Consumer-Ready Insect Hotels: An Assessment of Arthropod Visitation and Nesting Success[1]

B.A. Harris[3], E.M. Poole[4], S.K. Braman[4], and S.V. Pennisi[2]

University of Georgia Griffin Campus, 1109 Experiment Street, Griffin, Georgia 30223 USA

J. Entomol. Sci. 56(2): 141–155 (April 2021)

Abstract Insect nesting boxes and hotels have the potential to provide shelter and overwintering sites for beneficial insect communities such as pollinating bees, wasps, earwigs, and other predatory arthropods. This study evaluated beneficial arthropod visitation to consumer-ready, commercially available nesting boxes over a 2-yr period. Insect hotels were placed on mature river birch (*Betula nigra* L.) and crape myrtle (*Lagerstroemia indica* L.) in garden plots established with floral resources for pollinators and other beneficial insects. Paper and thread-waisted wasps, soldier flies, predatory ants, and spiders were observed visiting the boxes. Boxes located in garden plot treatments (with floral resources) had the greatest numbers and diversity of pollinator and beneficial insect taxa compared to control plot treatments (naturalized areas away from floral resources) in 2016. Insect hotels placed on *B. nigra* had a higher number of thread-waisted wasps in 2016 and spiders and total beneficial insects in 2017. Higher numbers of predatory ants and total beneficial arthropods were found in boxes placed on *L. indica* in 2016. During the study, bamboo stems and drilled tunnels in the insect boxes were evaluated for arthropod inhabitance. Largest counts of occupied stems and tunnels were observed in boxes placed in proximity to floral resources and on *L. indica* trees.

Key Words pollinating arthropods, biodiversity conservation, ecosystem services, insect hotels

Attracting beneficial arthropods to garden and landscape areas can increase insect biodiversity, promote arthropod-mediated ecosystem services, and promote overall ecological health (Häussler et al. 2017). To further encourage and increase insect visitation in gardens, insect hotels have been developed as a consumer product for homeowners and gardeners to use as a decorative addition to their landscape. Arthropod-mediated ecosystem services include biological control, pollination, and decomposition (Klein et al. 2007). Insect pests affect 37% of agricultural and ornamental crops in the United States annually and more than $30 billion is spent on pest control (Rufus et al. 2009). Biological control or the regulation of pests by beneficial insects is important not only for crop production but also for home gardens and landscape areas. Pollination is also necessary for crop production and wild plant species viability. Insect pollinators provide pollination for

[1]Received 08 April 2020; accepted for publication 02 June 2020.
[2]Corresponding author (email: bpennisi@uga.edu).
[3]Callaway Gardens, P.O. Box 2000, Pine Mountain, GA 31822-2000 USA.
[4]Department of Entomology, University of Georgia, 120 Cedar Street, Athens, GA 30602 USA.

35% of crop production and for 60–80% of wild plant species (National Research Council 2007).

Recent studies have evaluated habitat management to attract beneficial and pollinating insects to landscape and garden areas using flowering ornamental plant species (Davis et al. 2017, Harris et al. 2016, Motzke et al. 2016, Sutter et al. 2017, Tscharntke and Gathmann 1998). Habitat management provides insects with overwintering or nesting sites, alternative hosts, and pollen and nectar resources. The goal of habitat management is to increase pollinator and beneficial arthropod visitation and biodiversity in a garden, which can contribute to improved pollination and biological control, further reducing pesticide use (Gurr et al. 2017, Landis 2017).

Insect hotels can serve as potential habitats and overwintering sites for arthropods including bees, wasps, lady beetles, spiders, and lacewings. One study has reported increases in *Polistes* paper wasp species when insect boxes were established and monitored in residential locations (Frankie et al. 2005). Solitary bees utilize insect nesting boxes, and solitary bees include bumble, carpenter, leaf-cutter, mason, and sweat bees. The bee genera *Hylaeus* and *Osmia* occupy nesting boxes in urban gardens (Gaston et al. 2005). Likewise, other genera such as *Xylocopa*, *Megachile*, *Centris*, and *Andrena* inhabit nesting boxes (Gathmann and Tshcarntke 2002, Krombien 1967, Roubik and Villanueva-Gutiérrez 2009, Sihag 1993). Additionally, a few studies have reported the impact of nesting box distribution (i.e., location and nesting box placement) on visitation of pollinators and beneficial insects (Boyle and Pitts-Singer 2017, Fortel 2016, MacIvor 2016). Therefore, in the current study, we sought to evaluate the impact of insect hotel placement on arthropod visitation and diversity.

Commercially available insect hotels can be aesthetically pleasing when used in gardens, while acting as a functional nesting site for bees, wasps, and other beneficial arthropods (Rees 2008). Bee hotels have the potential to serve as alternative habitats for beneficial, pollinator, and plant-feeding insects (Le Roux et al. 2016). Although easily and inexpensively constructed from wooden blocks, bamboo stems, etc., a large variety of prefabricated “bee hotels,” “insect homes,” “nesting boxes,” etc. have been marketed in recent years. Various insect hotel designs and materials aimed at creating nesting habitats for different types of pollinators and other beneficial arthropods are often combined in a single design, for example, holes in a wooden block, hollow stems of different plant sources (smaller diameter straw and larger diameter bamboo). A pleasing aesthetic appearance is the goal, while also providing essential habitat features (e.g., metal roof to keep moisture from the box’s interior).

However, several studies report that insect hotels may serve as “population sinks” for native bees as they can harbor parasites and pathogens (Moenen 2012, Macivor and Packer 2015). This may potentially be due to their high nesting densities, which are two-dimensional rather than multidimensional as natural nesting locations such as plant stems or decaying wood logs (Wcislo 1996). While insect hotels encourage different insect species to nest in the box, this cohabitation may actually increase parasite visitation (Lee-Mäder et al. 2010, Rosenheim 1990). Brood parasitism occurs when hymenopteran, coleopteran, or dipteran parasites lay their eggs in cells of pollen-collecting bee hosts. For example, parasitic wasps *Melittobia acasta* (Walker) and *Coelopencyrtus* spp., and the parasitic fly

Cacoxenus indigator Loew attack mason bees (Moenen 2012). Microorganisms such as bacteria and fungi also may develop in the boxes due to condensation and moisture, affecting bee host health and potentially leading to brood mortality (Packer and Knerer 1986).

While ready-made nesting boxes are becoming widely available, their effectiveness to attract desirable insects has not been studied as well. The current study objectives were to (a) document pollinator and other predatory or beneficial insect taxa use of commercially available boxes, (b) quantify and compare arthropod visits and nesting among different taxa, (c) evaluate impact of floral resource proximity on abundance and diversity of arthropods visiting nesting boxes, (d) assess influence of tree placement on insect hotel visitation, and (e) determine potential of nesting boxes as arthropod overwintering sites. With answers to those questions, we hope to provide practical recommendations regarding arthropod visitation to the insect hotels, nesting box placement, and seasonality of insect nesting and visitation.

Materials and Methods

This study was conducted in the University of Georgia Research and Education Garden on the University of Georgia Griffin Campus (Spalding Co.; 33°24′67″N, 84°26′40″W). Below follows a general description of the garden, experimental design, and treatment layout. Butterfly and conservation theme gardens (hereto referred to as "the Garden") were established in October 2012, each with 75 commercially available annual and perennial, herbaceous and shrubby, native and exotic plant species (Harris et al. 2016). Plants were chosen based on their attractiveness to pollinating and beneficial arthropods, horticultural attributes, and adaptability to the southeastern United States as well as the overwintering resources provided. Efforts were made to create aesthetically pleasing landscape designs in each garden necessitating the use of various foliage textures and contrasts (e.g., fine vs. coarse), a variety of plant habits (e.g., groundcover vs. upright), extended blooming (spring to fall seasonal interest) and low maintenance. Nonnative exotic species were included due to desirable horticultural characteristics such as colorful foliage, and included taxa such as *Colocasia, Hibiscus*, *Stachys*, and gingers. *Foeniculum*, *Petroselinum*, *Melissa,* and *Passiflora* were included for larval food source. Each Garden plot contained one of each mature tree species: river birch, *Betula nigra* L. and crape myrtle, *Lagerstroemia indica* L.

There were four replicate plots (total 1,705.2 m^2, 426.3 m^2 per plot) within the Garden; three were contiguous and separated by buffer pathways, while the fourth was located approximately 500 m away. In addition, two naturalized areas located 46 m away from the Garden served as controls. Each naturalized area contained one *B. nigra* and one *L. indica* of the same age as in the Garden plots and was surrounded by vegetative cover including annual weeds and volunteer species. Therefore, treatments were nesting box location (proximity to floral resources [within the four Garden plots] and away from floral resources [naturalized area controls]), and nesting box placement on trees (*B. nigra* or *L. indica*).

Fig. 1. (A) Esschert Designs Insect Hotel, Gander Mountain, Greenville, NC. (B) Information included in promotional label of insect hotel. (C) Occupied bamboo stems (arrows) and wooden drilled tunnels which were counted at each observation date to assess pollinator and predatory or beneficial arthropod visitation and nesting success.

Insect hotels (18.62 cm × 14.36 cm × 32.19 cm) were purchased from a commercial supplier (Esschert Designs Insect Hotel, Gander Mountain, Greenville, NC; Fig. 1A, B). Insect boxes were secured with 2.54-cm brad nails at 1 m height on *B. nigra* and *L. indica* in each garden plot and in the naturalized area (control), for a total of 12 boxes. No insecticides, pesticides, or ant traps were used in proximity of the insect boxes.

Visual observations of nesting boxes were timed for optimal arthropod activity and took place at 10-min intervals from 1 p.m. to 3 p.m. Observations occurred twice a week over 3-mo period from June to August in both 2016 and 2017. During each 10-min observation time, arthropods landing on the insect hotel as well as those nesting in bamboo tubes and openings of the boxes were inspected and the number of bamboo stems and wooden drilled tunnels occupied were recorded (Fig. 1C). To assess overwintering arthropod populations, nesting boxes were removed in December 2017. Boxes were then stored in a freezer for preservation over a 3-wk period until arthropods were identified. Insect hotels were disassembled to expose inner tunnels and tubes. Bamboo tubes and wooden drilled tunnels were further examined for nesting and occupancy; determination of arthropod family was made based on presence of adults and/or other identifying features (i.e., leaf or mud material in brood cells) using keys including the online Discover Life Species Guides (Ascher et al. 2017).

Visual observations of arthropod visitors to the insect boxes, as well as the number of enclosed bamboo stems and drilled holes on the boxes were analyzed for each year. Efforts to distinguish returning female bees from new visitors were not made. Insect nesting box location (garden area vs. naturalized area) and nesting box placement (*B. nigra* vs. *L. indica*) were analyzed as the main effects. The main and interactions effects of the variables were included in the model. Data were subjected to analysis of variance using the general linear model procedure in SAS® (SAS Institute 2010). Data were transformed prior to analysis using the square root transformation for count data and back-transformed data are reported. Data from 2016 and 2017 were analyzed separately, and no direct comparison between both years was attempted. Main treatment means for visual observations and total enclosed bamboo stems and drilled holes were separated using Tukey's honestly significant difference test (SAS Institute 2010).

Results

We first report on total arthropod visitations by taxa and functional groups followed by treatment comparisons.

Abundance of pollinator and predatory arthropod taxa. Pollinator taxa observed on insect hotels during June through August in 2016 and 2017 consisted of small bees (i.e., Halictidae, Colletidae, Andrenidae, and Megachilidae), potter wasps (Vespidae), thread-waisted wasps (Sphecidae), house flies (Muscidae), soldier flies (Stratiomyidae), midges (Chironomidae), and moths (Lepidoptera) (Table 1). For the purposes of our study, these groups were combined into a single category "All Pollinators," which may include members of other functional groups as defined by Harris et al. (2017). Only one taxa, thread-waisted wasps (Sphecidae), had significantly higher numbers compared to other arthropod taxa in 2016 ($F = 1.69$; df $= 22, 203$; $P = 0.024$; Table 1). Predatory insect taxa observed at nesting boxes during June through August in 2016 and 2017 included spiders (Araneae), earwigs (Dermaptera), and predatory ants (Formicidae). For the purposes of our study, these groups were combined into a single category "All Predatory Arthropods," which may include members of other functional groups as defined by Harris et al. (2016). Within that category two groups were highly significant, predatory ants ($F = 6.14$; df $= 22, 203$; $P < 0.0001$) in 2016, and spiders ($F = 5.65$; df $= 24, 227$; $P < 0.0001$) in 2017. These two taxa were primarily responsible for the

Table 1. Influence of insect hotels on total pollinator and predatory or beneficial insect taxon or group occurrence observed ($n = 12$) in 2016 and 2017, University of Georgia Research and Education Garden (Spalding Co., GA; 33°24′67″N, 84°26′40″W).

Arthropod Taxon/Group	2016			2017		
	df	*P*	*F*	df	*P*	*F*
Small bees	—	—	—	24, 227	0.52	0.96
Sphecidae	22, 203	0.03*	1.69	24, 227	0.52	0.96
Vespidae	22, 203	0.32	1.13	24, 227	0.24	1.20
Muscidae	22, 203	0.49	0.98	—	—	—
Chironomidae	22, 203	0.47	1.00	24, 227	0.46	1.00
Stratiomyidae	22, 203	0.20	1.27	—	—	—
Lepidoptera	—	—	—	24, 227	0.47	1.00
All pollinators	22, 203	0.42	1.04	24, 227	0.40	1.05
Predatory Formicidae	22, 203	<0.0001***	6.14	—	—	—
Araneae	22, 203	0.25	1.20	24, 227	<0.0001***	5.65
Dermaptera	22, 203	0.29	1.16	24, 227	0.46	1.00
All predatory arthropods	22, 203	<0.0001***	6.16	24, 227	<0.0001***	5.67

* Significant at the $P < 0.09$ level; insect taxa were not observed.
** Significant at the $P < 0.01$ level; insect taxa were not observed.
*** Significant at the $P < 0.001$ level; insect taxa were not observed.

significance of All Predatory Arthropods in each respective year ($F = 6.16$; df = 22, 203; $P < 0.0001$ in 2016 and $F = 5.70$; df = 24, 227; $P < 0.0001$ in 2017; Table 1).

Proximity to floral resources. Visitation of potter wasps (Vespidae) ($F = 4.75$; df = 1, 203; $P = 0.031$), soldier flies (Stratiomyidae) ($F = 4.14$; df = 1, 203; $P = 0.04$), predatory ants (Formicidae) ($F = 27.99$; df = 1, 203; $P < 0.0001$), spiders (Araneae) ($F = 3.62$; df = 1, 203; $P = 0.06$), and All Predatory Arthropods ($F = 28.28$; df = 1, 203; $P < 0.0001$) were significantly influenced by nesting box location in 2016 (proximity to garden areas vs. naturalized insect nesting box location; Table 2). In 2017, insect nesting box location (proximity to garden areas vs. naturalized area) significantly influenced visitation of spiders (Araneae) ($F = 3.46$; df = 1, 227; $P = 0.064$), All Pollinators ($F = 3.26$; df = 1, 227; $P = 0.073$), and All Predatory Arthropods ($F = 4.05$; df = 1, 227; $P = 0.045$; Table 2). Insect nesting boxes placed in close proximity to floral resources were visited more frequently by potter wasps, predatory ants, spiders, and All Predatory Arthropods as compared to controls (naturalized location) in 2016 (Table 3). In 2016, higher visitations of soldier flies were observed in boxes placed in the naturalized area. In 2017, spiders and All Predatory Arthropods were most frequently found visiting insect boxes located within the naturalized area (Table 3). Insect nesting boxes placed in garden areas

Table 2. Comparison of insect nesting box location (garden area vs. naturalized control area) and box placement (*Betula nigra* vs. *Lagerstroemia indica*) in attracting pollinator and beneficial arthropod taxa/group 2016 and 2017, University of Georgia Research and Education Garden (Spalding Co., GA; 33°24′67″N, 84°26°40″W).

Arthropod Taxon/Group	Insect Box	2016			2017		
		df	*P*	*F*	df	*P*	*F*
Small bees	Location	—	—	—	1, 227	0.32	1.00
	Placement	—	—	—	1, 227	0.16	2.00
Sphecidae	Location	1, 203	0.36	0.83	1, 227	0.32	1.00
	Placement	1, 203	0.09*	2.94	1, 227	0.15	2.00
Vespidae	Location	1, 203	0.03*	4.75	1, 227	0.19	1.75
	Placement	1, 203	0.73	0.12	1, 227	0.18	1.78
Muscidae	Location	1, 203	0.48	0.50	—	—	—
	Placement	1, 203	0.32	1.00	—	—	—
Chironomidae	Location	1, 203	0.37	0.82	1, 227	0.48	0.50
	Placement	1, 203	0.85	0.03	1, 227	0.32	1.00
Stratiomyidae	Location	1, 203	0.04*	4.14	—	—	—
	Placement	1, 203	0.15	2.07	—	—	—
Lepidoptera	Location	—	—	—	1, 227	0.48	0.50
	Placement	—	—	—	1, 227	0.32	1.00
All pollinators	Location	1, 203	0.79	0.07	1, 227	0.07*	3.26
	Placement	1, 203	1.00	0.00	1, 227	0.20	1.63
Predatory Formicidae	Location	1, 203	<0.0001***	27.99	—	—	—
	Placement	1, 203	<0.0001***	59.75	—	—	—
Araneae	Location	1, 203	0.05*	3.62	1, 227	0.06*	3.46
	Placement	1, 203	0.13	2.29	1, 227	0.02*	5.36
Dermaptera	Location	1, 203	0.31	1.02	1, 227	0.16	2.00
	Placement	1, 203	1.00	0.00	1, 227	0.32	1.00
All predatory arthropods	Location	1, 203	<0.0001***	28.28	1, 227	0.04*	4.05
	Placement	1, 203	<0.0001***	59.59	1, 227	0.02*	5.88

* Significant at the $P < 0.09$ level; insect taxa were not observed.

** Significant at the $P < 0.01$ level; insect taxa were not observed.

*** Significant at the $P < 0.001$ level; insect taxa were not observed and counted.

Table 3. Mean ± SE number of pollinating and predatory or beneficial arthropod taxa/group observed visiting insect hotels placed in garden area (proximity to floral resources) versus naturalized area (control) in 2016 and 2017, University of Georgia Research and Education Garden (Spalding Co., GA; 33°24′67″N, 84°26°40″W).*

Arthropod Taxon/Group	Garden Area	Naturalized Area
2016		
Vespidae	0.07 ± 0.02a	0.00 ± 0.00b
Stratiomyidae	0.00 ± 0.00b	0.03 ± 0.02a
Predatory Formicidae	31.1 ± 4.38a	3.56 ± 0.58b
Araneae	0.16 ± 0.04a	0.04 ± 0.03b
All beneficial arthropods	31.2 ± 4.37a	3.60 ± 0.58b
2017		
Araneae	0.56 ± 0.06b	0.72 ± 0.09a
All beneficial arthropods	0.56 ± 0.06b	0.74 ± 0.09a
All pollinators	0.16 ± 0.04a	0.04 ± 0.02b

* Means in the same row bearing different letters are significantly different ($P \leq 0.09$).

had higher total visitations of All Pollinators compared to those in the naturalized areas (control) in 2017.

Placement on tree species. In 2016, nesting box placement significantly impacted visitation of thread-waisted wasps (Sphecidae) ($F = 2.94$; df = 1, 203; $P = 0.089$), predatory ants (Formicidae) ($F = 59.75$; df = 1, 203; $P < 0.0001$), and All Predatory Arthropods ($F = 59.59$; df = 1, 203; $P < 0.0001$) (Table 2). Predatory ants and All Predatory Arthropods primarily visited boxes placed on *L. indica* (Table 4). However, there were higher counts of thread-waisted wasps visiting insect boxes on *B. nigra* (Table 4). In 2017, nesting box placement was significant for spiders (Araneae) ($F = 2.29$; df = 1, 227; $P = 0.022$) and All Predatory Arthropods ($F = 5.88$; df = 1, 227; $P = 0.016$; Table 2). Higher counts of spiders and All Predatory Arthropods were found on insect boxes placed on *B. nigra* (Table 4).

Neither treatment (nesting box location or nesting box placement) significantly influenced total number of bamboo stems and drilled tunnels occupied during 2016 (Table 5). In 2017, however, location ($F = 5.26$; df = 1, 36; $P = 0.023$) and placement ($F = 37.65$; df = 1, 36; $P < 0.0001$) of nesting boxes significantly impacted arthropod occupancy (Table 5). Boxes placed in the plots with floral resources had higher number of bamboo stems and tunnels filled as compared to controls (naturalized area). When insect boxes were placed on *L. indica* trees, there were higher numbers of populated bamboo stems and drilled tunnels as compared to those placed on *B. nigra* trees (Table 5).

Although not subjected to statistical analysis, total counts for occupancy postexperiment (2017) were recorded (Table 6; Fig. 2). Out of 24 overwintering

Table 4. Mean ± SE number of pollinating and predatory or beneficial arthropod taxon or group observed visiting insect hotels placed on *Betula nigra* versus on *Lagerstroemia indica* in 2016 and 2017, University of Georgia Research and Education Garden (Spalding Co., GA; 33°24′67″N, 84°26°40″W).*

Arthropod Taxon/Group	*Betula nigra*	*Lagerstroemia indica*
2016		
Sphecidae	0.05 ± 0.01a	0.01 ± 0.01b
Predatory Formicidae	2.95 ± 0.39b	40.85 ± 5.51a
All predatory arthropods	3.12 ± 0.39b	40.94 ± 5.51a
2017		
Araneae	0.71 ± 0.08a	0.52 ± 0.06b
All predatory arthropods	0.72 ± 0.08a	0.52 ± 0.06b

* Means in same row bearing different letters are significantly different ($P \leq 0.09$).

Table 5. Statistical analysis results from comparisons of insect nesting box location and tree placement on number of bamboo stems and drilled holes filled in boxes by arthropods in 2016 and 2017, University of Georgia Research and Education Garden (Spalding Co., GA; 33°24′67″N, 84°26°40″W).

	2016			Treatments	
	df	***P***	***F***	**Location**	
Bamboo stems and drilled holes	1, 35	0.41	0.70	Not significant	
	1, 35	0.40	0.71	**Placement**	
				Not significant	
	2017				
	df	***P***	***F***	**Location†**	
Bamboo stems and drilled holes	1, 36	0.02*	5.26	**Garden**	**Naturalized**
				14.9 ± 0.70a	12.6 ± 0.44b
	1, 36	<0.0001***	37.65	**Placement†**	
				B. nigra	*L. indica*
				11.3 ± 0.53b	17.0 ± 0.75a

* Significant at the $P < 0.09$ level.
** Significant at the $P < 0.01$ level.
*** Significant at the $P < 0.001$ level.
† Means in the same row bearing different letters are significantly different ($P \leq 0.09$).

Table 6. Total number of overwintering arthropods counted in insect hotels postexperiment and after removal from garden versus naturalized area and *Betula nigra* versus *Lagerstroemia indica* in 2017, University of Georgia Research and Education Garden (Spalding Co., GA; 33°24′67″N, 84°26°40″W).

Tree Placement	Plot No.*	Small Bee Brood	Vespidae Brood	Araneae	Lepidoptera Pupae
Garden plots					
B. nigra	1	0	0	0	0
B. nigra	2	2	0	0	0
B. nigra	3	0	1	0	0
B. nigra	4	0	0	1	0
L. indica	1	0	0	0	0
L. indica	2	2	0	0	1
L. indica	3	4	3	0	0
L. indica	4	0	0	1	0
Total		8	4	2	1
Naturalized plots					
B. nigra	1	2	1	1	0
L. indica	2	0	0	1	0
B. nigra	1	0	0	1	0
L. indica	2	1	2	0	0
Total		3	3	3	0

* Plot no. corresponds to the replicate plot; four garden plots and two controls (naturalized areas).

arthropods counted, 15 were found in insect hotels placed in garden areas and identified as small bee brood ($n = 8$), potter wasp ($n = 4$) brood, Araneae ($n = 2$), and Lepidoptera pupa ($n = 1$). In boxes removed from the naturalized control areas, there was a total of nine overwintering arthropods: small bee brood ($n = 3$), potter wasp brood ($n = 3$), and Araneae ($n = 3$).

Discussion

Overall, in this 2-yr study, we observed low numbers of desirable pollinators and predatory arthropods visiting and/or nesting in consumer-marketed insect hotels. Highest numbers included predatory ants, which we did not attempt to control. For the average consumer, ants are not likely to be desirable insect visitors. To the best of our knowledge, this study is among the few to assess arthropod visits to consumer-ready insect hotels with respect to proximity to floral resources and

Fig. 2. Occupied bamboo stems from commercially available insect boxes split lengthwise to expose arthropod presence after two consecutive years in the field.

nesting box placement on different tree species. Several studies have reported the importance of providing dense plantings as well as other materials such as old wood, stems, or nesting boxes which can serve as overwintering and sheltering sites for pollinators and arthropod predators (Dumroese et al. 2016, Goulson 2003, Kudo 2014, MacLeod et al. 2004). Providing overwintering locations in gardens and landscapes could aid in creating beneficial arthropod habitats and in the conservation of bees, pollinators, and other beneficial insects. Woltz et al. (2012) affirm that most diversity and abundance of arthropods are observed in complex landscapes replete with flowering plants, overwintering refuges, alternative hosts, and prey.

Insect groups observed in this study included members of the taxa Vespidae, Sphecidae, Stratiomyidae, predatory Formicidae (*Solenopsis* sp.), and Araneae.

Our results suggest that insect boxes could serve as overwintering and nesting sites for certain pollinator and predatory arthropod groups including potter (i.e., *Euodynerus* sp.) and thread-waisted wasps. There was higher drilled tunnel and stem pollinator occupancy when insect hotels were placed in proximity to diverse floral resources (i.e., the Garden) and on *L. indica* mature trees. Although total overwintering arthropod counts were low, during certain study years, there were increased numbers of predatory and pollinator arthropods in boxes placed in garden areas.

MacIvor and Packer (2015) observed high numbers of solitary wasps (Vespidae) throughout their survey of insect hotels. Similarly, Jenkins and Matthews (2004) found high levels of Vespidae, Sphecidae, Megachilidae, and Apidae in nesting boxes in Georgia and South Carolina. Le Roux et al. (2016) also found that commercially available bee boxes have the potential to serve as alternative habitats for beneficial, pollinator, and plant-feeding insects. Solitary wasps have been known to nest in bee hotels placed in shaded areas (Taki et al. 2004). In the current study, although statistical significance was found for the tree species, results were not consistent from year to year and, in practical terms, the differences between the treatments were small. During summer boxes were shaded and in winter, boxes were in full sun as both tree species were deciduous. Therefore, further studies should be conducted to fully examine the importance of insect hotel placement and orientation on arthropod visits and nesting success.

The present study evaluates commercially available insect hotels specifically marketed for use by homeowners as a decorative addition to their landscape. Although marketing information on the box listed four types of pollinating and beneficial (predatory) insects—lady beetles (Coccinellidae), green lacewings (Chrysopidae), earwigs (Dermaptera), and mason bees (*Osmia* sp.) (Fig. 1B)—Dermaptera was the only taxon observed in the present study. With the exception of a single Dermaptera, none of these taxa were observed in our study. It is doubtful that the average consumer will be as accepting of wasp and ant visitors as mason bees and lady beetles. It is also pertinent to note that the structural integrity of the boxes was largely lost by the end of the 2-yr period; the red door fell off in over half of the boxes during the first year, necessitating frequent repair.

While there was pollinator and predator visitation and nesting within the commercially available nesting boxes in our study, it is important to note the potential of these insect hotels to negatively impact their targeted arthropods by promoting pathogens and parasites (MacIvor and Packer 2015, Rosenheim 1990). To gain deeper insights and to be able to provide practical guidelines to consumers, future studies should compare nesting success in naturally occurring overwintering sites versus marketed insect boxes in a single study. Through a study such as this, consumer-marketed insect hotel materials and designs may be improved to simulate natural nesting conditions and further boost nesting activity while stimulating brood maturation (Potts et al. 2005, Torné-Noguera et al. 2014).

With increased urbanization and natural habitat dispersion, the current study indicates that implementation of insect hotels in urban garden and in naturalized landscapes could successfully be utilized to enhance beneficial arthropod biodiversity. Further research is needed to increase understanding of insect hotel design and materials as well as insect hotel location and orientation which can further be provided to insect hotel manufacturers in order to minimize negative impacts of nesting boxes while serving as communal nesting sites for pollinator and predatory arthropod taxa.

Acknowledgments

We thank Martha Sikora, Asa Bradley, and Katie Gwaltney for technical assistance provided for the duration of this study and Jerry Davis for statistical assistance. We thank Scott Horn and Elizabeth McCarty for their internal reviews.

References Cited

Ascher, J.S. 2017. Discover Life Species Guides. 05 December 2017. (http://www.discoverlife.org/).

Boyle, N.K. and T.L. Pitts-Singer. 2017. The effect of nest box distribution on sustainable propagation of *Osmia lignaria* (Hymenoptera: Megachilidae) in commercial tart cherry orchards. J. Insect Sci. 17(2): 41.

Davis, A.Y., E.V. Lonsdorf, C.R. Shierk, K.C. Matteson, J.R. Taylor, S.T. Lovell and E.S. Minor. 2017. Enhancing pollination supply in an urban ecosystem through landscape modifications. Landscape Urban Plan. 162: 157–166.

Dumroese, R.K., T. Luna, J.R. Pinto and T.D. Landis. 2016. Forbs: Foundation for restoration of monarch butterflies, other pollinators, and greater sage-grouse in the western United States. Nat. Areas J. 36(4): 499–511.

Fortel, L., M. Henry, L. Guilbaud, H. Mouret and B.E. Vaissiere. 2016. Use of human-made nesting structures by wild bees in an urban environment. J. Insect Conserv. 20(2): 239–253.

Frankie, G.W., R.W. Thorp, M. Schnidler, J. Hernandez, B. Ertter and M. Rizzardi. 2005. Ecological patterns of bees and their host ornamental flowers in two northern California cities. J. Kans. Entomol. Soc. 78: 227–246.

Gaston, K.J., R.M. Smith, K. Thompson and P.H. Warren. 2005. Urban domestic gardens (II): Experimental tests of methods for increasing biodiversity. Biodivers. Conserv. 14: 395–413.

Gathmann, A. and T. Tscharntke. 2002. Foraging ranges of solitary bees. J. Anim. Ecol. 71: 757–764.

Goulson, D. 2003. Conserving wild bees for crop pollination. J. Food Agric. Environ. 1: 142–144.

Gurr, G.M., S.D. Wratten, D.A. Landis and M. You. 2017. Habitat management to suppress pest populations: Progress and prospects. Annu. Rev. Entomol. 62: 91–109.

Harris, B.A., S.K. Braman and S.V. Pennisi. 2016. Influence of plant taxa on pollinator, butterfly, and beneficial insect visitation. Hortic. Sci. 51: 1016–1019.

Harris, B.A., S.K. Braman and S.V. Pennisi. 2017. Pan trap designs for monitoring pollinators and other beneficial insects in conservation gardens. J. Entomol. Sci. 52: 9–14.

Häussler, J., U. Sahlin, C. Baey, H.G. Smith and Y. Clough. 2017. Pollinator population size and pollination ecosystem service responses to enhancing floral and nesting resources. Ecol. Evol. 7: 1898–1908.

Jenkins, D.A. and R.W. Matthews. 2004. Cavity-nesting Hymenoptera in disturbed habitats of Georgia and South Carolina: Nest architecture and seasonal occurrence. J. Kans. Entomol. Soc. 77: 203–214.

Klein, A., B. Vaissiere, J.H. Cane, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen and T. Tscharntke. 2007. Importance of pollinators in changing landscapes for world crops. Proc. Royal Soc. B. Biol. Sci. 274(1608): 303-313. (http://rspb.royalsocietypublishing.org/content/274/1608/303; last accessed 15 June 2020).

Krombien, K.V. 1967. Trap-Nesting Wasps and Bees: Life Histories, Nests, and Associates. Smithsonian Press. 15 June 2020. (https://library.si.edu/digital-library/book/trapnestingwasps00krom).

Landis, D.A. 2017. Designing agricultural landscapes for biodiversity-based ecosystem services. Basic Appl. Ecol. 18: 1–12.

Lee-Mäder, E., M. Spivak and E. Evans. 2010. Managing alternative pollinators. Natural Resources, Agriculture, and Engineering Service, Ithaca, NY.

Kudo, G. 2014. Vulnerability of phenological synchrony between plants and pollinators in an alpine ecosystem. Ecol. Res. 29(4): 571–581.

Le Roux, D.S., K. Ikin, D.B. Lindenmayer, G. Bistricer, A.D. Manning and P. Gibbons. 2016. Effects of entrance size, tree size and landscape context on nest box occupancy: considerations for management and biodiversity offsets. For. Ecol. Manag. 366:135–142.

MacIvor, J.S. 2016. Building height matters: nesting activity of bees and wasps on vegetated roofs. Isr. J. Ecol. Evol. 62(1–2): 88–96.

MacIvor, J.S. and L. Packer. 2015. 'Bee hotels' as tools for native pollinator conservation: A premature verdict? PLOS One 10(3): e0122126, 1-13. https://doi.org/10.1371/journal.pone.0122126.

MacLeod, A., S.D. Wratten, N.W. Sotherton and M.B. Thomas. 2004. 'Beetle banks' as refuges for beneficial arthropods in farmland: long-term changes in predator communities and habitat. Agric. For. Entomol. 6: 147–154.

Moenen, R. 2012. De broedparasiet Cacoxenus indagator (Drosophilidae) en de parasitoïden Melittobia acasta (Eulophidae) en Coelopencyrtus sp.(Encyrtidae) bij solitaire bijen in kunstmatige nestgelegenheid. Entomol. Berichten 72(1-2): 63–70.

Motzke, I., A.M. Klein, S. Saleh, T.C. Wanger and T. Tscharntke. 2016. Habitat management on multiple spatial scales can enhance bee pollination and crop yield in tropical homegardens. Agric. Ecosyst. Environ. 223: 144–151.

National Research Council. **2007.** Status of pollinators in North America 2007. National Academies Press, Washington, DC. 307 pp.

Packer, L. and G. Knerer. 1986. An analysis of variation in the nest architecture of *Halictus ligatus* in Ontario. Insect. Soc. 33(2): 190–205.

Potts, S.G., B. Vulliamy, S. Roberts, C. O'Toole, A. Dafni, G. Ne'eman and P. Willmer. 2005. Role of nesting resources in organising diverse bee communities in a Mediterranean landscape. Ecol. Entomol. 30(1): 78–85.

Rees, P.A. 2008. Urban Environments and Wildlife Law: A Manual for Sustainable Development. John Wiley & Sons, New York.

Rosenheim, J.A. 1990. Density-dependent parasitism and the evolution of aggregated nesting in the solitary Hymenoptera. Ann. Entomol. Soc. Am. 83(3): 277–286.

Roubik, D.W. and R. Villanueva-Gutiérrez. 2009. Invasive Africanized honey bee impact on native solitary bees: A pollen resource and trap analysis. Biol. J. Linn. Soc. 98: 152–160.

Rufus, I., J. Tuell, A. Fiedler, M. Gardiner and D. Landis. 2009. Maximizing arthropod-mediated ecosystem services in agricultural landscapes: The role of native plants. Front. Ecol. Environ. 7: 196–203.

SAS Institute. **2010.** SAS Guide for Personal Computers. 6th ed. SAS Institute, Cary, NC.

Sihag, R.C. 1993. Behaviour and ecology of the subtropical bee *Xylocopa fenestrata* F. 7. Nest preferences and response to nest translocation. J. Apic. Res. 32: 102–108.

Sutter, L., P. Jeanneret, A.M. Bartual, G. Bocci and M. Albrecht. 2017. Enhancing plant diversity in agricultural landscapes promotes both rare bees and dominant crop-pollinating bees through complementary increase in key floral resources. J. Appl. Ecol. 54: 1856–1864.

Taki, H., J.W. Boone, B.F. Viana, F.O. Silva, P.G. Kevan and C.S. Sheffield. 2004. Effect of shading on trap nest utilization by hole-nesting aculeate Hymenoptera. Can. Entomol. 136: 889–891.

Torné-Noguera, A., A. Rodrigo, X. Arnan, S. Osorio, H. Barril-Graells, L.C. da Rocha-Filho and J. Bosch. 2014. Determinants of spatial distribution in a bee community: Nesting resources, flower resources, and body size. PLOS One 9(5).

Tscharntke, T. and A. Gathmann. 1998. Bioindication using trap nesting bees and their natural enemies: community structure and interactions. J. Appl. Ecol. 35: 307–319.
Wcislo, W.T. 1996. Parasitism rates in relation to nest site in bees and wasps (Hymenoptera: Apoidea). J. Insect Behav. 9: 643–656.
Woltz, J.M., R. Isaacs and D.A. Landis. 2012. Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape. Agric. Ecosys. Environ. 152: 40–49.