PERFORMANCE OF *MONARDA* SPECIES AND CULTIVARS: AN ORNAMENTAL AND ECOLOGICAL STUDY IN GEORGIA, USA

by

RACHEL SCOTT SMITH

(Under the Direction of James Affolter)

ABSTRACT

We evaluated several horticultural cultivars and species of *Monarda*, a plant genus native to the southeastern United States, to assess landscape performance and ecological value to insect wildlife in Georgia Piedmont and montane habitats. We established two experimental sites, at the State Botanical Garden of Georgia in Athens, and the Georgia Mountain Education and Research Center in Blairsville. Our study included ten taxa of *Monarda*, representing five cultivars and four valid species. We saw significant differences in phenology, powdery mildew tolerance, flower morphology, nectar production, and insect communities at each site and year with *Monarda* taxa as the main effect. Differences in flower morphology and nectar production had no detectable impact on pollinators, beneficial insects, or plant pests. Our results demonstrate that floral resources of select Monarda taxa do support local wildlife, including a diversity of insect taxa. We observed variations in horticultural characteristics and performance that highlight the remarkable value of this genus in ornamental landscapes in Georgia.

INDEX WORDS: Beebalm, *Monarda*, Ornamental Trial, Nectar, Pollinators, Beneficial Insects, Plant Pests

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DEDICATION

This is for Mom, Tyrus, Thom, Leeza, and me.

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CHAPTER 1

INTRODUCTION TO THE STUDY

Weakley (2022) describes *Monarda* as a genus of 12 to 20 species of North American herbs, many cultivated in selected forms. Several species are native to Georgia and many cultivars are available commercially. Unlike some cultivars of native species that reduce the quality and accessibility of floral rewards (e.g., cultivars with doubled petal number) (Erickson et al., 2022), the majority of *Monarda* cultivars are simple hybrids or color selections bred for disease resistance or growth habits. The flowers remain relatively unobstructed in terms of pollinator access. In assessing the ecological value of cultivars, the effect of simple variations in floral phenotype on floral visitors has been an understudied area. It is important to document floral visitors on cultivars of *Monarda* because *Monarda* species are often used in seed mixes to provide summer forage to wildlife (Rubio et al. 2022; Wolf et al. 2022; Quinlan et al. 2021; Otto et al. 2017; Gray et al. 2007).

Many public gardens have reported their trials of *Monarda* taxa (Coombs, 2016; Hawke, 1998), but no trials have been conducted for the southeastern United States. Past trials have reported anecdotal observations of pollinator popularity among taxa but lack rigorous statistical evaluation of floral visitor abundance and diversity. The focus of most trials has been the level of powdery mildew resistance cultivars exhibit. The Southeast provides a favorable climate for the proliferation of powdery mildew in late summer. We conducted trials in the Southeast to make suitable recommendations to local growers for powdery mildew. *Monarda* is a good choice of study because it is native to our region, attracts a variety of pollinators (Cruden, 1984; Whitten, 1981), and has the potential to play an expanded role in the commercial trade due to its ornamental appeal.

Field trials of horticultural crops benefit growers by measuring regional variation, performance, and marketability (Arnold et al., 2001). Data collection on growth and development (such as height and width, flower phenology, and disease tolerance) are used to evaluate performance in an environment similar to where the taxon will be cultivated (Acquaah, 2012). The inclusion of ecological parameters in standard field trials can provide information to local industry partners on the abundance and diversity of arthropods a plant taxon may support (Braman and Quick, 2018). Information on variation in flower phenology and nectar characteristics may correlate to arthropod abundance and diversity differences. The empirical data yielded assesses the resource value of ornamental plants for insect communities (Kalaman et al., 2022b).

Diversity in native plant species has been shown to support diversity in native insects (Tallamy, 2007). Urban designs with mixed native and exotic species have the potential to provide floral resources for an extended period, compared to natives or exotics alone (Salisbury et al., 2015). Still exotic plants cannot support specialist species or lepidopterans that have coevolved with native plants by way of pollination and digestive enzymes (Tallamy, 2007).

The definition of a “native” plant varies depending on the objective of the grower, researcher, or gardener. For the purpose of this study, we define a native plant as a species with historic distributions in Georgia as shown by maps in the *Flora of the Southern and Mid-Atlantic States* (Weakley, 2022). This definition aligns with the broad criteria set by the Mimsie Lanier Center for Native Plant Studies (MLCNPS) at the State Botanical Garden of Georgia (SBG). The mission of MLCNPS is to source and grow Georgia native plants for habitat restoration, recovery of endangered species, and introduction to the Green Industry. Stricter interpretations of “native plants” that address watersheds, physiographic provenance, or soil profile are warranted for restoration and species recovery and are a valuable consideration in human landscapes and natural areas.

The availability of native plants in the commercial industry depends on a grower’s ability to propagate and produce a product efficiently and profitably (Wilde et al., 2015). Cultivars offer a means to this end by providing uniform growth in production, while patents on cultivars allow growers to sell for higher dollar value at market. Yet, the ability of cultivars to serve the same ecological function as more genetically diverse wild species may vary on a case-by-case basis (Poythress and Affolter, 2018).

The rate of insect species decline is predicted to cause dramatic loss of biodiversity within a few decades, especially in Lepidoptera, Hymenoptera, and Coleoptera taxa, if the rate continues its current trend (Decourtye et al., 2019). Invertebrates are indicators of ecosystem health due to their role in providing ecosystem services (directly and indirectly) and their sensitivity to climate change. Invertebrates support ecosystem function and stability by influencing water quality, disease transmission, pest prevalence, and pollination services (Prather et al., 2013). Yet relatively few published studies examining ecosystem services acknowledge the role of invertebrates (Prather et al., 2013). For example, pollinator decline over the past 120 years documented by Burkle et al. (2013) concluded both feral and managed pollinator populations are integral for managing crop pollination, and wild pollinators improve pollination efficiency in crop systems by twice that of honeybees alone (Burkle et al., 2013).

Traditional plant breeding and field trials can be enhanced by including parameters that reflect cultivar resource value to the ecosystem (Braman and Quick, 2018). As we meet consumer demand for the attractive ornamental plant, we must also analyze the functional value plants can provide to flower-visiting insects (Kalaman et al., 2022b). Traits commonly selected in cultivar development may exclude certain pollinator species but may also encourage interaction with generalist taxa and support pollinator diversity in human landscapes (Erickson et al., 2022). So it is important to study the effect of trait selection in breeding programs on the insect community and pollinator preference (Kalaman et al., 2022a).

Interdisciplinary research is vital to filling knowledge gaps on how invertebrates provide ecosystem services. As natural resources decline due to urbanization and habitat fragmentation, it is important to continue to provide native plant resources to coevolved arthropod partners in high-input landscapes and urban gardens. We selected ten *Monarda* taxa to evaluate performance in the Georgia landscape, document differences in phenology among species and cultivars, and measure the abundance of different insect functional groups. By integrating metrics on pollinator attractiveness in our cultivar assessment of *Monarda* in Georgia, we can inform Georgia growers and gardeners of the quality of commercially available *Monarda* taxa as a foraging resource, and address landscape form and function within the genus.

This study encompasses three following chapters and a conclusion (six chapters including this introduction). Chapter 2 is a horticultural evaluation of select *Monarda* taxa designed to inform the Green Industry on landscape performance and disease tolerance. Chapter 3 delves into empirical differences in floral morphology and nectar production among *Monarda* taxa to assess their correlation to insect abundance. Chapter 4 provides abundance and heat charts of insect groups found among the *Monarda* taxa for each site and year. The conclusion offers a few questions I’m left with at the end.

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CHAPTER 2

HORTICULTURAL EVALUATION OF SELECT *MONARDA* TAXA

Monarda, colloquially called beebalm, is known for its showy floral display suited to managed borders, roadsides and right of ways, and is naturally found in woodlands, meadows, and floodplains (Weakley, 2022). It has been the subject of extensive trials at the Chicago Botanic Garden and Mt. Cuba Center. The genus has many cultivars established in the trade and several species native to Georgia (Weakley, 2022; Coombs, 2016; Hawke, 1998). The flowers, seeds, and shoots of this North American perennial provide forage and habitat for many invertebrate and vertebrate species of wildlife, including butterflies, bees, wasps, and birds (Prather, 2002). The high concentration of thymol in the leaves of *Monarda* spp. has led to its human use for food and as a flavoring agent in the food industry (Paola et al. 2017). The genus has also been long used in traditional American medicine to treat digestive disorders, parasitic worms, cough, and stings. More recently it has been extensively studied for its antimicrobial properties (Paola et al. 2017; Zhilyakova et al. 2009; Savickiene et al. 2002; Chevallier and Nanba, 2000).

In the global horticulture trade, the best-known species include *M. didyma* (sweet bergamot), *M. fistulosa* (wild bergamot), *M. punctata* (dotted monarda), and *M. citriodora* (lemon bergamot). These taxa and *M. bradburiana* and *M.* x *hybrida hort.* (hybrids of *M. didyma* and *M. fistulosa*) have been extensively studied for their essential oil composition and ethnobotanical uses (Dudchenko et al. 2020; Mattarelli et al. 2017; Tabanca et al. 2013; Collicutt and Davidson, 1999). We chose to include *M. bradburiana* in our trial and not *M. citrodora* due to the USDA zones of the sites selected for study, species distribution maps, and the potential for *M. bradburiana* to show significant tolerance to powdery mildew (Weakley, 2022).

The popularity of *Monarda* as a medicinal plant and as a nectar source for wildlife makes the perennial a great candidate for landscape use and garden interest. *Monarda* taxa are often used in seed mixes to provide summer forage to wildlife (Rubio et al. 2022; Wolf et al. 2022; Quinlan et al. 2021; Otto et al. 2017; Gray et al. 2007). Robust evaluations from the Chicago Botanic Garden and Mt. Cuba Center on species and cultivars of native plants in the Midwest and Northeast provide growers and gardeners with regionally specific information on morphometrics, phenology, and disease tolerance (Coombs, 2016; Hawke, 1998). The Mt. Cuba trials further identify wildlife observed on *Monarda* flowers within the trial garden (Coombs, 2016). Systematic data on horticultural performance of *Monarda* in southeastern locales is lacking. The climate in this region is typified by longer growing seasons and milder winters. Additionally, plants grown in the Southeast are subjected to different and often significant disease pressures.

The diversity of floral and inflorescence morphologies and pollination systems within the genus make it an excellent candidate for studying plant/pollinator interactions among wild and cultivated forms (Prather, 2002). Of the ten taxa included in our study, eight were distinct in the coloration of floral parts. For example, within the species *M. punctata*, the GA and NJ provenances varied in bract color; *M. punctata* GA had pink bracts and the latter had white (Table 2.1). The role of hybridization in the evolution of *Monarda* (Prather, 2002) and the availability of cultivars in the trade make the genus an appropriate candidate to study the relationship between floral traits and wildlife. Along with assessing establishment and resiliency in the landscape, it is also important to provide empirical evidence on wildlife value. For this chapter, we focus primarily on the ornamental value of the landscape. We will address the effect of floral differences on wildlife abundance in chapters three and four.

Monarda spp. are susceptible to a variety of pathogens including powdery mildew (*Podosphaera pannosa* [syn. *Sphaerotheca pannosa* Wallr. Ex. Fr.], *Golovinomyces biocellatus* and *G. monardae*, and *Erysiphe cichoracearum*), aster yellows phytoplasma, stem rot (*Sclerotium rolfsii*), downy mildew (*Peronospora monardae*), and rust (Xu et al. 2022; Salgado-Salazar et al. 2020; Han et al. 2011; Davidson, 2002; Collicutt and Davidson, 1999; Perry, 1998; Hwang et al. 1997; Holcomb 1994;). All these pathologies were observed throughout our study. Still, our reported results focus on powdery mildew since the genus is highly susceptible and the disease is a significant problem for perennial growers (Perry, 1998).

Powdery mildew is the common name for many obligate, polycyclic fungi in the order Erysiphales. The fungi cover plant surfaces in epiphytic, sometime endophytic, white growth, especially in conditions with high humidity and temperature fluctuations (Heffer et al. 2006; Perry, 1998). The susceptibility of *Monarda* to powdery mildew has made tolerance to the disease an objective of many breeding and trial programs within the genus (Coombs, 2016; Hawke, 1998; Perry, 1998).

We evaluated select *Monarda* at two sites in the Georgia mountains and piedmont regions to assess horticultural performance in the landscape, flower phenology, and powdery mildew tolerance of ten *Monarda* taxa popular in the trade. We hypothesized that there would be differences in vegetative characteristics, reproductive behavior, and disease tolerance among the taxa in our trial.

MATERIALS AND METHODS

Propagation and plant material. Five cultivars, the two parent species, and two distinct species without known cultivars were chosen to demonstrate the diversity of habit, color, disease tolerance, and wildlife hospitality of *Monarda* available in the trade (Table 2.1 and Fig. 2.1). Plants were received as plugs from New Moon Nursery (Woodstown, NJ) and North Creek Nursery (Landenberg, PA) in 2019, then grown into 0.95 L (quart-sized) containers in a climate-controlled greenhouse at 21-24°C with twenty percent shade and natural photoperiod at the University of Georgia UGArden in Athens, GA. The growing media was a mix of peat, perlite, and composted pine bark amended with 12.30 kg.m-3 N-P-K fertilizer (Plant-tone Organic 5-3-3, 0.4% ammoniacal nitrogen, 1.6% other water-soluble nitrogen, 3.0% water insoluble nitrogen, 3.0% P_2O_5, and 3.0% K_2O; Epsoma, Millville, NJ). Plants were fertilized at 100 ppm N (Jack's Acid 20-20-20 General Purpose, 3.83% ammoniacal nitrogen, 6.07% nitrate nitrogen, 10.10% urea nitrogen, 20% P_2O_5, and 20% K_2O; J.R. Peters, Inc. Allentown, PA) liquid feed once per month until transplanting into the field. Containerized plants in the greenhouse were hand watered as needed over the summer of 2019.

Table 2.1 *Monarda* species and cultivars trialed in Blairsville and Athens, Georgia

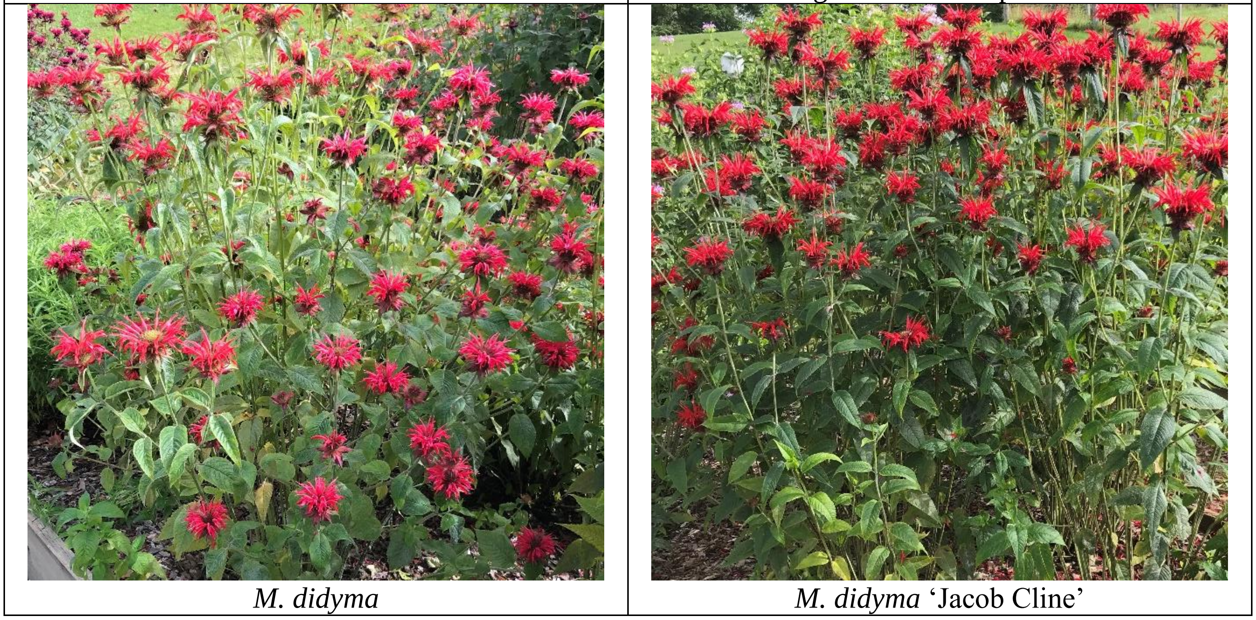
Taxa	Type	Parentage	Distribution[w]	
M. bradburiana[x]	Species	---	IN west to e. KS, south through KY, TN, and MO to AL, AR, and OK.	
M. Sugar Buzz ® Grape Gumball Bee Balm[⸸]	Cultivar	*M. didyma*	---	
M. didyma[x]	Species	---	ME west to MI, south to PA and OH, and in the Appalachians south to sw. NC, se. TN, and ne. GA (part of the northern range is likely only by introduction).	
M. didyma 'Jacob Cline'[*]	Cultivar	*M. didyma*	---	
M. x 'Judith's Fancy Fuchsia'[x]	Cultivar	*M. didyma*	---	
M. 'Raspberry Wine'[xy]	Cultivar	*M. didyma*	---	
M. fistulosa[x]	Species	---	**Var. *fistulosa*** CT south to sw. NC, nearly or entirely limited to the Appalachians. **Var. *mollis*** ME west to MN, south to GA, AL, and se. TX.	
M. fistulosa 'Claire Grace'[y]	Cultivar	*M. fistulosa*	---	
M. punctata GA[z]	Species	---	NJ to s. FL, west to TX, mainly on the Coastal Plain, but extending inland.	
M. punctata NJ[x]	Species	---	NJ to s. FL, west to TX, mainly on the Coastal Plain, but extending inland.	

[w] Distributions from Flora of the Southeastern United States (Weakley 2020).
Plant material sourced from New Moon Nursery[x], North Creek Nursery[y], Mimsie Lanier Center for Native Plant Studies[z]

Figure 2.1. Photo plates of *Monarda* taxa trialed in Blairsville and Athens, Georgia.

M. bradburiana

M. Sugar Buzz ® Grape Gumball



M. didyma

M. didyma ‘Jacob Cline’

 *M.* x ‘Judith’s Fancy Fuchsia’	 *M.* ‘Raspberry Wine’
 *M. fistulosa*	 *M. fistulosa* ‘Claire Grace’

M. punctata (GA)

M. punctata (NJ)

Site conditions. The first study was planted October 14, 2019, in raised beds at the University of Georgia Mountain Research and Education Center (GMREC) in Blairsville, GA (34.838800, -83.927941, USDA zone 6b) (Fig. 2.2). Plants were allowed to establish that fall and winter for data collection starting Spring 2020. This experiment ran from April to October in both 2020 and 2021. Raised beds were made up of mushroom compost, composted pine bark, and five centimeters of pine bark nuggets for mulch. Before amendments, soil tested very high in phosphorus and calcium, and high in potassium, magnesium, zinc, and manganese. The raised bed pH was 6.8. No limestone was added to the beds. An additional 0.45 kilograms of 15-9-12 (Osmocote Smart-Release Plant Food, 8.4% ammoniacal nitrogen, 6.6% nitrate nitrogen, 9% P_2O_5, 12% K_2O; The Scotts Company, Marysville, OH) was equally distributed among plants and top-dressed early spring each season.

The second study was conducted at the State Botanical Garden of Georgia's Mimsie Lanier Center for Native Plant Studies (MLCNPS) in Athens, GA (33.902371, -83.391072, USDA zone 7b) (Fig. 2.2). This garden was planted May 1, 2020 for plant establishment and data collection in Spring 2021. Data was collected from April to October in both 2021 and 2022. Beds comprised native soil (clay ultisol), gravel, and five centimeters of hardwood mulch. The area was previously a gravel nursery pad. The bed area was divided into two subplots for the soil tests. Before amendments, the north side of the bed tested medium in calcium, zinc, and manganese. Phosphorus, potassium, and magnesium tested low. The pH of the north side was 5.7. The south side of the bed tested very high in calcium and medium in phosphorus, potassium, magnesium, zinc, and manganese. The pH of the south side was 6.1. No lime was added to the plot. An additional 0.45 kilograms of 15-9-12 (Osmocote Smart-Release Plant Food, 8.4% ammoniacal nitrogen, 6.6% nitrate nitrogen, 9% P_2O_5, 12% K_2O; The Scotts Company, Marysville, OH) was equally distributed among plants and top-dressed early spring each season.

Figure 2.2. Study sites at the Georgia Mountain Research and Education Center in Blairsville, GA (A) and the State Botanical Garden of Georgia Mimsie Lanier Center for Native Plant Studies in Athens, GA (B).


A
B

Temperature and precipitation data were recorded by UGA weather stations (UGA Weather Network and SBG Weatherstem) at GMREC and MLCNPS. Data for each location is summarized per calendar year in Table 2.2.

Table 2.2 Weather data for GMREC and MLCNPS summarized per calendar year

Site	**Precipitation (cm)**	**Number of Rain Days**	**Avg. Max. Temperature (°C)**	**Avg. Min. Temperature (°C)**	**Avg. Temperature (°C)**
2020 GMREC Blairsville, Georgia[x]	196.5	177	21	9	15
2021 GMREC[x]	139.1	140	21	8	14
2021 MLCNPS Athens, Georgia[y]	120.7	151	23	12	17
2022 MLCNPS Athens, Georgia[z]	116.7	120	23	11	17

[x] Blairsville Station, Georgia Weather - Automated Environmental Monitoring Network Page

[y] State Botanical Garden of Georgia Station, State Botanical Garden of Georgia (weatherstem.com)

[z] Watkinsville Horticulture Farm Station, Georgia Weather - Automated Environmental Monitoring Network Page

Data Measurements.

Height and Width. The height and width (m) of plants were measured at peak flower. Shoot height was measured to the tallest node with foliage. Plant width was measured at the widest point of mature vegetation. Due to the symmetrical nature of the canopy, we deemed one width measurement was a sufficient estimation.

Flowers. Open inflorescences were counted during peak bloom at each study in 2021 and at the MLCNPS in 2022 (methods adapted from Ruane et al., 2014). Floral density was defined as the counted number of flowering stems with open inflorescences. Phenology (total length of bloom) for each site and year was calculated at the date of first flower opening and last flower senescing per treatment. Because peak bloom varied greatly between repetitions depending on plant health, we recorded this parameter when approximately 50 percent of set floral buds had opened or showed color. The end of peak was determined when roughly 50 percent of flowers had senesced.

Health. Health was evaluated as the percentage of plant leaf area infected with powdery mildew, a foliar disease known to be problematic for the genus (Davidson, 2007). Health was evaluated eight times during the April to October season in 2020, 2021, and 2022 for the respective sites. Percent of infected foliaged was assessed on a 1-5 point scale in 2020, 2021 and 2022, where 1 = no infected foliage, 2 = up to 25% infected foliage, 3 = 26-50% infected foliage, 4 = 51-75% infected foliage, and 5 = 76-100% infected (per methods in Long et al. 2010). The area under the disease progression curve (AUDPC) was calculated as the sum of trapezes (area) under the disease progression curve, which considered disease rating over time (Mendiburu, 2021). The score allows multiple observations of disease over a season to be compared among taxa using a single value.

Experimental design and data analyses. At both sites, plots were planted with *Monarda*'s ten taxa (treatments). Each plot had seven rows, and each row contained the ten treatments randomized in a unique order for a total of seventy plants per site. Plants were spaced on 1.5-

meter centers. Each site and year were analyzed independently. Taxon was considered the main effect and error consisted of each plant. Data were subjected to analysis of variance (ANOVA) followed by post hoc means separation by Tukey's Honestly Significant Difference test (HSD) using R core Team 2018 (R Core Team, 2018), with statistical significance determined at alpha equal or below 0.05. Model assumptions were checked visually with the residuals. Individual parameters, transformations, and models are addressed below.

Height and Width. Morphometric data (height and width) were subjected to analysis of variance (ANOVA) with *Monarda* taxa as the main effect and followed by post hoc mean separation by Tukey's Honestly Significant Difference test (HSD). Standard errors were calculated with **'plotrix'** (Lemon et al., 2021).

Flowers. Floral density, as count data, was subjected to a generalized linear model fitted to a negative binomial distribution with the following packages: **'stats', 'MASS', 'pscl', 'sandwich', 'lmtest', 'car',** and **'emmeans'** (Lenth et al., 2022; Jackman, 2020; Zeileis et al., 2020; Fox and Weisberg, 2019; R Core Team, 2018; Zeileis, 2004 and 2006; Venables and Ripley, 2002; Zeileis and Hothorn, 2002).

Health. AUDPC scores were calculated with **'agricolae'** (Mendiburu, 2021). Standard errors were calculated with **'plotrix'** (Lemon et. al. 2021).

Graphs and figures were generated using **'tidyverse'** and **'ggplot2'** (Wickham et al., 2019 and Wickham, 2016).

RESULTS

Height and width. Height and width significantly varied among *Monarda* taxa (Table 2.3) in both sites and both years. In the first season after establishment at Blairsville (2020) *M. bradburiana* and *M.* Sugar Buzz ® Grape Gumball were shorter than other taxa. This trend continued in 2021 in Blairsville and Athens, though some overlap occurred between *M. punctata* GA in Blairsville and *M. punctata* NJ in Athens. These four taxa tended to be shorter than other taxa, excluding some overlap between the *M. punctata* taxa and *M. fistulosa, M. didyma,* and *M. didyma* 'Jacob Cline' during the first year after establishment. *M.* x 'Judith's Fancy Fuchsia' and *M.* 'Raspberry Wine' ranked tallest among taxa in the first year after establishment in Blairsville. Otherwise, *M. fistulosa* was the tallest (Table 2.4).

Trends in width loosely paralleled trends in height. *M. bradburiana, M.* Sugar Buzz ® Grape Gumball, and *M. punctata* taxa had smaller spreads. The widest taxa were *M.* x 'Judith's Fancy Fuchsia', *M.* 'Raspberry Wine' and *M. fistulosa* (Table 2.4).

Table 2.3 Analysis of variance results for effect of 10 *Monarda* taxa on height and width during peak bloom in Blairsville 2020 and 2021 and Athens 2021 and 2022. Each site and year were subjected to independent analysis.

	Morphometric Parameters			
	Height		Width	
Source (df)	*F*	*Pr>F*	*F*	*Pr>F*
Taxa, Blairsville 2020 (9)	76.2	< 2e-16	48.6	< 2e-16
Taxa, Blairsville 2021 (9)	43.1	< 2e-16	12.5	7.3 e-11
Taxa, Athens 2021 (8)	33.9	< 2e-16	7.5	1.2 e-06
Taxa, Athens 2022 (9)	31.5	< 2e-16	6.8	3.19e-08

Table 2.4 Mean (+- SE) height (cm) and width (cm) of 10 *Monarda* taxa per year and site grown in Georgia. Measurements taken at peak bloom for 7 replicates per taxa at each site (70 plants per site). Means within a column followed by different letters are significantly different (P ≤ 0.05). Each site and year were subjected to independent analysis and comparisons are valid within columns.

	Blairsville				**Athens**			
Taxa	**2020**		**2021**		**2021**		**2022**	
	Height	**Width**	**Height**	**Width**	**Height**	**Width**	**Height**	**Width**
M. bradburiana	47.0 (1.5) a	46.9 (1.6) a	46.9 (3.3) ab	83.6 (9.4) abc	43.2 (2.5) a	95.1 (6.6) a	54.7 (7.0) ab	119.6 (13.3) abc
M. Sugar Buzz ® Grape Gumball	64.9 (3.6) a	54.0 (3.4) a	34.4 (2.3) a	65.3 (5.0) a	---	----	29.0 (8.3) a	63.6 (15.7) a
M. didyma	122.4 (4.9) cde	121.3 (5.2) bc	114.7 (10.4) cd	114.3 (10.4) bcd	101.2 (6.2) cd	109.5 (10.0) ab	77.5 (5.0) b	115.4 (9.4) ab
M. didyma ‘Jacob Cline’	105.1 (4.9) bc	143.7 (3.1) cd	123.6 (3.2) cd	168.6 (3.5) e	125.0 (7.6) def	123.9 (10.1) abc	124.9 (3.9) de	159.9 (7.3) c
M. x ‘Judith’s Fancy Fuchsia’	156.8 (4.5) g	140.7 (5.2) cd	124.6 (6.1) cd	144.1 (7.5) de	118.0 (3.7) def	144.3 (7.6) bc	108.6 (5.0) cd	159.5 (9.4) c
M. ‘Raspberry Wine’	143.7 (2.9) fg	154.6 (5.2) d	131.3 (3.3) cd	131.6 (4.3) de	127.6 (5.5) ef	163.5 (8.2) c	115.0 (5.0) cde	160.3 (9.4) c

Table 2.4 continued. Mean (+- SE) height (cm) and width (cm) of 10 *Monarda* taxa per year and site grown in Georgia. Measurements taken at peak bloom for 7 replicates per taxa at each site (70 plants per site). Means within a column followed by different letters are significantly different ($P \leq 0.05$). Each site and year were subjected to independent analysis and comparisons are valid within columns.

	Blairsville				**Athens**			
Taxa	**2020**		**2021**		**2021**		**2022**	
	Height	**Width**	**Height**	**Width**	**Height**	**Width**	**Height**	**Width**
M. fistulosa	133.1 (5.2) def	153.8 (5.2) d	153.8 (5.0) d	129.4 (8.1) de	140.4 (3.2) f	145.4 (8.0) bc	134.9 (4.5) e	148.6 (8.5) bc
M. fistulosa 'Claire Grace'	139.6 (4.7) efg	141.5 (2.9) cd	104.4 (6.8) c	118.1 (11.8) cd	113.4 (6.3) de	116.0 (8.6) ab	129.1 (3.9) e	140.7 (7.31) bc
M. punctata GA	113.6 (4.7) cd	111.0 (6.5) b	61.9 (5.4) ab	104.4 (8.0) abcd	75.6 (4.3) bc	109.0 (9.3) ab	96.8 (3.4) c	151.3 (6.4) bc
M. punctata NJ	88.4 (3.0) b	142.7 (12.3) cd	64.4 (8.7) b	75.1 (16.1) ab	60.8 (8.9) ab	96.4 (9.0) a	103.5 (3.5) c	166.7 (6.6) c

Floral density. In Blairsville, *M. punctata* GA had the fewest flowering stems and *M. fistulosa* had the most. Other taxa fell in between, with all but *M.* Sugar Buzz ® Grape Gumball setting more than 100 flowering stems on average (Table 2.6). On average in Athens, *M. bradburiana* set the least number of flowering stems and *M. fistulosa* 'Claire Grace' set the most. *M. didyma* taxa, *M. bradburiana*, and *M.* x 'Judith's Fancy Fuchsia' had under 100 flowering stems during peak bloom (Table 2.5).

Table 2.5 Mean floral density (±SE) for each site in 2021. Floral density was defined as the number of flowering stems during peak bloom (70 plants per site). Means within a column followed by different letters are significantly different (P ≤ 0.05). Each site and year were subjected to independent analysis and comparisons are valid within columns.

Taxa	**Blairsville**	**Athens**	
	2021	**2021**	**2022**
M. bradburiana	107 (24.5) abc	28 (5.0) a	46 (0.3) ab
M. Sugar Buzz ® Grape Gumball	89 (23.5) ab	---	14 (0.3) a
M. didyma	139 (23.3) abc	36 (8.5) ab	40 (0.2) ab
M. didyma 'Jacob Cline'	165 (12.7) abc	63 (7.4) abc	68 (0.1) b
M. x 'Judith's Fancy Fuchsia'	195 (21.2) bc	81 (17.4) abcd	139 (0.2) ab
M. 'Raspberry Wine'	160 (15.8) abc	122 (13.9) abcd	140 (0.2) c
M. fistulosa	210 (37.0) c	165 (34.7) cd	325 (0.2) d
M. fistulosa 'Claire Grace'	154 (19.2) abc	174 (23.9) d	306 (0.1) d
M. punctata GA	71 (12.6) a	168 (31.9) cd	127 (0.1) c
M. punctata NJ	119 (39.3) abc	139 (38.4) bcd	139 (0.1) c

Phenology. In Blairsville 2020, observations of start of bloom were not carried out for *M. didyma*, *M.* 'Raspberry Wine', *M.* Sugar Buzz ® Grape Gumball, nor *M. fistulosa* taxa due to the COVID-19 lock down in June. Regardless of site or year, *M. bradburiana* is the first *Monarda* taxon to bloom, spanning the months of late April and May – ending in June. *M. punctata* taxa bloom from late June, July, or August and end in September to October, depending on the plant and the USDA zone. All other taxa bloom throughout the summer, starting around June and ending between July and October. We observed *M. didyma* and *M. didyma* 'Jacob Cline' senesced in July and rebloomed in September. Peak bloom lasted between 7 and 21 days for most taxa. Notably, *M.* Sugar Buzz ® Grape Gumball did not peak in Athens 2021 (Figs. 2.3 and 2.4). Lack of establishment resulted in no more than ten flowers per repetition, and we did not consider this a "peak bloom".

Figure 2.3 *Monarda* phenology in Blairsville 2020 and 2021. First and last date of bloom (black bar) and estimated peak bloom period (grey bar) for each *Monarda* taxa (BRAD = *M. bradburiana*, JUDFF = *M. x* ‘Judith’s Fancy Fuchsia’, DIDY = *M. didyma*, DIDYJC = *M. didyma* ‘Jacob Cline’, RASW = *M.* ‘Raspberry Wine’, SBGUM = *M.* Sugar Buzz® ‘Grape Gumball’, FIST = *M. fistulosa*, FISCG = *M. fistulosa* ‘Claire Grace’, PUNNJ = *M. punctata* (unknown provenance sourced from New Moon Nursery), and PUNGA = *M. punctata* (Georgia seed sourced from MLCNPS).

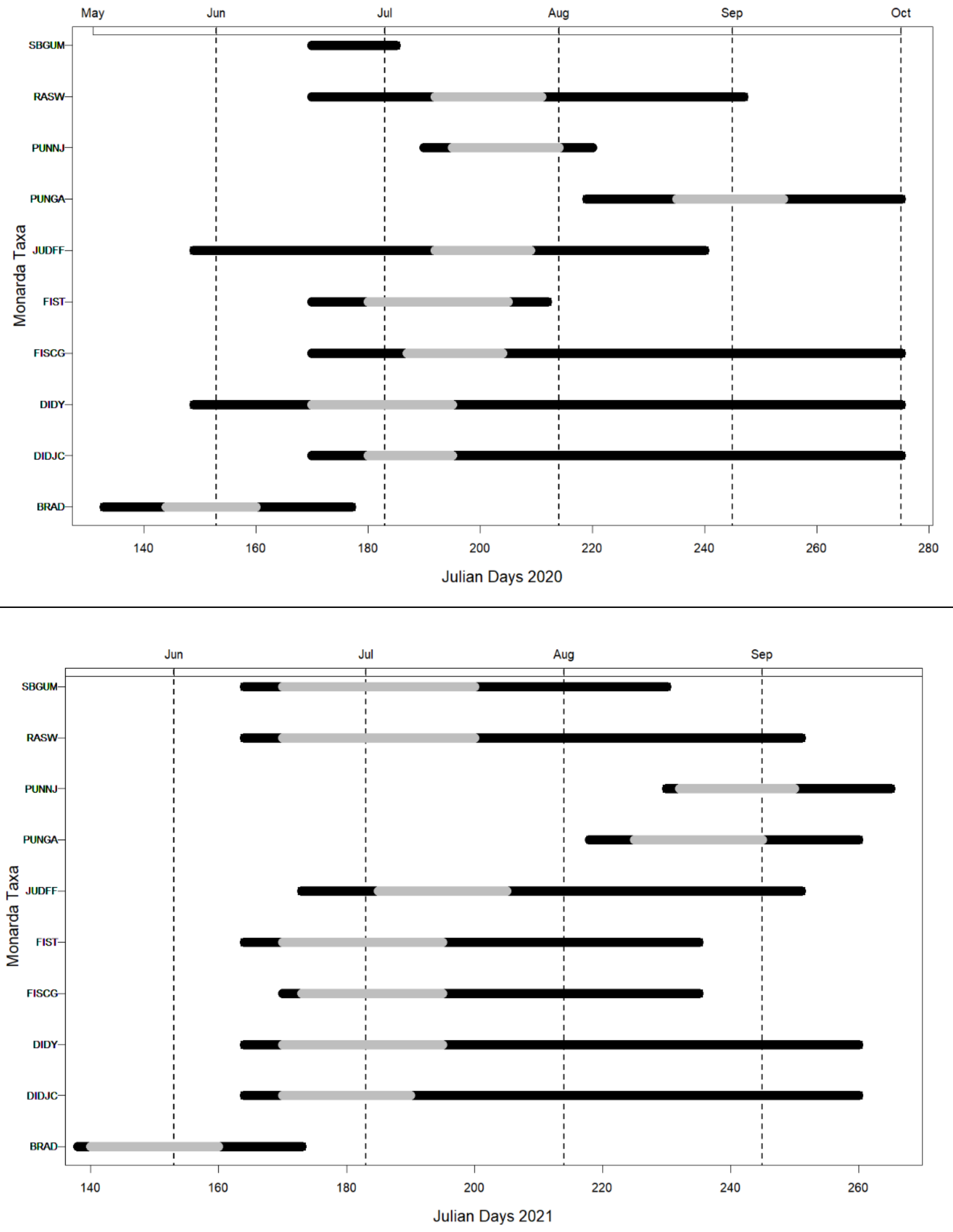
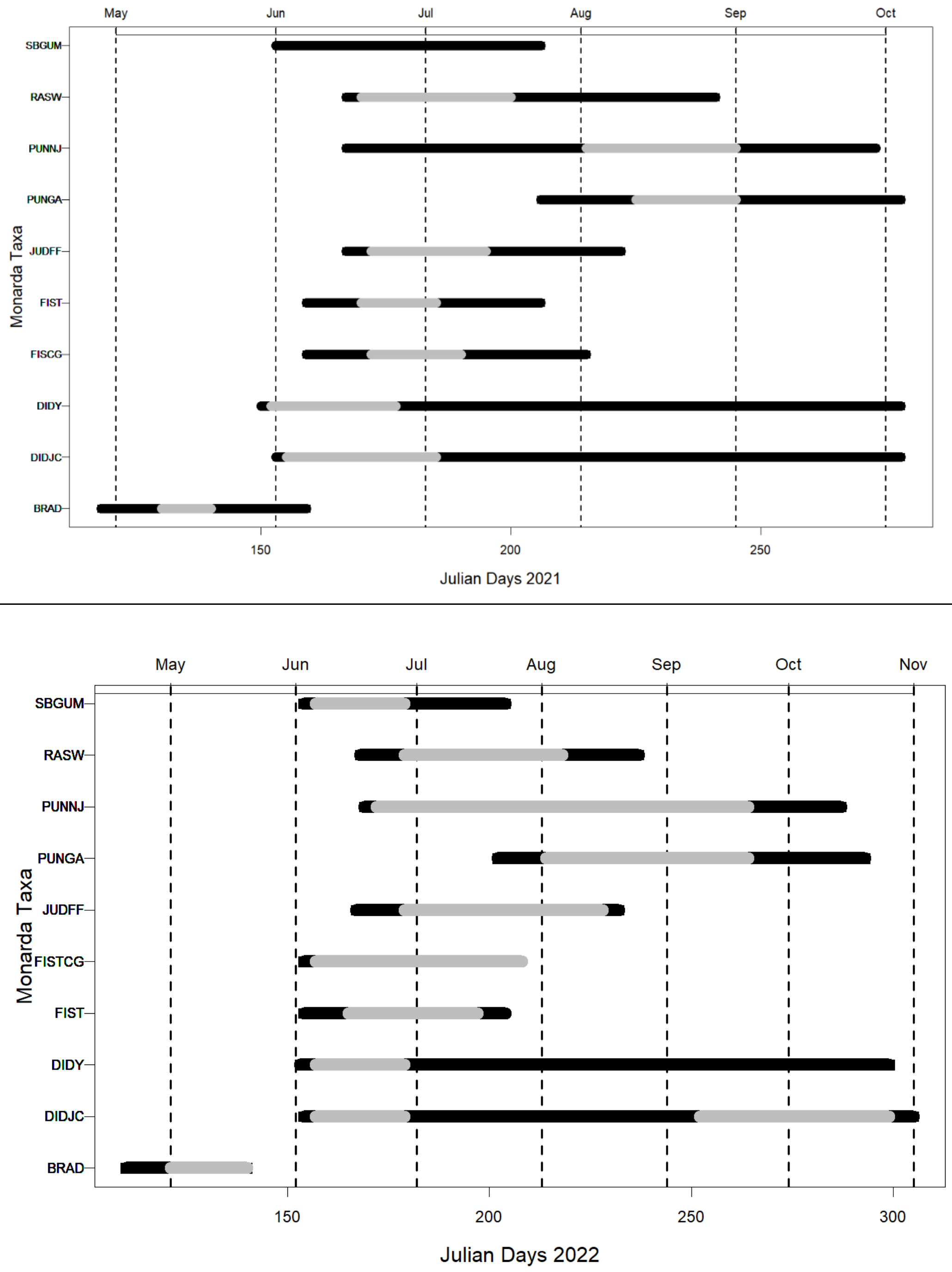


Figure 2.4. *Monarda* phenology in Athens 2021 and 2022. First and last date of bloom (black bar) and estimated peak bloom period (grey bar) for each *Monarda* taxa (BRAD = *M. bradburiana*, JUDFF = *M. x* ‘Judith’s Fancy Fuchsia’, DIDY = *M. didyma*, DIDYJC = *M. didyma* ‘Jacob Cline’, RASW = *M.* ‘Raspberry Wine’, SBGUM = *M.* Sugar Buzz® ‘Grape Gumball’, FIST = *M. fistulosa*, FISCG = *M. fistulosa* ‘Claire Grace’, PUNNJ = *M. punctata* (unknown provenance sourced from New Moon Nursery), and PUNGA = *M. punctata* (Georgia seed sourced from MLCNPS).



Health. AUDPC was significantly different between *Monarda* taxa (Blairsville 2020, $p < 2e-16$; 2021, $p = 2.15e-05$; Athens 2021, $p = 2.12e-12$; 2022, $p = 0.000647$). (Figs 2.5 and 2.6) show the progression of powdery mildew on each taxon throughout the growing season. Differences in disease tolerance among taxa were more pronounced in the first year of data collection than in the second. While all taxa showed some level of infection, *M. bradburiana* was the least impacted in each site and year. *M. didyma* and *M. fistulosa* had high scores (exhibited more symptoms) in each site and year. Cultivars showed some tolerance relative to parent species (Table 2.6). *M. punctata* taxa were excluded from disease analysis due to their short life cycle but did show signs of infection in the second year. *M.* Sugar Buzz® 'Grape Gumball' and *M. didyma* were excluded from AUDPC scoring because at least three repetitions of each died over the 2021-2022 winter.

Figure 2.5. Powdery mildew progression among *Monarda* taxa in Blairsville 2020 and 2021. Points plotted as percent infected foliage evaluated on a 1-5 point scale where 1 = no infected foliage, 2 = up to 25% infected foliage, 3 = 26-50% infected foliage, 4 = 51-75% infected foliage, and 5 = 76-100% infected, per technique in Long et. al. (2010). The line of best fit for each taxon is represented by colors, coded in legend, where BRAD = *M. bradburiana*, JUDFF = *M.* x 'Judith's Fancy Fuchsia', DIDY = M. didyma, DIDYJC = *M. didyma* 'Jacob Cline', RASW = *M.* 'Raspberry Wine', SBGUM = *M.* Sugar Buzz® 'Grape Gumball', FIST = *M. fistulosa*, FISCG = *M. fistulosa* 'Claire Grace', PUNNJ = *M. punctata* (unknown provenance sourced from New Moon Nursery), and PUNGA = *M. punctata* (Georgia seed sourced from MLCNPS). The shaded region around line shows the 95% percent confidence interval.

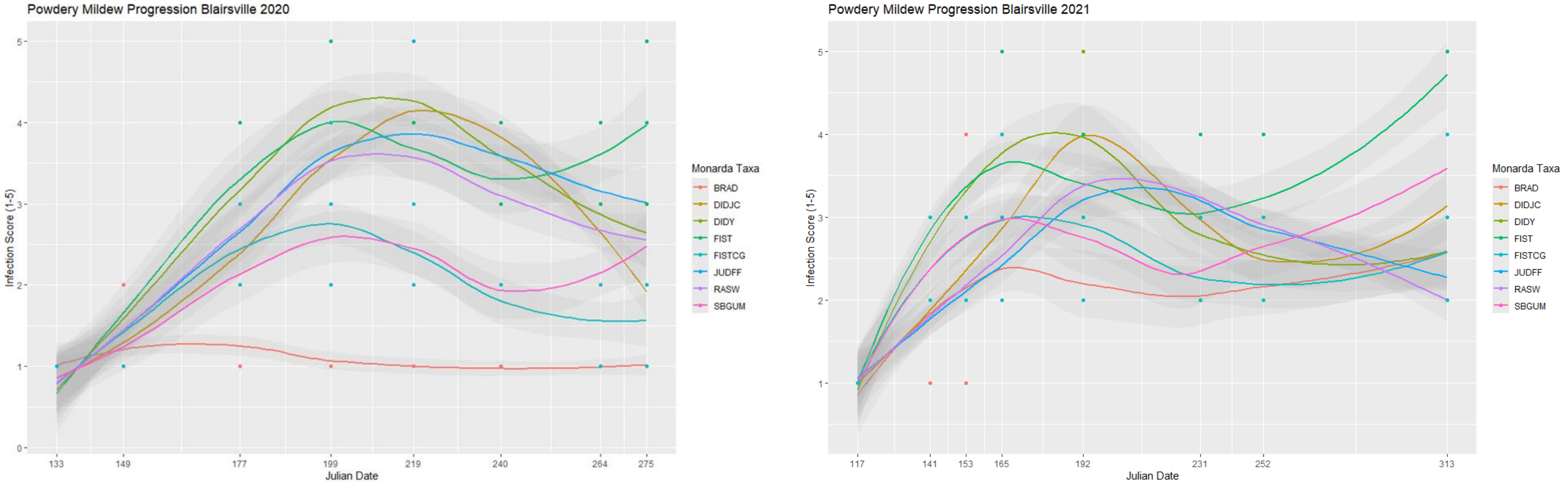


Figure 2.6. Powdery mildew progression among *Monarda* taxa in Athens 2021 and 2022. Points plotted as percent infected foliage evaluated on a 1-5 point scale where 1 = no infected foliage, 2 = up to 25% infected foliage, 3 = 26-50% infected foliage, 4 = 51-75% infected foliage, and 5 = 76-100% infected, per technique in Long et. al. (2010). The line of best fit for each taxon is represented by colors, coded in legend, where BRAD = *M. bradburiana*, JUDFF = *M.* x 'Judith's Fancy Fuchsia', DIDY = M. didyma, DIDYJC = *M. didyma* 'Jacob Cline', RASW = *M.* 'Raspberry Wine', SBGUM = *M.* Sugar Buzz® 'Grape Gumball', FIST = *M. fistulosa*, FISCG = *M. fistulosa* 'Claire Grace', PUNNJ = *M. punctata* (unknown provenance sourced from New Moon Nursery), and PUNGA = *M. punctata* (Georgia seed sourced from MLCNPS). The shaded region around line shows the 95% percent confidence interval.

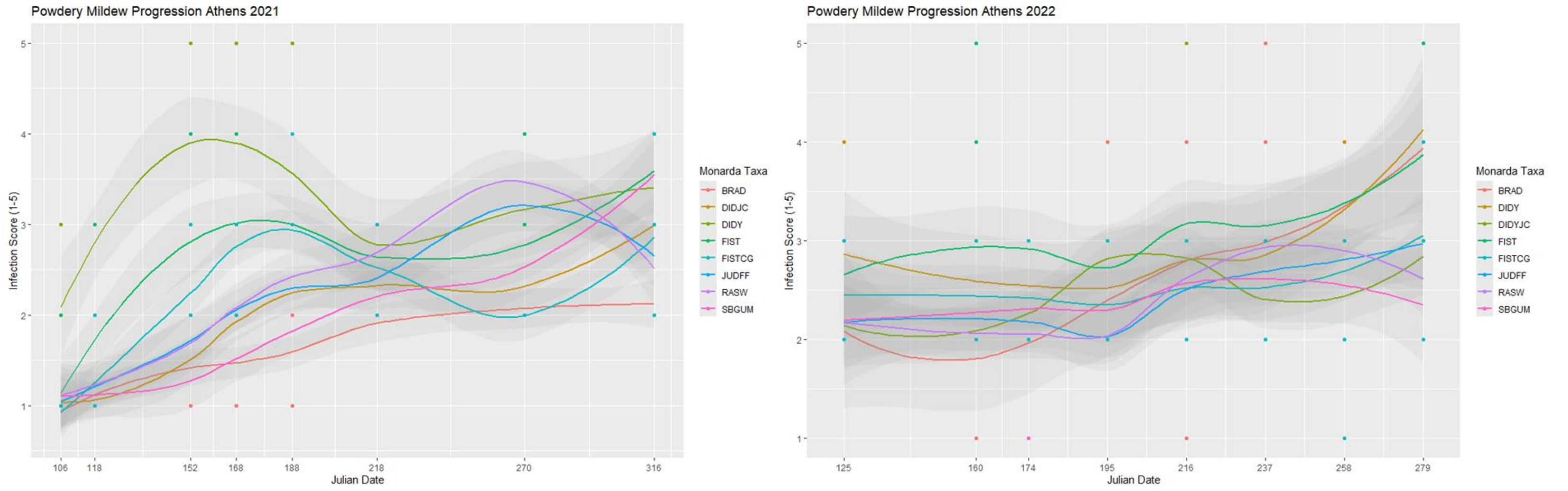


Table 2.6. Calculated area under the disease progression curve (AUDPC) averages and standard errors for powdery mildew[z]. AUDPC was calculated as the sum of trapezes (area) under the disease progression curve, which considered disease rating over time (Mendiburu, 2021). Each site and year were subjected to independent analysis; statistical comparisons are valid within columns.

	Blairsville		Athens	
	2020	2021	2021	2022
M. bradburiana	157 (8.0) a	410 (14.6) a	363 (9.5) a	390 (20.2) a
M. Sugar Buzz ® 'Grape Gumball'	263 (13.6) b	528 (18.2) bc	431 (14.8) ab	---
M. didyma	408 (19.0) d	568 (17.7) cd	725 (46.5) d	---
M. didyma 'Jacob Cline'	386 (4.2) cd	542 (9.5) bc	439 (9.8) ab	377 (17.4) a
M. x 'Judith's Fancy Fuchsia'	392 (12.1) cd	501 (20.4) bc	496 (14.7) bc	372 (13.6) a
M. 'Raspberry Wine'	338 (5.8) c	508 (13.1) bc	532 (20.3) bc	374 (9.6) a
M. fistulosa	402 (18.5) d	652 (25.1) d	574 (37.9) c	509 (18.5) b
M. fistulosa 'Claire Grace'	271 (6.0) b	461 (29.0) ab	473 (10.4) bc	388 (18.7) a

[z] Means of eight observation dates for each site and season.

DISCUSSION

Based on our two-site, two-year study, we have sufficient data to support the hypothesis that morphology and phenology vary among *Monarda* taxa. We provide detailed data on plant heights and widths, floral density, flowering phenology, and powdery mildew tolerance for *Monarda* in Georgia's piedmont and montane region.

Height and width. Our results show two distinct groups concerning height. Height at flowering ranged from just under half a meter to just over a meter and half depending on site and taxon (Table 2.4). The shorter group included *M. bradburiana*, *M.* Sugar Buzz ® Grape Gumball, and the *M. punctata* taxa. *M. fistulosa* 'Claire Grace' was shown to be more compact than the straight species, except in Blairsville 2020. The range of heights within *Monarda* provides a basis for selecting plants for different landscape uses. *M. bradburiana* and *M.* Sugar Buzz ® Grape Gumball are well suited for the front border, while *M. punctata* is more appropriately placed in the front or middle of a bed. The remaining taxa are tall enough to be visible from the back in a border planting or the center in an island planting.

Plant width at flowering was also distinct among taxa. Our estimates can be used to determine the amount of space taxa may require in a planting which is important in deciding number of plants and inputs (Table 2.4). Shorter taxa tended to spread less. We observed a more compact habit in *M. didyma* cultivars than the species. The *M. fistulosa* cultivar 'Claire Grace' was also bred to be more compact. *M.* Sugar Buzz ® Grape Gumball, which was bred as a dwarf cultivar of *M. didyma,* along with *M. bradburiana* could be spaced on half meter centers due to their shorter stature and tendency to mound. *M. punctata* taxa can be spaced on one-meter centers. All other taxa will spread well over a meter and should be on meter and a half spacing. Spread of *Monarda* throughout the garden is best managed by removing rhizomes from the center of the matt in the spring and summer to increase air flow through the stand (Thompson, 2007).

M. punctata spreads via stolons, unlike the other taxa that have rhizomes. Growth of this species during the second season was less robust than the first, yet *M. punctata* will readily reseed itself each fall. We observed *M. punctata* is short-lived, as an individual plant did not last more than two seasons. Yet, it tends to produce viable seeds which can spread throughout the garden or a naturalized right of way. This behavior is typical of short-lived perennials, and it differs from the other taxa we evaluated.

Flowers. Floral density differed among taxa, with less pronounced differences observed in Blairsville than in Athens (Table 2.5). Flowering periods varied between site and season (Figs. 2.3 and 2.4). When the number of flowers and flowering period are both considered it becomes difficult to determine which taxa have the most ‘flower power’. Rather it depends on the gardener’s needs and the context of the planting site. Each taxon provided different textures and colors that attract a multitude of wildlife to the garden, which will be discussed at greater length in Chapter 4.

Regarding flower power, *M. fistulosa* stands out in Blairsville, while *M. fistulosa* and *M. punctata* taxa stand out in Athens. *M didyma* taxa tended to set fewer flowering stems, but each inflorescence is quite large (Table 2.5). *M.* x ‘Judith’s Fancy Fuchsia’ and *M.* ‘Raspberry Wine’ provided an even split, each with relatively high flower set and long flowering period.

Phenology. Flowering phenology was not analyzed statistically but our observations estimated flowering period, which is important for producers, consumers, and wildlife. In 2021 we noted the Athens growing season was longer than the Blairsville season. Flowering generally started later and ended earlier in Blairsville (Figs. 2.3 and 2.4). There were several notable groupings, with *M. bradburiana* in spring, *M. didyma* and *M. fistulosa* taxa in midsummer, and *M. punctata* categories in late summer or early fall. *M. punctata* taxa bloom later than all other taxa, starting anywhere from late June, July or August and ending in September to October depending on the plant age and USDA zone.

By utilizing *Monarda* taxa that bloom early, mid, or late summer, careful selection by gardeners can provide continuous and robust floral displays for human enjoyment and wildlife consumption. With minimal care and fertilization, most taxa flower for two to three months, producing about 100 flowering stems, with peak bloom lasting one to three weeks (Table 2.6 and Figs. 2.3 and 2.4). We observed that *M. didyma* and *M. didyma* 'Jacob Cline' peak flower in June and again in late summer or early fall. The repeated flowering observed in the previously stated taxa was not observed among other *M. didyma* cultivars. *M. fistulosa* and *M. fistulosa* 'Claire Grace' had more flowering stems, but the length of bloom was longer for *M. didyma* taxa. While *M. bradburiana* and *M.* Sugar Buzz® 'Grape Gumball' could be considered low bloomers relative to other evaluated taxa, *M. bradburiana* set over 100 flowers in Blairsville and *M.* Sugar Buzz® 'Grape Gumball' can set 100 flowers in the first season after establishment (Table 2.5).

Health. We were also able to show the progression of powdery mildew for each site and season and then calculate AUPDC scores to rate tolerance among *Monarda* taxa (Table 2.6

and Figs. 2.5 and 2.6). The short lifecycle of *M. punctata* excluded the ecotypes from AUDPC scoring and analysis. We saw more differences in tolerance in the first season than in the second season at both sites. Cultivars were more tolerant of powdery mildew than the parent species, *M. didyma* and *M. fistulosa*, especially in the first season. We also saw good tolerance in *M. bradburiana*. We suspect that cultural methods like spring and summer divisions or removal of diseased stems and overwintering material would reduce the powdery mildew within stands, but we do not know how this would impact wildlife. Specifically, *Monarda* stems are hollow and could provide nesting material for cavity-nesting wasps and bees (O'Neill and O'Neill 2010). Removaling senesced foliage from the ground may be sufficient to minimize disease spread even if stem stubble is left to encourage insect nesting.

In terms of establishment, *M.* Sugar Buzz ® Grape Gumball was notably different from other tested taxa, and especially other *M. didyma* cultivars. Members of the Sugar Buzz ® series from the Walters Gardens are bred as compact hybrids significantly shorter than other cultivars in our trial (Walters Gardens, Inc.). The solid dome of color did not persist past one season after establishment in Athens, Georgia, and melted away at the end of the season (Fig. 2.7). The performance in the first season after the establishment was impressive at both sites, so we recommend its use in annual displays but doubt its longevity in more southern climates.

Figure 2.7. Performance of *M.* Sugar Buzz ® Grape Gumball in Blairsville, Georgia (A) compared to Athens, Georgia (B) in 2021.


A B

Compared to trials conducted at the Chicago Botanic Garden (CBG) and Mt. Cuba Center (MCC), the Georgia seasons are longer (Coombs, 2016; Hawke, 1998). Season length could explain the differences among results between the three studies. Not all taxa in our trial were trialed by CBG and MCC and vice versa, so we can only compare taxa that were included in our trial and at least one other study. Plant height at flowering, width after two years, and peak flower coverage were similar between the three studies. Phenology and tolerance to powdery mildew varied. Floral initiation started earlier and ended later in Georgia compared to CBG and MCC trials. Notably *M. didyma* and *M. didyma* 'Jacob Cline' had recurrent flowering in all sites and years of our study. All studies showed that *M. fistulosa* had the least tolerance to powdery mildew while *M. bradburiana* showed excellent tolerance. We note that the powdery mildew on *M. fistulosa* was not detrimental to its floral display. CBG and MCC drew more distinctions in powdery mildew tolerance among taxa than we observed in our study (Coombs, 2016; Hawke, 1998).

Conclusion. These studies were designed to inform the Georgia ornamental industry, landowners, park managers, civic entities, and consumers on the performance of select *Monarda* species and cultivars. Morphology, phenology, and tolerance to powdery mildew varied among taxa for each site and year. Taxa showed two height groups, less than or greater than one meter, and three flowering seasons, early, middle, and late summer. We saw most taxa set around 100 flowering stems at peak bloom, except for *M. bradburiana*, *M. didyma,* and *M. didyma* 'Jacob Cline' and *M. punctata* GA in Blairsville. Cultivars exhibited some tolerance to powdery mildew relative to straight species, except for *M. bradburiana* which has no known cultivar and *M. punctata* which has a shorter life span. We conclude most tested *Monarda* taxa are suitable candidates for adding summer color to gardens located in the piedmont and montane regions of Georgia. *M. punctata* taxa provide appealing texture, *M. bradburiana* exhibited high tolerance to powdery mildew, and dwarf varieties like *M.* Sugar Buzz ® Grape Gumball are well suited for annual beds. This information will be of value to consumers, garden designers, commercial nurseries, and growers in marketing their plants and designing their landscape uses.

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CHAPTER 3

DIFFERENCES IN FLORAL MORPHOLOGY AND NECTAR PRODUCTION AMONG FLOWERS OF *MONARDA* SPECIES AND CULTIVARS

Introduction.

Horticulturists can enrich urban landscapes aesthetically and ecologically by assessing the resource value of ornamental plants for pollinating insect communities (Kalaman et al. 2022). Nectar is a primary floral reward important for wildlife and pollination (Dafini, 1991), serving as a primary energy source for many adult pollinating insects (Hill et al., 2001; Whitham, 1977). Through intentional landscape design human habitat can provide resources for wildlife across multiple seasons. Studying differences in floral morphology and nectar production among native plants and their cultivars provides empirical evidence to choose plants that offer the most floral rewards to wildlife (Kalaman et al., 2022). Continued exploration of the subject is crucial due to the lack of consistent differences in floral rewards and pollinator preference between native and nonnative plants (Kalaman et. al. 2022, Affolter and Poythress, 2018).

Monarda species and cultivars provide an excellent opportunity to study the effect of floral morphology and nectar production because of their natural and intentional hybridization resulting in novel flower form and color (Dudchenko et al. 2020; Mattarelli et al. 2017; Coombs, 2016; Tabanca et al. 2013; Collicutt and Davidson, 1999; Hawke, 1998). The inflorescence of *Monarda* has individual flowers condensed into glomerules, a head-like cyme. The size of glomerules and individual flowers varies between species (Weakley, 2022). For instance, *M. didyma* has long-corollas and deep red flowers compared to the short-corollas and lavender flowers of *M. fistulosa*. Originators of *Monarda* cultivars often report *M. didyma* as the seed-bearing parent, while the pollen donor remains undocumented.

Research has shown a general pattern that flowers with longer corolla tubes produce more nectar and vice versa (Kalaman et. al. 2022; Gomez et. al. 2008; Petanidou et. al., 2000; Dafini, 1991; Harder and Cruzan 1990). Specifically, the depth of corolla tubes have been associated with differences in nectar volume (Gomez et al., 2008; Dafni, 1991; Harder and Cruzan, 1990), largely due to differences in photosynthate secretion, nectar holding capacity, and nectar evaporation rates (Kalaman et al. 2022; Ornela et al., 2007; Pleasants, 1983). In addition, an earlier study by Dafini et al. (1988) found that, within Labiatae, nectary size and nectar yield per flower were positively correlated.

There are many published comparisons concerning the relative nutrient value and pollinator attraction of nonnative cultivars and native plants (Braman et al. 2022; Tew et al., 2021; Seitz et al., 2020; Native Plant Partnership, 2014; Williams et al., 2011). Nectar production and foraging visitors are well documented by Cruden et al. (1984) and Whitten (1981) among *M. fistulosa* and *M. didyma*, respectively, but to our knowledge, no research has been conducted comparing floral morphology and nectar production among cultivars and species within the genus. Due to the site- and species- specific nature of published research, there is a need to evaluate pollinator use and nectar attributes among Georgia native plants (Kalaman et al., 2022). These properties are important from an applied perspective, as *Monarda* taxa are often included in seed mixes to provide summer forage to wildlife (Rubio et al. 2022; Wolf et al. 2022; Quinlan et al. 2021; Otto et al. 2017; Gray et al. 2007). Many species of *Monarda* are found in Georgia, native to different regions of the state (Weakley et al., 2022).

We used the same Athens and Blairsville, Georgia study sites described in Chapter 2 to test if floral morphology and nectar yield significantly differed among selected *Monarda* taxa. In Chapter 4, we examined the abundance of insect groups, such as bees, wasps, coleopterans and hemipterans, and beneficial dipterans among the same *Monarda* taxa.

Our objectives were to assess the variability of flower morphology and nectar production in select *Monarda* taxa. We then assessed if these measurements influenced the number of hymenoptera, coleoptera, hemiptera, and diptera present on a *Monarda* plant the day of sampling. To test the hypothesis that flower morphology will be different among taxa, we measured inflorescence diameter, corolla length and width, and petal length and width. To test the hypothesis that nectar properties are different among taxa, we measured nectar volume, sucrose concentration, and total sugar content per flower. Finally, to correlate flower morphology and nectar production to insect abundance, we counted number of hymenoptera, coleoptera, hemiptera, and diptera using the snap-shot method (Braman and Quick, 2018).

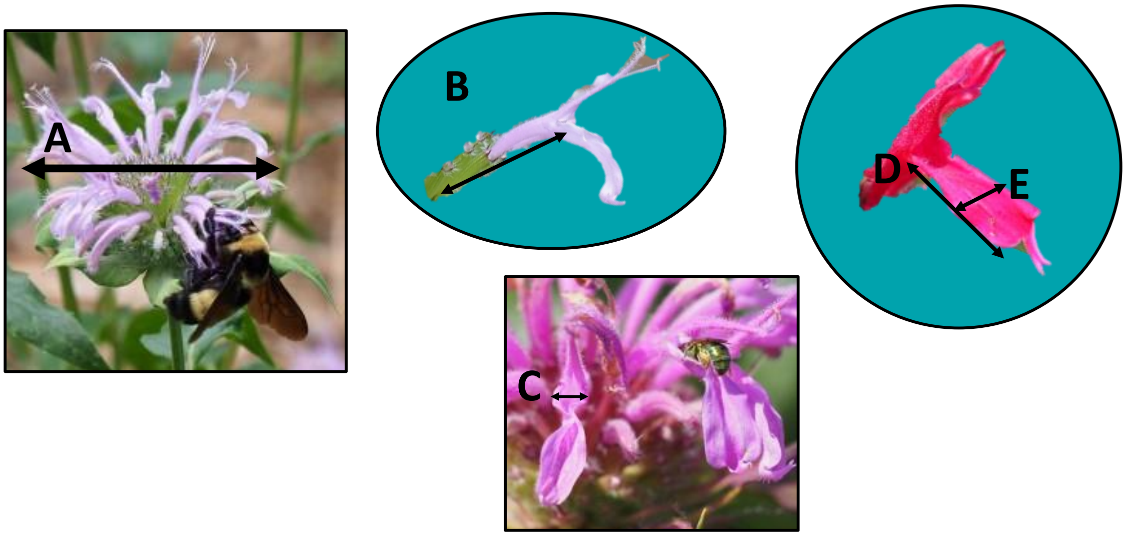
MATERIALS AND METHODS

Flower Morphology Measurements. Plant material was established at the Georgia Mountain Research and Education Center (GMREC) site in 2020 and at the Mimsie Lanier Center for Native Plant Studies (MLCNPS) site in 2021 (as described in Chapter 2). Ten *Monarda* taxa were evaluated during the 2020 and 2021 growing seasons. Inflorescence size (mm) was measured as the petal-to-petal width of the inflorescence on two random glomerules per plant (Fig. 3.1) in 2021 at the GMREC and MLCNPS. In 2020 at the GMREC, 12-32 random flowers per *Monarda* taxon were measured for corolla and petal length and width (mm). The length of the corolla was determined from where the nectary meets the receptacle to the opening where the petals fuse. The width of the corolla was the opening measured lengthwise from each union of the upper to lower petal. Length of the lower petal was measured from the corolla opening to the tip of the lip. The width of the lower petal was measured at the widest horizontal point (Figure 3.1). These measurements were chosen because we observed insects use the lower petal as a landing platform and saw the exclusion of certain animals due to corolla length. For example, hummingbirds are slowed by the lower petal (Temeles and Rankin, 2000) and *Xylocopa* spp. preferentially rob nectar from taxa with longer corollas (personal observation). Measurements were made with digital calipers during peak bloom.

Nectar Measurements. Nectar volume (µL) and sucrose concentration (as % w/w sucrose) were measured at the GMREC in 2020 and at both sites in 2021. For each repetition and treatment, a random glomerule was bagged for 24 hours to exclude visitors, after which the flowers were probed for nectar. The samples were taken between 9 and 10 AM to collect nectar after it had been secreted and before significant evaporation had taken place. In total, 50 random flowers were sampled per *Monarda* taxon. One flower per inflorescence was used per nectar sample. Volume was measured by inserting a microcapillary tube into the corolla. The nectar was then deposited onto a hand-held refractometer (Bellingham Stanley Limited Delta Refractometer Code Range 0-50% sucrose w/w) to measure the percent sucrose per flower. The refractometer was rinsed with deionized water and dried after each sample. As µg sucrose per flower, the total sugar content was the product of volume times concentration times nectar density, the latter taken from existing tables. At micro volumes nectar density is negligible and for the purpose of this study is considered one microliter per microgram (Petanidou et al., 2000; Dafini, 1991; Bolton et al., 1979).

Insect Visualization. Wildlife observations were made during the peak period of anthesis between 10 AM and 2 PM on sunny days with light, variable wind, and low cloud cover. While some flower-visiting insects are active outside of these conditions, this is the standard period for flower visitation assessment (Braman et. al. 2022). On both sides of a *Monarda* plant, a square foot of flowers per taxon and repetition was observed, two observers per subject, during peak anthesis, for one minute per side. Counted groups included hymenoptera, coleoptera, hemiptera, and diptera. Visits were counted if an individual landed on a flower during observation. This method, from Braman and Quick's (2018) crepe myrtle study, was adapted to suit *Monarda* species and cultivars. This methodology was not suitable for lepidoptera or bird visitors, which were observed photographically (featured in the appendix of Chapter 4). When the observer approached the stand of flowers, these taxa tended to move away from the stand under observation. Despite seeing activity in both gardens from these groups, we could not record these observations.

Figure 3.1 Methodology used to assess inflorescence (glomerule) and flower characteristics of *Monarda* taxa. A = diameter of inflorescence; B = corolla length; C = corolla width; D = petal length; E = petal width.



Data analysis. All measurements were subjected to analysis of variance (ANOVA) for *Monarda* taxa as the main effect, followed by post-hoc Tukey's Honestly Significant Difference test (HSD) to separate the means, unless transformed. Transformed data were subjected to a generalized linear model (GLM) for *Monarda* taxa as the main effect, followed by post- hoc Tukey's HSD test to separate the means. Data were analyzed using R software (R Core Team, 2018). Individual parameters and transformations are addressed below. Model assumptions were checked visually with the residuals. The statistical significance was determined at alpha equal to or below 0.05. Standard errors were calculated with **'plotrix'** (Lemon et al. 2021). **'emmeans'** was used to separate means with multiple comparisons using Tukey's HSD and also calculate standard errors of GLMs (Lenth et al. 2022). *M. bradburiana* and *M.* Sugar Buzz ® Grape

Gumball were excluded from corolla and petal measurements due to the COVID-19 lockdown in 2020.

Inflorescence size. Data were analyzed separately by the site. No transformations were necessary to meet model assumptions.

Flower Characteristics. No transformations were necessary to meet model assumptions.

Nectar Production. For 2020 GMREC data, nectar volume (µL) and total sugar content per flower (µg) were square root transformed. Reported means were then back transformed. No transformations were needed for sucrose concentration, as no difference was found between *Monarda* taxa. For 2021 GMREC and MLCNPS data, nectar volume, sucrose concentration, and total sugar content per flower were square root transformed. Reported means were then back transformed. Sucrose concentration data from this site and year failed to meet model assumptions. Analysis was carried out to calculate means and standard errors, but differences are not reported.

Linear Regression. Correlations between measurements could only be conducted with data from the same site and year. For GMREC 2020 we ran correlations between corolla, petal, and nectar measurements. For both sites in 2021 we ran correlations between nectar measurements and inflorescence diameter. Stated data were subjected to linear regression using R software (R Core Team, 2018), and only significant relationships were reported.

Insect Visualizations. Following the previous analysis, linear regression correlated the same measures to insect abundance. Correlations between measurements could only be conducted with data from the same site and year. Stated data was subjected to linear regression using R software (R Core Team, 2018) and only significant relationships were reported.

In a separate analysis, insect visualization data was pooled between sites and subjected to ANOVA using GLM fitted to a negative binomial with *Monarda* taxa as the main effect. Results were then back-transformed and subjected to Tukey's HSD for separation of means. Figures were created using '**ggplot2**' and reported in the appendix (Wickham, 2016).

RESULTS

Flower Morphology. ANOVA results for the diameter of inflorescence for *Monarda* taxa at GMREC in 2021 were F (9, 130) = 121.3, with $p < 2e-16$. At MLCNPS the same year results were F (8, 117) = 40.05, with $p < 2e-16$ (*M.* Sugar Buzz ® Grape Gumball Bee Balm did not establish at MLCNPS; thus there is one less degree of freedom). Following the separate analyses, the mean diameter of inflorescence was different among taxa at both sites in 2021 (Table 3.1). At the GMREC, the glomerule size ranged from 23.0 mm to 82.3 mm, and at the MLCNPS sizes ranged from 23.2 mm to 62.0 mm. At both sites, *M. punctata* taxa had smaller glomerules. On the other hand, *M. didyma* taxa, *M.* x 'Judith's Fancy Fuchsia, and *M.* 'Raspberry Wine' had the largest inflorescence. The other taxa fell between the two extremes, with *M. fistulosa* 'Claire Grace' having larger glomerules than *M. fistulosa*.

Table 3.1 Mean (±SE) diameter of inflorescence (mm) of *Monarda* taxa grown at Georgia Mountain Research and Education Center (GMREC) and Mimsie Lanier Center for Native Plant Studies (MLCNPS) in 2021. Means followed by different letters are significantly different ($P \leq 0.05$) within columns.

Taxa	**Diameter of Inflorescence (mm)**	
	GMREC	**MLCNPS**
M. bradburiana	41.5 (2.1) b^{z}	45.4 (1.3) bc
M. Sugar Buzz ® Grape Gumball Bee Balm	48.7 (2.0) bc	---
M. didyma	68.3 (1.9) d	54.7 (1.7) cd
M. didyma ‘Jacob Cline’	82.3 (2.6) e	61.8 (4.7) d
M. x ‘Judith’s Fancy Fuchsia’	72.0 (1.4) d	56.8 (1.5) d
M. ‘Raspberry Wine’	69.0 (2.0) d	62.0 (2.2) d
M. fistulosa	47.3 (2.1) bc	42.2 (1.4) b
M. fistulosa ‘Claire Grace’	53.0 (2.3) c	54.4 (2.2) cd
M. punctata GA	23.2 (0.9) a	29.4 (1.2) a
M. punctata NJ	23.0 (0.9) a	23.2 (1.5) a

^{z}Means of 14 random glomerules per taxon at each site.

The mean length and width of corolla and lower petal were different among taxa, with ANOVA results reported in Table 3.2. Corolla length ranged from 10.7 mm to 27.5 mm, while corolla width ranged from 2.4 mm to 3.6 mm (Table 3.3). Mean length of corolla was longest for *M. didyma* ‘Jacob Cline’ and shortest for *M. punctata* ecotypes and *M. fistulosa*. *M. didyma*, *M.* x ‘Judith’s Fancy Fuchsia’, and *M.* ‘Raspberry Wine’ did not have different corolla lengths. *M.* ‘Raspberry Wine’ and *M.* x ‘Judith’s Fancy Fuchsia’ had the widest corolla, but this was no different from *M. punctata* ecotypes or *M. didyma* and cultivars. *M. fistulosa* had the narrowest corolla, significantly smaller than *M. fistulosa* ‘Claire Grace’.

Lower petal length ranged from 8.2 mm to 19.5 mm, while petal width ranged from 3.7 mm to 5.8 mm (Table 3.3). Mean petal length was longest for *M. didyma* ‘Jacob Cline’ and shortest for *M. punctata* NJ. Mean petal length was not significantly different among *M. didyma*, *M.* x ‘Judith’s Fancy Fuchsia’, and *M.* ‘Raspberry Wine’. Nor was petal length different among *M. fistulosa* and *M. punctata* GA. Mean petal width was the widest for *M. punctata* GA and narrowest for *M. fistulosa*. *M. didyma* ‘Jacob Cline’, *M.* x ‘Judith’s Fancy Fuchsia’, *M.* ‘Raspberry Wine’, *M. fistulosa* ‘Claire Grace’, and *M. punctata* NJ represented the middle group of petal widths. *M. didyma* petal width was not significantly different from *M. fistulosa* or the middle group.

Table 3.2 Analysis of variance results for the effect of eight[z] *Monarda* taxa on corolla and lower petal length and width during peak bloom at Georgia Mountain Research and Education Center in 2020.

Source (df)	*F*	*Pr > F*
Corolla, Length (7)	269.9	< 2e-16
Corolla, Width (7)	13.27	2.97e-13
Petal, Length (7)	79.63	< 2e-16
Petal, Width (7)	20.15	< 2e-16

[z] *M. bradburiana* and *M.* Sugar Buzz ® Grape Gumball were not assessed.

Table 3.3 Mean (±SE) (mm) length and width of corolla and lower petal of eight *Monarda* taxa during peak bloom at the Georgia Mountain Research and Education Center in 2020. Means within a column followed by different letters are significantly different ($P < 0.05$).

Taxa	**Corolla**		**Petal**	
	Length (mm)	**Width (mm)**	**Length (mm)**	**Width (mm)**
M. bradburiana ^{zy}	---	---	---	---
M. Sugar Buzz ® Grape Gumball ^{z}	---	---	---	---
M. didyma	23.7 (0.5) e	3.1 (0.1) bc	16.2 (0.8) d	4.2 (0.2) ab
M. didyma ‘Jacob Cline’	27.5 (0.6) f	3.3 (0.2) bc	19.5 (0.8) e	4.6 (0.1) b
M. x ‘Judith’s Fancy Fuchsia’	22.7 (0.3) de	3.6 (0.1) c	15.5 (0.4) d	4.8 (0.1) b
M. ‘Raspberry Wine’	22.8 (0.3) e	3.6 (0.1) c	15.8 (0.4) d	4.8 (0.1) b
M. fistulosa	15.7 (0.6) c	2.4 (0.1) a	10.4 (0.4) b	3.7 (0.2) a
M. fistulosa ‘Claire Grace’	21.3 (0.3) d	2.9 (0.1) b	12.8 (0.2) c	4.8 (0.1) b
M. punctata GA	14.1 (0.2) b	3.3 (0.1) bc	10.3 (0.2) b	5.8 (0.1) c
M. punctata NJ	10.7 (0.1) a	3.3 (0.1) bc	8.2 (0.2) a	4.6 (0.1) b

^{z} *M. bradburiana* and *M.* Sugar Buzz ® Grape Gumball were not assessed because of the 2020 COVID-19 lockdown.

^{y} Means of 12-32 random flowers per taxon.

Nectar. For each site and year mean nectar volume (µL) and total sugar content per flower (µg) were different among taxa, while sucrose concentration (w/w) was not different among *Monarda* taxa (Table 3.4). At GMREC in 2020 nectar volume ranged from 0.7 µL to 2.8 µL. The NJ ecotype of *M. punctata* had the lowest nectar volume and *M. didyma* ‘Jacob Cline’ had the highest. *M. punctata* ecotypes and *M. fistulosa* differed from *M. didyma* ‘Jacob Cline’. At the same site in 2021 nectar volume ranged from 0.4 to 3.9 µL. Nectar volume was lowest in *M.* Sugar Buzz ® Grape Gumball (not sampled in 2020) and highest in *M.* ‘Raspberry Wine’. *M.* Sugar Buzz ® Grape Gumball, *M. bradburiana*, and *M. fistulosa* taxa had lower volumes than *M.*

‘Raspberry Wine’, *M.* x ‘Judith’s Fancy Fuchsia’, and *M. didyma* taxa. *M. didyma* nectar volume was lower than *M.* ‘Raspberry Wine’ and *M.* x ‘Judith’s Fancy Fuchsia’. At MLCNPS in 2021 nectar volume ranged from 0.3 to 7.2 µL. Nectar volume was lowest in *M. fistulosa* ‘Claire Grace’ and highest in *M. didyma* ‘Jacob Cline’. *M. didyma* ‘Jacob Cline’ nectar volume was higher than all other taxa. The volume of *M. fistulosa* ‘Claire Grace’ nectar was no different from *M. fistulosa*, *M. punctata* ecotypes, or *M. bradburiana* (Table 3.4)

At GMREC in 2020 total sugar content per flower (µg) ranged from 0.21 µg to 0.89 µg. Sugar content was lowest among the NJ ecotype of *M. punctata* and highest among *M. didyma* ‘Jacob Cline’. The sugar content of *M. punctata* NJ was no different from *M. punctata* GA, *M. fistulosa* taxa or *M. didyma*. The sugar content of *M. didyma* ‘Jacob Cline’ was no different from *M. didyma*, *M.* x ‘Judith’s Fancy Fuchsia’, or *M.* ‘Raspberry Wine’. At the same site in 2021 total sugar content per flower ranged from 0.13 to 1.04 µg. Sugar content was lowest among the GA ecotype of *M. punctata* and highest among *M. didyma* ‘Jacob Cline’. The sugar content of *M. punctata* GA was no different from *M. punctata* NJ, *M. fistulosa* taxa, or *M.* Sugar Buzz ® Grape Gumball. The sugar content of *M. didyma* ‘Jacob Cline’ was no different from *M. didyma*, *M.* x ‘Judith’s Fancy Fuchsia’, or *M.* ‘Raspberry Wine’. *M. bradburiana* was different from *M. punctata* GA, *M. didyma* ‘Jacob Cline’, *M.* ‘Raspberry Wine’, and *M. fistulosa* taxa. At MLCNPS in 2021 total sugar content per flower ranged from 0.14 to 2.14 µg. Sugar content was lowest among *M. fistulosa* ‘Claire Grace’ and highest among *M. didyma* ‘Jacob Cline’. The sugar content of *M. fistulosa* ‘Claire Grace’ was no different from *M. fistulosa*, *M. bradburiana*, or *M. punctata* ecotypes. *M. didyma* ‘Jacob Cline’ sugar content was no different from *M.* x ‘Judith’s Fancy Fuchsia’ (Table 3.4).

At GMREC in 2020 sucrose concentration (w/w) ranged from 29% to 39 %. This was lowest in *M. didyma* ‘Jacob Cline’ and highest in *M. fistulosa.* At the same site in 2021 sucrose concentration ranged from 19% to 50%. Sucrose concentration was lowest in the GA ecotype of *M. punctata* and highest in *M. bradburiana* (not sampled in 2020). At MLCNPS in 2021 sucrose concentration ranged from 26% to 49%. This was lowest in *M. didyma* and highest in *M. fistulosa* ‘Claire Grace’ (Table 3.4).

Table 3.4 Mean (±SE) nectar volume (μL), concentration sucrose (w/w), and total sugar content per flower (μg) in ten *Monarda* taxa during peak bloom at the Georgia Mountain Research Center (GMREC) in 2020 and 2021, and the Mimsie Lanier Center for Native Plant Studies (MLCNPS) in 2021. Means within a column followed by different letters are significantly different (P ≤ 0.05).

	GMREC 2020			**GMREC 2021**			**MLCNPS 2021**		
Taxa	**Volume (μL)**	**Sucrose (w/w)**	**Total Sugar Content (μg)^{z}**	**Volume (μL)**	**Sucrose (w/w)**	**Total Sugar Content (μg)^{z}**	**Volume (μL)**	**Sucrose (w/w)**	**Total Sugar Content (μg)^{z}**
M. bradburiana	---	---	---	1.1 (0.2) b	0.50 (0.05)	0.53 (0.08) bc	1.2 (0.3) abc	0.37 (0.04)	0.44 (0.01) abc
M. Sugar Buzz ® Grape Gumball	---	---	---	0.4 (0.1) a	0.37 (0.04)	0.15 (0.04) a	---	---	---
M. didyma	1.6 (0.3) abcd	0.31 (0.03)	0.47 (0.10) abcd	2.0 (0.2) c	0.33 (0.04)	0.69 (0.09) cd	3.0 (0.5) cd	0.26 (0.03)	0.73 (0.15) bcd
M. didyma 'Jacob Cline'	2.8 (0.4) d	0.29 (0.03)	0.89 (0.12) d	2.9 (0.3) cd	0.35 (0.04)	1.04 (0.11) d	7.2 (0.8) e	0.30 (0.03)	2.14 (0.25) e
M. x 'Judith's Fancy Fuchsia'	1.8 (0.2) bcd	0.36 (0.02)	0.66 (0.08) bcd	3.5 (0.3) d	0.27 (0.03)	0.94 (0.11) cd	3.3 (0.5) d	0.37 (0.04)	1.22 (0.19) de

M. ‘Raspberry Wine’	2.0 (0.2) cd	0.36 (0.02)	0.70 (0.09) cd	3.9 (0.3) d	0.26 (0.03)	1.00 (0.11) d	2.3 (0.4) bcd	0.41 (0.04)	0.92 (0.16) cd
M. fistulosa	0.85 (0.2) ab	0.34 (0.03)	0.27 (0.07) a	0.6 (0.1) ab	0.25 (0.03)	0.14 (0.04) a	0.8 (0.3) ab	0.44 (0.04)	0.32 (0.10) abc
M. fistulosa ‘Claire Grace’	1.0 (0.2) abc	0.39 (0.03)	0.36 (0.08) abc	0.5 (0.1) ab	0.39 (0.04)	0.19 (0.05) a	0.3 (0.2) a	0.49 (0.04)	0.14 (0.06) a
M. punctata GA	1.2 (0.2) abc	0.33 (0.02)	0.37 (0.05) ab	0.7 (0.1) ab	0.19 (0.03)	0.13 (0.04) a	1.3 (0.3) abcd	0.27 (0.03)	0.34 (0.10) abc
M. punctata NJ	0.7 (0.2) a	0.34 (0.02)	0.21 (0.05) a	0.8 (0.1) ab	0.33 (0.04)	0.25 (0.06) ab	0.9 (0.3) ab	0.31 (0.03)	0.30 (0.09) ab

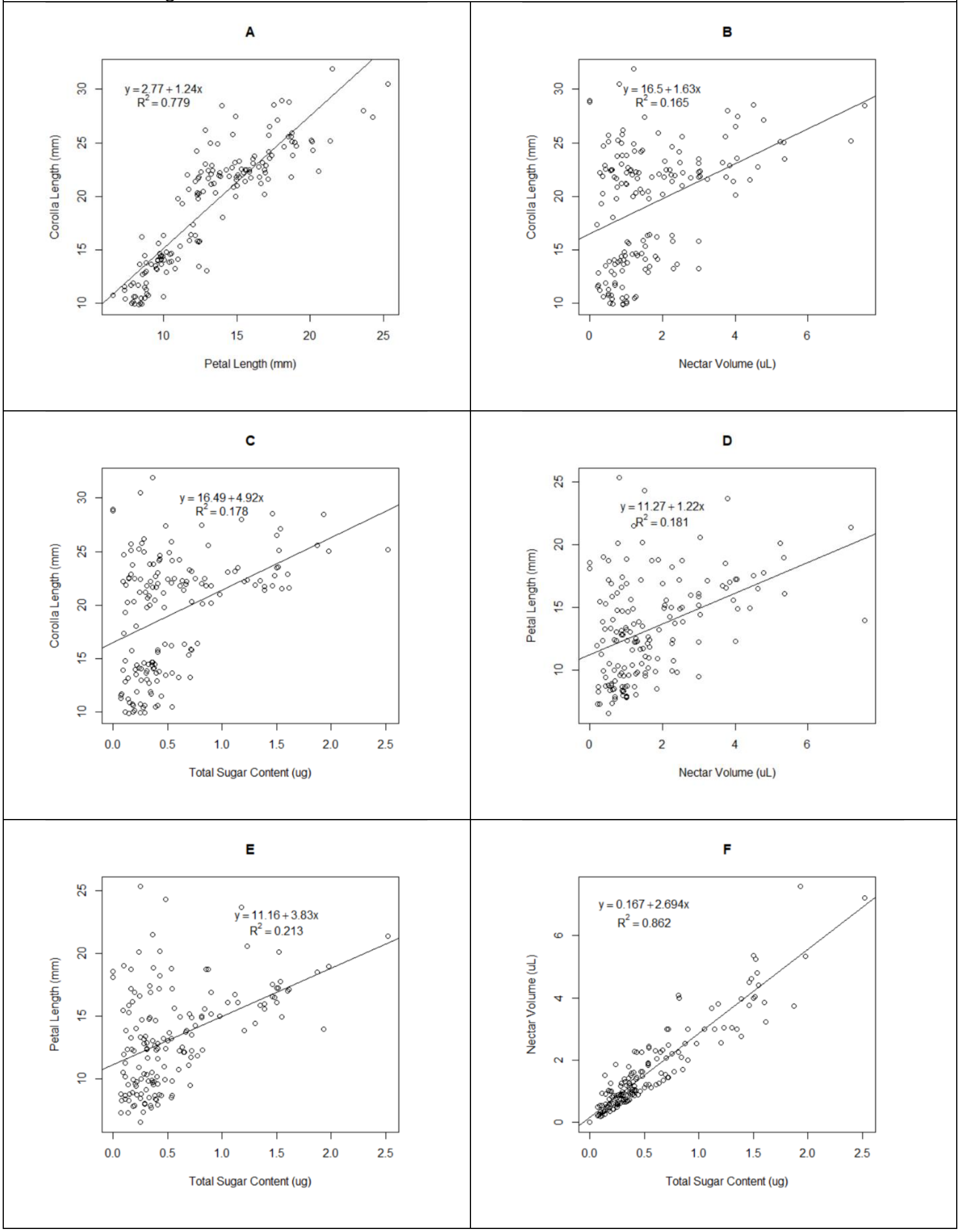
[z] Total sugar content, as µg sucrose per flower [volume x concentration x nectar density (1 µL/ µg)].

Linear Regression. For GMREC 2020 we performed separate linear regression analyses among corolla, petal, and nectar measurements. We found no correlations between corolla length and corolla width, petal width, or sucrose concentration. Corolla length and petal length linear regression results were F (1, 156) = 549.8, with $p < 2.2$ e-16 (Fig. 3.2.A). Corolla length and nectar volume results were F (1, 156) = 30.82, with p = 1.188e-7 (Fig.3.2.B). The results for corolla length and total sugar content were F (1, 156) = 33.78, with p = 3.376e-08 (Fig.3.2.C). Again, we found no correlations between corolla width and petal length or width, nectar volume, sucrose concentration, or total sugar content.

Along with the previous analyses, we also found no correlation between petal length and sucrose concentration. Linear regression results for petal length and nectar volume were F (1, 156) = 34.37, with p = 2.634e-08 (Fig.3.2.D). Results for petal length and total sugar content were F (1, 156) = 42.12, with p = 1.085 e-09 (Fig.3.2.E).

We found no correlation between sucrose concentration and nectar volume, or sucrose concentration and total sugar content. Nectar volume and total sugar content were strongly related, and results from the linear regression were F (1, 156) = 972.9, with $p < 2.2$ e-16 (Fig.3.2.F).

Figure 3.2 Linear regression results among *Monarda* flower morphology and nectar production in 2020 at the Georgia Mountain Research and Education Center.



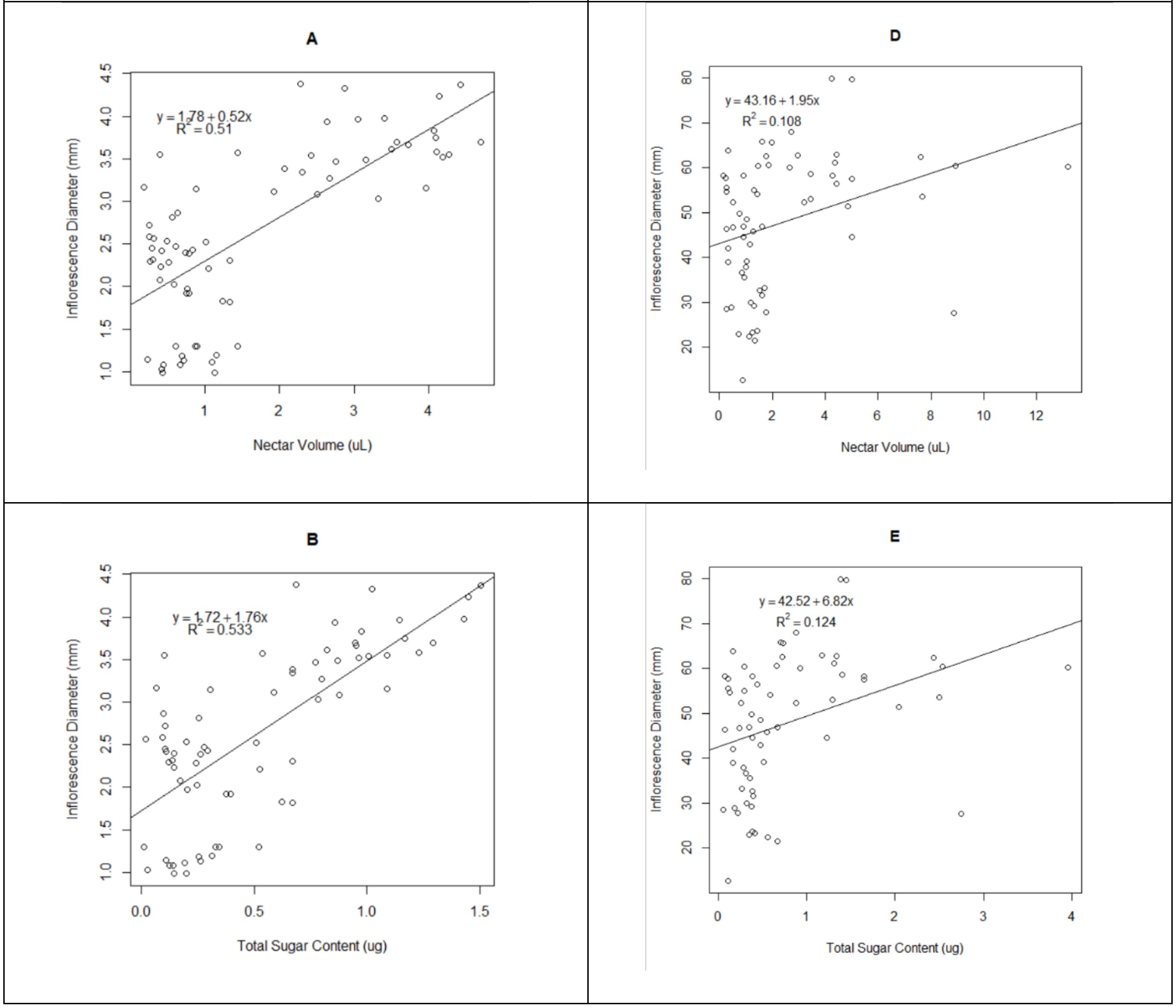
For both sites in 2021 we ran separate linear regressions for each nectar measurement and inflorescence diameter. The GMREC linear regression results for inflorescence diameter and nectar volume was F (1, 68) = 72.92, with p = 2.3 e-12 (Fig. 3.3.A). Inflorescence diameter and total sugar content results were F (1, 68) = 77.64, with p = 7.397 e-13 (Fig. 3.3.B). We found no correlation between inflorescence diameter and sucrose concentration. At the same site and year, the linear regression results between total sugar content and nectar volume were F (1, 68) = 586.2, with $p < 2.2$ e-16 (Fig.3.3.C). Again, there was no linear relationship found between sucrose concentration and nectar volume or total sugar content.

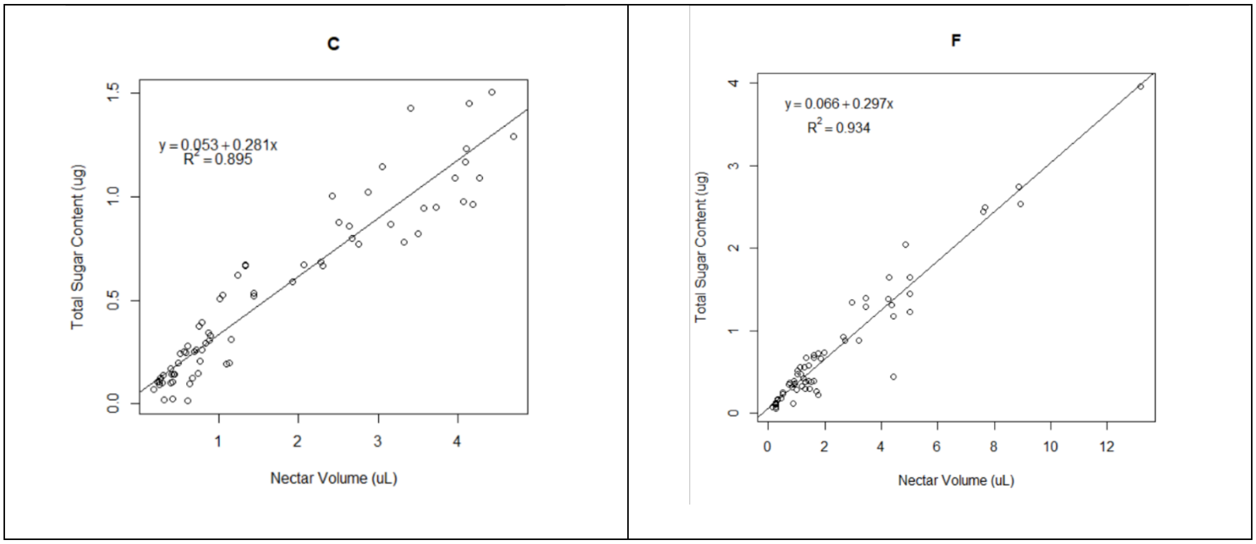
At the MLCNPS in 2021 linear regression results for inflorescence diameter and nectar volume were F (1, 61) = 7.35, with p = 0.00871 (Fig.3.3.D). Inflorescence diameter and total sugar content results were F (1, 61) = 8.65, with p = 0.00462 (Fig.3.3.E). We found no correlation between inflorescence diameter and sucrose concentration. At the same site and year the linear regression results between total sugar content and nectar volume were F (1, 61) = 875.1, $p < 2.2$e-16 (Fig.3.3.F). No linear relationship was found between sucrose concentration and nectar volume or total sugar content.

Figure 3.3 Linear regression results among *Monarda* inflorescence diameter and nectar production in 2021 at the Georgia Mountain Research Education Center (GMREC) and Mimsie Lanier Center for Native Plant Studies (MLCNPS).

GMREC

MLCNPS





Insect Visualization. For GMREC 2020 we performed separate linear regression analyses among corolla, petal, nectar measurements, and insect abundance. We found no correlations between insect abundance and corolla width or length, petal width or length, nectar volume, sucrose concentration, or total sugar content among observed *Monarda* taxa.

For both sites in 2021 we ran separate linear regressions among nectar measurements, inflorescence diameter, and insect abundance. At the GMREC we found no correlations between insect abundance and nectar volume, sucrose concentration, total sugar content, or inflorescence diameter. At the MLCNPS we found no correlations between insect abundance and nectar volume, sucrose concentration, total sugar content, or inflorescence diameter.

Insect abundance was significantly different between *Monarda* taxa when site data were pooled in a separate analysis (Appendix 3.1).

DISCUSSION

We found sufficient evidence to support our hypotheses that flower morphology and nectar properties vary among *Monarda* taxa. Such empirical evidence provides detailed resource value of *Monarda* species and cultivars, which allows considerations for wildlife when designing urban landscapes (Kalaman et al., 2022). As we increase the use of native ornamental plants in the landscape, we must also continue to assess the tradeoffs between resource value and novel color, form, and disease tolerance (Wilde et al., 2015).

The diameter of inflorescence, length and width of corolla and petal, and nectar volume and total sugar content all displayed significant differences among taxa. We did not detect any differences in nectar sucrose concentration, nor did we see any correlation between our measurements and insect abundance. Lack of linear correlation between flower morphology and insect abundance, or nectar production and insect abundance, was despite seeing differences in insect abundance between *Monarda* taxa (Appendix A). Our result was consistent with findings from a similar study on pollinator choice among *Salvia* species and cultivars (Braman et al., 2022).

Length and width of the corolla and petal differed among taxa, so inflorescence diameter may be explained by the size of individual flowers. Indeed, we found a strong positive linear correlation between corolla and petal length within tested *Monarda* taxa (Fig. 3.2.A). Furthermore, the length of corollas and lower petals show several distinct groups (Table 3.3).

The size of individual flowers was comparable between *M. fistulosa* taxa and *M. punctata* GA which does not explain the differences found in overall inflorescence size between the two taxa. Lack of relation among results in flower size and inflorescence diameter could be due to a difference in number of individual flowers per glomerule or number of glomerules per flowering stem (Weakley, 2022).

There were significant differences in nectar production among *Monarda* taxa. Three groups were observed with respect to total sucrose per flower. We found strong positive linear correlations between nectar volume and total sugar content in all years and sites but failed to see any relationship between flower morphology and nectar production. Our linear regressions also showed no relationship between nectar production and insect abundance. Typically flowers with longer corollas produce higher volumes of nectar, while smaller-flowered taxa generally produce less nectar per flower (Kalaman, 2022; Gomez, 2008; Petanidou et al., 2000; Dafini, 1991; Harder and Cruzan 1990). Our study supported those findings, except for *M. punctata* GA, which has a short corolla with a wide opening and nectar volume no different from *M. didyma* hybrids nor *M. fistulosa*.

Results assessing nectar volume and total sucrose per flower have been used to rate the value of ornamental flowers for wildlife in the garden (Braman et al., 2022; Kalaman et al., 2022). We did not see a correlation between nectar production and insect abundance, but sampling methods could explain this. It has been suggested that butterflies may be more responsive to nectar quantity than bees because bees – unlike butterflies – also forage for pollen (Kalaman et al., 2022). Although butterflies (and ruby-throated hummingbirds) were present at both experimental sites, the snap-shot method for insect visualization did not allow enough time to capture these observations. It is recommended to allow at least ten minutes to capture lepidoptera diversity, while our samples consisted of two-minute observation periods (Erickson et al., 2022). Differences in insect communities among the tested *Monarda* taxa will be discussed in greater detail in Chapter 4.

In Chapter 2 we reported that *M. fistulosa* and *M. punctata* taxa had a greater number of flowers per plant compared to *M. didyma* and *M. didyma* cultivars, excluding *M.* Sugar Buzz ® Grape Gumball (Table 2.6, Chapter 2). In Chapter 3, we found that *M. didyma* taxa had larger inflorescence diameter, longer corollas and petals, and higher nectar volume and total sugar content per flower. *M. fistulosa* and *M. punctata* taxa had smaller inflorescence diameters, corolla and petal lengths, and total sugar content per flower. There was some overlap between nectar volume in *M. punctata* taxa and *M. didyma* cultivars and this could be due to larger corolla and petal width in *M. punctata* relative to *M. fistulosa*. The wider floral organs could be linked to a larger cavity for nectar (Erickson et al., 2022). Like conclusions in a study of ornamental asters, it is important to consider high flower density regarding nectar since the collective stand of flowers provides a rich nectar resource (Kalaman et al., 2022; Solman Raju, 2004). As seen in Chapter 2, most taxa had more inflorescences than *M. didyma* and *M. didyma* 'Jacob Cline', especially in Athens (Table 2.5). Furthermore, the nutrient requirements of bee species are based on body size, maturity, and, for social species, colony size. These factors will also influence the foraging patterns and preferences by bee pollinators (Kalaman et al., 2022; Leonhardt and Blüthgen, 2012).

Pollinators are important for many cultivated crops to ensure seed set and fruit production (Torrez et al., in press; Thapa, 2006; Kevan, 1990; McGregor, 1976). However, due to factors including habitat fragmentation and loss, pesticide usage, disease, parasites, competition with invasive species, and climate change (Torrez et al., in press; Wagner et al., 2021; Goulson et al., 2015 Potts et al., 2010) we have seen pollinator declines in and outside of the United States (Torrez et al., in press; Dicks et al., 2021; Vasiliev and Greenwood, 2021; Zattara and Aizen, 2021; Johnson, 2010). Many private and public organizations, including the Xerces Society, Natural Resources Conservation Service, and State Botanical Garden of Georgia, have been promoting pollinator conservation by encouraging land-owners to mitigate habitat loss through programs that use native plants in human-dominated landscapes, such as home gardens, pastures, and urban landscapes (Torrez et al., in press; State Botanical Garden of Georgia, 2023; Xerces Society, 2022; United States Department of Agriculture, 2021). As human cultivation of native plants influences trait selection in a traditionally mutualistic relationship between plant and pollinator, it is important to continue to assess new ornamental varieties for their resource value in a site- and species- specific context, allowing us to make informed choices in creating landscape designs that support wildlife (Kalaman et al., 2022).

Conclusion. These studies were designed to inform the Georgia ornamental industry, landowners, park managers, civic entities, and consumers on the resource value of select *Monarda* species and cultivars and assess the effect of differences in flower morphology on insect abundance. We documented significant differences in diameter of inflorescence, length and width of corolla and petal, and nectar volume and total sugar content among ten *Monarda* taxa grown in montane and piedmont sites in Georgia. However, these differences did not correlate to overall insect abundance, despite seeing differences in insect abundance among select *Monarda* taxa. Studies that quantify differences in floral phenotypes within a genus are useful in understanding the relationships between floral morphology, nectar production, and pollination under human-mediated trait selection. The following chapter will detail differences in insect communities visiting the same *Monarda* taxa.

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CHAPTER 4

THE INSECT GROUPS FOUND ON SELECT *MONARDA* TAXA IN GEORGIA

Introduction.

Not all plants, or native plants, provide equal value to wildlife. Some can be considered more helpful than others, like plants that benefit specialist insects (i.e. larval host plants and obligate pollination mutualisms) versus those that benefit generalist pollinators versus those that provide no value to wildlife (i.e. non-native, cultivated varieties that render floral parts absent or inaccessible) (Tallamy, 2007). Pollinators are crucial to ensure seed set and fruit production of many cultivated crops (Torrez et al., in press; Thapa, 2006; Kevan, 1990; McGregor, 1976). However, pollinator declines in and outside of the United States (Torrez et al., In Press; Dicks et al., 2021; Vasiliev and Greenwood, 2021; Zattara and Aizen, 2021; Johnson, 2010) due to habitat fragmentation and loss, pesticide usage, disease, parasites, competition with invasive species, and climate change (Torrez et al., in press; Wagner et al., 2021; Goulson et al., 2015; Potts et al., 2010) have led many private and public organizations to encourage the use of native plants in human landscapes to mitigate habitat loss (Torrez et al., in press; State Botanical Garden of Georgia, 2023; Xerces Society, 2022; United States Department of Agriculture, 2021).

We use cultivars in the Green Industry to streamline production and marketing appeal to consumers (Erickson, 2022). Cultivars of native plants increase their availability and desirability to consumers, but we also need to understand the effect of human-mediated trait selection on wildlife (Erickson, 2022). Publications that compare the value of native plants and cultivars in their ability to attract wildlife are becoming numerous (Braman et al. 2022; Tew et al., 2021; Seitz et al., 2020; Native Plant Partnership, 2014; Williams et al., 2011). The value of *Monarda* taxa for insects is well documented. The glomerule inflorescence (a condensed cyme of flowers), provide a dense nectar source and calories for pollinators and beneficial insects (such as predatory and parasitic wasps) (Willmer, 2011). Beebalms are often included in seed mixes to provide summer forage to wildlife (Rubio et al. 2022; Wolf et al. 2022; Quinlan et al. 2021; Otto et al. 2017; Gray et al. 2007) and provides nectar and pollen to the Ruby-throated Hummingbird (*Archilochus colubris*), bumblebees (*Bombus* spp.), and a variety of other wild bees, Lepidoptera, Diptera, Coleoptera, and Hemiptera (Cruden et al., 1984; Whitten, 1981).

We evaluated select *Monarda* species native to Georgia and cultivars established in the trade to document floral visitor abundance among species and cultivars. Our objective was to determine if *Monarda* cultivars are less valuable for supporting wildlife than native *Monarda* species. As we strive to understand the influence of breeding and commercial production practices on the ability of native plant species to support wildlife, we must continue to gather empirical information to guide consumer choice (Braman et al., 2022; Lewis et al., 2020; Rollings and Goulson, 2019; Poythress and Affolter, 2018; Garbuzov and Ratneiks, 2014).

To test the hypothesis that select cultivars of *Monarda* taxa have different abundance and density of insects than some *Monarda* species native to Georgia, we sampled the insect communities among the taxa represented at our Georgia Mountain Research and Education Center (GMREC) and Mimsie Lanier Center for Native Plant Studies (MCLNPS) experimental sites in the Georgia mountains and piedmont. In this chapter, we document the phenology; differences in the sample mean of pollinators, beneficial insects, and plant pests; and density, range, and diversity of captured insects among select *Monarda* taxa at these two sites (for two years at GMREC and for one year at MLCNPS).

MATERIALS AND METHODS

This study was conducted at the two University of Georgia experimental plots described in Chapter 2. The Blairsville site has been abbreviated as GMREC (Georgia Mountain Research and Education Center) and the Athens site has been abbreviated as MLCNPS (Mimsie Lanier Center for Native Plant Studies) to present the results. Each garden site had one plant per replication and seven replications per taxon. Replications were randomized per row and one of each treatment (taxa) per row. The raised beds were provided with drip irrigation for the establishment and supplemental watering during periods of severe drought. Plants were top-dressed with slow-release fertilizer and mulched with pine bark nuggets each spring.

Wildlife observations were made during the peak period of anthesis between 10 AM and 2 PM on sunny days with light, variable wind, and low cloud cover. While some flower-visiting insects are active outside of these conditions, that is the standard period for flower visitation assessment (Braman et. al. 2022). Insects were aspirated and then the plants were sweep netted in a randomized order for all plants in peak anthesis. The insect samples were frozen until being pinned with capture labels. Then, they were identified to order, superfamily, family, genus, or species (*Apis mellifera mellifera* only) where possible. There were 173 total observations in Blairsville 2020, Blairsville 2021, and Athens 2021. In 2020 at GMREC, plants were observed on seventeen days between June and October (Fig. 4.1). At the same site in 2021, observations were on twelve days between June and October (Fig. 4.1). In the same year (2021) at MLCNPS, observations were made on twelve days between June and October (Fig. 4.2).

The methodology for wildlife observations did not accommodate lepidoptera or avian visitors. These were documented photographically (Appendix B). When the observer approached a stand of flowers, lepidoptera and birds tended to move away from the stand under observation. Despite seeing activity in both gardens from these groups, we were not able to statistically analyze these observations.

Data analysis. Methods were adapted from Torrez et al. (in press) to suit our experimental design. Independently for replication all insect visitation counts, in their respective insect order, were added across each year and site. Additionally, the abundance of three functional groups was counted. These groups were pollinators (Apidae, Coletidae, Halicitidae, Megachilidae, and Lepidoptera), beneficial insects [Araneae, aculeate and parasitic wasps (Parasitica, defined as a paraphyletic group without formal taxonomic status), Dolichopodidae, Syrphidae, Tachinidae, Anthocoridae, Geocoridae, Cantharidae, Coccinellidae, and Mordellidae), and plant pests (Scarabaeidae, Chrysomelidae, Curculionidae, Anthocoridae, Aphididae, Berytidae, Cercopoidea, Cicadellidae, Coreidae, Lygaeidae, Miridae, Pentatomidae, Rhopalidae, Rhyparochromidae, and Thyreocoridae).

Data was analyzed separately by site and year as a one-way ANOVA (P<0.05) by GLM procedure in R (R Core Team, 2018). *Monarda* taxon was assigned as the fixed effect in the ANOVA table for each insect group. Multiple comparisons were made using Tukey’s honestly significant difference (HSD) test and separation of means with the **’emmeans’** package (Lenth et al. 2022) at alpha less than or equal to 0.05 in R (R Core Team, 2018). For all sites and years, counts for total insects captured showed too much variation to run ANOVA with transformation. Therefore, all insect group data was log-transformed and run with a negative binomial distribution, then back-transformed to report means and significant differences with **‘MASS’** and **‘emmeans’** (Lenth et al., 2022; Venables and Ripley, 2002).

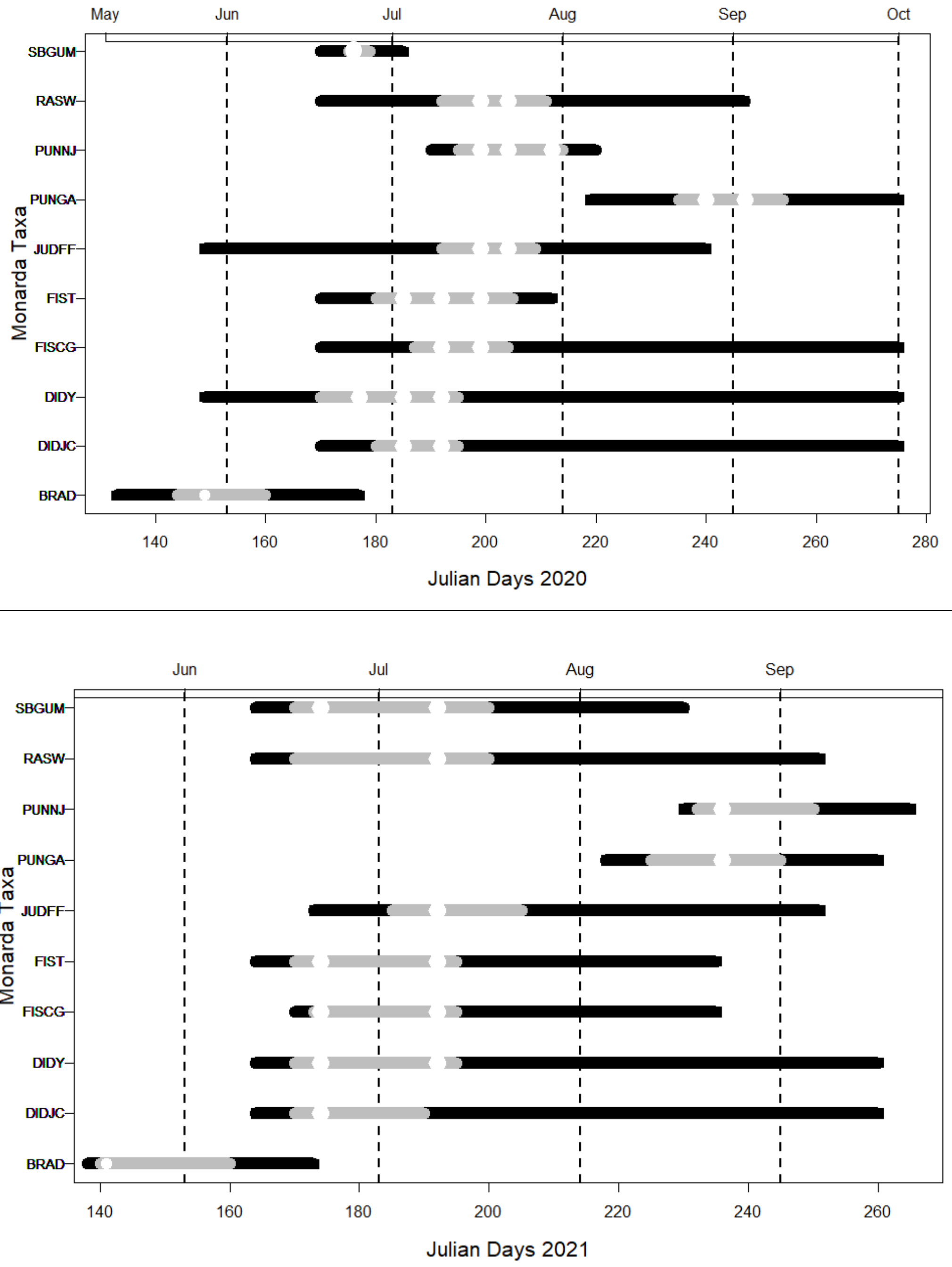
To show the density, range, and diversity of captured insects per *Monarda* taxon, heat charts were generated using conditional formatting in Microsoft Excel 2016, following methods in Torrez et al. (in press). Colors on heat charts represent the density ranges of insect families on each *Monarda* taxon. Columns were included to indicate the percent composition of insect families or genera of each insect order.

RESULTS

Bloom time varied among *Monarda* taxa in all sites and years (Fig.4.1 and 4.2). Due to the early bloom of *M. bradburiana*, this taxon was excluded from the insect analysis, as the plot did not attract enough insects when only a single taxon was in flower in late spring or early summer. In all sites and years, other taxa began to bloom in June, except *M. punctata* ecotypes. *M. punctata* began flowering in June, July, or August and ended flowering in September or October. *M.* Sugar Buzz® 'Grape Gumball' was the first to stop blooming in July or August. *M. fistulosa* taxa tended to stop blooming in late July but could continue blooming until October. Some *M. didyma* and *M. didyma* cultivars also continued to produce flowers until October.

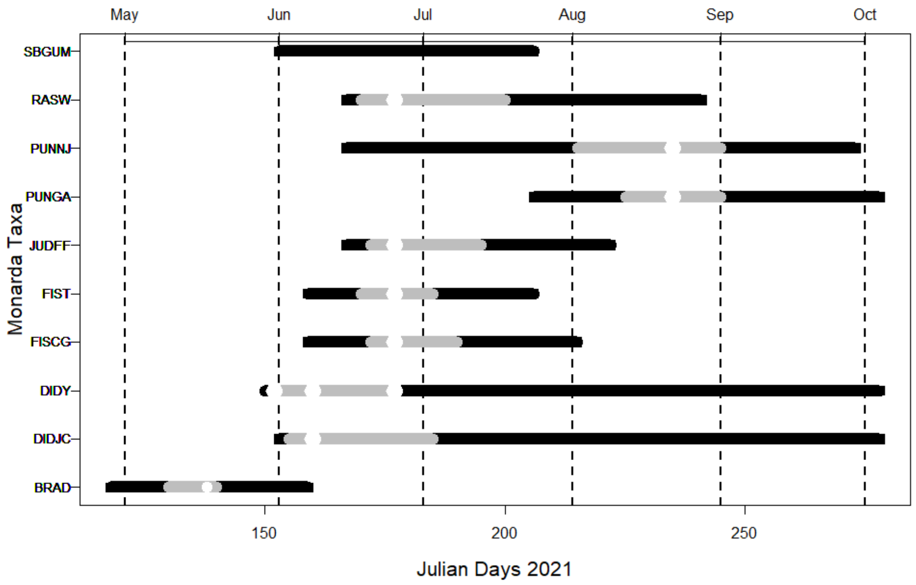
At all sites and years, plants were only sampled during peak bloom. For example, at GMREC in 2020, *M.* Sugar Buzz® 'Grape Gumball' was sampled in June, *M. didyma* was sampled in June and July, and all other taxa, except *M. punctata* (GA), were sampled in July. *M. punctata* (GA) was sampled in August and September (Fig. 4.1). At the same site (GMREC) in 2021, most taxa were sampled in June and July, excluding *M. didyma* 'Jacob Cline' (sampled in June), *M.* x 'Raspberry Wine' and *M.* x 'Judith's Fancy Fuchsia' (sampled in June), and *M. punctata* ecotypes (sampled in August) (Fig. 4.1).

Figure 4.1 *Monarda* phenology in Blairsville 2020 and 2021. First and last date of bloom (represented by left and right ends of the black bar), estimated peak bloom period (grey bar), and insect observation dates (white dots) for each *Monarda* taxon (BRAD = *M. bradburiana*, JUDFF = *M. x* 'Judith's Fancy Fuchsia', DIDY = *M. didyma*, DIDYJC = *M. didyma* 'Jacob Cline', RASW = *M.* 'Raspberry Wine', SBGUM = *M.* Sugar Buzz® 'Grape Gumball', FIST = *M. fistulosa*, FISCG = *M. fistulosa* 'Claire Grace', PUNNJ = *M. punctata* (unknown provenance sourced from New Moon Nursery), and PUNGA = *M. punctata* (Georgia seed sourced from MLCNPS).



At MLCNPS in 2021 most taxa were sampled in June. *M. punctata* ecotypes were sampled in August (Fig. 4.2). *M.* Sugar Buzz® 'Grape Gumball' was not sampled due to lack of establishment and low flower set.

Figure 4.2. *Monarda* phenology in Athens 2021. First and last date of bloom (represented by left and right ends of the black bar), estimated peak bloom period (grey bar), and insect observation dates (white dots) for each *Monarda* taxon (BRAD = *M. bradburiana*, JUDFF = *M. x* 'Judith's Fancy Fuchsia', DIDY = *M. didyma*, DIDYJC = *M. didyma* 'Jacob Cline', RASW = *M.* 'Raspberry Wine', SBGUM = *M.* Sugar Buzz® 'Grape Gumball', FIST = *M. fistulosa*, FISCG = *M. fistulosa* 'Claire Grace', PUNNJ = *M. punctata* (unknown provenance sourced from New Moon Nursery), and PUNGA = *M. punctata* (Georgia seed sourced from MLCNPS).



At GMREC in 2020, mean visitation values of pollinator and beneficial insect groups differed among some *Monarda* taxa. The plant pest group did not differ in abundance among tested *Monarda* taxa (Table 4.1). *M.* x ‘Judith’s Fancy Fuchsia’ had the most pollinators and was significantly higher than *M.* Sugar Buzz ® Grape Gumball Bee Balm, *M. fistulosa* ‘Claire Grace’, and *M. punctata* ecotypes. *M.* Sugar Buzz ® Grape Gumball Bee Balm had the least visitation from the pollinator group. *M. didyma* ‘Jacob Cline’ and *M. punctata* GA had the most beneficial insect abundance, higher than *M.* Sugar Buzz ® Grape Gumball Bee Balm.

Table 4.1. Visitation mean (± SE) comparison for *Monarda* taxa and insect pollinators, beneficial insects, and plant pests (average number of insects per plant) across the 2020 sampling period at Georgia Mountain Research and Education Center.

***Monarda* taxa**	**Pollinators**		**Beneficial Insects**		**Plant Pests**
M. Sugar Buzz ® Grape Gumball Bee Balm	2.33 (± 0.89)	a	0.17 (± 0.19)	a	0.67 (± 0.41)
M. didyma	10.00 (± 2.79)	ab	1.29 (± 0.72)	ab	2.57 (± 1.04)
M. didyma ‘Jacob Cline’	6.57 (± 1.92)	ab	8.00 (± 3.77)	b	2.43 (± 0.99)
M. x ‘Judith’s Fancy Fuchsia’	15.29 (± 4.12)	b	1.71 (± 0.92)	ab	0.86 (± 0.45)
M. ‘Raspberry Wine’	7.43 (± 2.13)	ab	1.00 (± 0.32)	ab	1.43 (± 0.65)
M. fistulosa	7.14 (± 2.06)	ab	1.86 (± 0.99)	ab	0.57 (0.34)
M. fistulosa ‘Claire Grace’	3.57 (± 1.15)	a	0.71 (± 0.45)	ab	0.14 (± 0.15)
M. punctata GA	3.71 (± 1.19)	a	7.71 (± 3.64)	b	1.86 (± 0.80)
M. punctata NJ	3.71 (± 1.19)	a	4.71 (± 2.28)	ab	2.57 (± 1.04)

Means sharing the same letter within a column for each insect group indicate no statistically significant difference based on a one-way ANOVA ($p < 0.05$) and Tukey’s at an alpha level of 0.05.

At GMREC in 2021, mean visitation within the pollinator group differed among some *Monarda* taxa. The beneficial insect and plant pest groups did not differ in abundance among tested *Monarda* taxa (Table 4.2). *M. fistulosa* had the most pollinators and was significantly higher than all taxa except *M.* x 'Judith's Fancy Fuchsia' and *M.* 'Raspberry Wine'. *M.* Sugar Buzz ® Grape Gumball Bee Balm had the least visitation within the pollinator group, but was no different from *M. didyma*, *M. didyma* 'Jacob Cline', *M. fistulosa* 'Claire Grace', or *M. punctata* ecotypes.

Table 4.2. Visitation mean (± SE) comparison for *Monarda* taxa and insect pollinators, beneficial insects, and plant pests (average number of insects per plant) across the 2021 sampling period at Georgia Mountain Research and Education Center.

***Monarda* taxa**	**Pollinators**		**Beneficial Insects**	**Plant Pests**
M. Sugar Buzz ® Grape Gumball Bee Balm	3.57 (± 0.92)	a	0.29 (± 0.24)	0.00 (±0.01)
M. didyma	3.71 (± 1.08)	a	0.00 (± 0.01)	0.71 (± 0.48)
M. didyma 'Jacob Cline'	5.43 (± 1.25)	a	2.14 (± 1.06)	0.14 (± 0.16)
M. x 'Judith's Fancy Fuchsia'	16.00 (± 3.03)	bc	0.57 (± 0.37)	1.71 (± 1.00)
M. 'Raspberry Wine'	15.29 (± 2.91)	bc	1.14 (± 0.63)	0.86 (± 0.56)
M. fistulosa	19.14 (± 3.55)	c	1.00 (± 0.57)	0.29 (± 0.25)
M. fistulosa 'Claire Grace'	7.14 (± 1.55)	ab	1.14 (± 0.63)	1.86 (± 1.07)
M. punctata GA	4.43 (± 1.08)	a	2.43 (± 1.06)	1.57 (± 0.92)
M. punctata NJ	5.20 (± 1.44)	a	0.60 (± 0.46)	1.00 (± 0.75)

Means sharing the same letter within a column for each insect group indicate no statistically significant difference based on a one-way ANOVA ($p < 0.05$) and Tukey's at an alpha level of 0.05.

At MLCNPS in 2021, mean visitation of pollinator and beneficial insect groups differed among some *Monarda* taxa. The plant pest group did not differ in abundance among tested *Monarda* taxa (Table 4.3). *M. punctata* NJ had the most pollinators and was significantly higher than *M. didyma* 'Jacob Cline' and *M. punctata* GA. *M. didyma* and *M. didyma* 'Jacob Cline' had the least visitation from the pollinator group. *M. punctata* NJ had the most beneficial insect abundance, higher than all taxa.

Table 4.3. Visitation mean (± SE) comparison for *Monarda* taxa^{z} and insect pollinators, beneficial insects, and plant pests (average number of insects per plant) across the 2021 sampling period at Mimsie Lanier Center for Native Plant Studies.

***Monarda* taxa**	**Pollinators**		**Beneficial Insects**		**Plant Pests**
M. didyma	0.00 (± 0.01)	abc	0.00 (± 0.01)	ab	02.50 (± 1.82)
M. didyma 'Jacob Cline'	0.50 (± 0.32)	a	0.00 (± 0.01)	ab	0.83 (± 0.46)
M. x 'Judith's Fancy Fuchsia'	6.57 (± 1.83)	bc	0.86 (± 0.43)	a	0.71 (± 0.39)
M. 'Raspberry Wine'	7.00 (± 1.93)	bc	0.43 (± 0.28)	a	1.00 (± 0.49)
M. fistulosa	5.43 (± 1.55)	bc	0.43 (± 0.28)	a	0.29 (± 0.22)
M. fistulosa 'Claire Grace'	4.57 (± 1.35)	bc	0.86 (± 0.43)	a	0.57 (± 0.34)
M. punctata GA	2.00 (± 0.71)	ab	1.00 (± 0.48)	a	0.00 (± 0.01)
M. punctata NJ	7.86 (± 2.13)	c	7.00 (± 2.26)	b	2.71 (± 1.04)

Means sharing the same letter within a column for each insect group indicate no statistically significant difference based on a one-way ANOVA ($p < 0.05$) and Tukey's at an alpha level of 0.05.
^{z} *M.* Sugar Buzz ® Grape Gumball Bee Balm Did not establish at this site.

In total, 2,228 insects were captured and counted at GMREC in 2020 and 2021 and at MLCNPS in 2021. At GMREC in 2020, 1,058 insects were captured (Fig. 4.3); these were split among the orders as follows: Hymenoptera (562), Diptera (388), Hemiptera (82), Coleoptera (23), and Lepidoptera (3). Hymenoptera counts were composed of Halicitidae (273), Apidae (137), Parasitica (103), wasps in Aculeata (35), Formicidae (5), and Coletidae (3). Diptera counts consisted of Syrphidae (16), Tachinidae (12), and Dolichopodidae (4). The remaining Diptera (356) were not identified to family. Hemiptera counts consisted of Rhopalidae (30), Cicadellidae (16), Miridae (12), Geocoridae (6), Pentatomidae (6), Rhyparochromidae (6), Anthocoridae (2), Berytidae (2), Coreidae (1), and Lygaeidae (1). Coleoptera counts included family representation from Scarabaeidae (15), Coccinellidae (4), Cantharidae (1), Chrysomelidae (1), Curculionidae (1), and Mordellidae (1). Lepidoptera counts were composed of the family Hesperiidae (3). There were 416 individuals in the pollinator group, 190 beneficial, and 91 plant pests.

At the same site in 2021 774 insects were captured (Fig. 4.4); these were split among the orders as follows: Hymenoptera (585), Diptera (121), Hemiptera (55), Coleoptera (7), Lepidoptera (4), and Aranaeae (2). Hymenoptera consisted of Halicitidae (420), Apidae (122), wasps in Aculeata (24), Parasitica (12), Formicidae (4), and Megachilidae (3). Diptera counts included Syrphidae (18), Tachnidae (1), and one-hundred-two individuals that were not identified to family. The Hemiptera order was composed of Cicadellidae (16), Miridae (15), Rhopalidae (10), Coreidae (5), Anthocoridae (3), Geocoridae (3), Berytidae (1), Pentatomidae (1), and Reduviidae (1). Coleoptera consisted of Scarabaeidae (5), Mordellidae (1), and Chrysomelidae (1). The order Lepidoptera included representation from Hesperiidae (4); individuals counted in Aranaeae were not identified below order. There were 549 individuals in the pollinator group, 64 beneficial, and 55 plant pests.

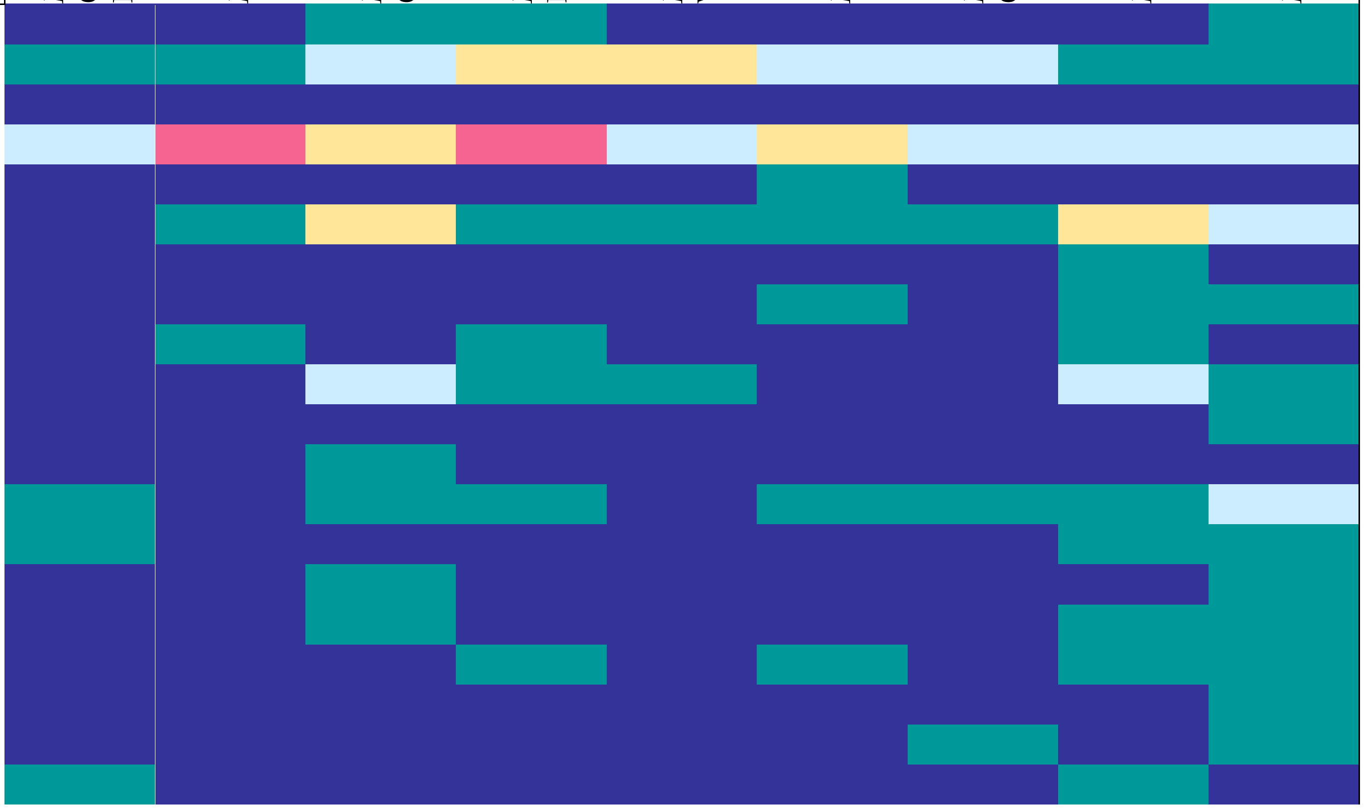
At MLCNPS in 2021 396 insects were captured (Fig. 4.5); these were split among the orders as follows: Hymenoptera (291), Hemiptera (48), Diptera (44), Coleoptera (9), Aranaeae (3), and Lepidoptera (1). The Hymenoptera order was composed of Apidae (163), Halicitidae (70), Aculeata (30), Parasitica (25), and Megachilidae (3). Hemiptera counts consisted of Miridae (14), Cicadellidae (12), Rhopalidae (7), Anthocoridae (3), Geocoridae (3), Pentatomidae (3), Aphidoidea (1), Cercopoidea (1), Lygaeidae (1), Reduviidae (1), Rhyparochromidae (1), and Thyreocoridae (1). Captured Diptera included Syrphidae (5) and Dolichopodidae (1), where the remaining individuals were not identified to family. Coleoptera counts were composed of Mordellidae (4), Chrysomelidae (3), Curculionidae (1), and Scarabaeidae (1). Captured Lepidoptera were not identified past moth and Aranaeae individuals were not identified below order. There were 237 individuals in the pollinator group, 74 beneficial, and 47 plant pests.

At GMREC in 2020 Apidae was captured on all taxa but was mostly found on *M.* x 'Judith's Fancy Fuchsia' and *M.* x ‘Raspberry Wine’ (Fig. 4.3). Halictidae was also captured on all taxa but was mostly found on *M. didyma* and *M.* x 'Judith's Fancy Fuchsia'. Parasitic wasps were found on all taxa except *M.* Sugar Buzz ® Grape Gumball Bee Balm, and mostly on *M. didyma* ‘Jacob Cline’ and *M. punctata* ecotypes. Of the parasitic wasps, Cynipidae was the most common, found on *M. didyma* ‘Jacob Cline’, *M.* x ‘Judith’s Fancy Fuchsia’, *M.* x ‘Raspberry Wine’, and *M. punctata* ecotypes. Wasps in Aculeata were captured on all taxa except *M.* x ‘Raspberry Wine’ and *M. didyma*. Rhopalidae was the most common hemipteran, found mostly on *M. punctata*.

At GMREC in 2021 Apidae and Halictidae were captured on all taxa. Apidae had lower counts among *M.* Sugar Buzz ® Grape Gumball Bee Balm and *M. didyma* ‘Jacob Cline’ (Fig. 4.4). Halictidae counts were highest among *M. fistulosa* and lowest among *M. punctata* (NJ). Parasitic wasps were only captured on *M.* x ‘Judith’s Fancy Fuchsia’, *M.* x ‘Raspberry Wine’, *M. fistulosa* taxa and *M. punctata* (GA). Wasps in aculeata were not captured on *M.* Sugar Buzz ® Grape Gumball Bee Balm, *M. didyma, M.* x ‘Judith’s Fancy Fuchsia’, or *M. fistulosa*. Wasps in aculeata were most captured on *M. punctata* (GA).

At MLCNPS in 2021 Apidae and Halictidae were the most captured families (Fig. 4.5). Apidae was not captured on *M. didyma* and was most captured on *M.* x ‘Judith’s Fancy Fuchsia’, *M.* x ‘Raspberry Wine’, *M. fistulosa* and *M. punctata* (NJ). Halictidae was not captured on *M. didyma, M. didyma* ‘Jacob Cline’, or *M. punctata* (GA). Halictidae was most captured on *M. punctata* (NJ). Aculeate wasps were found in high numbers on *M. punctata* (NJ), most counts being Sphecidae.

Figure 4.3 Heat chart for insect families captured in *Monarda* taxa at Georgia Mountain Research and Education Center, Blairsville, Georgia in 2020. The percent composition of insect family column indicates the percentage of counts of that family relative to total individuals captured within the same order.



Insect family	Percent composition of insect family	*M.* Sugar Buzz ® Grape Gumball Bee Balm	*M. didyma*	*M. didyma* 'Jacob Cline'	*M.* x 'Judith's Fancy Fuchsia'	*M.* x 'Raspberry Wine'	*M. fistulosa*	*M. fistulosa* 'Claire Grace'	*M. punctata* (GA)	*M. punctata* (NJ)
Formicidae	1	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟦	🟩
Apidae	24	🟩	🟩	⬜	🟨	🟨	⬜	⬜	🟩	🟩
Megachilidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Halicitidae	49	⬜	🟥	🟨	🟥	⬜	🟨	⬜	⬜	⬜
Coletidae	1	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦
Parasitica	19	🟦	🟩	🟨	🟩	🟩	🟩	🟩	🟨	⬜
Bethylidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦
Braconidae	1	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟩	🟩
Ichneumonidae	1	🟦	🟩	🟦	🟩	🟦	🟦	🟦	🟩	🟦
Cynipidae	8	🟦	🟦	⬜	🟩	🟩	🟦	🟦	⬜	🟩
Platygastridae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Scelionidae	0	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦
Aculeata	6	🟩	🟦	🟩	🟩	🟦	🟩	🟩	🟩	⬜
Vespidae	1	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
Sphecidae	2	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟩
Scoliidae	2	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟩	🟩
Crabronidae	2	🟦	🟦	🟦	🟩	🟦	🟩	🟦	🟩	🟩
Pompilidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Thynnidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟩
Hesperiidae	100	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦

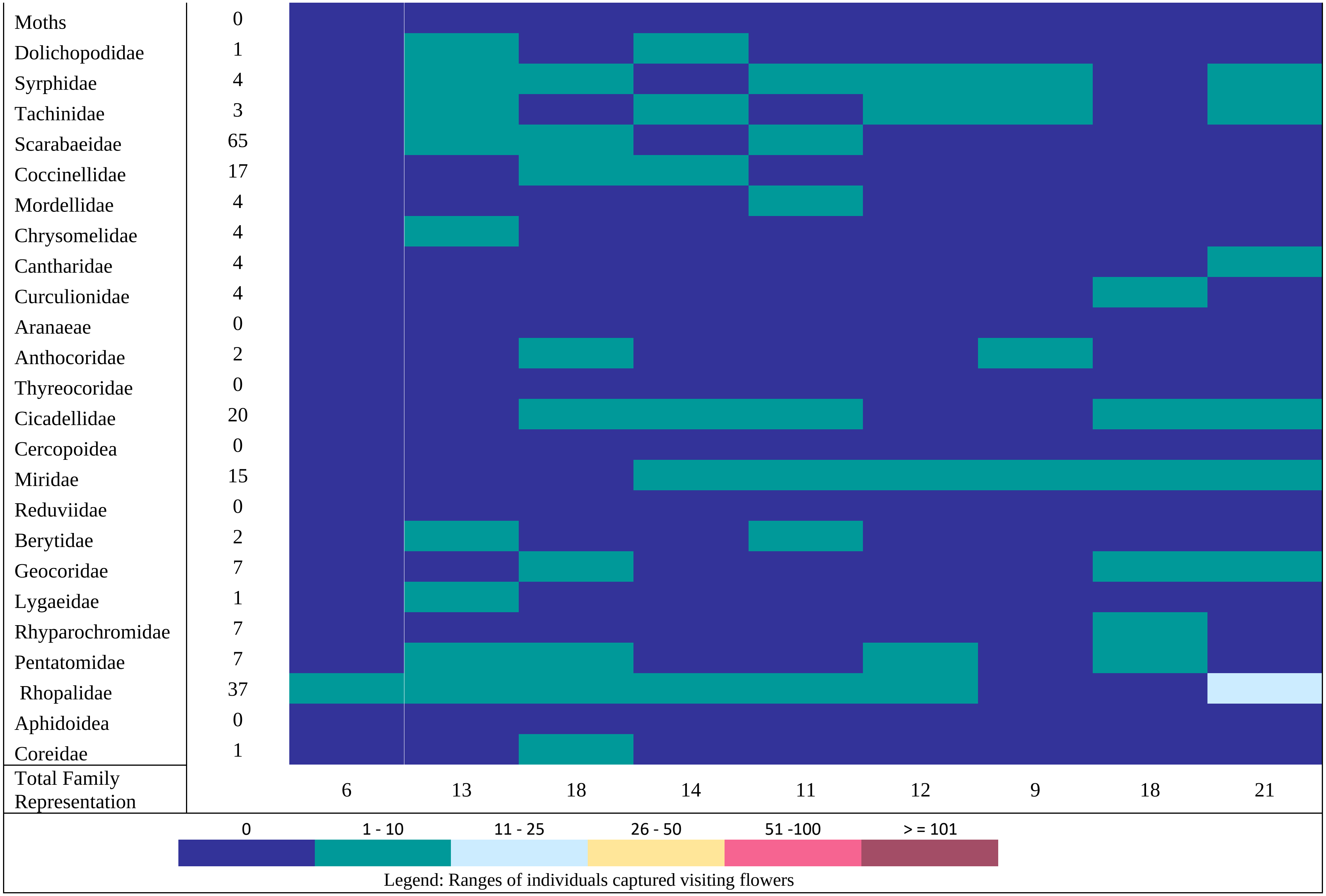
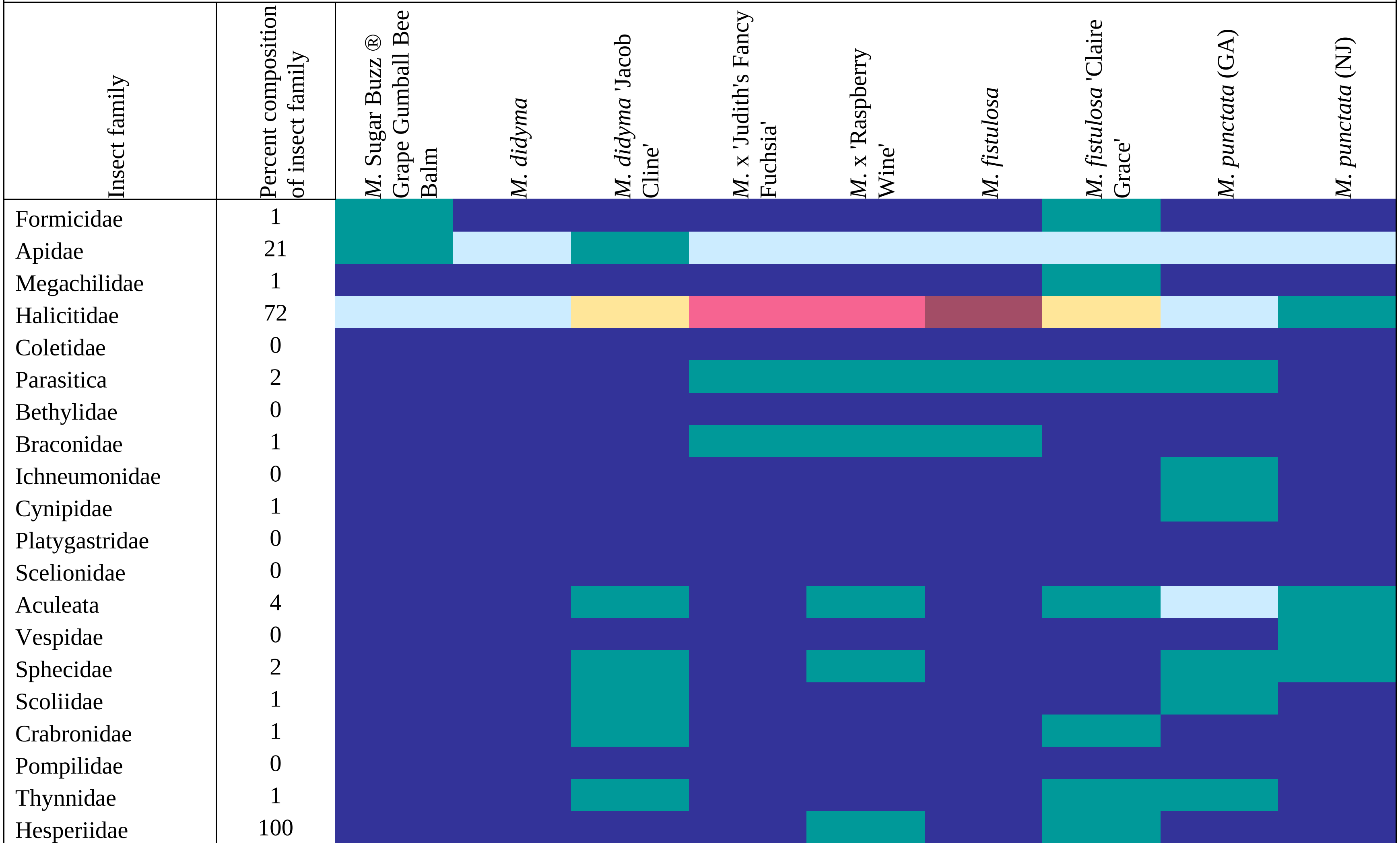
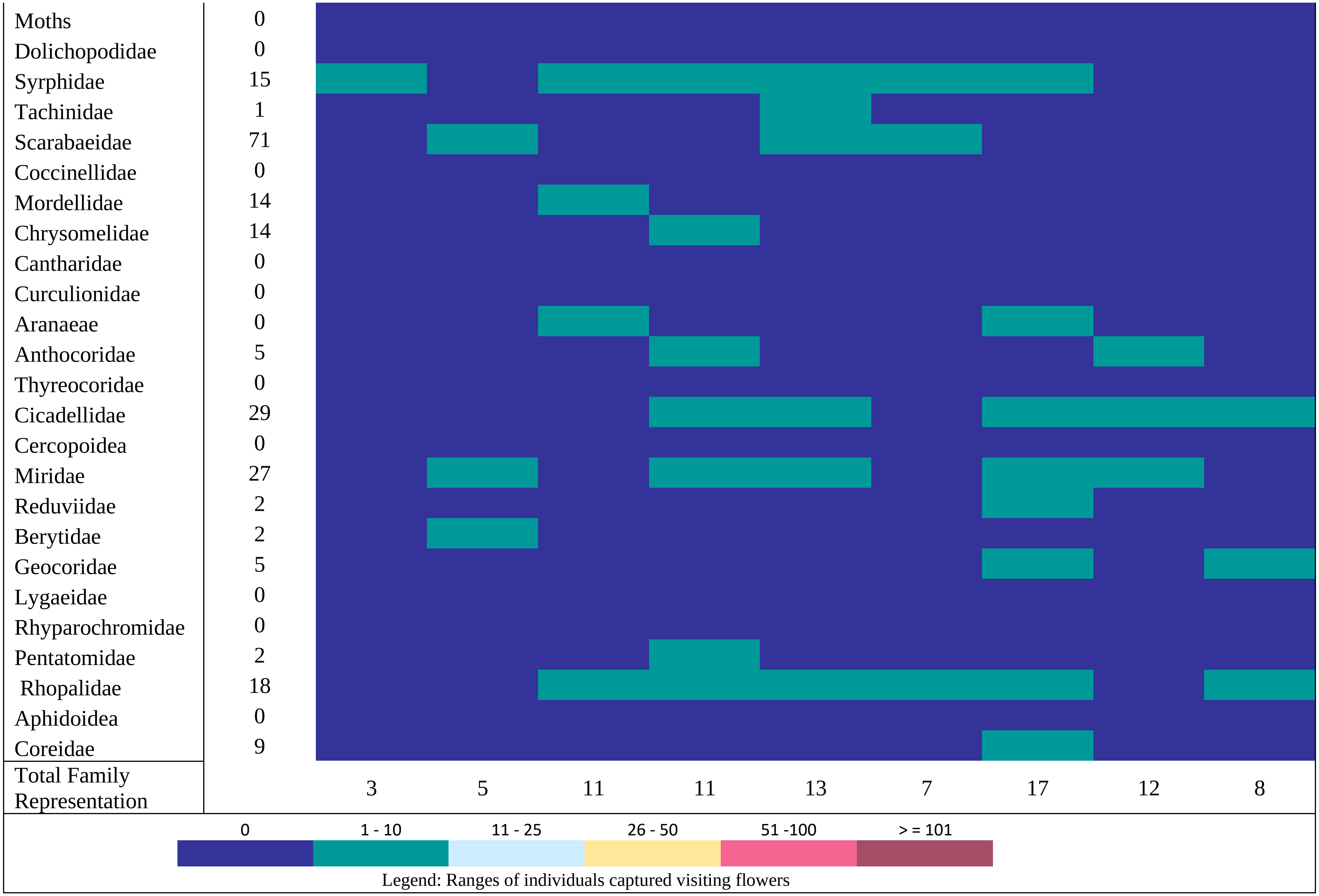


Figure 4.4 Heat chart for insect families captured in *Monarda* taxa at Georgia Mountain Research and Education Center, Blairsville, Georgia in 2021. The percent composition of insect family column indicates the percentage of counts of that family relative to total individuals captured within the same order.



Insect family	Percent composition of insect family	*M.* Sugar Buzz ® Grape Gumball Bee Balm	*M. didyma*	*M. didyma* 'Jacob Cline'	*M.* x 'Judith's Fancy Fuchsia'	*M.* x 'Raspberry Wine'	*M. fistulosa*	*M. fistulosa* 'Claire Grace'	*M. punctata* (GA)	*M. punctata* (NJ)
Formicidae	1	🟩	🟪	🟪	🟪	🟪	🟪	🟩	🟪	🟪
Apidae	21	🟩	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜
Megachilidae	1	🟪	🟪	🟪	🟪	🟪	🟪	🟩	🟪	🟪
Halicitidae	72	⬜	⬜	🟨	🟥	🟥	🟫	🟨	⬜	🟩
Coletidae	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Parasitica	2	🟪	🟪	🟪	🟩	🟩	🟩	🟩	🟩	🟪
Bethylidae	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Braconidae	1	🟪	🟪	🟪	🟩	🟩	🟩	🟪	🟪	🟪
Ichneumonidae	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟩	🟪
Cynipidae	1	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟩	🟪
Platygastridae	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Scelionidae	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Aculeata	4	🟪	🟪	🟩	🟪	🟩	🟪	🟩	⬜	🟩
Vespidae	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟩
Sphecidae	2	🟪	🟪	🟩	🟪	🟩	🟪	🟪	🟩	🟩
Scoliidae	1	🟪	🟪	🟩	🟪	🟪	🟪	🟪	🟩	🟪
Crabronidae	1	🟪	🟪	🟩	🟪	🟪	🟪	🟩	🟪	🟪
Pompilidae	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Thynnidae	1	🟪	🟪	🟩	🟪	🟪	🟪	🟩	🟩	🟪
Hesperiidae	100	🟪	🟪	🟪	🟪	🟩	🟪	🟩	🟪	🟪

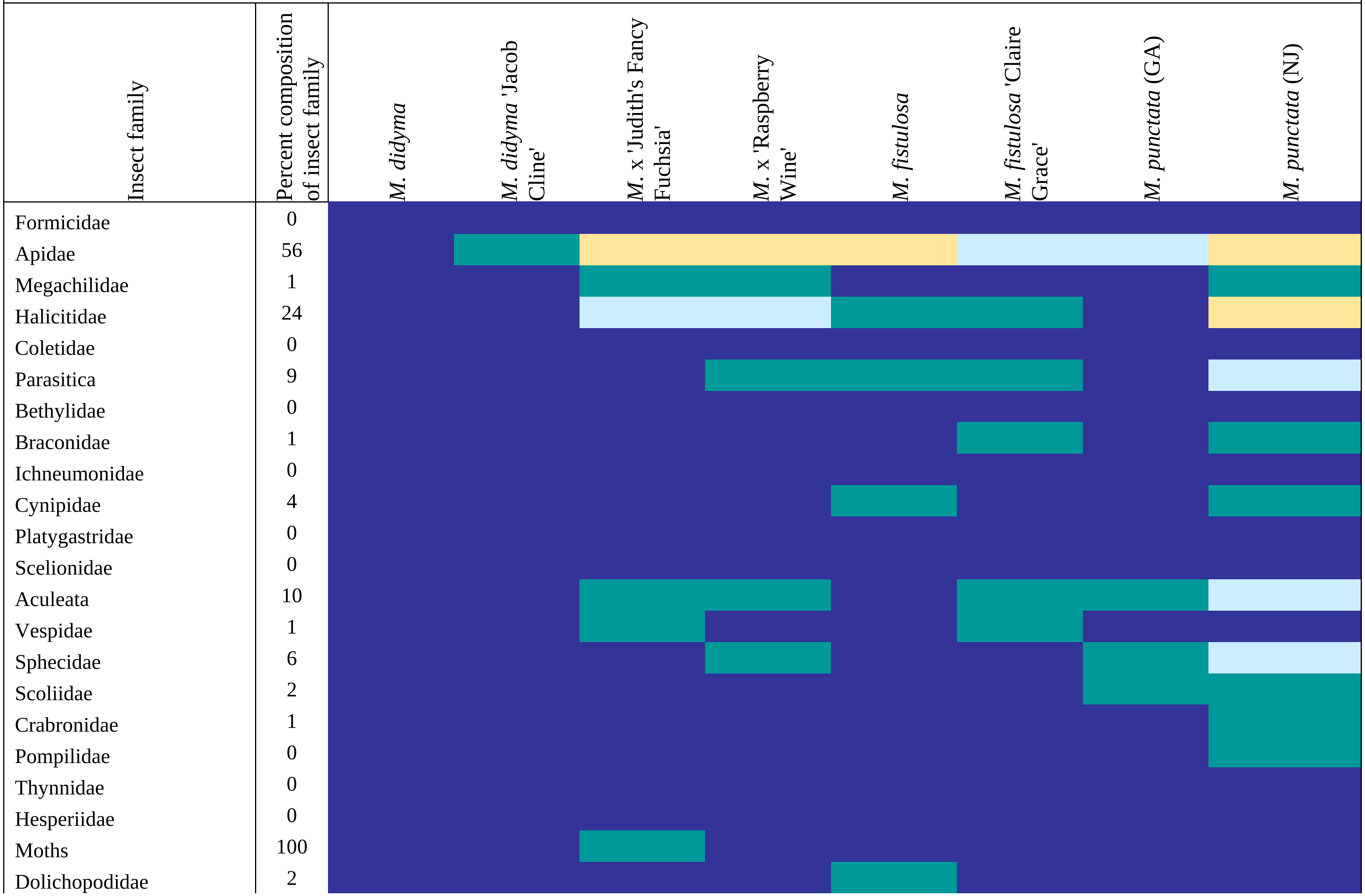


Moths	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Dolichopodidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Syrphidae	15	🟩	🟦	🟩	🟩	🟩	🟩	🟩	🟦	🟦
Tachinidae	1	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦
Scarabaeidae	71	🟦	🟩	🟦	🟦	🟩	🟩	🟦	🟦	🟦
Coccinellidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Mordellidae	14	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦
Chrysomelidae	14	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
Cantharidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Curculionidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Aranaeae	0	🟦	🟦	🟩	🟦	🟦	🟦	🟩	🟦	🟦
Anthocoridae	5	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟩	🟦
Thyreocoridae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Cicadellidae	29	🟦	🟦	🟦	🟩	🟩	🟦	🟩	🟩	🟩
Cercopoidea	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Miridae	27	🟦	🟩	🟦	🟩	🟩	🟦	🟩	🟩	🟦
Reduviidae	2	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
Berytidae	2	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Geocoridae	5	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟩
Lygaeidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Rhyparochromidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Pentatomidae	2	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
Rhopalidae	18	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟦	🟩
Aphidoidea	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Coreidae	9	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
Total Family Representation		3	5	11	11	13	7	17	12	8

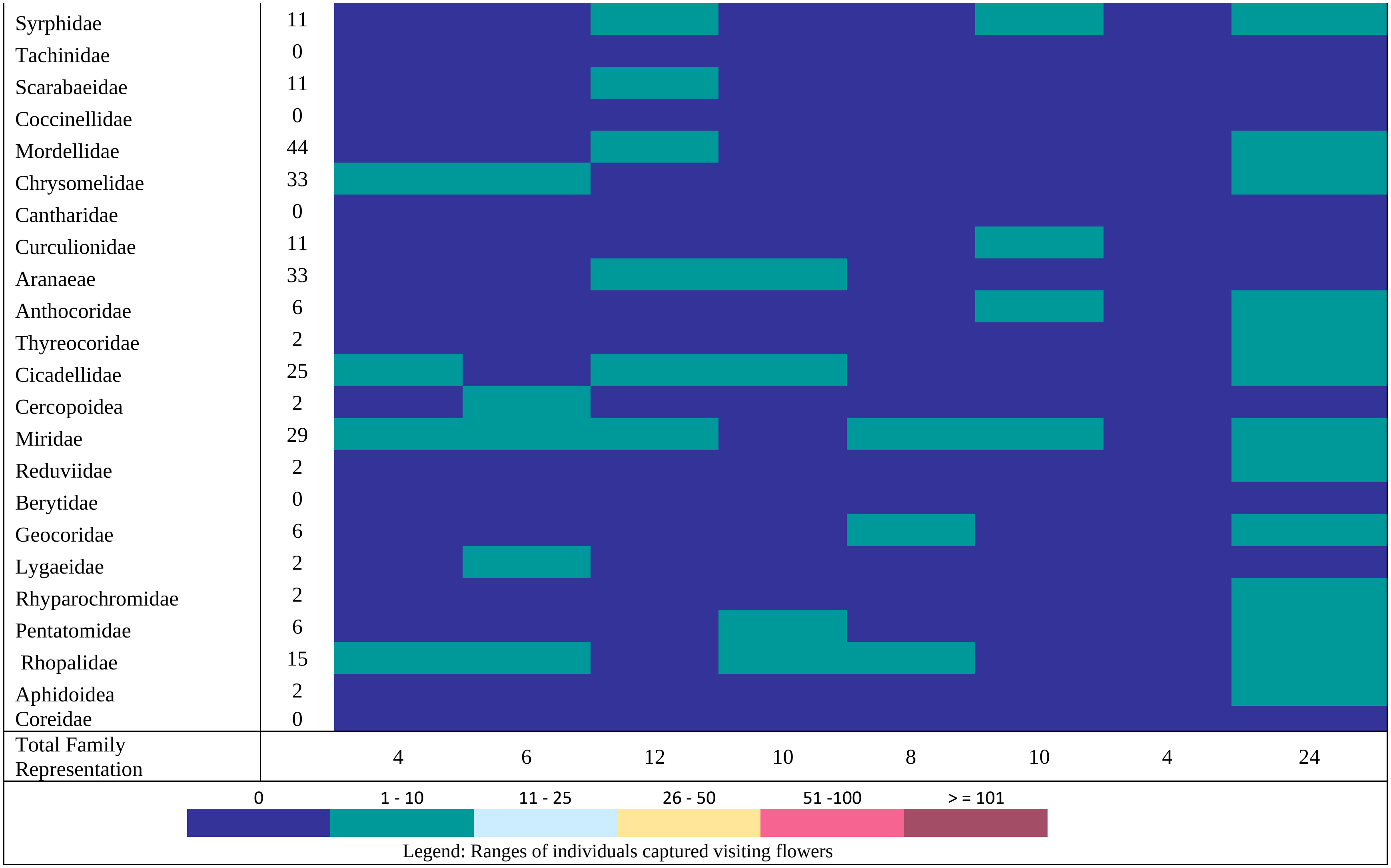
0	1 - 10	11 - 25	26 - 50	51 -100	> = 101
🟦	🟩	⬜	🟨	🟥	🟫

Legend: Ranges of individuals captured visiting flowers

Figure 4.5 Heat chart for insect families captured in *Monarda* taxa at Mimsie Lanier Center for Native Plant Studies, Athens, Georgia in 2021. The percent composition of insect family column indicates the percentage counts of that family relative to total individuals captured within the same order.



Insect family	Percent composition of insect family	*M. didyma*	*M. didyma* 'Jacob Cline'	*M.* x 'Judith's Fancy Fuchsia'	*M.* x 'Raspberry Wine'	*M. fistulosa*	*M. fistulosa* 'Claire Grace'	*M. punctata* (GA)	*M. punctata* (NJ)
Formicidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Apidae	56	🟦	🟩	🟨	🟨	🟨	⬜	⬜	🟨
Megachilidae	1	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩
Halicitidae	24	🟦	🟦	⬜	⬜	🟩	🟩	🟦	🟨
Coletidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Parasitica	9	🟦	🟦	🟦	🟩	🟩	🟩	🟦	⬜
Bethylidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Braconidae	1	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟩
Ichneumonidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Cynipidae	4	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟩
Platygastridae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Scelionidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Aculeata	10	🟦	🟦	🟩	🟩	🟦	🟩	🟩	⬜
Vespidae	1	🟦	🟦	🟩	🟦	🟦	🟩	🟦	🟦
Sphecidae	6	🟦	🟦	🟦	🟩	🟦	🟦	🟩	⬜
Scoliidae	2	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
Crabronidae	1	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Pompilidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Thynnidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Hesperiidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Moths	100	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
Dolichopodidae	2	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦



Syrphidae	11	🟦	🟦	🟩	🟦	🟦	🟩	🟦	🟩
Tachinidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Scarabaeidae	11	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
Coccinellidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Mordellidae	44	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟩
Chrysomelidae	33	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟩
Cantharidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Curculionidae	11	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
Aranaeae	33	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟦
Anthocoridae	6	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟩
Thyreocoridae	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Cicadellidae	25	🟩	🟦	🟩	🟩	🟦	🟦	🟦	🟩
Cercopoidea	2	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦
Miridae	29	🟩	🟩	🟩	🟦	🟩	🟩	🟦	🟩
Reduviidae	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Berytidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Geocoridae	6	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟩
Lygaeidae	2	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦
Rhyparochromidae	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Pentatomidae	6	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟩
Rhopalidae	15	🟩	🟩	🟦	🟩	🟩	🟦	🟦	🟩
Aphidoidea	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Coreidae	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Total Family Representation		4	6	12	10	8	10	4	24

0	1 - 10	11 - 25	26 - 50	51 -100	> = 101
🟦	🟩	⬜	🟨	🟥	🟫

Legend: Ranges of individuals captured visiting flowers

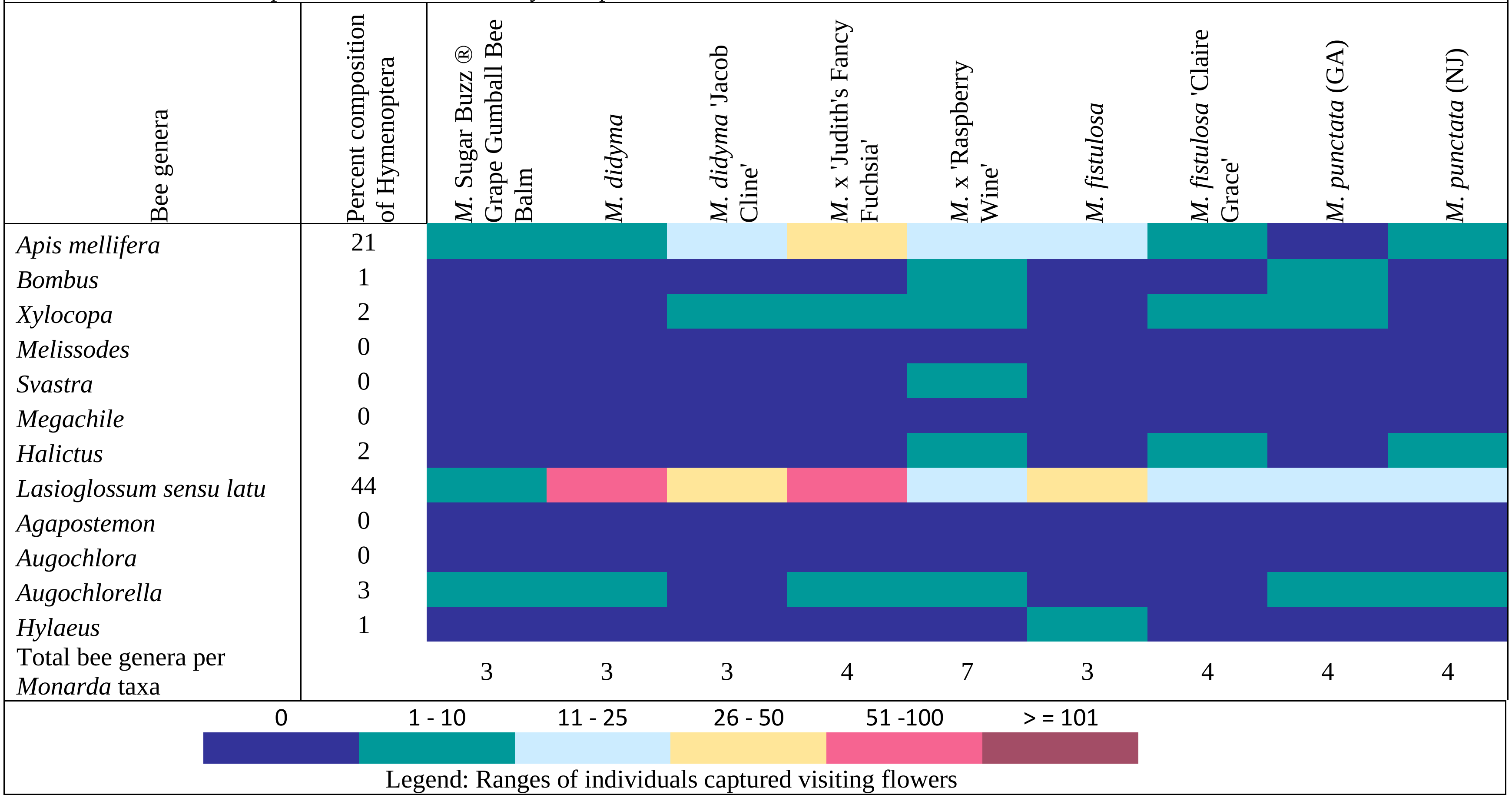
Halictidae accounted for at least 26 visits to at least one *Monarda* taxa in all sites and years. Apidae was also popular and accounted for at least 11 visits to at least five *Monarda* taxa (Figs. 4.3 – 4.5). Within Hymenoptera, the most captured genera were *Lasioglossum sensu latu, Apis mellifera, Bombus,* and *Xylocopa* (Figs. 4.6 to 4.8). *Agapostemon, Augochlora, Augochlorella, Hylaeus, Melissodes* and *Svastra* were only captured at GMREC. *Hylaeus* was only captured in 2020. *Agapostemon, Melissodes* and *Svastra* were only captured at GMREC in 2021. *Megachile* and *Halictus* were captured at all sites.

At GMREC in 2020 *Apis mellifera* made up twenty-one percent of Hymenoptera visits. They were captured on all taxa except *M. punctata* (GA) and were captured most often on *M.* x 'Judith's Fancy Fuchsia' (Fig. 4.6). *Lasioglossum sensu latu* made up forty-four percent of Hymenoptera visits and were captured on all *Monarda* taxa. *Lasioglossum sensu latu* were captured most often on *M. didyma* and *M.* x 'Judith's Fancy Fuchsia'. They were least frequently captured on *M.* Sugar Buzz® 'Grape Gumball'. Other bee genera made up less than ten percent of captured Hymenoptera.

At GMREC in 2021 *Apis mellifera* made up only six percent of Hymenoptera visits, less than *Bombus* at eight percent and *Xylocopa* at seven percent (Fig. 4.7). *Apis mellifera* were not captured on *M.* Sugar Buzz® 'Grape Gumball' or *M. didyma* 'Jacob Cline' and were captured most often on *M.* x 'Judith's Fancy Fuchsia'. *Bombus* were captured on all *Monarda* taxa, but most often on *M. fistulosa*. *Xylocopa* were not captured on Sugar Buzz® 'Grape Gumball' or *M. fistulosa* taxa. *Xylocopa* were captured most often on *M. punctata* ecotypes. *Lasioglossum sensu latu* made up 66% of Hymenoptera visits and were captured on all *Monarda* taxa. They were captured most often on *M. fistulosa* and least often on *M. punctata* (NJ). Other bee genera made up less than eight percent of captured Hymenoptera.

At MLCNPS in 2021 *Apis mellifera* made up eight percent of captured Hymenoptera, *Bombus* accounted for twenty-six percent, *Xylocopa* were twenty-two percent, and *Lasioglossum sensu latu* made up twenty-three percent (Fig. 4.8). *Apis mellifera* were not captured on *M. didyma* or *M. punctata* (GA) but were not captured in different densities among the remaining *Monarda* taxa. *Bombus* were not captured on *M. didyma* or *M. punctata* (GA) and were captured most often on *M. punctata* (NJ). *Xylocopa* were not captured on *M. didyma, M. didyma* 'Jacob Cline', or *M. fistulosa* 'Claire Grace'. They were captured most often on *M.* x 'Raspberry Wine'. *Lasioglossum sensu latu* were not captured on *M. didyma, M. didyma* 'Jacob Cline', or *M. punctata* (GA) and showed higher densities on *M.* x 'Judith's Fancy Fuchsia', *M.* x 'Raspberry Wine' and *M. punctata* (NJ) than other visited taxa. Other bee genera made up less than three percent of captured Hymenoptera.

Figure 4.6 Heat chart for bee genera captured in *Monarda* taxa at Georgia Mountain Research and Education Center, Blairsville, Georgia in 2020. The percent composition of insect family column indicates the percentage of the number of that genus captured relative to the total number of individuals captured within the order Hymenoptera.

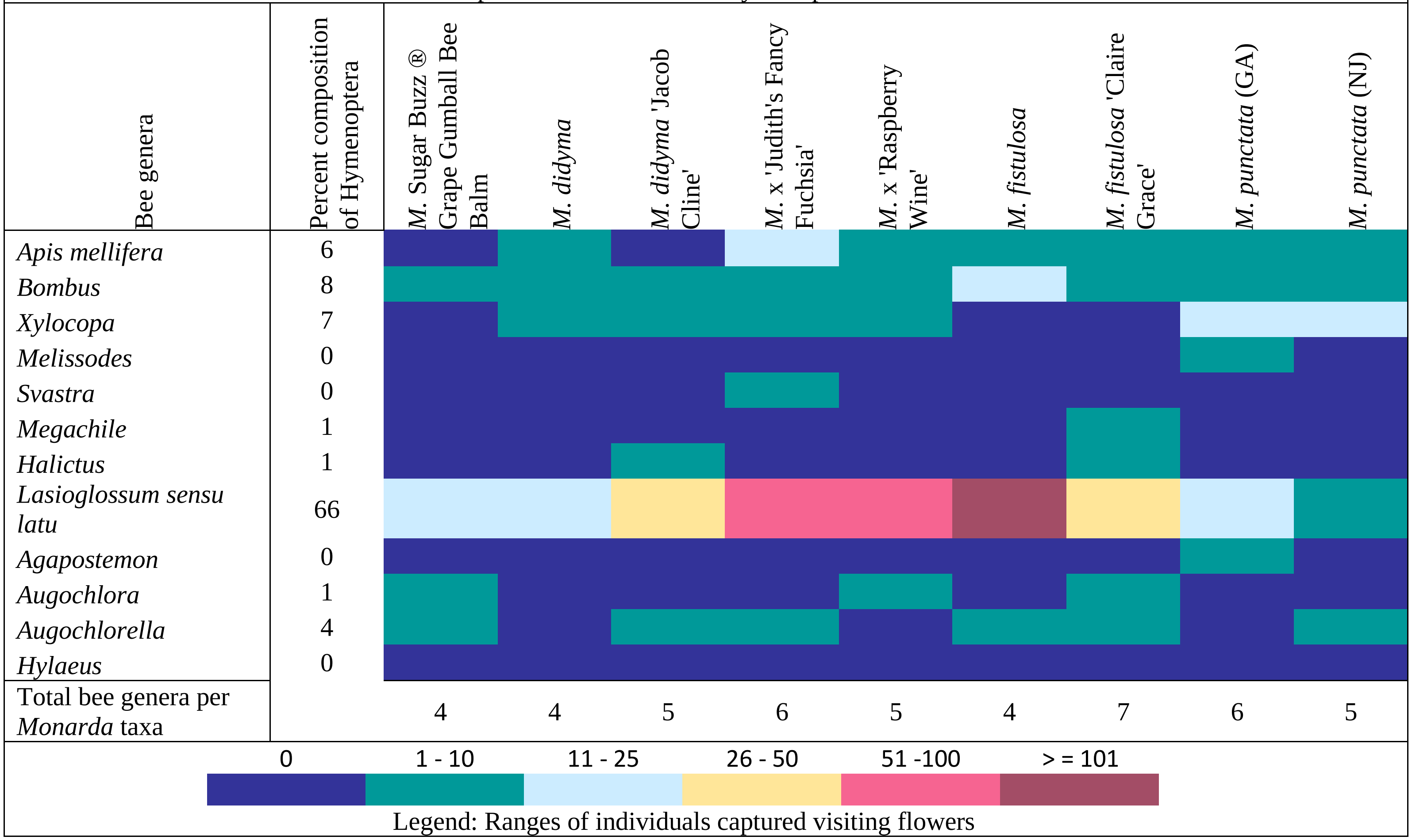


Bee genera	Percent composition of Hymenoptera	*M.* Sugar Buzz ® Grape Gumball Bee Balm	*M. didyma*	*M. didyma* 'Jacob Cline'	*M.* x 'Judith's Fancy Fuchsia'	*M.* x 'Raspberry Wine'	*M. fistulosa*	*M. fistulosa* 'Claire Grace'	*M. punctata* (GA)	*M. punctata* (NJ)
Apis mellifera	21	🟩	🟩	🟦	🟨	🟦	🟦	🟩	🟪	🟩
Bombus	1	🟪	🟪	🟪	🟪	🟩	🟪	🟪	🟩	🟪
Xylocopa	2	🟪	🟪	🟩	🟩	🟩	🟪	🟩	🟩	🟪
Melissodes	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Svastra	0	🟪	🟪	🟪	🟪	🟩	🟪	🟪	🟪	🟪
Megachile	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Halictus	2	🟪	🟪	🟪	🟪	🟩	🟪	🟩	🟪	🟩
Lasioglossum sensu latu	44	🟩	🟥	🟨	🟥	🟦	🟨	🟦	🟦	🟦
Agapostemon	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Augochlora	0	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Augochlorella	3	🟩	🟩	🟪	🟩	🟩	🟪	🟪	🟩	🟩
Hylaeus	1	🟪	🟪	🟪	🟪	🟪	🟩	🟪	🟪	🟪
Total bee genera per *Monarda* taxa		3	3	3	4	7	3	4	4	4

0	1 - 10	11 - 25	26 - 50	51 -100	> = 101
🟪	🟩	🟦	🟨	🟥	🟫

Legend: Ranges of individuals captured visiting flowers

Figure 4.7 Heat chart for bee genera captured in *Monarda* taxa at Georgia Mountain Research and Education Center, Blairsville, Georgia in 2021. The percent composition of insect family column indicates the percentage of the number of that genus captured relative to the total number of individuals captured within the order Hymenoptera.

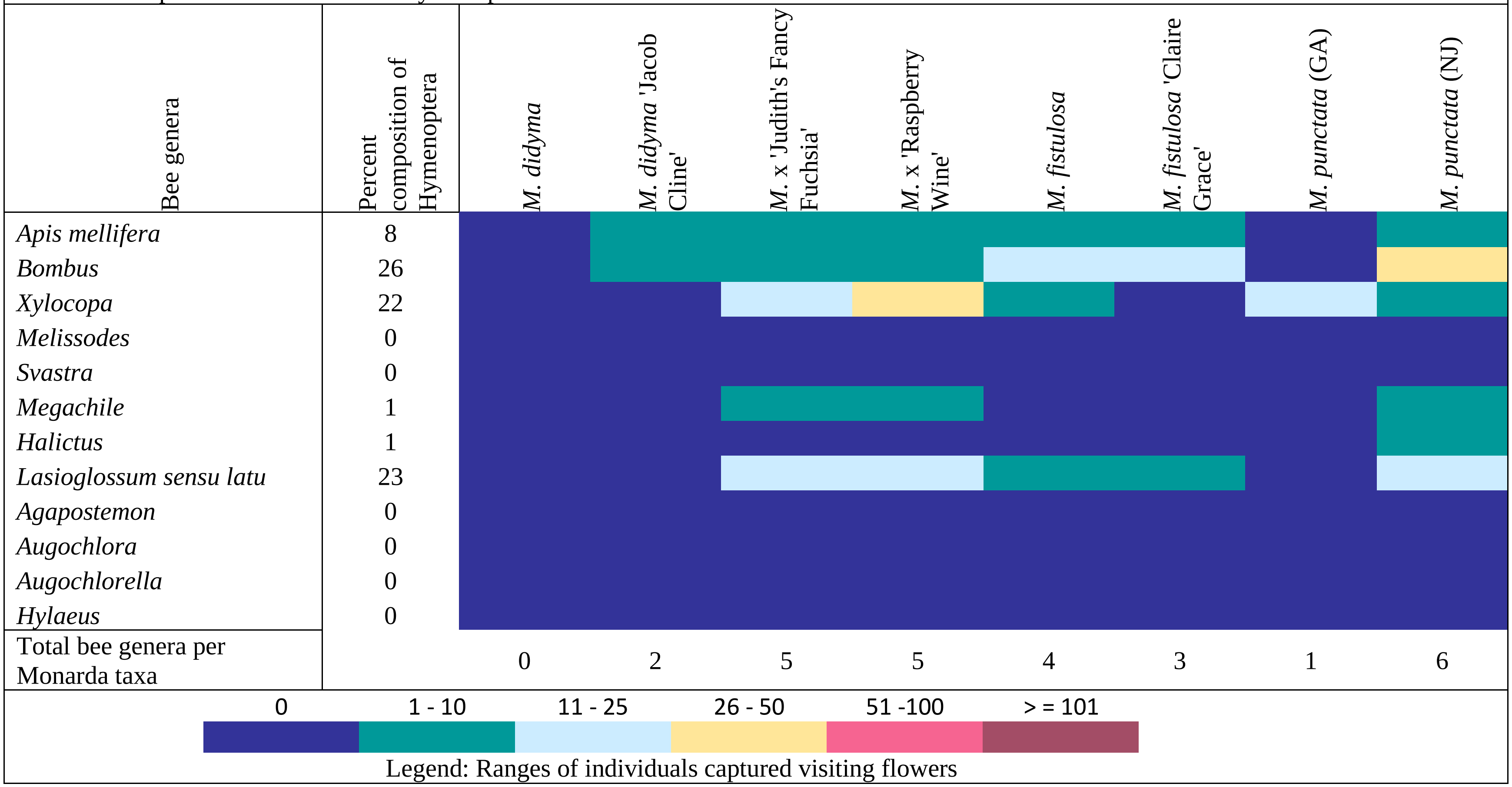


Bee genera	Percent composition of Hymenoptera	*M.* Sugar Buzz ® Grape Gumball Bee Balm	*M. didyma*	*M. didyma* 'Jacob Cline'	*M.* x 'Judith's Fancy Fuchsia'	*M.* x 'Raspberry Wine'	*M. fistulosa*	*M. fistulosa* 'Claire Grace'	*M. punctata* (GA)	*M. punctata* (NJ)
Apis mellifera	6	🟦	🟩	🟦	⬜	🟩	🟩	🟩	🟩	🟩
Bombus	8	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩
Xylocopa	7	🟦	🟩	🟩	🟩	🟩	🟦	🟦	⬜	⬜
Melissodes	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦
Svastra	0	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
Megachile	1	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
Halictus	1	🟦	🟦	🟩	🟦	🟦	🟦	🟩	🟦	🟦
Lasioglossum sensu latu	66	⬜	⬜	🟨	🟥	🟥	🟫	🟨	⬜	🟩
Agapostemon	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦
Augochlora	1	🟩	🟦	🟦	🟦	🟩	🟦	🟩	🟦	🟦
Augochlorella	4	🟩	🟦	🟩	🟩	🟦	🟩	🟩	🟦	🟩
Hylaeus	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Total bee genera per *Monarda* taxa		4	4	5	6	5	4	7	6	5

0	1 - 10	11 - 25	26 - 50	51 -100	> = 101
🟦	🟩	⬜	🟨	🟥	🟫

Legend: Ranges of individuals captured visiting flowers

Figure 4.8 Heat chart for bee genera captured in *Monarda* taxa at Mimsie Lanier Center for Native Plant Studies, Athens, Georgia in 2021. The percent composition of insect family column indicates the percentage of the number of that genus captured relative to the total number of individuals captured within the order Hymenoptera.



Bee genera	Percent composition of Hymenoptera	*M. didyma*	*M. didyma* 'Jacob Cline'	M. x 'Judith's Fancy Fuchsia'	M. x 'Raspberry Wine'	*M. fistulosa*	*M. fistulosa* 'Claire Grace'	*M. punctata* (GA)	*M. punctata* (NJ)
Apis mellifera	8	🟦	🟩	🟩	🟩	🟩	🟩	🟦	🟩
Bombus	26	🟦	🟩	🟩	🟩	⬜	⬜	🟦	🟨
Xylocopa	22	🟦	🟦	⬜	🟨	🟩	🟦	⬜	🟩
Melissodes	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Svastra	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Megachile	1	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩
Halictus	1	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
Lasioglossum sensu latu	23	🟦	🟦	⬜	⬜	🟩	🟩	🟦	⬜
Agapostemon	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Augochlora	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Augochlorella	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Hylaeus	0	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Total bee genera per Monarda taxa		0	2	5	5	4	3	1	6

0	1 - 10	11 - 25	26 - 50	51 -100	> = 101
🟦	🟩	⬜	🟨	🟥	🟫

Legend: Ranges of individuals captured visiting flowers

DISCUSSION

The objective of this study was to understand pollinator, beneficial insect, and plant pest preference for ornamental cultivars and native congeners within *Monarda*, a genus that is commonly advertised as a pollinator plant for use in gardens, agricultural conservation easements, and the like. We found small but at times significant differences among the species and cultivars of *Monarda* in their ability to attract pollinator and beneficial insect groups, but such differences were not consistent across sites and years. In addition, we saw no significant difference in plant pest abundance among species and cultivars.

Monarda phenology does make it an appropriate choice for providing nectar and pollen to generalist pollinators during the summer season, as advertised in seed mixes (Rubio et al. 2022; Wolf et al. 2022; Quinlan et al. 2021; Otto et al. 2017; Gray et al. 2007). Extending the flowering season with *M. bradburiana* (late spring, early summer) and *M. punctata* (late summer, early fall) is possible. In our study insect visitation on *M. bradburiana* was not observed due to low flower density in the experimental site early in the season and the availability of competing floral resources outside of the plots (Kalaman et al., 2022). *M. didyma* and *M. didyma* 'Jacob Cline' also continued to produce flowers into late summer and early fall, though the number of flowers was low. Nonetheless, we had *Monarda* blooms throughout the sites from May to October in Blairsville 2020, June to September in Blairsville 2021, and late April to October in Athens 2021.

In 2020 at GMREC, *M.* x 'Judith's Fancy Fuchsia' had the most pollinators observed. Yet, no significant difference was found among taxa of the lowest pollinator abundance. The beneficial insect group was most observed on *M. didyma* 'Jacob Cline' and *M. punctata* (GA) at that same site and year. Again, no difference was observed among taxa with the lowest abundance of beneficial insects. At the same site in 2021 *M. fistulosa* had the most pollinator visitation, with few differences observed among other taxa, and there was no difference in beneficial insect abundance. At MLCNPS in 2021, *M. punctata* NJ had the most pollinator and beneficial insect visitation.

At the same site (GMREC) but in a different year, *Apis mellifera* and *Bombus* abundance flipped rank. *Lasioglossum sensu latu* was more consistent, but was overall more abundant in 2021, notably on *M. fistulosa* and *M.* x 'Raspberry Wine'. Yet, captures were not the same at MLCNPS. *M.* x 'Judith's Fancy Fuchsia', *M.* x 'Raspberry Wine' and *M. punctata* (NJ) had the most captures. *M. punctata* (GA), *M. didyma*, and *M. didyma* 'Jacob Cline' had no captures at MLCNPS, despite having captures among those *Monarda* taxa at GMREC in both years. *Bombus* and *Xylocopa* were caught in more abundance than *Apis mellifera* at MLCNPS, unlike GMREC captures. Thus, all taxa showed an ability to support individuals in the pollinator group, but the *Monarda* taxon with highest mean pollinator abundance differed each site and year.

When mean beneficial insect abundance was significant among Monarda taxa, M. punctata ecotypes showed significantly higher means than some taxa. For example, in 2020 at GMREC M. didyma 'Jacob Cline' also had significantly higher mean beneficial insect abundance. This information is of importance to farmers or gardeners who select *Monarda* species as a means of habitat for biological control. While ornamental plants are not often marketed for wasps, these insects serve as important pollinators for a range of flowering plant species (Kalaman et al., 2022; Rader et al., 2016; Wiemer et al., 2011) and act as a biological control on garden pests (Kalaman et al., 2022; Goldsmith and Henshaw, 2011; Kimber at al., 2010; Cox and Pinniger, 2007; Rebek et al., 2005).

Though pollinators were consistently the most abundant group, all insect functional groups were present at both sites and years. Beneficial insect counts were consistently higher than plant pests among sites and years, which tracks with low pest damage observed among *Monarda* taxa. Rather, plant disease, like powdery mildew, was more of a problem within sites than plant pest damage (Chapter 2).

The lack of consistency in visitation among insect functional groups to *Monarda* taxa could be due to experimental design, phenology variance, or plant health changes, all by site and year. If site conditions are appropriate and plant health is optimal, visitation by all functional groups to any *Monarda* taxon was possible during peak bloom. The only plants that were not visited were dead plants. *M.* Sugar Buzz® 'Grape Gumball' consistently had the lowest family representation. *M. didyma* declined in family representation with declining health; *M. didyma* had high representation at GMREC in 2020, but low representation at GMREC and MLCNPS in 2021.

These results were also consistent with low representation of bee genera on the same taxa. Low representation of bee genera coincides with decreased health in *M.* Sugar Buzz® 'Grape Gumball' and M. *didyma* taxa documented in Chapter 2. While *M. didyma* had a capture from the Parasitica group at GMREC in 2020, *M.* Sugar Buzz® 'Grape Gumball' had no captures from the parasitic wasp group, nor did *M. didyma* in other sites and years. There were also no beneficial dipterans captured on the aforementioned taxa. Aculeate wasps were captured on *M.* Sugar Buzz® 'Grape Gumball' at GMREC in 2020.

Conclusion. To inform the Green Industry and consumers, we have empirically studied the claims that *Monarda* cultivars are as pollinator-friendly as their native congeners (Kalaman et al., 2022; Garbuzov et al., 2017; Garbuzov and Ratnieks, 2015). When plant health was optimal, all insect functional groups we studied were observed on all taxa during peak bloom. While we did not investigate the role of *Monarda* taxa as larval host plants – or as partners with obligate pollinators – we can support the use of *Monarda* as forage for generalist insect taxa. Recommendations for the use of specific *Monarda* taxa depend on site conditions, plant availability, and project goals. We have provided empirical data to growers and gardeners to make such decisions in the Georgia mountain and piedmont regions. Future studies should continue to examine factors that influence insect diversity and abundance across cultivars and native congeners.

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CONCLUSIONS

The following conclusions are presented in a question-and-answer format to address questions that have come to my attention throughout this study.

For the objectives of this study, how important was it to repeat the experiment in the two selected locations?

For the ornamental trial portion of the study (Chapter 2) and because of the natural distribution of *Monarda* species (Weakley et al., 2022), I think it was useful to study the phenology and health of select *Monarda* taxa at GMREC (Blairsville, GA) and MLCNPS (Athens, GA). As stated by Dr. Bodie Pennisi, it would have been more ideal to include the Griffin Campus as a site location due to the natural distribution of *M. punctata (M. punctata* has a more southern, coastal plain distribution). It was crucial to study plant performance within different USDA zones.

Regarding the study of insect functional group abundance, it was not the ideal design. A global review by Prendergast et al. (2022) provides a great deal of information on the importance of surrounding land use in determining native bee assemblages. To account for this variation, and provide specific insight to the city of Athens, Georgia, it would have been interesting to repeat the experiment in several locations within the city. Each location would be blocked along the urban to rural gradient. I think this could have provided evidence on how preference for different *Monarda* taxa by insect functional groups is influenced or not influenced by the surrounding landscape. With our experimental design it was impossible to tease apart this interaction because the two sites were in different USDA zones and regions.

Even though flower morphology and nectar production have been shown to influence insect foraging behavior in many flowering plant species, why did we see no correlation between our measurements in Chapter 3 and insect abundance?

The angiosperm trait complex of structural, visual, chemical, and nutritional cues, especially within flowers, influence pollinator foraging behavior (Erickson et al, 2022; Junker and Parachnowitsch, 2015; Armbruster, 2014; Leonard et al., 2011; Willmer, 2011). Variation among pollinators and other beneficial insects in the perception and preference for different floral suites depends on natural history, sensory abilities, learned associations, and cognition (Erickson et. al, 2022; Willmer, 2011; Raine and Chittka, 2007; Chittka and Raine, 2006). We saw *Monarda* cultivars differ in flower color and size, length and time of flowering, petal and corolla length and width, nectar volume, sugar concentration in nectar, and sugar content in nectar. In addition to observed differences in floral traits, we also found significant differences in height, width, health, and floral abundance (Chapter 2 and 3). Despite these differences, the statistical correlations explored in Chapter 3 showed no relationship between phenotype and relative insect abundance, nor did nectar production. This could be due to small sample size, variance between sites and years, exclusion of bird and lepidoptera pollinators, exclusion of pollen analysis; variance among maculations on corolla or lip or throat, upper lip arcuate or straight, lower lip revolute or straight, the ratio of one organ to another (Prather 2002), or some unknown experimental factor. Regarding sampling technique specifically, larger insect samples and species level identification of insects could have also provided more insight.

Concerning the need to evaluate the resource value of ornamental cultivars on a case-by-case basis, what did you learn about the viability of the methods presented in this research?

I discovered the complexity of the question, “Do cultivars provide equal resource value as their native congeners to region-specific wildlife?” It’s quite the question, not answered by a single experiment, but incredibly important to answer. My bias is that I believe we must learn to support a diversity of life within rural to urban areas because it will ensure the health of the planet for our foreseeable future. To do so we must find a way that coincides with the natural flow of human society. Our culture demands consistency in its design, we rely on cultivars in the commercialization of the Green Industry, not open pollinated seed of regional native-plants (although I wish this was not the case).

The pursuit of conservation and expansion of natural areas must continue. The ecological value of landscapes, from rural to urban areas, must increase. The function of human dominated landscapes is different from natural areas, working from a different design. This human landscape greatly benefits from the introduction of cultivated native plants. Cultivation streamlines production, increases availability, and advertises to the consumer. So, we must continue to evaluate cultivars for resource value.

The barrier to this research is that it is time consuming, and stakeholders ask “Where is my monetary benefit?” To really answer this question there is a lot to look at empirically for each cultivar. How much nectar and pollen are produced? What is the sugar content of the nectar? What is the protein content of the pollen? What are the main insect groups and species supported by the cultivar? Butterflies? Larval host? Birds? When and for how long? Expand these questions to include the native congeners, and each USDA zone and region along the rural to urban gradient, and in natural areas.

For now, the best we can do is to continue to collect data in systematic ways that allow future scientists an opportunity to model and analyze the data at greater scales. I think it is important to get as much specific data as possible using comparable methods. To do so, it is crucial to dedicate a certain amount of time from a project to collaborate with agencies of similar goals, like public gardens and Universities conducting native plant trials.

As a horticulturalist, I found it informative to sweep sample, pin, and identify plant visitors to family, and sometimes genus, -level identification. It was an opportunity to learn about the value of each plant and the neighborhood of wildlife associated with it. This knowledge is of great value when plants need to be managed for pests and disease in the greenhouse, nursery, or landscape. Such insect collections can then be passed onto entomologists with similar goals, experts with the ability to identify the collection to species level, or meta-barcode pollen, etc. Scientists in the field of plant biology and physiology may have special interest in the genomics, chemotypes, and phenotypes of cultivars and native plants.

Given the opportunity to plan, an interdisciplinary approach from multiple departments could split the work into manageable and impactful pieces. Especially if data is collected in a manner that allows multivariate analysis. I don’t think our approach was the best, but it was insightful. As a horticulturist, I think my research could have been more impactful to my discipline had I the opportunity to focus on propagation, nutrient management, and integrated pest management in nursery production of *Monarda*. It would have been interesting to study the interaction between plant health and insect diversity and abundance. For public service and outreach, the trial component is valuable for communicating to the common gardener the habit, form, and disease tolerance of a series of ornamental plants. The additional layer of wildlife visitation is a point of advertisement for native plants and should be empirically evaluated by growers.

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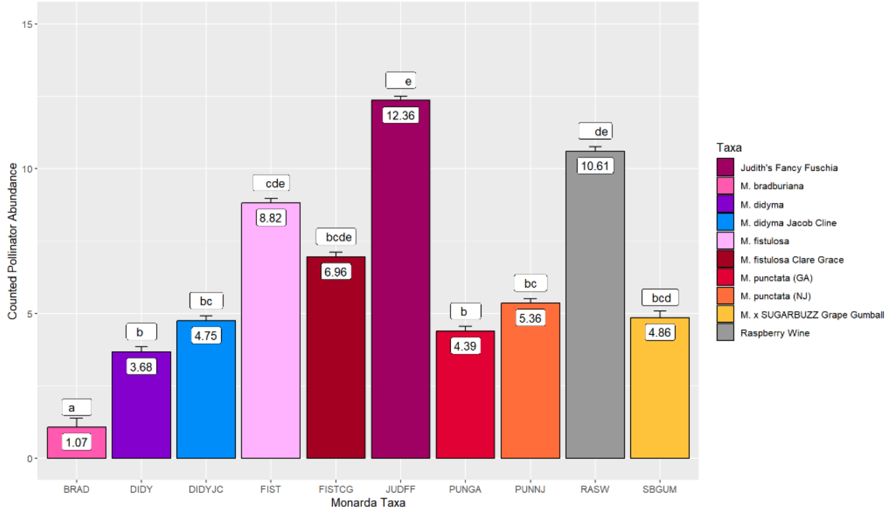
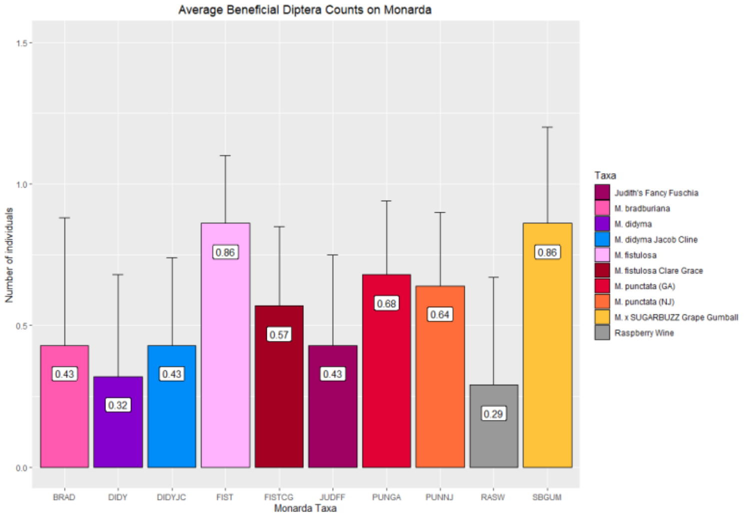
APPENDICES

Appendix.A Mean ± se^{z} visually observed insect abundance^{x} among *Monarda* taxa in a 2-year study in Blairsville and Athens, Georgia, USA. (A = Pollinators, *Xylocopa*, *Apis mellifera*, *bombus* and other small bees; B = Beneficial diptera, syrphidae and dolichopodidae; C = Large wasps; D = Hemiptera and coeloptera; E = Honeybee, *Apis mellifera melifera*; F = Bumble bees, *Bombus* spp.; G = Carpenter bees, *Xylocopa* spp.; H = small bees).

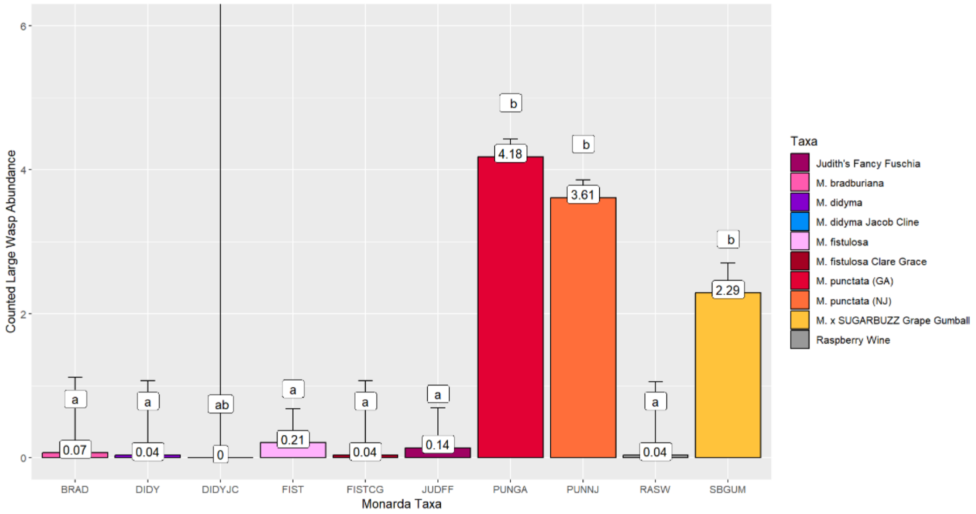
A



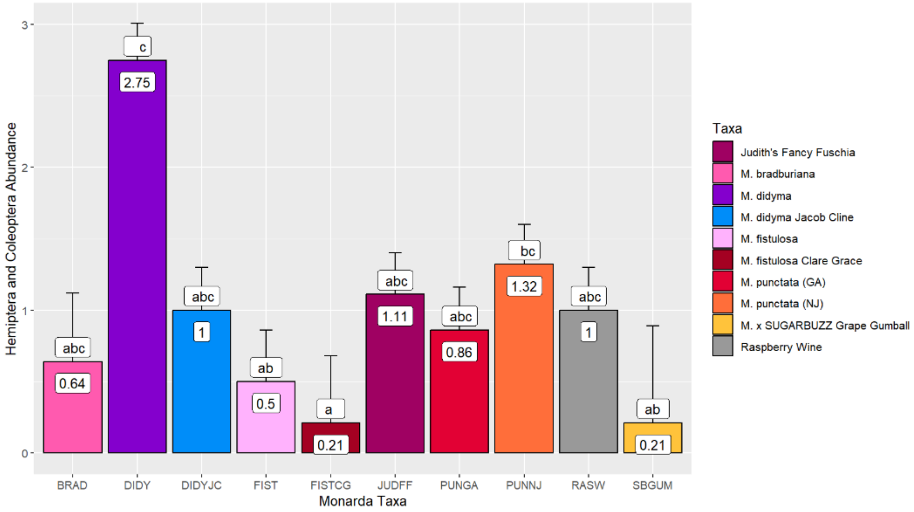
B


Average Beneficial Diptera Counts on Monarda
Number of individuals
0.0
0.5
1.0
1.5
0.43
0.32
0.43
0.86
0.57
0.43
0.68
0.64
0.29
0.86
BRAD
DIDY
DIDYJC
FIST
FISTCG
JUDFF
PUNGA
PUNNJ
RASW
SBGUM
Monarda Taxa
Taxa
Judith's Fancy Fuschia
M. bradburiana
M. didyma
M. didyma Jacob Cline
M. fistulosa
M. fistulosa Clare Grace
M. punctata (GA)
M. punctata (NJ)
M. x SUGARBUZZ Grape Gumball
Raspberry Wine

C

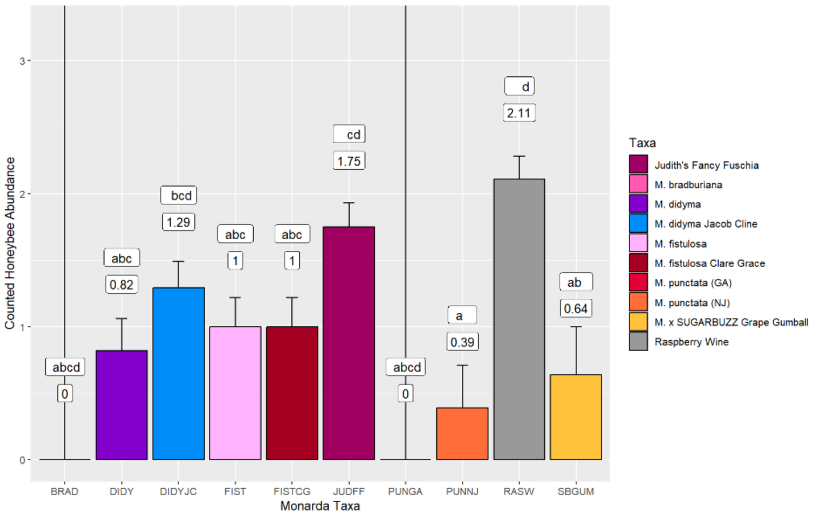

Counted Large Wasp Abundance
0
2
4
6
a
0.07
a
0.04
ab
0
a
0.21
a
0.04
a
0.14
b
4.18
b
3.61
a
0.04
b
2.29
BRAD
DIDY
DIDYJC
FIST
FISTCG
JUDFF
PUNGA
PUNNJ
RASW
SBGUM
Monarda Taxa
Taxa
Judith's Fancy Fuschia
M. bradburiana
M. didyma
M. didyma Jacob Cline
M. fistulosa
M. fistulosa Clare Grace
M. punctata (GA)
M. punctata (NJ)
M. x SUGARBUZZ Grape Gumball
Raspberry Wine

D

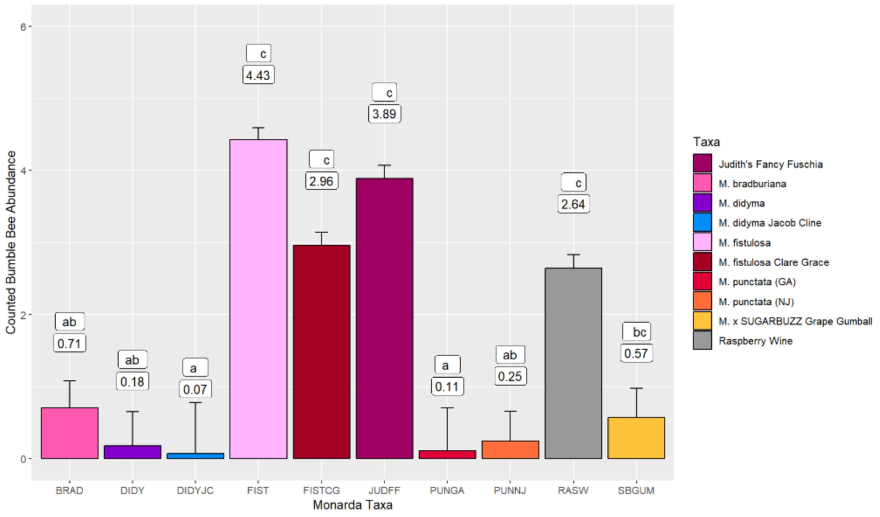


Hemiptera and Coleoptera Abundance
0
1
2
3
c
2.75
abc
0.64
abc
1
ab
0.5
a
0.21
abc
1.11
abc
0.86
bc
1.32
abc
1
ab
0.21
BRAD
DIDY
DIDYJC
FIST
FISTCG
JUDFF
PUNGA
PUNNJ
RASW
SBGUM
Monarda Taxa
Taxa
Judith's Fancy Fuschia
M. bradburiana
M. didyma
M. didyma Jacob Cline
M. fistulosa
M. fistulosa Clare Grace
M. punctata (GA)
M. punctata (NJ)
M. x SUGARBUZZ Grape Gumball
Raspberry Wine

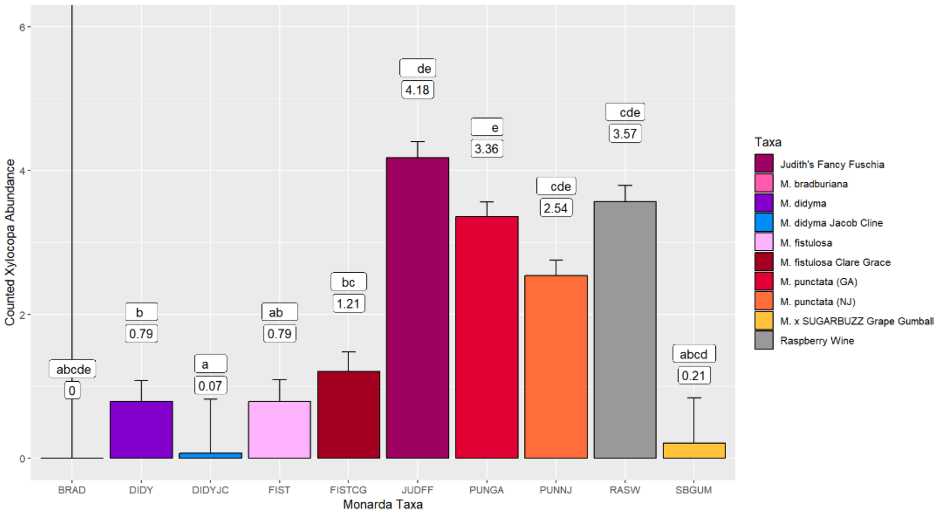
E


Counted Honeybee Abundance
0
1
2
3
abcd
0
abc
0.82
bcd
1.29
abc
1
abc
1
cd
1.75
abcd
0
a
0.39
d
2.11
ab
0.64
BRAD
DIDY
DIDYJC
FIST
FISTCG
JUDFF
PUNGA
PUNNJ
RASW
SBGUM
Monarda Taxa
Taxa
Judith's Fancy Fuschia
M. bradburiana
M. didyma
M. didyma Jacob Cline
M. fistulosa
M. fistulosa Clare Grace
M. punctata (GA)
M. punctata (NJ)
M. x SUGARBUZZ Grape Gumball
Raspberry Wine

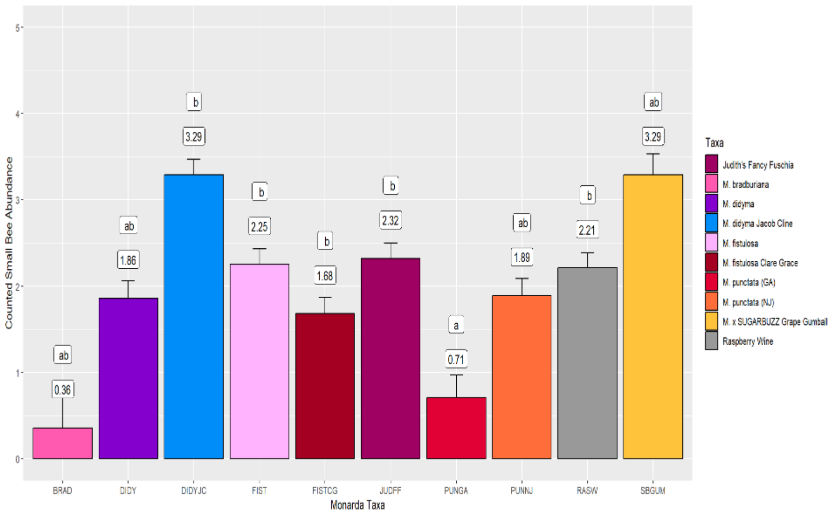
F


Counted Bumble Bee Abundance
0
2
4
6
ab
0.71
ab
0.18
a
0.07
c
4.43
c
2.96
c
3.89
a
0.11
ab
0.25
c
2.64
bc
0.57
BRAD
DIDY
DIDYJC
FIST
FISTCG
JUDFF
PUNGA
PUNNJ
RASW
SBGUM
Monarda Taxa
Taxa
Judith's Fancy Fuschia
M. bradburiana
M. didyma
M. didyma Jacob Cline
M. fistulosa
M. fistulosa Clare Grace
M. punctata (GA)
M. punctata (NJ)
M. x SUGARBUZZ Grape Gumball
Raspberry Wine

G


Counted Xylocopa Abundance
0
2
4
6
abcde
0
b
0.79
a
0.07
ab
0.79
bc
1.21
de
4.18
e
3.36
cde
2.54
cde
3.57
abcd
0.21
BRAD
DIDY
DIDYJC
FIST
FISTCG
JUDFF
PUNGA
PUNNJ
RASW
SBGUM
Monarda Taxa
Taxa
Judith's Fancy Fuschia
M. bradburiana
M. didyma
M. didyma Jacob Cline
M. fistulosa
M. fistulosa Clare Grace
M. punctata (GA)
M. punctata (NJ)
M. x SUGARBUZZ Grape Gumball
Raspberry Wine

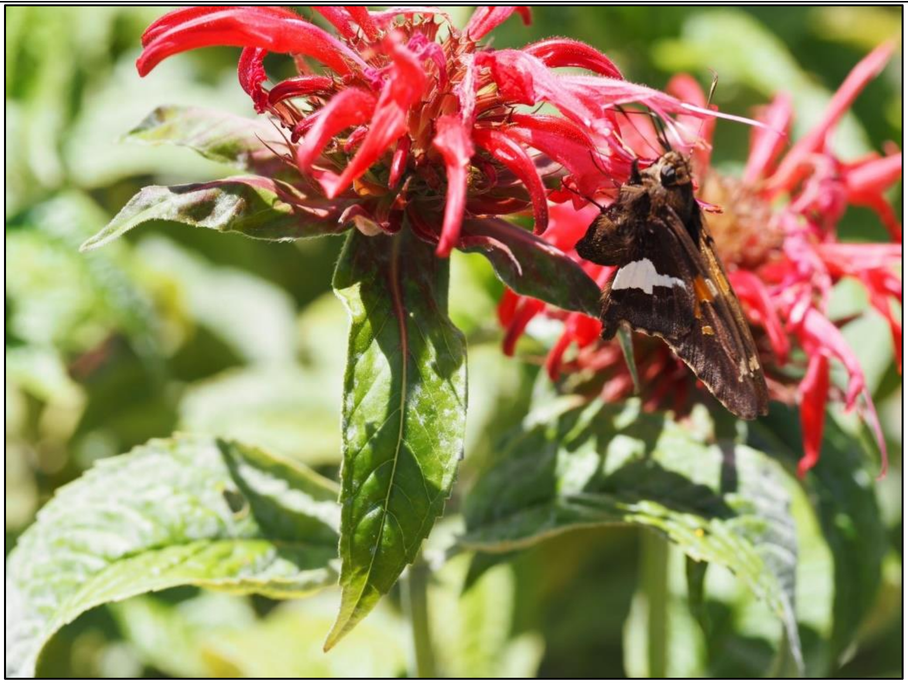
H



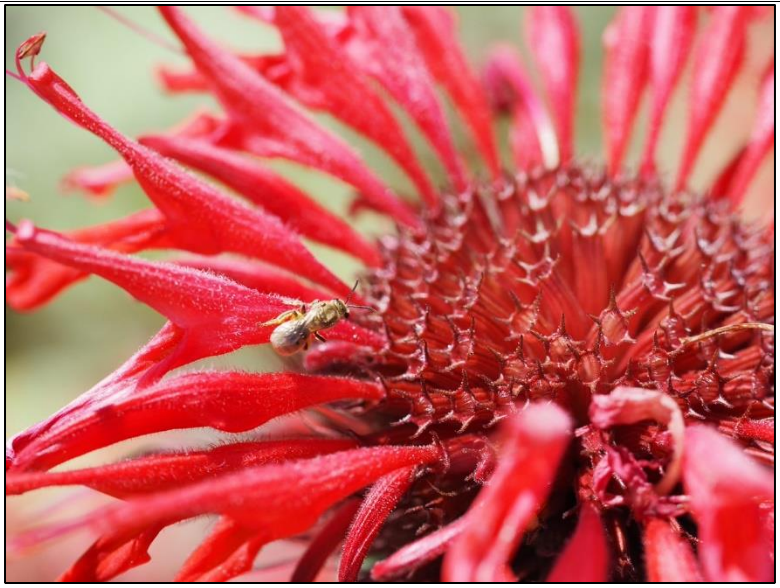
[z] The superscript alphabets means with the same letters are not significantly different, $p > 0.05$.

[x] Counts were on a stand of *Monarda* flowers for 1 minute during peak bloom on sunny days with light wind.

Appendix.B Photo plates^{z} of floral visitors among *Monarda* taxa at Georgia Mountain Research and Education Center (GMREC) Blairsville, GA and Mimsie Lanier Center for Native Plant Studies (MLCNPS) Athens, GA in 2021 and 2022. Each photo is labeled with the *Monarda* taxa (BRAD = *M. bradburiana*, JUDFF = *M. x* 'Judith's Fancy Fuchsia', DIDY = *M. didyma*, DIDYJC = *M. didyma* 'Jacob Cline', RASW = *M.* 'Raspberry Wine', SBGUM = *M.* Sugar Buzz® 'Grape Gumball', FIST = *M. fistulosa*, FISCG = *M. fistulosa* 'Claire Grace', PUNNJ = *M. punctata* (unknown provenance sourced from New Moon Nursery), and PUNGA = *M. punctata* (Georgia seed sourced from MLCNPS), location, and year.



DIDY, GMREC, 2021



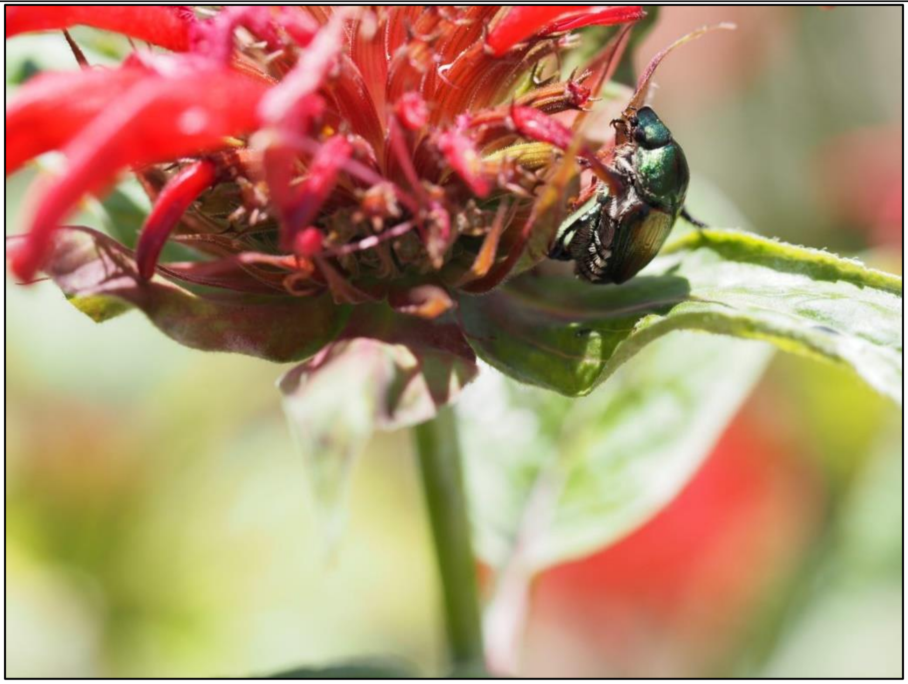
DIDY, GMREC, 2021

DIDY, GMREC, 2021

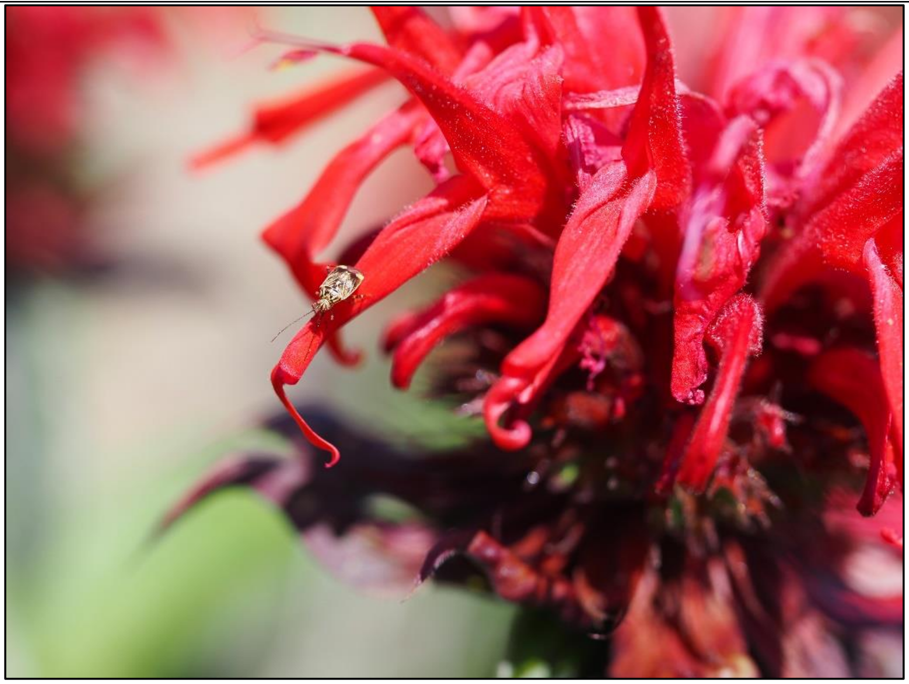
DIDY, GMREC, 2021

DIDY, GMREC, 2021

DIDY, GMREC, 2021

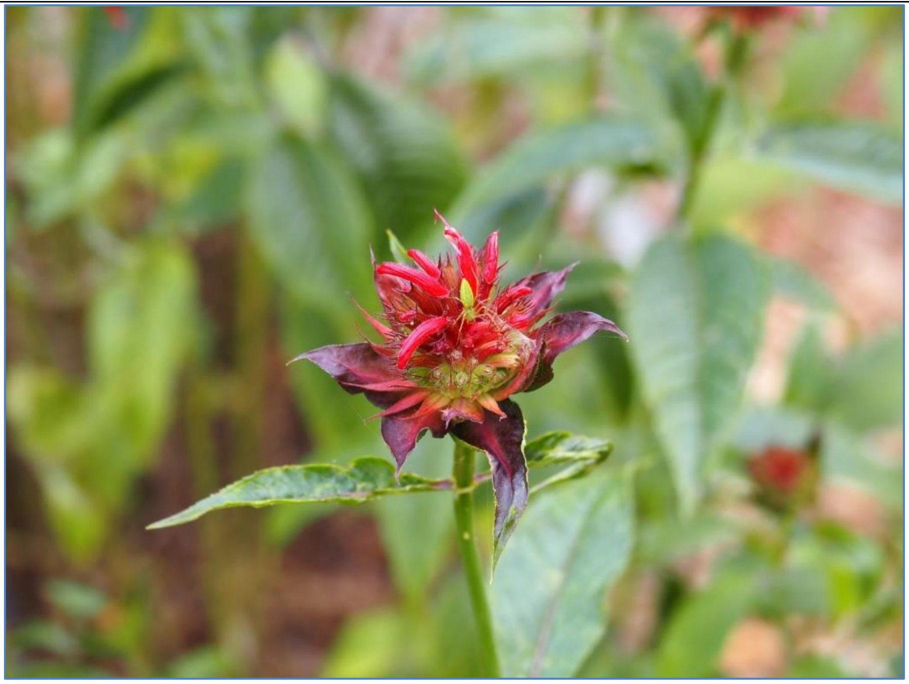


DIDY, GMREC, 2021



DIDY, GMREC, 2021

DIDYJC, MLCNPS, 2022

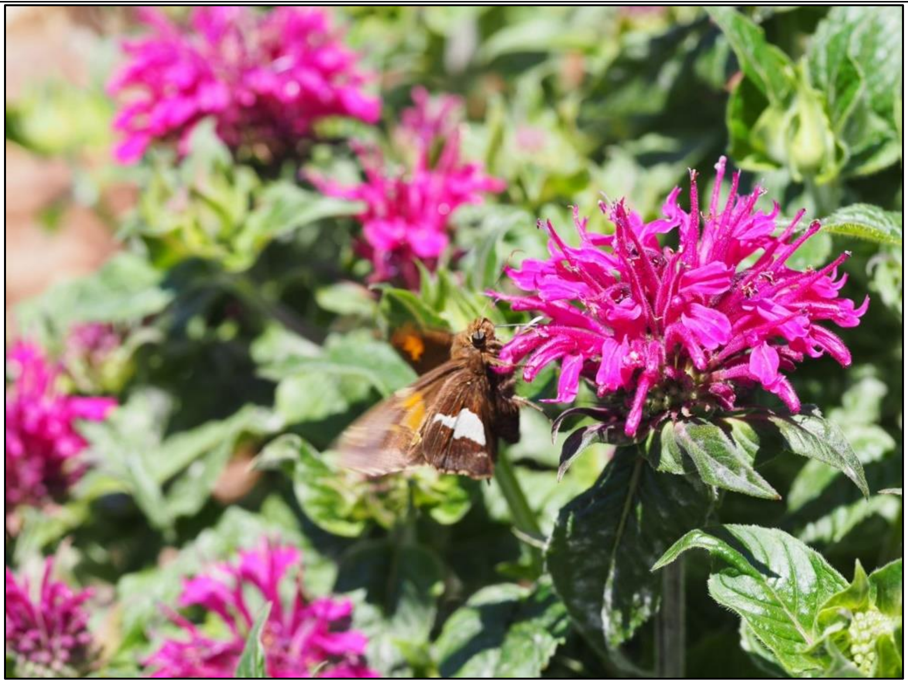


DIDYJC, MLCNPS, 2022

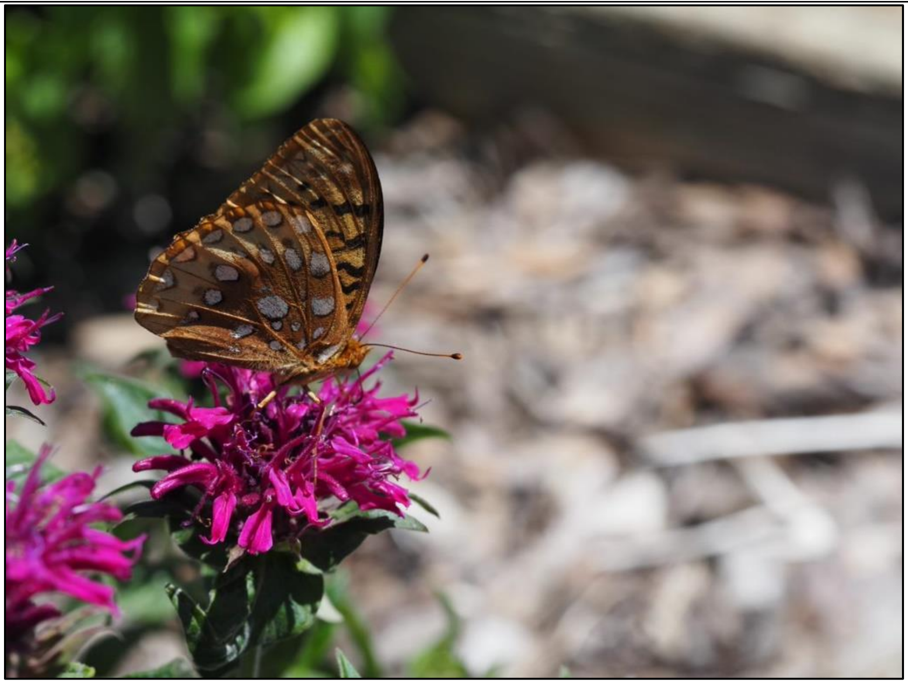
JUDFF, GMREC, 2021

RASW, MLCNPS, 2022

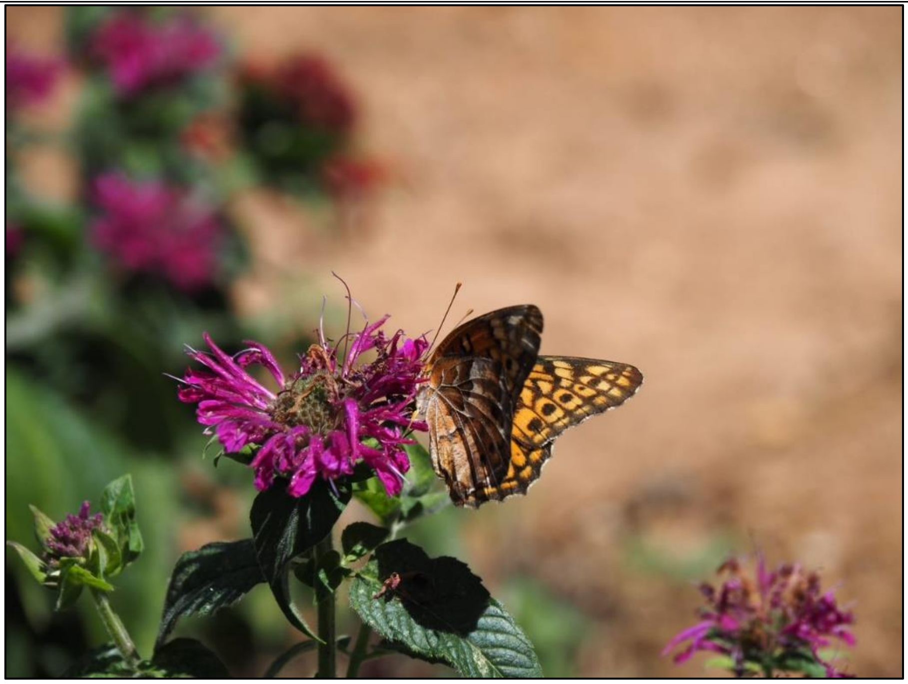
RASW, MLCNPS, 2021



SBGUM, GMREC, 2021



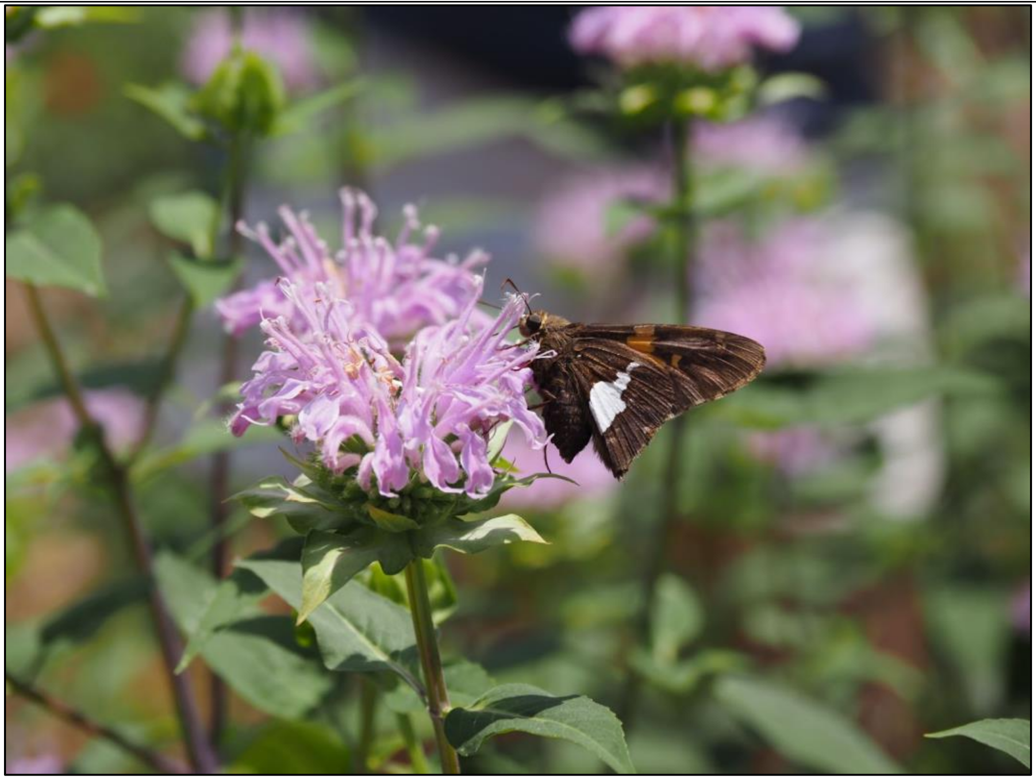
SBGUM, GMREC, 2021



SBGUM, MLCNPS, 2021

SBGUM, GMREC, 2021

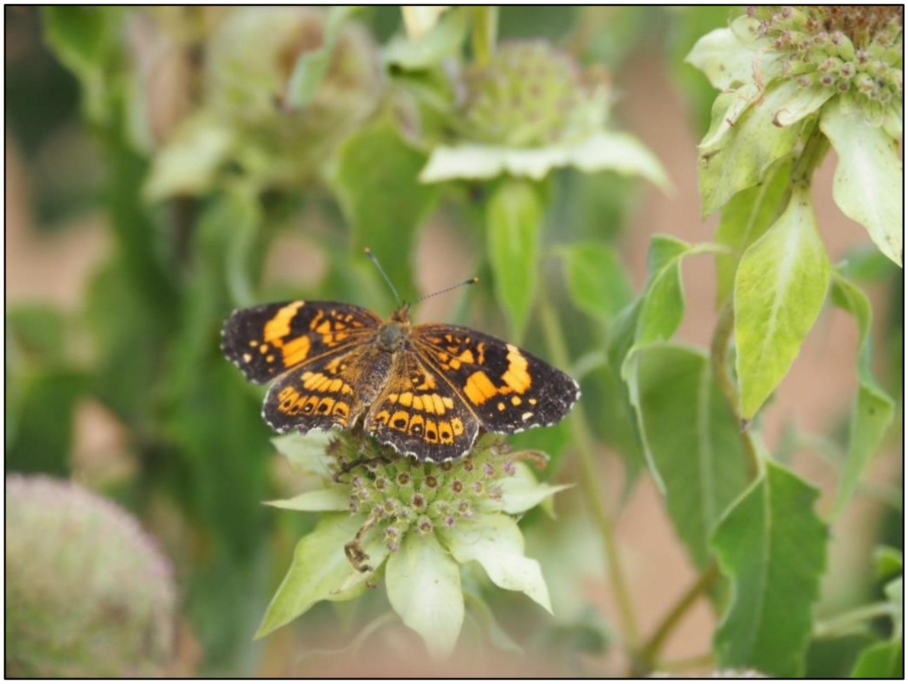
FIST, MLCNPS, 2022



FIST, MLCNPS, 2022

FIST, MLCNPS, 2022

FIST, MLCNPS, 2022

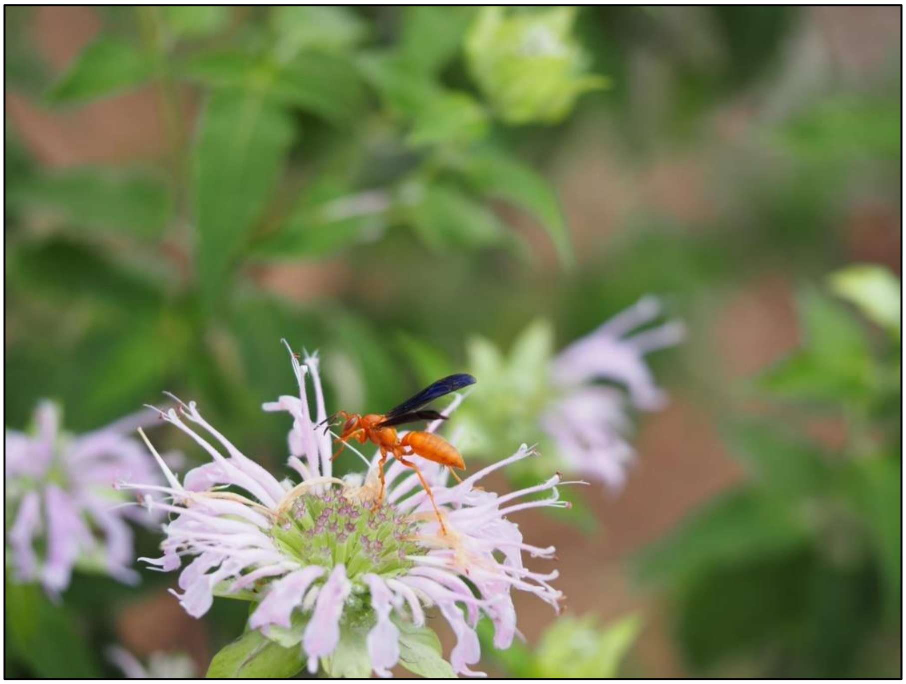


FIST, MLCNPS, 2021

FIST, MLCNPS, 2021

FIST, MLCNPS, 2021

FIST, MLCNPS, 2021

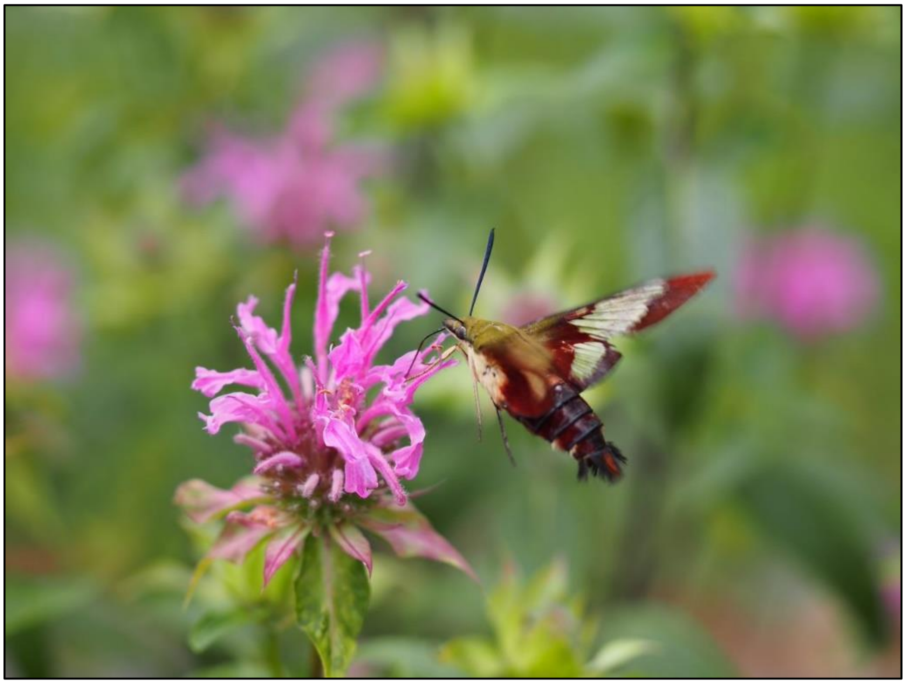


FIST, MLCNPS, 2021

FIST, MLCNPS, 2021

FISTCG, MLCNPS, 2022

FISTCG, MLCNPS, 2021



FISTCG, MLCNPS, 2021

FISTCG, GMREC, 2021

PUNGA, GMREC, 2021

PUNNJ, MLCNPS, 2022

PUNNJ, MLCNPS, 2022

PUNNJ, MLCNPS, 2022

[z] Photos taken by Kirtus Brown, Rachel Smith, and Tina Thanh-Lan Vu.