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NEW RECORDS OF PREDATORY SLUGS FROM SINGAPORE WITH NOTES ON THEIR FEEDING BEHAVIOUR

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INTRODUCTION

The terrestrial molluscs consist of an estimated 30,000–35,000 species (Baker, 1984; Abbott, 1989; Tsai, 2004) with about 500 species of slugs and more than 1,000 species of semi-slugs (Tsai, 2004), and of these, only a few genera in a couple of families are known to be predatory. Better known are the European *Testacella* species capable of following earthworms into their burrows (Abbott, 1989), and are also known to prey on slugs and even centipedes (Barnes & Weil, 1944). Several species of slugs have been recorded from Singapore (e.g., Lim, 1969; Ho, 1995), but none are known to be predatory even though a number of species are known from adjacent areas such as Peninsular Malaysia, Sumatra and Borneo (e.g., Collinge, 1902; Laidlaw, 1940; Schilthuizen & Liew, 2008). Here, we report the first known occurrence of predatory slugs from the genus *Atopos* (Soleolifera: Rathouisiidae) in Singapore. We also discuss the taxonomy and feeding habits of *Atopos* based on the literature and direct observations.

MATERIAL AND METHODS

A slug, discovered on the toilet wall of the National Parks Board office at Bukit Kallang in Jun.2008, was kept for observation and later preserved in 75% ethanol (T. M. Leong, pers. comm.), and deposited in the Zoological Reference Collection (ZRC), Raffles Museum of Biodiversity Research of the National University of Singapore. The specimen (ZRC.MOL.2844), measured 60 mm long and 9.9 mm at the widest in the preserved state. In Sep.2008, a second similar, albeit much smaller, slug was discovered attached to the underside of a dead leaf amongst leaf litter consisting mainly of the leaves of *Macaranga gigantea* and *Campnosperma* species at the forest edge along Upper Thomson Road. This specimen measured 14 mm in total body length when contracted at rest and is currently being kept in captivity for further observations. Both slugs have not been positively identified to the species level and will be referred to as *Atopos* species 1 (Figs. 1–2), and *Atopos* species 2 (Figs. 3–4, 6), respectively, in this article.

For our observational study, *Atopos* species 2 was kept in a clear plastic container with a piece of moistened, dead *Macaranga gigantea* leaf for shelter, and different prey species were added intermittently with the date of introduction and results noted. Prey species included *Coneuplecta olivacea*, *Diplommatina nevilli*, *Liardetia* species, *Microcystina* species, *Microparmarion* , *Subulina octona*, and unidentified juveniles of possibly ariophantid species. The container was checked thrice daily whenever “fresh” prey was introduced, and the results noted. We include some observations on the feeding habits of *Atopos* species 2.

RESULTS AND DISCUSSION

***Taxonomy.* –** The discovery of *Atopos* species 1 (Figs. 1 & 2), was first communicated via T. M. Leong, but initial attempts to identify the slug with locally-relevant literature (e.g., Lim, 1969; Ho, 1995), and treatments of the region (e.g., van Benthem Jutting, 1950; Vermeulen & Whitten, 1998) were unsuccessful. The discovery of *Atopos* species 2 (Figs. 3–4, 5) months later and a chance observation of it feeding on a snail was a vital clue in determining the identity of these slugs. Both slugs were thereafter determined to be species of the genus *Atopos* of the family Rathouisiidae based on Collinge (1902), Schilthuizen et al.(2006), and Schilthuizen & Liew (2008), aided much by the knowledge that the animals are carnivorous in nature. There are at least five distinct species of the *Atopos* in Peninsular Malaysia (Collinge, 1902; Laidlaw, 1940; Maassen, 2001), but the actual number could be much higher. However, the rathouisiids probably consists of a large number of species and possibly genera (Collinge, 1902), and as a taxonomic revision on the family is lacking, the true extent of species diversity is presently difficult to determine (Barker, 2001; Schilthuizen & Liew, 2008). Hence, we consider it prudent in not attempting even tentative identifications to the species level.

Fig. 1. *Atopos* species 1, found at Bukit Kallang by S. L. Tay on 24 Jun.2008. Specimen length (fully extended) = 7.0 cm. (Photograph by: Leong Tzi Ming).

Fig. 2. *Atopos* species 1, at rest in a curled position. Specimen length (fully extended) = 7.0 cm. (Photograph by: Leong Tzi Ming).

Fig. 3. *Atopos* species 2, found amongst leaf litter at Upper Thomson Road on 7 Sep.2008. Specimen length = 1.5 cm. (Photograph by: Tan Heok Hui).

Fig. 4. *Atopos* species 2, at rest. Specimen length = 1.4 cm.

Fig. 5. *Laevicaulis* species, a veronicellid slug. Specimen length = 4.0 cm.

Diagnosis. **–** Slugs without internal shells. Body slender, and high, nearly cylindrical, somewhat triangular in cross section, posterior end pointed. Notum granulated, non-slimy, with pronounced dorsal median keel (perinotum) along the entire body length, completely enclosing the dorsal part. Sole of foot broad, and large, separated by a pedal groove from the notum. Second pair of tentacles partially fused to the snout, well developed and bilobed, and serves as modified labial palps.

Remarks – *Laevicaulis* species (Fig. 5), a veronicellid slug common in Singapore, may be mistaken for an *Atopos* species by the casual observer, but they can be distinguished by the body of *Laevicaulis* species being more dorso-ventrally flattened, the relatively ovate general outline, and the absence of the granulated, rather dry surface of the notum found in *Atopus* species.

Ecology and biology – An account of the habits of *Atopos leonina* (Heude, 1884) from China was given by Rathouis (in Laidlaw, 1940), but available information on rathouisiids remains scarce and little is certain apart from the fact that *Atopos* species are carnivorous. Laidlaw (1940) described the anatomy of *Atopos* in detail and has shown that the animal lacks a jaw and has instead, a mouth with a protrusible proboscis and eversible radula sac. The radula is composed of simple, short, and pointed teeth that are identical to those of the carnivorous *Streptaxis* and *Testacella* species (Stoliczka, 1873), and according to Collinge (1902), and Laidlaw (1940), the teeth, proboscis, and lack of jaw show that *Atopos* species are adapted to a carnivorous diet. Despite this common knowledge, examination of the contents of the oesophagus, and mid-gut gland revealed that the food consists of fungi as well as flesh (Collinge, 1902). However, we do not know of any account of *Atopos* species apparently feeding on fungi or vegetable matter, and based on our limited understanding of these creatures, it seems certain that their diet consists predominantly of snails. On another note, Scott (2006) mentioned that *Atopos australis*, and their relatives prey on earthworms, and beetle larvae, but this observation does not appear to have been made by other authors, and is treated as unconfirmed here. *Atopos* species are also known to be nocturnal in habit, spending the day hiding in crevices, and emerging to feed on snails at night (Schilthuizen et al., 2006; Schilthuizen & Liew, 2008).

Observations. – Feeding has been observed in *Atopos* species 2 during the day on many occasions, but as captive conditions are hardly natural, we cannot establish if this is normal or if this slug is being opportunistic at the availability of prey. Prey is always held with the anterior part of the foot arched in a straddling position, with the head bowed, and with the proboscis inserted into the aperture of the victim's shell (Fig. 6). Despite frequent checks on the individual of *Atopos* species 2, we were unable to elicit much response from the animal in regard to prey detection or capture. It did not seem active, and was usually motionless, and contracted, either with its body straight or with its posterior half curled in the shape of the letter "J" (similar to Fig. 2), at its choice resting place throughout the day. Although predatory

Fig. 6. *Atopos* species 2, feeding upon *Liardetia* species. Shell diameter = 2.5 mm.

snails have been known to be able to distinguish and follow the mucus trails laid by potential prey (e.g., Shaheen et al., 2005), *Atopos* species 2 was not once noticed to be actively prowling its enclosure or seemingly on the trail of prey.

In an experiment, 12 micro-snails (2–4 mm in maximum shell length or diameter)—*Coneuplecta olivacea*, *Diplommatina nevilli*, *Liardetia* species, *Microcystina* species, and an unidentified juvenile of possibly ariophantid species—were introduced into the enclosure, and were all found to be dead within four days. Only the single larger specimen (unidentified species, 4 mm in shell diameter) had considerable amount of flesh in the upper whorls of its shell while the others were empty except for the some bits in the topmost whorls of the spire. Although we cannot ascertain if any of the snails died of other causes, the remnant empty shells suggest that all were predated upon. On another occasion, two slug species (*Microparmarion* species), one similarly sized as *Atopos* species 2, were also readily consumed. Hence, our observations suggest that the animal is voracious and is not particularly discriminating towards most prey items.

On occasions when feeding was observed, it was noticed that *Atopos* species 2 never did move far from its original resting place, and we have yet to witness the method of prey capture. The actual sequence remains mysterious to us and it is uncertain if *Atopos* species 2 prefers to wait in ambush of prey hapless enough to approach it in preference over actively following the slime trails of its potential victims, or if congenerics in the wild behave similarly.

Schilthuizen et al. (2006) and Schilthuizen & Liew (2008) mentioned that the *Atopos* species of their study feed on juvenile prey (*Opisthostoma* species) via the aperture while the shells of larger sized adults were bored using the radula. While studying the microgeographic evolution of shell shape in the *Opisthostoma concinnum* complex, Schilthuizen et al. (2006) discovered evidence of the correlation between the predatory behaviour of their *Atopos* species and aspects of the shell shape of its prey. The evolutionary implications are intriguing as they noted that the predatory behaviour of *Atopos* species varies geographically, and suggested that the shell-boring behaviour of *Atopos* has a more important role on the divergence in shell morphology of their prey taxon than previously thought. However, the ecology of the local *Atopos* species is virtually unknown, and therefore this aspect of predatory behaviour, and whether they are exerting selection pressure on any local snail species deserves closer scrutiny.

Shells of victims of *Atopos* species 2 were examined, but none were found to have holes bored in them. This concurs with our observation that prey was always absorbed through the aperture, but as prey items offered thus far were a quarter or less of its size, it remains uncertain if *Atopos* species 2 is capable of shell-boring. In an attempt to clarify, an individual *Subulina octona* (shell length 12 mm) was introduced to determine if shells of larger prey are bored.

However, the subulinid was not attacked despite being left for a week without choice of other prey items. Although *Atopos* species 2 was not starved before the subulinid was added, satiation of its appetite was unlikely, and two *Liardetia* species added on the eighth day were rapidly captured and consumed within an hour suggesting that the slug was very hungry. Although this exception raises a few questions such as whether the prey item was too large or if *Atopos* species 2 recognises subulinids as part of its regular diet, we deem it premature to speculate. Bearing in mind that a slightly larger sized *Microparmarion* species was devoured in an earlier experiment, the relative size of prey versus predator also seems too subjective for us to judge and it remains uncertain if *Atopos* species 2 has the same habit of shell-boring on larger prey.

Origin and Distribution. – Prior to the discovery of *Atopos* species, *Gulella bicolor* (Hutton, 1834) was the only predatory terrestrial mollusc known to occur in Singapore. Although having a circumtropical distribution (van Benthem Jutting, 1950), *Gulella bicolor* is an exotic species, probably originating from India (Vermeulen & Whitten, 1998), or more likely, the African continent or one of its outlying islands (van Benthem Jutting, 1961), and there were no other reports of predatory terrestrial snails or slugs native to Singapore. Rathouisiids are distributed from southeastern China, Taiwan, Myanmar, Thailand, Peninsular Malaysia, Borneo, parts of Indonesia, New Guinea, the Bismarcks to northern Queensland of Australia (e.g., Collinge, 1902; Laidlaw, 1940; Barker, 2001; Tsai, 2004; Dharma, 2005; Schilthuizen et al., 2006), and because the geographical position of Singapore lies well within the natural range of these animals, plus the fact that both individuals were found in relatively old and undisturbed forest, the *Atopos* species reported here are believed to be native. Even though the family Rathouisiidae has a rather wide distribution, they are evidently sparsely distributed (Collinge, 1902; Laidlaw, 1940), and probably the reason why the local rathouisiids have eluded earlier surveys. As apparent from the literature, a taxonomic revision, and ecological as well as behavioural information is still wanting, and further studies will be much desired to better enhance our knowledge of these slugs. The discovery of *Atopos* occurring locally also highlights the need for more work to elucidate the true extent of the local terrestrial malacofauna diversity.

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