# Bumble Bee and Honey Bee Density is Greater in Fields with a Diverse Seed Mix when Compared to Fields Planted to Timothy in Central Ohio, USA

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**ABSTRACT. Pollinators are important for global food production and provide ecosystem services. However, many species of insect pollinators have declined in recent decades. Drivers of pollinator decline include habitat loss, invasive species, pesticides, and climate change. In Ohio, many species of pollinators (including butterflies, moths, and bumble bees) are considered species of greatest conservation need, while others have undergone population declines. This study evaluated butterfly species richness and diversity; butterfly, bumble bee, and honey bee density; and plant species composition of 2 planting regimes on state wildlife areas. Butterflies, bumble bees, and honey bees were recorded along 100 m transects within fields planted with timothy (*Phleum pratense*) and a diverse seed mix. Plant communities were assessed by measuring percent cover within quadrats placed every 10 m along the same transects. Mean plant species richness and diversity were significantly greater in fields planted in the diverse mix than in the timothy fields. As plant diversity increased, butterfly diversity increased. Density estimates of bumble bees (*Bombus* spp.) and honey bees (*Apis* spp.) were significantly greater in fields planted to the diverse mix than fields planted to timothy, with densities of bumble bees and honey bees being 536% and 529% greater, respectively, in the diverse mix fields than timothy fields. There were greater densities of butterflies in fields planted to the diverse mix than in the timothy fields; however, the differences were not statistically significant. Working to increase plant diversity in planted and restored grasslands benefits bumble bees, honey bees, butterflies, and likely other species of insects as well.**

**Publication Date: November 2025** **https://doi.org/10.18061/ojs.6507** **OHIO J SCI 124(2):90-101**

## INTRODUCTION

Insects play a wide array of important roles in both wild terrestrial ecosystems and in agricultural plant communities. Among these roles, pollination is one of the most important. Pollination is responsible for an estimated 35% of global agricultural food production, which has an economic value ranging from $195 billion to $387 billion (Klein et al. 2006; Porto et al. 2020). Observed declines in managed honey bee (*Apis mellifera*) populations (Pettis and Delaplane 2010) garnered increased concern for other pollinating insect species and led to the examination of these declines and the impacts of pollinator loss in related ecosystems (Bauer and Wing 2010; Mathiasson and Rehan 2020; Wood et al. 2020). Climate change, habitat loss, invasive species, pesticides, and land management decisions were identified as important drivers of native insect pollinator biodiversity loss on a global scale (Sammataro et al. 2000; Potts et al. 2010; Dicks et al. 2021; Vasiliev and Greenwood 2021).

Several partnerships in the United States launched largescale initiatives in an effort to conserve declining pollinators, including the North American Pollinator Protection Campaign, Pollinator Partnership™, Monarch Joint Venture, and the Midwest Association of Fish and Wildlife Agencies'® (MAFWA) Mid-America Monarch Conservation Strategy, among many others. Although some initiatives are concerned with all pollinator species, many are focused on improving land management for a single species or genus (i.e., monarch butterfly (*Danaus plexippus*), honey bees, or bumble bees (*Bombus* spp.)) and consist of plans to plant only a small number of focal flowering species to increase available host plants or nectaring plants. Conversely, largescale initiatives such as the US Department of Agriculture's Pollinator Habitat Initiative have seed mixes with a minimum of 9 flower species, but can contain more than 50 plant species, designed specifically to provide pollinator nectar sources (USDA 2013; Pheasants Forever 2023).

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Because of the growing concern for pollinator declines, several areas of research have been pursued with increasing urgency. For example, recent studies explored the relationship between plant diversity and insect pollinator diversity and have found positive correlations between the two (Ebeling et al. 2008; Fründ et al. 2010; Zhang et al. 2016; Tanis et al. 2020; Kral-O'Brien, O'Brien, et al. 2021). Others have examined flower selection among insect pollinator groups (Roswell et al. 2019; Simanonok et al. 2021; Erickson et al. 2022). As interest in management for declining insect pollinator populations increases, the topic of pollinator movement between natural cover types around agricultural fields has also garnered attention. Such research explores if restoring agricultural landcover to more natural cover types improves insect pollinator dispersal and establishment in higher quality habitats (e.g., Kells et al. 2001; Jauker et al. 2009; Potts et al. 2009; Woodcock et al. 2014; Feltham et al. 2015; Nayak et al. 2015; Orford et al. 2016; Cole et al. 2017; McHugh et al. 2022). Despite the growing breadth of knowledge, little research has been conducted to combine these 2 areas of interest: do deliberate planting regimes in managed natural grasslands increase density or diversity of butterflies, bumble bees, or honey bees compared to nearby agricultural fields, and which plant species in these managed areas are these species detected on?

Ohio is home to many insect species commonly classified as pollinators, including approximately 500 bees, 130 butterflies, 400 hoverflies, and 3,000 moths. At least 25% of pollinator species are in decline, and 65 species are currently listed as species of greatest conservation need (1 bee, 13 butterflies, and 51 moths) (Ohio Division of Wildlife 2015). Meanwhile, pending review, several other species may be added to this list.

Population declines are not only occurring in the currently listed species. One long-term study of Lepidoptera populations in Ohio has documented declines in 32 species that are not currently considered species of greatest conservation need (Wepprich et al. 2019). For elusive (i.e., difficult to detect) and rare (i.e., species with low abundance or restricted distribution) butterflies and other insect pollinator groups—such as solitary bees, hoverflies, and moths—abundance and distribution are still unknown. Documented declines are minimum conservative estimates of pollinator loss across Ohio's landscape.

Approximately 3% of Ohio's land is managed by the Ohio Department of Natural Resources (ODNR). Among these properties are wildlife areas, which are managed by the Ohio Department of Natural Resources, Division of Wildlife (ODNR Division of Wildlife) to provide both habitat for wildlife and outdoor recreation opportunities for the public (ODNR 2024). The ODNR Division of Wildlife maintains a variety of ecosystems —such as wetlands, forests, and grasslands—in wildlife areas across the state.

Grasslands on wildlife areas are often plagued with woody encroachment from invasive and aggressive trees and shrubs (e.g., autumn olive (*Elaeagnus umbellata*) and black locust (*Robinia pseudoacacia*)) (Lautenbach et al. 2020); however, agriculture can be used as a cost-effective method to set back succession accelerated by aggressive woody species. In this practice, fields are typically planted with crops for 2 to 3 years, then planted with either a diverse mix of grass and forb species or a single grass species selected to provide habitat for grassland wildlife species.

The current study explores relationships between Ohio's butterfly species richness and diversity; butterfly, bumble bee, and honey bee density; and plant species composition in planted fields on state wildlife areas. This study examines butterfly richness and diversity in several fields that are planted either with timothy (*Phleum pratense*) or a more diverse seed mix to assess if butterfly, bumble bee, and honey bee communities were linked with plant diversity in a managed wildlife area setting.

For this study, species richness is defined as the total number of species observed (Colwell 2009). Species diversity takes into account not only the number of species, but also the number of individuals (Colwell 2009). Density is the measure of individuals within a unit area, typically corrected for detection probability (Buckland et al. 2001).

It was hypothesized that fields planted to the diverse seed mix (including 8 wildflower species and 6 grass species) would have greater butterfly richness and diversity and greater butterfly, bumble bee, and honey bee density than fields planted with timothy. It was also hypothesized that as plant species richness and diversity increased, butterfly, bumble bee, and honey bee density and diversity would increase.

## METHODS

### Study Sites

A total of 4 fields were evaluated at the Delaware Wildlife Area (Delaware, Marion, and Morrow Counties, Ohio; lat 40°24'44"N, long 83°01'08"W), 3 fields at Deer Creek Wildlife Area (Fayette, Madison, and Pickaway Counties; lat 39°39'08"N, long 83°16'29"W), and 1 field at Fayette County Wildlife Area 1 (Fayette County; lat 39°31'27"N, long 83°31'15"W). All 3 properties are managed by the ODNR Division of Wildlife and consist of a mixture of forest, shrubland, grassland, wetland, and row-crop agriculture. The areas surrounding these properties are dominated by row-crop agriculture. Primary crops surrounding the wildlife areas consist of corn (*Zea mays*), soybeans (*Glycine max*), and, to a lesser extent, winter wheat (*Triticum aestivum*). Fields evaluated at the wildlife areas were either planted to timothy or a diverse seed mix consisting of 14 different grass and forb species (Table 1). There were 4 fields evaluated at Delaware Wildlife Area (3 diverse seed mix fields, 1 timothy field), 3 fields evaluated at Deer Creek Wildlife Area (2 timothy fields, 1 diverse seed mix field), and 1 field evaluated at Fayette County Wildlife Area 1 (1 timothy field). Fields were planted prior to the implementation of this study in 2020 (4 fields) or 2021 (4 fields), following the ODNR wildlife area management practices.

### Field Methods

The authors randomly placed two, 100 m long transects in each field, at least 10 m from the field edge: a total of 16 transects. To select transects, 2 points were placed at random in each field, at least 50 m apart, using ArcMap (ESRI® Inc., Redlands, California USA). An azimuth was selected for each transect using a random number table and a second point was placed 100 m away in that direction. To minimize double counting of butterflies and bees between transects, all transects were a minimum of 50 m from another transect. All field measurements were collected along the established transects. Transects were marked within a handheld GPS unit and flagged every 20 m to ensure the same locations were visited by observers during both plant and insect sampling.

**Table 1**
**Species and planting rate by field type on 3 wildlife areas in central Ohio**

| Field type | Common name | Scientific name | lbs/acre | kg/ha |
|---|---|---|---|---|
| Timothy | Timothy | *Phleum pratense* | 6.000 | 6.725 |
| | **Total** | | **6.000** | **6.725** |
| Diverse mix | Orchardgrass | *Dactylis glomerata* | 0.450 | 0.504 |
| | Timothy | *Phleum pratense* | 0.300 | 0.336 |
| | Little bluestem | *Schizachyrium scoparium* | 0.500 | 0.560 |
| | Sand dropseed | *Sporobolus cryptandrus* | 0.020 | 0.022 |
| | Sideoats grama | *Bouteloua curtipendula* | 0.400 | 0.448 |
| | Switchgrass (Blackwell) | *Panicum virgatum* | 0.080 | 0.090 |
| | Alfalfa | *Medicago* spp. | 0.600 | 0.673 |
| | Alsike clover | *Trifolium hybridum* | 0.200 | 0.224 |
| | Black-eyed Susan | *Rudbeckia hirta* | 0.125 | 0.140 |
| | Crimson clover | *Trifolium incarnatum* | 0.750 | 0.841 |
| | Ladino or white clover | *Trifolium repens* | 0.150 | 0.168 |
| | Korean (perennial) lespedeza | *Kummerowia stipulacea* | 0.400 | 0.448 |
| | Common evening primrose | *Oenothera biennis* | 0.040 | 0.045 |
| | Wild bergamot | *Monarda fistulosa* | 0.015 | 0.017 |
| | **Total** | | **4.030** | **4.516** |

The plant community was sampled using a 1.0 m × 0.5 m Daubenmire frame (Daubenmire 1959). A 100 m tape was placed along each transect and the percent cover of all plant species was estimated within the frame. Plant foliage cover viewed from above was recorded every 10 m along each transect. Plant cover was recorded to species level using visual traits where possible; however, some species were only able to be recorded to genus. Plant cover was recorded in 7 different categories: <1%, 1 to 5%, 6 to 25%, 26 to 50%, 51 to 75%, 76 to 95%, and 96 to 100% cover of the frame for each species (Daubenmire 1959). The median value of each cover class was used for each plant species in a Daubenmire frame. The plant community was sampled once. The percent cover of each plant species was then averaged across each transect to estimate the total cover of each plant species detected along each transect.

Butterflies, bumble bees, and honey bees were surveyed during 2 rounds between June 30 and August 1, 2022. The transects were walked in opposite directions during each visit (i.e., if the transects were walked from east to west the first time, they were walked from west to east the second time). All transects were completed between 10:00 and 15:00 EDT. Surveys were completed if winds were <20 km/h, cloud cover <50%, and temperatures >20 °C. Butterflies, bumble bees, and honey bees were sampled during this timeframe, as this is one of the peak emergence periods for most butterfly species. Many bumble bees and honey bees were active during the sampling period. An attempt was made to identify each individual to species level. However, this was not always possible for some of the bumble bees and they were recorded to genus in some cases. To assess density, line-transect distance sampling was used for 10-minute intervals (Moranz et al. 2012; Kral et al. 2018; McNeil et al. 2019; Kral-O'Brien, Antonsen, et al. 2021).

Distance sampling accounts for differences in detection at varying distances, as individuals close to the transect are easier to detect (Buckland et al. 2001). The distance sampling methodology also allows the generation of a density estimate which can then be used to calculate abundance estimates, if desired (Buckland et al. 2001). Previous work showed that distance sampling is an effective method for sampling butterflies, bumble bees, and honey bees (Moranz et al. 2012; Kral et al. 2018; McNeil et al. 2019; Kral-O'Brien, Antonsen, et al. 2021). As a result, all adult bumble bees, adult honey bees, and adult butterflies that were detected visually were recorded, regardless of the distance from the transect and on either side of the transect. Each time a butterfly, bumble bee, or honey bee was detected, observers stopped, stopped the stopwatch, and recorded the perpendicular distance to where the individual was first detected, plus the species, activity, and sex, when possible (Buckland et al. 2001; Moranz et al. 2012). (An underlying assumption of the distance sampling methodology was that an ocular estimation was used when observing <5 m and a laser range finder was used when ≥5 m.)

## Statistical Methods

All statistical analyses were carried out using R Version 4.2.0 (R Core Team 2022). The *vegan* package for R was used to estimate butterfly and plant species richness and diversity (Oksanen et al. 2022). The Shannon diversity index (H) was used to compare diversity between transects in different field types. A Welch's 2 sample t-test was used to compare species richness and diversity along transects between field type for both plants and butterflies. Linear regression was used to identify if there was any correlation between plant species richness and diversity and butterfly species richness and diversity across all field types. Percent cover of planted and volunteer (i.e., plants that were not included in a seed mix but emerged from the seed bank) plant species was compared between field types.

Density was estimated using a hierarchical distance sampling framework through the "distsamp" function in the *unmarked* package for program R (Royle et al. 2004; Fiske and Chandler 2011). There was not sufficient data for any species of bumble bee; therefore, all observations of honey bees and bumble bees were pooled into 2 distinct groups: honey bees and bumble bees. Distance values were binned as the *unmarked* package requires. The farthest 5% of all detections for each group were truncated to achieve better model fit (Buckland et al. 2001). The data was stacked from multiple visits, treating each visit to a transect as a unique site (Kéry and Royle 2016). The area surveyed was derived from the effective width of

the transect and the length of the transect (i.e., area = transect length * 2 * width). Models were fit to assess differences in density of pollinator groups between field types and density compared to plant species richness and diversity along transects. Program CONTRAST was used to compare density estimates of pollinators between field types (Hines and Sauer 1989).

## RESULTS

There were 52 and 44 species of plants observed in the diverse mix and timothy fields, respectively. The 5 most common planted species that occurred in the fields with the diverse mix were: alsike clover (*Trifolium hybridum*), ladino clover (*Trifolium repens*), black-eyed Susan (*Rudbeckia hirta*), timothy, and wild bergamot (*Monarda fistulosa*). The 5 most common volunteer species in the fields planted to the diverse mix were: foxtail (*Setaria* sp.), heath aster (*Symphyotrichum ericoides*), common yarrow (*Achillea millefolium*), daisy fleabane (*Erigeron annuus*), and yellow nutsedge (*Cyperus esculentus*). The 5 most common volunteer species that occurred in fields planted to timothy were: heath aster, Canada goldenrod (*Solidago canadensis*), foxtail, teasel (*Dipsacus* sp.), and yellow nutsedge. Along transects in fields planted to the diverse mix, an average of 20.9% of the species encountered were species that were included in the diverse seed mix (SE = 4.78; range: 6.8 to 43.8%). Transects in fields planted to timothy were composed of 35.9% timothy (SE = 11.8; range: 3.8 to 88.7%). There was no significant difference between the percentage of planted or volunteer species along transects between field types ($p = 0.267$; $t = 1.181$; df = 9.245). Some transects and fields had poor establishment rates of planted species. Mean plant species richness was significantly greater in the diverse mix fields ($\mu = 21.6$, SE = 2.3) than timothy fields ($\mu = 14.9$, SE = 1.0; $p = 0.024$, $t = 2.67$, df = 9.56). Plant diversity was significantly greater in the diverse mix fields (H = 2.03, SE = 0.16) than timothy fields (H = 1.44, SE = 0.21; $p = 0.041$, $t = 2.26$, df = 13.12).

In total, there were 69 (17.25/field, SE = 13.8) and 11 (2.75/field, SE = 1.3) honey bees (80 total), 42 (10.5/field, SE = 1.8) and 6 (1.5/field, SE = 0.6) bumble bees (48 total), and 151 (37.8/field, SE = 7.4) and 97 (23.5/field, SE = 1.6) butterflies (288 total) recorded in the diverse mix and timothy fields, respectively (see Table 2 for a full list of butterfly species observed). The 151 butterflies in the diverse mix fields consisted of 14 species, and the 97 butterflies in the timothy fields consisted of 12 species. Cabbage white (*Pieris rapae*) accounted for 43.1%, clouded sulphur (*Colias philodice*) accounted for 20.6%, orange sulphur (*Colias eurytheme*) accounted for 9.3%, pearl crescent (*Phyciodes tharos*) accounted for 7.3%, eastern tailed blue (*Cupido comyntas*) accounted for 6.5%, and black swallowtail (*Papilio polyxenes*) accounted for 4.8% of all butterfly observations. All other species made up the remainder of the butterfly observations (8.5%).

Butterfly species richness was not significantly ($p = 0.067$, $t = 2.03$, df = 11.17) different between diverse mix fields ($\mu = 6.5$, SE = 0.8) when compared to timothy fields ($\mu = 4.6$, SE = 0.5). Butterfly diversity was greater in the diverse mix fields (H = 1.5, SE = 0.1) when compared to the timothy fields (H = 1.2, SE = 0.1), although this was not statistically significant ($p = 0.135$, $t = 1.604$, df = 12.12). When compared across both field types, there was no trend between butterfly species richness and plant species richness ($\beta = 1.304$, SE = 0.707, $p = 0.087$) (Fig. 1A). As plant diversity increased butterfly diversity increased ($\beta = 0.975$, SE = 0.351, $p = 0.015$) (Fig. 1B).

The transect width used for calculating density was 20 m for butterflies, 6 m for bumble bees, and 6 m for honey bees. Density estimates were significantly greater in diverse mix fields than in timothy fields for both bumble bees ($\chi^2 = 14.46$, DF = 1, $p < 0.001$) (Table 3) and honey bees ($\chi^2 = 77.40$, DF = 1, $p < 0.001$) (Table 3). Densities of bumble bees and honey bees were 536% and 529% greater in the diverse mix fields than timothy fields, respectively. Differences among field type were not statistically significant at alpha = 0.05 ($\chi^2 = 1.30$, DF = 1, $p = 0.255$) (Table 3) for butterflies.

When comparing plant species richness to pollinator densities at the transect level, it was found that densities of bumble bees ($\beta = 0.105$; 95% CI: 0.046 to 0.164), and honey bees ($\beta = 0.293$; 95% CI: 0.238 to 0.348) increased as plant species richness increased (Fig. 2C and 2E). However, plant richness was not a significant predictor of butterfly density (Fig. 2A). Estimated density of bumble bees and honey bees increased 146% and 214%, respectively, when plant species richness increased from 10 to 20 species.

**Table 2**
**Full list of butterflies observed during transects and number of observations in each field type on 3 wildlife areas in central Ohio, 2022**

| Species | Timothy field | Diverse mix field |
|---|---|---|
| Cabbage white (*Pieris rapae*) | 49 | 58 |
| Clouded sulphur (*Colias philodice*) | 16 | 35 |
| Orange sulphur (*Colias eurytheme*) | 13 | 10 |
| Pearl crescent (*Phyciodes tharos*) | 6 | 12 |
| Eastern tailed-blue (*Cupido comyntas*) | 1 | 15 |
| Black swallowtail (*Papilio polyxenes*) | 2 | 10 |
| Red admiral (*Vanessa atalanta*) | 4 | 3 |
| Monarch (*Danaus plexippus*) | 2 | 2 |
| European skipper (*Thymelicus lineola*) | 1 | 0 |
| Giant swallowtail (*Papilio cresphontes*) | 0 | 1 |
| Meadow fritillary (*Boloria bellona*) | 0 | 1 |
| Painted lady (*Vanessa cardui*) | 1 | 0 |
| Peck's skipper (*Polites peckius*) | 1 | 0 |
| Red spotted purple (*Limenitis arthemis*) | 0 | 1 |
| Summer azure (*Celastrina neglecta*) | 0 | 1 |
| Eastern tiger swallowtail (*Papilio glaucus*) | 1 | 0 |
| Viceroy (*Limenitis archippus*) | 0 | 1 |
| Skipper (Hesperiidae spp.) | 0 | 1 |

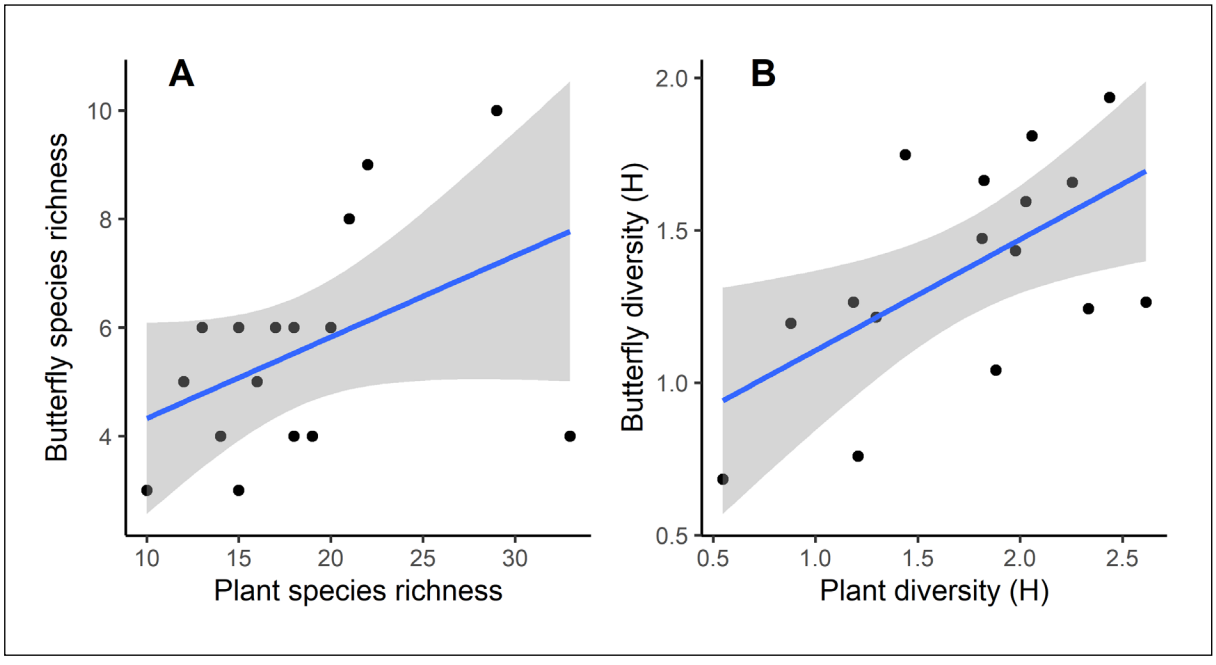


**FIGURE 1. Regression analyses comparing (A) plant species richness to butterfly species richness ($p = 0.087$) and (B) comparing plant diversity to butterfly diversity ($p = 0.015$) in central Ohio, USA. H = Shannon diversity index. Shown with standard errors (gray band).**

Densities of butterflies ($\beta$ = 0.163; 95% CI: 0.0089 to 0.4871), bumble bees ($\beta$ = 1.259; 95% CI: 0.614 to 1.904), and honey bees ($\beta$ = 3.38; 95% CI: 1.592 to 5.167) increased as plant species diversity increased on a transect (Fig. 2B, 2D, and 2F). Bumble bee and honey bee densities increased 209% and 316%, respectively, when the Shannon diversity index increased from 1.0 to 2.0.

## DISCUSSION

The results of the current study suggest (1) bumble bee and honey bee estimated densities correlate with both plant species richness and diversity and (2) that estimated density of butterflies increased with plant diversity, but not species richness. For the fields in this study, increased plant richness is comparable with increased flowering species richness. Fields planted in grass monocultures, such as the timothy fields in this mix, have a reduced abundance of flowers. This reduced abundance of flowers, in turn, decreases foraging opportunities for insect pollinators, like bumble bees, honey bees, and butterflies. Conversely, increasing the number of flowering plants in an area, even without considering flower diversity, increases foraging opportunities. Several studies have found that increasing floral abundance in a variety of settings (i.e., cropland, urban areas, etc.) increases abundance of insect pollinators (Jauker et al. 2009; Matteson and Langellotto 2010; Woodcock et al. 2014; Tanis et al. 2020; McHugh et al. 2022). It is important to note that the decrease in pollinating insect abundance and diversity in timothy fields was still observable despite the prevalence of volunteer flowering forbs in the timothy fields that likely reduced the significance of the relationship between field type and pollinator presence.

Bumble bee and honey bee density had the strongest relationship with field type in this study, when compared to butterfly density. The high density of bees in fields planted to the diverse seed mix may be related to the species included in the diverse seed mix as well as volunteer flowering plants in the mix fields. Native wild bees tend to select native flower species to visit, and honey bees tend to select introduced flower species (Simanonok et al. 2021; Lanterman Novotny et al. 2023). The mixed fields in this study contained a combination of native and introduced species, providing foraging opportunities for both bumble bees and honey bees with minimal competition. Preferred flower species for both bee groups were also present in the diverse fields. Deliberately planted species with evidence of strong bee preference include wild bergamot (*Monarda fistulosa*) and black-eyed Susan (*Rudbeckia hirta*) for wild bumble bees and alfalfa (*Medicago sativa*) for honey bees (Roswell et al. 2019; Simanonok et al. 2021; Lanterman Novotny et al. 2023). Goldenrods (*Solidago* spp.), thistles (*Cirsium* spp.), and sweetclover (*Melilotus* spp.) were also prominent volunteers in the diverse fields. Wild bumble bees have been shown to frequently visit goldenrods and thistles, and honey bees exhibited preference for sweetclover (Simanonok et al. 2021).

**Table 3**
**Estimated density (individuals/ha), standard error (SE), lower 95% confidence limit (LCL), and 95% upper confidence limit (UCL) of butterflies, bumble bees, and honey bees in fields planted to a diverse mix (mix) and timothy grass (timothy) in central Ohio, 2022**

| Group | Field type | Density | SE | LCL | UCL |
|---|---|---|---|---|---|
| Butterflies | Mix | 104.8 | 26.1 | 64.3 | 170.7 |
| | Timothy | 68.9 | 17.6 | 41.7 | 113.8 |
| Bumble bee | Mix | 35.7 | 7.5 | 23.6 | 53.9 |
| | Timothy | 5.6 | 2.4 | 2.4 | 13.1 |
| Honey bee | Mix | 77.4 | 12.0 | 57.1 | 104.9 |
| | Timothy | 12.3 | 3.9 | 6.6 | 23.0 |

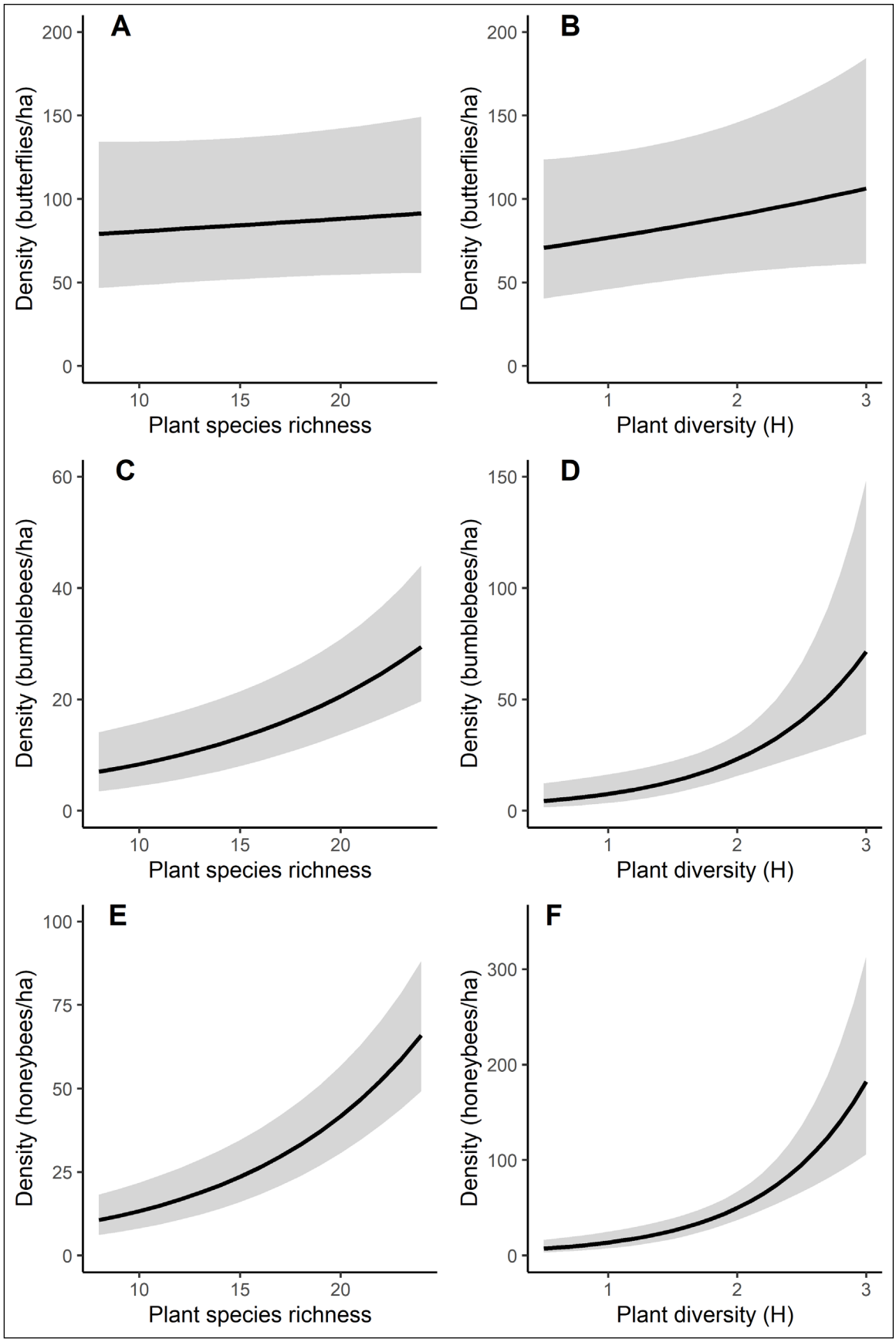


**FIGURE 2. Estimated density of pollinator groups when compared to plant species richness (A: butterflies [$p = 0.405$]; C: bumble bees [$p < 0.001$]; E: honey bees [$p < 0.001$]) and plant diversity (B: butterflies [$p = 0.158$]; D: bumble bees [$p = 0.001$]; F: honey bees [$p < 0.001$]) along transects in central Ohio, 2022. H = Shannon diversity index. Shown with standard errors (gray band).**

The density of both bumble bees and honey bees increased with increasing plant diversity. This pattern has been documented in similar field types in other studies: pollinators are more abundant in native grasslands with higher species richness than in monoculture grass fields comprised of species such as timothy and old-world bluestem (*Bothriochloa* spp.) (Potts et al. 2009; Roulston and Goodell 2011; Bhandari et al. 2018). Similarly, bee species richness in Germany was highest in semi-natural grassland areas (i.e., meadows, orchards, and fallows), with richness significantly declining in areas where natural grassland cover was less than 10% (Jauker et al. 2009). Finally, a study in New Zealand documented limited native bee movement from areas with native plants to surrounding agricultural landscapes (Schmidlin et al. 2021).

Butterfly density increased with plant species richness, albeit not significantly. Higher butterfly species richness and abundance in natural grasslands, as compared to heavily managed agricultural fields, has been documented in other studies (Habel et al. 2019).

The weak correlation between butterfly species richness and field type in the current study may be due to the high percentage of pest and generalist butterfly species documented in both field types. Cabbage whites were the most frequently encountered during field surveys. This species is considered a pest and thrives in areas with agricultural disturbance (Theunissen et al. 1985; Ryan et al. 2019; Abdel-Galil et al. 2021). Native butterflies that are generalists, like clouded sulphur, orange sulphur, and pearl crescent, were also among the most common butterflies in the current surveys (Swengel 1996; Cech and Tudor 2005; Grass et al. 2013). Because of generalist species' adaptability to disturbance, their relative densities were not significantly different between field types. Finally, it is possible that butterfly density was impacted by the presence of non-nectaring resources such as larval host plants, although no search for caterpillars was conducted to test this. Host plants for the 3 most commonly observed native butterflies were present in both fields: alfalfa and clover for clouded sulphur and orange sulphur, and asters for pearl crescent. The presence of these host plants in both the timothy and diverse field mixes may account for the similarity in densities between field types.

## Management Implications

Natural grassland areas that have a diverse selection of flowering plants support a greater abundance and diversity of pollinator species than monoculture grass fields. Not only does providing habitat for pollinators positively impact a group that has been experiencing significant declines due to past land management practices, but it also increases foraging opportunities for other wildlife that rely on pollinators as a food source. For instance, Lepidoptera caterpillars are an important component of the diet of Ring-necked Pheasants (*Phasianus colchicus*), Northern Bobwhite (*Colinus virginianus*), and other bird species dependent on grassland systems (Wiens and Rotenberry 1979; Hill 1985; Doxon and Carroll 2010). When planning future grassland restorations, managers may want to consider planting a diverse mix of native flowering plants to support species diversity. Some management actions may be used to increase establishment rates of planted seed mixes by controlling volunteer plant species. However, while not evaluated in this study, volunteer plants can add plant diversity and can be beneficial for a wide variety of pollinators (e.g., Turo et al. 2021).

## ACKNOWLEDGEMENTS

The authors wish to thank J. Barber, R. Carter, R. Cuellar, R. Dorn, and E. Vermillion for assistance with implementation and management of the treatments. Thanks to G. Stamper and A. Mancini for assistance with data collection. C. Grasser and M. Retterer provided valuable advice for developing the diverse seed mix. We thank 3 anonymous reviewers and the Editor for providing useful comments that greatly improved the manuscript. This project was funded by Ohio license and stamp buyers and a grant through the Federal Aid in Wildlife Restoration Act awarded to Ohio Department of Natural Resources, Division of Wildlife.

## LITERATURE CITED


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