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Little prairie under the panel: testing native pollinator habitat seed mix establishment at three utility-scale solar sites in Minnesota

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Abstract

As more land is being utilized for large-scale solar energy projects, there are increasing discussions from stakeholders on how to utilize land under solar panels to promote biodiversity. One path is to plant habitat beneficial to pollinators and other insects, but there have been few long-term studies that examine how different vegetation and seed mixes establish underneath solar panels. This study addresses a scientific gap to determine whether native pollinator seed mixes successfully establish over time under solar arrays using a systematic assessment of eight seed mixes planted at three utility-scale solar sites in Minnesota. We assess establishment with a percent native coverage metric, which is an assessment of native species observations compared to total observations during percent cover analyses in our vegetative test plots. The percent native coverage metric allows for a measurement of how the seed mix established and how the seed mix persists over time. The percent native coverage under and in between the solar photovoltaic (PV) arrays rose from 10% after one year of planting to 58% after three years across all sites, while the native coverage of the full sun control area rose from 9.6% to 70% under the same period, showing that native prairie and pollinator plants successfully established under the array, although to a lesser extent than in full sun conditions. Percent native coverage under the PV arrays rose 5- to 8-fold for each of the three sites from over the course of the study, while the coverage of weeds decreased for all three sites over the same period. Percent native coverage varied by seed mix over the project years, but every seed mix experienced a higher percent native coverage year after year under the PV arrays. Our results did not indicate a difference in establishment across placement within the array; the center, west, and east portions of the areas in between panels had similar establishment rates at two out of three sites, indicating that the same seed mix can be applied throughout the array. Out of 101 plant species seeded, we observed the establishment of 68 species in our vegetative test plots, and we detailed the top 20 observed species to inform future seed mix development. Based on these findings, native pollinator vegetation can establish over time at solar arrays, and it can be suitable for creating habitat at utility-scale solar sites.

1. Introduction

Under the most aggressive deployment strategy, up to 10.3 million acres of land (0.5% of the US contiguous land area) for utility-scale solar may be needed by 2050 to meet the United States (US) decarbonization goals [1]. Although the percentage of total land area needed in the US for utility-scale solar is very low, solar site deployment can impact local communities and lead to land-use conflicts [1, 2]. There is an opportunity to respond to community concerns and utilize land underneath solar arrays for other beneficial purposes, including establishing pollinator habitat to address multiple ecological challenges, such as declines in pollinator populations and the loss of prairie habitat [3].

These ecological challenges are not separate from one another, but directly connected. One of the primary factors of the decline in pollinator populations is habitat loss [4, 5]. Therefore, the creation of pollinator habitat, consisting of forbs and grasses, often native to the region, helps support pollinators and other beneficial insects and can restore land back to native prairie. Pollinator habitat is not only beneficial to pollinators, but also provides many other ecological services such as erosion management and agricultural pest control [6, 7]. Pollinator habitat has previously been established on highway and utility right of ways and it is now being planted at solar facilities in the US and internationally [7, 8].

Establishing pollinator habitat at solar sites has been referred to as both agrivoltaics and ecovoltaics in current literature, but agrivoltaics can include other land uses such as animal grazing and crop production [9, 10]. Pollinator habitat at solar facilities may also directly contribute to agriculture production through honey production from apiaries located on site [11]. Currently in the US, 15 states have published guidelines or scorecards for establishing pollinator habitat at utility-scale solar sites [12]. While these scorecards are voluntary and are not mandatory for development, many solar developers are establishing pollinator-friendly habitat at their projects within these states and others without scorecards [13]. Many developers perceive that incorporating pollinator habitat can bolster a solar project's appeal to the local community and potentially lead to energy increases from cooling from vegetation [14, 15]. Even though pollinator habitat is being established at solar sites, there are not many proven site- and solar-specific seed mixes available to solar developers, especially in different regions of the country.

Designing and selecting a seed mix can often be time consuming and lead to project delays during development and potentially impact the success and timing of seed mix establishment [10, 16]. Factors that can affect the design of seed mixes include precipitation rates, height of the panels, soil type, availability and cost of native plant seeds, and plant blooming period [17]. The economics of creating pollinator habitat at a solar site includes not only the cost of the seed mix, but also costs associated with vegetation establishment and maintenance over the life of the project [10]. Also, there is no currently available research to detail what specific plant species will successfully establish in different climatic and geographic regions considering the microclimate effects from solar installations. While some sources have promoted frameworks on how to design and establish seed mixes [17, 18], there has been no coordinated study to assess what plant species best establish in the microclimate created by solar energy installations.

Prior to settlement, much of the Midwest, including the state of Minnesota consisted of upland and wetland prairies managed by fire [19]. The pollinator habitat created at solar sites is intended to mimic these prairie habitats and is managed by grazing or mowing, instead of fire. The State of Minnesota was one of the first states to develop a pollinator protection program and the state adopted a voluntary pollinator scorecard for PV projects in 2016 [20]. While many projects have met the requirements of this program [20], prior to this study the current 'solar-ready' seed mixes offered by Minnesota Board of Water & Soil Resources have yet not been assessed underneath solar arrays over a multi-year period. Local PV developers, vegetation management contractors, and prairie restoration firms have developed mixes specific for the altered shade and micro-climate environments that exist underneath PV panels, but there has been no systematic assessment of the establishment rate and plant community diversity of these different mixes. While our study only takes place in Minnesota, findings about establishment and persistence of pollinator habitat can be applicable to other solar sites if a region-appropriate seed mix is utilized.

To provide an initial assessment of different seed mixes, our project team planted and established eight seed mixes at three different Minnesota utility scale solar sites to compare plant diversity and establishment rates over time. The guiding research questions are:

(1) Does native vegetation coverage increase over time, and do site and soil conditions have an impact on percent native coverage?

(2) Does seed mix design have an impact on percent native coverage?

(3) Does shading and position of vegetation impact percent native coverage?

(4) What species were observed the most and were any species planted not observed?

This paper will detail the findings from three consecutive years of plant and biologic surveys to provide initial input into seed mix design for pollinator friendly solar sites. Other research was conducted at our test sites that examined the effects of this habitat creation on increased pollinator abundance and diversity with seed mix establishment, as well as microclimate changes and their mixed impact on energy production [21, 22].

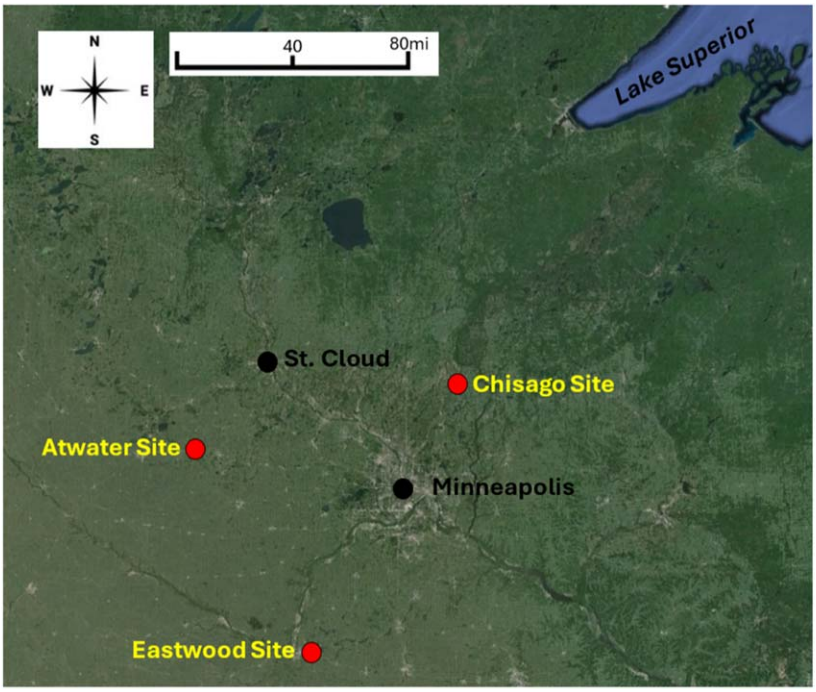

Figure 1. Location map of study sites in Minnesota. Maps Data: Google ©2013 Landsat/Copernicus, NOAA.

2. Methods

2.1. Site selection

In 2018, our project team coordinated with Enel Green Power North America, Inc. to identify three PV sites in different climatic and soil conditions for native pollinator habitat and vegetation establishment testing. All sites were a part of the 100 MW Aurora Distributed Solar Project in and around the Minneapolis, MN area [23]. At the time of planting our test seed mixes, each site was operational. Each site was between 2–5 MWdc of total installed capacity covering 10–25 acres (4–10 hectares). Each site has mono-facial c-Si modules installed with a one-axis tracking system in a 1P orientation (i.e., a row of individual panels in portrait orientation rotating around a central hub to track the sun from east to west). The minimum height of the PV panels was 48 inches (122 cm) on the trailing edge allowing for wide variety in seed species selection with varying establishment heights. The distance between rows in the arrays, post to post, was roughly 18 ft (5.5 m).

The three PV sites selected, Atwater, Chisago, and Eastwood (figure 1), are in three different level IV ecoregions: McGrath Till Plain and Drumlins, Mississippi Valley Outwash, and Des Moines Lobe, respectively. Each of these ecoregions' pre settlement vegetation included prairies, but currently these areas, including our study sites prior to solar facility development, consist primarily of farmland [24, 25]. These sites are representative of different soil textures; sandy loam at Atwater, silt loam at Eastwood, and sand at Chisago [21, 26]. Both the Atwater and Eastwood sites are low lying and adjacent to a wetland, while the Chisago site is upland. Figure 2 highlights the difference in seed mix establishment across the three sites for a comparison in soil conditions.

2.2. Seed mix design

For our vegetative test plots, we chose six commercially available seed mixes and developed two alternate seed mixes to test a wide variety of flora species at these sites. The alternate seed mix (SolCon, Ltd wet and dry mixes) compositions were designed to test out specific native plant species that were not commonly found in the other commercially available mixes to test whether other species might establish better in the solar array conditions. This study tested both wet and dry condition specific mixes at all three sites. The seed mixes planted are shown in table 1 and shows the environmental use case for the mixes and a breakdown of % grass, sedge, and forbs planted by mix. These mixes represent 101 different species of grass, sedge, and forb taxa and represent several commercially available seed mixes specific to solar development at the time of seed establishment.

Figure 2. Photos of seed mix testing areas at each study site in September 2021. The photos below show the ground cover establishment at each site for the same seed mix in year 3.

Table 1. Test seed mixes identifying information. Note that the SolCon mixes are the two non-commercially available seed mixes.

Seed mix name	Seed mix designation	Use	Grass % of mix (PLS)[a]	Sedge % of mix (PLS)	Forb % of mix (PLS)
MNL Inc. wet short [27]	Z (MNL Wet)	Wet array mix	71.25%	3.75%	25%
MNL Inc. dry upland [28]	Y (MNL Dry)	Dry prairie mix, short grass	68.75%	1%	30.25%
SolCon, Ltd wet[b]	X (SolCon Wet)	Wet MN array mix	0%	60%	40%
SolCon, Ltd dry[b]	W (SolCon Dry)	Dry MN array mix	60%	15%	25%
BWSR wet native sedge [29]	V (BWSR Wet)	Wet meadow	20.4%	48.1%	31.5%
BWSR dry native SW [30]	U (BWSR dry)	Short grass prairie	92%	0%	8%
Prairie Restorations Inc. pollinator [31]	T (PR Pollinator)	Pollinator mix for dry to mesic soil	60%	0%	40%
Shooting Star pollinator [32]	S (SS Pollinator)	Pollinator mix	50%	0%	50%

[a] Pure live seed - the percentage of seed that will germinate in a mix and does not include any inert matter, which is normally added for seeding.

[b] Information about this seed mix can be found in the Supplemental Information, SI-1.

2.3. Seed mix layout and establishment

At each of the three PV sites, our project team established a 0.35-acre (14 hectare) vegetative research zones under the solar array. Herbicide was used beforehand on the test plot areas to remove existing vegetative growth, and then mixes were broadcast seeded in May of 2018. Each of the chosen seed mixes were established in replicated 18 × 25 ft (5.5 × 7.6 m) vegetative test plots under and in between the solar arrays for each site (figures 2 and 3). This allowed for three replications of the different seed mixes at each site, which were randomly assigned. The size was chosen based on the array post spacing for easy demarcation and identification. Because the seed mixes were established adjacent to one another, a small buffer area of 4 in (10 cm) was utilized at the plot edges to limit seed mix contamination. A scaled down control plot was planted outside of the solar array at each site to represent full sun conditions for each of the 24 vegetative test plots. The vegetative test plot areas were not mowed and while this is not common management practice at most solar sites, this was performed for the sake of the research project to allow for full establishment of the seed mix. There were plans to perform spot-spraying with herbicide (glyphosate) on an as-needed basis to control invasive species in the test plots, but there were no recorded events for where this was needed.

2.4. Percent cover analysis

After the planting of the seed mixes in 2018, the project team performed three percent cover analyses at each site in: (1) August of 2019 (2) August of 2020 and (3) September of 2021. The timing of visits was based on local growing conditions and team availability but represented the same time of year for each observation. Percent cover analyses were adopted from methodology established in Beatty *et al* 2017 [33]. For each vegetative test plot, a transect was laid in the west, center, and east sections of the test plot area to represent different shading and rain runoff areas. For each transect, a laser pointer was affixed, pointing downward, to a rotatable tripod arm and researchers recorded both the first and second observations of vegetation the laser hit, replicating on both sides. This method is a modification of the point intercept method to observe the first two plants observed for a simple representation of ground cover [34]. The tripod was then moved 1 ft (30 cm) along the transect to document 50–60 observations for each test plot within the array and in the full sun control area. When identifiable, the flora species was recorded along with observations of weeds, bare ground, and thatch. If not identifiable to species

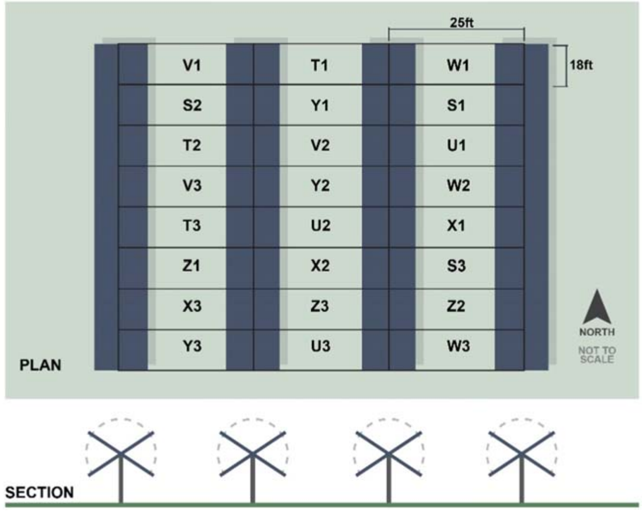

Figure 3. Seed mix test plot layout established at the Chisago location. Letters indicate the seed mix designation from table 1 while numbers indicate the replicate number. The layout was determined through randomization and changes across the three sites.

level, the team recorded native or non-native for the observation. The purpose of these classifications was to determine the native coverage percentage based on what was observed versus planted in the individual test plots. While each site has three replications of each seed mix (e.g., S1, S2, S3), only two of the three seed mix test plots were sampled each year due to time limitations and to provide randomness.

2.5. Statistical analysis

After data collection, an analysis was performed to examine the changes over time, as well as statistically significant impacts of various parameters (e.g., by site, by seed mix, by location in the test plot) on the final pollinator habitat makeup in year 3 (2021) at the end of the trial period. We define a 'percent native coverage' metric based on the observations of what species were seeded and established over the study period. Percent native coverage is the sum of observations of native species divided by the total number of observations in the test plot for one year. Observed native species that were not in the seed mix (seeded through contamination, preexisting in the latent seed bank, and/or seeded by dispersion from other plots) were included in the numerator for the percent native coverage.

To investigate the impact of seed mix and environmental conditions on pollinator habitat establishment, a three-way ANOVA was conducted on the percent native coverage values in year 3, at the end of the study period. The three independent variables are site (Atwater, Chisago, or Eastwood); planting location under the array (east, center, or west transect under the PV array, or the full sun control plot); and seed mix type (wet or dry). The dependent variable is the percent native coverage calculated for each test plot (e.g., Atwater, plot S2, west transect) for year 3. Due to limited sample size for each seed mix, the seed mixes were grouped by the seed mix type to increase the sample size for each treatment combination. The two pollinator mixes were grouped with the dry seed mix types. Then, a Type III three-way ANOVA was selected due to the unbalanced sample sizes among groups (R's rstatix package) [35, 36].

For significant two-way interactions, the three-way ANOVA analysis was followed with simple main effects analyses using Bonferroni adjustment of the p-values. Where necessary, the simple main effects analysis was followed by a pairwise estimated marginal means test with a Bonferroni adjustment (R's emmeans package) [37]. More information on statistical methods can be found in SI-2.

3. Results

3.1. Does native vegetation coverage increase over time, and do site and soil conditions have an impact on native coverage establishment?

Percent native coverage under the PV array rose 5- to 8-fold for each of the three sites over the three years of the study, as shown in figure 4(a), while the coverage of weeds decreased for all three sites over the same period (figure 4(b)). This verifies that the prairie species established underneath the solar panels over the three-year period and weed pressure reduced over time.

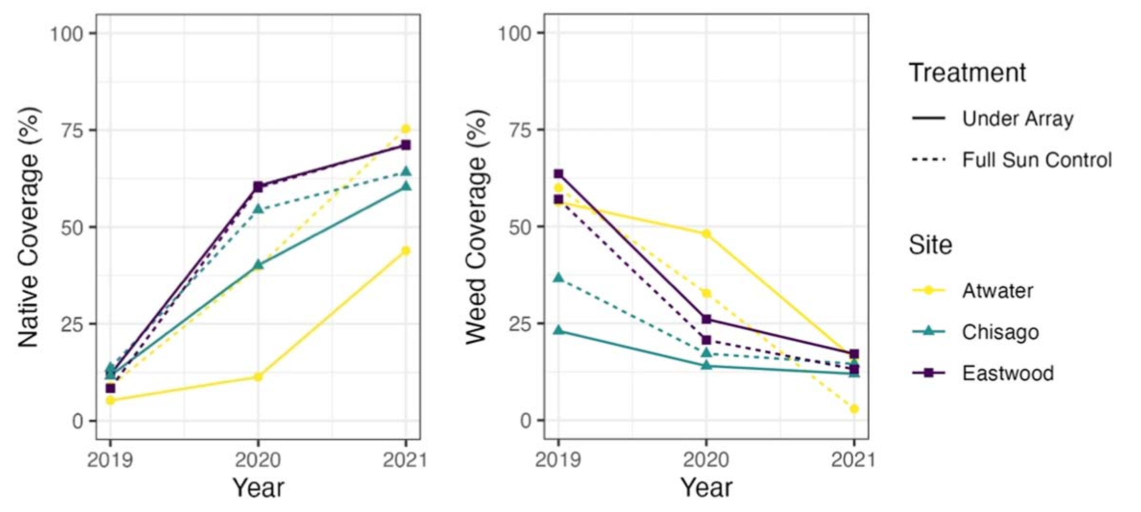

Figure 4. (a) Percent native coverage and (b) percent weed coverage by test site over the three-year study.

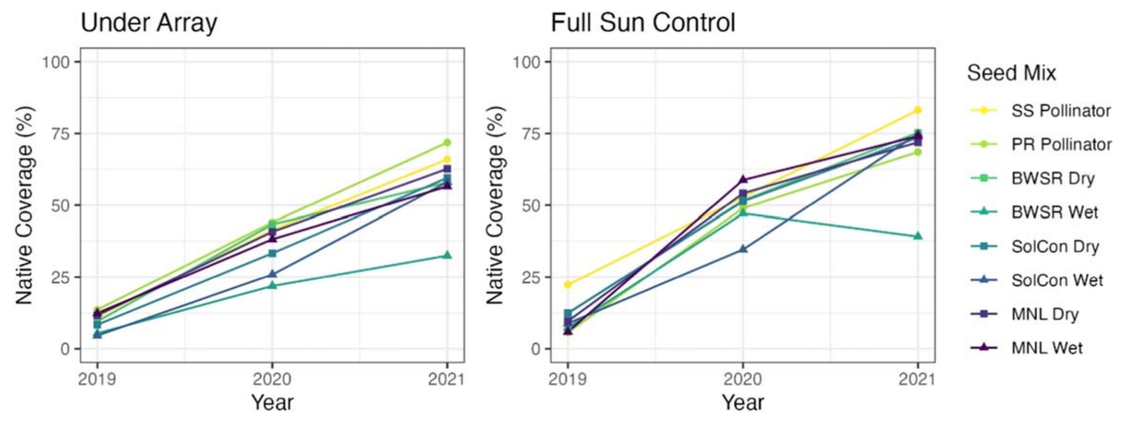

Figure 5. Percent native coverage by seed mix aggregated across all sites, 2019–2021. Note: SolCon seed mixes are non-commercially available. All seed mixes showed an increase over time aggregated across all sites (BWSR wet being an exception for Year 3 mainly due to lack of establishment at Chisago). Rate of establishment was similar but higher in the full sun control plots.

In Eastwood, percent native coverage under the PV array and in the full sun control increased at very similar rates. In year 1, percent native coverage was 12% under the panels and 14% in full-sun control, which rose to 71% for both treatments in year 3. Similarly, percent native coverage under the PV array at Chisago rose from 12% in year 1 to 60% in year 3, although coverage grew more slowly in year 2 compared to Eastwood. This could be explained by the cool and wet year experienced in year 2 (2020) with Eastwood being in a wetter climatic zone. Atwater's percent native coverage under the PV array was the lowest among the sites for all three years. Percent native coverage at Atwater under the panels rose from 5% in year 1 to 43% in year 3, while the coverage in the full sun control reached 75% in year 3.

3.2. Does seed mix design have an impact on native vegetation coverage?

Percent native coverage varied by seed mix over the project years, but every seed mix experienced a higher percent native coverage year after year under the PV array as shown in figure 5. The SS Pollinator and PR Pollinator seed mixes had higher percent native coverage every year, with the BWSR wet seed mix being the lowest or tied for lowest every year. All other seed mixes varied in percent native coverage over the years but were mostly similar across our observations. Performance of the individual seed mixes at the different sites can be found in SI-3.

3.3. Does shading and position of vegetation impact native coverage?

The site, seed mix type, and planting location all had significant impacts on the percent native coverage by the third year of the study (site: $F(2, 144) = 14.6$, $p < 0.001$; seed mix type: $F(1, 144) = 23.6$, $p < 0.001$; planting

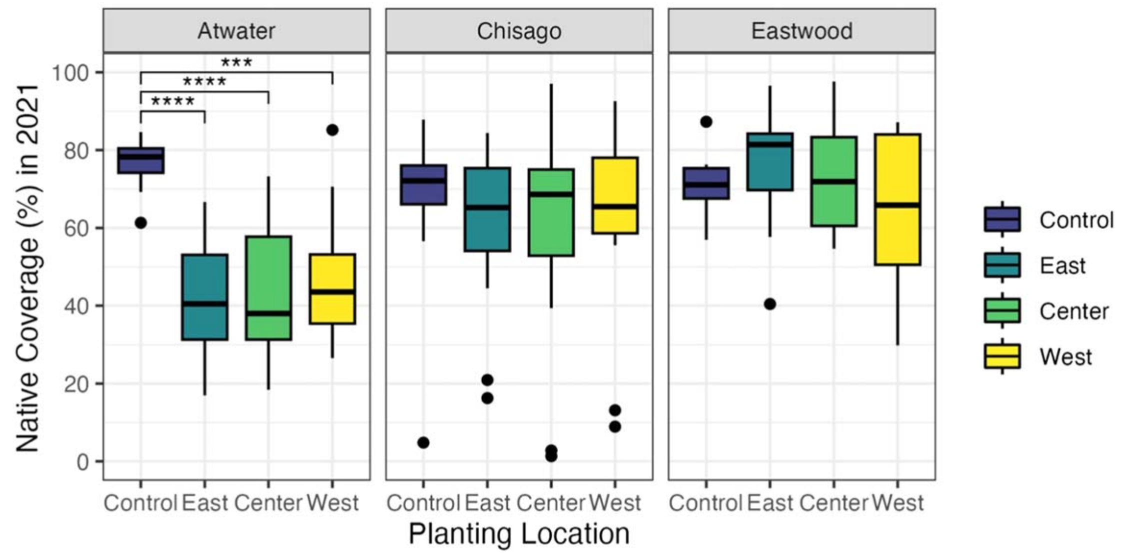

Figure 6. Difference in percent native coverage in year 3, based on planting location at the three sites, where percent native coverage is calculated for each test plot. Locations under the PV array at Atwater had significantly lower coverage than the full sun control.

location: $F(3, 144) = 4.3$, $p < 0.01$). Additionally, there was a significant interaction between site and planting location ($F(6, 144) = 4.1$, $p < 0.001$).

As shown in figure 6, there were significant differences in the percent native coverage between the full sun control and the PV array at Atwater (loamy soil) (simple main effect: $F(3, 144) = 10.2$, $p < 0.001$; pairwise tests: east, $p < 0.001$; center, $p < 0.001$; west, $p < 0.001$). However, there were no statistically significant differences among the planting locations within the PV array at Atwater. At Chisago and Eastwood, there was more variability in percent native coverage under the PV array, but there was no significant difference compared to the full-sun control. The interaction between site and seed mix type also had a significant impact on percent native coverage by year 3, and results are presented in SI-4.

3.4. What species were observed the most on site and were any species planted not observed?

Of the 101 species seeded, we observed 68 of those species in year 3. Of those 68 species observed, only 20 species were observed, more than 1% of the total observations (not including non-native and/or bare coverage values) as shown in the SI (Table SI-5). Differences in observations between year 2 and year 3 highlight yearly differences in climate (on average 2020 being wetter and cooler than 2021) [25].

4. Discussion

Our observations confirm that native prairie seed mixes can successfully establish underneath solar panels in Minnesota across a variety of soil and climatic conditions. While this study only focused on Minnesota, the results can be applicable to other solar projects if the seed mix is designed specifically for those site conditions (soil, ecoregion, water availability, etc). Establishment of native vegetation can take at least 3 years and, from other project observations, may need the assistance of reseeding, spot-spraying of herbicide, and strategic mowing [10, 17]. As a result, ongoing O&M activities will be needed after seeding to ensure successful establishment. For all our seed test plots, our project team did little to no O&M activities. Most vegetation at solar sites is mowed annually, if not more frequently, to control plant height. By not mowing these sites there could be an impact on which seeds establish over time. Not mowing likely benefited opportunistic plant species and possibly impeded long establishing species, impacting species diversity. Future research plans include incorporating more traditional O&M events into our test plots to determine any impacts.

Establishment rates for the same seed mixes at the same site can vary by year based on plant biology and ambient conditions. Broader weather patterns (drought versus wet years) could have impacted establishment of different seed species, impacting results on a year-to-year basis and skewed results to species that might have performed better in that year. Our observations did show that seed mix selection had an impact on establishment at Chisago, the driest and sandiest soil site, where some of the wetland species did not establish. However, our wettest climactic site, Eastwood, was more varied in which seed mix established well with several dry mixes having the highest percent native coverage in year 3. The underperformance of seed mixes at Atwater compared to the other two sites likely has to do with site soil conditions, previous land use, and site selection. At Atwater, the PV array is located next to a wetland, while the full sun control plot is on slightly elevated ground. In year 2, the wetland overflowed, flooding the PV array area possibly resulting in a redistribution of seeds and impacting the results. This leads to a need for careful site selection if establishing pollinator species is a goal of a PV development project.

While seed mixes generally performed better in the full sun control plots, there was not a large difference in establishment rates between control and under panel conditions by year 3. As for the location of observations within the test plots, there was not a large difference in where within the array species established, highlighting that a single seed mix could be used throughout a site (i.e., different mixes under versus in-between the arrays are likely not needed). The average percent native coverage was lower on the west position of test plots, but there was not a statistically significant difference compared to the other two positions. A potential explanation for some observed differences on the west edge of the plot may be from increased erosion due to the drip edge of water off the solar panels, but further research is required to confirm this. Along with location, there was a potential for contamination during the broadcast seedings process by wind dispersal of seeds to other plots, seeds sticking to clothing and/or shoes that moved to another plot, or rainwater transferring seed to other plots. Where the plots met one another there were noticeable observations of encroachment from other plots based on species present that could have affected results. This could be remedied by seeding during low wind conditions and not establishing seed mixes adjacent to one another.

This study highlights 20 species that could be used as a starting point for generic seed mix design for that establish at the highest rate at Minnesota solar sites, as shown in SI-5. Black-eyed susan (R*udbeckia hirta*), Canada wild rye (*Elymus canadensis)*, and slender wheatgrass (*Elymus trachycaulus*) had higher observations in year 2 than year 3 that could be based on plant biology (e.g., some black-eyed susan variants are biennial, meaning they bloom the second year after planting seed, thereafter the plant dies, although self-seeding may extend the bloom on these plants) or on weather conditions for those years. To ensure successful vegetation establishment it may be necessary to plant a variety of species that can adapt to different conditions and consider the biological growth patterns of the plants. One limitation of the species list results is our small, infrequent sample size with observations occurring only once per year in the fall. There is potential that our results are only applicable to this region and climactic zones for these given years. A small number of sites and the relatively small test plot size made replication of weather and soil conditions difficult and could affect significance.

Note that some species planted can take more than 3 years to establish and their observational absence from should not bias the potential seed mix design if other species could provide long term ecological benefit. This will require further location specific research to ascertain which plants are early successional and can assist early in establishment, balanced with plant species that can provide long term benefits to pollinators over the life of the project. As for the seeding rates of these species and different grass/forb ratios of seed mix design, we are unable to draw conclusions as that often depends on specific site conditions, cost, availability that year, and project goals for establishment. The purpose of this study was to look at establishment rates of different available seed mixes for these sites and did not look at seed mix composition alterations, which could be a future area of study. At all sites, there was a previous seeding event to meet stormwater permit requirements on site prior to test plot establishment. While this vegetation was sprayed out with herbicide prior to our test seed mix establishment some of the seed may have stayed in or changed the latent seed bank of the site causing non-planted native species to grow that could have an impact on results.

Many of the limitations of this study reflect real-life conditions the solar industry faces in vegetation establishment, however. Further studies are needed to provide a larger sample size across much more varied conditions to draw many conclusions outside of Minnesota and the surrounding region. Our percent cover methodology can be time-consuming, costly, and only provided a single point in time that year, which limits the applicability to the overall solar industry. Future research could consider more frequent but less rigorous abundance surveys to highlight specific establishment rates of different seed mixes and species, especially if there is a smaller starting number of planted species.

5. Conclusion

This paper reported the first systematic and long-term study of its kind to assess the establishment of native prairie seed mixes underneath solar arrays in Minnesota. While this study only looked at sites in Minnesota, it can apply to other areas where seed mixes are designed for the local climate and soil conditions. Our study showed that native pollinator habitat can establish underneath solar arrays, but that establishment can take anywhere from 3–5 years. We observed 5–8 times increase in percent native coverage from 2019 to 2021, showing that the seeded native plant species established over other non-native species present in the seed bank. The dry-use intended seed mixes had a statistically significantly greater establishment rates compared to the wet-used intended seed mixes at the Chisago and Eastwood sites; however, there was no statistically significant difference in the seed mix types observed at Atwater. Based on the results and individual plant identification, we outlined 20 different flora species that were observed at a higher rate than the others to inform future seed mix design. This study filled a research gap to assess how native vegetation can establish in the altered microclimate underneath solar panels and for solar to be used for increasing native pollinator habitat. For future research, the inclusion O&M activities in the test plots may be needed, including herbicide and mowing, to counteract the effects of successional changes of plant species composition in different seed mixes and more accurately reflect real-world conditions at solar sites. Future studies are needed to validate these results over the life of the project, expand knowledge to other regions of the country, and to address the study limitations identified.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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