Journal *of* Melittology

Bee Biology, Ecology, Evolution, & Systematics

No. 143, 1–9 23 February 2026

Nesting material preferences of cavity-nesting insects in man-made insect hotels

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Abstract. Artificial "insect hotels" are increasingly promoted as tools to support beneficial insects, yet the effectiveness of different nesting materials remains unclear. We compared weekly occupancy of wooden blocks, reed stems, and paper straws at five sites in northern Utah and found that occupancy differed strongly among materials, with wooden blocks used most frequently, reeds at intermediate levels, and paper straws rarely used. These results show that material choice strongly influences insect use of artificial nests and that durable natural materials such as wood or reeds are more effective than paper straws for supporting cavity-nesting bees and wasps.

INTRODUCTION

Insects play vital roles in the fragmented habitats of urban and suburban areas as pollinators, natural pest management, decomposers, and as a food source for wildlife (Collins *et al.*, 2024). Recent reports, however, suggest insect populations may be declining worldwide (Wagner, 2020). To provide habitat for these imperiled insect populations, many people have started constructing artificial nesting structures, often referred to as "bee hotels" or "insect hotels" (Rahimi *et al.*, 2021; Prendergast, 2023). While these artificial nests can successfully provide nesting resources, where natural nesting sites are limited (Prendergast, 2023), some researchers have suggested the insect hotels might do more harm than good by promoting invasive species and leading to increased spread of pathogens (*e.g.*, Maclvor & Packer, 2015; Fortel *et al.*, 2016). Despite the concerns about insect hotels, they continue to be promoted by a variety of conservation organizations (*e.g.*, Conservation Volunteers Australia, 2022; Kuyer, 2022; Steele, 2024).

Broadly, insect hotels have been suggested as a tool for observing and conserving beneficial insects (particularly bees), yet a wide variety of nesting materials are recommended in the construction of these artificial nests (*e.g.*, Wilson & Carril, 2015; Brokaw & Isaacs, 2017; Youngsteadt & Favre, 2022; Lavoipierre, 2025; The Wildlife Trusts, 2025). Studies have shown that the material used in the insect hotel can affect occupancy rates (Guimarães-Brasil *et al.*, 2020; Maclvor, 2017; Rahimi *et al.*, 2021). In

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ISSN 2325-4467

a review of nesting materials often used in bee hotels, Maclvor (2017) suggests that wooden nest boxes are more attractive to bees than other materials, but that bundles of reeds or hollow stems are also commonly used. Despite these findings, paper or cardboard straws are often promoted as nesting materials for ease of cleaning (*e.g.*, Mader *et al.*, 2010; Brokaw & Isaacs, 2017; Mull *et al.*, 2022; Youngsteadt & Favre, 2022; Crown Bees, 2025). Paper straws are even available commercially, marketed under names like "Mason Bee Tubes" or "Bee Tube Refills."

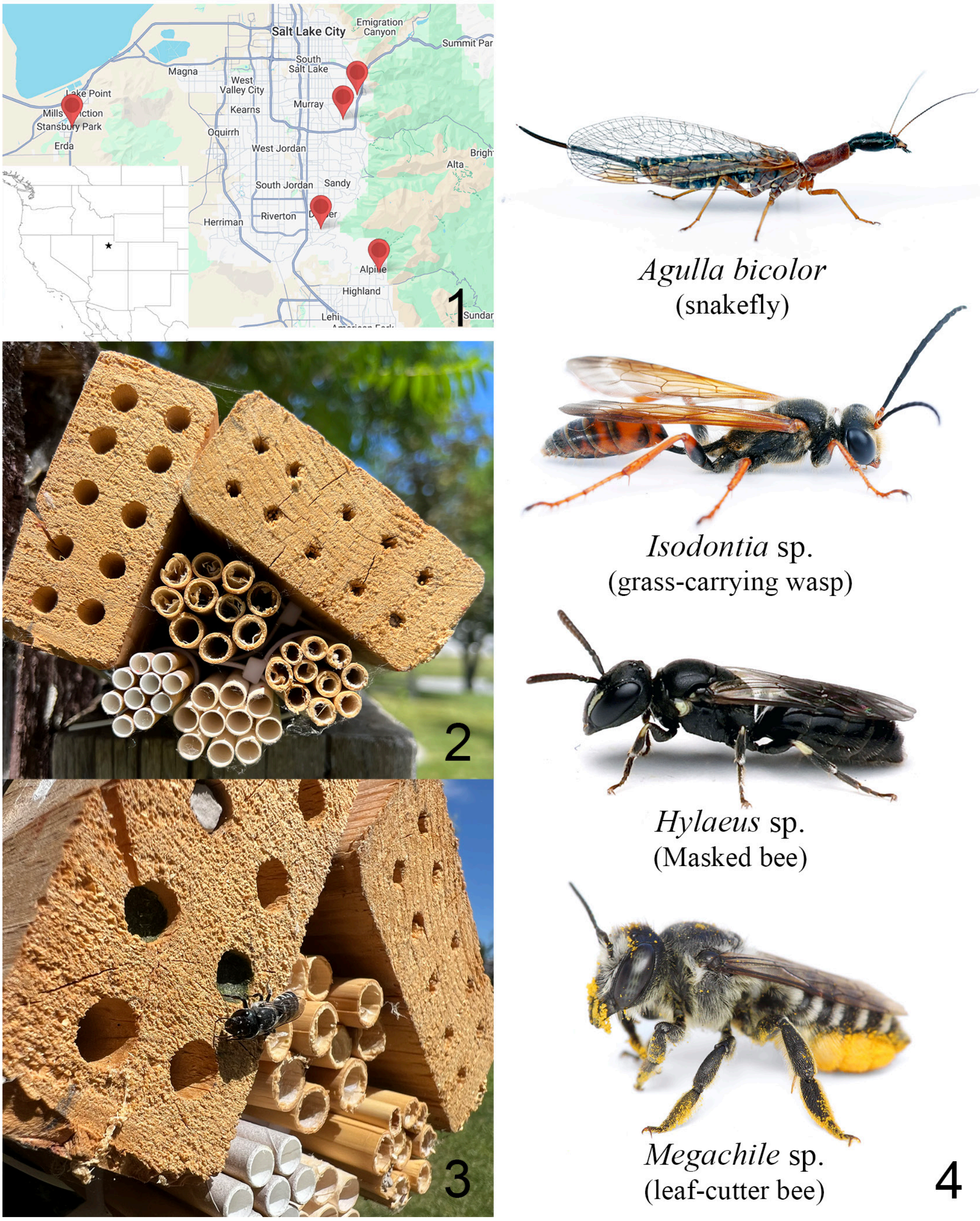
In this study, we test nest occupancy rates of three different nesting materials: wooden blocks, Phragmites cut reeds, and paper straws. These three nesting materials were selected as they are often among the most used and readily available materials used for insect hotels. We conducted a field experiment across multiple sites in northern Utah to quantify material preferences of cavity-nesting insects. Because different types of insects use different diameters of nesting cavities, we used two sizes for each nesting type: 8 mm diameter cavities and 5 mm diameter cavities. In addition to bees, several other beneficial insects use insect hotels (Harris *et al.*, 2021). We wanted to understand how different nesting materials are used by insects in general.

MATERIAL AND METHODS

We deployed standardized insect hotels at five locations near Salt Lake City in northern Utah (Fig. 1) during the 2024 nesting season (Late April through September). Each hotel contained six distinct nest types: a wood block with large (8 mm) holes, a wood block with small (5 mm) holes, reed stems bundled together as large (8 mm) and small (5 mm) diameters, and paper straws bundled together as large (8 mm) and small (5 mm) diameters (Fig. 2). These large and smaller diameter nests were selected because they represent the commercially available paper straws that people might use for insect hotels. Wood blocks were made from pine 2×4s, reeds were made from Phragmites reeds, cut and sorted by diameter, and paper straws were purchased online and sealed on the back end using tape. Each nest type had 10 individual tubes (10 small diameter straws, 10 large diameter straws, 10 small diameter reeds, 10 large diameter reeds, 10 large drilled holes, and 10 small diameter holes) (Fig. 2) and all nest types were bundled together to make insect hotels using zip ties. Hotels were mounted at approximately 1.5 meters heigh and attached to fence posts or trees, oriented south or southeast, and left in place for the duration of the nesting season. Many publicly available instructions for building insect hotels recommend south or southeast orientations so insects can get sun early in the morning (*e.g.*, Wilson & Carril, 2015). We made an effort to face all of our insect hotels in a southeastern direction, however, in some cases the orientation of the fence or tree we were attaching the hotel to only allowed us to face the hotel directly south.

Occupancy was recorded weekly by visually inspecting cavity entrances for completed plugs made of mud, leaves, or resin or other materials (Fig. 3). The proportion of occupied cavities was calculated for each material type at each site. Nests were collected at the end of the season and stored in a lab in a terrarium with a mesh lid allowing nest occupants to emerge after the completion of their development. Emerged insects were collected (Fig. 4) and identified using online resources (*e.g.*, iNaturalist).

To compare how insects used different nest materials, weekly occupancy data were summarized by site and nest type. Occupancy for each nest was calculated as the proportion of occupied cavities (out of 10 available holes or tubes) during each weekly check. For each of the six nest types (small and large blocks, straws, and reeds), mean occupancy rates were averaged across the five study sites to obtain site-level replicates.



Figures 1–4. Study locations, nest types, and representative insect occupants. **1.** Map of the five study sites near Salt Lake City, Utah, where standardized insect hotels were deployed during the 2024 nesting season (late April – September). The map was generated using GoogleMaps. **2.** Example of an insect hotel showing the six nest types: large (8 mm) and small (5 mm) wooden blocks, reed bundles, and paper-straw bundles. Wooden blocks were made from pine 2×4s; reed stems were cut and sorted from *Phragmites*; and paper straws were sealed at the back with tape. **3.** A leaf-cutter bee (*Megachile* sp.) on a wooden block showing filled nests. **4.** Insects reared from these nests included leaf-cutter bees (*Megachile* sp.), masked bees (*Hylaeus* sp.), grass-carrying wasps (*Isodontia* sp.), and snakeflies (*Agulla bicolor*).

Differences in occupancy among nest types were evaluated using a non-parametric Kruskal–Wallis test, which does not assume normality or equal variances among groups. When the overall test indicated significant differences among nest types, pairwise Dunn's tests were performed to identify which specific nest types differed. Resulting *P*-values were adjusted for multiple comparisons using the Benjamini–Hochberg false discovery rate (FDR) procedure ($\alpha = 0.05$) to control for false positives.

To visualize these results, occupancy distributions were shown as boxplots for each nest type, with compact letter displays (CLD) indicating groups that did not differ significantly under the FDR-adjusted pairwise comparisons (Fig. 5). All statistical analyses were performed in R (R Core Team, 2024) using the *FSA* (Ogle & Ogle, 2017), *multcompView* (Graves *et al*., 2015), and *ggplot2* (Wickham, 2011) packages.

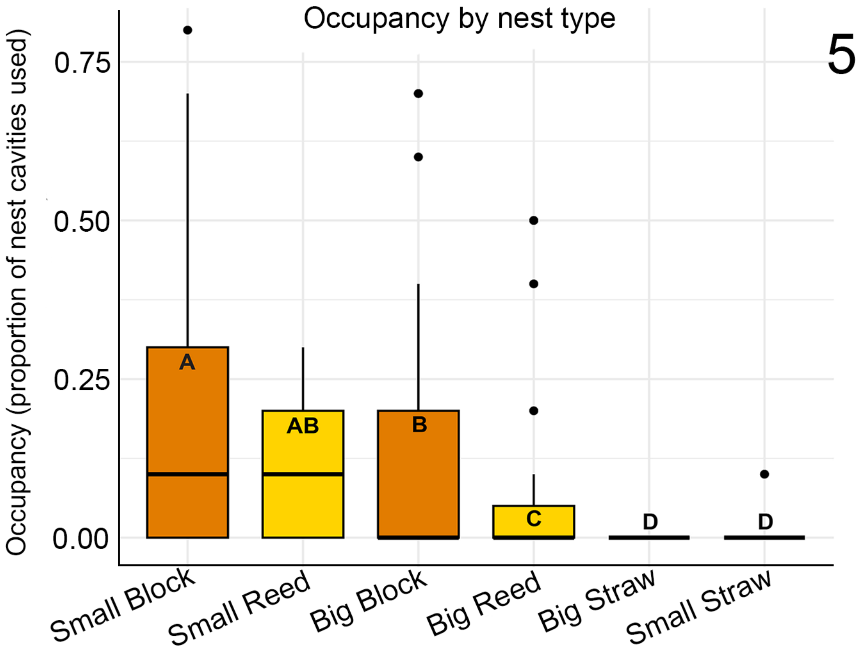
RESULTS

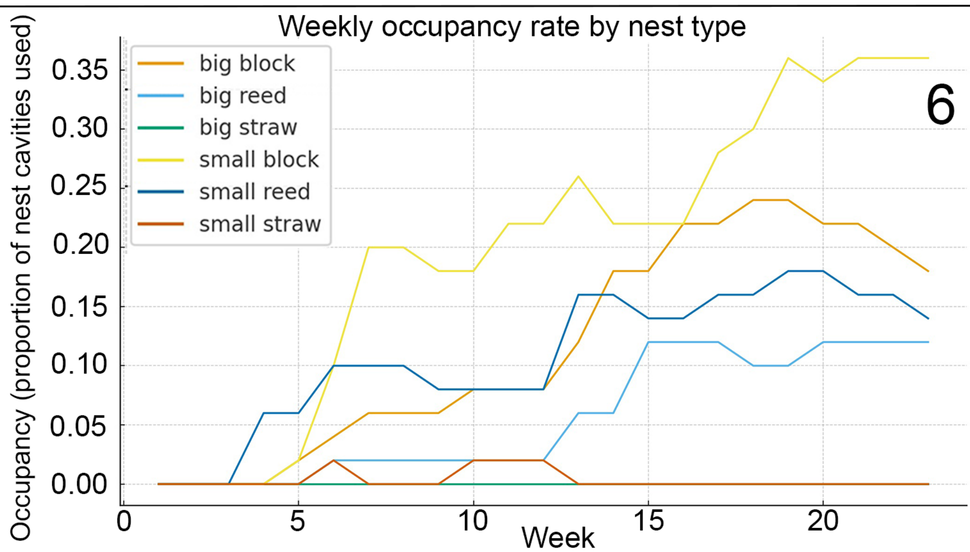
Across the five study sites, insects used the artificial nests throughout the 23-week deployment, and occupancy varied strongly among nest materials. A Kruskal–Wallis test detected highly significant differences among the six nest types ($\chi^2 = 188.45$, df = 5, $P < 2.2 \times 10^{-16}$). Post-hoc Dunn tests with Benjamini–Hochberg FDR adjustment ($\alpha = 0.05$) showed that nearly all pairwise contrasts were significant except three: Small Block vs. Small Reed ($P_{adj} = 0.26$), Big Block vs. Small Reed ($P_{adj} = 0.069$), and Big Straw vs. Small Straw ($P_{adj} = 0.66$). Thus, the two straw designs did not differ from each other and were markedly lower than all other materials, while Small Reed was statistically indistinguishable from both Small Block and Big Block under FDR control.

Mean occupancy across sites followed a clear gradient: Small Block (20.0%) and Big Block (11.7%) were highest, Small Reed (10.8%) and Big Reed (5.7%) were intermediate, and Small Straw (0.3%) and Big Straw (0.0%) were near zero. A compact-letter display consistent with the FDR-adjusted Dunn results assigned Small Block = A, Small Reed = AB, Big Block = B, Big Reed = C, and Small Straw = Big Straw = D, indicating groups that are not significantly different share a letter (Fig. 5).

Nest occupancy increased steadily through midsummer before leveling off by early September (Fig. 6). Across all sites, an average of 13% of available cavities were occupied by the end of the season. Occupancy trends varied by nest type: small block nests showed the highest final occupancy rate (36%), followed by big block (18%), small reed (14%), and big reed (12%), while both straw-based nests remained largely unused throughout the season. Because occupied nests were stored indoors, insects emerged earlier than expected. Therefore, we were unable to associate individual insects with the different nest types. Several kinds of insects were reared from nests. Several kinds of bees utilized insect hotels, including leaf-cutter bees (*Megachile* sp. *n*=3) and masked bees (*Hylaeus* sp. *n*=27). In addition to bees, we found grass-carrying wasps (*Isodontia* sp. *n*=5) using the hotels, as well as snakeflies (likely *Agulla bicolor* *n*=2) (Fig. 4).

Across nearly all nest types, there were one or more weeks in which occupancy rates temporarily declined. These decreases (weather mid-season or near the end of the season) likely reflect natural changes in nest status rather than measurement error. In some cases, the drop in occupancy may have resulted from the emergence of adult insects that had completed development, leaving their cavities vacant (*e.g.*, *Isodontia* wasps are known to be multivoltine, having multiple generations per year). However, nest predation or parasitism likely also contributed to these declines, as evidenced by partially damaged or emptied nest cavities observed in the field. Multiple earwigs were observed on the insect hotels (often at night). Some reports have suggested that earwigs (Dermaptera) can negatively influence nesting in insect hotels because they eat pollen provisions, leaf nest materials, and sometimes bee eggs (Mader *et al*., 2010).





Figures 5, 6. 5. Comparison of mean nest occupancy rates among six nest types across five study sites in northern Utah. Boxplots show median (bold line), interquartile range, and outliers based on weekly occupancy data averaged by site. Differences among nest types were evaluated using a Kruskal–Wallis test followed by pairwise Dunn's tests with Benjamini–Hochberg false discovery rate (FDR) adjustment ($\alpha = 0.05$). Letters indicate groups that did not differ significantly under the FDR-adjusted comparisons. **6.**Weekly occupancy rate of six nest types. Lines represent mean occupancy (proportion of occupied cavities) for each nest type, averaged across sites. Periodic declines in occupancy likely reflect emergence of adult insects or nest predation.

DISCUSSION

Our results demonstrate that nest occupancy in insect hotels varied strongly by nesting material, with wooden blocks supporting the highest rates of use, followed by reeds with intermediate rates, and paper straws showing almost no activity. This clear gradient aligns with previous studies showing that material type can strongly influence the attractiveness and usability of artificial cavities (MacIvor, 2017; Guimarães-Brasil *et al.*, 2020). The high occupancy of wooden blocks suggests that solid substrates with clean uniform holes may be more suitable for many cavity-nesting insects than loose or flexible materials such as paper straws. Similar findings have been reported where bees showed strong preferences for wood, bamboo or reeds over cardboard or paper straws (Mader *et al.*, 2010; Maclvor, 2017). However, other studies have found a preference for paper straws (Eeraerts *et al.*, 2022), but in this study the paper straws were inserted into wooden blocks rather than free-standing as in our study. There could be multiple explanations as to why paper straws were favored in studies inserting them into wood but avoided in this study. Perhaps the walls of the paper straws are too thin, allowing too much light in, causing insects to select other, darker cavities. Another possibility is that the paper straws by themselves are not rigid enough, so insects will select other, more rigid cavities. It is also possible that the thin walls of the paper did not insulate the cavity sufficiently so other, more insulated nesting substrates were selected. Temperature has been shown to affect nest selection by solitary bees (Wilson *et al*., 2020), so it is possible that the unmeasured temperature differences in the nesting substrates affected nest choice selection. These possibilities should be investigated in future studies.

Although reed nests were used at intermediate rates in our study, their variable internal diameters and irregular surfaces may limit use by some species while attracting others, as internal diameter has been shown to affect nesting preferences (Campbell *et al.*, 2017; Michołap *et al.*, 2020). Reed bundles can also inadvertently increase the spread of parasites and pathogens due to unnaturally high nest densities (MacIvor & Packer, 2015). Still, reed bundles remain a popular option that is often used by scientists and backyard enthusiasts to provide nesting for both bees and wasps (*e.g.*, Stabb *et al.*, 2018; Peterson *et al.*, 2021; Beyer *et al.*, 2023). While our results show the near-complete avoidance of paper straws, they have been shown to be effective when inserted into wood blocks as liners rather than stand-alone nests (Eeraerts *et al.*, 2022; Mull *et al.*, 2022; Youngsteadt & Favre, 2022). Other authors have reported similar results, noting that cardboard or paper tubes often had lower nesting success than wood or reed nests (Wilkaniec & Giejdasz, 2003).

All nest types (aside from paper straws, which had few occupants) showed a general increase in occupancy through most of the summer (Fig. 6). Occupancy rates for the large and small reed nests, as well as the large wood block, plateaued around weeks 15–16 (early August), whereas the small wood block continued to increase throughout the season. These patterns may reflect differences in phenology among the insect taxa selecting each nest type. Several nest types showed declines in occupancy during late summer (Fig. 6), suggesting that emergence, predation, or parasitism outpaced new nest formation during that period.

Although several bee genera were reared from the hotels, including *Megachile* and *Hylaeus*, alongside wasps such as *Isodontia*, our study did not allow clear assignment of taxa to specific nest types. Future work could incorporate trap-nest dissection or emergence-trap designs that preserve nest identity, enabling direct linkage of species to materials and cavity diameters. Such studies could also quantify parasitism rates and identify non-target occupants, which are important for evaluating whether insect hotels truly benefit local insect populations or primarily attract opportunistic or invasive species and understanding which materials are most effective at attracting which taxa.

Overall, this study reinforces that not all nesting materials perform equally in insect hotels. While wooden blocks appear most suitable for cavity-nesting bees and wasps in this region, reed bundles can provide supplemental nesting options. In contrast, paper straws were largely ineffective under field conditions. For conservation practitioners and landowners installing insect hotels, these results highlight the importance of material choice and regular monitoring. Selecting durable, natural materials and avoiding cardboard straws may improve the likelihood that insect hotels function as genuine tools for supporting wild pollinators rather than as decorative features with limited ecological value.

ACKNOWLEDGMENTS

We thank Utah State University undergraduate research for supporting this work. We also thank the various homeowners that allowed us to install our insect hotels in their yards. Finally, we thank the anonymous reviewers for their insightful comments and helpful suggestions.

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Journal of Melittology

A Journal of Bee Biology, Ecology, Evolution, & Systematics

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The *Journal of Melittology* was established at the University of Kansas through the efforts of Michael S. Engel, Victor H. Gonzalez, Ismael A. Hinojosa-Díaz, and Charles D. Michener in 2013 and each article is published as its own number, with issues appearing online as soon as they are ready. Papers are composed using Microsoft Word® and Adobe InDesign® in Lawrence, Kansas, USA.

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ISSN 2325-4467