appendix 1). We followed up with an additional email if we received no response. From the 390 respondents, we received 113 seed mixes We were able to build a dataset of 83 CP-42 plantings with management and seeding time data associated with them. Of the sites with management and seeding time data, 79 had an associated seed mix with enough legible information to calculate seeding rate (seeds/m2) for each species. Landowners who did not wish to cooperate in the study were removed from the pool. From this pool, we chose 45 random sites that had been planted in 2016 and 2017. In 2018, we surveyed 26 sites for vegetation, 16 for butterflies (June, July) and 8 for bees (June, July, August)(Fig. a). In 2019, we surveyed 19 sites for vegetation, 12 for butterflies and 10 for bees.

Data Collection and Analysis

After obtaining landowner permission, we generated five, randomly positioned 100m transects within each field using ARC GIS (cite) We loaded transect endpoints on a handheld GPS device in the lab prior to fieldwork. We sampled 0.5 x 2m quadrats at 7m intervals along the length of each transect to achieve 75, 1m^2 quadrats. In each quadrat, we recorded total plants and stems/plant of all forbs over 20cm height. To obtain a more holistic accounting of overall vegetation, we measured canopy percent cover of bare ground, sown warm-season grasses, sown cool-season grasses, and unsown cool-season grasses.

To conduct floral surveys**,** four random 100 m transects were generated for each site using ArcGIS. These were separate from transects for forb stem density. We surveyed the first 50 m of each transect for floral resources. We placed a 1.0 x 0.5 m^2 every 2 m along the transect and recorded each flowering species and the number of ramets and inflorescences in bloom. Floral resource surveys were completed for each site once in June and once in July 2019.

Following the floral resource surveys, butterflies were recorded visually while walking approximately 10 m/min along the second 50 m of each 100 m transect. Butterfly surveys took place between 9 AM and 5 PM on days with temperatures above 80 °F and mostly clear skies.

Butterflies were identified during the walks when possible. If not possible, individuals were captured using a sweep net and identified in the hand or taken back to the lab in an envelope for further examination. Survey time was paused when capturing and handling butterflies that needed subsequent identification. We recorded the behavior of each individual under the following categories: searching (flying erratically over the plot), feeding on a nectar source, flushed from resting on the vegetation, or mating or courting with other individuals. For butterflies observed feeding we also recorded the species of flower being used. Surveys were conducted on warm days with temperatures greater than 70 degrees, mostly sunny skies, and low wind speeds. Each site was surveyed once in July and once in August of 2018 and 2019. We also surveyed once at 13 of the 15 sites in June of 2019. Sampling of all 15 sites was done within one week out of each month.

To conduct bee surveys, we used the ArcGIS program to randomly locate four, 2500m^2 square plots at each site. Within each generated plot, a researcher would start a 15-minute stopwatch, pausing the timer to collect bees from flowers using a sweep net. We recorded the floral resource used by each specimen and brought the bees back to the lab to be washed, dried, and pinned for later identification. Two separate surveys were completed for each site in 2018 and 2019 once in June and once in July. Bees are still in the process of being identified.

Vegetation data from summer 2018 (26 sites, approximately 20,000 data cells per site) were organized for analysis and summarized using R. Plant establishment (plants per seed planted) was calculated for each species in the seed mix for each site. Non-metric multidimensional scaling (NMDS) analysis was used to compare the species composition of the seed mixes planted versus the vegetation obtained. In a second analysis, NMDS was used to compare the composition of the seed mix to its corresponding plant community. If the stem densities and species of plants detected in our quadrats closely mirrored the numbers and types of seeds planted, this analysis would show no separate clusters of points. Distinct clustering would show consistent differences between the seed mix and the plant community.

Data analysis for the full dataset of 45 sites (2018 and 2019) is still in progress. Dr. Mark Myers is supervising graduate student Corinne Myers (no relation) who is characterizing butterfly communities and correlating this with seed mix, vegetation data and floral resource data. Results of her study are expected in May 2020. Dr. Ai Wen is almost finished identifying the bees collected in the 2018 and 2019 surveys, and will hire a graduate student to assist in analyzing those data relative to floral resources and forb stem densities across sites.

Analysis of the vegetation data related to seed mix characteristics, seed cost, planting time etc. is in progress. This work will be led by Laura Jackson, Mark Sherrard, and Justin Meissen.

Results and Discussion

Iowa CP-42 plantings in their third year of establishment were highly variable but in general, numbers of sown forbs and the establishment rates were far lower than could reasonably be expected in a well-planned restoration planting. Total plant density (sown plus unsown forbs) ranged from 5 to 126 plants m^{-2}, (mean = 28.3, median = 19.75, $\pm$ 4.0 s.e.; Table 8). Sown forb density ranged from 0 to 119 m^{-2}

(mean = 9.87, median = 5.4, ±3.04 s.e.). In a few sites, the annual native plant *Chamaecrista fasciculata* produced dense populations that inflated average native plant densities.

While seed mixes in 2018 averaged nearly 25 species of forbs, average species richness of the resulting plant communities was 13 species (data not shown).

Anecdotally, farmers and landowners were generally enthusiastic about their enrollment in CP-42, and curious about our findings. Each landowner received a report with quantitative findings (Appendix 4).

Mean forb establishment from seed across all sites ranged from 0.1% to 35.8% (mean 2.98%, median = 1.60, ±0.91 s.e.; Table 8). These numbers exclude grasses, which cannot be measured in the same way due prolific basal tillering. Mean establishment masks individual species performance. Some species established at characteristically high (10-15%) rates, e.g. *Heliopsis helianthoides*, while other species (e.g. *Heuchera richardsonii*) were almost never found in our quadrats, but were planted at high densities, likely included in the seed mix because they were inexpensive on a per-seed basis. These numbers also do not include plants under 20 cm in height. By year three of a planting, some species are reproducing from seed, such as *Rudbeckia hirta*. Small seedlings could well become an important component in later years.

The cost (US$) to produce 1000 forb plants, where seed cost data could be obtained, varied from $2.79 to $148.25, and averaged $45.63 (median = $14.97, ±9.38 s.e.; Table 8). While the seed cost data are incomplete, they do span a wide range of costs. Plant establishment rate will have a much more powerful influence on cost/1000 plants than initial cost of the seed mix.

NMDS analysis of 2018 data (26 sites) revealed three distinct kinds of plantings (Figure 12). The first group consisted of plantings we defined as successful, in which the majority of the plants sampled had been sown (>50% sown). About half the plantings in 2018 fell into this group. The second group consisted of “unsuccessful” plantings, where the majority of plants in the stand were not sown (i.e. weeds and other plants that arrived on their own). Approximately half the plantings we sampled in 2018 were classified into this group. The smallest (2 sites) group in 2018 consisted of sites where virtually no plants we sampled were reported in the original seed mix. We intend to repeat this analysis with the full set of 45 sites surveyed in 2018 and 2019.

Seed mix specifications are designed to achieve certain vegetation goals given constraints on cost. Correspondence between the seed mix and the resulting plant community is not expected to be identical due to differential seedling establishment of species in the mix. However, we would hope to see some resemblance between the two. Absence of strong clustering between seed mixes and resulting stands would tell us the seed mix produced a stand that was similar to the seed mix. However, NMDS results for 2018 (Figure 13) reveal that the seed mixes planted were distinct from established stands. There was not as much variation among seed mixes as among established stands, and a lot of that was due to many identical seed mixes.

Next steps are to incorporate 2019 sites (19 in all) into the general analysis of plant species richness, species-specific plant establishment, and community composition. Measures of vegetation quality may include species richness and dominance-diversity (Shannon’s D index), weed density, density of particular weed species such as Canada thistle, distribution of flowering times across the spring, summer and fall, and coefficient of conservatism. Finally, we will compare plant community measures to the cost and quality of the seed mix .

Ultimately at least half of these plantings were dominated by what most farmers would consider weeds, which do not have to be purchased and planted. (However, many of these weeds, such as common milkweed, nevertheless provide beneficial pollinator habitat.) This fact could readily be missed without monitoring. Spot checks and other informal methods of evaluating the stand would not provide satisfactory answers or suggest avenues for improvement. These results are consistent with conclusions of Meissen et al. (2019) that the forb-dominated pollinator mix lacked sufficient grass cover to discourage weeds.

Mid-contract management will be important for these plantings, particularly if overseeding can be encouraged. We need more research about what made some of these plantings so unsuccessful, and that information needs to be incorporated into future CRP programs. Analysis of the vegetation, butterfly and bee data (still in progress) may help us learn what aspects of CP-42 fields are working for pollinators, and how to improve ecosystem services provided by the CRP and other agricultural conservation programs in the future.

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Tables

Table 1. Composition of species planted among all 81 seed mixes analyzed. Top 20 of the 132 species planted are shown.

Common Name	*Scientific Name*	*Functional Group*	*% of seeds sown among all mixes*
little bluestem	*Schizachyrium scoparium*	Grass	10.66%
black-eyed susan	*Rudbeckia hirta*	Summer Forb	9.20%
wild beebalm	*Monarda fistulosa*	Summer Forb	6.00%
prairie cinquefoil	*Drymocallis arguta*	Summer Forb	5.05%
purple prairie clover	*Dalea purpurea*	Summer Forb	4.70%
yellow coneflower	*Ratibida pinnata*	Summer Forb	3.83%
swamp vervain	*Verbena hastata*	Summer Forb	3.58%
stiff goldenrod	*Solidago rigida*	Fall Forb	3.30%
common fox sedge	*Carex vulpinoidea*	Grass	2.83%
sideoats grama	*Bouteloua curtipendula*	Grass	2.69%
Richardson's alumroot	*Heuchera richardsonii*	Spring Forb	2.67%
common evening primrose	*Oenothera biennis*	Fall Forb	2.57%
common yarrow	*Achillea millefolium*	Spring Forb	2.40%
common mountain mint	*Pycnanthemum virginianum*	Summer Forb	2.37%
field goldenrod	*Solidago nemoralis*	Fall Forb	2.33%
sky-blue aster	*Symphyotrichum oolentangiense*	Fall Forb	2.27%
junegrass	*Koeleria macrantha*	Grass	2.24%
heath aster	*Symphyotrichum ericoides*	Fall Forb	2.20%
composite dropseed	*Sporobolus compositus*	Grass	2.02%
Culver's root	*Veronicastrum virginicum*	Summer Forb	1.59%

Table 2. Frequency of species planted among all 81 seed mixes analyzed. Top 20 of the 132 species planted are shown.

Common Name	*Scientific Name*	*Functional Group*	*% presence among all mixes*
black-eyed susan	*Rudbeckia hirta*	Summer Forb	98.78%
big bluestem	*Andropogon gerardii*	Grass	98.78%
little bluestem	*Schizachyrium scoparium*	Grass	97.33%
sideoats grama	*Bouteloua curtipendula*	Grass	94.67%
purple prairie clover	*Dalea purpurea*	Summer Forb	94.67%
wild beebalm	*Monarda fistulosa*	Summer Forb	90.67%
junegrass	*Koeleria macrantha*	Grass	90.67%
showy partridge pea	*Chamaecrista fasciculata*	Summer Forb	86.67%
golden alexander	*Zizia aurea*	Spring Forb	85.33%
prairie cinquefoil	*Drymocallis arguta*	Summer Forb	82.67%
smooth oxeye	*Heliopsis helianthoides*	Summer Forb	81.33%
common evening primrose	*Oenothera biennis*	Fall Forb	78.67%
yellow coneflower	*Ratibida pinnata*	Summer Forb	76.00%
common milkweed	*Asclepias syriaca*	Summer Forb	74.67%
butterfly milkweed	*Asclepias tuberosa*	Summer Forb	74.67%
Canadian milkvetch	*Astragalus canadensis*	Summer Forb	74.67%
common fox sedge	*Carex vulpinoidea*	Grass	72.00%
Illinois bundleflower	*Desmanthus illinoensis*	Summer Forb	70.67%
stiff goldenrod	*Solidago rigida*	Fall Forb	70.67%
prairie dropseed	*Sporobolus heterolepis*	Grass	69.33%

Table 3. Composition of seed origin by seeds planted among all 81 seed mixes analyzed. Origin is reported as the state listed on the seed mix for each seed lot (when available). Designations of appropriate seed sourcing are based on BLM seed transfer zones and EPA Level III Ecoregions (see Bower et al., 2014).

Origin	*% of seeds*
Source Not Reported	*47.48%*
Appropriate Source	*41.43%*
Iowa	35.43%
Minnesota	6.00%
Moderately Appropriate Source	*1.17%*
Illinois	0.02%
Wisconsin	1.15%
Inappropriate Source	*3.17%*
Missouri	0.31%
Nebraska	1.02%
South Dakota	0.86%
Kansas	0.97%
Midwest	0.00%
Highly Inappropriate Source	*6.75%*
Canada	0.21%
Colorado	0.14%
Idaho	0.53%
Kentucky	0.10%
Maine	0.05%
Michigan	0.25%
Montana	0.36%
North Dakota	0.36%
New York	0.16%
Oregon	1.56%
Pennsylvania	2.68%
Texas	0.07%
Washington	0.19%
Wyoming	0.05%

Table 4. Time of seeding for CP-42 plantings. Data is based on survey responses for 90 sites in eastern IA.

Timing of seeding	*% of sites*
Dormant - Fall (Nov-Dec)	10.00%
Dormant - Frost (Jan-Mar)	3.33%
Growing Season - Spring (Apr-May)	54.44%
Growing Season - Summer (Jun-Jul)	32.22%

Table 5. Number of times CP-42 plantings were mowed as part of establishment management. Data is based on survey responses for 90 sites in eastern IA.

Times mowed	*% of sites*
0	4.44%
1	14.44%
1.5	1.11%
2	23.33%
3	23.33%
4	14.44%
5	4.44%
7	4.44%
8	2.22%
No response	7.78%

Table 6. A comparison of floral richness and floral evenness between seed mixes. Values represent the percentage of total inflorescence production (2016–2018) for each species within a given seed mix. Species are listed based on relative rank within each seed mix.

Economy Mix		Diversity Mix		Pollinator Mix	
Ratibida pinnata	47.85%	*Ratibida pinnata*	30.62%	*Ratibida pinnata*	50.71%
Heliopsis helianthoides	37.83%	*Heliopsis helianthoides*	20.01%	*Rudbeckia hirta*	36.14%
Rudbeckia hirta	8.69%	*Rudbeckia hirta*	14.70%	*Zizia aurea*	6.05%
Solidago speciosa	2.25%	*Desmodium canadense*	9.85%	*Echinacea pallida*	2.47%
Zizia aurea	1.82%	*Symphyotrichum laeve*	7.14%	*Oligoneuron rigidum*	1.68%
Monarda fistulosa	1.47%	*Oligoneuron rigidum*	3.62%	*Monarda fistulosa*	1.22%
Astragalus canadensis	0.09%	*Desmanthus illinoensis*	3.60%	*Vernonia fasciculata*	0.74%
		Silphium integrifolium	2.52%	*Helenium autumnale*	0.40%
		Helianthus grosseserratus	2.28%	*Symphyotrichum laeve*	0.19%
		Zizia aurea	1.38%	*Desmodium canadense*	0.19%
		Astragalus canadensis	1.26%	*Solidago speciosa*	0.09%
		Monarda fistulosa	1.18%	*Eryngium yuccifolium*	0.07%
		Chamaecrista fasciculata	0.97%	*Astragalus canadensis*	0.05%
		Echinacea pallida	0.49%		
		Euthamia graminifolia	0.24%		
		Anemone cylindrica	0.12%		

Table 7. Assessing the influence of seed mix design and first year management on cost-effectiveness in prairie reconstruction. Cost-effectiveness was determined as the cost of the seed mix per plot divided by either: (1) the number of 1K native stems in 2018; or (2) the number of 1k inflorescences produced between 2016 and 2018, per plot. Significant differences between seed mixes (within a given mowing treatment) based on Tukey's post hoc tests are indicated with different letters.

		Economy	Diversity	Pollinator
1K native stems	Mow	$0.06 (0.00)a	$0.15 (0.01)b	$0.56 (0.10)b
	No mow	$0.07 (0.01)	$0.15 (0.02)	$0.51 (0.16)
1K inflorescences	Mow	$0.39 (0.07)	$0.20 (0.02)	$0.13 (0.03)
	No mow	$0.18 (0.03)	$0.33 (0.05)	$0.23 (0.05)

Table 8. Summary of vegetation outcomes for 45 CRP-42 sites surveyed in 2018-2019.

Site ID	Planting Month	seed cost/ac	forb seeds/m2	all plants/m2	sown forbs/m2	% of forbs Sown	% seeds established	$/1k forbs
1493	June-16	NA	333	126	119	94	35.8	NA
1524	April-17	NA	333	87	76	87	22.9	NA
1403	May-16	NA	326	45	28	61	8.5	NA
1269	April-16	275.95	326	33	24	74	7.5	2.79
1720	April-17	320.00	325	26	14	54	4.2	5.75
1517	April-16	NA	346	15	11	71	3.1	NA
1430	April-16	NA	318	19	10	51	3.1	NA
1388	May-16	NA	333	22	9	39	2.6	NA
1832	May-17	NA	304	19	8	45	2.8	NA
1167	May-16	383.82	293	10	8	78	2.7	12.14
1154	May-16	292.83	350	10	8	76	2.2	9.34
1766	May-16	245.90	333	56	8	14	2.3	7.90
1879	May-16	NA	342	22	7	34	2.2	NA
1727	November-16	266.77	316	12	7	59	2.3	8.94
1275	May-16	NA	343	13	7	54	2.1	NA
1277	May-16	275.99	350	14	7	50	2.0	9.89
1417	May-16	NA	342	37	6	18	1.9	NA
1356	May-16	312.54	339	13	6	49	1.9	12.22
1288	May-16	259.83	318	17	6	37	2.0	10.20
1518	May-17	NA	309	20	6	30	2.0	NA
1478	June-17	NA	348	13	6	45	1.7	NA
1607	June-17	360.86	314	10	6	56	1.9	15.06
1750B	June-17	NA	318	17	6	34	1.8	NA
1437	May-16	NA	368	11	6	52	1.5	NA
1779	June-17	274.03	433	18	5	30	1.2	12.54
1593	June-17	295.05	390	12	5	40	1.3	14.43
1567	May-16	190.03	343	41	5	12	1.4	9.54
1630	May-17	NA	325	7	4	59	1.3	NA
1447	May-16	NA	333	21	4	20	1.3	NA
1407	May-16	245.00	318	42	4	10	1.3	14.89
1526	June-16	NA	346	30	4	12	1.1	NA
1295	June-16	245.00	318	21	3	13	0.9	22.04
1534	June-17	NA	324	22	3	13	0.8	NA
1536	April-16	245.00	318	17	3	15	0.8	23.28
1279	June-16	NA	343	42	2	6	0.7	NA
1166	June-16	293.00	347	24	2	9	0.6	35.03
1730	May-17	249.97	359	11	2	19	0.6	30.48
1691	June-17	321.41	298	18	2	10	0.6	43.80
1042	April-16	NA	266	47	2	3	0.6	NA

1843	April-17	221.58	315	21	1	7	0.5	38.02
1675	December-16	210.50	317	26	1	5	0.4	38.25
1173	June-16	319.98	333	95	1	1	0.2	128.92
1615	June-17	279.98	324	5	0.47	9	0.1	148.25
1669	June-17	256.30	296	5	0.45	9	0.2	139.70
1750	June-16	245.01	318	105	0.43	0	0.1	141.90
1669B	June-17	298.00	328	5	0.29	6	0.1	251.04
average		**276.32**	**330.78**	**28.35**	**9.87**	**34.15**	**2.98**	**45.63**
median		274.99	327.16	19.75	5.70	32.10	1.60	14.97
standard error		10.09	3.90	4.00	3.04	3.94	0.91	9.38

Figures

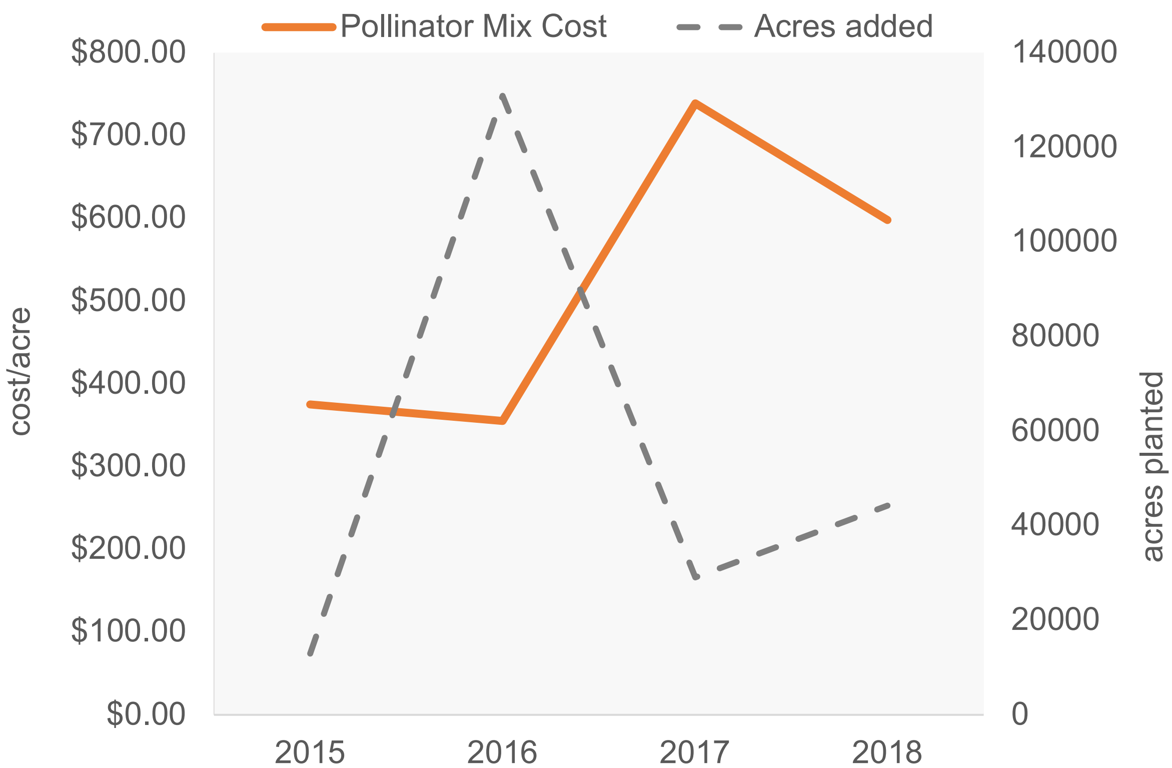

Figure 1. Cost of one representative pollinator mix (species composition static over time) during implementation of CP-42 Pollinator Habitat Initiative.

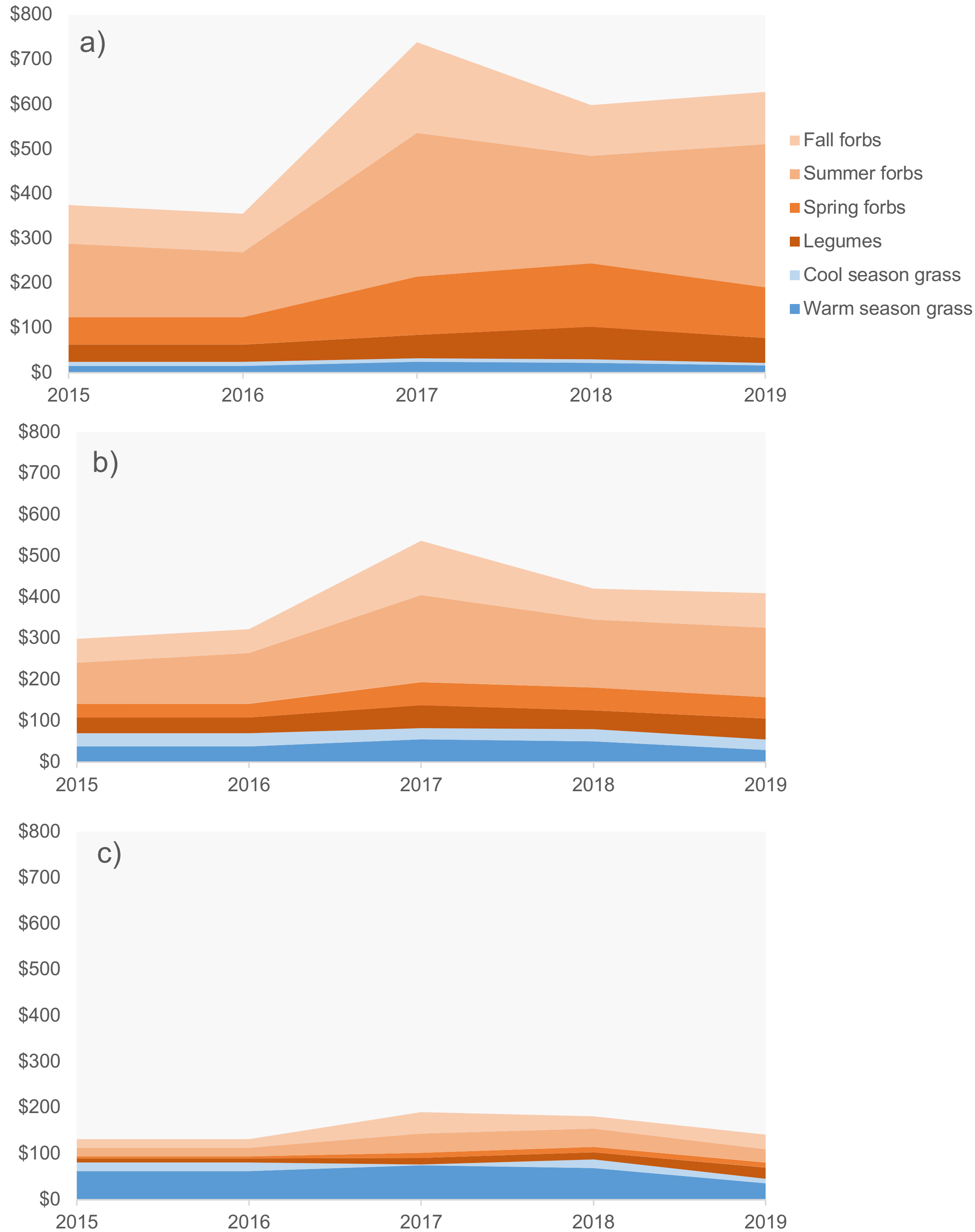

Figure **2. Cost of a) representative CP-42 mix** with 1:3 grass to forb seeding ratio b) representative mix for ecosystem restoration with 1:1 grass to forb seeding ratio, and 3) representative CP-25 mix with 3:1 grass to forb ratio during the CP-42 program roll-out. Shading indicates proportion of cost

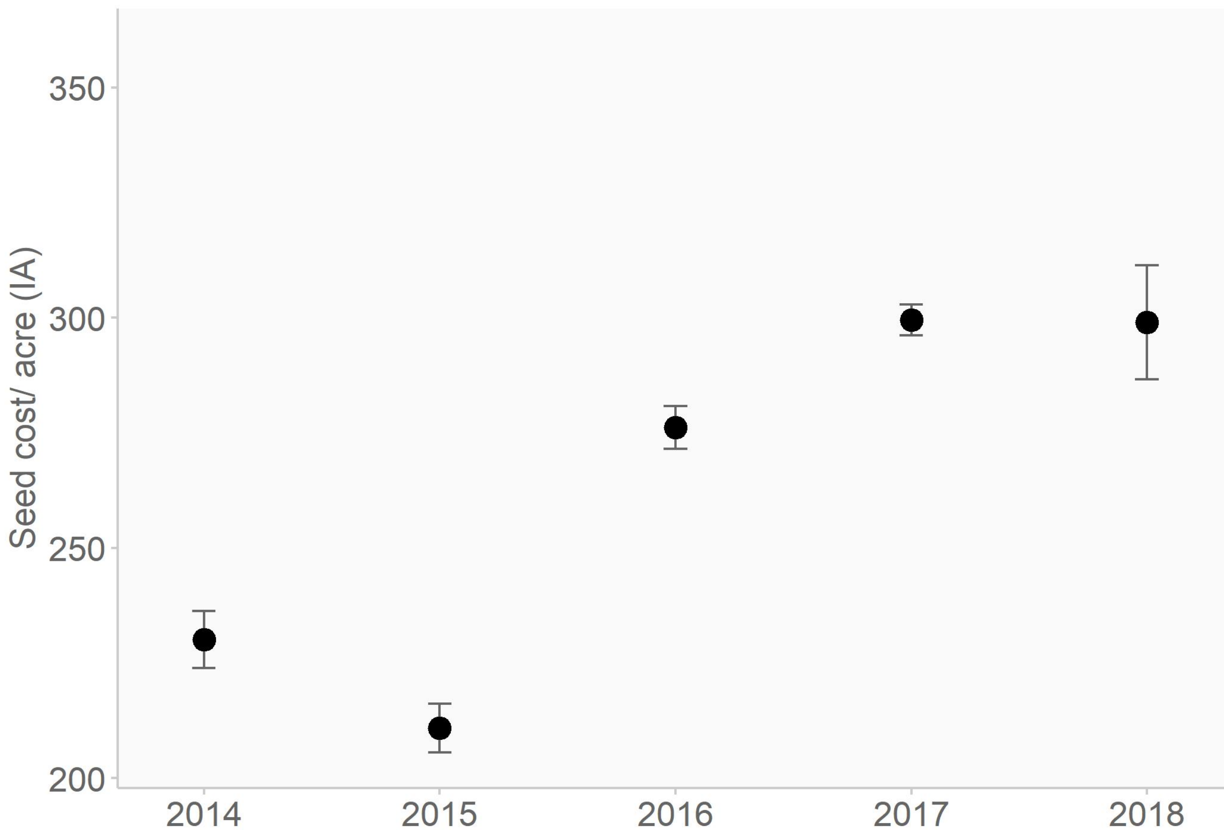

Figure 3. Average cost per acre of CP-42 seed mixes planted over the course of general enrollment in the Pollinator Habitat Initiative. Data based on FSA cost share data from fields enrolled in CP-42 (*n*= 920).

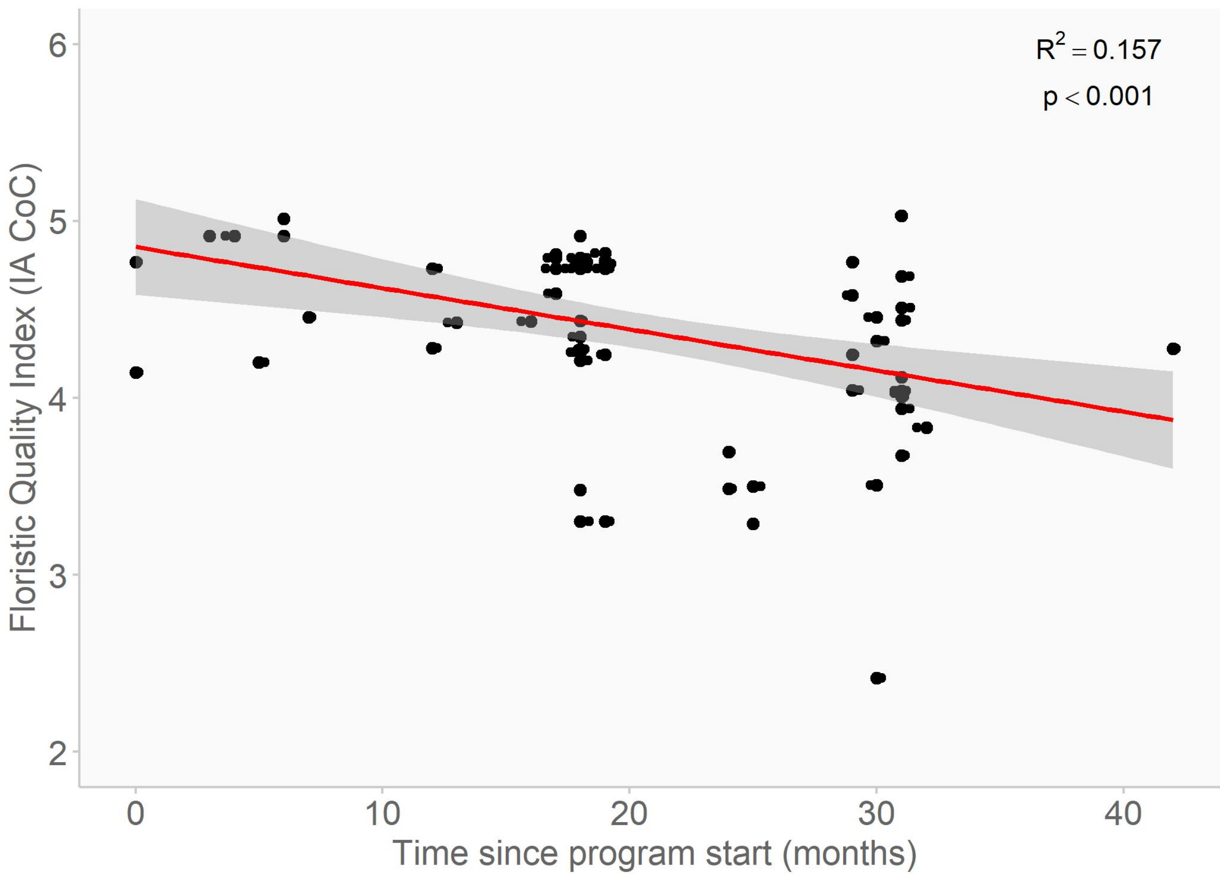

Figure 4. Weighted mean floristic quality index (Iowa Coefficient of Conservatism) of seed mixes planted over the course of the CP-42 program. Data based on seed mixes collected through farmer surveys (*n*=75).

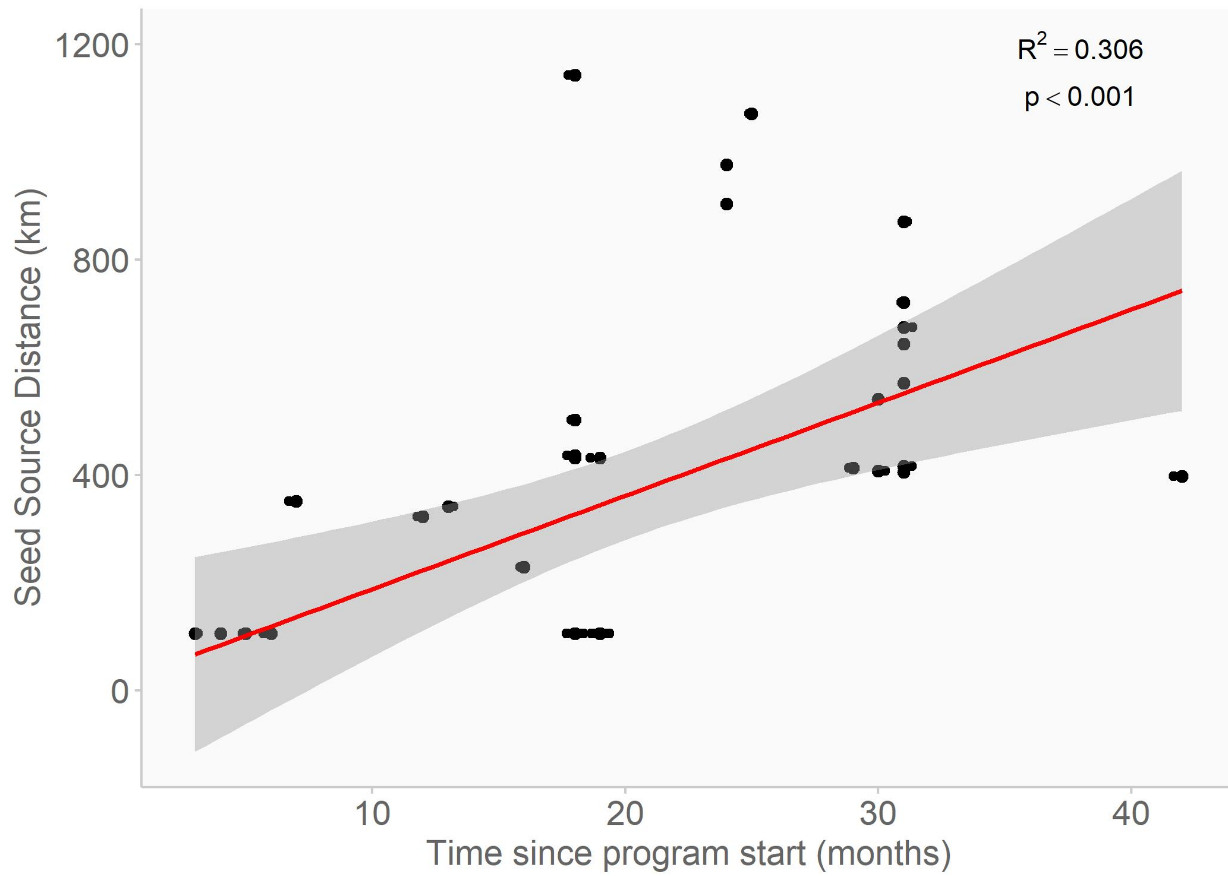

Figure 5. Weighted mean seed source distance of seed mixes planted over the course of the CP-42 program. Data based on seed mixes collected through farmer surveys with origin data (*n*=40).

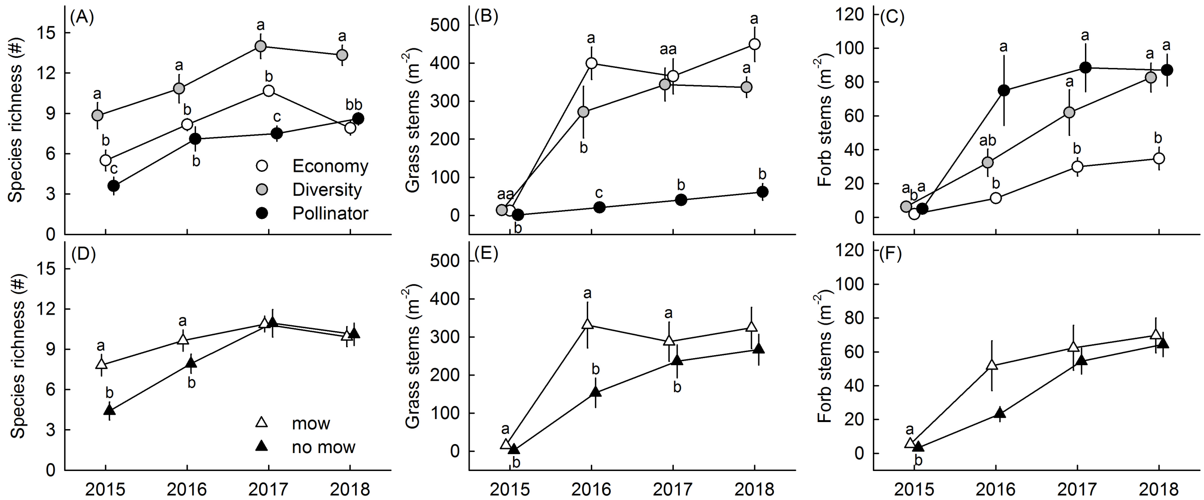

Figure 6. Differences in native species richness, native grass stem density, and native forb stem density between seed mixes (A -C) and mowing treatments (D–F). Values presented are annual averages (± 1 SE). Significant differences between seed mixes and mowing treatments (within a given year) based on Tukey's post hoc tests are indicated with different lowercase letters.

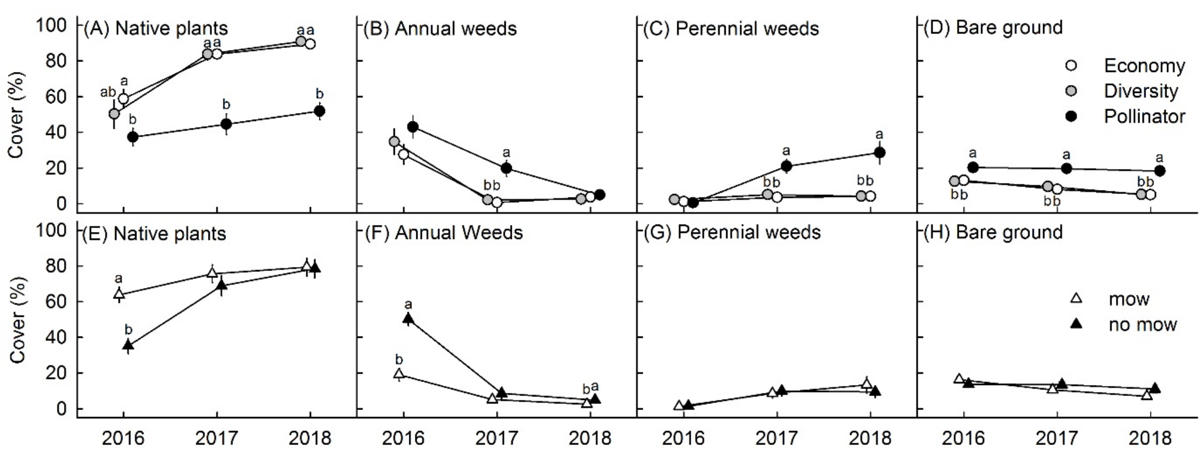

Figure 7. Differences in percent cover by native plants, annual weeds, perennial weeds, and bare ground between seed mixes (A–D) and mowing treatments (E – H). Values presented are annual averages (± 1 SE). Significant differences between seed mixes and mowing treatments (within a given year) based on Tukey's post hoc tests are indicated with different lowercase letters.

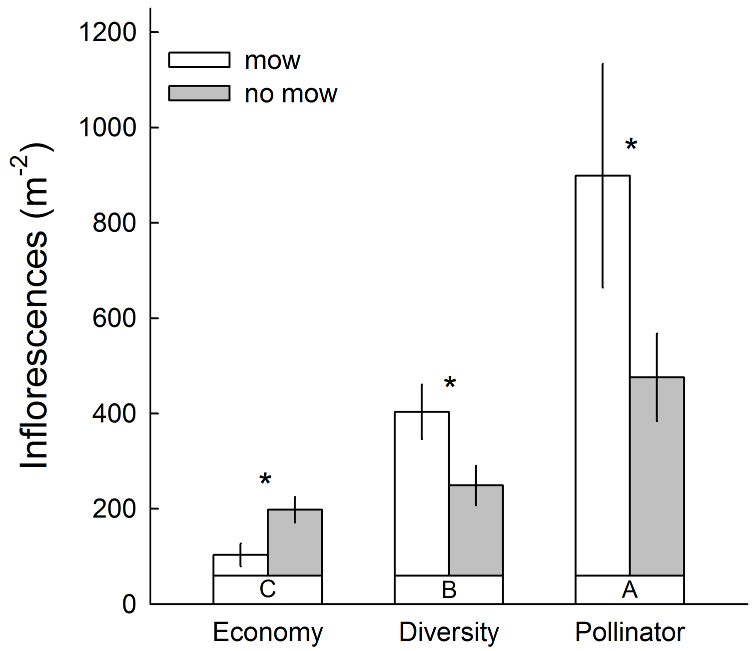

Figure 8. Differences in cumulative inflorescence production (2016-2018) between seed mixes and mowing treatments. Values presented are the average cumulative inflorescence production (± 1 SE) in a given treatment combination. Significant differences between seed mixes based on Tukey's post hoc tests are indicated by different letters on the bottom of the bars and significant differences between mowing treatments (within a given seed mix) based on Tukey's post hoc tests are indicated with asterisks.

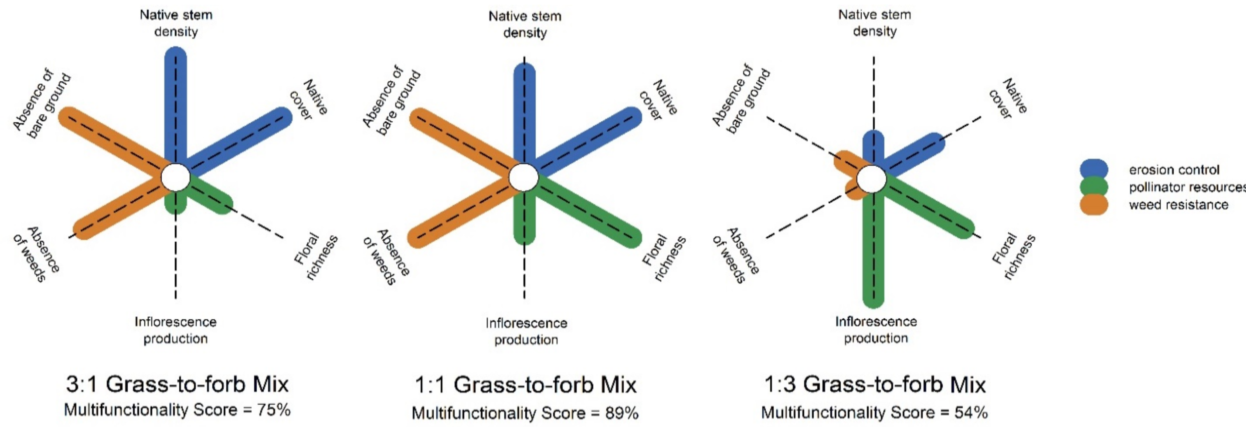

Figure 9. “Mulitfunctionality flowers” depicting the relative abilities of each seed mix to provide ecosystem services. Ability to provide erosion control was assessed using native cover (in 2018) and native stem density (in 2018). Ability to provide weed resistance was assessed using weed cover-1 (in 2018) and bare ground cover-1 (in 2018). Ability to provide pollinator resources was assessed using inflorescence production (total inflorescences produced, 2016 – 2018) and floral richness (total species that produced inflorescences, 2016 – 2018). The seed mix with the highest value for each variable was scored as a 1.0 and other seed mixes were scored as a relative proportion of that total. For clarity, we present each seed mix’s multifunctionality score as a percentage out of 100.

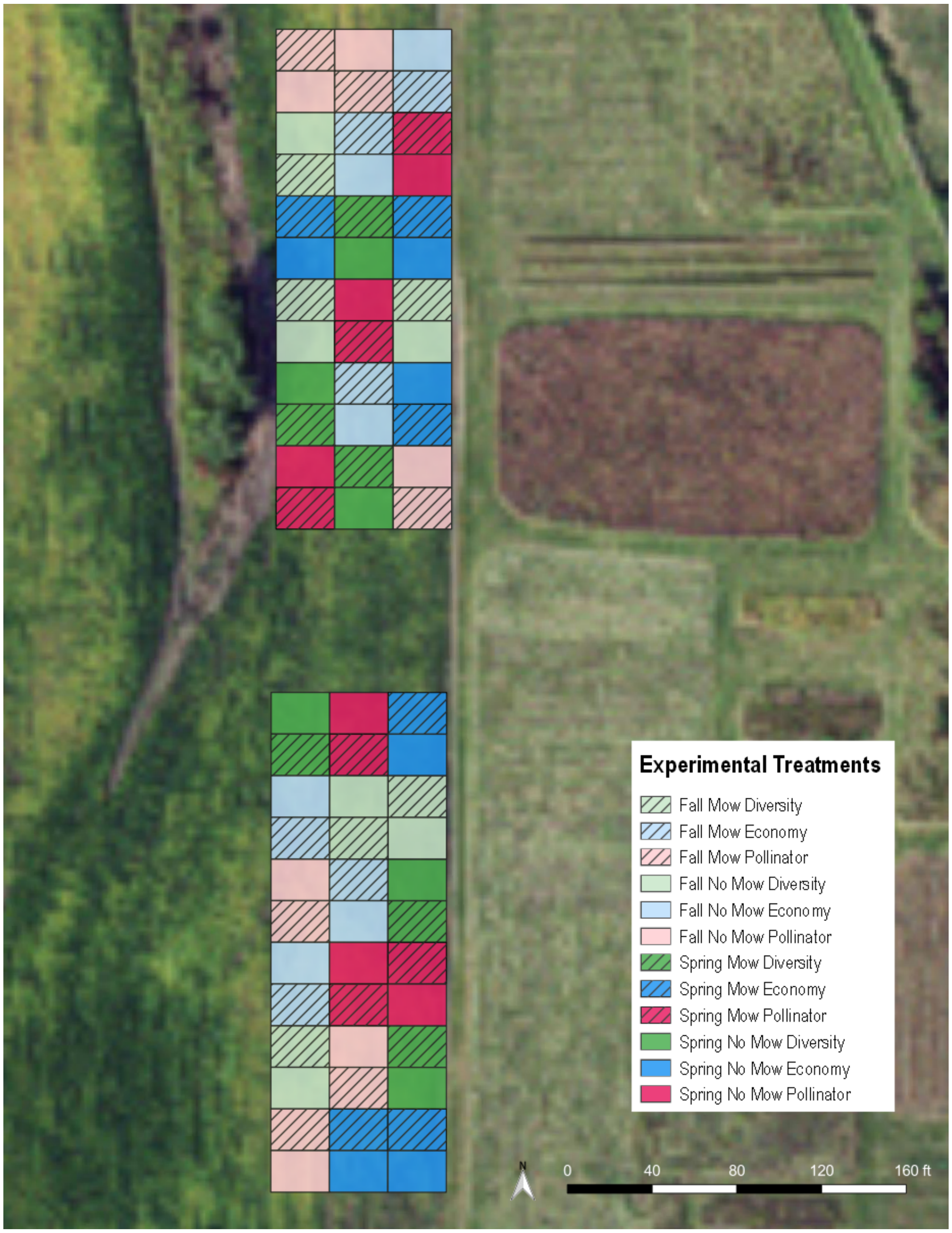

Figure 10. Experimental layout at the University of Northern Iowa in Cedar Falls, Iowa.

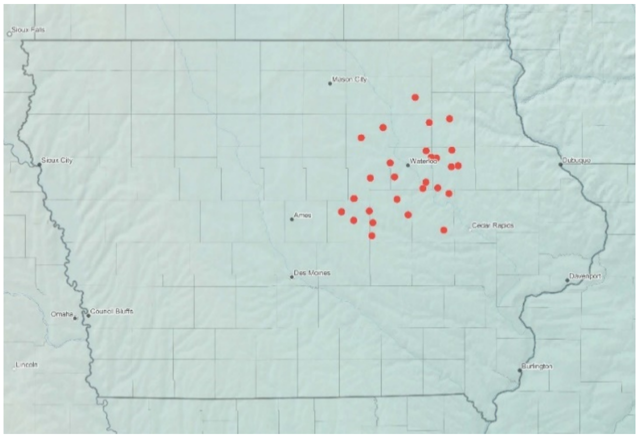

Figure 11. Vegetation sampling sites in 2018. An additional 19 sites were added in 2019.

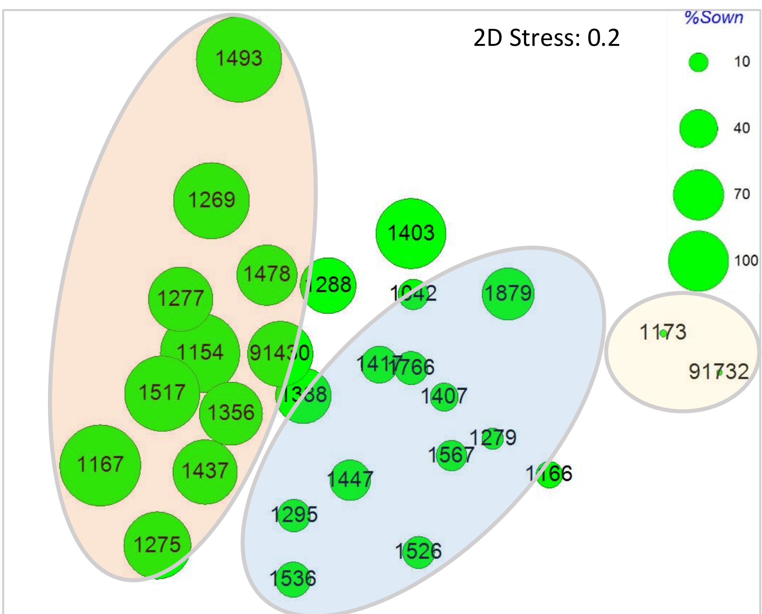

Figure 12. NMDS plot of plant community structure measured in 2018, at 26 CP-42 sites planted in 2016. Numbers within circles are site ID numbers (see table for vegetation summary). Size of green circle reflects classes of percent sown (forb plants m^{-2} x /total plants m^{-2}. Ovals separate clusters of sites into >50% sown, less than 50% sown, and <1% sown.

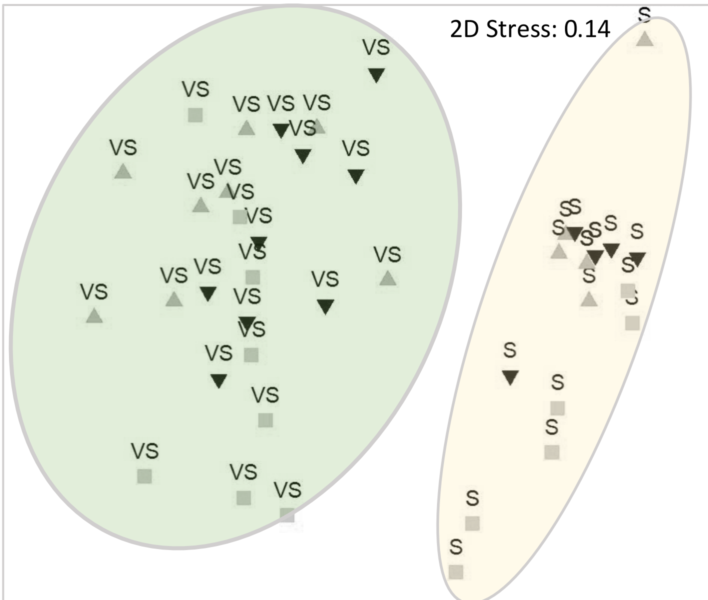

Figure 13. Non-metric multidimensional scaling of seeding density per species (seeds/m2), "S." versus forb plants/m2 ("VS"). The large ovals indicate clusters of sites that are more similar to one another.

List of Appendices and Supplements

Appendix 1. Survey sent to farmers.

Appendix 2. Native Seed Stakeholders Meeting report.

Appendix 3. *Restoration Ecology* paper.

Appendix 4. Farmer report, Pollinator Habitat Evaluation Project

Supplement 1. R script and site key /Excel template for seed mix analysis.

Supplement 2. Maps used to determine source appropriateness.

Supplement 3. Cost effectiveness template.