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The soft-coral associated pistol shrimp *Synalpheus neomeris* (De Man) (Decapoda: Alpheidae) defends its host against nudibranchs in Okinawa, Japan

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Abstract. The present study provides the first detailed observations of mutualism between the pistol shrimp *Synalpheus neomeris* (De Man, 1897), and its host, the soft coral *Dendronephthya hyalina* Kükenthal, 1905 in Okinawa, Japan. The host-defensive behaviour of *S. neomeris* against two soft coral predators, the nudibranchs *Tritonia* sp. and *Dermatobraunchus caeruleomaculatus* Gosliner & Fahey, 2011, is documented for the first time, based on aquarium and field observations.

Key words. mutualism, pistol shrimp, *Synalpheus*, soft coral, *Dendronephthya*, nudibranch

INTRODUCTION

Mutualistic relationships are common in the ocean, especially among animals living on coral reefs. Decapod crustaceans are particularly well-known for their obligate and often biologically complex mutualism with various sessile invertebrates. Associations between decapods and hermatypic corals, as well as between decapods such as *Thor amboinensis* and sea anemones (e.g., *Stichodactyla haddoni*, *Lebrunia danae*, and *Cryptodendrum adhaesivum*), are particularly well documented. For instance, coral crabs (*Trapezia* sp.; Trapeziidae) and pistol shrimp (*Alpheus lottini* Guérin; Alpheidae), which often interact with each other (Vannini, 1985), are known to defend their pocilloporid coral hosts against the corallivorous crown-of thorns starfish *Acanthaster planci* (Glynn, 1987; Pratchett et al., 2000). Mucus and organic matter trapped inside the coral represent an important food source for coral crabs and shrimps (Wild et al., 2004), while faecal products of anemone-associated shrimps are a valuable additional source of nitrogen for their hosts (Spotte, 1996). In contrast, associations between decapods and octocoralline soft corals remain relatively poorly known.

In the present study we report on the behaviour of a pistol shrimp *Synalpheus neomeris*, in defending its soft coral host against two soft coral-eating nudibranchs, via both laboratory (aquarium) and field observations.

MATERIAL AND METHODS

Aquarium observations. A pink-coloured colony of the octocoralline coral *Dendronephthya hyalina* Kükenthal, 1905 (Alcyonacea: Nephtheidae) and an undetermined white *Tritonia* sp. (Nudibranchia: Tritoniidae), were found at the sandy bottom at a depth of 15 m in Oura Bay, Okinawa Island, Okinawa, Japan (Fig. 1) on 20 May 2011. *Tritonia* species are known as octocoral predators (Behrens, 2005). Thus both *D. hyalina* and the *Tritonia* sp. were kept in the same tank to determine if the nudibranch can feed on the soft coral. However, the *Tritonia* specimen did not feed on the polyps of *D. hyalina*, and in fact never touched the octocoral. On 24 May 2011, we discovered a pair of pistol shrimp *Synalpheus neomeris* (De Man, 1897) (Decapoda: Alpheidae) on *D. hyalina*. In order to determine if the presence of pistol shrimps affected prey-predator interaction between the nudibranch and soft coral, we prepared three tanks: tank A for *D. hyalina* containing a pair of *S. neomeris*, tank B for *Tritonia* sp., and tank C to house the pair of shrimps.

Both shrimps were removed from *D. hyalina* and kept in tank C. Then the nudibranch *Tritonia* sp. was placed directly on *D. hyalina* in tank A and its behaviour was recorded by video for one minute. Subsequently, *Tritonia* sp. was separated from *D. hyalina* and after another short interval (about one minute), *Tritonia* sp. was placed near *D. hyalina* and its behaviour was recorded. These observations were repeated 10 times over a period of 12 hours after which *Tritonia* sp. was returned to tank B.

After 24–48 hours, the pistol shrimp pair in tank C was returned to tank A and placed on *D. hyalina*. Then *Tritonia* sp. from tank B was placed near *D. hyalina* in tank A, and

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Table 1. Feeding behaviour of *Tritonia* sp. in the presence and absence of the pistol shrimp *Synalpheus neomeris* on a colony of *Dendronephthya hyalina* (aquarium observations)

S. neomeris	Date	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Present	20 May 2011	–	–	–	NO	NO	NO	NO	NO	NO	NO
	26 May 2011	–	–	–	–	–	–	NF	NF	NF	NF
	31 May 2011	–	–	–	–	–	–	–	–	NF	NF
	4 June 2011	–	–	–	–	–	–	NF	NF	NF	NF
Absent	24 May 2011	+	+	+	NO	NO	NO	NO	NO	NO	NO
	27 May 2011	+	+	+	+	+	+	+	+	+	+
	29 May 2011	+	+	+	+	+	+	+	+	+	+
	1 June 2011	+	+	+	+	+	+	+	+	NO	NO

When a pair of shrimp was present, *Tritonia* sp. left the *D. hyalina* colony within one minute. After 7th to 9th instances of each observation, *Tritonia* sp. did not approach the soft coral.

+: *Tritonia* sp. continued feeding on the polyps of *D. hyalina* for over one minute.

–: *Tritonia* sp. withdrew from *D. hyalina* within 1 minute.

NF: No feeding behavior observed (*Tritonia* sp. stayed away from the soft coral).

NO: No observation.

the behaviour of *Tritonia* sp. was recorded for one minute. After which it was separated from *D. hyalina*. After a further interval of one minute, *Tritonia* sp. was placed near *D. hyalina* again and its behaviour was recorded. These observations were also repeated 10 times over a period of 12 hours.

The observations without manipulation of pistol shrimps were carried out on 20, 26, 31 May and 4 June 2011, while the pistol shrimp removal observations were carried out on 24, 27, 29 May and 1 June 2011 (Table 1). We conducted these aquarium observations eight times in total. Although the conditions of the soft coral did not change from beginning to end of the observation, the pistol shrimps were not doing well. Therefore we terminated the observations after eight 1-minute observations. After the final observation, *D. hyalina*, *S. neomeris*, and *Tritonia* sp. specimens were preserved in 70% ethanol.

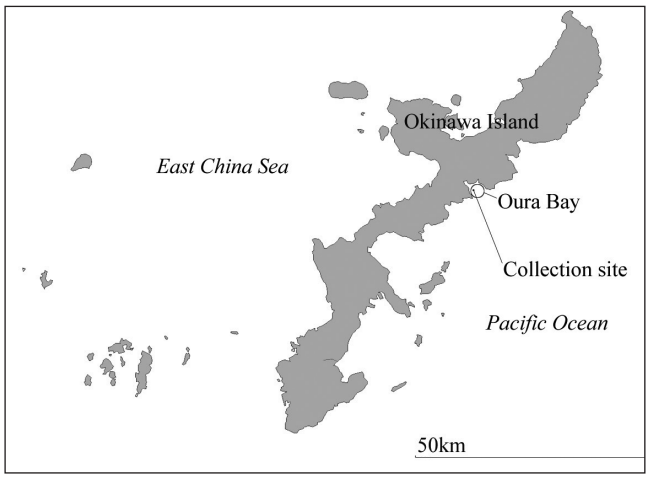

Fig. 1. Collection sites of soft coral, pistol shrimps and nudibranchs: Oura Bay, Okinawa Island, Japan (26°32′N, 128°03′E). The octocoral *Dendronephthya hyalina*, the pistol shrimp *Synalpheus neomeris*, and the nudibranchs, *Tritonia* sp. and *Dermatobranchus caeruleomaculatus*, were collected in the inner part of the bay at a depth range of 15 to 30 m.

Field observations. An individual of *Dermatobranchus caeruleomaculatus* Gosliner & Fahey, 2011 (Nudibranchia: Arminidae) was observed on a colony of *Dendronephthya hyalina* at a depth of 30 m in Oura Bay on 16 November 2011, at the same location where *Tritonia* sp. had previously been collected. *Dermatobranchus* species are also known as octocoral predators (Gosliner & Fahey, 2011). Thus we transferred the colony of *D. hyalina* and *D. caeruleomaculatus* to a shallower area to avoid decompression sickness and observed the behaviour of the nudibranch for 30 minutes. After observation, the soft coral and the nudibranch were preserved in 70% ethanol.

Several colonies of *D. hyalina* and a second individual of *D. caeruleomaculatus* were found at the same location on 7 April 2012. We placed *D. caeruleomaculatus* near the colony of *D. hyalina* and observed its behaviour. When *D. caeruleomaculatus* did not show any feeding behaviour, we placed the nudibranch again near *D. hyalina* and made observations for a further 15 minutes. The nudibranch and several octocoral colonies were subsequently preserved in 70% ethanol. After preservation, we checked whether or not any mutualistic animals (e.g., *Synalpheus neomeris*) were present on the soft coral colonies, and removed them.

RESULTS

Aquarium observations. The results of the aquarium observations are summarised in Table 1. Regardless of the presence or absence of *Synalpheus neomeris* on *Dendronephthya hyalina*, when *Tritonia* sp. was placed into tank A, it immediately moved onto the soft coral colony and began to feed on its polyps. On *D. hyalina* without *S. neomeris*, *Tritonia* sp. continued to feed on soft coral polyps for over one minute (Fig. 2A). However, if a pair of shrimp was present, *Tritonia* sp. left the *D. hyalina* colony within one minute (Fig. 2B; Video 1). After 7th to 9th instance of each observation, *Tritonia* sp. never came again close (i.e., within 5 cm) to the soft coral.

Field observations. *Dermatobranchus caeruleomaculatus* never left *Dendronephthya hyalina* and continued feeding on the polyps of the soft coral for 30 minutes (Fig. 3A). After preservation of *D. hyalina*, we found no mutualistic animals associated with this colony.

Dermatobranchus caeruleomaculatus was attacked by *Synalpheus neomeris* during the second and third of 12 experiments (Fig. 3B; Video 2). After the fourth instance, *D. caeruleomaculatus* either burrowed into the sand near *D. hyalina*, without feeding on its polyps, or kept a safe distance from *D. hyalina* (Video 3). After preservation of all six colonies of *D. hyalina*, one pair of *S. neomeris* was found on the colony observed in the field (Fig. 3C). The results of the field observations are summarised in Table 2.

DISCUSSION

The present study suggests that the pistol shrimp *Synalpheus neomeris*, living on soft corals of the genus *Dendronephthya* (Banner & Banner, 1975), can protect its host against two different nudibranchs feeding on soft coral polyps. On 16 November 2011, *Dendronephthya* colonies without shrimps were exposed to grazing by nudibranchs and resulted in the partial loss of polyps (Fig. 3A). On the contrary, if shrimps were present on the soft coral, the nudibranchs are attacked with the shrimps' powerful snapping claws, resulting in their immediate withdrawal from the soft coral colony and temporary loss of interest in feeding on the same colony again (Fig. 3B). This protective behaviour appears similar to previously known relationships between coral crabs and pistol shrimps living on stony corals.

However, we also found another five soft coral colonies that did not have symbiotic shrimp (Fig. 3C). Not all soft

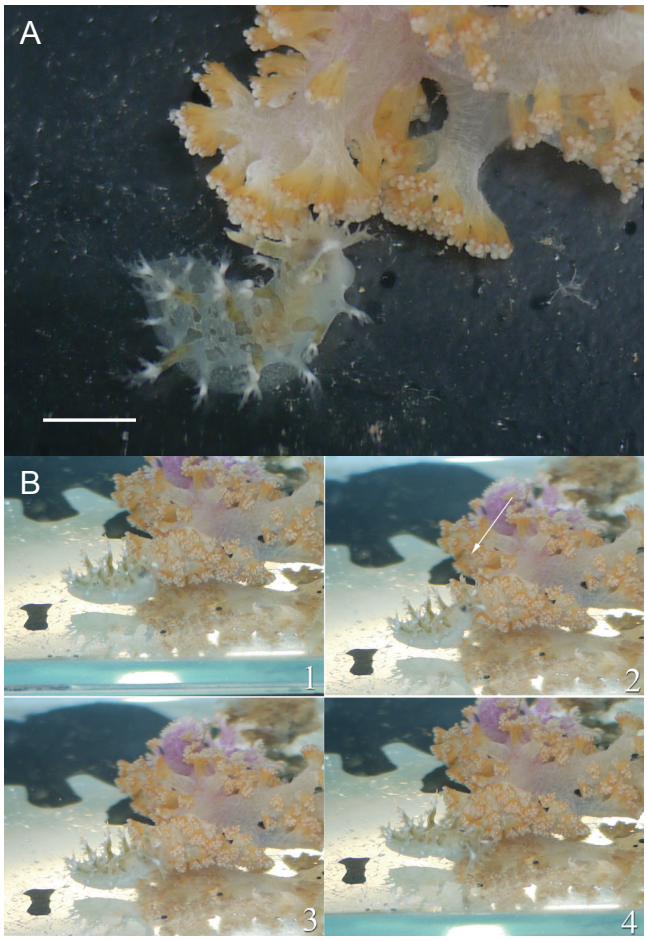

Fig. 2. Feeding behaviour of *Tritonia* sp. on polyps of the soft coral *Dendronephthya hyalina*, in the aquarium. A, *Tritonia* sp. continued feeding on polyps of *D. hyalina* in the absence of *Synalpheus neomeris*; B, *Tritonia* sp. is being attacked by *S. neomeris* (1) and leaves the *D. hyalin*a colony soon after (2–4). Scale bar = 10 mm

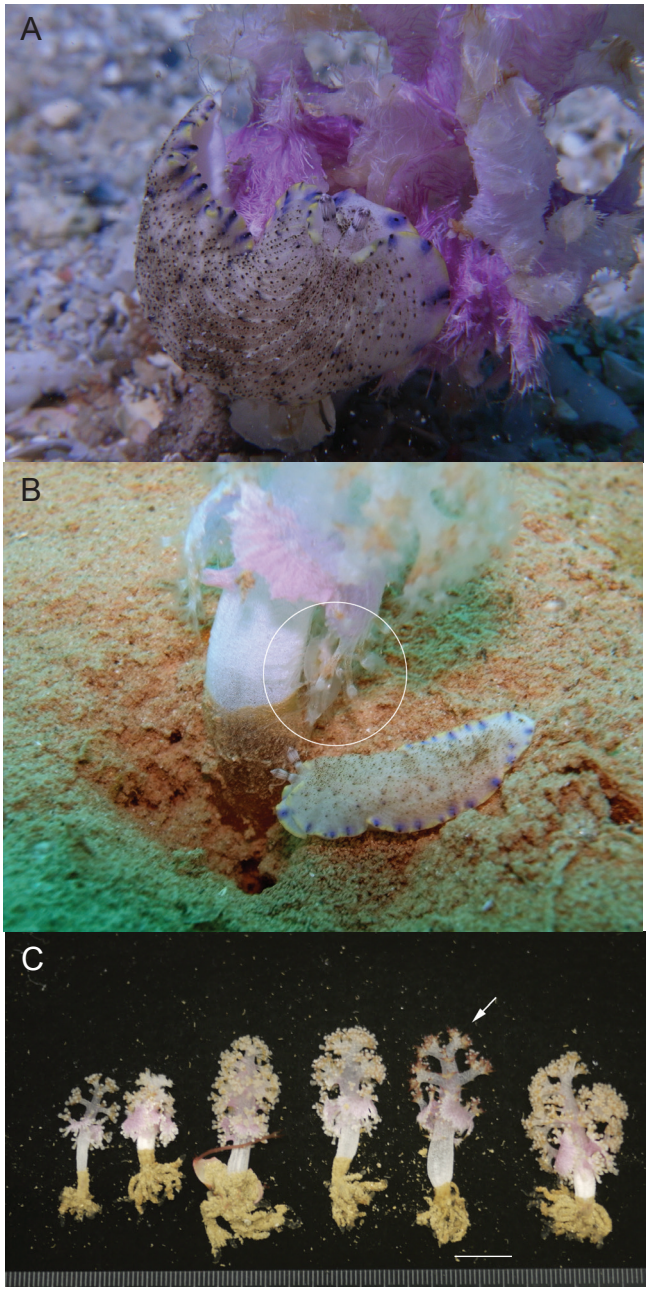

Fig. 3. Behaviour of *Dermatobranchus caeruleomaculatus* observed in the field. A, On 16 November 2011, *D. caeruleomaculatus* continued feeding on the polyps of *D. hyalina* in the absence of pistol shrimps; B, On 7 April 2012, *Synalpheus neomeris* (encircled) attacked *D. caeruleomaculatus*, which immediately stopped feeding on *D. hyalina* polyps; C, Six colonies of *Dendronephthya hyalina* collected on 7 April 2012; arrow pointing to observed colony. Scale bar = 10 mm.

Table 2. Feeding behaviour of the nudibranch *Dermatbrunchus caeruleomaculatus* on a colony of soft coral *Dendronephthya hyalina* with and without the pistol shrimp *Synalpheus neomeris* (field conditions).

S. neomeris	Date	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Absent	16 November 2011	+	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Present	7 April 2012	+	–	–	NF	NF	NF	NF	NF	NF	NF	NF	NF

When *Synalpheus neomeris* was present, *Dermatobrunchus caeruleomaculatus* was attacked on two occasions by *Synalpheus neomeris*. After the fourth instance, *D. caeruleomaculatus* either burrowed into the sand near *D. hyalina* without feeding on its polyps, or kept a distance from *D. hyalina.*
+: *D. caeruleomaculatus* continued feeding on the polyps of *D. hyalina*.
–: *D. caeruleomaculatus* was attacked by *S. neomeris* and moved away from *D. hyalina.*
NO: No observation. On 16 November 2011, we observed feeding behaviour of *D. caeruleomaculatus* only once.
NF: No Feeding behaviour (*D. caeruleomaculatus* stayed away from the soft coral).

coral are protected by pistol shrimps. Additionally, it is still unknown whether only one pair of pistol shrimp can protect a host octocoral completely, as *Synalpheus neomeris* is much smaller than the host and predator.

The numbers of colonies of *D. hyalina* in Oura Bay vary greatly with season or year (M. Obuchi, pers. comm.), but the reasons for this frequency variation remain unknown. *Synalpheus neomeris* appears to be relatively common in the Ryukyu Archipelago (Hayashi, 1996; Nomura & Asakura, 1998), its geographic range continuing further northwards as far as Hachijo-jima off Izu islands (Kato & Okuno, 2001) and southern Korea (Koo & Kim, 2003). On the other hand, the two nudibranchs, *Tritonia* sp. and *Dermatobranchus caeruleomaculatus*, are extremely rare in Okinawa, and this report represents in fact the first records of both species in Japanese waters. Therefore, further observations with *D. hyalina* and *S. neomeris* should be carried out using more common nudibranchs in the area, which are known to feed on soft coral polyps.

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ADDITIONAL MATERIAL

Video 1. *Tritonia* sp. bent backwards and stopped feeding on the polyps of *Dendronephthya hyalina,* after being attacked by *Synalpheus neomeris*. [http://lkcnhm.nus.edu.sg/nus/images/data/raffles_bulletin_of_zoology/zoology_volume_62/video/Video1.mp4]

Video 2. *Dermatobranchus caeruleomaculatus* being attacked by *Synalpheus neomeris* on a colony of *Dendronephthya hyalina*. [http://lkcnhm.nus.edu.sg/nus/images/data/raffles_bulletin_of_zoology/zoology_volume_62/video/Video2.mp4]

Video 3. *Dermatobranchus caeruleomaculatus* stopped feeding on polyps of *Dendronephthya hyalina* after subjected to snapping by *Synalpheus neomeris*. [http://lkcnhm.nus.edu.sg/nus/images/data/raffles_bulletin_of_zoology/zoology_volume_62/video/Video3.mp4]