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First report of a gynandromorph of *Florilegus condignus* (Cresson, 1878) (Hymenoptera, Apidae), with notes on phenology and abundance

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Abstract

Gynandromorphs are individuals that exhibit aspects of both males and females simultaneously and are the most commonly reported sexual anomalies in bees. We describe the first known specimen of a gynandromorph of the specialist pollinator *Florilegus condignus* (Cresson, 1878) (Hymenoptera: Apidae: Eucerini) collected in an agricultural field in northwestern Mississippi, USA. Additionally, we include and discuss phenological data from collections made in Mississippi and the Mid-Atlantic region of the United States.

Keywords

Development, morphology

Introduction

Gynandromorphs are individuals that exhibit both male and female characteristics at the same time and are the most commonly reported sexual anomalies in bees (Hinojosa-Díaz et al. 2012). Several general overviews listing known gynandromorphs of bees have been previously published (Dalla Torre and Friese 1899; Wolf 2001, 2006; Wcislo et al. 2004; Michez et al. 2009; Hinojosa-Díaz et al. 2012). As of the latest comprehensive review published in 2012, over 150 gynandromorphs have been described from most bee families representing over thirty genera and are more frequently observed in *Andrena* (Andrenidae) and *Megachile* (Megachilidae). Other recent review papers have focused on gynandromorphs within individual genera of bees including *Megachile* (Sommaggio et al. 2021), *Osmia* (Kratochwil 2021), and *Xylocopa* (Lucia and Gonzalez 2013). Gynandromorphs are broadly divided into several categories following Wcislo et al. (2004) and Dalla Torre and Friese (1899): bilateral (divided left to right), transverse (divided dorsal to lateral), anterior-posterior (divided front to back), and mixed (mosaics, or combinations of the other types).

Florilegus condignus (Cresson, 1878) (Hymenoptera: Apidae: Eucerini) is the sole North American representative of its genus. LaBerge and Ribble (1966) describe the range within the United States as encompassing the east coast from New Jersey to Florida, west to Colorado, and south to the Mexico border. *Florilegus condignus* is considered a specialist pollinator across its entire range in the USA (Fowler 2020a, b; Fowler and Droege 2020), and is reported to be oligolectic on pickerelweed (*Pontederia* sp.). It has also been reported as an important pollinator for production of watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) and alfalfa (*Medicago sativa* L.) (Mitchell 1962; LaBerge and Ribble 1966; Brewer 1974). Individuals were also collected in cotton fields in both Mississippi and Texas (Parys et al. 2020). Additional floral visitation records include sweet clover (*Melilotus* sp.), prairie milkweed (*Asclepias sullivantii* Engelm. ex A.Gray), common milkweed (*Asclepias syriaca* L.), wood mint (*Blephilia hirsute* (Pursh) Benth.), partridge pea (*Chamaecrista fasciculata* (Michx.) Greene), common buttonbush (*Cephalanthus occidentalis* L.), water willow (*Justicia americana* (L.) Vahl), lanceleaf frogfruit (*Phyla lanceolata* (Michx.) Greene), French grass (*Psoralea onobrychis* Nutt.), Appalachian mountain mint (*Pycnanthemum flexuosum* (Walter) Britton, Sterns & Poggenb.), mountain mint (*Pycnanthemum virginianum* (L.) T.Durand & B.D.Jacks. ex B.L.Rob. & Fernald), and hoary vervain (*Verbena stricta* Vent.) (Robertson 1928). The species is primarily observed from May through August in most eastern states of the USA, but records from April and September have been noted from Florida (Mitchell 1962). Here we describe the first known gynandromorph of the species *F. condignus* (Cresson, 1878), also the first known from the genus *Florilegus* along with information about phenology in two regions of the USA.

Materials and methods

Specimens of *F. condignus* in Mississippi were collected through widespread sampling across Mississippi between 2015 and 2018 as part of ongoing pollinator studies at the USDA Agricultural Research Service located in Stoneville, MS. Additional data from

2017 was provided by a project at the Mississippi State University Department of Wildlife, Fisheries and Aquaculture in Mississippi State, MS. These projects used a variety of collecting techniques including directed netting, malaise traps (BugDorm, Taiwan), blue and yellow vane traps (BanfieldBio Inc./Springstar, Seattle, WA, USA), bee bowls (modified pan traps), and examining bycatch from other studies. Bee bowls were constructed and used following previously published protocols (Droege 2015; Parys et al. 2020).

Observations from the Mid-Atlantic region were obtained from the United States Geological Survey's Bee Inventory and Monitoring Lab (BIML) based at the Patuxent Wildlife Research Center in Maryland. The original dataset included 191 specimen records of *F. condignus*. We eliminated records all records with no collection dates and those that were beyond the Mid-Atlantic region of the United States (this left records from Delaware, District of Columbia, Maryland, and Virginia), leaving 187 records for analysis. Some of these records are included in a recently published data set that only included pan trapping efforts from BIML (Kammerer et al. 2020).

The gynandromorph specimen in our Mississippi study was collected in a blue vane trap filled with propylene glycol between 9–16 June, 2016. The trap was placed in a commercially farmed sunflower field (*Helianthus annuus* L.) planted for recreational hunting purposes, which was surrounded by cotton (*Gossypium hirsutum* L.) and soybean (*Glycine max* (L.) Merr.) production. Photographs of external morphology were taken using a Keyence VHX-7000, and the images were cropped and shadows removed using an airbrush in GNU Image Manipulation Program (GIMP v2.1). The specimen is currently housed at the Parys Laboratory (USDA Agricultural Research Service, Pollinator Health in Southern Crop Ecosystems Research Unit, Stoneville, MS). For identification the specimen was keyed out using Mitchell (1962).

Specimen data were only used in phenology analyses when greater than 10 specimens including both sexes were collected in any given year and region. The first and last two observations of each calendar year were used (n = 8 per year per sex). Collection dates were converted to date within the calendar year (1–365) for use in analyses. Data sets were tested for normality using a Shapiro-Wilk test and for homogenous variances using an F-test (Box 1953; Shapiro and Wilk 1965). When the data were normally distributed and variances were similar, phenology between genders within a state or region was analyzed using Welch's two-sample t-tests (Murtaugh et al. 2012). When data were not normally distributed, a Mann-Whitney-Wilcoxon test was used (Mann and Whitney 1947). All statistical analyses were completed in R version 4.0.4 "Lost Library Book" (R Core Team 2019).

Results

Gynandromorph: *Florilegus* (*Florilegus*) *condignus* (Cresson, 1878)

Descriptive remarks: Specimen appears primarily female with the head bilaterally split and having both male and female characters. The specimen shows wear and some loss of hair, similar to most specimens collected in vane traps and washed.

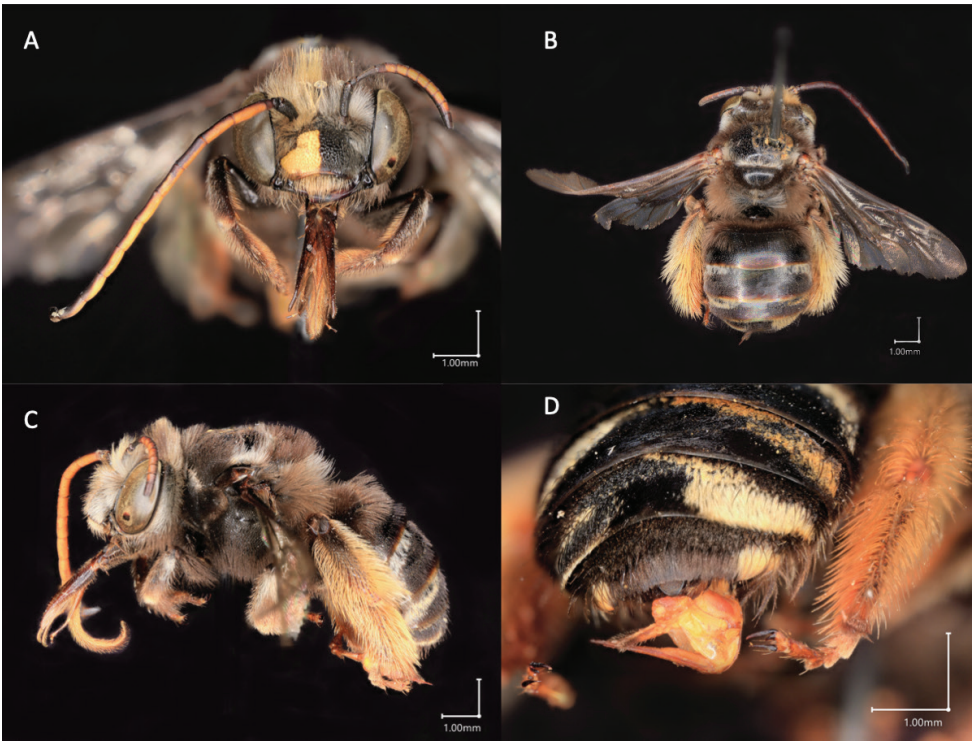

Figure 1. Images of the gynandromorph of *Florilegus condignus* **a** front view of the head and antennae **b** dorsal view **c** lateral view **d** final tergites of the abdomen with ovipositor.

Head: Bilaterally asymmetrical, right side with only male features as listed (Fig. 1A): right side of clypeus bright yellow. Flagellum of right antennae elongate, 13 segments and 11 flagellomeres as in other male Eucerini, median segments brown beneath and piceous above. Hairs along right side of face and vertex yellow as in typical male specimens. Left side of head typically female (Fig. 1A), as follows: dark clypeus, left antennal flagellum not elongate with 12 segments and 10 flagellomeres as in other female Eucerini, median segments brown beneath and black above. Hairs along left side of face and vertex brown as in typical female specimens. Both mandibles appear similar and are dark.

Mesosoma and metasoma: The mesosoma and metasoma present as fully female with ovipositor visible (Fig. 1B–D). Integument and legs black, tegulae brown, scutum shining with coarse punctures. Legs all appear as female, with light colored plumose scopa on both hind legs. Abdominal terga punctate almost to rim, with apical rim of terga alone impunctate. Terga are slightly iridescent. Full description of typical specimens available in Mitchell (1962).

Material examined: SIMRU5775, USA: Mississippi: Sunflower Co., Holly Ridge Plantation Sunflowers, 33.462079, -90.707222, 9–16 June 2016 – Blue Vane Trap, coll. Parys et. al.

Table 1. Collection methodology and abundance of *F. condignus* specimens collected in two regions.

Collection type	Mississippi			Mid-Atlantic/BIML		
	Female	Male	Total	Female	Male	Total
Pan Traps (no color given)	-	-	-	10	12	32
Pan Trap (Blue)	126	70	196	-	-	-
Pan Trap (White)	8	6	14	-	-	-
Pan Trap (Yellow)	12	0	12	-	-	-
Vane Trap (no color given)	-	-	-	25	8	33
Vane Trap (Blue)	387	167	554	-	-	-
Vane Trap (Yellow)	3	1	4	-	-	-
Malaise Trap	5	2	7	-	-	-
Agricultural Sweeping	1	1	2	-	-	-
Lepidopteran Pheromone Trap	1	0	1	-	-	-
Netting	8	3	11	12	109	121
Pitfall Trap	-	-	-	1	0	1

F. condignus phenology

Overall, 999 specimen records were used from Mississippi and the Mid-Atlantic regions of the USA. Across both regions, the specimens were collected by various methods; most specimens (96%) were collected with pan and vane traps in Mississippi while the specimens from the Mid-Atlantic were primarily collected by netting (64.7%) (Table 1).

Between May 3 and November 10, 2018 a total of 812 specimens of *F. condignus* were collected from 12 counties in northern Mississippi (Fig. 2). There was no significant difference in date of first collected specimens between males and females (W = 29, $P = 0.79$), or in last date of specimen collection ($t = 1.22$; $df = 14$; $P = 0.24$) (Fig. 3a, c).

An additional 187 specimens of *F. condignus* were collected from seven counties across three states: Virginia, Maryland, and the District of Columbia between 2003 and 2020. Of these 187 records, nine were included in the clean and publicly available dataset released by Kammerer et al. (2020). All individuals were collected between June and August (Fig. 4). There was no significant difference in date of first collected specimens between males and females (W = 45; P = 0.18), or in last date of specimen collection (W = 39.5; P = 0.46) (Fig. 3b, d).

Discussion

The sexual dimorphism present in many species of bees offers unique opportunities to study gynandromorphs while using morphology to positively associate males and females of the same species in which only one sex is distinctive. Several theories of the occurrence of gynandromorphs have been proposed, especially in honeybees (*Apis mellifera* L.). Jones et al. (2021) provide a recent review of developmental mechanisms and the production of gynandromorphs. Multiple studies have suggested that extreme temperatures can increase the incidence of this phenomenon in bees and other

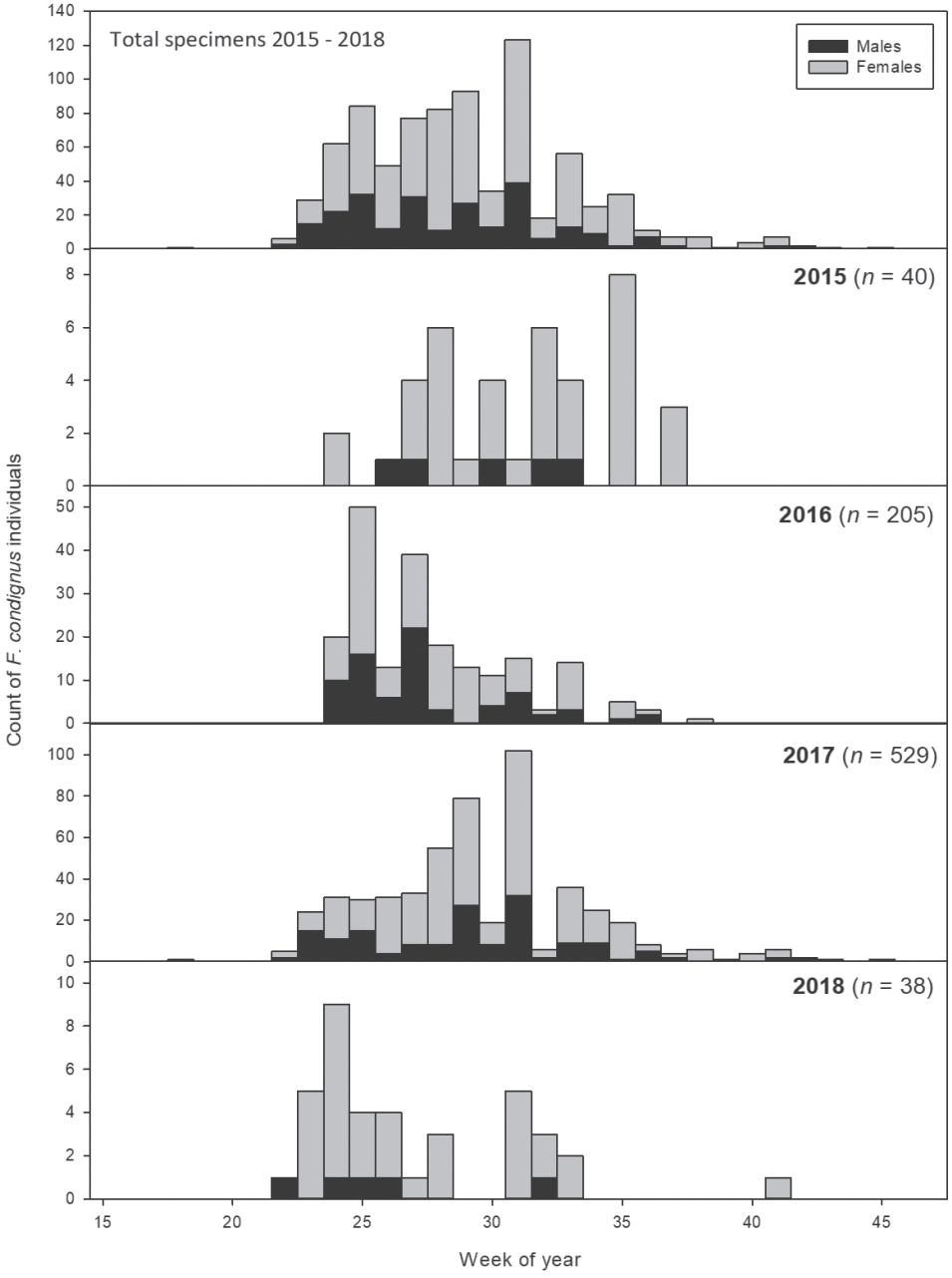

Figure 2. Total collections of *F. condignus* specimens in Mississippi in total by week of the year (top), and by individual years below.

hymenopterans (Drescher and Rothenbuhler 1963; Berndt and Kremer 1981; Kamping et al. 2007). Bees in the genus *Andrena* are known to be more likely intersex or gynandromorph if parasitized by stylopids (Salt 1931). Other studies suggest that bee gynandromorphs, at least in the genus *Megachile*, could have epigenetic origins

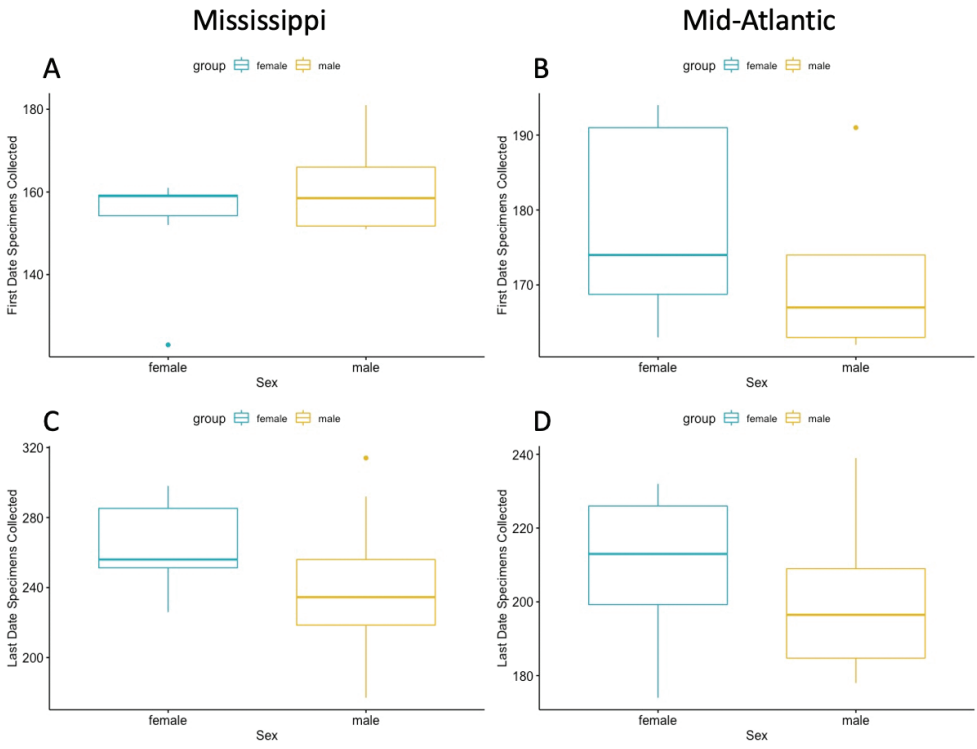

Figure 3. Box plots showing average first and last specimen collections of each year from two regions for four year (2015–2018).

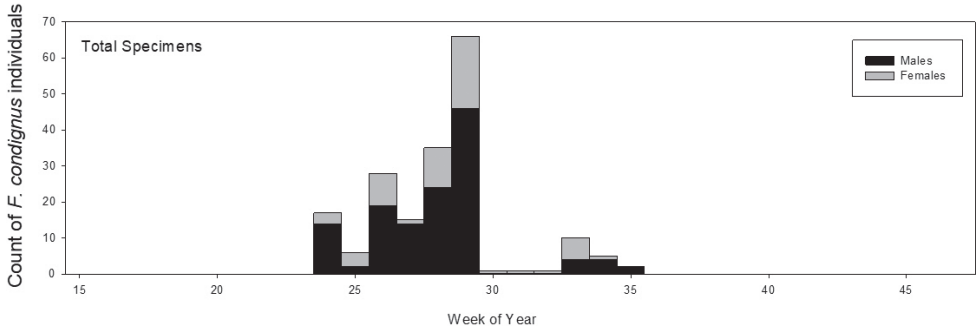

Figure 4. Total collections of *F. condignus* specimens in the Mid-Atlantic in total by week of the year.

(Sommaggio et al. 2021). Since gynandromorphs are rarely collected, especially in wild populations of bee species, little is known about the developmental mechanism or causes. Further research is needed, along with updated documentation of known occurrences of deviant phenotypes and their distribution across the phylogenetic landscape of bees and other Hymenoptera.

In addition to gynandromorphs, a variety of other mutations and deformities are known from bees including: variation in submarginal cells and other wing deformities

(Schneider and Feitz 2003; Sheffield and Heron 2017; Scarpulla 2018), missing antennae (Portman and Griswold 2016), eyes or ocelli (Lohrmann and Engel 2015), and malformed mouthparts (Orr and Tripodi 2017). Additionally, many of the newer observations available since the last comprehensive review are either citizen science records from platforms like buggide and iNaturalist or observations published online alone from the USGS' Bee Monitoring and Inventory Lab (Kelly 2020; USGS BIML 2014). Such specimens are rare given the number of insects regularly collected and the recent worldwide focus on pollinator research.

Florilegus condignus is not commonly encountered in either Mississippi or the Mid-Atlantic region of the USA. Between 2015 and 2018, the USDA and MSU labs collected roughly 50 thousand specimens of bees across the northern part of the state as part of other studies, making *F. condignus* only 1.6% of specimens collected during that time frame. Kammerer et al. (2020) contains 99,053 specimen records from BIML pan traps in Maryland, Delaware, and the District of Columbia and only has nine *F. condignus* records suggesting that this species is only a fraction of the overall community that exists within the larger Mid-Atlantic region as well. Despite being overall uncommon, this is the first record of a specimen of *F. condignus* displaying morphological characteristics of both sexes. Additional records of gynandromorphs in the Eucerini are known from *Alloscirtetica* (Urban 1999), *Eucera* (Dalla Torre and Friese 1899; Morice 1903; Masuda 1940; Levchenko 2011; Jones et al. 2021), *Melissodes* (Cockerell 1906), and *Tetraloniella* (Dalla Torre and Friese 1899).

Florilegus condignus was active as early as May 3 and as late as November 10 during in Mississippi during the period of this study. In Nebraska, LaBerge and Ribble (1966) suggested a much shorter period of activity from July 3 to August 13, with peak abundance occurring in late July, while Mitchell (1962) noted early and late records of April and September from Florida. Other studies note protandrous patterns with male *F. condignus* emerged before females in Nebraska (LaBerge and Ribble 1966), our data appears to suggest that males were collected prior to females but the difference in collection dates between males and females were not statistically significant. Total data from the MidAtlantic region appear bimodal in Fig. 4, but that pattern was not seen in the total specimens in Fig. 2. These patterns are likely an artifact of sampling since this is aggregate data from many separate studies and collection methods. While we've only examined collection dates here, phenology and emergence of many wild or native non-*Apis* bee species are often strongly tied to temperature (Forrest and Thompson 2011; Ovaskainen et al. 2013; Kehrberger and Holzschuh 2019), and further studies should be done on this species.

As noted above, this species appears to be oligolectic, but additional studies are needed to determine whether it is narrowly specialized on pickerelweed and only visits other plants for nectar. The possibility remains that it is, in fact, polylectic and has been incorrectly reported as a specialist. Within the Southeastern US, some habitats or landcover types of western Mississippi, for example, may provide important resources for this species as many of the plant species listed by Robertson (1928) as visited by *F. condignus* are frequently present in or amid wetland habitats in western Mississippi (Gunn et al. 1980). *Florilegus condignus* was also recently detected in Arkansas

wetlands, across the Mississippi River from where collections were made in Mississippi (Stephenson et al. 2018). The phenological findings included in this paper alongside the description of a gynandromorph of *F. condignus* in Mississippi add to the generally limited knowledge about this species.

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