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The potential management of a ground-nesting, solitary bee: *Anthophora abrupta* (Hymenoptera: Apidae)

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Abstract

In Apr 2010, *Anthophora abrupta* (Say) (Hymenoptera: Apidae) was discovered nesting in open bags of colloidal clay in Gainesville, Florida, USA, in an open-air shed. Label data from *A. abrupta* specimens in the Hymenoptera holdings of the Florida State Collection of Arthropods indicated that no specimen had been collected previously from Alachua County and that the most recent Floridian specimen was collected in 1987. This suggests that *A. abrupta* may be locally rare and possibly in decline or threatened regionally. Many of the plants that *A. abrupta* is reported to visit are listed as threatened or endangered in 1 or more states. In an effort to study the potential management and conservation of this species, the original nest aggregation was split in 2012 and 2013, and the splits were moved to new nest sites to see if they would establish at the new sites. Both mother and daughter nest aggregations were monitored in Spring of 2012–2014. Herein, a brief review of *A. abrupta* natural history, an account of the attempts to split the aggregations for new nest establishment, and suggestions for the potential management of this beneficial insect are discussed.

Key Words: chimney bee; artificial nest; miner bee

Resumen

En abril 2010, *Anthophora abrupta* (Say) (Hymenoptera: Apidae) fue descubierto haciendo nidos en bolsas abiertas de arcilla coloidal en Gainesville, Florida, en un cobertizo al aire libre. Los datos de las etiquetas de los especímenes de *A. abrupta* en la Sección de Himenóptera de la Colección de Artrópodos del Estado de Florida indicaron que ningún ejemplar fue recolectado previamente en el Condado de Alachua y que el espécimen más reciente recolectado en la Florida fue en 1987. Esto sugiere que la occurencia de *A. abrupta* puede ser rara localmente y posiblemente en declive o amenazada regionalmente. Muchas de las plantas que son reportadas que *A. abrupta* visita estan alistadas como en peligro amenazadas de extinción en uno o más estados. En un esfuerzo por estudiar el manejo potencial y la conservación de esta especie, la agregación del nido original se dividió en el 2012 y el 2013 y las divisiones fueron trasladadas a nuevos sitios para anidación para ver si se establecían en los nuevos sitios. Las agregaciones de nidos madre e de hija fueron monitoreados en la primavera del 2012–2014. Aquí, se discute una breve reseña de la historia natural de *A. abrupta*,se describe los intentos de divición de las agregaciones para el nuevo establecimiento de nidos y sugerencias para el manejo potencial de este insecto beneficioso.

Palabras Clave: abeja de chimenea; nido artificial; abeja minero

Anthophora abrupta Say (Hymenoptera: Apidae), also called the chimney or miner bee, nests gregariously in clay or adobe substrate in the eastern half of the U.S. (Graham et al. 2013). A female *A. abrupta* digs a tunnel for her nest and uses the excavated earth to sculpt a chimney-like turret around the nest entrance. Each turret corresponds to a single nest (Frison 1922; Norden 1984). The neighboring nests are clustered together in such a way that at first glance the bee activity resembles that of a social bee colony. However, the chimney bees exhibit no generational overlap and each female builds and provisions only her own nest for the benefit of her own offspring (Rau 1929; Norden 1984).

Male and female *A. abrupta* visit a variety of flowers to collect pollen, nectar, or other plant compounds. Mating occurs on flowers. After mating, the female begins nesting, usually in the same location from which she emerged (Frison 1922). The later-emerging females nest in a clumped distribution around the early-emerging females' nests (Norden 1984).

Mated female *A. abrupta* collect water to soften the hard-packed clay and begin excavating a tunnel (Rau 1929). The clay removed from the tunnel is built up around the entrance, creating a chimney-like turret. The turrets are smooth on the interior, rough exteriorly, oriented in various directions with no obvious pattern, have a characteristic dorsal slit on the ceiling, and average approximately 8 cm in length (Frison 1922; Norden 1984). There have been many suggestions for the purpose of the turrets including: (1) protection from rain, nearby excavations, windblown debris, or parasites; (2) functioning as a landmark for nest recognition; (3) providing a social significance for the nest aggregation; or (4) serving a thermoregulatory function for the nest (North & Lillywhite 1980; Brooks 1983; Norden 1984).

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After turret construction concludes, the female finishes excavating the tunnel and begins constructing the cells. The completed tunnels average about 11 cm in length and contain around seven urn-shaped cells that are excavated into the sidewalls of the tunnel (Frison 1922; Norden 1984). The females waterproof the tunnel and cells using a glandular secretion excreted from their Dufour's gland (Norden 1984). The cells are provisioned by the female with pollen and nectar that they collect from several plants and mix with more secretions from the Dufour's gland (Norden et al. 1980). The female oviposits a single egg onto the pollen mixture, seals the cell with a clay capping, and proceeds to provision a new cell (Frison 1922). The female plugs the tunnel entrance with clay once all cells are provisioned with food and an egg (Rau 1929; Norden 1984).

The eggs hatch after about 5 d (Frison 1922; Norden 1984). The larvae develop over the next 3 wk, all while consuming the food pellet and much of the cell lining (Norden 1984). Fourth instar larvae transform into prepupae without molting. They remain prepupae for about 9.5 mo, with their head capsule oriented below the cell capping (Norden 1984). The bees shed their pupal skin at the end of the pupation period, darken for about 2.5 wk, and emerge from their burrows to begin life as adult bees (Frison 1922; Norden 1984).

The current project is an attempt to determine if *A. abrupta* from an identified nesting site will: 1) nest in containers of clay provided close to their original nests; 2) survive being transported as nest splits to a new location and emerge the following year; and 3) nest in clay provided at their new nest location. Furthermore, *A. abrupta* distribution in Florida and elsewhere is discussed based on a review of the *A. abrupa* collection at the Florida State Collection of Arthropods (FSCA), Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Florida, USA, and a review of the literature. Next, plant visitation habits of *A. abrupta* are considered. This is followed by a discussion of conservation efforts for *A. abrupta*, of its potential use as a provider of crop pollination services, and of ways to promote educational awareness for native bees. We conclude with suggestions for the future management of *A. abrupta*.

Materials and Methods

In 2010, *A. abrupta* was discovered nesting in Gainesville, Florida, USA (29°40ˈ45"N, 82°22ˈ2"W), in an open air shed, in horizontally oriented open, weathered bags of loose, colloidal clay and soft rock phosphate (Fig. 1). The nesting site was investigated in Apr 2010 and an adult bee specimen was collected for identification. The *A. abrupta* collection in the Hymenoptera holdings of the Museum of Entomology of the FSCA was examined to understand better the local and national distribution of this bee. According to these collection data, the most recent specimen of *A. abrupta* in Florida was collected in 1987. Furthermore, there are no records of *A. abrupta* specimens being collected from Alachua County (Table 1).

Observations of the *A. abrupta* nest continued in Apr, May, and Jun in 2010. Adults were seen only rarely in mid Jun 2010. After Jun 28, adults were not observed until the following Spring. The observations of the 1st season led to the hypothesis that *A. abrupta* adults emerging from the existing nest in Spring 2011 would excavate and provision nests in nearby clay if it was provided in portable containers. By using the containers, the nests could be dispersed to seed new areas. With only 1 nesting aggregation of locally rare *A. abrupta* identified for use, attempts at augmenting the population carried the risk of causing unintended harm to the very population being studied. However, a small split was taken carefully from the original

Fig. 1. The original (mother) nest aggregation of *Anthophora abrupta* discovered in Apr 2010. The bees were nesting in colloidal clay, in an open air shed, in Gainesville, Florida. Photo: Jason R. Graham.

(mother) aggregation and used to seed a new area (daughter nest aggregation).

Artificial nest material was created in order to encourage the bees to nest in portable containers. Naturally occurring, unacidulated, soft rock phosphate colloidal clay (Manko, Co., Dunnellon, Florida, USA) was mixed with water in plastic storage bins (17.9 L). The mix was allowed to set and dry for 6 mo with excess moisture poured off as needed. After the clay had hardened, about 20 "starter holes" (9.5 mm ID, 2.5 cm deep) were drilled into the face of each of the clay blocks. The dry clay blocks, contained in the plastic storage bins, were placed around the periphery of the existing, dormant mother nest aggregation in Apr 2011. These artificial nesting sites were positioned horizontally (n = 3) and vertically (n = 6). Loose clay also was provided horizontally (n = 3) in containers.

In Mar 2012, a split was made from the mother nest aggregation at a time when the larvae were known to have grown large enough and to have consumed enough food to avoid their drowning in the liquid diet when moved (Frison 1922; Norden 1984). This same day, 3 male bees were observed emerging from the original aggregation. Splitting the original mother aggregation consisted of carefully removing about one-eighth of the original mother nest aggregation and removing 2 of the clay blocks that had been prepared in containers and in which some bees nested the previous year. This material was transported to the University of Florida Bee Biology Unit, Gainesville, FL, USA (29°37ˈ63"N, 82°21ˈ41") and placed under an open-air shed, on a large metal tray filled with clay premixed as before (Fig. 2). This daughter aggregation (daughter 1) was positioned on a workspace approximately 1 m above the ground.

In Mar 2014, another split was made from the mother aggregation. This split (daughter 2) was moved to High Springs, Florida, USA (29°47ˈ43"N, 82°36ˈ20"W), placed under an open-air shed, and supplemented with unprocessed blocks of clay that had been obtained from the mine site (Fig. 3).

Nesting activity was observed and recorded at each site when the bees began emerging from nests the weeks of Apr 5, 2012; Apr 25, 2013, and Apr 26, 2014. The activity levels were monitored as frequently as possible at each site using hand-held push button counters to record each time a bee returned to a nest entrance. These observations were taken at various times of the day, and for various lengths of

Table 1. The distribution and seasonality of *Anthophora abrupta* according to data from the Florida State Collections of Arthropods (FSCA, Florida Department of Agriculture and Consumer Services, Division of Plant Industry) and found in the literature.

State	County	Month	Day or range	Year	Collection method	References
AK	Fulton	Jun	28	1988	Field collected	FSCA
AK	Fulton	Jun	30	1988	Field collected	FSCA
FL	Columbia	Mar	1	1934	—	FSCA
FL	Franklin	Mar	18	1974	—	FSCA
FL	Gulf	May	8	1987	—	FSCA
FL	Lee	Apr	30	1968	—	FSCA
FL	Liberty	Apr	30	1973	Malaise trap	FSCA
FL	Liberty	May	13	1964	—	FSCA
FL	Liberty	May	17	1968	Malaise trap	FSCA
FL	Liberty	May	18	1970	Insect flight trap	FSCA
FL	Liberty	May	23	1970	Insect flight trap	FSCA
FL	Nassau	Apr	20	1984	—	FSCA
FL	Nassau	Apr	24	1986	—	FSCA
FL	Osceola	May	4	1936	—	FSCA
GA	Clarke	Jun	2	1978	Insect flight trap	FSCA
GA	Clarke	Apr	16	1979	Insect flight trap	FSCA
GA	Fulton	May	26	1935	—	FSCA
GA	Richmond	May	31	1958	—	FSCA
IL	Champaign	Jun	15	1973	—	FSCA
IL	Champaign	Jul	6	1973	—	FSCA
IL	Vermilion	Jun	7–26	1919	Nest observations	Frison 1922
MD	Baltimore	May	13–15	1977	Nest observation	Norden 1984
MD	Baltimore	May	28	1978	Nest observation	Norden 1984
MD	Baltimore	Jun	15–17	1982	Mating area observation	Norden & Batra 1985
MD	Baltimore	Jun	11, 14, 21	1984	Mating area observation	Norden & Batra 1985
MO	Boone	Jun	20	1985	Field collected	FSCA
MO	Clay	Jul	1	1986	—	FSCA
MO	Johnson	Jun	5	1966	Field collected	FSCA
MO	St. Louis	Jun	25	1917	Nest observation	Rau 1929
MO	St. Louis	May	28	1918	Nest observation	Rau 1929
MO	St. Louis	May	27	1921	Nest observation	Rau 1929
MO	Texas	Jun	17	1988	Field collected	FSCA
MO	Texas	Jun	16	1988	Field collected	FSCA
NC	Avery	Jun	1	1993	—	FSCA
OH	Champaign	Jun	28	1968	Malaise trap	FSCA
OK	Latimer	Apr	—	1986	Malaise trap	FSCA

time. The flight data were standardized as the average number of bees returning to the nesting site per minute in order to compare activity between sites (Fig. 4).

Results

The bees at the original mother site did not use any of the 3 containers housing loose colloidal clay and positioned horizontally. On the other hand, 4 of the 6 hardened clay blocks positioned vertically in containers were observed to have nesting activity in Apr 2011. In 2012, 2 blocks in which bees successfully nested at the original mother site were transported to the Bee Biology Unit along with all of the unused loose and hardened clay from the 2 horizontally oriented containers. In 2013, nesting at the 1st daughter site was observed in all of the hardened blocks that had been provided to the mother nest aggregation but not used in 2011. Nesting continued and spread at the mother nest aggregation into an additional 5 horizontally oriented containers filled with hardened clay as before. Nesting continued in hardened clay that was provided to both the mother and daughter nest aggregations after the split was made. The 1st split was a success as both mother and 1st daughter nest aggregations survived the split and were active in 2013, the season following the split (Fig. 4).

On Apr 5, 2012 the first adult bees, 15 male *A. abrupta*, were observed emerging from the 1st daughter aggregation of nests. Female *A. abrupta* were seen inspecting holes at the daughter nest aggregation on Apr 10, 2012 and actively building nests on Apr 11, 2012. The first pollen observed being brought back by foraging females at the daughter nest aggregation was on Apr 14, 2012. Three male bees were observed emerging from the nesting material at the mother nest aggregation on Mar 30, 2012, and nesting females were observed on Apr 10, 2012. Nesting continued at the daughter site until May 7, 2012 and at the mother site until May 11, 2012, after which no adult bees were seen until the following spring.

In Apr 2013, the nest sites were checked daily for the anticipated emergence of the adult *A. abrupta*. On Apr 20, 2013 a crackling sound was heard coming from the clay nesting material at the mother nest aggregation. Upon inspection, the sound was heard at the 1st daughter nest aggregation the following day. On Apr 25, 2013, the first male adults were seen emerging from the daughter site, and the first adults were observed on Apr 27, 2013 at the mother site. Nesting continued until May 20, 2013 at the 1st daughter site and May 26, 2013 at the mother site, after which adult bees were not seen at either nest site for the rest of the season.

Fig. 2. The 1st daughter nesting aggregation of *Anthophora abrupta* established 10.3 km from the original nest site in Gainesville, Florida. It was created as a split from the mother nesting aggregation in Mar 2012. Photo: Jason R. Graham.

In Apr 2014, the nest aggregations were observed in anticipation of emerging adult *A. abrupta*. At the mother nest aggregation, on Apr 21, a faint crackling sound in the clay was noted, and adult *A. abrupta* bees were observed emerging at the mother site on Apr 26, 2014. At the 1st daughter site, the adults were seen emerging on Apr 28, 2014. Adults were not observed emerging at the 2nd daughter site until Apr 30, 2014. Nesting by *A. abrupta* continued at the mother site and 1st daughter nest sites until Jun 10 and Jun 9 2014, respectively. The last recorded *A. abrupta* activity at the 2nd daughter nest site was May 20, 2014.

Fig. 3. A 2nd daughter nesting aggregation of *Anthophora abrupta* established 35.7 km from the original nest site in Gainesville, Florida. It was created as a split from the mother nesting aggregation in Mar 2014. Photo: Amanda M. Ellis.

The activity levels at the mother and both daughter nest aggregations followed similar patterns each year (Fig. 4), although the mother nest aggregation was more active each year than was either daughter nest aggregation. Both the mother and the 1st daughter nest aggregations peaked in activity in late Apr in 2012 and 2013 (Fig. 4). In 2014, the activity at the daughter nest aggregations peaked in early May whereas the activity at the mother nest aggregation peaked in late May (Fig. 4).

Discussion

In this study, *A. abrupta* from an identified nesting site were shown to: 1) nest in containers of clay provided close to their original nests; 2) survive being transported as dormant nest splits to a new location and to emerge the following year; and 3) nest in clay provided at their new nest location.

SUCCESSFUL ESTABLISHMENT OF NEW NESTING SITES

Our observations at the daughter nest aggregations suggest that we were able to establish 2 new nest aggregations of chimney bees successfully. Flight activity at the daughter nest sites was lower than that at the mother nest site. However, this gradually increased in the 1st daughter nest aggregation to reach that of the mother nest aggregation by the 3rd year after the establishment of the 1st daughter nest aggregation. The 2nd daughter nest aggregation had comparable activ-

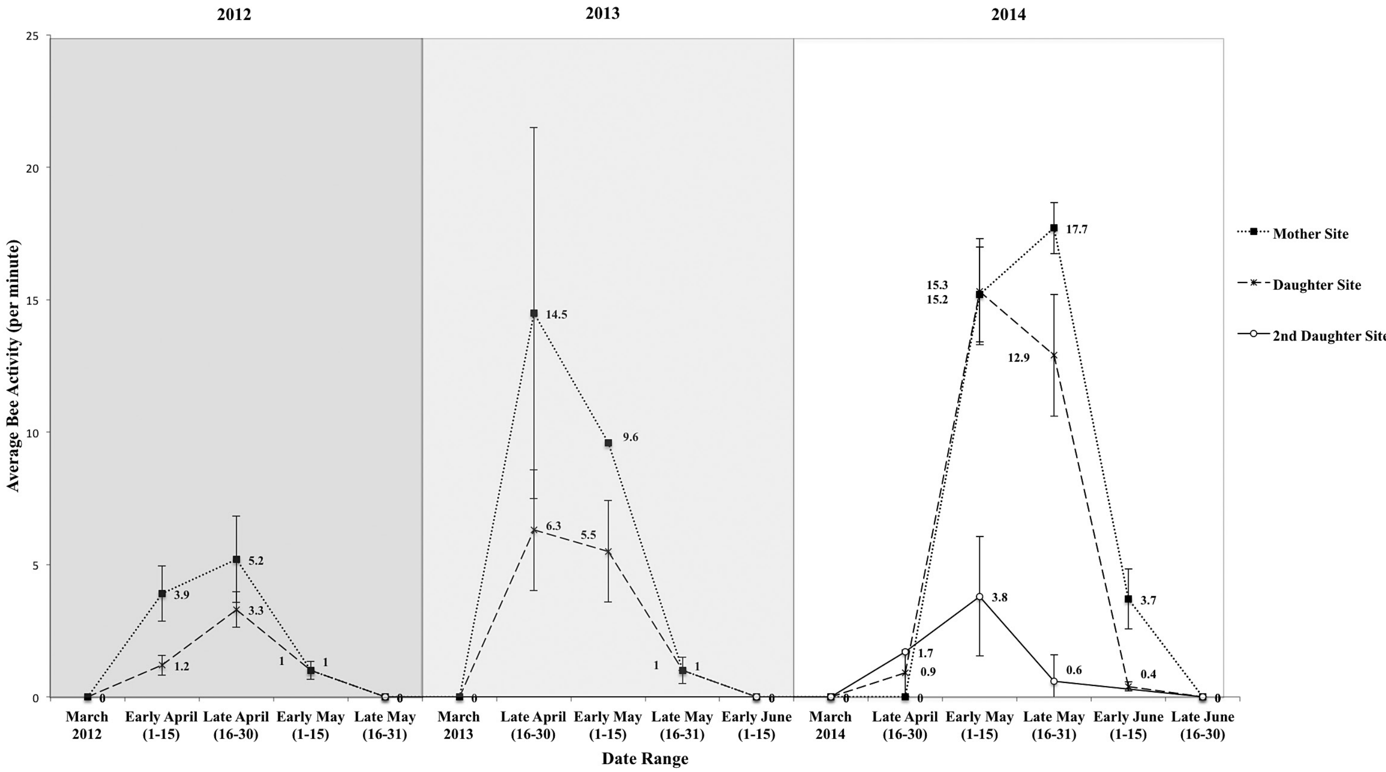

Fig. 4. Bee activity as indicated by the average number of *Anthophora abrupta* returning to the nesting site per minute at the mother and daughter nesting aggregations in 2012, 2013, and 2014. The error bars indicate standard error.

ity levels in 2014, its first season post establishment, to that of the 1st daughter nest aggregation in 2012, its first season post establishment. The activity of each nest aggregation increased yearly.

Nest sites of *A. abrupta* have been observed persisting in the same location for over 50 yr (Norden 1984), and nest sites have been estimated as having as many as 5,000 brood cells (Frison 1922). If the 3 nesting aggregations observed in this study continue to grow, each could provide additional splits, thus producing more colonies for future, involved studies of this bee species.

CHARACTERISTICS FAVORING MANAGEMENT

Other *Anthophora* species are managed commercially around the world. In Germany, *A. pilipes acervorum*, which has a nearly identical life history to the closely related *A. abrupta*, is managed commercially as a pollinator of orchard crops (Thalmann & Dorn 1990; Thalmann 1991) as reported by Batra (1997). The closely related subspecies *A. p. villosula* was imported from Japan, where it is considered a superior pollinator of blueberries (Maeta et al. 1990), and was tested as a potential pollinator of blueberries in Beltsville, Maryland (Batra 1994, 1997), and Maine (Stubbs & Drummond 1999), USA. In both cases, *A. p. villosula* was considered an excellent candidate for commercial management as a provider of crop pollination services. However, the concern that mass importation and rearing could impact closely related native species negatively apparently hindered the commercialization of *A.p. villosula* in North America (Batra 1997; Stubbs & Drummond 1999).

Anthophora abrupta is native to North America and exhibits several characteristics that support its potential for management. First, they tend to nest where they emerge as adults (termed "philopatry," see Cane 1997), even after they have been moved prior to emerging, provided that they have the requisite materials in which to nest, as demonstrated in this study. Nest sites of *A. abrupta* have been observed persisting in the same location for over 50 yr (Norden 1984). Second, female *A. abrupta,* although endowed with a sting, do not defend their nests by stinging (Frison 1922) and apparently are unable to sting humans (Norden 1984). This makes them a good candidate to use because the threat of stings is minimal. Third, *A. abrupta* will feed readily on a honey-water solution in captivity as an artificial diet (Frison 1922). Fourth, adults of *A. abrupta* have emerged successfully under laboratory conditions from collected pupae (Frison 1922; Norden 1984), suggesting the possibility for population augmentation using rearing programs. Fifth, *A. abrupta* has a flight range of up to 3.2 km (Batra 1997), thus making these bees able to pollinate large areas. Sixth, male and female *A. abrupta* visit a variety of flowers, foraging in light rain and in temperatures of 11–39 °C (Rau 1929; Norden 1984). Finally, mature nest sites found in the wild have been estimated conservatively to contain as many as 5,000 cells based on nest dissections from a portion of the sites (Frison 1922). These characteristics make *A. abrupta* a good candidate for use as a managed pollinator.

MANAGEMENT CONSIDERATIONS

Nest Characteristics

Anthophora abrupta nests have been found on cliff banks (Rau 1929), on clay adobe walls (Norden 1984), on clay banks at the edge of creeks and rivers (Frison 1922), and often under a protective overhang such as a bridge or tree (Frison 1922; Rau 1929). The 3 requisites, a patch of hardened clay, shelter from the rain, and close proximity to a water source, were found at the mother nesting aggregation in Gainesville, Florida, USA. Frison (1922) noted that *A. abrupta* prefers perpendicular or steeply inclined surfaces in which to nest, a finding supported by the data presented herein. The adobe walls in which Norden (1984) observed *A. abrupta* nesting had a pH of 6.0 and were composed predominantly of clay and mica. Cane (1991) surveyed and compared nest characteristics and other variables associated with 32 species of ground-nesting bees and reported the soil of an *A. abrupta* nest from Alabama to be a sandy clay loam (29.5% clay, 11.9% silt, 58.6% sand). Analysis of the nest material used in the present study indicated that the soil at both the mother and daughter site was clay (58.6% clay, 27.1% silt, 14.2% sand) with a pH of 6.7.

Protecting Nests

Birds, lizards (at the mother site), and squirrels (at the 1st daughter site) damaged portions of nests. Consequently, the nest aggregations were protected from additional bird or mammal predation by using galvanized steel chicken wire having 5 cm hexagonal gaps and 19-gauge (1 mm) wire. The first few foraging bees that encountered the newly installed chicken wire seemed to hesitate before flying through it. However, all flying bees navigated through the chicken wire with apparent ease shortly thereafter. There was no further observed predation or destruction of the nesting material, until 2014, when at the mother site, broad-headed skinks (*Plestiodon laticeps* (Schneider); Squamata: Scincidae) were observed preying on adult *A. abrupta* on multiple occasions from inside the chicken wire. It is unclear what level of predation these *A. abrupta* populations can tolerate, or if the exclusion of predators is necessary for the success of the nest aggregation.

Mating System

Norden & Batra (1985) studied groups of male chimney bees chewing parsnip (*Pastinaca sativa* L.; Apiales: Apiaceae) tissue. The fragrant plant liquids are absorbed into the male bees' labral hairs and reportedly are mixed with mandibular gland secretions. Males then use these compounds to attract females by marking mating areas with these volatile components (Norden & Batra 1985; Lee 1998). In Missouri, USA, Rau (1929) observed males biting rambler roses (perhaps to collect oils) and eating rust from several metal objects, a behavior that may or may not be important to the mating system.

VALUE OF MANAGEMENT

Most of the literature about this organism comes from researchers who found *A. abrupta* nest aggregations in the wild (Frison 1922; Rau 1929, 1930) or on the property of a concerned homeowner (Norden et al. 1980; Norden & Scarborough 1982; Norden 1984; Norden & Batra 1985; Giblin-Davis et al. 1993; Lee 1998; current study). Management of *A. abrupta* colonies could provide future native bee researchers with a consistent population with which to investigate life history parameters, catalogue nest commensals, conduct pollination studies, and more.

There is also an educational value to managing *A. abrupta* that can be extended to the general public. Like most solitary bees, *A. abrupta* is not defensive of its nests and does not sting readily, if at all. When roughly handled, these bees are reported to defend themselves by biting but are otherwise docile and typically should not be considered a threat (Frison 1922; Rau 1929; Norden 1984). The bees are not timid around humans, so the interested observer can watch as the turrets multiply and the bees stock their burrows with pollen and nectar. Managed colonies located in public parks, zoos, and botanical gardens can be used to teach the general public a variety of concepts such as the development of sociality in hymenopterans, animal architecture, native bee diversity, and the ecological service of pollination. Due to their docile nature and ecological importance, solitary bees make excellent model organisms for citizen science projects (Graham et al. 2014). Interaction with *A. abrupta* could reduce the innate fear of bees as stinging insects and replace this emotion with a healthy respect for and appreciation of bees as beneficial organisms.

The value of *A. abrupta* as pollinators can be demonstrated by the diversity of flowers that they visit. A summary of the plants which *A. abrupta* has been recorded to visit is provided in Table 2. Plant species that are listed as threatened or endangered in 1 or more states (USDA, NRCS 2013) are indicated as such under the column heading "Conservation Need." Of the 59 plants that *A. abrupta* has been reported visiting, 26 plants (44%) are listed in 1 or more states as endangered or threatened (USDA, NRCS 2013). Parallel declines between plants and their pollinators emphasize the importance of pollinator conservation for ecological health (Buchmann & Nabhan 1996; Biesmeijer et al. 2006). Also shown on Table 2, among plants visited by *A. abrupta* are several fruit, vegetable, and forage plants such as asparagus, blackberry, clover, cranberry, parsnip, persimmon, raspberry, and tomato. This suggests that *A. abrupta* may be helpful for the pollination of agricultural crops. The wide variety of plants on this list, representing 28 different families, indicates that *A. abrupta* is a generalist forager.

The natural population of *A. abrupta* appears limited in Florida, and further study should focus on the health and population dynamics of this species throughout the native range of eastern North America. In Florida, these bees are represented in the FSCA from Columbia, Franklin, Gulf, Lee, Liberty, Nassau, and Osceola Counties, although the collected specimens date to the 1930s, 1960s, 1970s, and 1980s (Table 1). Although this lack of specimens may be due in part to collector biases, *A. abrupta* also has not been reported in any of the major bee surveys that have been conducted in Florida (Graenicher 1927, 1928, 1930; Krombein 1967; Pascarella et al. 1999; Deyrup et al. 2002; Serrano 2006; Deyrup 2011; Hall & Ascher 2011, 2012) except for the web resource "Bees of Florida" that lists *A. abrupta* from Lee and Liberty Counties (Pascarella & Hall 2013). There were no *A. abrupta* specimens collected in Florida present in the FSCA collection more recently than 1987 and none present in the FSCA collection from the rest of the country after 1994 (Table 1). Correspondence with the curators at The Stuart M. Fullerton Collection of Arthropods at the University of Central Florida (UCF) and the Archbold Biological Station Reference Collection (ABS), confirmed an absence of *A. abrupta* from both collections (Stuart M. Fullerton (UCF) and Mark Deyrup (ABS), personal communication). Between 2006 and 2014, there were 74 specimens of *A. abrupta* reported to the United States Geological Survey (USGS) Patuxent Wildlife Research Center in Beltsville, Maryland, USA, from: Delaware (1), Georgia (3), Maryland (47), Michigan (10), Virginia (2), and West Virginia (11) (Sam Droege (USGS), personal communication). Other entomology reference collections around the state and country should be evaluated to see if a decline in curated specimens is a regional or nationwide trend. If *A. abrupta* populations are in decline, then conservation management techniques such as those presented here should be applied to avoid losing this bee as a natural resource.

The agricultural sector and food security are primarily dependent on the pollination services provided by the European honey bee (*Apis mellifera* L.). Alternative pollinators are needed to support the U.S. agricultural industry and reduce overdependence on a single species. Most bee species in the U.S. are solitary, ground-nesting bees (Michener 2007), and ground-nesting bees continue to be underutilized as managed pollinators for agriculture (Cane 1997). Through development of management techniques for *A. abrupta*, challenges may be overcome that will accelerate our ability to manage additional species of ground-nesting bees.

Table 2. A summary of plants that *Anthophora abrupta* has been reported to visit. This list should not be considered all-inclusive, as this bee seems to be a polylectic flower generalist. The "conservation need" column indicates plants that have been listed as of special concern, threatened, and/or endangered in 1 or more states (USDA, NRCS, 2013).

Family	Species	Common name	References	Conservation need
Acanthaceae	*Justicia americana* L.	American water-willow	Robertson 1929	Yes
Anacardiaceae	*Rhus typhina* L.	Staghorn sumac	Norden 1984	No
Apiaceae	*Pastinaca sativa* L.	Wild parsnip	Robertson 1929; Norden & Batra 1985	No
Asclepiadaceae	*Asclepias meadii* Torr.	Mead's milkweed	Betz et al. 1994	Yes
	Asclepias purpurascens L.	Purple milkweed	Frison 1922; Robertson 1929	Yes
	Asclepias syriaca L.	Common milkweed	Robertson 1929	No
	Asclepias viridis Walter	Green milkweed	Clinebell II 2003	Yes
Asteraceae	*Taraxacum officinale* Wiggers	Common dandelion	Norden 1984	No
Balsaminaceae	*Impatiens pallida* Nutt.	Jewelweed	Norden 1984	Yes
Berberidaceae	*Nandina domestica* Thunb.	Heavenly bamboo	This study	No
	Hydrophyllum virginianum L.	Virginia waterleaf	Robertson 1891; Frison 1922	Yes
Boraginaceae	*Mertensia virginica* L.	Virginia bluebells	Robertson 1929	Yes
Caprifoliaceae	*Lonicera japonica* Thunb.	Japanese honeysuckle	Norden 1984	No
Celastraceae	*Celastrus orbiculatus* Thunb.	Oriental bittersweet	Norden 1984	No
Convolvulaceae	*Calystegia sepium* L.	Hedge false bindweed	Frison 1922; Robertson 1929	No
Cornaceae	*Cornus obliqua* Raf.	Pale dogwood	Robertson 1929	Yes
Ebenaceae	*Diospyros virginiana* L.	American persimmon	Norden 1984; Robertson 1929; this study	Yes
Ericaceae	*Vaccinium oxycoccos* L.	Cranberry	Lee 1998	Yes
Fabaceae	*Albizia julibrissin* Durazz.	Persian silk tree	This study	No
	Securigera varia L.	Crown vetch	Norden 1984	No
	Melilotus alba L.	Sweet clover	Robertson 1929	No
	Trifolium pratense L.	Red clover	Robertson 1892	No
	Trifolium repens L.	White clover	Robertson 1929; Norden 1984	No
	Vicia caroliniana Walter	Carolina vetch	Norden 1984	Yes
Fagaceae	*Castanea mollissima* Blume	Chinese chestnut	Norden 1984	No
Gentianaceae	*Frasera caroliniensis* Walter	American columbo	Robertson 1929	Yes
Hippocastanaceae	*Aesculus hippocastanum* L.	Horse chestnut tree	Robertson 1929	No
Hydrangeaceae	*Deutzia scabra* Thunb.	Fuzzy deutzia	Norden 1984	No
Hydrophyllaceae	*Hydrophyllum virginianum* L.	Eastern waterleaf	Robertson 1929	Yes
Iridaceae	*Iris brevicaulis* Raf.	Zigzag iris	Robertson 1929	Yes
Lamiaceae	*Blephilia ciliata* L.	Downy woodmint	Robertson 1929	Yes
	Glechoma hederacea L.	Ground ivy	Robertson 1929	No
	Leonurus cardiaca L.	Common motherwort	Robertson 1929	No
	Monarda fistulosa L.	Wild bergamot	Clinebell II 2003	No
	Nepeta cataria L.	Catnip	Norden 1984	No
	Scutellaria ovata Hill	Heartleaf skullcap	Robertson 1929	Yes
	Stachys palustris L.	Marsh hedge nettle	Robertson 1929	No
	Teucrium canadense L.	Canada germander	Robertson 1929	No
Liliaceae	*Asparagus officinalis* L.	Asparagus	Norden 1984	No
	Polygonatum commutatum Walter	Giant Solomon's seal	Robertson 1929	Yes
Ranunculaceae	*Delphinium tricorne* Michx.	Dwarf larkspur	Robertson 1929	No
Rhamnaceae	*Ranunculus bulbosus* L.	Bulbous buttercup	Norden 1984	No
	Ceanothus americanus L.	New Jersey tea	Banks 1912; Frison 1922	Yes
Rosaceae	*Gillenia stipulata* Baill.	American ipecac, Indian physic	Robertson 1896; Frison 1922	Yes
	Rosa carolina L.	Carolina rose	Robertson 1929	No
	Rosa humilis L.	Carolina rose	Robertson 1894; Frison 1922	No
	Rosa setigera Michx.	Climbing rose	Robertson 1894; Frison 1922; Robertson 1929	No
	Rubus allegheniensis Porter	Allegheny blackberry	Robertson 1929; Norden 1984	No
	Rubus idaeus Rich.	Red raspberry	Norden 1984	No
Scrophulariaceae	*Penstemon digitalis* Nutt.	Foxglove beardtongue	Robertson 1929	Yes
	Penstemon hirsutus (L.) Willd.	Hairy beardtongue	Robertson 1929	Yes
	Penstemon laevigatus Aiton	Eastern smooth beardtongue	Frison 1922	Yes
	Penstemon multiflorus Chapm.	Manyflower beardtongue	Robertson 1891; Frison 1922	No
	Penstemon tubaeflorus Nutt.	White wand beardtongue	Robertson 1929	Yes
Solanaceae	*Solanum dulcamara* L.	Nightshade	Norden 1984	No
	Solanum lycopersicum L.	Tomato	Norden 1984	No

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