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Bees collect polyurethane and polyethylene plastics as novel nest materials

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Abstract. Plastic waste pervades the global landscape. Although adverse impacts on both species and ecosystems have been documented, there are few observations of behavioral flexibility and adaptation in species, especially insects, to increasingly plastic-rich environments. Here, two species of megachilid bee are described independently using different types of polyurethane and polyethylene plastics in place of natural materials to construct and close brood cells in nests containing successfully emerging brood. The plastics collected by each bee species resembled the natural materials usually sought; *Megachile rotundata*, which uses cut plant leaves, was found constructing brood cells out of cut pieces of polyethylene-based plastic bags, and *Megachile campanulae*, which uses plant and tree resins, had brood cells constructed out of a polyurethane-based exterior building sealant. Although perhaps incidentally collected, the novel use of plastics in the nests of bees could reflect ecologically adaptive traits necessary for survival in an increasingly human-dominated environment.

Key words: adaptive behavior; cavity-nesting bee; *Megachile campanulae*; *Megachile rotundata*; megachilid bees; nest box; plasticity; polyethylene-based plastic bags; polyurethane-based exterior house sealant; Toronto, Ontario, Canada; trap nest; urban environment.

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Introduction

Urbanization and other forms of human-caused land use change can alter both the diversity and behavior of wild species (Slabbekoorn and Peet 2003, Winfree et al. 2009). Flexibility in adapting to selective pressures exerted in these landscapes that are different from those arising in natural areas enables some species to persist over others (Yeh and Price 2004, Shochat et al. 2006). One trait potentially indicative of a successful urban species is the recognition and novel use of human made products to enhance foraging or nesting opportunities. With more novel material accumulating in the landscape the chance some will act as analogues to natural materials might result in their incidental, but successful use by animal species.

Although not easily determined, novel uses of human made materials might result in an adaptive advantage, leading to more widespread use after multiple successful occurrences in a given population. Bowerbirds (Passeriformes: Ptilonorhynchidae) are one example that, in order to stand out during courtship, decorate nests with human-made products of specific colors (Diamond 1986). Additionally, house sparrows (*Passer domesticus*) and house finches (*Carpodacus mexicanus*) have been reported to use discarded nicotine-laden cigarette butts in their nests that reduce ectoparasites (Suárez-Rodrıguez et al. 2012).

One pervasive human-made compound common in all landscapes is plastic waste. Plastics are made to be strong, durable, and cheap, and as such are discarded as trash once used but resistance to degradation causes their accumulation in the natural landscape (Barnes et al., 2009). Plastics concentrate in landfills but also disperse across large areas in all habitat types, persisting in some cases for decades. Microorganisms and fungi have been studied colonizing or consuming them (Mergaert and Swings 1996, Barratt et al. 2003), and both altricial (e.g., robins, sparrows, pigeons) and precocial (e.g., geese, swans) birds have been documented using plastics as materials in nest building. Few other examples of animals using plastics in place of natural nest-building resources have been recorded and that by insects is almost non-existent. One observation made over 50 years ago noted the stingless bee *Tetragonula hockingsi* Cockerell (Apidae: Meliponinae) collecting fresh house paint as it dried, presumably for use as nesting material (Medler 1966).

The materials collected or secreted to construct brood cells and close a nest vary considerably by bee species. The majority of bees in the family Megachilidae collect materials from the landscape ranging from muds and small pebbles, to different plant leaves, stems, and resins (Michener 2007, Cane et al. 2007). One species in particular, *Megachile* (Eutricharaea) *rotundata* (Fabricius) (Hymenoptera: Megachilidae) is known to bring back a plethora of different natural materials, including cut leaves and flower petals (Hobbs 1967, Mader et al. 2010). The bee is Eurasian in origin and introduced to our study region, arriving in North America some time in the mid-1930s (Stephen and Torchio 1961, Cane 2003) and soon after managed as an alternative pollinator (Bohart 1972). Other megachilids, such as *Megachile* (Chelostomoides) *campanulae* (Robertson) (Hymenoptera: Megachilidae) collect plant resins in place of cut leaves (Krombein 1967). Unlike *M. rotundata*, this species is native to Southern Ontario (Sheffield et al. 2011). In this paper, we describe the use of polyurethane and polyethylene-based products as alternatives to natural plant-based nesting materials by these two bee species. *Megachile rotundata* was discovered using pieces of polyethylene-based plastic shopping bags and *M. campanulae* used a polyurethane-based exterior house sealant. Both of these bees provision brood above ground in cavities such as holes in wood, or plant stems, or in pre-excavated holes in anthropogenic structures such as fences, awnings, brick walls, and human-made trap nests (Mader et al. 2010).

Methods

Trap nests were set up in Toronto in 2012 for research investigating urban landscape factors influencing bee populations. See MacIvor et al. (2013) for methodological details. Cavity-nesting bees use trap nests as alternatives to natural nesting locations where brood cell series are laid in a row, from the back of a pre-excavated nesting hole to the front. These nesting galleries were opened, brood cells inspected, and larvae reared to adults individually in a walk-in growth room where temperature (27°C) and humidity (70%) were controlled. It was during inspection of the nesting tubes we discovered non-natural materials built into the nests of two different bee species.

One brood cell series constructed by *Megachile campanulae* contained 7 brood cells (#1–7 from back to front), two of which (#4, #5) was made of a whitish green material of a less-gluey consistency than the natural nest material (Fig. 1). An FTIR spectroscopy analysis with a Bruker Hyperion 1000 infrared microscope attached to a Tensor 27 FTIR Spectrometer were used to examine the material and a natural resin reference sample. These were analyzed directly by spreading on a potassium chloride window then compared with other reference materials including polyurethane polymers. An elemental analysis was done in a Hitachi S-4500 Field Emission Scanning Electron Microscope at 15 kv using a Quartz XOne x-ray microanalysis system. The samples were analyzed directly, without any coating.

A second cell series, constructed by *Megachile rotundata*, had 8 brood cells (#1–8 from back to front). Three of the cells were partially constructed with fragments of plastic bag, replacing on average 23% of the cut leaves in each cell. The first was cell #5 and 4 of 17 pieces were plastic, #6

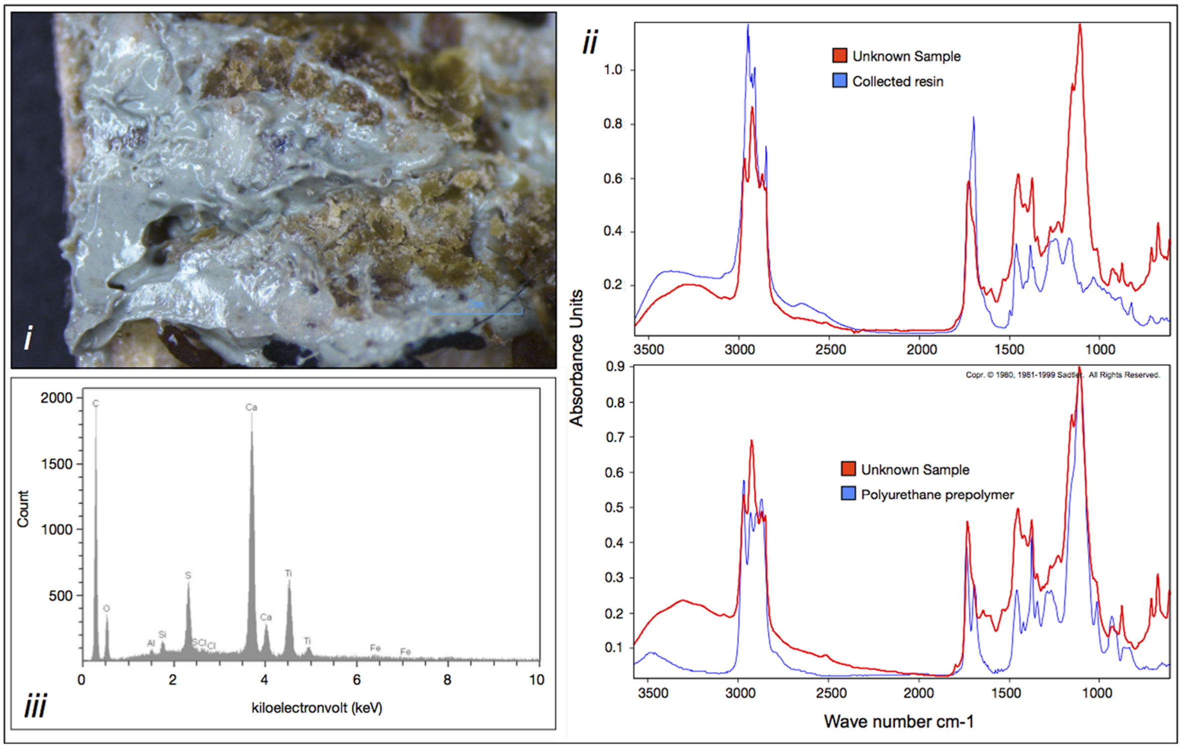

Fig. 1. Plate depicting the novel nesting material and the analyses used to determine its structural and chemical composition. (i) Non-resin material found in the nest of *Megachile campanulae* in downtown Toronto, Canada. (ii) FTIR spectra demonstrating how the composition differs from the *M. campanulae* natural nest resin and has similar characteristics to common polyurethane polymers. (iii) Energy dispersive x-ray spectrum reading of the substance collected by *M. campanulae* as a nesting material substitute.

had 3 of 15, and #7 had 4 of 16 (mean number of leaves in non-plastic containing cells was 16). All pieces were of the same white glossy color and 'plastic bag' consistency and thus presumably from the same source (Fig. 2).

Results and Discussion

Of the two polyurethane-based brood cells provisioned by *Megachile campanulae*, one (cell #4) was parasitized by the generalist brood parasite, *Monodontomerus obscurus* Westwood (Hymenoptera: Torymidae) (7 individuals emerged [4 female, 3 male]), and a female *M. campanulae* emerged from the second (cell #5). This bee species is common throughout Toronto, occupying 13.8% of all sites in 2011 and 8.6% in 2012 (polyurethane-containing cells amounting to only 0.74% of all cells collected). The FTIR spectroscopy analysis demonstrated that the unknown sample from the *M. campanulae* nest most closely resembled polyurethane polymers (Fig. 1). The X-ray microanalysis further supported this by revealing that Calcium (Ca), Titanium (Ti), and Iron (Fe) were present in the material, each of these being common elements in polyurethane-based sealants and caulking (3M Company 2012) (Fig. 1C). Polyurethane-based sealants are commonly applied to the exteriors of all forms of buildings. Resin providing plants and trees are also common in the city in forested areas, home gardens, and in municipal landscape design. Since natural resins were found in the nesting cell series both in behind and in front of the plastic material, the use of polyurethane-based sealants might be incidental and not due to a lack of natural resin options.

Megachile rotundata was the most common bee surveyed in trap nests in both sampling years. The bee occupied 18.0% of all sites in 2011 and

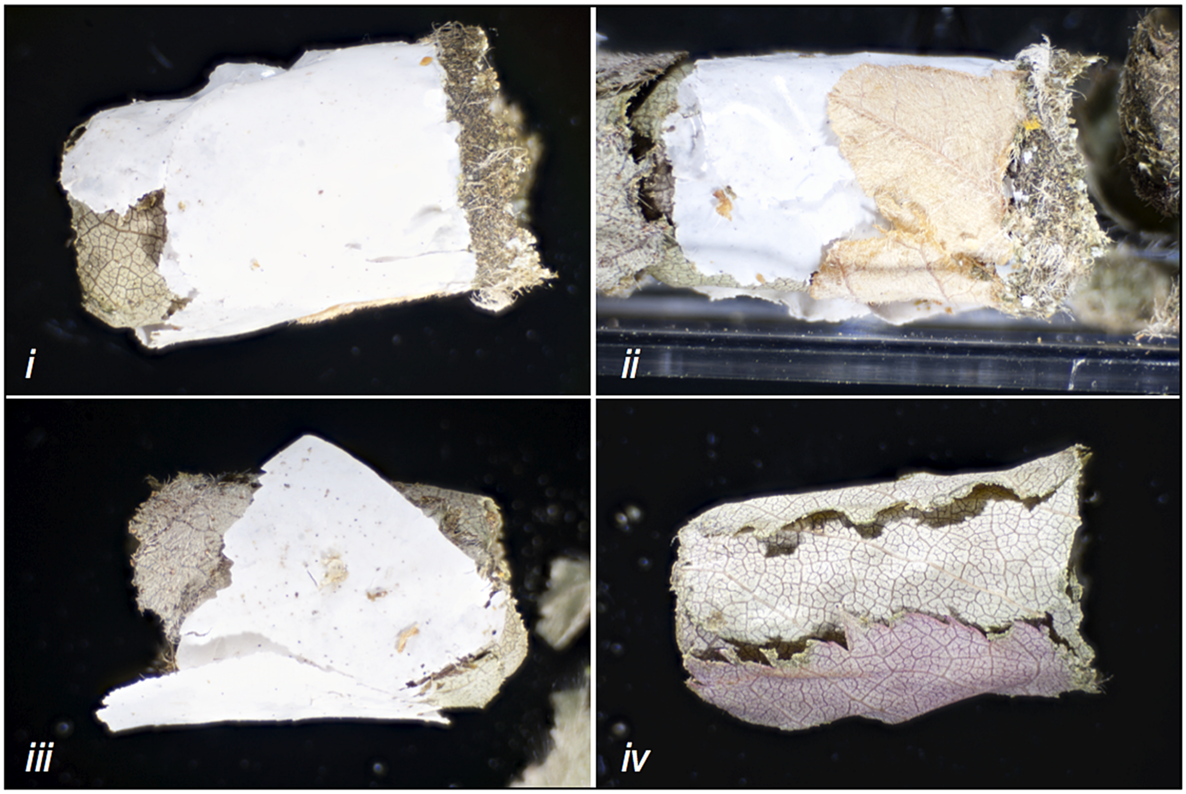

Fig. 2. Plate depicting *Megachile rotundata* brood cells made with and without polyethylene plastics. *M. rotundata* brood cell #5 (i), #6 (ii), #7 (iii) are partially constructed using polyethylene plastic bag fragments and one cell comprised of leaves only (iv).

19.9% of sites in 2012. Brood cells partially constructed with fragments of polyethylene-based plastic bags represented 0.85% of all brood cells constructed. All were males and emerged successfully, parasite-free. The mandibular teeth markings in the cuts along the plastic bag nesting fragments were noticeably coarser and less uniform than those made in leaves from the same brood cell (Fig. 2), suggesting the use of plastic bags represented an aberrant behavior. Dried juices and pulp created from the chewing of leaf pieces by megachilid bees contribute to them attaching together to form each cell (Trostle and Torchio 1994). This natural process was presumably lost when the plastic pieces were used as they did not adhere to the other leaf pieces that comprised the cells, and easily flaked off when inspecting the brood cell architecture. Furthermore, since plastic pieces were found in combination with leaves in brood cells, and found only near the end of the cell series, bee naivete does not appear to be the cause for the use of plastic. The fact that *M. rotundata* returned to collecting leaves to finish the brood cells after using plastic suggests that leaf nesting materials were not limiting. It is interesting to note that in both bee species, the type of plastic used structurally reflects the native nesting material, suggesting that nesting material structure is more important than chemical or other innate traits of the material.

There may be some advantage in using plastic as a nesting material, as it might physically impede parasites infecting a recognized host. Stephen and Every (1970) noted that *Megachile rotundata* constructing cell series in plastic drinking straws were free of *Monodontomerus* parasitoids, which were unable to sting through the plastic wall; however up to 90% of brood were lost to mold because plastic inhibited diffusion of moisture. Certainly, polyurethane and polyethylene based plastics could also be a detriment to brood survival. Although this too was not evident in the study as all specimens survived to adulthood after artificial rearing in the lab, many other examples of plastics inhibiting essential functions including mobility, foraging, and respiration in other animals is documented (Barnes et al. 2009).

Our understanding of how plastics spontaneous integrate into natural ecological processes will increase as more human-made material and products build up in both urban and non-urban landscapes. Even more so, as ecologists, naturalists, and all hobbyists having access to a camera and Internet can quickly disseminate unique observations, which can be used to both engage the public, and contribute to empirical research (Silvertown 2009). The extent to which human-made products such as plastic become a fixed part of the landscape might act as a novel selective pressure further delineating urban-adaptive and urban-avoiding species and sub-populations.

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