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Could bats be also spreading fig wasps? Insights into the occurrence of agaonid wasps (Hymenoptera) in guano samples and litter baits from Caves of Burdeos, Polillo Island, Philippines

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ABSTRACT. The occurrence of live winged and wingless fig wasps in guano and litter baits from caves, based on a review of published and unpublished data sets, is highlighted. The study postulates that tritrophic interactions involving figs, fig wasps, and fruit bats are common among forests, especially in karst areas, but poorly documented or studied. Within such interactions, the role of fruit bats as dispersers of pollinating fig wasps aside from fig seeds, albeit consequential, helps ensure the continuity of these ecosystem processes and the health of forests. The occurrence of fig wasps in cave guano makes them vagrants or accidentals under the trogloxene classification of cave organisms. Nevertheless, accidentals are important contributions to the food chain in the cave floor communities.

Keywords: Agaonidae, cave litter-baits, *Ficus*, fig wasps, fruit bat guano

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INTRODUCTION

It has been established that Old World fruit bats (Pteropodidae) help spread seeds of fruit-bearing trees, especially figs (*Ficus* spp.) (Shilton *et al*., 1999). Fig trees include strangling (parasitic) and free-living types. Although trees and other plants parasitizing timber sources may be considered not economically beneficial, in general, *Ficus* species are important components of tropical forest ecosystems (Harrison, 2005) because they provide food and habitat sources (including nesting sites) for macro- and micro-herbivores and other organisms.

Ficus Dumort belongs to the family Moraceae, and the fig fruit is botanically known as a syconium, a type of multiple fruit (Galil, 1989). Syconia are technically also inflorescences (Souza *et al*., 2015). Except for the self-fertilizing, cultivated edible fig, each species of *Ficus* has a complex and obligate mutualistic relationship with one or more pollinators aptly called fig wasps. Fig wasps (Hymenoptera: Agaonidae) include a diverse species under about 27 genera from four subfamilies (Cruaud *et al*., 2010; Heraty *et al*., 2013). Each fig tree produces a few hundred to

about a million fruits, sometimes twice a year. This fact makes it one of the more reliable, year-round food sources for frugivorous bats.

However, each syconium needs the action of at least one wasp to set seeds. Gullan & Cranston (2014) summarized the processes in the relationship as described in *F. macrophylla* by Galil & Eisikowitch (1968). The steps begin with a female wasp entering into the syconium through a small hole called ostiole and pollinating female flowers lining the cavity inside. She oviposits in some of them and dies. Each wasp larva develops within a flower's ovary, which becomes a gall flower. Female flowers (usually long-styled ones) that escape wasp oviposition form seeds. About a month after oviposition, wingless male wasps emerge from their seeds and mate with female wasps within the fig ovaries. Shortly after, the female wasps emerge from their seeds, gather pollen from another lot of flowers within the syconium (which is now in the male phase), and depart the mature fig to locate another conspecific fig tree in the phase of fig development suitable for oviposition. Different fig trees in a population have different sexual stages, but all figs on one tree are synchronized. Species-specific volatile attractants produced by the trees allow for the accurate, error-free location of another fig tree by the wasps. These and those of other accounts (Dumont *et al*., 2004; Rodriguez *et al*., 2017) have established the necessity of the obligate mutualistic relationship between figs and fig wasps to produce one of the major food sources for frugivorous bats. Whereas the Philippine fig flora (*Ficus* spp.) constitute around 100 species (or more if exotic species are included) (Pelser *et al*., 2023), there are only about 30-40 reported fig wasps species and Rodriguez *et al*. (2020) believed that "low sampling effort and high genetic isolation" mutually or severally contribute to this numerically low fig wasp diversity in the Philippines. More studies on local Agaonidae are needed on aspects of taxonomy and ecology.

This paper aims to report observations that seem to point to bats' possible contribution to the spread of fig wasps. This is probably a mere consequence of their feeding activities, but it may support the hypothesized tritrophic interaction involving figs, fig wasps, and fruit bats. It also highlights the importance of caves to ensure the continuity of these ecosystem processes.

MATERIALS AND METHODS

Data on insects extracted from guano and trapped in leaf litter baits included in previous publications (Encinares & Lit, 2014) as well as terminal reports, summarized reports of collections, cave assessments, and student theses and special projects (Lit *et al*., 2010; Encinares, 2011; Lit, 2023) were reviewed. The data were based mainly on observations as well as samples gathered from Mapanghi Cave (Lit, 2023), Bulalon Cave (Encinares, 2011; Lit, 2023), and the caves of Puting Bato, mostly from Cave 3–4 (Lit *et al*., 2010), all located on the eastern part of Polillo Island and politically part of the municipality of Burdeos, Quezon Province (**Figure 1**). These caves serve as roosts to large populations of at least five species of Old-World frugivorous bats (Alviola *et al*., 2022; 2023).

Encinares & Lit (2014) used wet and dry combinations of dried narra (*Pterocarpus indicus* Wild.) and bamboo (*Bambusa vulgaris* Schrad. ex J.C. Wendl.) leaves as litter baits, whereas Lit (2023) utilized rice hay. All litter baits and guano samples were run through Berlese-Tullgren funnels for 24–48 hrs to extract insects and other arthropods. From the list of identified insects, fig wasp incidences were recorded. The key to Indo-Australian Agaoninae was used to identify the fig wasps up to near-genus level (Wiebes, 1994). The occurrence of living wasps was noted and photographs were taken when possible.

RESULTS AND DISCUSSION

The occurrence of fig wasps in cave guano and litter samples had been ignored or lumped with other Hymenoptera in the previous collection of samples for assessment and other studies (**Table 1**). However, live fig wasps, both winged and wingless, were first documented among samples from Bulalon and Mapanghi Caves in Sitio Bulalon, Barangay Poblacion, Burdeos, Polillo Island, Quezon Province, in 2007. They were collected through boxed dry and wet litter baits of rice hay (Lit, 2023).

During subsequent cave explorations, especially in 2009–2010, a study that evaluated wet and dry litter baits for sampling cave arthropods also yielded living individuals of fig wasps (Encinares,

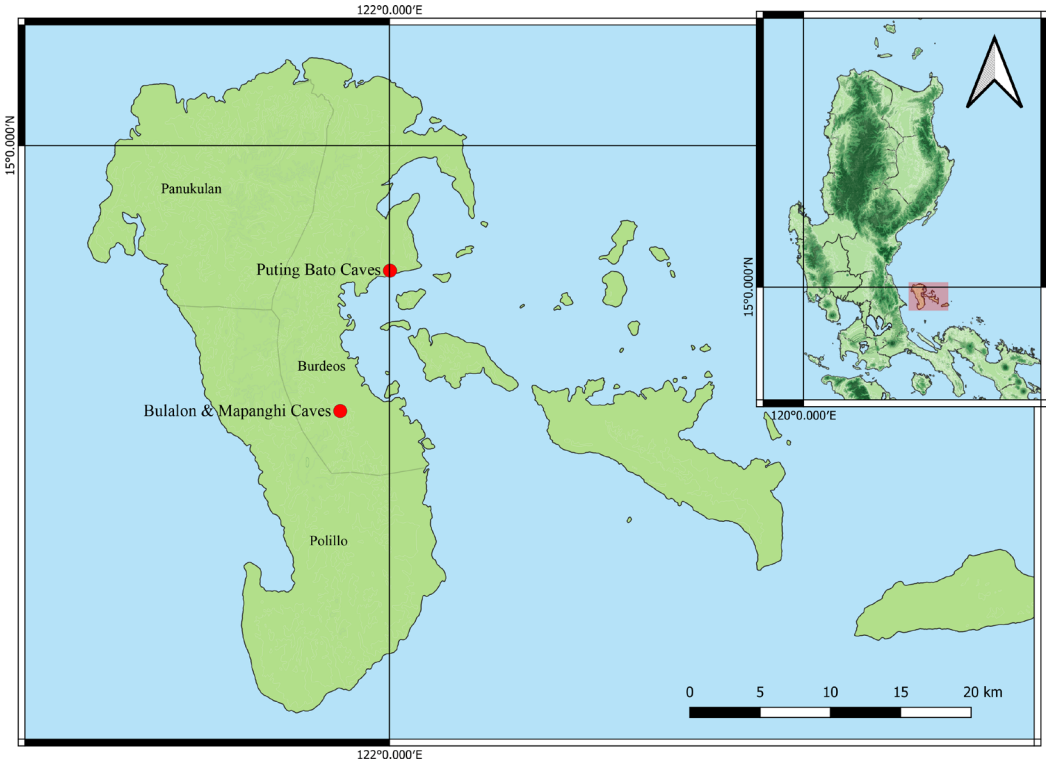

Figure 1. Localities of observed caves in Burdeos, Quezon on Polillo Island, east of Luzon, Philippines.

2011; Encinares & Lit, 2014), among many other species of guano and cave litter arthropods.

At least two species were present in Caves 1, 2, and 3–4, Sitio Puting Bato, Barangay Aluyon, Burdeos, Polillo Island, Quezon Province, here identified and reported as species of the genus *Ceratosolen* (**Figure 2**) and another species belonging to another genus *Valisia* Wiebes (1993). Another undetermined species was collected in both the Mapanghi and Bulalon Caves.

The occurrence of living individuals of fig wasps among litter baits (wet and dry) set inside caves and in guano samples gathered from them presents several insights and possibilities. First, it is clear that, at least for a limited time, the fig wasps can survive within the cave environment. Their longevity within such an inhospitable environment remains to be investigated. Secondly, their occurrence suggests several possibilities that present interesting aspects of the ecology of forests, caves, figs, fig wasps, and fruit bats. For instance, identifying fig wasps from guano piles directly under roosts of identified fruit bats may provide good clues to the species of figs that the bats consume. In the case of fig wasps identified from samples, species of *Ceratosolen* are known to be pollinators of *Ficus* species under the subgenus *Sycomorus* (Rodriguez *et al*., 2020). Within the Bulalon-Mapanghi area and around Puting Bato, *Ficus* species under *Sycomorus* include *F. nota, F. minahassae, F. pseudopalma, F. septica,* and *F. variegata.*

There is no definitive explanation about how the fig wasps arrived or landed in cave guano and litter baits. Some portions of figs (fruits) may still be intact as the bats return to the cave and drop some of them together with the fig wasps to the

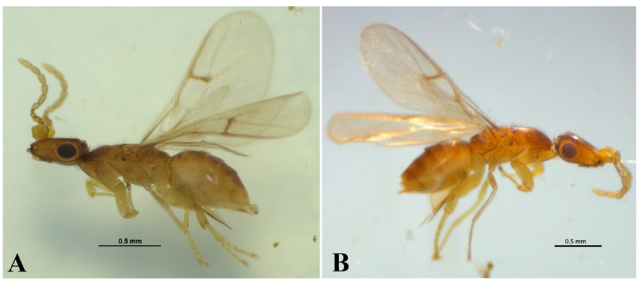

Figure 2. Unidentified *Ceratosolen* spp. (Hymenoptera: Agaonidae) from the cave litter and guano samples from (A) Cave 1 and (B) Bulalon Cave in Burdeos, Polillo Island, Quezon Province, Philippines.

Table 1. Occurrence of fig wasps (Hymenoptera: Agaonidae) in samples of cave guano, litter, and leaf litter baits from Burdeos (Polillo Island), Quezon Province.

Date/Cave	Sample taken	Identification	Reference(s)	Remarks
2007/ Mapanghi and Bulalon Caves	guano samples; wet and dry rice hay baits	Agaonidae	Lit (2023)	live fig wasps in both guano samples and rice hay baits
2009/ Cave 3–4 & Puting Bato	guano samples	Agaonidae: near *Blastophaga*	Lit *et al.* (2010)	fig wasps preserved together with other arthropods (Berlese-Tullgren funnel extracts)
2010/ Bulalon Cave	wet and dry leaf litter baits (narra + bamboo leaves)	Agaonidae	Encinares (2011); Encinares & Lit (2014)	live fig wasps observed; fig wasps preserved together with other arthropods (Berlese-Tullgren funnel extracts)
2014–2019/ Caves 2 & 3–4, Puting Bato	guano samples	various Hymenoptera	Compiled unpublished reports of cave assessments by students	fig wasps preserved together with other arthropods extracted using Berlese-Tullgren funnel

cave floor. The fig wasps possibly crawl and find their way into the litter baits.

Fig seeds are known to maintain their viability as they pass through the gastrointestinal tract of fruit bats (Shilton *et al*., 1999). Differential ingestion has been documented in the field and through experimental tests (Reiter, 2002; Munin *et al*., 2011). The preceding section has already mentioned the emergence of wasps from fig seeds based on the detailed investigation by Galil & Eisikowitch (1968). It is, therefore, highly probable that fig wasp pupae within fig seeds also pass unharmed through the digestive system of bats and likely emerge later as the seeds are excreted together with the bat feces. Indirectly, then, the fruit bats also help disperse the fig wasps.

On the other hand, these individuals who emerge from the seed cannot gather pollen since they are out of their host syconium and, therefore, do not perform cross-pollination directly. Nonetheless, they may continue to find a suitable syconium and reproduce, given that they are females and have been fertilized before the bat consumed their original fig. At this rate, the indirect dispersion service done by the fruit bat through seeds that pass through their guts might have an insignificant effect on the maintenance of fig wasp populations near the roosting sites.

The occurrence of fig wasps in caves places these organisms in the category of accidentals. Howarth (1983) mentioned that "accidentals are often omitted from cave studies, but their contribution to the food web is significant, as they support many cave predators." To date, there is no documentation on the number of these tiny wasps in the guano accumulated under roosts of fruit bats. Estimating their numbers therein, as well as studies on the aspects above in the biology of figs, fig wasps, and bats, may be worth pursuing further empirical evidence to contribute to a better understanding of a possible tritrophic interaction among these three important biotic components of forest ecosystems, and of an interesting aspect of forest and cave ecology.

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