Surface structures of *Pugettia quadridens* and *P. intermedia* (Majidae, Decapoda)

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*Abstract.*—Surface structures of *Pugettia quadridens* and *P. intermedia* were examined by scanning electron microscopy. Both crabs attach pieces of sea algae to six hooked setae sites on the carapace. In addition to the hooked setae, the crabs develop plate setae, which cover the entire surface except the tips of the chelae. The plate setae of *P. quadridens* were flat and played no role in decoration, whereas those of *P. intermedia* were variously modified in shape. For example, the setae on the abdominal carapace surface were flat, whereas those on the walking legs and the dorsal carapace were conical and in some cases considerably elongated. These modified plate setae served as attachment sites for algae and other small materials on the carapace and walking legs, blurring the outline of *P. intermedia*.

Introduction

*Pugettia quadridens* (De Haan, 1837) is a spider crab that occurs in the lower intertidal areas or shallow seas of Japan, Korea, and the northern coast of China (Miyake, 1983). The crab decorates itself by attaching pieces of algae to hooked setae on the dorsal surface of its carapace (Sato & Wada, 2000). *Pugettia intermedia* was described by Sakai (1938) as a new subspecies of *P. quadridens*. However, Yamaguchi *et al.* (1987) confirmed that *P. intermedia* was a cohabitant with *P. quadridens* in Amakusa, Japan, and concluded that *P. intermedia* should not be treated as a subspecies of *P. quadridens* but rather as a separate species, in accordance with the view of Griffin & Tranter (1986). A recent compendium assembled by Ng *et al.* (2008) also treats these crabs as separate species. Unlike *P. quadridens*, *P. intermedia* attaches small pieces of algae, sponges, or other materials to the dorsal carapace surface and walking legs, in addition to the small areas where hooked setae arise (Yamaguchi & Henmi, unpublished). We investigated the different attachment sites of the two species by examining the surface structures using scanning electron microscopy. The setae herein called “plate setae” are short bent and flattened, forming an even mat over the surface, and seem to be of a kind not previously recognized (see Jacques, 1989; Szebeni & Hartnoll, 2005; Watling, 1989).

Materials and Methods

Specimens were collected on Tsuji Island located at the entrance of Ariake Sea in the 1980s and 1990s and deposited at the Aitsu Marine Station, Kumamoto University, Kumamoto, Japan. We used a stereomicroscope to observe the distribution of hooked setae on a total of 56 *Pugettia quadridens* (21 males and 35 females) and ten *Pugettia intermedia* (three males and seven females). The carapace and walking leg surface structures were observed on three *P. quadridens* (two males and one female) and two *P. intermedia* (one male and one female), using a JEOL 5400-LV scanning electron microscope. The crabs were dissected and separated into 12 parts (dorsal carapace, abdomen, two chelipeds and eight walking legs). The parts were dehydrated in a grad-
ed ethanol-t-butanol series. After freeze-drying, each part was attached to a metal stub and coated with gold-palladium. The accelerating voltage was 5–15 kV.

Results

Distribution of hooked setae

In addition to the divided rostrum, hooked setae occurred on Pugettia quadridens and Pugettia intermedia in two small areas on both sides of the dorsal carapace: behind the eyes and on the lateral fringe (Fig. 1). The setae formed double rows, with hooks in opposite directions facing each other. Pugettia quadridens showed a sexual difference in setae distribution. Hooked setae on the 35 female specimens occurred on six sites on the carapace, whereas some males (n=12) had hooked setae only on the rostrum. Most of these males were large, ranging from 15.05 mm to 18.8 mm in carapace width (CW). The majority of the other nine crabs were <15 mm CW, although four crabs measured 16.25–17.3 mm CW. All P. intermedia female specimens had hooked setae on the six areas. We found no sexual difference in hooked setae distribution in P. intermedia. All males in our small sample (n=3), including a very large one (20.1 mm CW), possessed hooked setae in the three areas on both sides of the carapace. The setae behind the eyes and lateral fringes occupied longer areas than on P. quadridens. In addition to the six areas shown in Figure 1, P. intermedia had sporadically occurring solitary hooked setae on the dorsal carapace, especially the posterior half, in numbers from several tens to one hundred.

Distribution of plate setae

The surface of the carapace and walking legs of P. quadridens looked smooth to the naked eye, with no specific structures. However, the scanning electron microscope showed the entire surface, except for the tips of the chelae, to be covered with flat, plate-like setae, which formed a tight pave-
Fig. 2. Comparison of the rostrums and dorsal carapaces of Pugettia quadridens (De Haan) and P. intermedia Sakai. A: Anterior portion of a 17.55-mm CW P. quadridens male (dorsal view). The rostrum is covered with rows of hooked setae. Two pieces of algae are attached to the rostrum, with about half of the rows of hooked setae under the algal pieces. B: Posterior portion of the dorsal carapace of the crab in A. Plate setae form a tight surface pavement. C: Enlarged view of the plate setae. D: Anterior portion of a 14.55-mm CW P. intermedia male (dorsal view). Pieces of algae and fragments of unknown organisms are attached, and only a portion of the rows of hooked setae is visible. E: Posterior portion of the dorsal carapace of the crab in D. F: Posterior portion of the dorsal carapace of a 13.5-mm CW P. intermedia female. This crab had attached a few materials, and its carapace is covered with plate setae of various shapes. A bundle of elongated setae occurs in the upper central portion of the photograph.
Fig. 3. Comparison of setae on the right second walking legs and abdomens of Pugettia quadridens and P. intermedia. A: The right second walking leg of a 13.95-mm CW P. quadridens female. Plate setae cover the entire surface. B: Enlarged view of the manus of the same walking leg. Plate setae form a tight pavement. About 20 setae are exceptionally elongated and protruded from the surface. C: Setae on the surface of the abdomen of a 13.95-mm CW P. quadridens female. Flat plate setae cover the entire surface of the abdomen. D: Setae on the abdomen of a 13.5-mm CW P. intermedia female are covered with numerous small, short setulae. E: Right second walking leg of a 14.55-mm P. intermedia CW male. Variously shaped plate setae cover the entire surface. F: Enlarged view of the manus of the same walking leg, showing the same area as in B. The highly modified plate setae are pointed and shaped like a cone or cucumber. Numerous small, short setula cover their surfaces. G: Enlarged view of the merus of the same walking leg as in F, showing variously modified plate setae.
ment on the surface (Figs. 2-B, -C, 3-A–C). Their shape and distribution condition accorded with the plate setae reported by Hamilton (1983) on the kelp crab *Pugettia producta*. Although the plate setae of *P. quadridens* were flat and formed tight pavements, some exceptions occurring on the manus of the walking legs were elongated (Fig. 3-B). The entire surface of *P. intermedia* was also covered with plate setae (Figs. 2-F, 3-D–G). However, their shapes differed greatly, depending on their placement. Those covering the abdominal surface were as flat as those on *P. quadridens* and formed a pavement, but were larger in size and were covered with numerous small, short setulae (Fig. 3-D). Most of the setae occurring on the walking legs and dorsal carapace were pointed and conical (Fig. 3-E–G). Some were elongated into a cucumber-like shape and covered with small, short setulae (Figs. 2-F, 3-F, -G).

**Attachment of algae**

*Pugettia quadridens* attached pieces of algae only at hooked setae locations (Fig. 2-A). *Pugettia intermedia* also decorated themselves by attaching algae to the hooked setae (Fig. 2-D), including the few sporadic solitary hooked setae on the dorsal carapace. These never formed double rows. Although no hooked setae occurred on the walking legs, *P. intermedia* also attached very small pieces of algae to them. They also attached decorating materials, such as very small pieces of algae and sponge, to the dorsal surface of the carapace (Fig. 2-E), which was covered with variously shaped plate setae (Fig. 2-F).

**Discussion**

Wicksten (1980, 1993) found that spider crabs attach decorating materials to their bodies by holding them with a cheliped and attaching them to the hooked setae. However, she did not include the methods of attachment to other kinds of setae. She only mentioned as follows: “other kind of setae on the crab’s shell function as tactile sensory structure and probably provide information about the position of the decorating materials” (p. 116, Wicksten, 1980). Specific setae do function to detect suitable decorating materials, but Wicksten’s failure to discuss the involvement of other kinds of setae in decoration is puzzling. Yamaguchi *et al.* (2006) confirmed the presence of barbed setae in the majid crab *Hyastenus diacanthus*. These setae occur over the whole surface, except for small areas of hooked setae and on chelae tips, and contribute greatly to the attachment of living material to the surface. Although *H. diacanthus* attaches materials directly only to hooked setae, the barbed setae hold living materials that have grown beyond the hooked setae sites or have fallen on the barbed setae. The barbed setae allow *H. diacanthus* to decorate heavily, making them difficult for predators to detect.

In this study, we confirmed that the plate setae of *P. intermedia* also serve as attachment sites for algae and other materials. In addition, the presence of elongated plate setae on the walking legs blurs the outline of the legs. Well-decorated crabs look less like crabs (Wicksten, 1980) and are probably attacked less frequently by predators. The appearance of the elongated plate setae of *P. intermedia* was very different from that of the plate setae of *P. quadridens*. However, the two types of setae are homologous, as morphological changes were progressive, with numerous intermediate forms. The barbed setae of *H. diacanthus* have the same distribution as the plate setae of the two *Pugettia* species (Yamaguchi *et al.*, 2006) and are somewhat similar in appearance to the elongated plate setae of *P. intermedia*. The barbed setae, which are specialized for attaching materials, are not only pointed, but also covered with short spines. The plate setae of *P. intermedia* are covered with not spines but numerous setula. They are very small compared to the spines of *H. diacanthus*. *Pugettia intermedia* is small in size and does not attach living materials as extensive-
ly as *H. diacanthus* does.

The distribution of the plate setae of the two *Pugettia* species is also homologous to that of the barbed setae of *H. diacanthus*. Miyake (1983) listed nine *Pugettia* species and two subspecies among Japanese crabs. More extensive comparative morphological studies of the surface setae are needed to clarify their origin and roles in *Pugettia* and other majid crabs.

The question of why the entire surface of the body of *P. quadridentis* is covered by plate setae is a puzzle. These setae are different from those of *P. intermedia* and play no role in decoration. *Pugettia quadridentis* attaches pieces of algae at spots where hooked setae occur, but other areas are devoid of attached materials. The surface of the kelp crab *P. producta* is covered with flat plate setae very similar to those of *P. quadridentis* (see Figs. 2 & 5, Hamilton, 1983). Hamilton (1983) found that the plate setae of a very small crab (slightly less than 4 mm carapace length) were not yet flattened and that the plate setae enlarge in size with increasing crab size. Examining the inner structure of plate setae using electron microscopy, Hamilton *et al.* (1985) observed a shaft located inside the setae, surrounded by cuticular lamellae. The shaft included dendrites, and Hamilton *et al.* (1985) suggested that plate setae mediate chemosensitivity. However, the plate setae covered all, not just part, of the surface of the crab. Thus, plate setae are thought to play some other unknown important role in the life history of the crabs.

Sato & Wada (2000) studied the decoration materials of three species of decorator crabs, including *P. quadridentis*. The most preferred algal species of *P. quadridentis* was the brown alga *Sargassum hemiphyllum*, which served not only as decorative material but also as an important food item. The distribution of *P. quadridentis* was generally limited to the lower tidal levels, where *S. hemiphyllum* is abundant. To avoid predation, decorator crabs must match their background, and Sato & Wada (2000) reported that *P. quadridentis* resembled *S. hemiphyllum* in color. Thus, the greatest imperative for *P. quadridentis* is to make itself resemble the alga, and not attach various kinds of materials as does *P. intermedia*. The flat plate setae of *P. quadridentis* appear to be an adaptation to imitate the color and the appearance of *S. hemiphyllum*.

Our knowledge of the habits of *P. intermedia* is very limited. We examined only ten specimens, none of which had attachments of *S. hemiphyllum*. *Pugettia intermedia* appears to have taken a different course of adaptation: it does not imitate the color and appearance of a particular algal species, but has modified the shape of its plate setae into an apparatus for attaching materials. Thus, it avoids predators by appearing less like a crab and more like a bunch of seaweed.

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Literature Cited


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