Impacts of conservation practices at solar facilities: vegetation, pollinator, and wildlife monitoring (2018-2021)

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EXECUTIVE SUMMARY

The North Carolina chapter of The Nature Conservancy, the NC Wildlife Resources Commission, and the US Fish and Wildlife Service began collaborating in 2018 to develop best management practices for the growing solar industry in North Carolina. We established working relationships with 4 solar developers who implemented one or more types of conservation practices at their facilities, including: pollinator habitat (wildflower mixes and/or clover), wildlife-friendly fencing, and wetland features. After implementation, The Nature Conservancy monitored the facilities for vegetation, pollinators, and wildlife (as appropriate). Because every facility is different, with different initial conditions and implemented management practices, there is no true replication and we were unable to sample and test for statistical differences; however, our monitoring approach was applied systematically to each site and was able to identify important differences in plant and wildlife outcomes that help with our understanding of solar site management.

Each site showed different patterns in plant composition and succession over time, but we were still able to identify some patterns (Figure 1). Our site with the earliest pollinator planting (Phipps Bend) in two discrete patches had high wildflower cover in the first year after implementation but transitioned to native grass over the 4 years of monitoring. Another site with minimum maintenance (Page) has persisted over 3 years at low but fairly uniform wildflower coverage across the entire site. The site with the most noticeable increase in wildflower cover (Redmon) has pollinator vegetation planted between rows of the array and has been more deliberately maintained (Figure 1). Two facilities were only sampled in the first year after planting (Arborgate and Howell Midland) and also showed high initial wildflower cover. In contrast, two facilities implemented a clover mix rather than wildflowers. At the older site (Solar Facility 1) we have seen a transition from clover to grass and weeds over time. The newer site (Solar Facility 2) is persisting with fairly consistent cover of clover over 3 years, but anecdotally at this site and others (Phipps Bend), we have seen a decrease in clover cover over time (Figure 1).

Pollinator abundance followed similar patterns (Figure 2); we saw increases in pollinators at the two sites with the most persistent wildflower cover (Redmon and Page) and decreases at the sites where the wildflower or clover cover decreased over time (Phipps Bend, Solar Facility 1, Solar Facility 2). The two sites with one year of sampling (Arborgate and Howell Midland) has similarly high pollinator counts and diversity. The clover sites (Solar Facility 1 and Solar Facility 2) had comparable counts of pollinators with sites with similar percent cover of wildflowers (e.g., Redmon) but lower pollinator diversity (Figure 2).

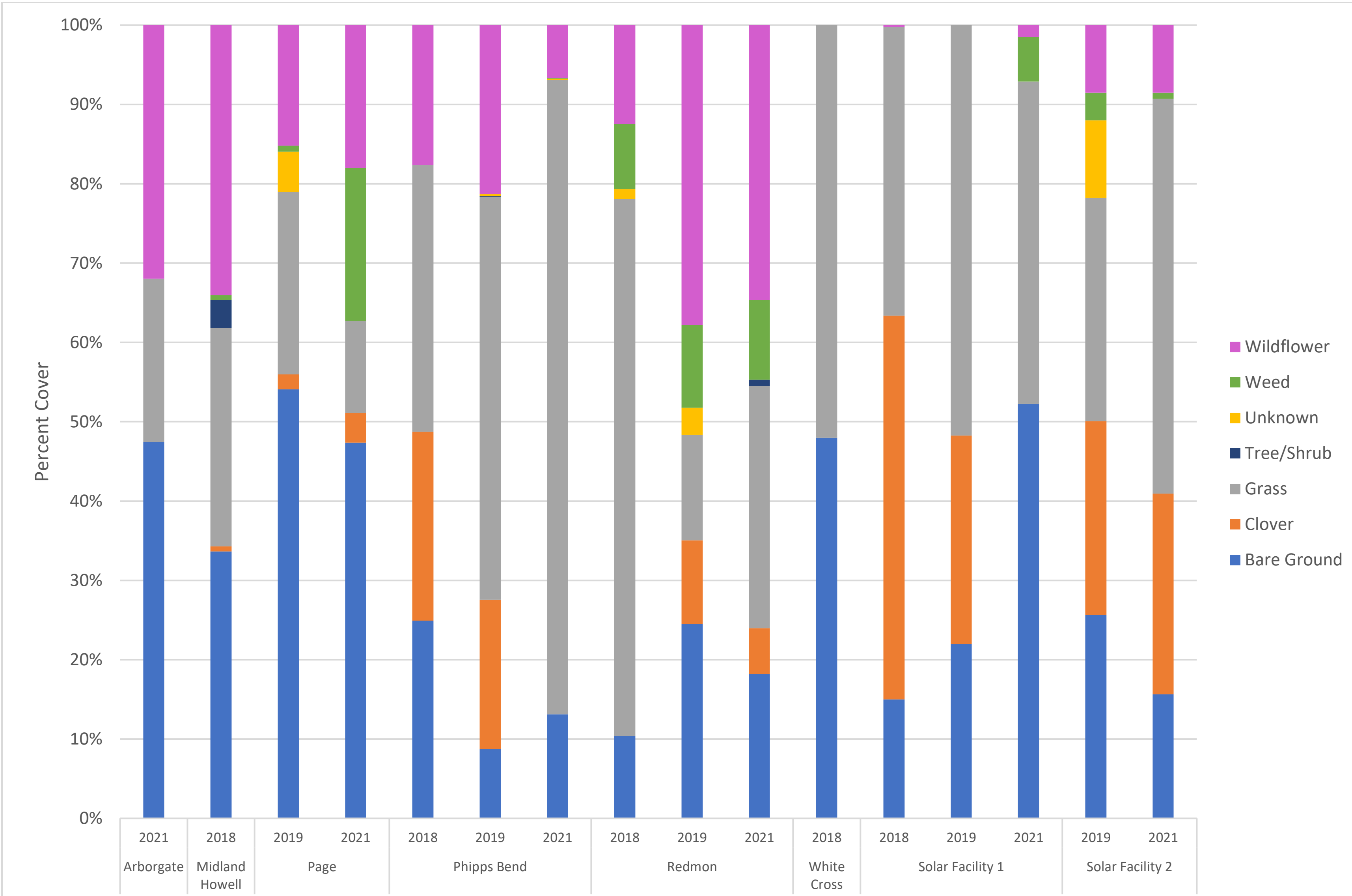


Figure 1. Vegetation percent cover by site, by year. "Weed" is used to describe any ground cover that generally does not flower or attract pollinators (other than "Grass"). White Cross was a facility with no pollinator vegetation, sampled as a control in 2018.

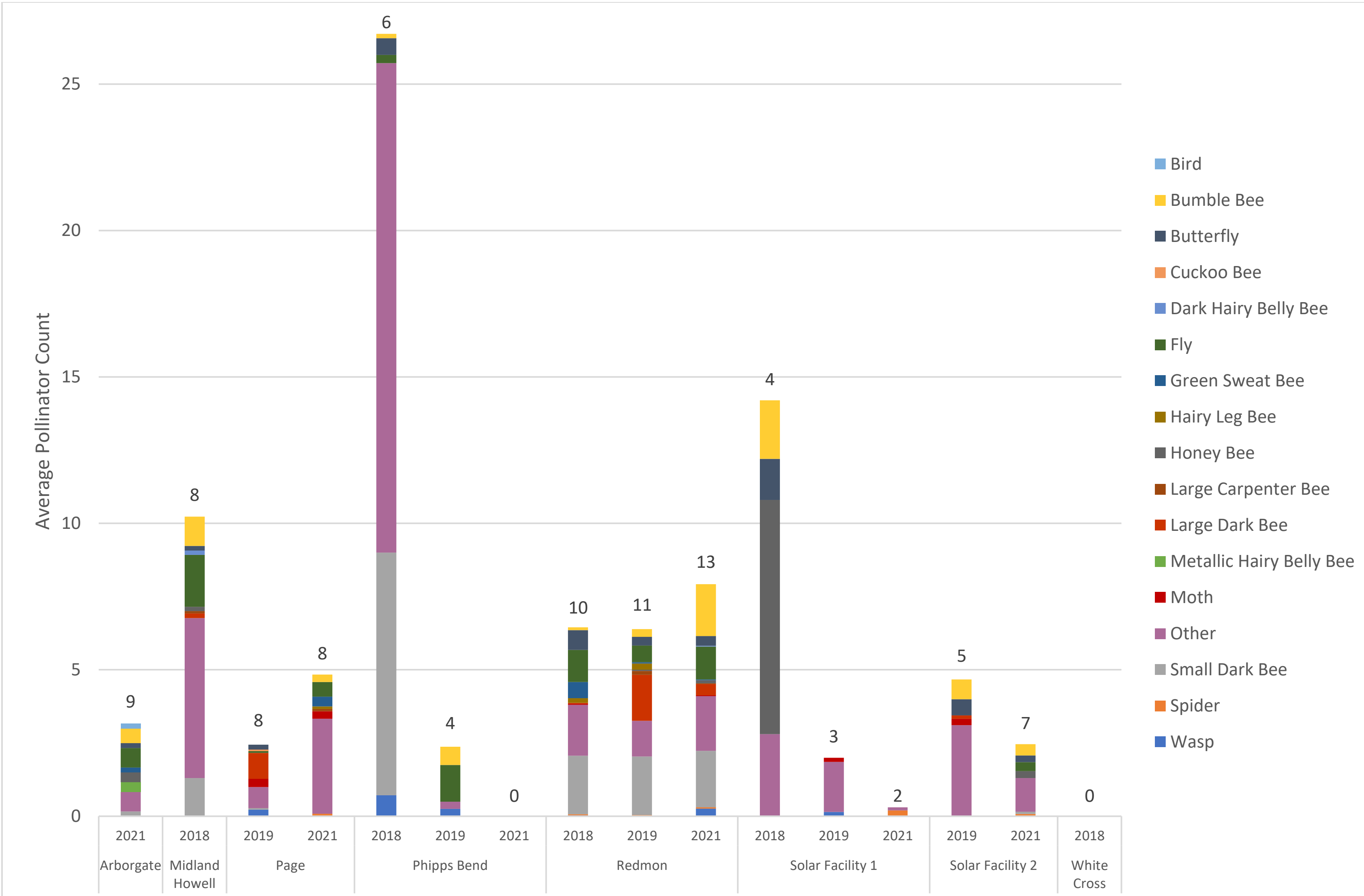


Figure 2. Average pollinator counts by site, by year. White Cross was a facility with no pollinator vegetation, sampled as a control in 2018. Numbers above bars represent the species diversity at that site for that year, based on number of pollinator categories.

We compared the total percent cover of flowering vegetation (wildflowers and clover) with pollinator counts, and as expected, we found a roughly positive relationship, indicating that higher cover of wildflowers leads to higher numbers of pollinators (Figure 3).

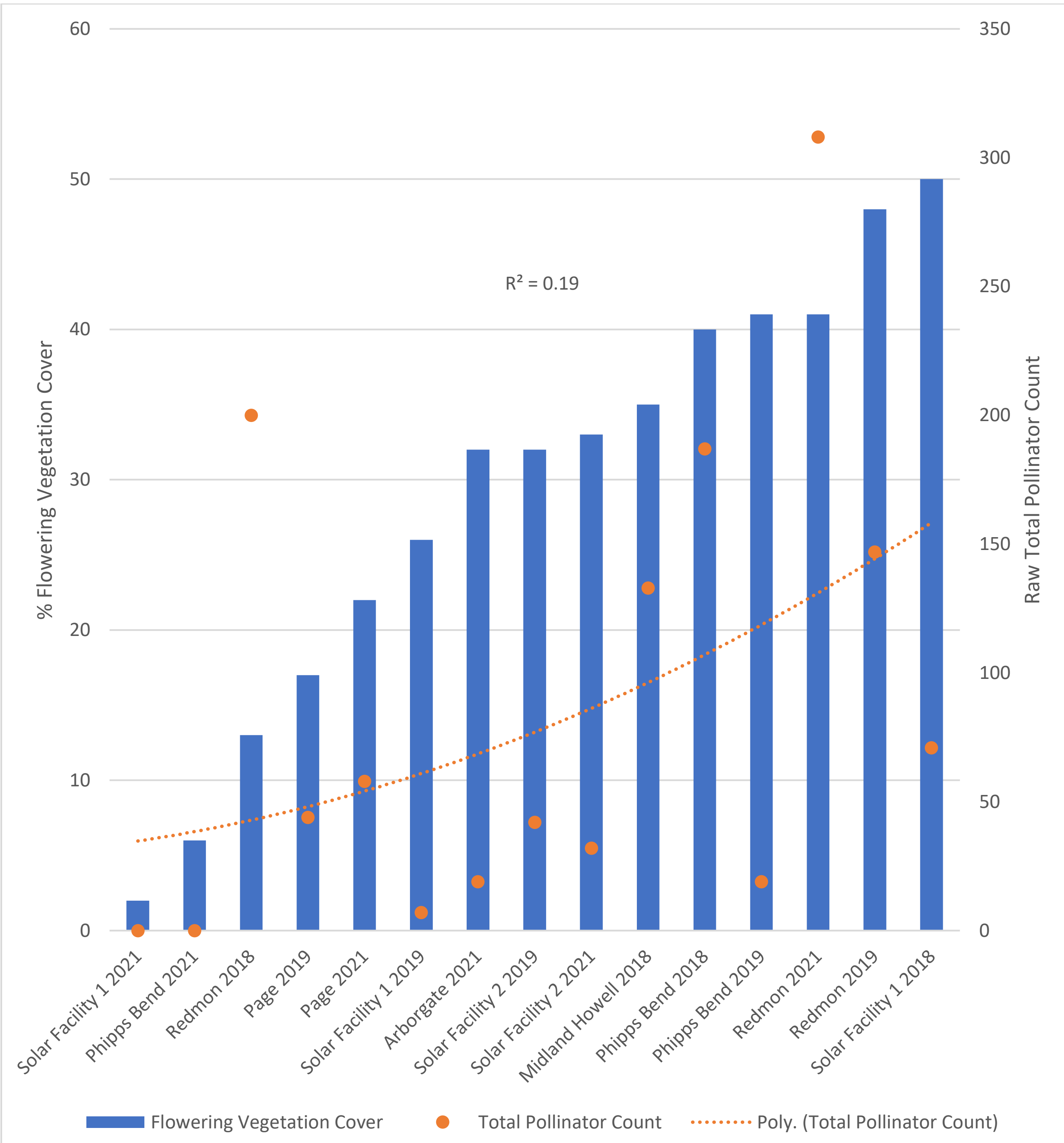


Figure 3. Relationship between percent of vegetation type that is a flowering plant (i.e. wildflowers and/or clover) and the total count of pollinators.

Wildlife-friendly fencing is a recommended conservation practice, because it allows small-to-medium sized animals (e.g., turtles, racoons, birds) to pass through the facility and potentially use the facility for foraging, nesting, etc. The fencing used at our sites was 1.8m tall with the gaps between wires measuring approximately 18 x 13 cm (specs: 12.5 gauge Fixed Knot “Deer Busters” 17/75/6 deer mesh galvanized fence with three strands of 12.5 gauge 4 point barbed wire, Fortress Fencing).

Camera traps were placed on the inside of the fences to capture wildlife activity through the wildlife-friendly fence. We compared three facilities with wildlife-friendly fencing (Moore, Page, Phipps Bend) with a site with chain link (Solar Facility 2) (Figure 4). The wildlife-friendly fencing was generally effective in keeping larger animals out of the sites (e.g., no coyotes at the first 3 sites), but white-tailed deer often managed to get in the fence regardless of fence type (Figure 4). Otherwise, sites with wildlife-friendly fencing show a diversity of small-to-medium sized mammals using the site, which otherwise likely could not have penetrated a chain-link fence.

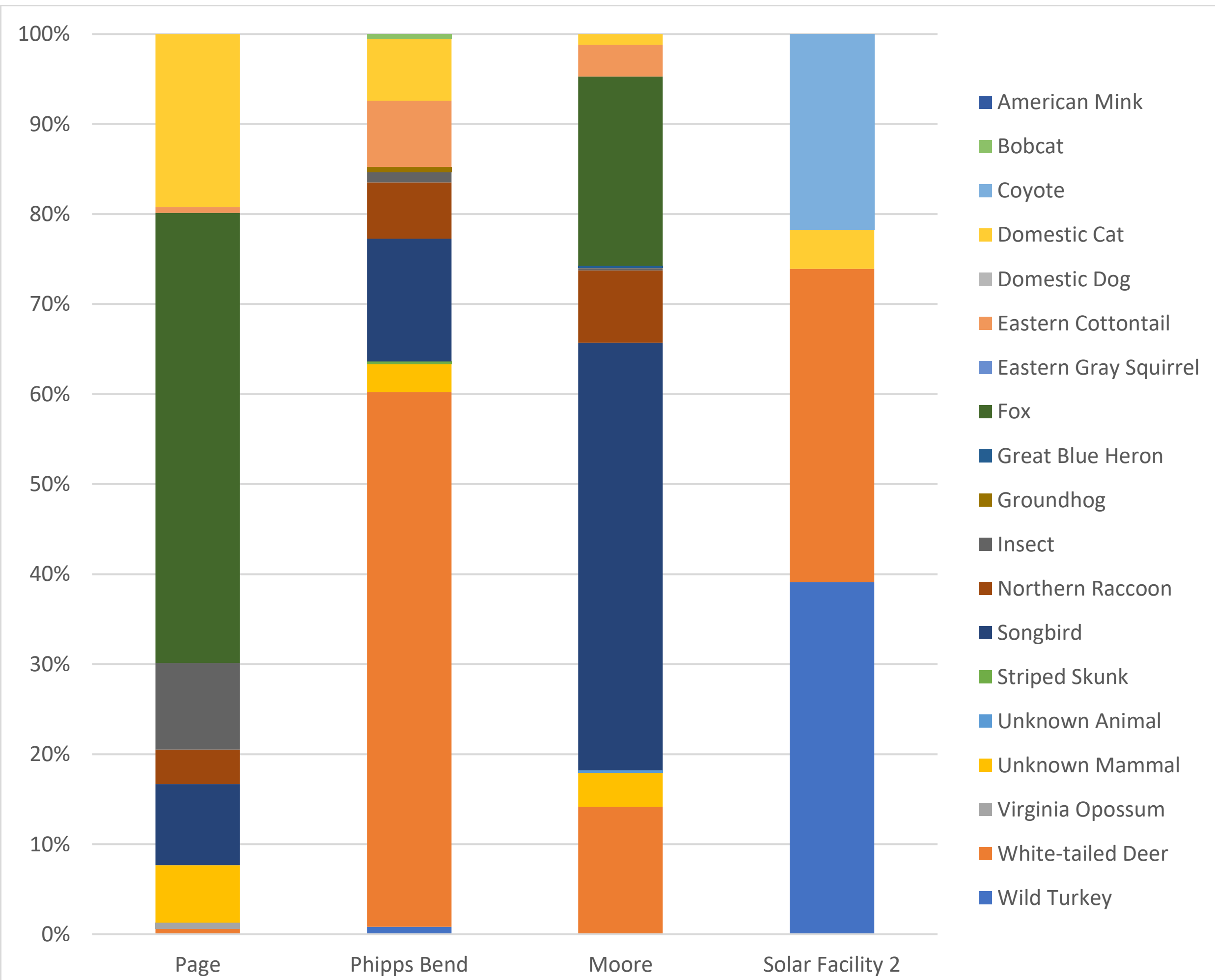


Figure 4. Species compositions from camera-trap images inside solar facilities, across all sites. All sites except Solar Facility 2 have wildlife-friendly fencing; Solar Facility 2 has chain-link fencing with a low spot that animals were using to access the site.

Recommendations:

- Continue monitoring plant successional dynamics at solar facilities and increase sample size to allow for better generalizations and conclusions.
- Implementing and maintaining pollinator habitat takes some effort in terms of maintenance, including management of invasive plant species. Vegetation management is an extensive topic; recommended guidance documents include the NC Solar Technical Guidance and the NC Pollinator Toolkit.
- Our longest running site transitioned from wildflower cover to a grassland over 4 years; this may be a desirable outcome, as this condition resembles a natural state. However, a native grassland would still likely have a small but diverse wildflower component, whereas the site we observed was dominated by native warm season grasses and just a few blooms.
- We did not see clover persist at solar facilities, although more sites are needed to draw conclusions. Unless managers are willing to re-seed annually, or mow often, clover is not likely to have long-term success. Since the objective of many developers is to reduce the amount of mowing, clover may not be an effective strategy.
- Wildlife-friendly fencing is effective in keeping large animals out (e.g., deer and coyotes) and allowing medium-sized animals (e.g., bobcats, foxes, rabbits) into the facility. Facilities with wildlife-friendly fencing should also maintain wildlife habitat in the form of unmowed vegetation that provides cover.
- Large animals may benefit from unfenced wildlife passageways through larger facilities, since they were not able to use the wildlife-friendly fencing and instead relied on opportunistic gaps in the fence. The topic of wildlife passageways needs research.

Guide to this report

The North Carolina chapter of The Nature Conservancy, the NC Wildlife Resources Commission, and the US Fish and Wildlife Service began collaborating in 2018 to develop best management practices for the growing solar industry in North Carolina. We established working relationships with 4 solar developers who were interested in incorporating conservation practices at their facilities: Birdseye Renewable Energy (Charlotte, NC), Strata Clean Energy (Durham, NC), Pine Gate Renewables (Asheville, NC), and an anonymous developer. These developers were either already implementing or agreed to implement one or more types of conservation practices at their facilities, in consultation with us, including: pollinator habitat (wildflower mixes and/or clover), wildlife-friendly fencing, and wetland features. After implementation, the developers agreed to allow The Nature Conservancy to monitor the facilities for vegetation, pollinators, and wildlife (as appropriate). This is considered to be an "adaptive management" framework where we implement practices based on best available science, test them using a monitoring approach, and then tweak or improve the practices based on what we learned. Because every facility is different, with different initial conditions and implemented management practices, there is no true replication and we were unable to sample and test for statistical differences; however, our robust monitoring approach was applied systematically to each site and was able to identify important differences in plant and wildlife outcomes that help with our understanding of solar site management. Note that no monitoring occurred in 2020 due to the COVID-19 pandemic, creating logistical, travel, and staffing challenges.

Pollinator and vegetation monitoring protocols are included as Appendix A. For the vegetation sampling, at least 2 transects were places in each "treatment" (areas with wildflowers, clover, or other pollinator-friendly habitat), and 2 more in areas identified as "controls" (turfgrass or weedy vegetation). We recorded each pollinating insect seen along each transect, and the species of flower it was visiting. These counts yielded figures, shown in this report, of average pollinator counts by treatment. This conveys whether pollinators were more frequently found in the pollinator habitat compared to the controls. We also provide figures of average counts of pollinators per plant species, to get a sense of what flower species are most visited by insects. We then surveyed 2 vegetation plots along each transect and recorded the percent cover of each species. This allowed us to provide figures of plant cover, by treatment, as well as by year. This helps us understand changes in plant composition over time.

We adapted a citizen science protocol that groups bees and other pollinators by visual characteristics. Pollinator groups we used include:

- Honey bee
- Bumble bee
- Large carpenter bee
- Hairy leg bee
- Large dark bee (mining and plasterer bees)

- Small dark bee (dark sweat bees, small carpenter bees, yellow-faced bees and small mining bees)
- Green sweat bee
- Dark hairy belly bee (leaf-cutter bees)
- Metallic hairy belly bee (orchard and mason bees)
- Cuckoo bee
- Bird
- Butterfly
- Moth
- Fly
- Wasp
- Spider
- Other- all other groups and species, including beetles which are good pollinators, but also many non-pollinating insects

Scientific names of all plant and animal species are provided in Appendix B.

Phipps Bend Solar Facility- Hawkins Solar II

Surgoinsville, Tennessee

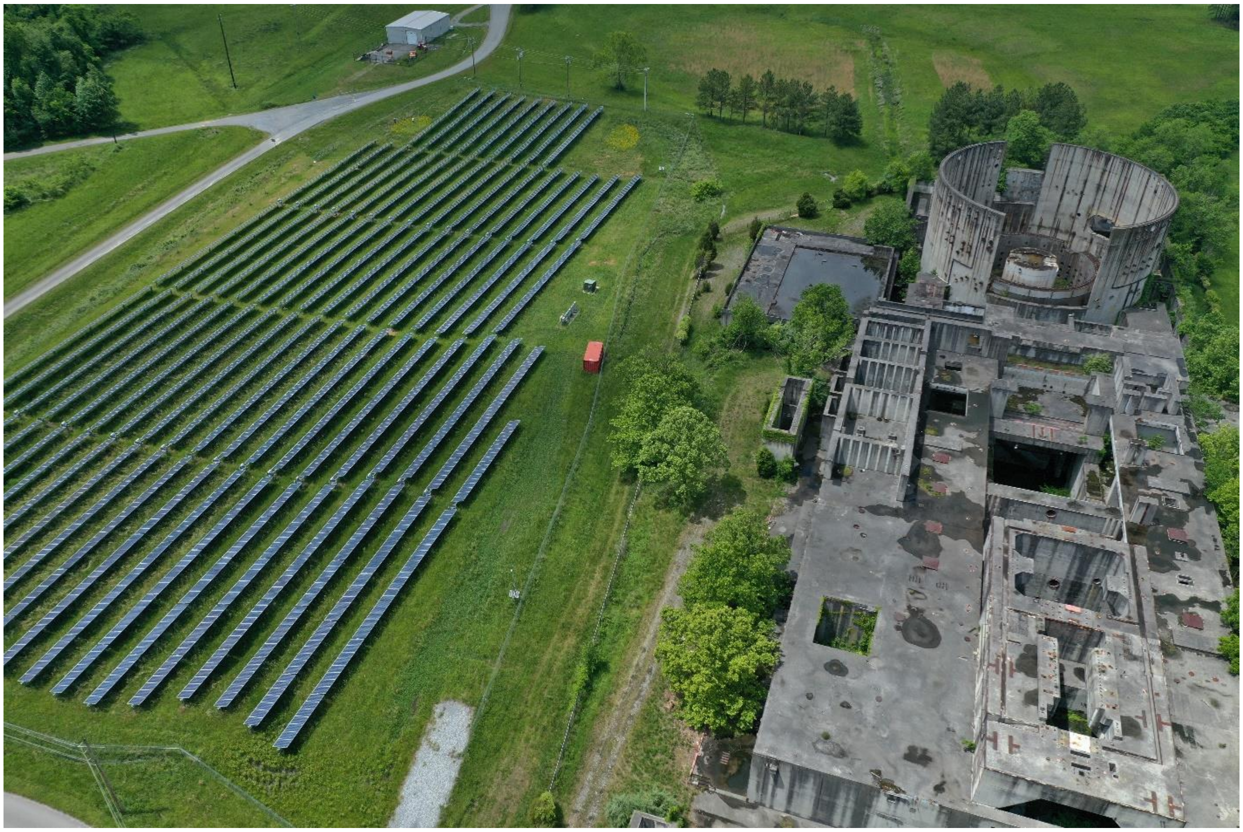


Photo 1. Drone-captured image of the Phipps Bend solar facility, looking west (Credit: M. Fields).

This 6-acre, 1MW solar facility was built by Birdseye Renewable Energy and is now privately owned. It is located next to an abandoned nuclear power plant in Surgoinsville, Tennessee, within Tennessee Valley Authority territory. The panels utilize NEXTracker racking to track the sun throughout the day, allowing for optimal energy output. Phipps Bend also features a pollinator-friendly seed mix, including both wildflowers (native upland mix) and grass-clover (pasture mix), and a wildlife-friendly fence that enables smaller animals to move through the solar facility.

The wildflower mix was implemented in Fall 2017 and planted in two distinct patches on the north and south side of the facility. The clover seed was spread mostly along the north end of the facility and in other open places throughout the array. Plant and pollinator monitoring occurred in 2018, 2019, and 2021.

Wildflower mix:

- Partridge pea
- Lanceleaf coreopsis
- Common yarrow
- Beggar-tick

- Indian blanket
- Canada wild rye
- Virginia wild rye
- Eastern gammagrass
- Indian grass
- Black-eyed Susan
- Little bluestem
- Purple top vervain
- Purple coneflower
- Wild senna
- Swamp sunflower
- Maximillian's sunflower
- Spotted beebalm
- Blue vervain
- Butterfly milkweed
- Heather aster

Clover mix:

- Creeping red fescue
- White clover
- Crimson clover

Photo 2. Camera-trap photos from Phipps Bend: northern raccoon (top left), raptor (top right), Virginia opossum (bottom left), bobcat (bottom left).

Camera-traps were placed along the fence line to provide anecdotal evidence of the fence's effectiveness. We operated cameras for the duration of the 4-year sampling period. Animals seen using or inside the fence include songbirds, domestic cats, eastern cottontails, wild turkeys, striped skunks, bobcats, Virginia opossums, northern raccoons, groundhogs, and American minks. Deer are also occasionally seen inside the fence, presumably finding a low spot under the fence or jumping over the fence.

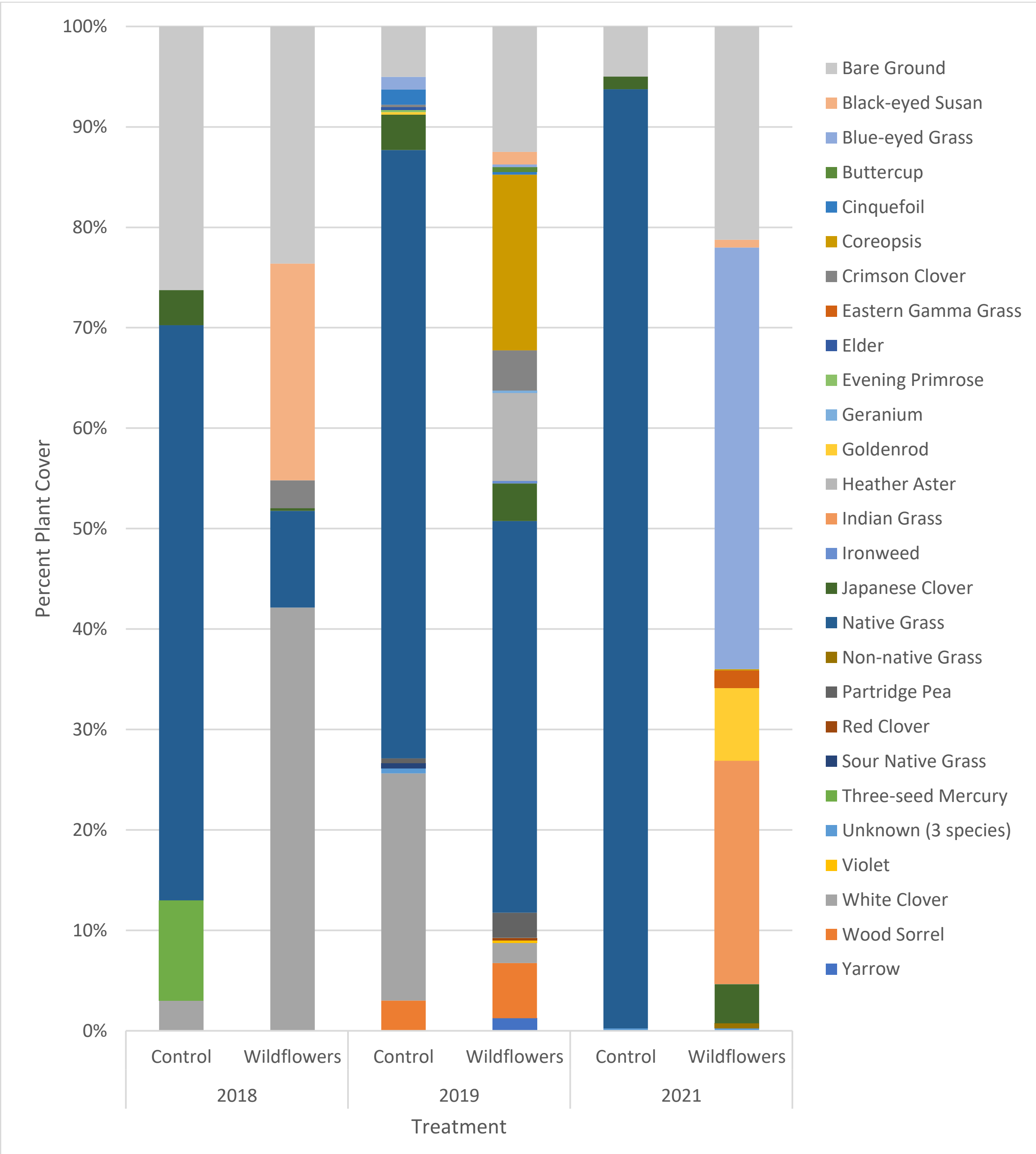


Figure 5. Phipps Bend vegetation cover by treatment, per year.

Black-eyed Susan dominated the pollinator patches in 2018 but diminished the next year and were nearly gone by 2021 (Figure 5, light salmon). Similarly, white clover that was measured in 2018 (Figure 5, medium gray at bottom) decreased in 2019 and was completely absent in 2021. The invasive Japanese clover (Figure 5, dark green) became increasingly prevalent over the sampling period.

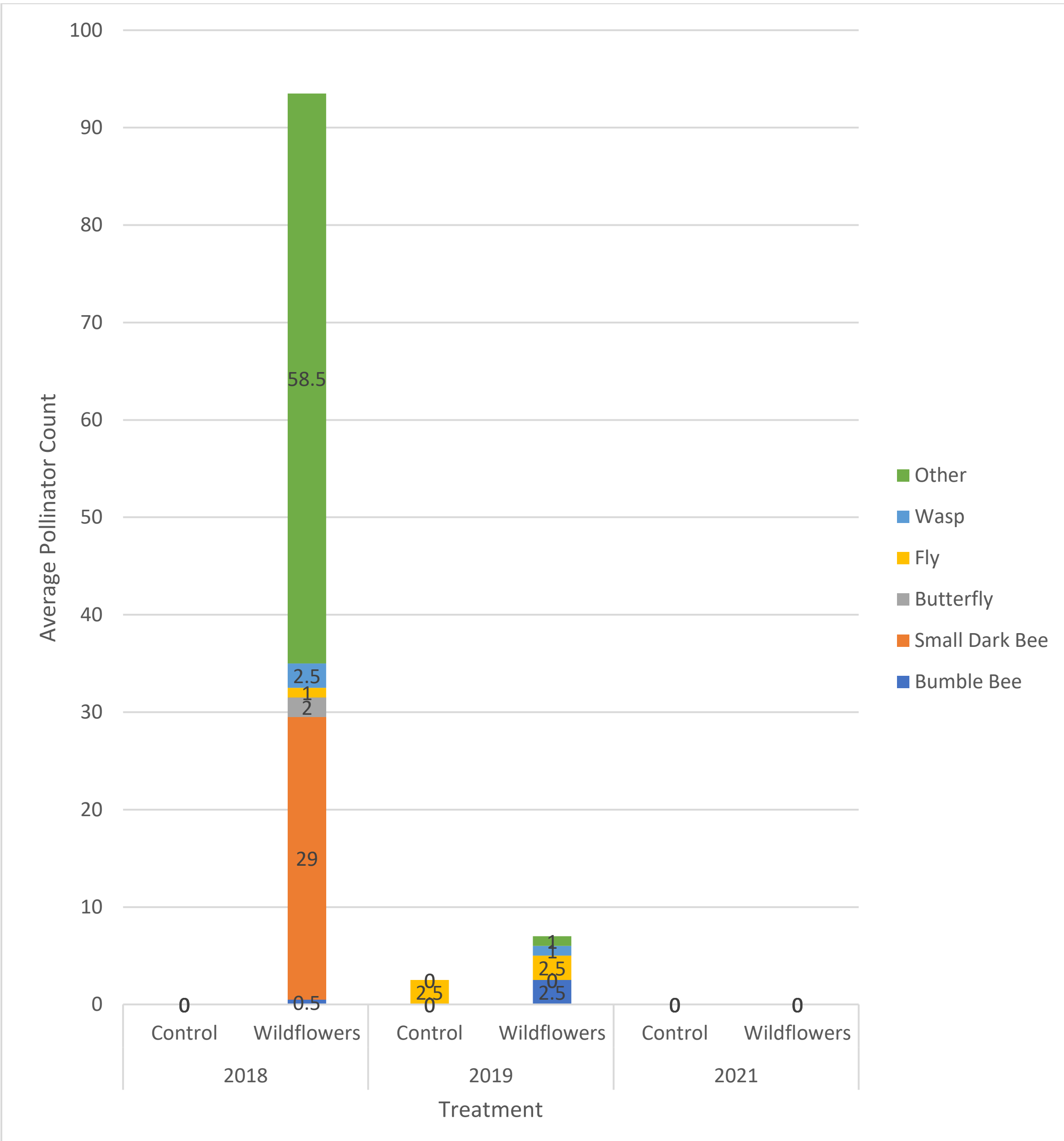


Figure 6. Phipps Bend pollinator counts by treatment, by year.

Pollinator sampling amidst patches of black-eyed Susan and white clover (among other plants) resulted in a total of almost 185 pollinators in 2018, a number that has declined over the sampling years (Figure 6), presumably with the decline in flowering species (Figure 5). No pollinators were found on any of the 2021 transects due to a scarcity of blooming flowers at the site.

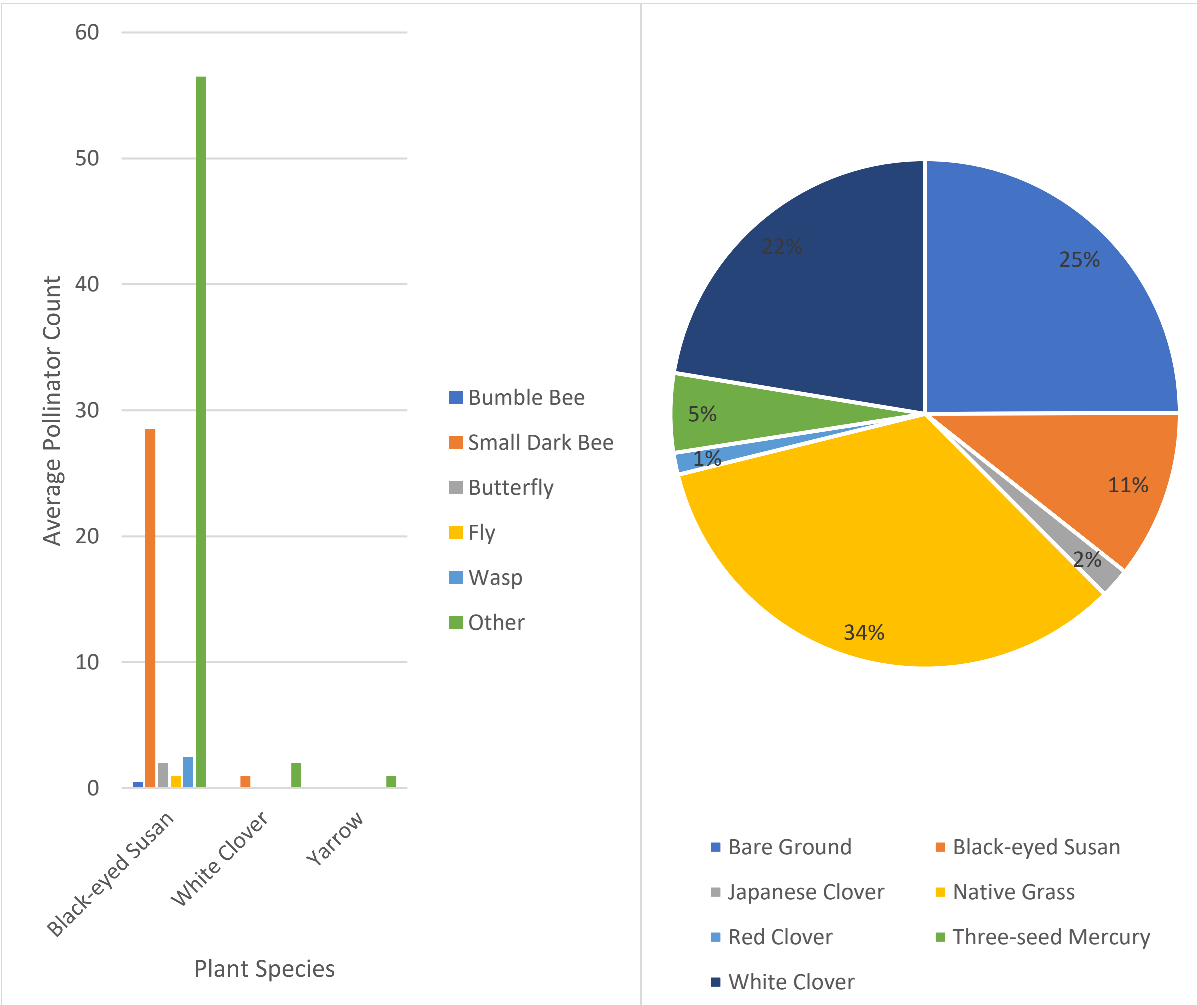
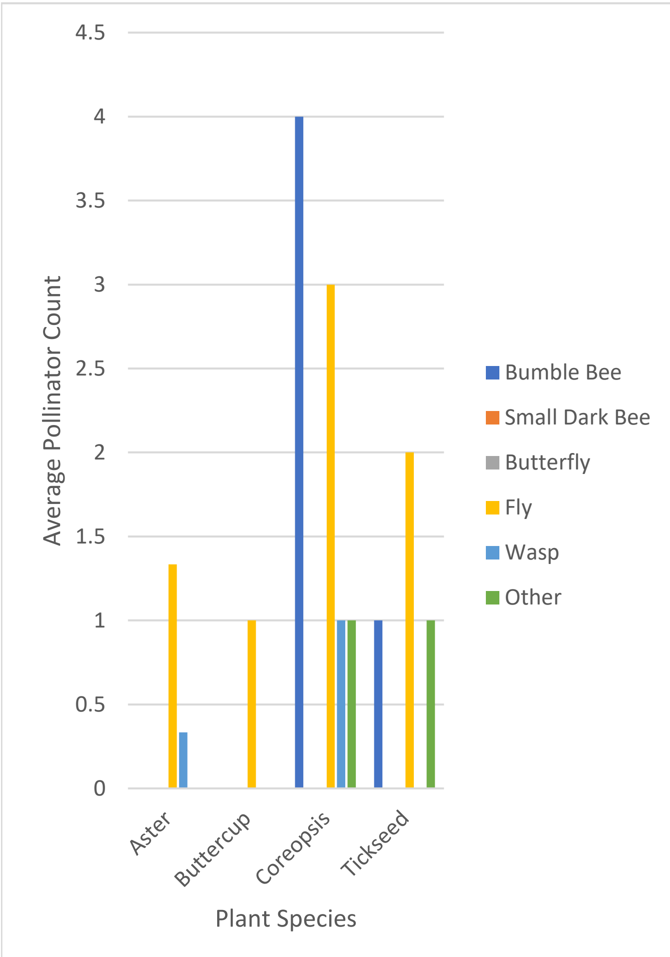


Figure 7. Phipps Bend 2018 count of pollinators per plant (left) and vegetation percent cover (right). Both graphs show averages across all transects (treatment and control).



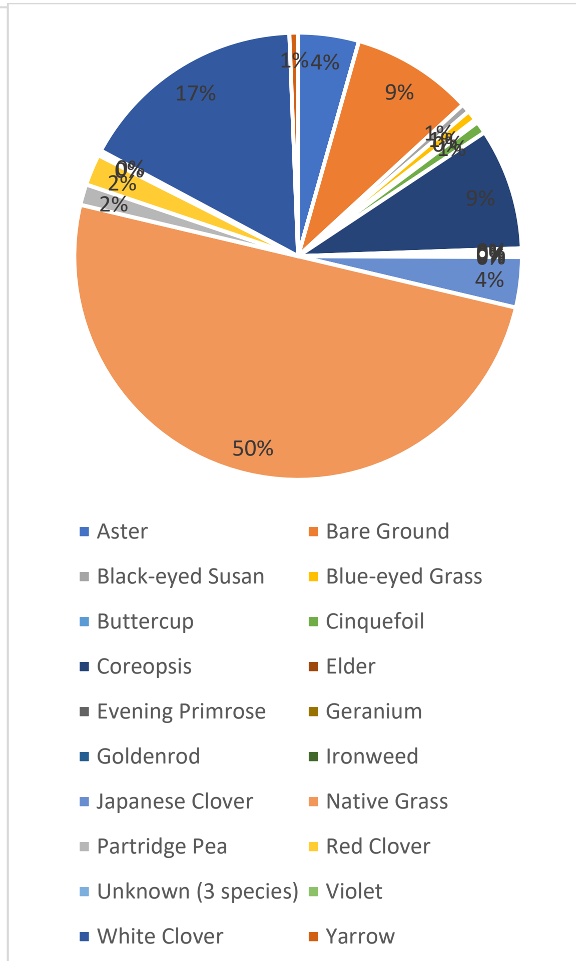


Figure 8. Phipps Bend 2019 count of pollinators per plant (left) and vegetation percent cover (right). Both graphs show averages across all transects (treatment and control).

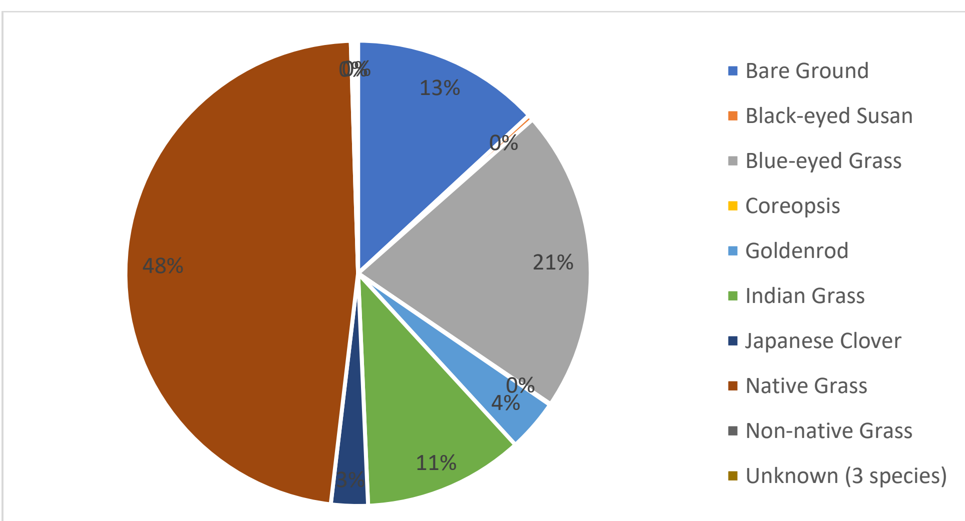


Figure 9. Phipps Bend 2021 vegetation percent cover. Graph shows averages across all transects (treatment and control).

Black-eyed Susan hosted the most pollinating species in 2018 (Figure 7). As black-eyed Susan declined, pollinators were mostly found on coreopsis and aster in 2019 (Figure 8), both of which also disappeared by 2021 (Figure 9). Wildflowers made up only 5% of the vegetation cover in 2021 and no clover was present (Figure 9), which could be why pollinators were not found in any of the transects. In the pollinator patches, it appears that the wildflower planted areas reverted to a mostly grass (native warm season grasses), with a few wildflowers mixed in (Photo 3).

Photo 3. In 2018, pollinator patches consisted almost entirely of black-eyed Susan (left) (Credit: M. Fields). Aerial view of pollinator patch in 2021; red line roughly indicates the extent of the original pollinator patch (top right) (Credit: M. Fields). In 2021, native grasses dominate the pollinator patch with Lespedeza *encroaching around the edges (bottom right) (Credit: L. Kalies).*

Solar Facility 1

Photo 4. Drone-captured aerial view of Solar Facility 1; all monitoring occurred in the foreground (southern end) of the site (Credit: M. Fields).

Solar Facility 1 (Photo 4) is connected to Dominion Power's electrical grid. The site does not have wildlife-friendly fencing and no wildlife monitoring was conducted.

The site was planted in 2018 features a pollinator-friendly seed mix both in the array and the perimeter, including:

- Sahara Bermuda
- Creeping red fescue
- Browntop millet
- White clover
- Crimson clover
- Red clover

Monitoring for plant cover and pollinating insects occurred from 2018-2021.

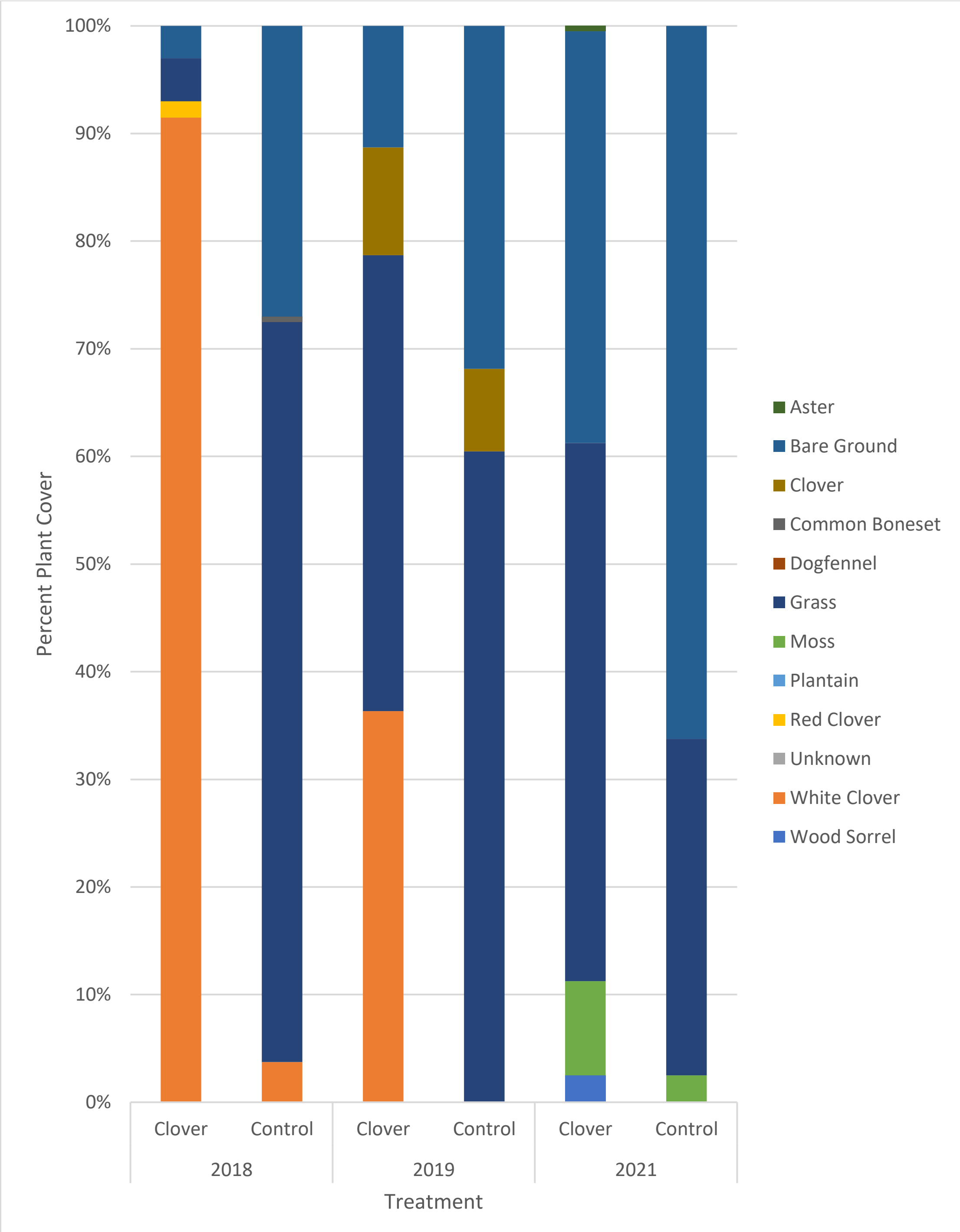


Figure 10. Solar Facility 1 vegetation cover by treatment, per year.

White clover dominated the treatment areas in 2018, but reduced by half in 2019 and then was not present in 2021 (Figure 10). Non-native turf grasses generally replaced the clover.

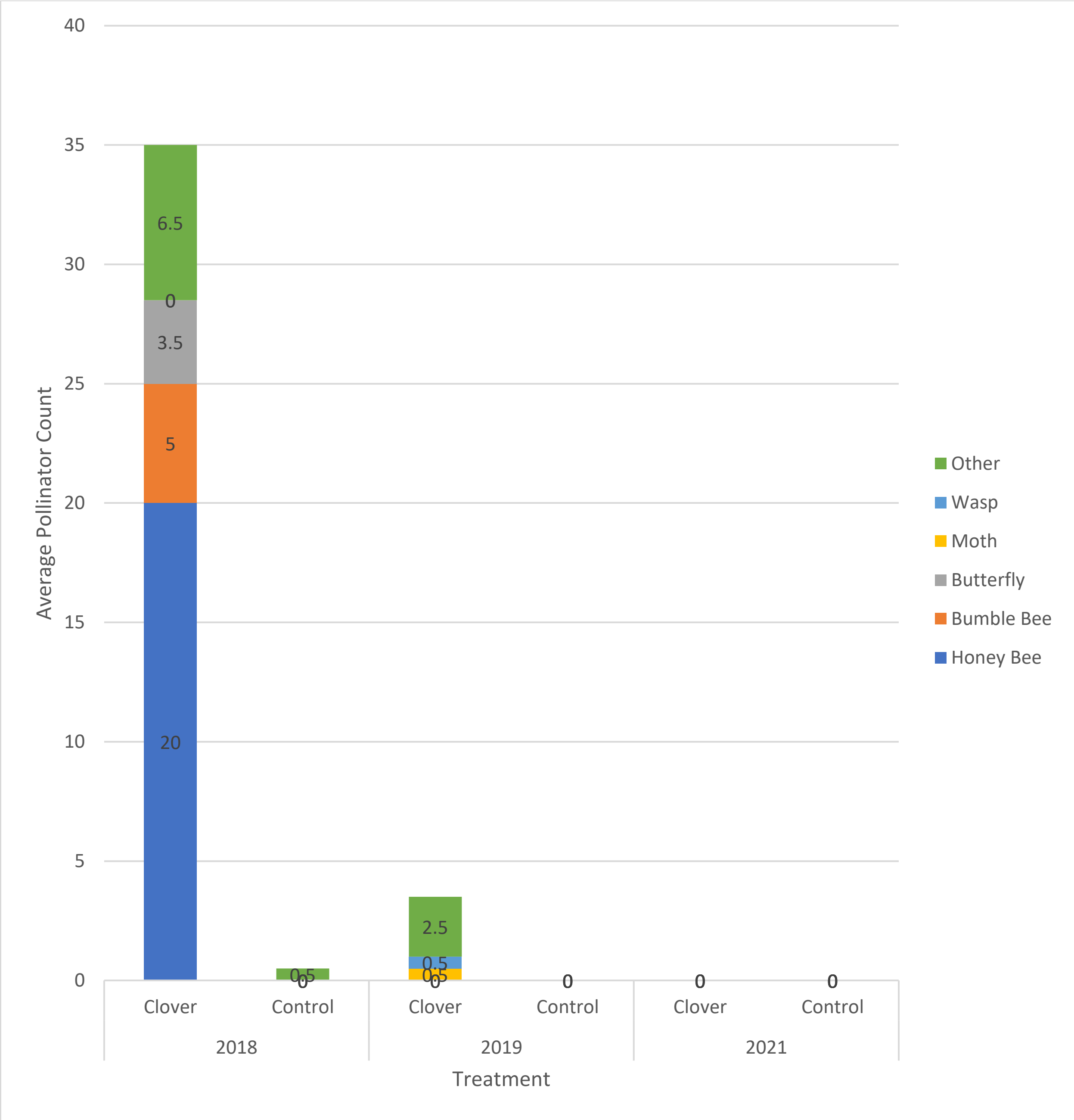


Figure 11. Solar Facility 1 pollinator counts by transect, per year.

The number of pollinators declined drastically from 2018 to 2021 (Figure 11), presumably due to the reduction of clover and other flowering species at the site (Figure 10).

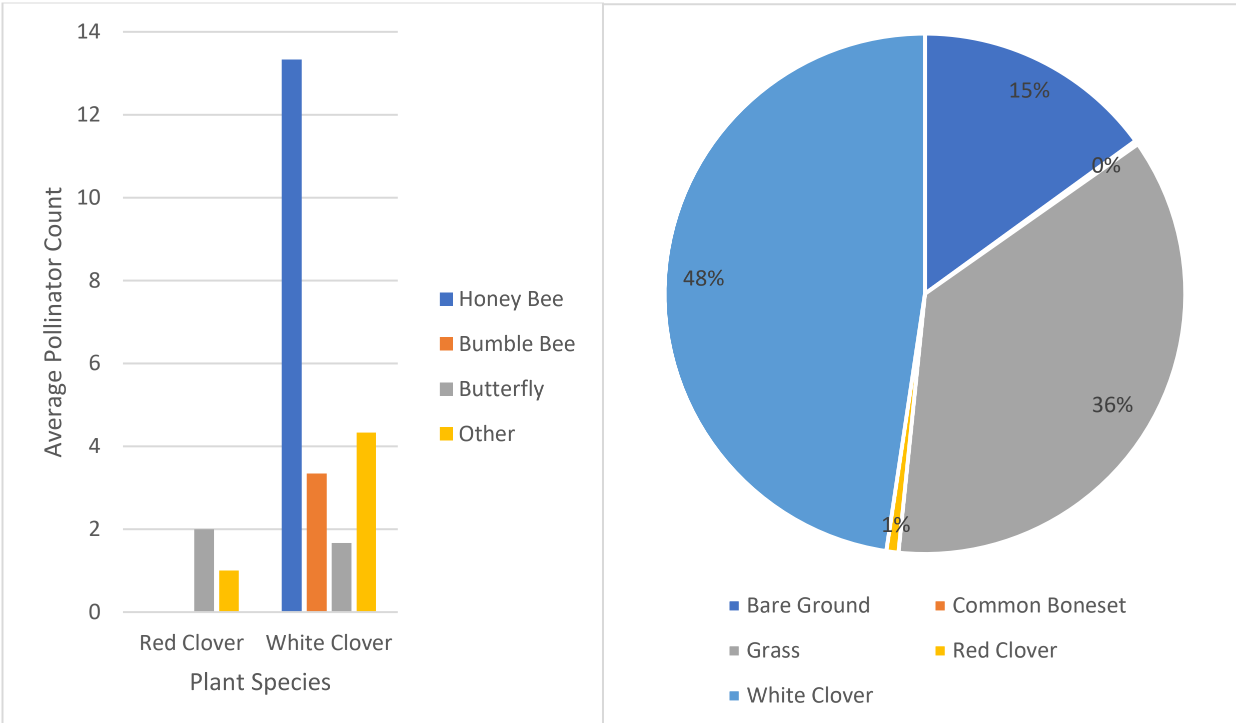


Figure 12. Solar Facility 1 2018 pollinators per plant data (left) and percent vegetation cover (right). Both graphs show averages across all transects (treatment and control).

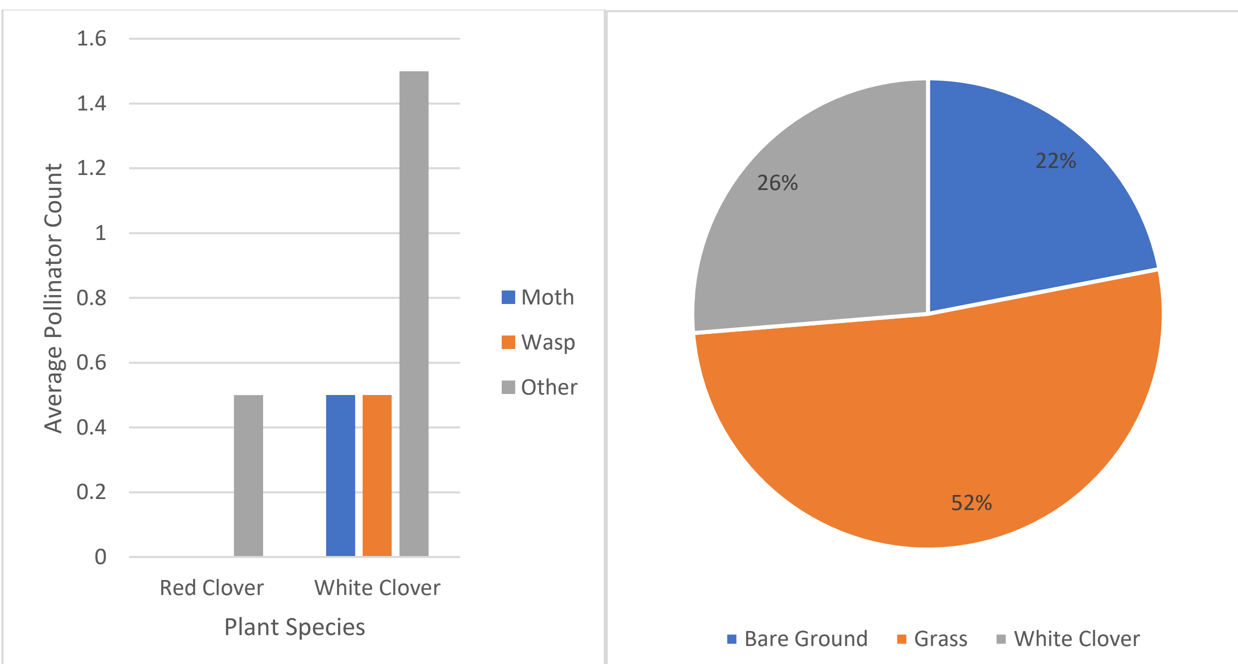


Figure 13. Solar Facility 1 2019 pollinators per plant data (left) and percent vegetation cover (right). Both graphs show averages across all transects (treatment and control).

Pollinators more frequently visit white clover compared to red clover (Figures 12 and 13) but given the relative lower amount of red clover, the latter seems to have potential as a good pollinator resource.

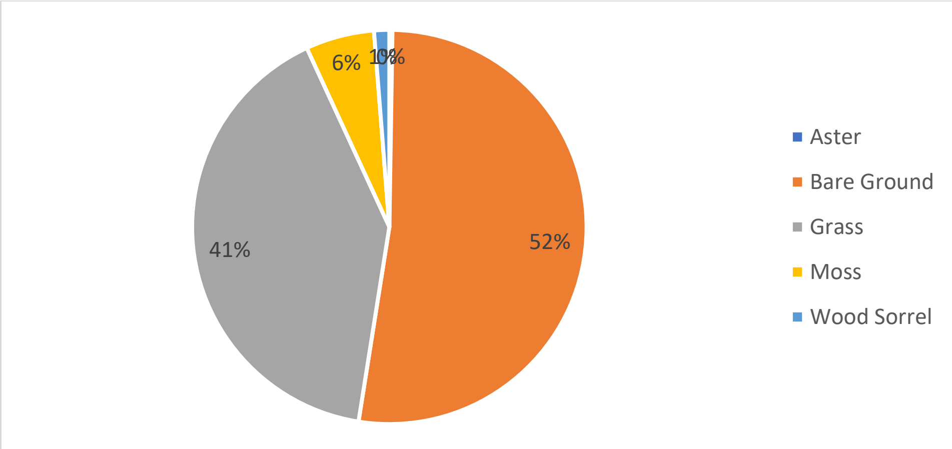


Figure 14. Solar Facility 1 2021 percent vegetation cover data, averaged across all transects (treatment and control).

Solar Facility 1 was dominated by clover (mostly white clover) in 2018, but the site gradually transitioned to grasses by 2021 (Figure 10, Photo 5). The grass was a mix of native and non-native, and the percent of bare ground increased over time. In the 2021 transects, small patches of aster wildflowers were identified (Figure 14), and there were also large patches of asters seen outside of the fence; this plant is often a good resource for pollinating insects. Although clover seemed promising at the start, low-growing and attractive to pollinators, it proved to be short-lived and does not seem to continue to support pollinators.

Photo 5. Clover was planted in the arrays and was abundant in 2018 (left) but noticeably reduced in 2019 (right) (Credit: L. Kalies).

Solar Facility 2

Photo 6. Aerial view of Solar Facility 2 (Credit: Microsoft Bing Maps).

Solar Facility 2 features a pollinator-friendly seed mix of mostly red and white clover. There is a small stream running west to east through the middle of the site (vegetated area in the middle of Photo 6) where the riparian vegetation and trees were left intact (Photo 7). The stream narrows to a wetland towards the eastern side of the site where the vegetation was cleared, but early-successional vegetation has grown back in, which will be mowed occasionally when the trees grow high enough to shade the panels. There are also settling ponds that were created to keep water off the arrays, located to the north and south of the treed area. After construction, the developer kept these ponds in place and allowed natural vegetation to grow back; they now support macroinvertebrate (mostly dragonflies) and amphibian communities (Photo 7).

Much of the site was seeded with the pollinator-friendly vegetation in 2019 and is regularly mowed. The seed mix includes:

- Little bluestem
- Bermuda grass
- Tall fescue
- Creeping red fescue
- White clover
- Crimson clover
- Browntop millet

We conducted vegetation and insect monitoring in 2019 and 2021. We also installed camera-traps in 2020-2021 to see if animals were using the riparian and wetland areas.

Photo 7. Forested area surrounding stream in 2020 (left); pond in between solar panel blocks in 2021 (right) (Credit: L. Kalies).

Photo 8. Camera-trap images from 2020 of wildlife using a gap under the fence: coyote (left) and white-tailed deer (right).

Solar Facility 2 does not have wildlife fencing but there is a low spot under the fence near the eastern end of the site where the stream enters the facility. The camera trap images show coyote, numerous deer, and some wild turkeys using this hole to access the site (Photo 8).

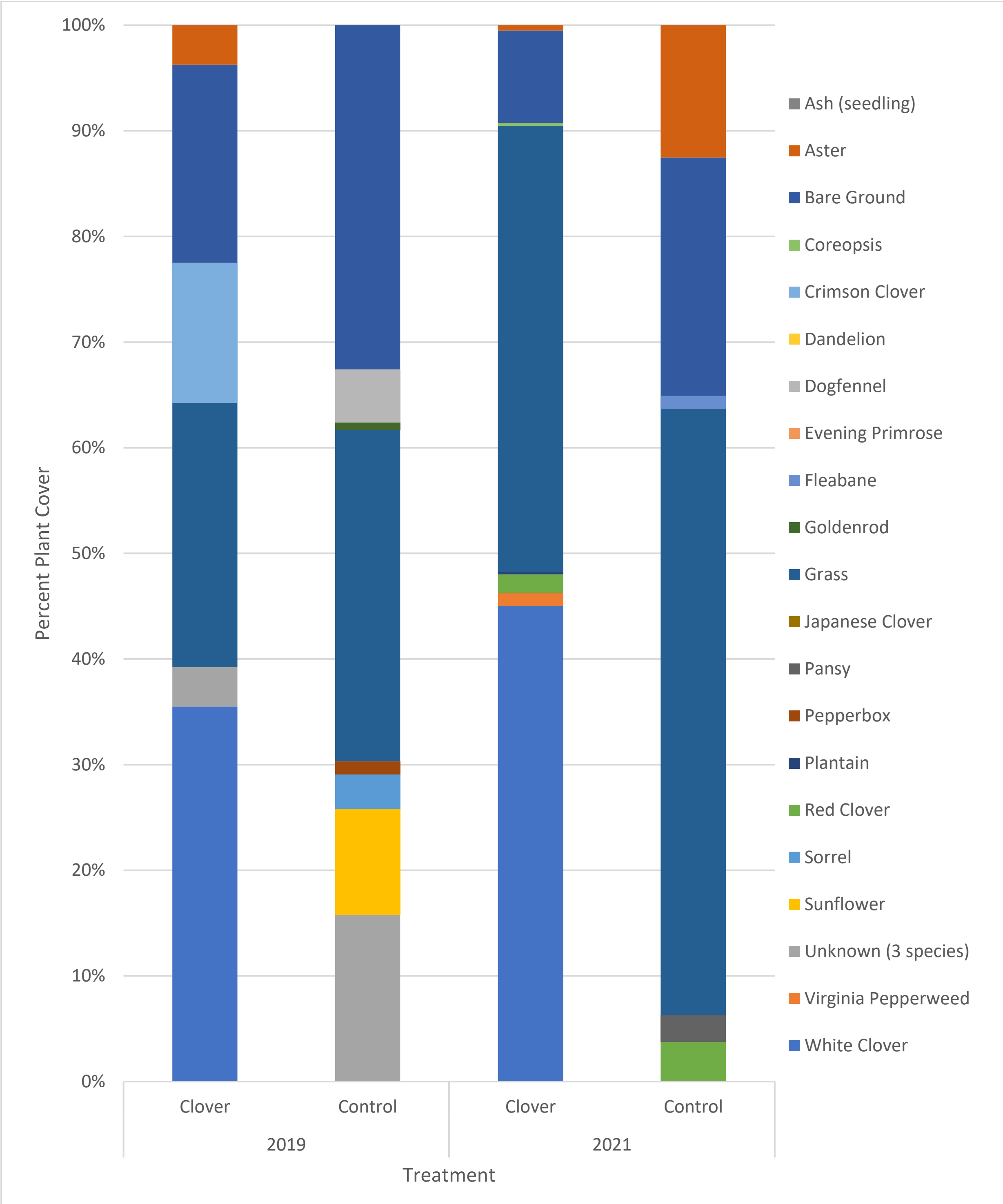


Figure 15. Solar Facility 2 vegetation cover by treatment, per year.

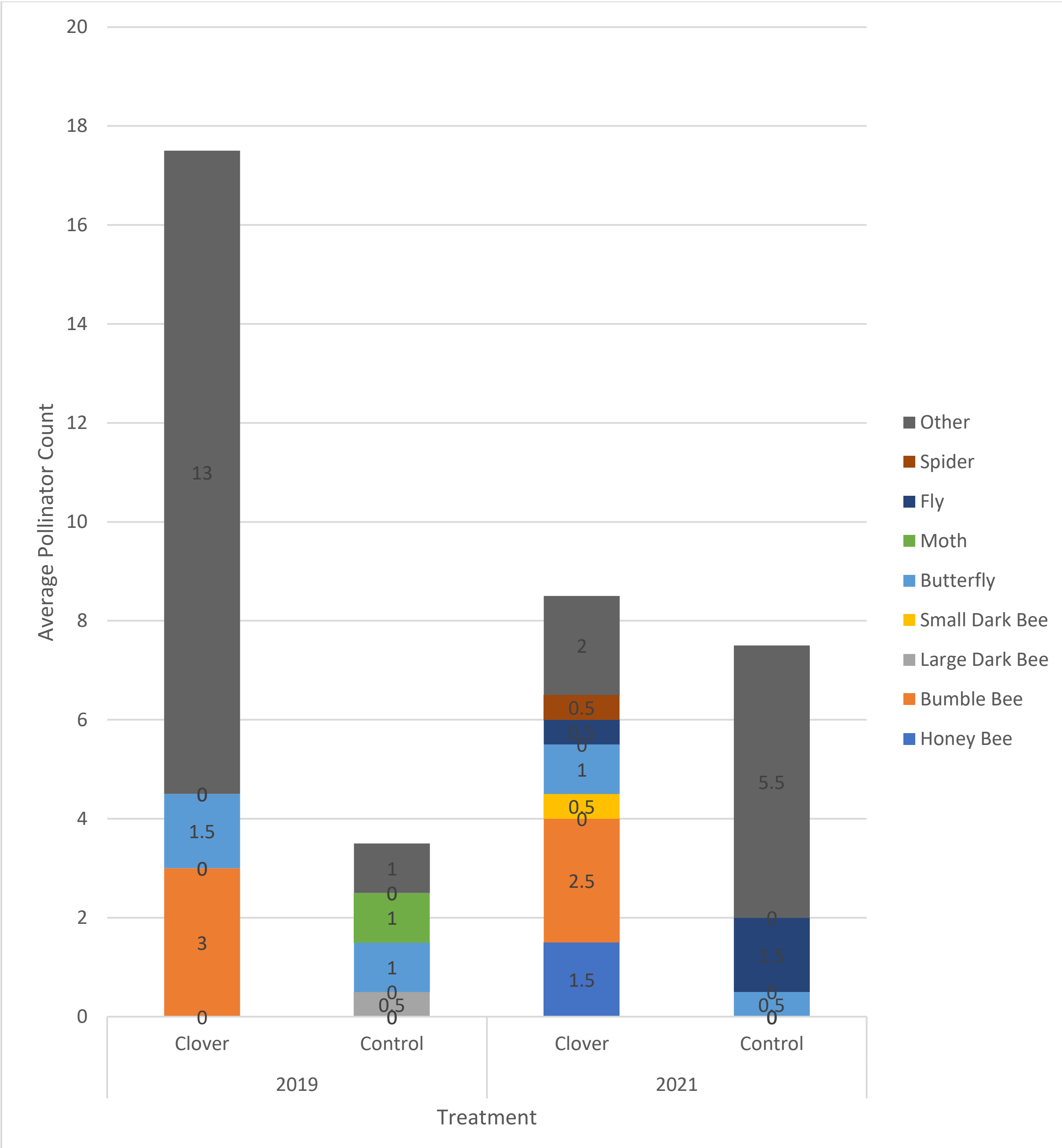


Figure 16. Solar Facility 2 pollinator counts by treatment, per year.

Similar amounts of clover (a combination of white and crimson) were seen in 2019 and 2021 (Figure 15). Pollinator diversity and counts were also similar during these years (Figure 16; note that the “other” category is comprised of miscellaneous insects that are not known to be pollinators, e.g., beetles).

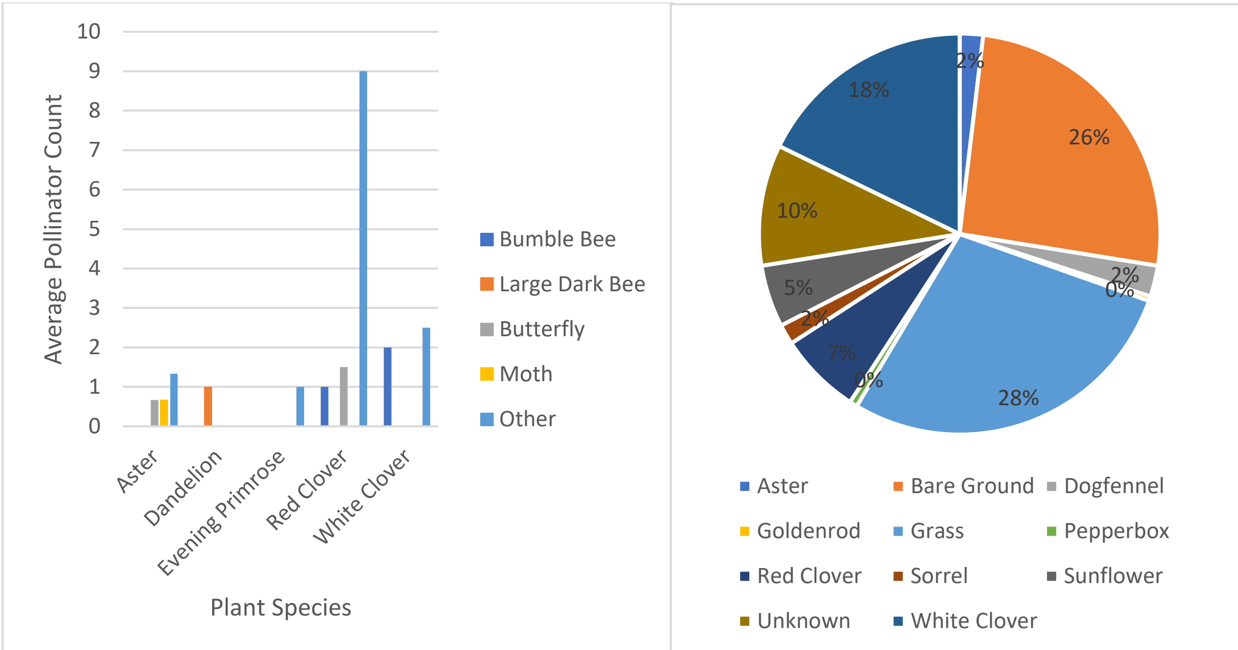


Figure 17. Solar Facility 2 2019 count of pollinators per plant (left) and vegetation percent cover (right). Both graphs show averages across all transects (treatment and control).

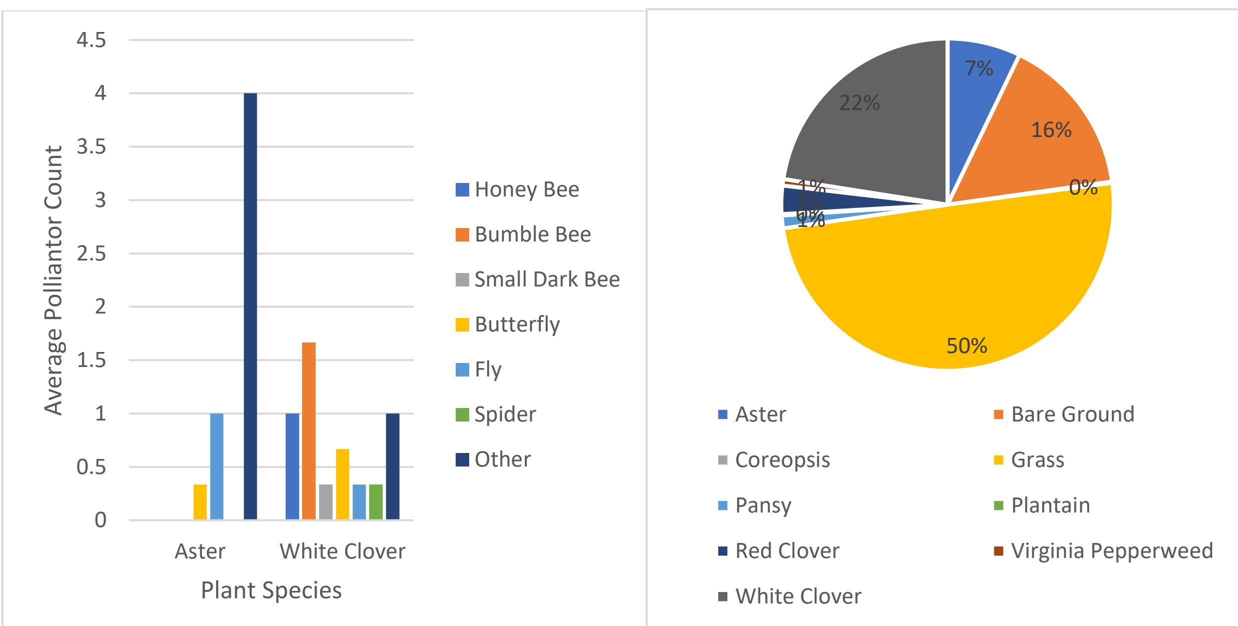


Figure 18. Solar Facility 2 2021 count of pollinators per plant (left) and vegetation percent cover (right). Both graphs show averages across all transects (treatment and control).

We observed similar amounts of clover in 2019 (Photo 9) and 2021, but fewer wildflowers and more grass in 2021, although the aster cover increased (Figures 17 and 18). Unlike at Solar Facility 1, the clover cover at Solar Facility 2 seems to be stable. However, we have learned at other sites (e.g., Phipps, Solar Facility 1) that it may take 4-5 years to see a transition in vegetation composition.

Photo 9. Abundant clover at the site in 2019 (Credit: L. Kalies).

Howell Midland Solar Facility – Strata Clean Energy

Midland, NC

Photo 10. Aerial view of Howell Midland (Credit: Strata Clean Energy).

This 36-acre, 6.5MWdc solar facility is located in Midland, North Carolina, in the Duke Energy service area. Howell Midland was built and is operated by Strata Clean Energy, one of the state's largest solar energy developers. The solar facility features a wildlife-friendly seed mix planted in late 2016, as well as 100-foot buffers. All pollinator habitat was planted outside of the fences of the facility (Photo 11).

The seed mix included:

- Canada wild rye
- Virginia wild rye
- Eastern gammagrass
- Little bluestem
- Indian grass
- Purple top vervain
- Beggar-tick
- Partridge pea
- Lanceleaf coreopsis
- Indian blanket
- Common yarrow
- Black-eyed Susan
- Purple coneflower
- Wild senna
- Swamp sunflower
- Maximilian's sunflower
- Blue vervain
- Butterfly milkweed
- Spotted beebalm
- Heather aster

Photo 11. Vegetation at Howell Midland in 2018; all vegetation was planted outside the fence (Credit: L. Kalies).

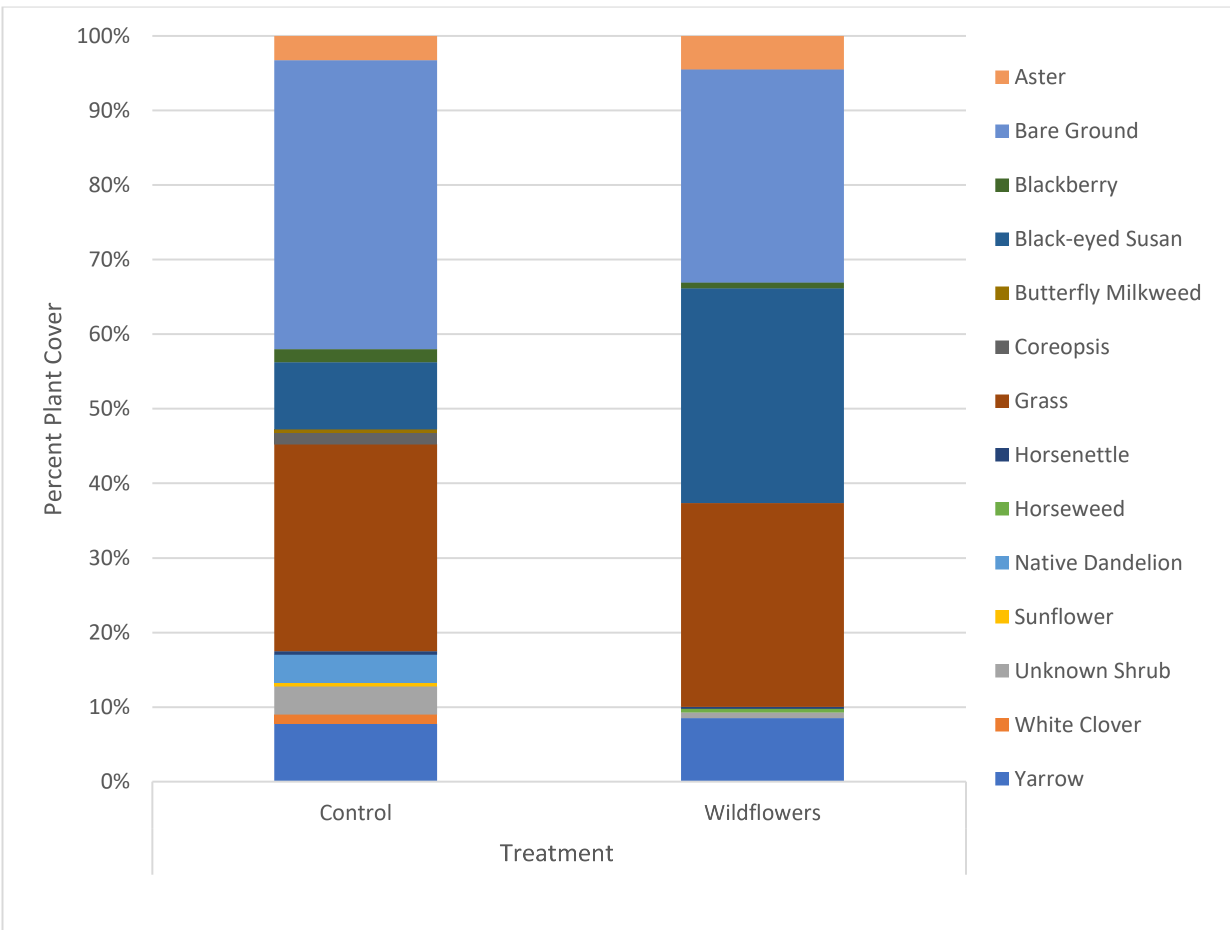


Figure 19. Howell Midland vegetation cover by treatment, 2018.

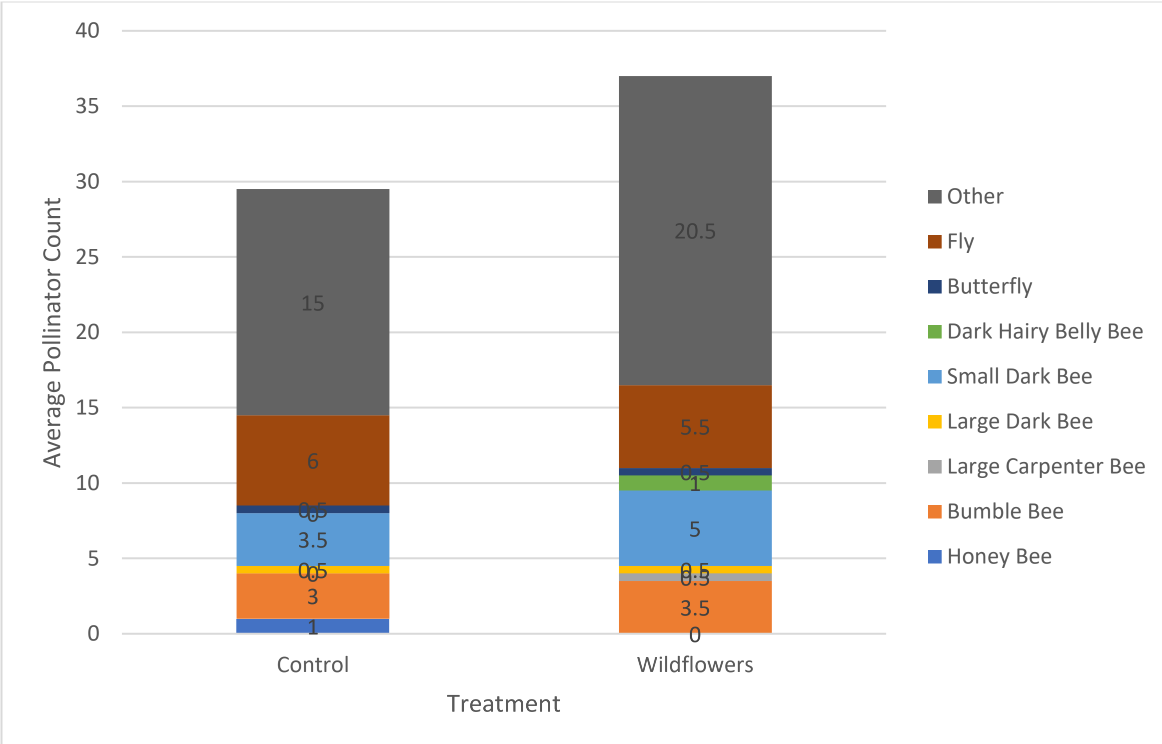


Figure 20. Howell Midland pollinator counts by treatment, 2018.

With nine different groups of pollinators (Figure 20), Howell Midland demonstrated the second greatest pollinator diversity of all sites during our initial sampling in 2018. Overall, more than 130 insects were counted at the solar facility in 2018, with most of them visiting black-eyed Susan, common yarrow, and aster (Figure 21). We found that both the vegetation and insect composition of the controls and treatments were similar (Figures 19 and 20), likely due to the large number of black-eyed Susan and other wildflowers that had spread from the planted areas to other parts of the facility. Unfortunately, due to logistical constraints, we were unable to repeat sampling at this site in later years.

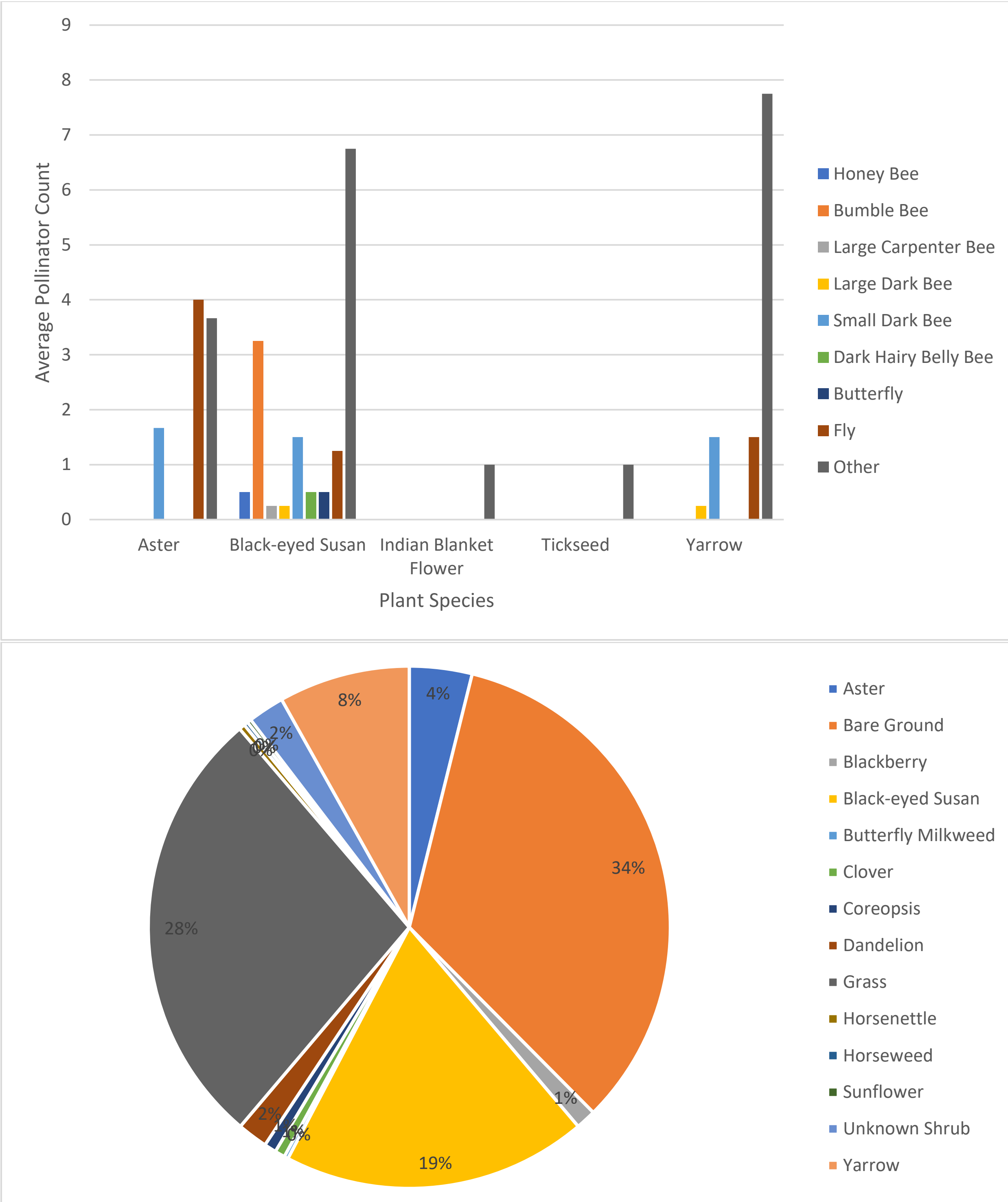


Figure 21. Howell Midland 2018 count of pollinators per plant (top) and vegetation percent cover (bottom). Both graphs show averages across all transects (treatment and control).

Arborgate Solar Facility - Strata Clean Energy

Pittsboro, NC

Photo 12. Aerial view of Arborgate solar facility; monitoring was conducted at the northern array (Credit: Google Maps).

This 7 MWdc 44-acre facility was built and is operated by Strata Clean Energy, and located in Pittsboro, NC in the Duke Energy service area. Arborgate is our newest monitoring site, and the 2021 data will serve as a baseline for subsequent years. All pollinator habitat was planted outside the fence in 2019, mostly to the north and south of the northern array. In 2021, the site was very showy but mostly consisted of coreopsis and black-eyed Susan (Photo 13). Goldfinches were seen in flocks in the wildflower patches.

The seed mix included:

- Canada wild rye
- Virginia wild rye
- Eastern gammagrass
- Little bluestem
- Indian grass
- Purple top
- Bidens
- Partridge pea
- Lance leaf tickseed
- Indian blanket
- Common yarrow
- Black-eyed Susan
- Cone flower
- Wild senna
- Swamp sunflower
- Maximilian's sunflower
- Blue vervain
- Butterfly weed
- Spotted beebalm
- Heather aster

Photo 13.Wildflowers to the north of the site (left) and between the two sites (right); all planted outside the fence (Credit: L. Kalies).

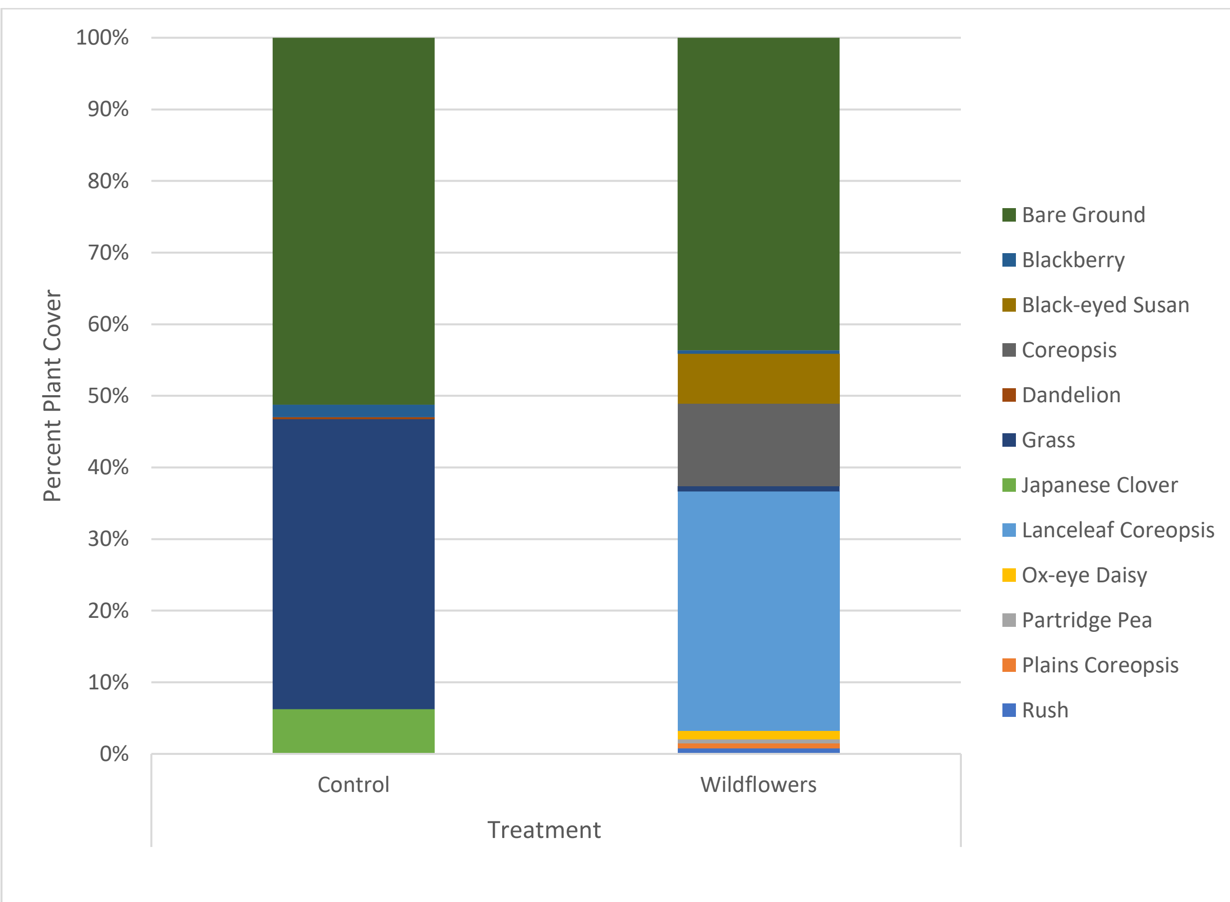


Figure 22. Arborgate vegetation cover by treatment, 2021.

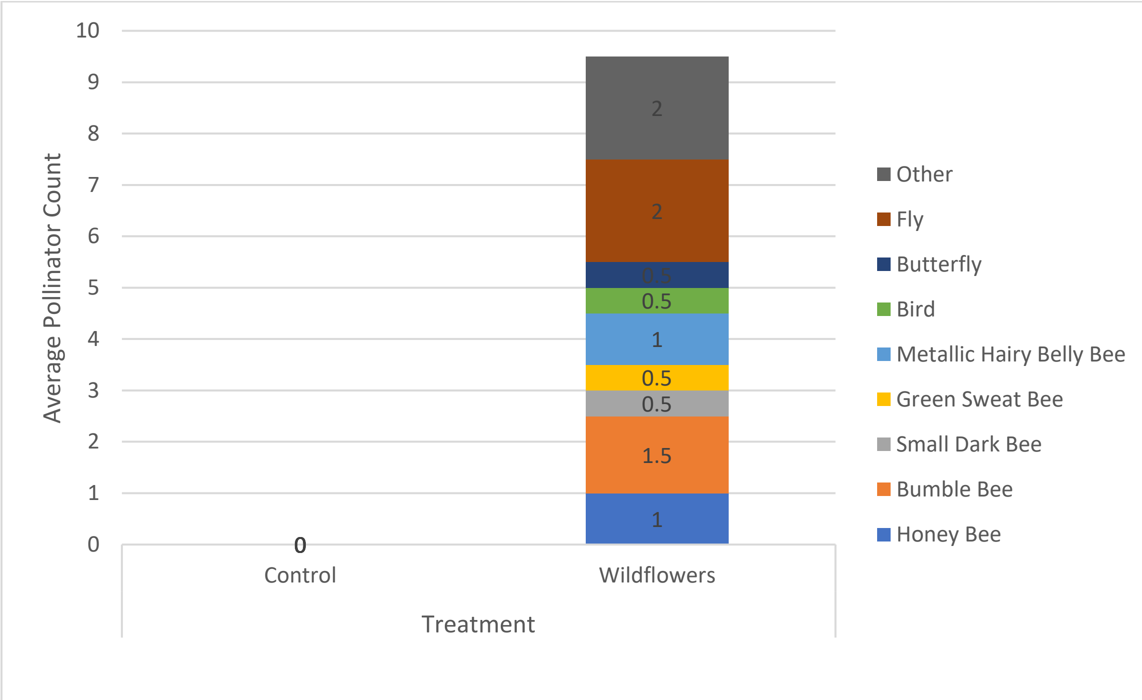


Figure 23. Arborgate pollinator counts by treatment, 2021. An American goldfinch (bird) was counted on a transect.

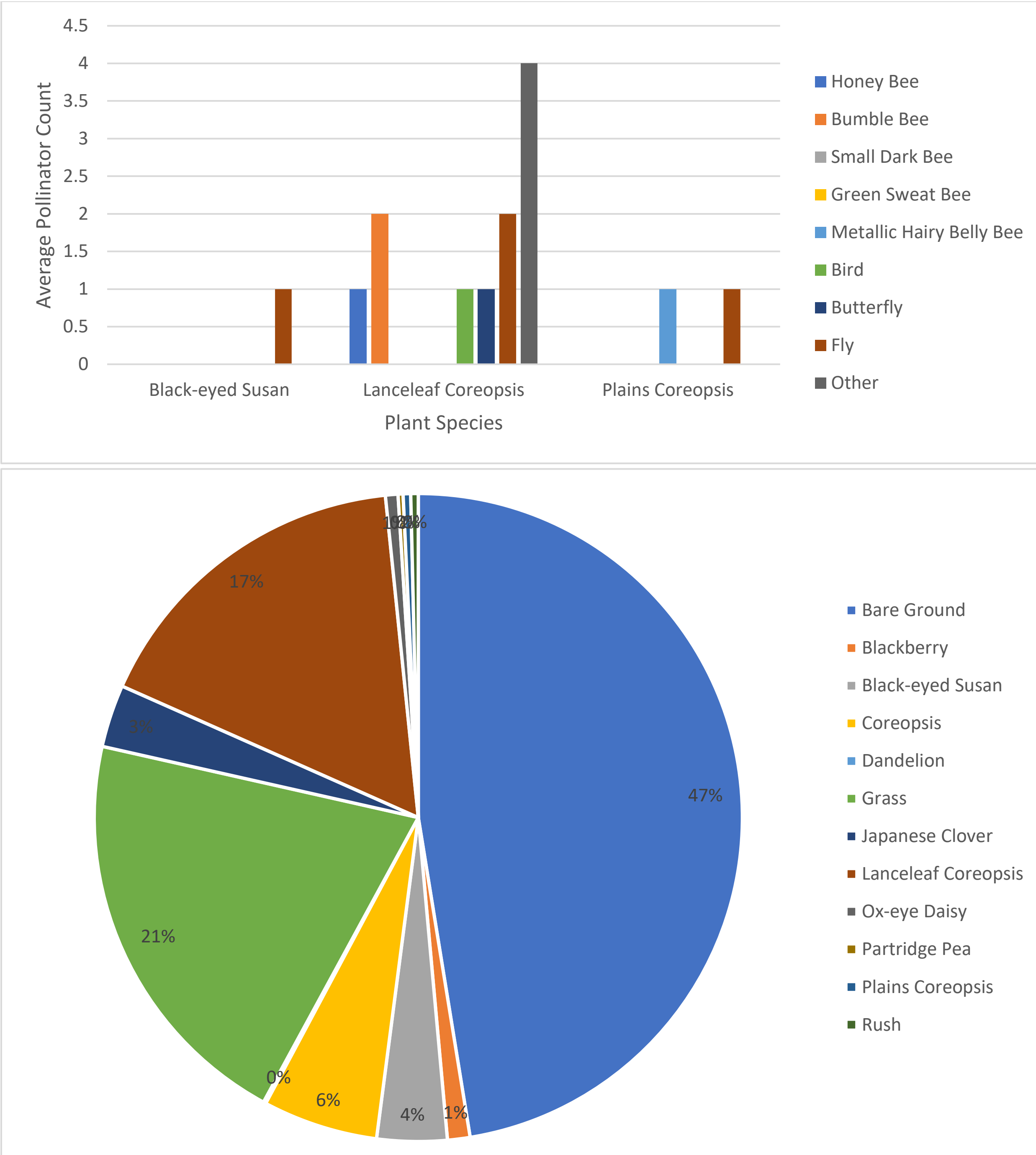


Figure 24. Arborgate 2021 count of pollinators per plant (top) and vegetation percent cover (bottom). Both graphs show averages across all transects (treatment and control).

The vegetation cover in the treatment areas was >50% wildflowers, predominantly black-eyed Susan and coreopsis (Figure 22). Pollinator counts were relatively low but very diverse (Figure 23). Pollinators were mostly found on coreopsis (plains and lanceleaf), which make up ~20% of the vegetation mix. They were less prevalent on black-eyed Susan, in a stark difference from other sites.

Redmon Solar Facility – Strata Clean Energy

Cleveland, NC

Photo 14. An orthomasaic image of Redmon farm created with a drone in Fall 2021 (Credit: M. Fields).

This 2.9MWdc 14-acre solar facility built and operated by Strata Clean Energy is located in Cleveland, North Carolina within the Duke Energy service area. The site had been retrofitted just prior to 2018 to improve pollinator habitat; a pollinator-friendly seed mix was planted early in 2018. Redmon Solar Facility also contains experimental plots to test different herbicide treatments, including Glyphosate only (treatment: Wildflowers 1) and Glyphosate + Imazapic (treatment: Wildflowers 2). This is one of the few solar facilities to try planting wildflowers between the rows of the solar array. A clover mix was planted in front of the facility, outside the fence. We conducted plant and insect monitoring in 2018, 2019, and 2021. No camera traps were placed at Redmon.

The seed mix included:

- Plains, lanceleaf, and basalis coreopsis
- Blue lupine
- Purple coneflower
- Common yarrow
- Spiderwort
- Butterfly milkweed
- Black-eyed Susan
- Sensitive pea
- Blanket flower
- Roundhead Japanese clover
- Mistflower
- Tufted hairgrass
- Deertongue grass

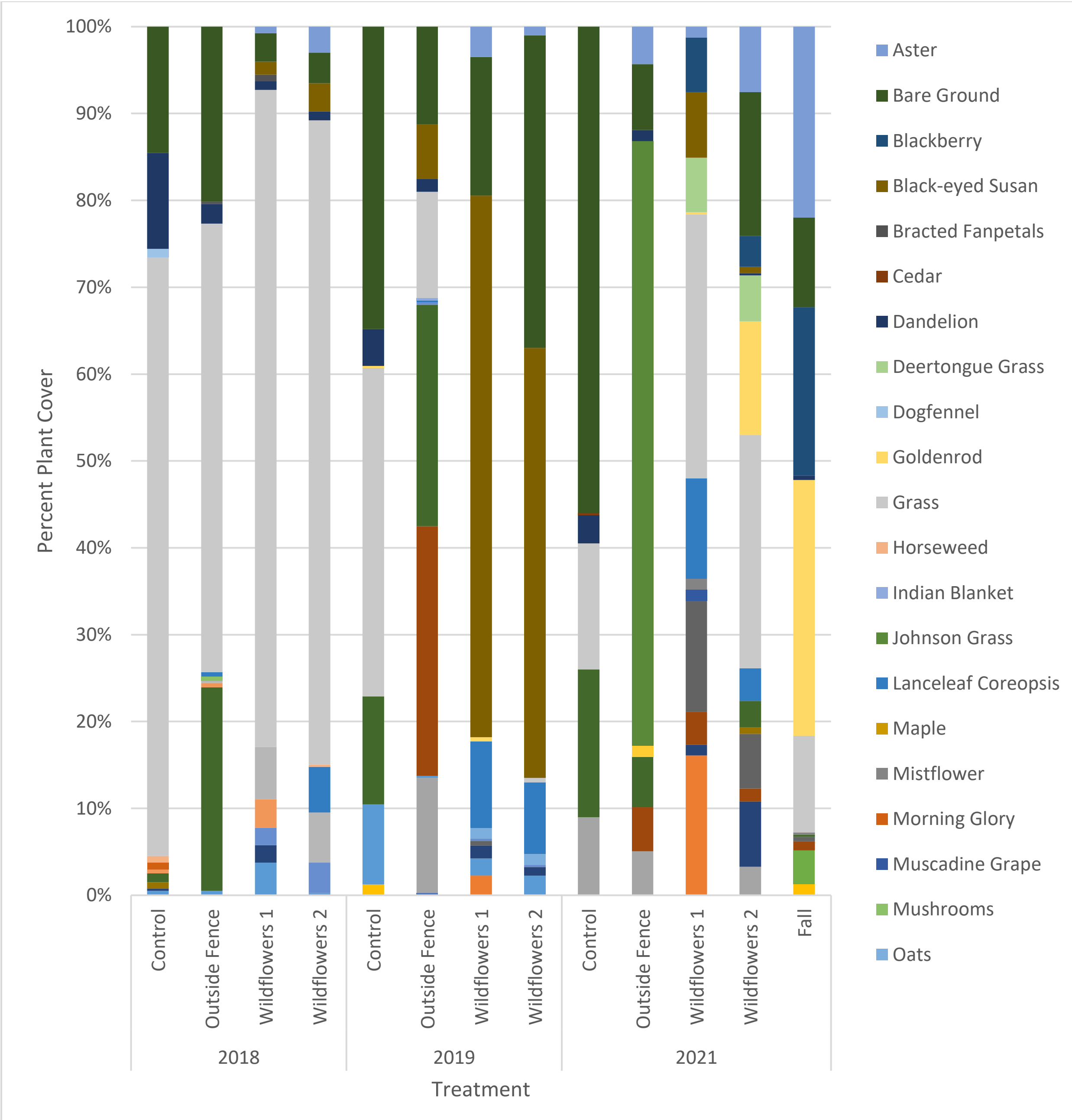


Figure 25. Redmon vegetation cover by treatment, by year.

In 2018, the treatment transects (wildflower mix) were mostly grass but about 20% wildflowers, primarily black-eyed Susan, coreopsis, and partridge pea (Figure 25). In 2019, the black-eyed Susan exploded, comprising 50-60% of the cover in the treatment transects. Two years later, the treatments were still over 50% wildflower cover, with the emergence of deertongue, purple coneflower, mistflower, and black-eyed Susan at <20% of total cover. We also sampled in Fall of 2021 and while we did not detect any species from the seed mix (the only fall-blooming plant included was mistflower), the transects were blooming with goldenrod and asters (Figure 25).

Outside the fence, we saw a peak of about 40% clover cover in 2019, followed by a reduction in clover as seen at other sites; in this case, it was replaced by invasive Johnson grass which was already present onsite but in low abundance (Figure 25).

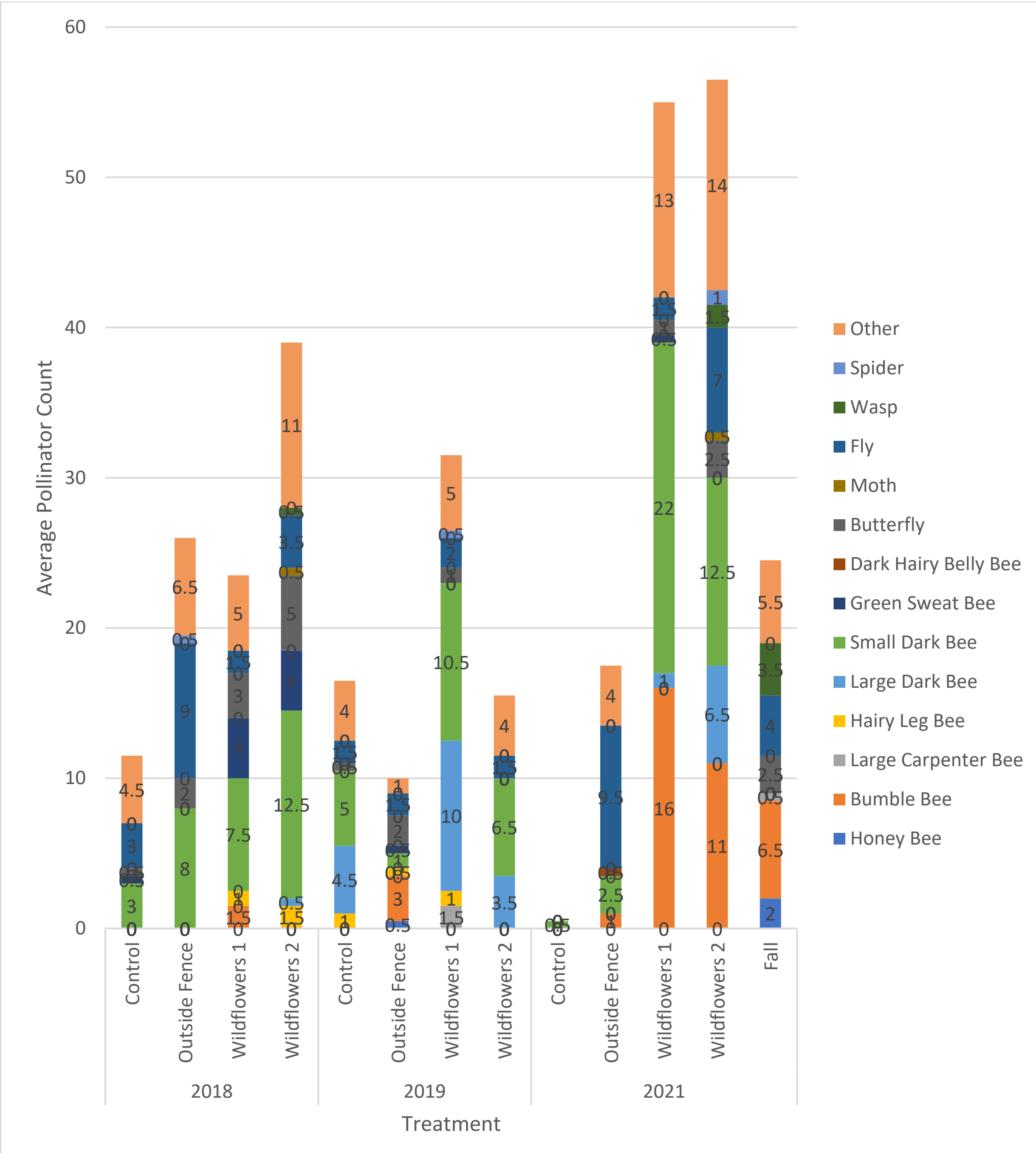


Figure 26. Redmon pollinator counts by treatment, per year.

Redmon had high abundance and diversity of pollinating insects in most of the treatment transects (particularly wildflowers 1 and 2) compared to controls in each year (Figure 26). This diversity and abundance remained high over the sampling years, with the highest total counts in 2021 (Figure 26). The two wildflower treatments did not seem to consistently differ in pollinator numbers (Figure 26) or vegetation composition (Figure 25), and by 2021 appeared very similar; however, we could not test this statistically given our sample size. The sampling we conducted in Fall 2021 resulted in counts of abundance and diversity that exceeded those of several of the wildflower transects in earlier summers (Figure 26), indicating that these native species that emerged (not in the seed mix) can be a fall resource to pollinators. The relatively lower counts of pollinators outside the fence (Figure 26) compared to other treatments likely reflect the less diverse seed mix (mostly clover) and the transition to Johnson grass over the sampling period.

The pollinators predominantly visited black-eyed Susan and coreopsis species, plus purple coneflower and aster in 2021, neither of which make up a large percentage in the vegetation mix (Figures 27-29).

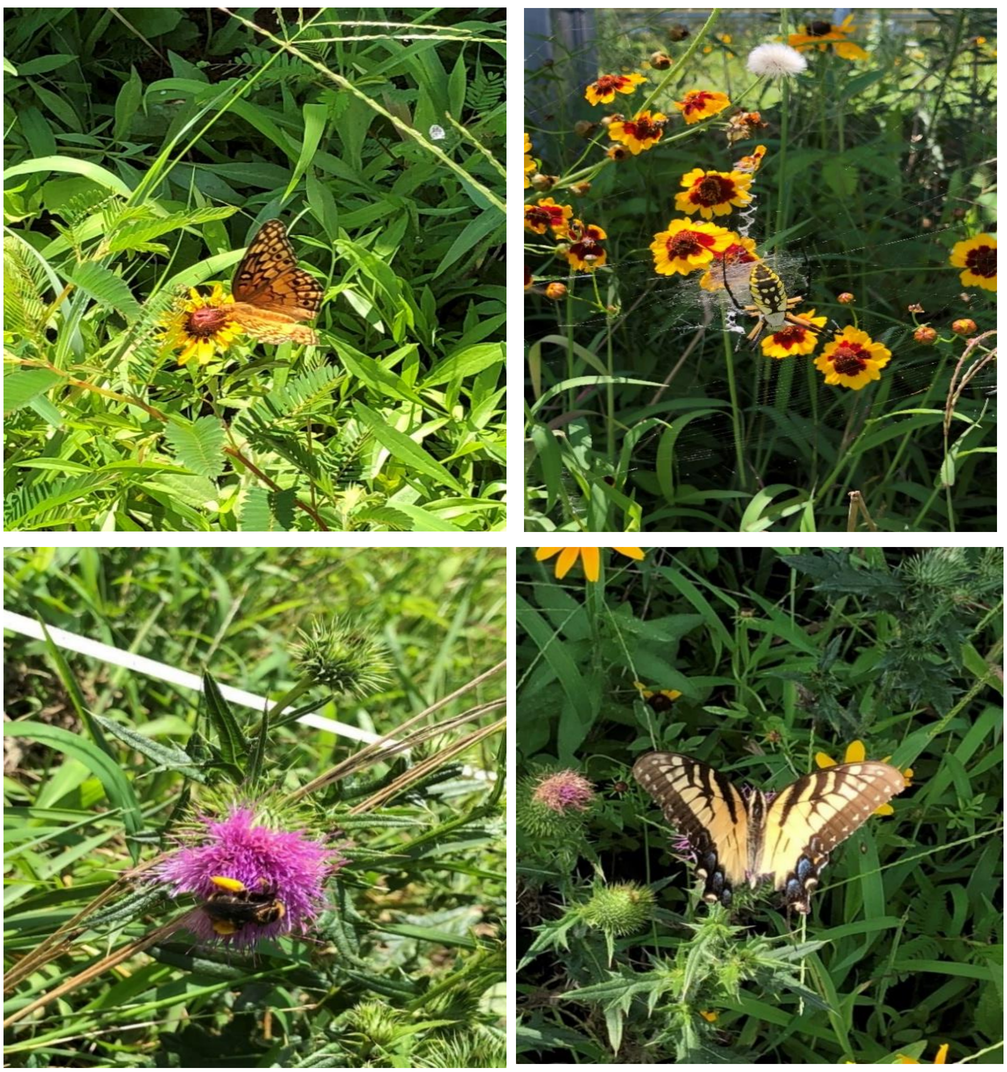
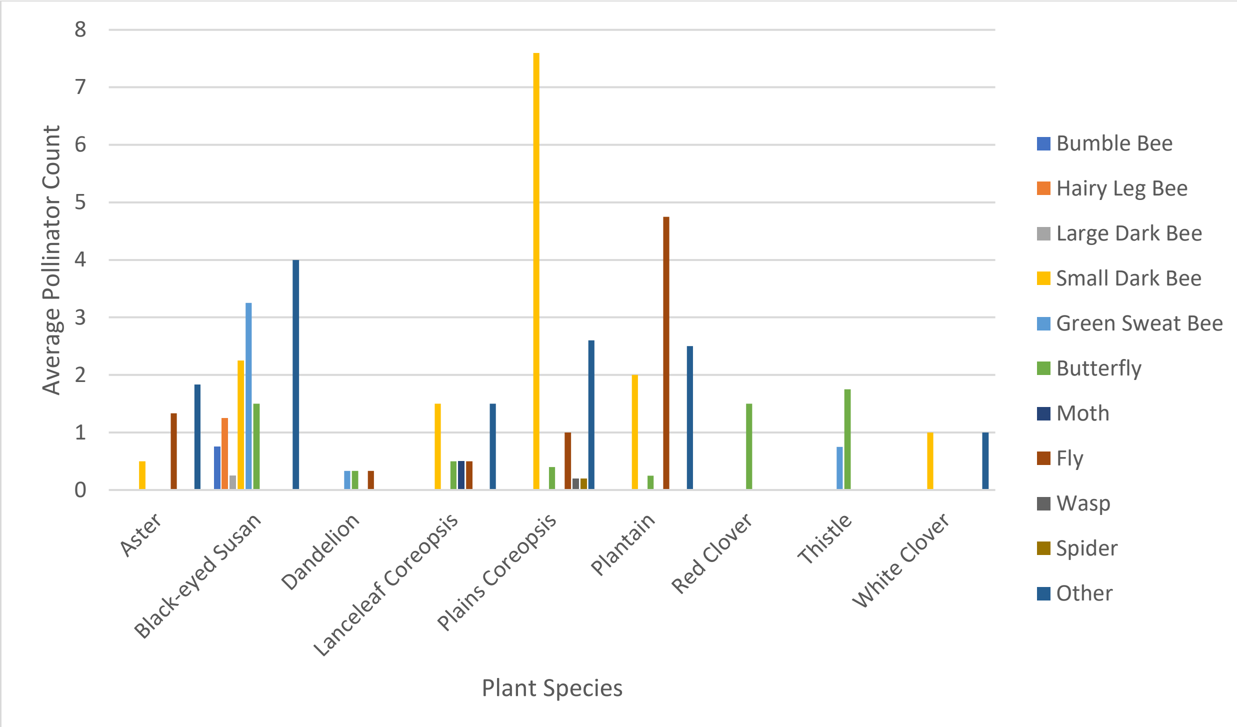


Photo 15. Pollinators in July 2018: Variegated fritillary butterfly (top left), yellow garden spider (top right), eastern tiger swallowtail (bottom right), native bee (bottom left) (Credit: L. Kalies).



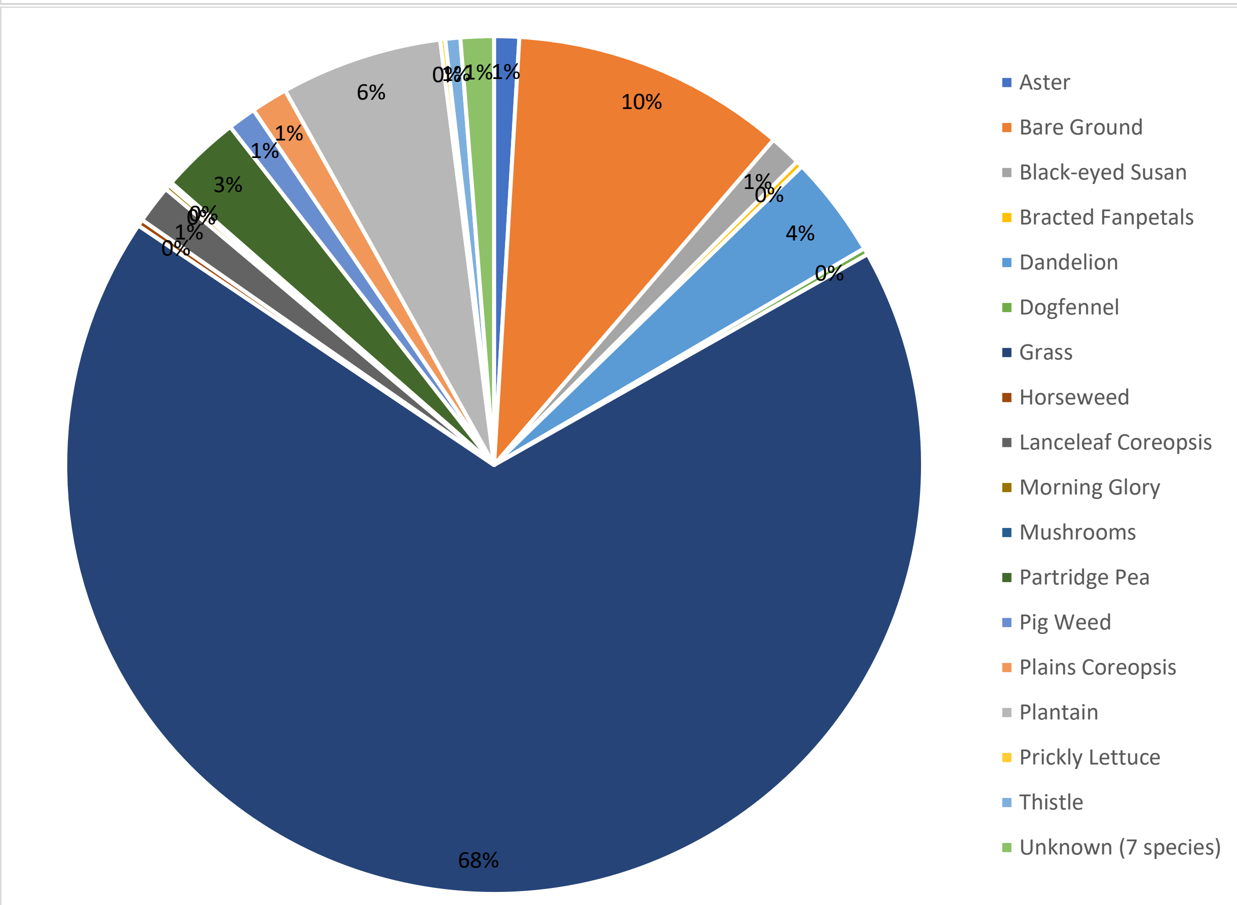
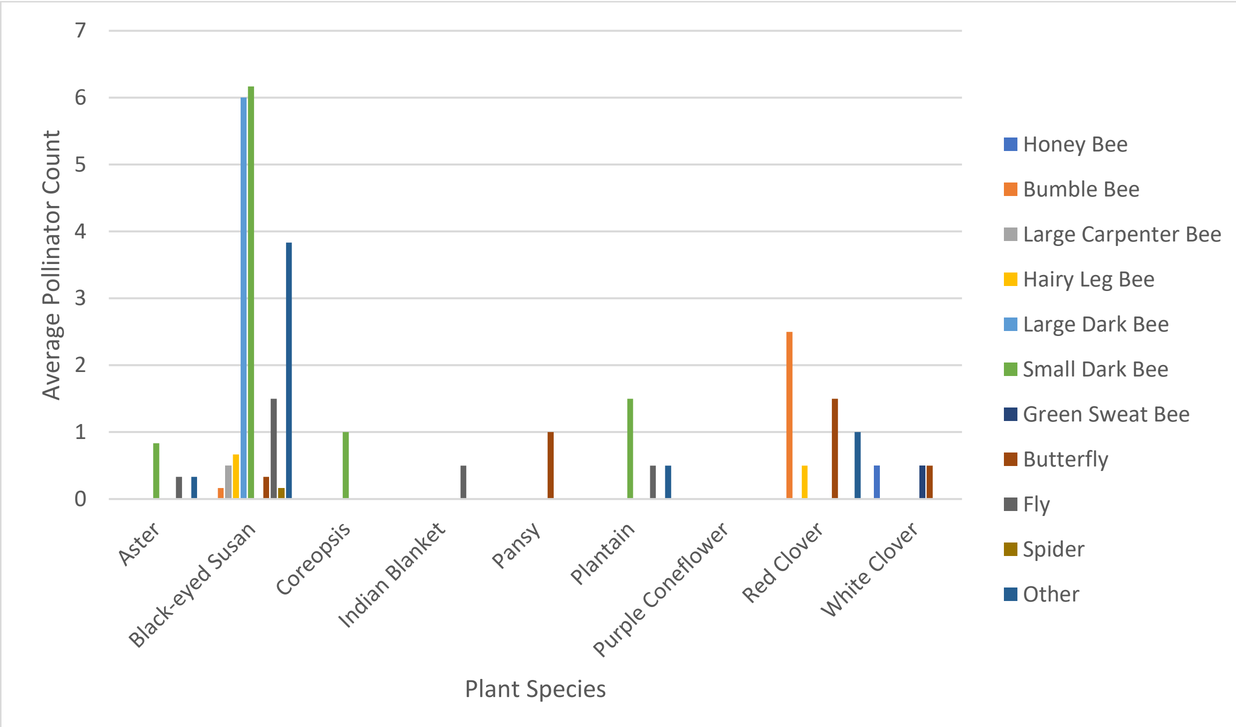


Figure 27. Redmon 2018 count of pollinators per plant (top) and vegetation percent cover (bottom). Both graphs show averages across all transects (treatment and control).



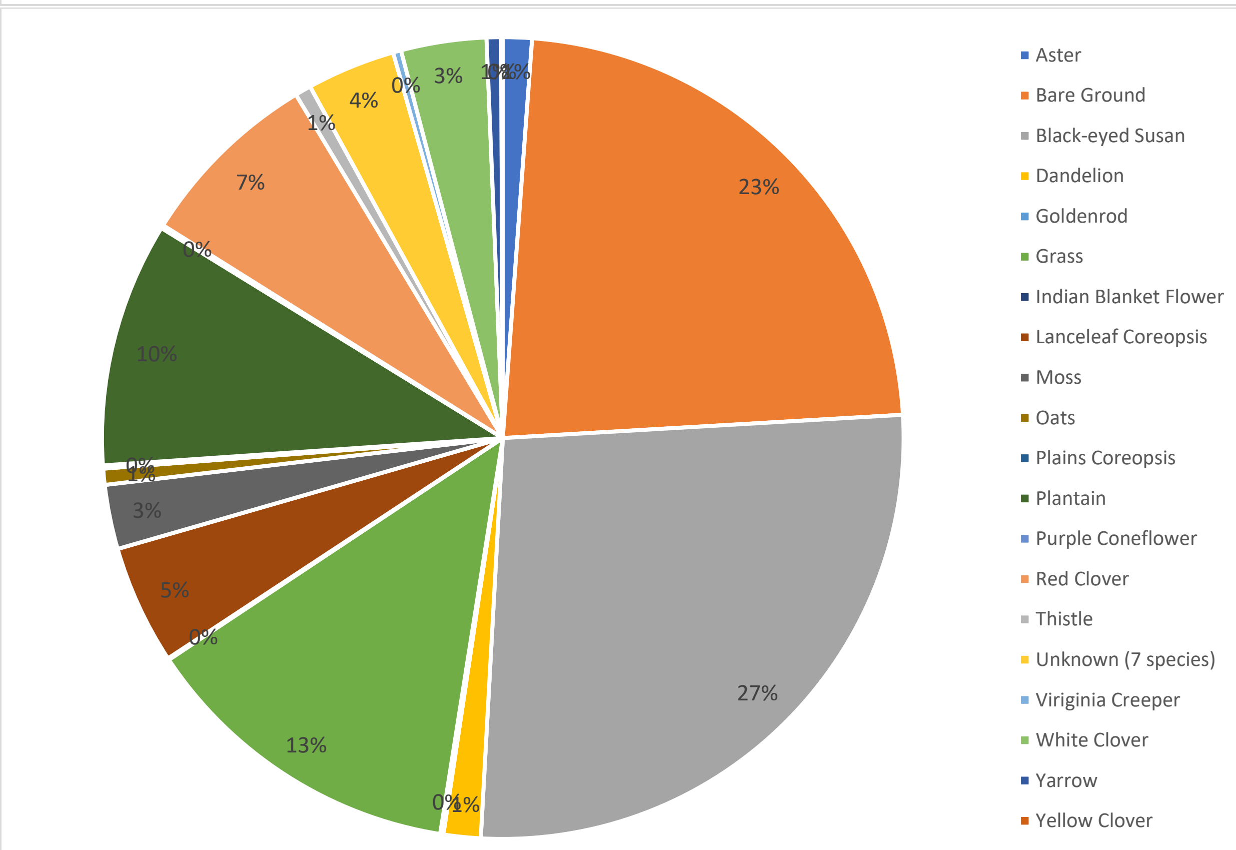
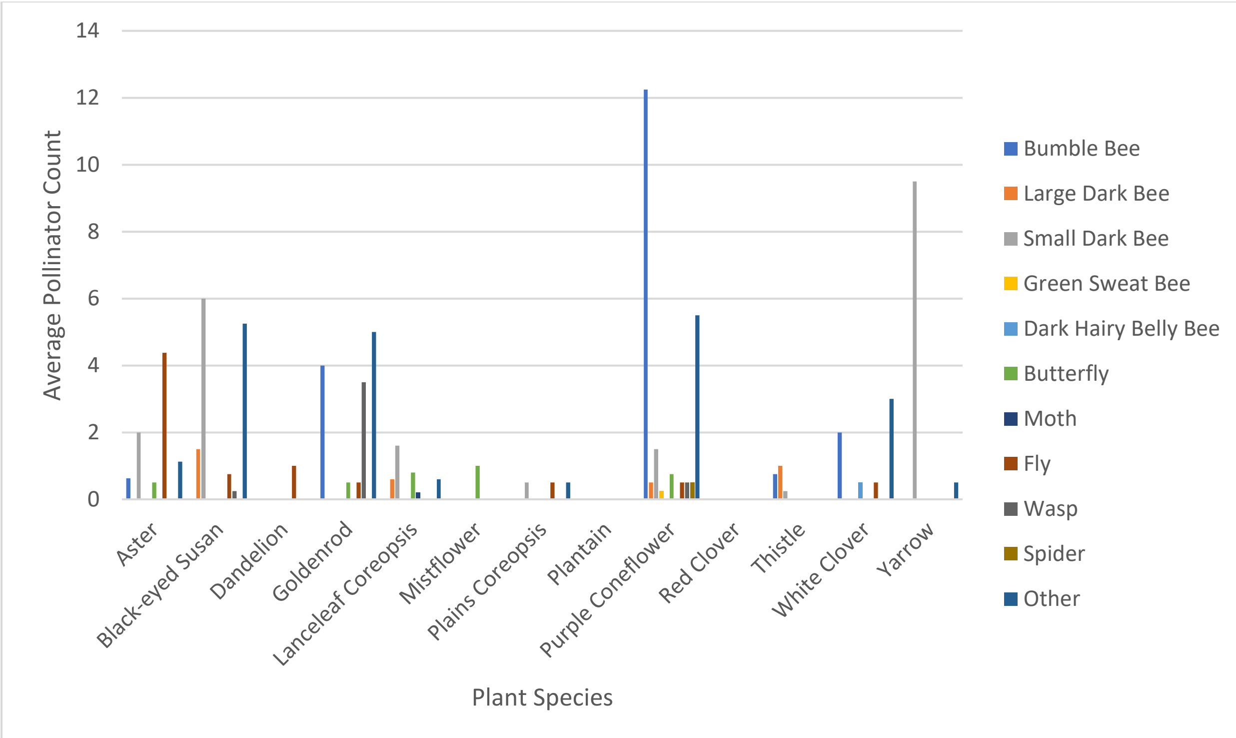


Figure 28. Redmon 2019 count of pollinators per plant (top) and vegetation percent cover (bottom). Both graphs show averages across all transects (treatment and control).



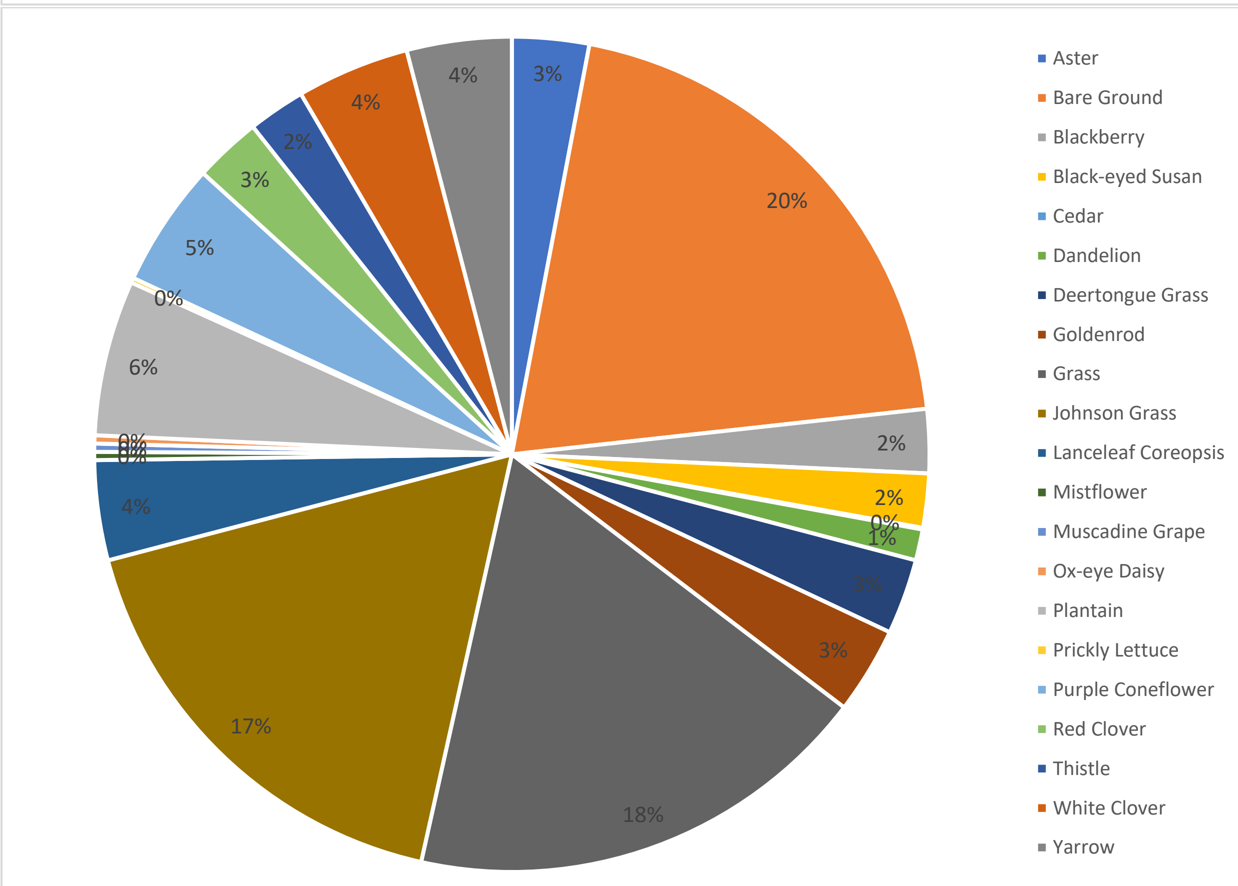


Figure 29. Redmon 2021 count of pollinators per plant (top) and vegetation percent cover (bottom). Both graphs show averages across all transects (treatment and control).

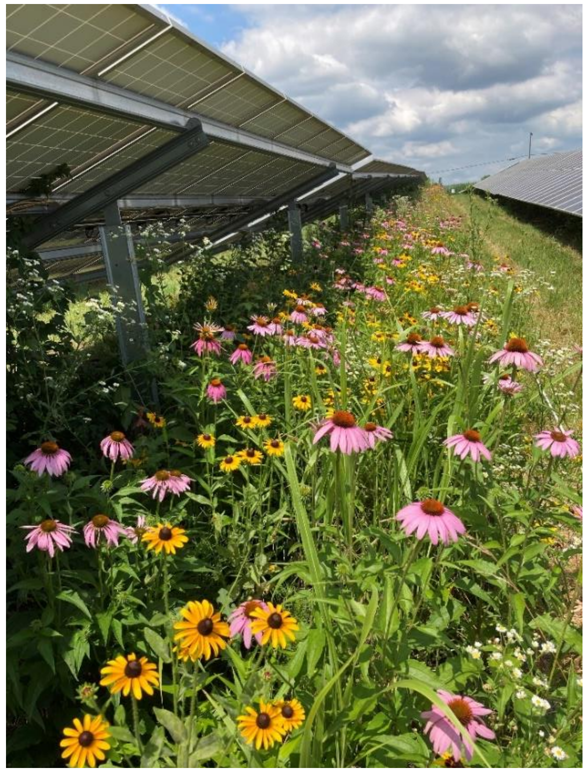



Photo 16. Wildflower transects in 2018 were dominated by coreopsis and black-eyed Susan (left); in 2021, purple coneflower was abundant (right) (Credit: L. Kalies). Note that flowers were planted along the high side of the panels to avoid any shading.

The wildflower transects increased in diversity from 2018 to 2021 (Photo 16). Invasive plant species also became more abundant over time. The powerline right-of-way became dominated by knapweed, and the clover that was planted outside the fence in 2018 was overtaken by Johnson grass by 2021 (Photo 17).


Photo 17. Front of the facility in 2018, comprised of clover (left); same transect in 2021, entirely Johnson grass (right).

Page Solar Facility – Pine Gate Renewables

Willow Spring, NC

Photo 18. Drone-captured image of the Page solar facility under construction in 2019, with settling pond visible and natural riparian area in the background (Credit: M. Fields).

The 1.67 MW, 15-acre Page solar facility was constructed by Pine Gate Renewables in 2019 and is in the Duke Energy service area. The facility features a wildflower seed mix provided by the Bee & Butterfly Habitat Fund with over 50 species of at least 50% wildflowers and herbs. Pine Gate also installed a wildlife-permeable fence around the entire facility, which potentially connects the site to the riparian area that runs along the southeast end (Photo 18). Two settling ponds were left onsite after construction and allowed to convert to onsite wetlands. We conducted vegetation and insect sampling in 2019 and 2021, and deployed camera-traps from 2019-2020.

Page features wildlife fencing that has allowed many foxes and other animals including Virginia opossums, raccoons, songbirds, and domestic cats into the facility (Photo 19).

Photo 19. Camera-trap photos; gray fox (top left), northern raccoon (top right), domestic cat in (bottom right), flock of starlings (bottom left).

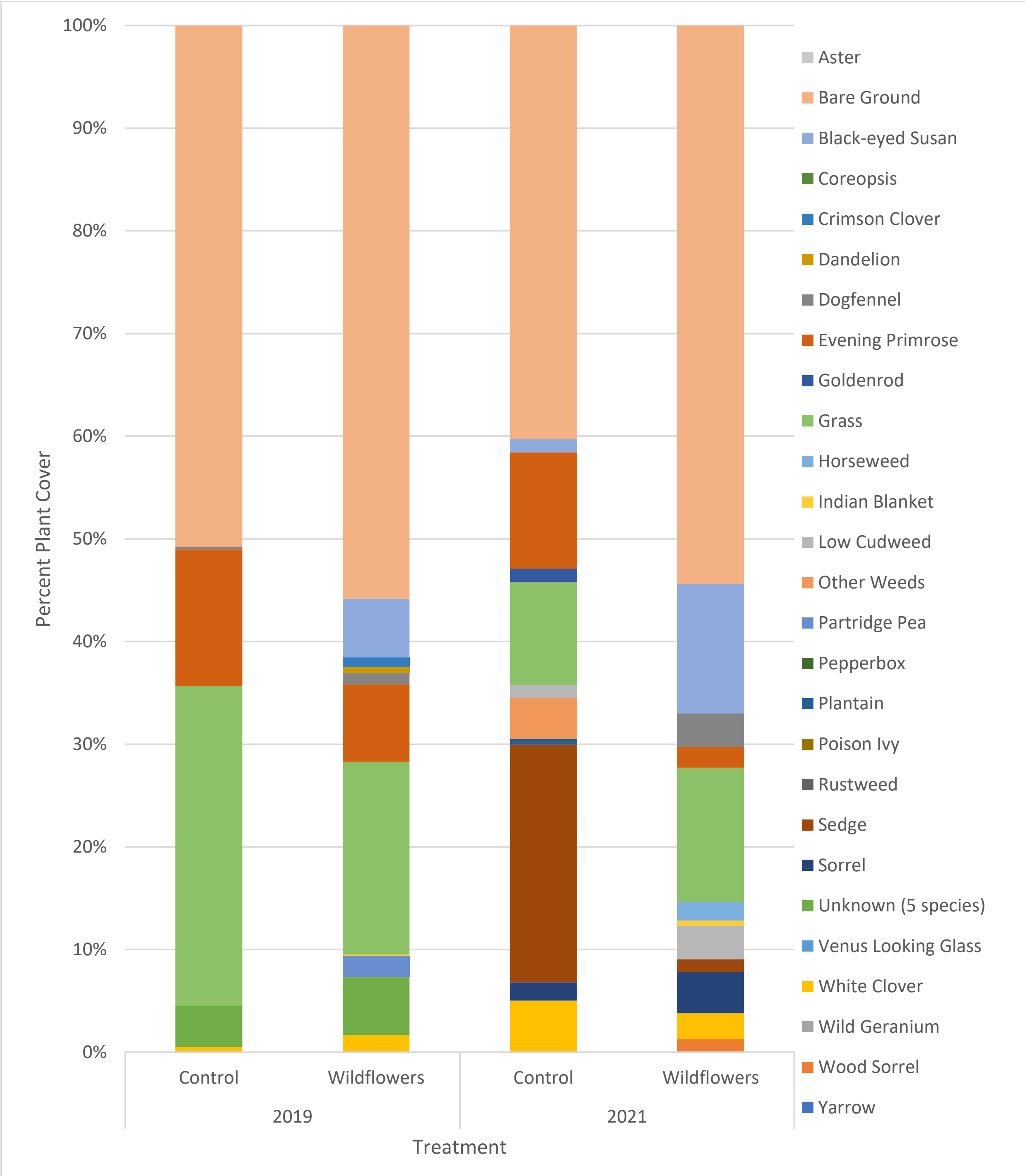


Figure 30. Page vegetation cover by treatment, by year.

Page was comprised of <20% wildflower cover in 2019 and 2021, including mostly black-eyed Susan, plus partridge pea, clover, and Indian blanketflower in the seeded areas (Figure 30, Photo 20). We consisently measured bare ground (Photo 20, right) at over 50% of the total cover, but the end result is a sparse but relatively showy wildflower cover that is mostly uniform throughout the facility. The “bare ground” is actually comprised of organic material and does not include exposed soil or present risk of erosion.

Photo 20. Image of the wildlife-friendly fencing and the cover of wildflowers across the site in 2021 (left); Indian blanket flower was widely present but not abundant (right). Both photos show the high percentage of bare ground at the site (Credit: L. Kalies).

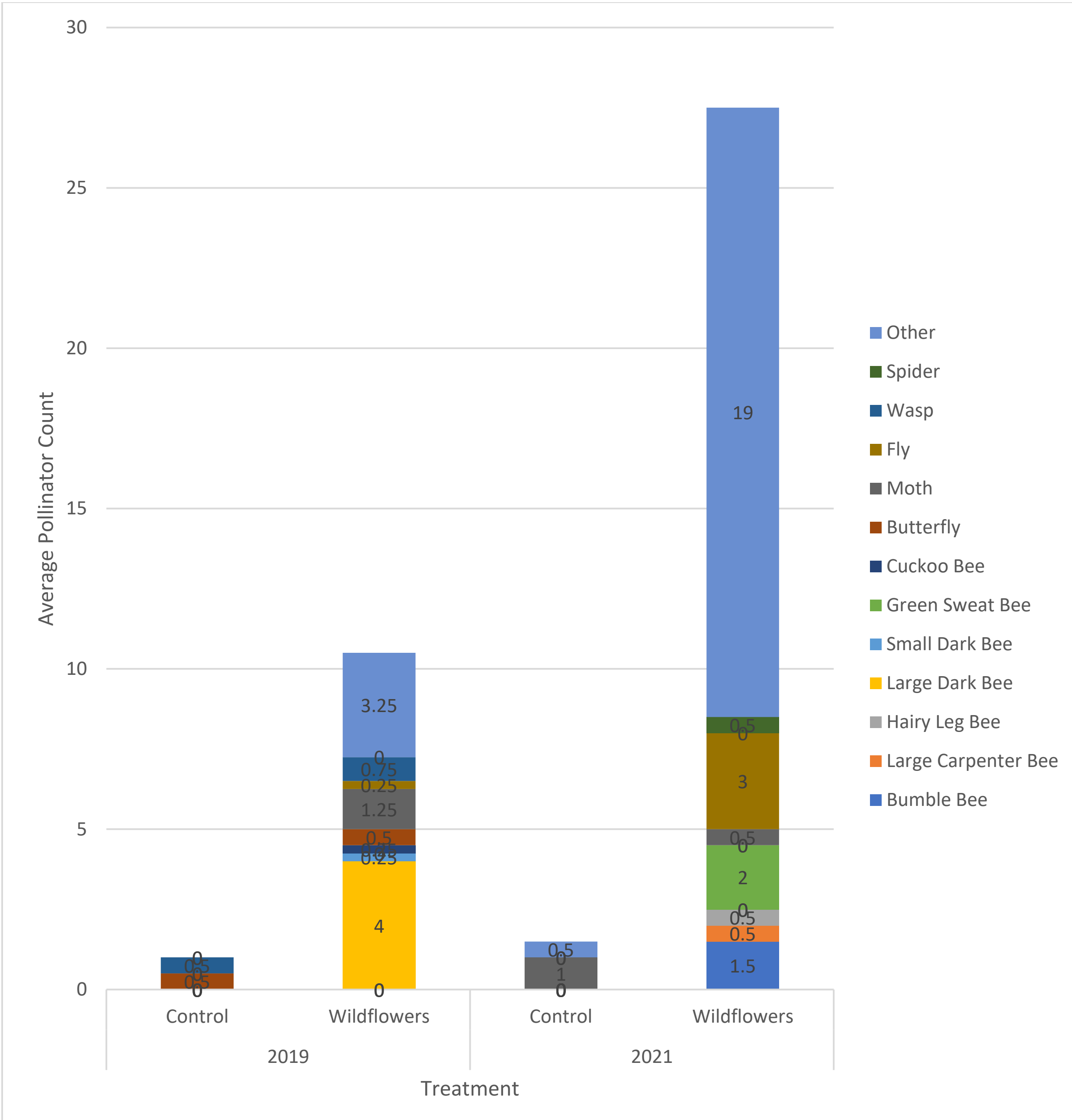
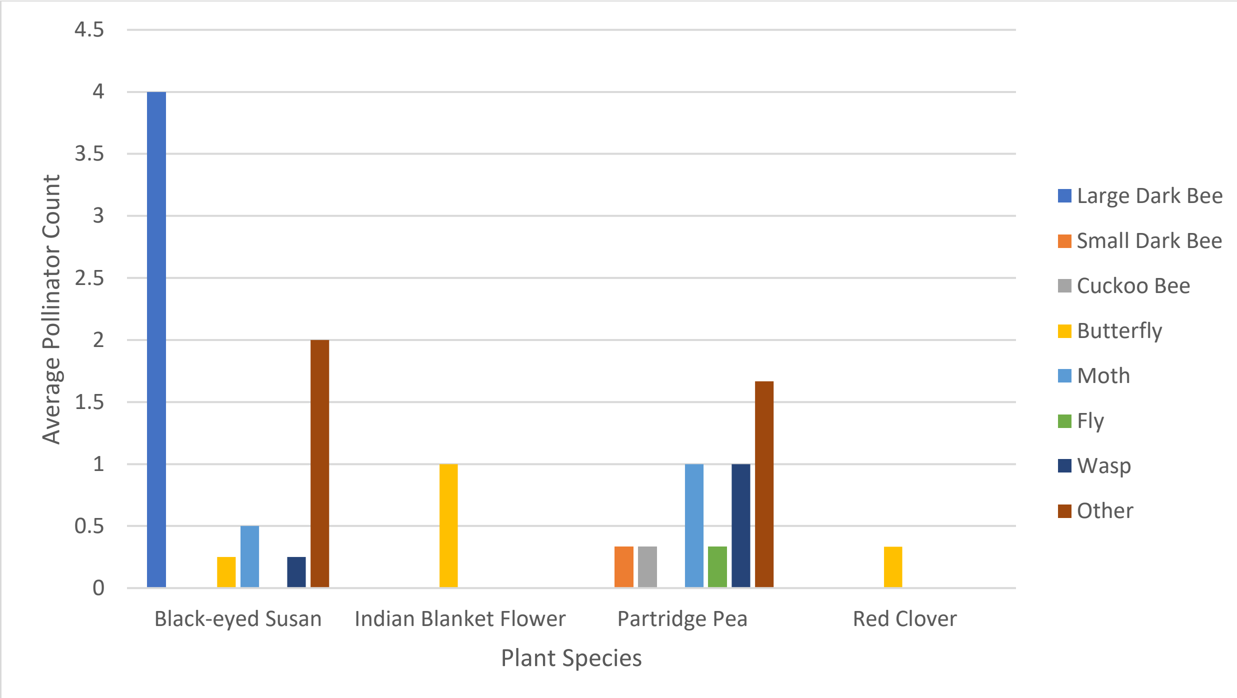


Figure 31. Page pollinator counts by treatment, by year.

Pollinator species composition changed over the two sampling years, but had consistent levels of abundance and diversity (Figure 31). A majority of the "other" pollinators were beetles and grasshoppers in both years.



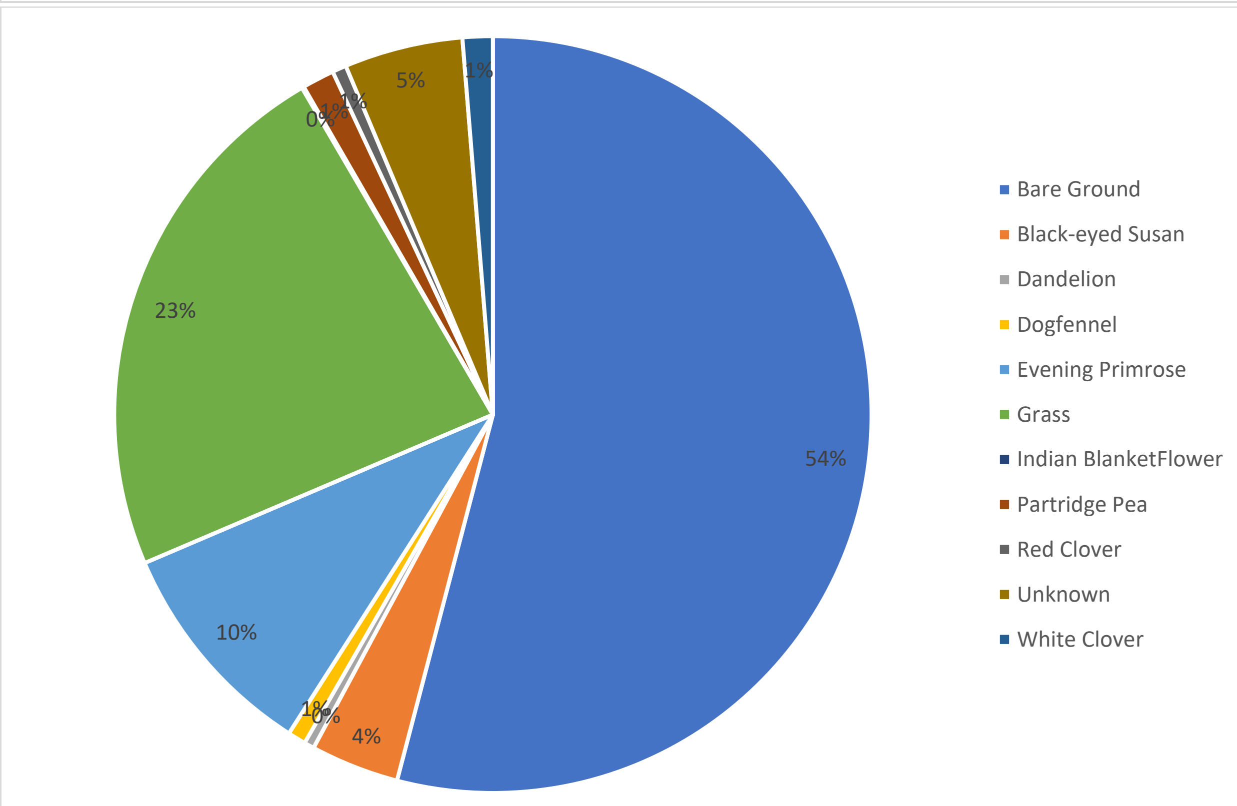
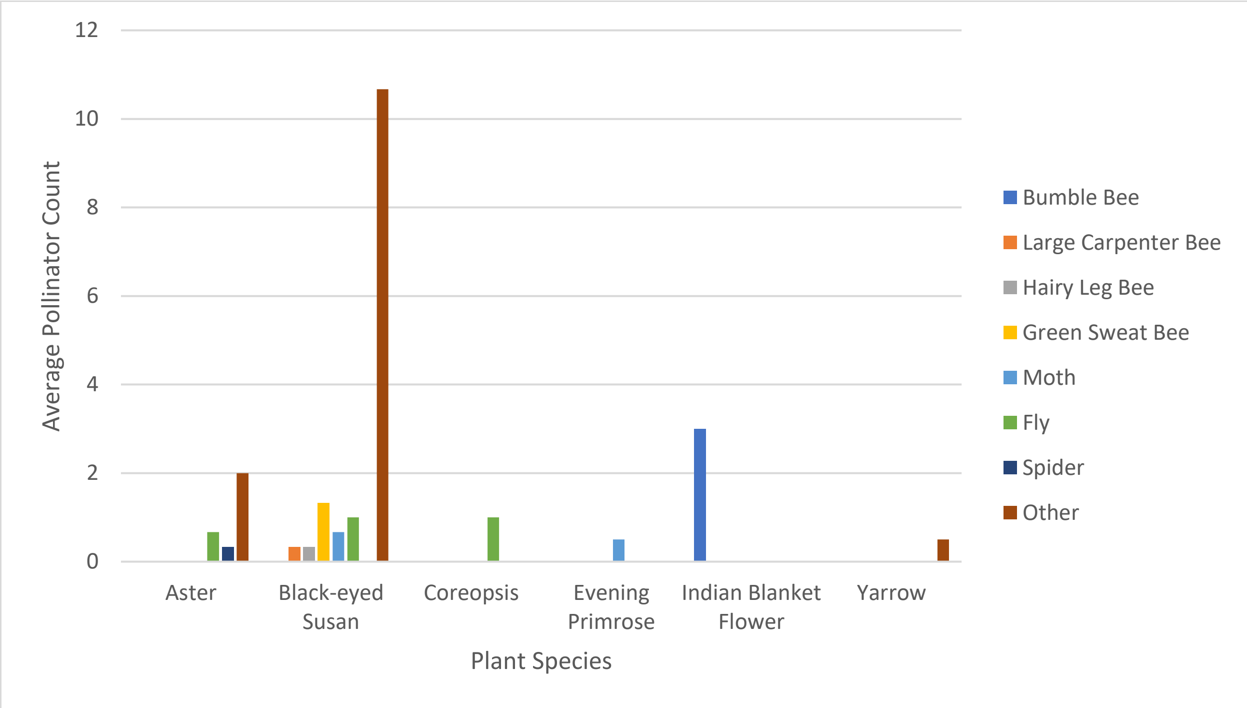


Figure 32. Page 2019 count of pollinators per plant (top) and vegetation percent cover (bottom). Both graphs show averages across all transects (treatment and control).



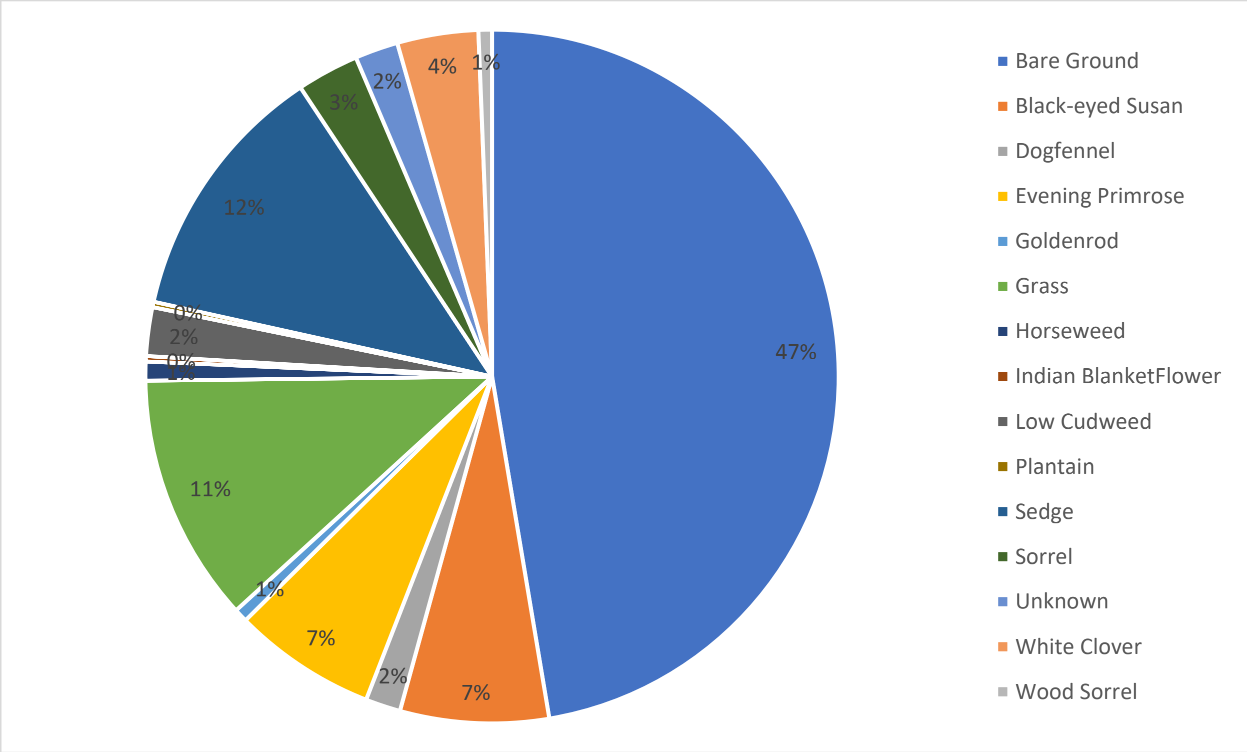


Figure 33. Page 2021 count of pollinators per plant (top) and vegetation percent cover (bottom). Both graphs show averages across all transects (treatment and control).

Black-eyed Susan remained the most frequently visited wildflower species for pollinators but remained a low percentage of the vegetation mix (Figures 32 and 33). After the plants established in 2019, there was some concern that weeds would invade and dominant the site, especially given the high percentage of bare ground. However, after missing the 2020 sampling year, we returned in 2021 to find that the wildflower cover had remained stable or perhaps increased. The overall vegetation composition across the facility seemed to increase in diversity from 2019 to 2021, partly due to the establishment of some weedy species (e.g., evening primrose, goldenrod, aster) (Figures 32 and 33). While not captured by our sampling, we also observed the constructed settling ponds' transition to natural areas and become thick with wetland-adapted plant species (Photo 21). We visited the site in the fall of 2021 and found the vegetation community across the site had transitioned to native and weedy fall plant species, including narrow-leafed sunflowers. The site had to be mowed to control the height of the fall species but were allowed to flourish outside the fence (Photo 21).

Photo 21. The constructed settling ponds were thick with wetland plant species in summer 2021 (left); narrow-leafed sunflowers in front of the facility in Fall 2021 (right) (Credit: L. Kalies).

Moore Solar Facility – Pine Gate Renewables

Aberdeen, NC

Photo 22. Drone-captured image of Moore Solar Facility during construction in 2019 (Credit: M. Fields).

Moore is a 2 MW, 12-acre facility owned by Pine Gate Renewables and is within the Duke Energy service area. The site was cleared of vegetation for construction and remains surrounded by forest (Photo 22). We determined it was particularly important to use wildlife-friendly fencing at this site, to allow movement of animals from the adjacent forest. There is also a stream that runs along the north side of the facility, which is protected from run-off from the site by a synthetic silt fence that runs east-west. A settling pond contains sediment along the west side of the facility, within the fence. We monitored wildlife use of the site using camera-traps from 2019-2021.

A plethora of wildlife used the wildlife fencing at Moore, including songbirds, gray foxes, raccoons, eastern cottontails, white-tailed deer, and domestic dogs and cats (Photo 23). The fence was down for a while at this site, which allowed larger wildlife like deer to enter, but we also discovered that fawns are small enough to use the fence.

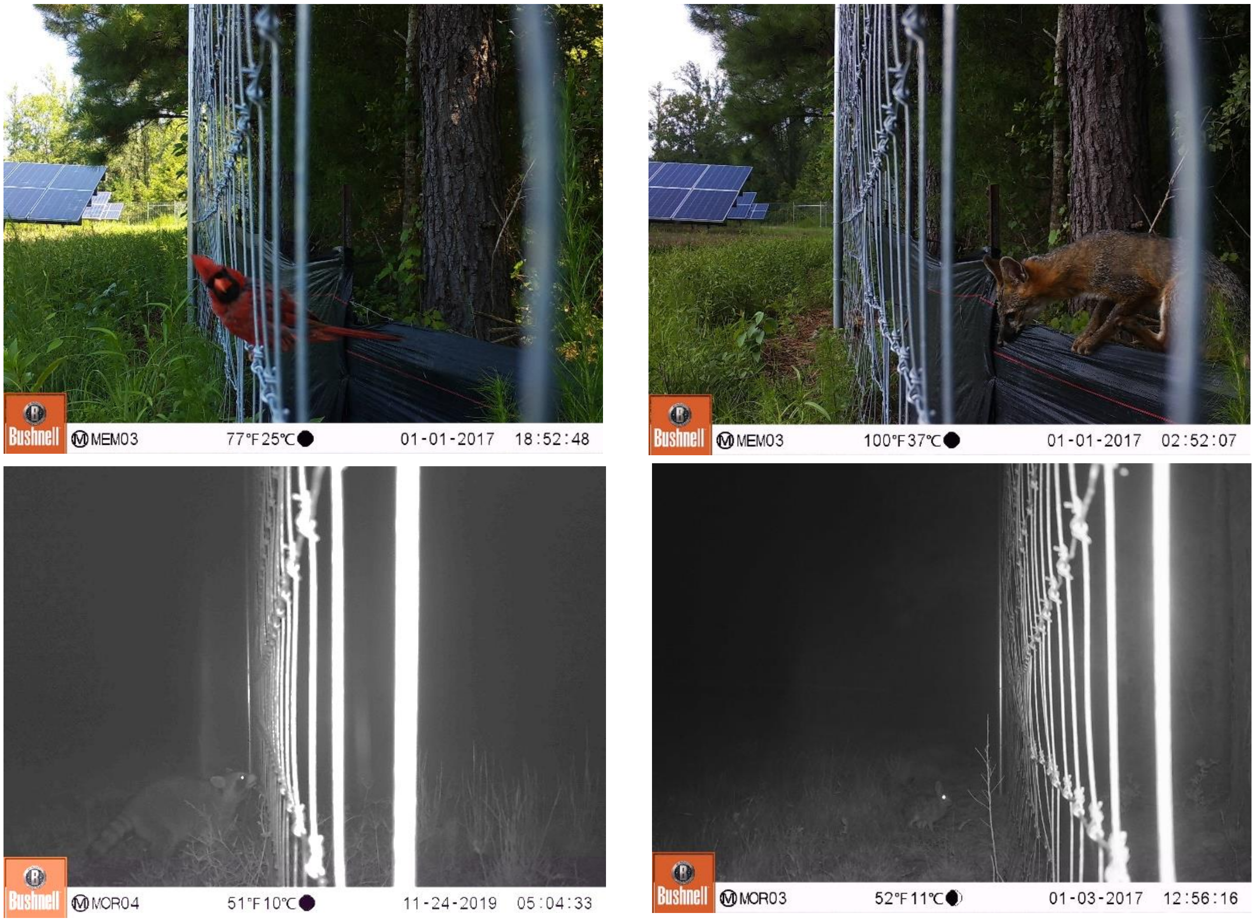


Photo 23. Camera-trap photos from Moore; northern cardinal (top left), gray fox (top right), cottontail (bottom right), raccoon (bottom left). Synthetic silt fence is visible in the background.

Photo 24. Camera-trap photo of a gray fox using the Moore Solar Facility.

We have multiple photos and videos of a pair of gray foxes visiting this site (e.g., Photo 24), not long after construction, potentially using the facility for daily activities while also retreating to the adjacent forested site. We have recorded a coyote on the outside of the fence (Photo 25), but it is not seen inside the facility, potentially releasing the fox from this competition pressure (coyotes are known to kill foxes, not as prey, but to reduce competition for resources).

Photo 25. Camera-trap photo of a coyote outside of the fence at Moore Solar Facility.

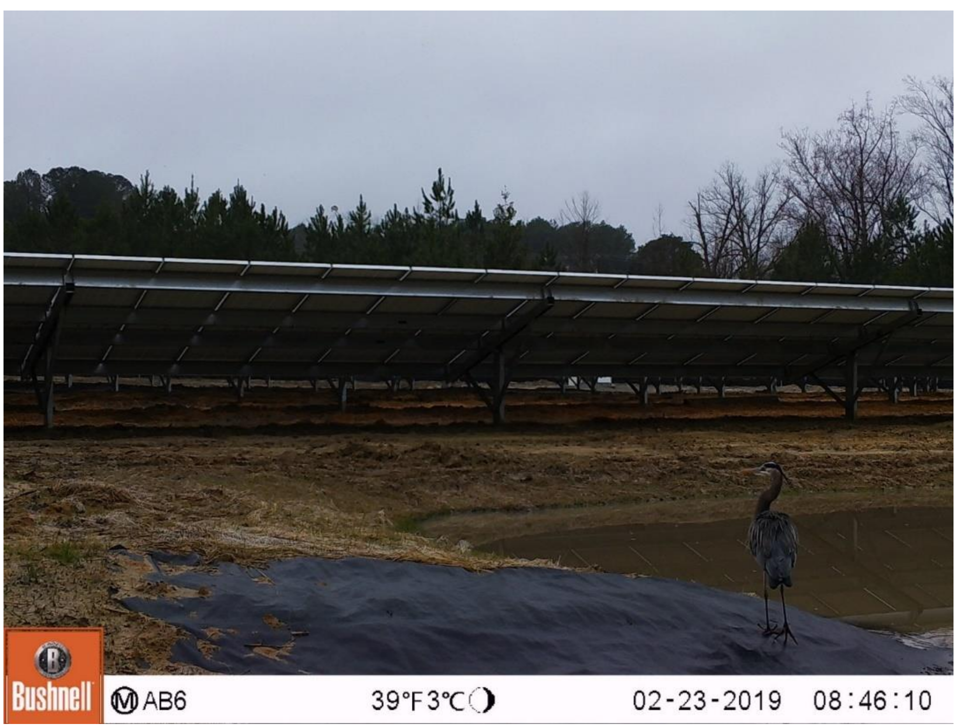


Photo 26. Camera-trap photo of great blue heron at Moore Solar Facility settling pond during construction.

We also observed wildlife visiting the settling pond; camera-trap images (Photo 26) show a great blue heron visiting the site not long after construction. This suggests the potential for wildlife use of wetland features at solar facilities.

Photo 27. Yellow-bellied slider found at Moore Solar Facility in 2019 (Credit: L. Kalies).

We found yellow-bellied slider turtle hatchlings on the site (Photo 27), likely from eggs laid on the solar facility and dispersing to the wetland behind the facility. This observation underscores the importance of maintaining wildlife habitat on site and providing connectivity with adjacent habitat

Acknowledgements

Our sincere thanks to our NC State University collaborations for their advice and guidance: Becky Irwin, Elsa Youngsteadt, and Chris Moorman. Many TNC staff members helped with field work, analysis, and report formatting, especially Margaret Fields (also our incredible drone photographer), Brenda Wichmann, Sydney Bezanson, Gretchen Coll, and Tiffany Hartung. Intern Jana Woerner did an incredible job getting this project started and implemented in 2018. Finally, this work would have been impossible without the cooperation and enthusiastic support of the solar developers, particularly: Brian Bednar, Landon Abernethy, Katie Hill, Claudia Weeks, and Susan Bruno. We would also like to thank the NC Pollinator Conservation Alliance for bringing together the solar industry, wildlife agencies, and conservation community on this topic. Finally, we greatly appreciate the support of the Duke Energy Foundation in funding this work.

Appendix A Sampling methodology

Pollinators

We used 30-meter transects to sample pollinator diversity at the solar farms. Because pollinator activity may vary based on weather conditions, we recorded temperatures, cloud cover, and wind before starting our transects. Using a long measuring tape, we walked 30 meters adjacent to the pollinator habitat – this minimizes any disturbances to the pollinators from rustling through the plants. Two people then grabbed either end of the measuring tape and moved it to the middle of the pollinator habitat, ensuring that the tape is above the plants while moving it. If this is not possible, we suggest waiting for a few minutes between rolling out the measuring tape and starting the sampling to allow pollinators to return. We recorded the start and end times of each transect to evaluate sampling effort and to control for pollinator activity variations throughout the day (morning vs. afternoon). For each transect, we surveyed 1 meter within each side of the measuring tape, recording all pollinators that visited flowers. To ensure accuracy while recording data, one person would scan for pollinators, while the other recorded the counts on our data sheet. We ignored all pollinators that were on different parts of the plant, merely hovered around the flower, or visited for less than 0.5 seconds. Additionally, we tried to avoid counting any pollinator more than once if it visited more than one flower. Due to difficulties with accurately identifying each distinct bee species, we used broad categories in our sampling protocol (see data sheet). While walking each transect, we recommend walking so that your shadow does not move in front of you, as this may disturb pollinators. In addition, we switched which side of the measuring tape we were walking on around the 15-meter mark to ensure that we did not trample the plants we sampled in our vegetation plots (see below). For each solar farm, we used two treatment and two control transects. The control transects were usually conducted between solar panels where no pollinator mix was planted.

Vegetation

We used the same transects for the vegetation sampling as we did for pollinator sampling. However, we recommend that pollinator sampling is conducted first as vegetation sampling may disturb the pollinators. For each transect, we sampled two 1m by 1m plots – the first was at the 10-meter mark and the second at the 20-meter plot. The two plots were on opposite sides of the measuring tape. For each plot, we recorded percentage cover for each plant species, including bare ground – the total percentage should amount to 100%. Additionally, we counted the number of flowering stems, as well as the total flowers for each plant (if present). If we were unable to identify certain plants within the plot using the plant guide, we collected samples for our botanist to later identify.

Solar Farm: ________________________________ **Date:** ______________________

Transect: ______ **Team:** _____________________

Plot: ______

Species	**% Cover**	**# Stems**	**# Total Flowers**
Bare Ground			

Plot: ______

Species	**% Cover**	**# Stems**	**# Total Flowers**
Bare Ground			

Solar Farm: ________________________________ **Team:** _______________________ **Date:**______________________

Transect: ______

Start Time: _________

Total Time: __________

☐ **Lat/Long**

☐ **Netting**

Flowering Species	Honey Bee	Bumble Bee	Large Carpenter Bee	Hairy Leg Bee	Large Dark Bee	Small Dark Bee	Green Sweat Bee	Dark Hairy Belly Bee	Metallic Hairy Belly Bee	Cuckoo Bee	Bird	Butterfly	Moth	Fly	Wasp	Spider	Other	**Notes**

Appendix B. Scientific and common names of plant and animal species

PLANTS

Common name	Scientific name
Ash	*Fraxinus spp.*
Aster	*Aster* amellus
Basalis Coreopsis, Goldenman Tickseed	*Coreopsis basalis*
Beggar-tick	*Bidens spp.*
Blackberry	*Rubus fruticosus*
Black-eyed Susan	*Rudbeckia hirta*
Blue-eyed Grass	*Sisyrinchium angustifolium*
Blue Lupine	*Lupinus perennis*
Blue Vervain	*Verbena hastata*
Bracted Fanpetals	*Sida ciliaris*
Browntop Millet	*Brachiaria ramosa*
Buttercup	*Ranunculus spp.*
Butterfly Milkweed	*Asclepias tuberosa*
Canada Wild Rye	*Elymus canadensis*
Cedar	*Cedrus spp.*
Cinquefoil	*Potentilla recta*
Common Boneset	*Eupatorium perfoliatum*
Common Yarrow	*Achillea millefolium*
Coreopsis, Tickseed	*Coreopsis spp.*
Creeping Red Fescue	*Festuca rubra*
Crimson Clover	*Trifolium incarnatum*
Dandelion	*Taraxacum spp.*
Deertongue Grass	*Dichanthelium clandestinum*
Dogfennel	*Eupatorium capillifolium*
Eastern Gammagrass	*Tripsacum dactyloides*
Elder	*Sambucus spp.*
Evening Primrose	*Oenothera biennis*
Fleabane	*Erigeron* annuus
Geranium	*Geranium maculatum*
Goldenrod	*Solidago spp.*
Heather Aster, White Heath Aster?	*Symphyotrichum ericoides*
Horsenettle	*Solanum carolinense*
Horseweed	*Erigeron canadensis*
Indian Blanket	*Gaillardia pulchella*
Indian Grass	*Sorghastrum nutans*
Ironweed	*Bechium spp.*

Common name	Scientific name
Japanese clovers	*Lespedeza spp.*
Johnson Grass	*Sorghum halepense*
Lanceleaf Coreopsis, Lanceleaf Tickseed	*Coreopsis lanceolata*
Low Cudweed	*Gnaphalium uliginosum*
Little Bluestem	*Schizachyrium scoparium*
Maple	*Acer spp.*
Maximillian's Sunflower	*Helianthus maximiliani*
Mistflower	*Conoclinium coelestinum*
Morning Glory	*Ipomoea purpurea*
Muscadine Grape	*Vitis rotundifolia*
Oats	*Avena fatua*
Ox-eye Daisy	*Leucanthemum vulgare*
Pansy	*Viola tricolor*
Partridge pea	*Chamaecrista fasciculata*
Pepperbox Poppy?	*Papaver somniferum*
Pig Weed	*Amaranthus spp.*
Plains Coreopsis, Golden Tickseed	*Coreopsis tinctoria*
Plantain	*Plantago major*
Poison Ivy	*Toxicodendron radicans*
Prickly Lettuce	*Lactuca serriola*
Purple Coneflower	*Echinacea purpurea*
Purple Top Vervain	*Verbena bonariensis*
Red Clover	*Trifolium pratense*
Rush	*Juncus effusus*
Rustweed	*Polypremum procumbens*
Sahara Bermuda Grass	*Cynodon dactylon*
Sedge	*Carex spp.*
Sensitive Pea	*Chamaecrista nictitans*
Sorrel	*Rumex acetosa*
Sour Native Grass	*Digitaria insularis*
Spiderwort	*Tradescantia spp.*
Spotted Beebalm	*Monarda punctata*
Sunflower	*Helianthus spp.*
Swamp Sunflower	*Helianthus angustifolius*
Tall Fescue	*Festuca arundinacea*
Thistle	*Cirsium vulgare*
Three-seed Mercury	*Acalypha rhomboidea*
Tufted Hairgrass	*Deschampsia cespitosa*
Venus Looking Glass	*Triodanis perfoliata*
Violet, Common Blue Violet	*Viola sororia*
Virginia Creeper	*Parthenocissus quinquefolia*

Common name	Scientific name
Virginia Pepperweed	*Lepidium virginicum*
Virginia Wild Rye	*Elymus virginicus*
Wild Senna	*Senna hebecarpa*
White Clover	*Trifolium repens*
Wood Sorrel, Irish Shamrock	*Oxalis*

ANIMALS

Common name	Scientific name
American Mink	*Neovison* vison
Beetle	Coleoptera (order)
Bird	Aves (class)
Bobcat	*Lynx rufus*
Bumble Bee	*Bombus spp.*
Butterfly	Rhopalocera (suborder)
Coyote	*Canis latrans*
Cuckoo Bee	*Sphecodes spp.*
Dark Sweat Bee**	Halictidae (family)
Domestic Cat	*Felis catus*
Domestic Dog	*Canis lupus familiaris*
Eastern Cottontail	*Sylvilagus floridanus*
Eastern Gray Squirrel	*Sciurus carolinensis*
Fly	Diptera (order)
Gray Fox	*Urocyon cinereoargenteus*
Great Blue Heron	*Ardea herodias*
Green Sweat Bee	*Agapostemon spp.*
Groundhog	*Marmota monax*
Hairy Leg Bee	*Anthophora plumipes*
Honeybee	*Apis spp.*
Large Carpenter Bee	*Xylocopa spp.*
Large Mining Bee*	*Anthophora abrupta*
Leaf-cutter Bee***	Megachilidae (family)
Mason Bee****	Megachilidae (family)
Moth	Heterocera (suborder)
Northern Cardinal	*Cardinalis cardinalis*
Northern Raccoon	*Procyon lotor*
Orchard Bee****	*Osmia spp.*
Plasterer Bee, Polyester Bee*	Celletidae (family)
Red Fox	*Vulpes vulpes*
Small Carpenter Bee**	*Ceratina spp.*
Small Mining Bee**	*Andrena spp.*

Common name	**Scientific name**
Spider	Araneae (order)
Starling	*Sturnus vulgaris*
Striped Skunk	*Mephitis mephitis*
Virginia Opossum	*Didelphis virginiana*
Wasp	Vespidae (family)
White-tailed Deer	*Odocoileus virginianus*
Wild Turkey	*Meleagris gallopavo*
Yellow-bellied Slider	*Trachemys scripta scripta*
Yellow-faced Bee**	*Hylaeus spp.*

*included in “Large Dark Bee” category

**included in “Small Dark Bee” category

***included in “Dark Hairy Belly Bee” category

****included in “Metallic Hairy Belly bee” category