2021. Journal of Arachnology 49:151–155

SHORT COMMUNICATION

Paternal care in the Neotropical harvestman *Cynorta bromeliacia* (Opiliones: Cosmetidae).

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Abstract. We report observations over several field seasons of egg and juvenile guarding by males of a Central American species of cosmetid harvestman (Opiliones: Cosmetidae), *Cynorta bromeliacia* Goodnight & Goodnight, 1947. This represents only the second species of the family Cosmetidae that has been reported to exhibit paternal care. Importantly, we observed multiple instances of solitary male egg-guarding, including examples where eggs and young were at different stages of development. We also observed a few cases of mate guarding by a male at an oviposition site, where the female was near to eggs that appeared to have been recently laid. We discuss these observations in relation to the arboreal tendency of this species and speculate that oviposition sites are close to roosting sites or other such refuges for either the male or both sexes. Given the weak sexual dimorphism displayed by the species, we discuss that the externally visible characters we used to identify males are unlikely to provide any advantage in fighting off conspecific males. We also suspect that females may produce multiple clutches in this species, but this remains to be verified. Finally, we discuss how our findings at the end of the wet season may relate to the local microclimate and suggest further standardized observations throughout the year are required.

Keywords: Male egg-guarding, mate guarding, reproduction, Honduras, Cusuco

https://doi.org/10.1636/JoA-S-19-028

Many aspects of the biology of the arachnids are well studied, including diverse facets of their reproduction. While various degrees of maternal care are rather common for arachnids, paternal care is rare. For the latter, egg-guarding by males has only been observed in seven families of the harvestmen Order Opiliones (after Machado & Macías-Ordóñez 2007; Requena et al. 2014) namely; Assamiidae (Martens 1993), Gonyleptidae (Stefanini-Jim et al. 1987; Machado & Raimundo 2001; Hara et al. 2003; Machado et al. 2004; Machado & Macías-Ordóñez 2007; Nazareth & Machado 2009, 2010; Requena et al. 2009), Nomoclastidae (Rodríguez & Guerrero 1976; Mora 1990), Podoctidae (Martens 1993), Stygnidae (Villarreal & Machado 2011), Triaenonychidae (Forster 1954, see Machado 2007), and most importantly for our study, only once before for Cosmetidae (Proud et al. 2011). In the few known cases of egg-guarding in harvestmen, behavior varies depending on the sex of the caring individual (i.e., female or male). Maternal care is typically of eggs that are all of the same age, which the mother will protect from predation by shielding with her body or by actively attacking predators, as recorded in some Gonyleptidae (e.g., as in Machado & Oliveira 1998, 2002; Buzatto et al. 2007) and some other families most notably Stygnopsidae and Cranaidae (e.g., Machado & Warfel 2006; Hunter et al. 2007), but also in some Cosmetidae (e.g., as per Goodnight & Goodnight 1976). In such cases, females can forgo foraging or other activities to persistently guard the eggs (reviewed in Machado & Macías-Ordóñez 2007). Paternal care in harvestmen, however, typically involves a male caring for eggs of varying ages and can include continuous mating with multiple females that approach, resulting in eggs being placed together from several different mothers (reviewed in Requena et al. 2014). In such cases, the male will usually spend time cleaning eggs and protecting them from fungal infection and cannibalism (Mora 1990; Machado & Raimundo 2001). Initially, male harvestmen were believed to be less effective at egg care than females (Hara et al. 2003; Machado et al. 2004), but more recent studies have shown that there is no difference in success between maternal and paternal care (Requena et al. 2009).

Below, we provide a series of non-standardized observations on a Honduran harvestman, *Cynorta bromeliacia* Goodnight & Goodnight, 1947, from the family Cosmetidae, which were made with the objective to provide an outline of seemingly novel behavior for the species and to encourage further in-depth studies of paternal care in this and other cosmetids. No techniques were applied to mark individuals (e.g., florescent paint, etc.), although we were able to easily determine individual sex in the field through direct observation of external anatomy (or in two cases from photographs). There is slight external sexual dimorphism in our focal species, which Goodnight & Goodnight (1947, p.22) described originally from the same locality where we made our behavioral observations. Those authors specified that adult males of *C. bromeliacia* have the “Distal portion of the fourth femur somewhat widened, with a row of ten or twelve larger tubercles on either side” and “Basitarsus of first tarsus slightly enlarged.” From our observations of many individuals in 2012 and thereafter, we were able to visually identify the sex of all observed individuals by these attributes, noting that while the distal femur of the fourth leg of mature males is indeed incrassate (i.e., “somewhat widened”) and has slight armature compared to females (i.e., row of tubercles), the latter consists of up to 15 tubercles on both dorsal and ventral surfaces. In addition, for males, the basitarsus of the first leg is better characterized as being slightly swollen, while also the male chelicerae can be marginally enlarged in comparison to females.

Over the course of multiple field seasons (all June to August, mainly 2012–2013) at Cusuco National park (15°29.8′N – 15°32.1′N, 88°13.0′W – 88°16.3′W), Department Cortés, Honduras, the cosmetid *Cynorta bromeliacia* was observed engaging in behaviors that would indicate that this species exhibits paternal care of eggs and even of recently hatched juveniles. Our first observation of this kind was made in the month of June 2012 in the early morning (at around

08:00), whereby a male was resting at an oviposition site on the underside of a palm frond (Fig. 1A). When first observed, this male was at the base of the palm frond (*Synechanthus fibrosus*), facing the eggs, but not in contact with the eggs on the frond. A handful of other similar early morning observations were made in July and August 2012 at nearby localities (within a few kilometers of the first observation), again typically of a lone male resting in close vicinity to eggs. We are also aware of another photograph of this behavior in late July of the previous year by our field collaborator Ethan Staats, again showing what appears to be a lone male resting near to some recently laid eggs.

More extensive observations were made of this species in the same months (June to August) of 2013 plus some in 2015. These were again non-standardized. Many such observations in these years were made after nightfall (from after 19:00 to 22:00 hours) with each oviposition site found using white light, and typically observed only once under red light. These observations involved multiple interactions of a male and sometimes a female adjacent to clutches of eggs, and nearly all were on plant fronds or leaves over 1 m above ground level. We rarely observed (2 cases in 2013) a pair mating near a clutch (e.g., Fig. 1B), but more importantly, we observed multiple instances (9 cases in 2013) of solitary male egg-guarding. In three such cases, we also observed a thick clear mucus coat covering the eggs (e.g., Fig. 1C), while in others any such coating was either inconspicuous or absent. Also, we less frequently observed (4 cases in 2013) mate guarding by a male while a female was closely associated with freshly laid eggs (e.g., Fig. 2B,C). This latter aspect was again observed in 2015 (see below and Fig. 2A). When females were observed at oviposition sites, they were either engaging in mating, or apparently ovipositing. However, unlike known examples of maternal care from the literature, we observed multiple instances (at 6 of the above cases in 2013) where broods had eggs of various ages. In such cases, those eggs towards a tip of leaf of an oviposition site were often darker and had more advanced development than others closer to the leaf base. One instance we recorded over several days in late July 2013 (Fig. 2B–D) initially had a female close to newly laid eggs underneath a palm frond (at 21:30–22:00 hours) at approximately 1m above the ground (Fig. 2B,C). Here, in addition to some more recent eggs close to a female, at least one or possibly two batches of notably older eggs (being much darker orange-brown) were adjacent but closer to the frond-tip, while even older nascent juveniles were closest to the tip (Fig. 2C). In this case, a male was roaming nearby during the initial observation, and may have been disturbed by our presence. This brood was the largest of those observed during 2013, where adding the juveniles to eggs, we can be sure of at least three clutches laid at different times, although up to five observed clutches is possible given slight differences in coloration and positioning of eggs or visible juveniles. Clutch size is uncertain, though a possible size can be estimated from photographs taken during the observations discussed here. Using color variation between eggs as described above, it can be estimated that a clutch from a single female can be anywhere from 20–70 eggs. Four nights later when we returned for reassessment (around the same time as before), the previously observed juveniles had dispersed and only the male was present (Fig. 2D). This latter aspect was consistent with other cases we had casually observed where only a male was found guarding eggs. In addition, the seemingly older eggs had darkened slightly, while younger eggs further from the tip appeared to be covered by a mucus coat that had not been apparent on the previous observation. However, the next night (same time), both a male and a female were present, and there were no further apparent changes to the eggs. Whether either adult (at various observation times) was a parent of the various clutches was unclear to us, although we suspect the male was likely the father of all eggs and young present. When alone near egg clutches, males were usually observed close to the base of the leaf, with legs spread out, not usually engaging with the eggs.

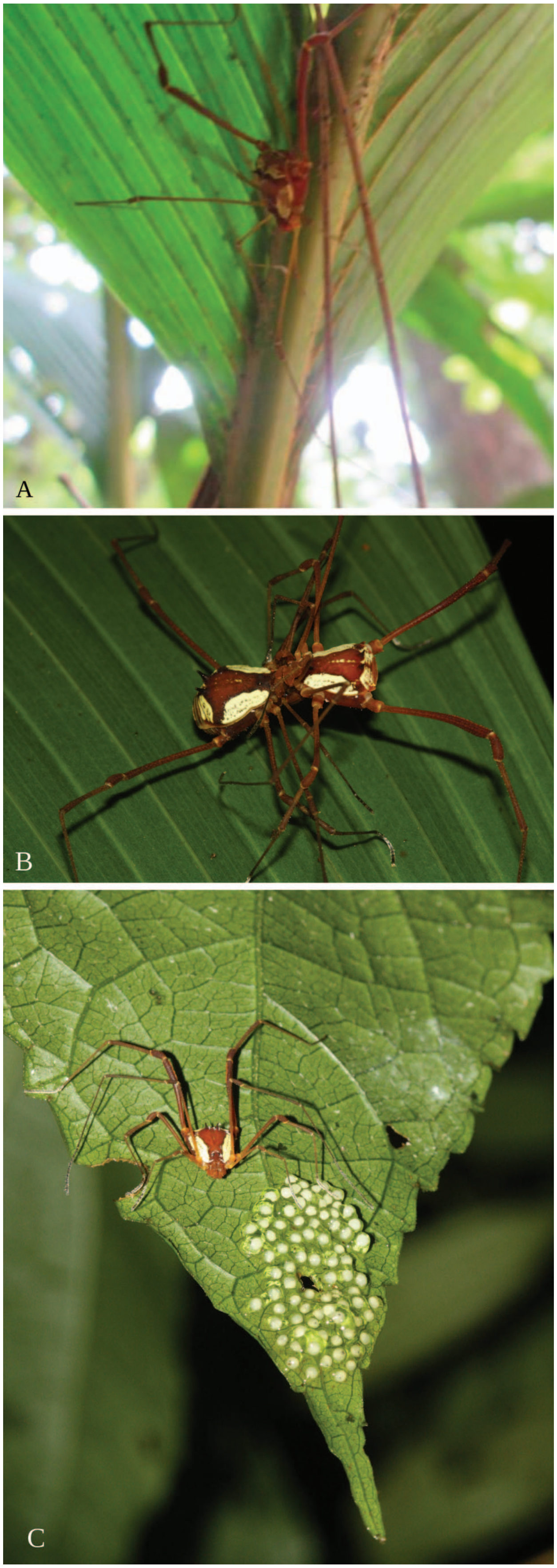

Figure 1.—(A) Male during day at base of palm frond with eggs (2012). (B) Pair mating (female left, male right, 2013). (C) Male guarding freshly laid eggs on underside of leaf (2013).

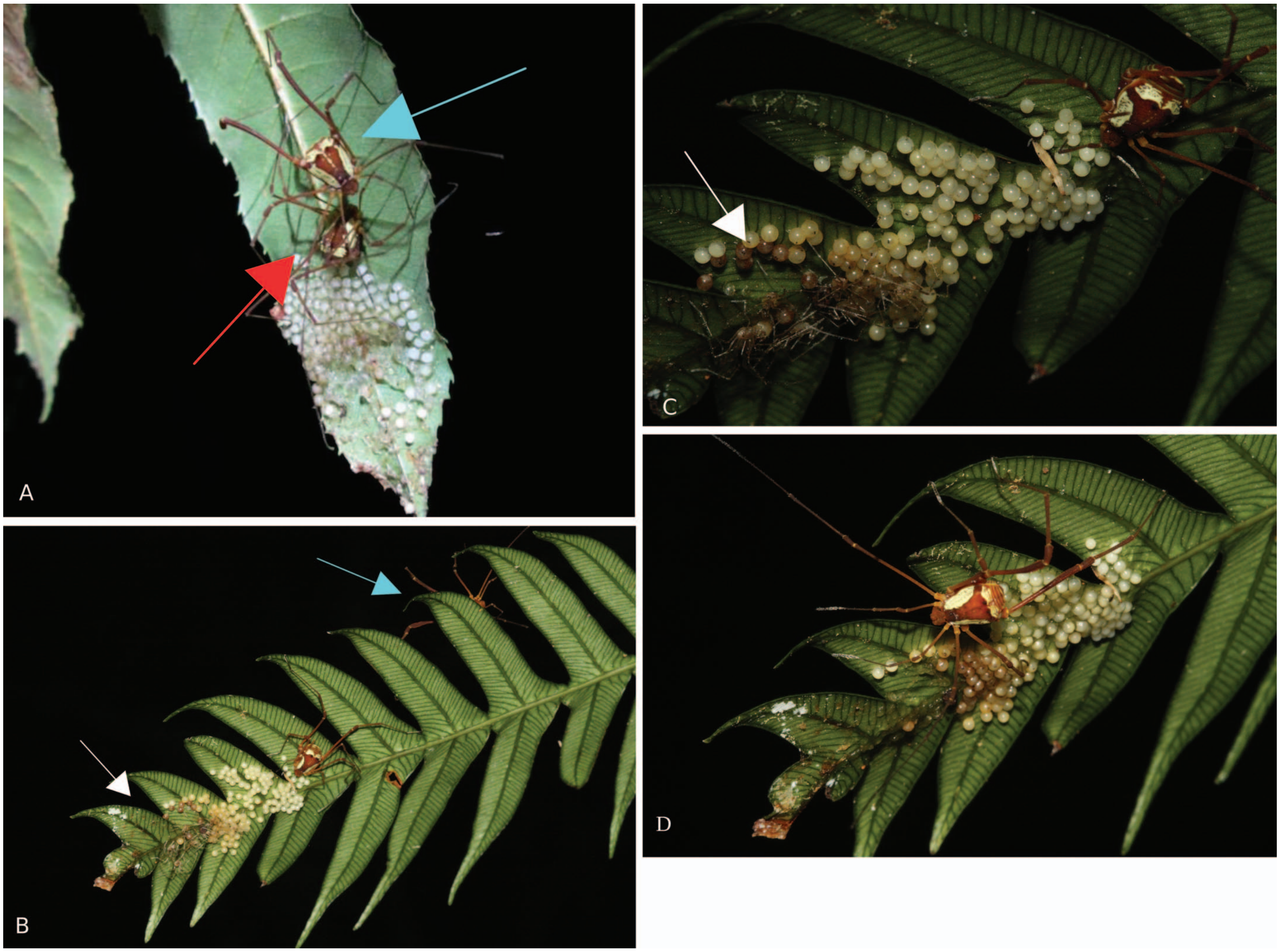

Figure 2.—(A) Male (blue arrow) guarding female (red arrow) while she oviposits at night (2015). B-D, same clutch, 2013. (B) Female at night laying eggs at an established nest site (male indicated with blue arrow, juveniles with white arrow). (C) Closer view of same event. (D) Male alone guarding eggs at same site in following night; juveniles have dispersed.

Few observations of any oviposition site were made during the day in any year of study. However, in the few daylight observations during the same months of 2012–2013 (and some in 2015), it seems females may remain near oviposition sites, as females alone were sometimes observed during daylight hours. At the site detailed above with multiple observations (Fig. 2B–D) in 2013, a single female was observed resting near eggs in the afternoon (around 16:00 hours) on the day following the initial observation, while the male was not seen. In another instance in the same year, a male and female were observed together in the afternoon (from 16:00–16:30 hours) near a different oviposition site on the underside of a palm leaf. Neither were interacting with the eggs, but instead were either closer to the base of the leaf, or in the center of the palm, which may act as a potential roost site for both these adults. In 2015, the final observations (made by BND) were in agreement with findings in previous years. Only a few photographs were taken, but again a male and female were observed together at one of the oviposition sites. Here, it appeared that the male was guarding the female with his entire body while she interacted with the oviposition site: either touching the eggs and leaf surface with her appendages, in particular the elongated second pair of legs, or touching the male (Fig. 2A). Here about 100 eggs were observed, with some towards the periphery of others and closer to the leaf tip, possibly representing an older clutch than the rest. Furthermore, a thick mucus coat could be seen to cover most of the eggs, especially those nearest the leaf center (adjacent to where we observed the adult pair), which we suspect the female was actively laying, but another plausible option could be that she was instead adding a mucus coat to some eggs laid earlier.

Overall, for the various reproductive behaviors in this species, copulation was observed occasionally but the entire process was never observed, leaving us unclear about which partner initiates mating, and what the process for this is. With regards to interactions at an oviposition site, males of this species appeared to not only cover and tend the eggs already existing in a brood, but the male was occasionally seen to exhibit behavior that was akin to mate guarding, by placing his body over that of a female visiting the site. This may be to protect the female while she oviposited, or to prevent a newly-visiting female from cannibalizing any pre-existing eggs (perhaps especially if the pair had not yet copulated). Mate guarding is a behavior believed to increase the likelihood of paternity, since without such a strategy, internal fertilization may reduce the rate of paternal care due to potential decreases in the number of eggs sired. Until recently this was assumed to be the case in cosmetids as there was no evidence of mating-plugs to increase the likelihood of paternity. However, subsequently amorphous gel-like structures have been observed in the ovipositors of some other species of Cosmetidae as well as other families of Opiliones, which are believed to be mating-plugs (Townsend et al. 2019). If such mating-plugs are also used by males of our focal species alongside behavioral strategies such as the observed mate guarding, these factors could act in synergy to help ensure paternity.

In the case of this species with an arboreal tendency, all egg-broods were typically found on various types of plants that other studies have shown can also be common roosting sites of Neotropical Cosmetidae (Proud et al. 2011), but many were observed near frond tips of tree ferns or leaf tips of palms, which have a secure refuge of sorts nearby for adults at the heart of the plant (Proud et al. 2011). Using the underside tip of a nearby frond/leaf would allow the males (or perhaps both sexes) to protect or tend nearby broods with little effort, since their placement would be difficult for most predators to reach (particularly terrestrial ones) yet close to a secure refuge for adults if needed. However, the positioning of the eggs alone may not prove effective against winged parasites and predators, such as predatory wasps, which have been shown to be capable of causing great mortality in the gonyleptid harvestmen *Acutisoma proximum* Mello-Leitão, 1922 that also primarily lays its eggs on the underside of leaves but only displays maternal care (Buzatto et al. 2007). However, a few other Opiliones with paternal care also appear to display similar preference for arboreal oviposition sites on the undersides of leaves. For example, in Gonyleptidae (Caelopyginae), males of *Ampheres leucopheus* Mello-Leitão, 1922 were observed guarding eggs in a manner much like our own observations, including a similar resting position of males (Hara et al. 2003). Other similar observations in some Gonyleptidae (Progonyleptoidellinae) involve *Iguapeia melanocephala* Mello-Leitão, 1935, *Iporangaia pustulosa* Mello-Leitão, 1935, *Progonyleptoidellus striatus* (Roewer, 1913) (all in Machado et al. 2004) or briefly later *Progonyleptoidellus orguensis* (Soares & Soares, 1954) (Machado & Macías-Ordóñez (2007). In all these, male guarding was similarly reported to occur on the underside of leaves, and also involved a mucus coat, as we observed on some eggs in our focal species. In particular, *I. pustulosa* was shown to have the same general pattern of egg distribution as we often observed, with differently aged eggs and the oldest towards the leaf apex (Machado et al. 2004). Finally, for the same taxonomic family as our focal species, the only other Cosmetidae for which paternal care has been reported (an undescribed species from Costa Rica) again showed a similar placement of male-guarded eggs—often differently aged eggs—on leaf undersides, and a thick mucus coat was apparent (Proud et al. 2011).

No observations were made of any interactions between two conspecific males. As above, our focal species exhibits only relatively minor secondary sexual characters in the sexually mature males (i.e., slightly swollen basitarsi on the first leg, marginally enlarged chelicerae, and an incrassate slightly armed fourth femur). However, none of these are strongly dimorphic characters nor is there much heterogeneity between males (besides slight differences in number of tubercles on the femurs of fourth legs as noted above), and so to our eyes, none of these aspects clearly act as an indicator of male fitness nor seemingly provide much of an apparent advantage for males to fight off rivals from the oviposition site (as suggested for some species by Solano-Brenes et al. 2018). Some other Opiliones with paternal care involving guarding eggs on the underside of leaves such as *I. pustulosa* (Machado et al. 2004) or the undescribed Cosmetidae (Proud et al. 2011) also display little sexual dimorphism, especially in terms of weaponry that might be used by males in intra-specific male competition or against potential predators or parasites. However, the existence of some external sexual dimorphism in our focal species, although seemingly minor in comparison to that known in many other Neotropical harvestmen (e.g., see Townsend et al. 2010 for other Central American Cosmetidae), indicates that some selective differences in fitness can exist between the sexes (or have existed) of our focal species, which should be further investigated in relation to various intra- and inter-specific behaviors, including those outlined above.

Some of our casual observations would indicate that females may not stray far from the males with whom they have already interacted with. This may mean that mothers can also be involved in some active care of their own eggs (though this was not directly tested, nor observed), perhaps especially if the plants used as oviposition site are also adjacent to preferred roosting sites of these females due to high roost site fidelity (which is common in other Opiliones in the Neotropics, e.g., Grether & Donaldson 2007). Since a female was observed on multiple occasions to be interacting with eggs nearby a male, or instead towards the heart of the host plant near to the clutches, it could be surmised that a given female may repeatedly mate with the same male to produce multiple clutches. However, due to the casual nature of our observations, we are left uncertain about whether any observed females at oviposition sites were actively guarding or tending existing eggs, so this possibility remains. This leaves us unable to classify this species as exhibiting exclusive paternal care given the current limited data, but instead may involve some biparental care of oviposition sites.

Finally, we note that all our observations above (regardless of year) occurred at the end of the wet season, heading into the drier season. This is counter to what is found in many other harvestmen species with parental care. Most of those species discussed above (i.e., with similar paternal behavior to our own observations) have offspring during the wettest months when perhaps there will be more food available for emerging offspring than in a later dry season, when food is less available (e.g., Proud et al. 2011). It should be noted that many such cases appear to be restricted to species found in moderate elevation habitats (e.g., *A. leucopheus* around 700 m (from Hara et al. 2003), *I. melanocephala, I. pustulosa* and *P. striatus* all reported around 800 m (Machado et al. 2004), and the previously reported Cosmetidae around 1000 m elevation (Proud et al. 2011). In this study, all observations were made in Cusuco National park, which is a montane cloud forest. Although the temperature and rainfall do fluctuate during the year in this region (recorded at weather station in San Pedro Sula, 30 km away in lowland habitat), there is limited information about actual annual precipitation in the relatively higher elevations (i.e., 1500–1900 meters) of this national park, where our focal species is found in abundance. Evapotranspiration in the other montane parks of Honduras have been observed to vary depending on the altitude, ranging between 3–5 mm/day at the highest zones of similar altitudes to those of Cusuco, with mean humidity ranging from 82–90%. Even during the driest times of year (90 mm/month), this "horizontal precipitation" provides a continually moist microclimate, which we anticipate would not restrict food availability for offspring and would maintain an appropriately moist habitat for successful development (Townsend et al. 2012). However, further observations of our focal species throughout the year are required to clarify the extent of any breeding period beyond the few months where we recorded our findings. We also recommend standardization of data recording and marking of individuals to clarify our remaining uncertainties.

ACKNOWLEDGMENTS

We thank Operation Wallacea for providing support and logistics for our field observations in Honduras, as part of general surveys of arachnid diversity. We thank Andrés Garcia, Dan Proud, Victor Townsend, Adriano Kury, Abel Pérez González and especially Ricardo Pinto-da-Rocha for support of various aspects relating to improving knowledge of Honduran cosmetids. We also greatly thank

Glauco Machado and one other anonymous reviewer for helpful suggestions, and further thank Glauco Machado for providing literature and other general guidance. We also thank Expediciones y Servicios Ambientales de Cusuco for logistical support and Instituto de Conservacion Forestal for administering annual permits for research work in Cusuco.

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Manuscript received 7 May 2019, revised 16 August 2020.