**Abstract.**—Mating pairs of the potamid crab *Geothelphusa dehaani* were observed in a mountain stream of Fukuoka Prefecture, Japan, during the survey of over ca. 3-year period. Five mating pairs in copulatory posture were found in the afternoon in October and November. Mating pairs remained immobile for at least several minutes. No guarding behavior was observed after the release of copulation. They were all found on the bottom substrate under the water in pools. Females were either in the soft-shell or hard-shell condition, and even included one juvenile among the adults.

**Key words:** potamid crab, *Geothelphusa dehaani*, copulation, Japanese freshwater crab

**Introduction**

Potamidae is a true freshwater crab family, species of which complete their life cycle independently of the marine environment. They undergo direct development in which a small number of large, yolky eggs hatch directly into juvenile crabs. Recently, remarkable progress has been made in taxonomic and phylogenetic studies for this family (Shih *et al.*, 2009; Shih and Ng, 2011). However, information regarding their ecology is limited, except for *Potamon fluviatile* Herbst in southern Italy (Vanini *et al.*, 1983; Gherardi *et al.*, 1988a, b; Micheli *et al.*, 2006) and *Geothelphusa dehaani* (White) in Japan (Yamaguchi and Takamatsu, 1980; Shimoji and Wada 1995; Araki and Matsuura 1995; Okano *et al.*, 2000, 2003). *Geothelphusa dehaani* is a species endemic to Japan, which is widely distributed from Nakanoshima, which is one of the Tokara Islands in Kagoshima Prefecture, northward to the Shimokita Peninsula in Aomori Prefecture (Suzuki and Naruse, 2012). Biological studies of *G. dehaani* have a long history in Japan (Koba, 1935, 1936a, b), but there have been few studies describing its life history covering all stages, and especially focusing on their reproductive ecology. Thus recently we conducted a detailed investigation on its life history. During the survey in a mountain stream, the first author found mating pairs of this crab. Mating behavior of potamid crabs has been scarcely reported, and this is the first observation report of *G. dehaani*’s mating behavior in their natural habitat.

**Materials and Methods**

The study site is within a 2 km area of a mountain stream of the Shinken River, which is located in the upstream area of the Tatara River system in Hisayama Town, Fukuoka Prefecture, western part of Japan (33°39′16″N, 130°31′58″E). The first author conducted aquatic surveys on the population of *G. dehaani* in the riverbed and also terrestrial sampling in the forest floor during the daytime twice a month from April to September 2016 and once a month from October 2016 to September 2017. In the riverbeds of mountain streams, the researcher wandered along the stream for about an hour, and walked through the woods on the hillside along the stream for about an hour. In addition, daytime and night-
time surveys for crabs moving in the riverbed (underwater) in the same survey area were also conducted once a month from February 2018 to January 2019. During this survey, the researcher searched for mating crab pairs. For each pair, the date and type of environment (under or above water, and pool, riffle or run) and the maximum carapace width (CW) of the crabs were recorded. Females were further categorized into juveniles (immature stage) and adults (reproductive stage) based on their morphological differences. Juveniles showed nearly flattened bell-shaped abdomens and exposed edges of the thoracic sterna similar to males; while in female adults the abdomen was swollen, nearly oval and all parts of their thoracic sterna were covered. The shell condition of the crabs was categorized after Sather (1966); Stage A (post-molt just after molting, with very soft shell that is easily deformed under pressure), Stage B (later post-molt, hardening of shell proceeded, but shell is softer and thinner than Stage C), Stage C (intermolt) and Stage D (pre-molt, new shell is formed under the outer shell).

### Results

Mating pairs were found in the afternoon of 13 October (2 pairs) and 2 November 2017 (3 pairs) (Table 1). They were coupled in a copulatory posture; facing each other with their abdomens extended and the males’ pleopods attached to the females’ genital apertures. They maintained this posture and remained immobile at least for several minutes. One crab placed itself over the other, and the upper one was not constantly of the same sex; male over female

| Year   | Date          | Number | Time of day | Sex   | Stage | Shell condition | Carapace width (mm) | Environment       |
|--------|---------------|--------|-------------|-------|-------|-----------------|---------------------|-------------------|
| 2017   | October 13    | 1      | 16:07       | Male  | —     | Hard shell (Stage C) | —                   | Under water/pool   |
|        |               | Female | —           | Adult | Hard shell (Stage C) | —                   |                    |
|        |               | 2      | 17:24       | Male  | —     | Hard shell (Stage C) | 27.3                | Under water/pool   |
|        |               | Female | —           | Adult | Hard shell (Stage C) | 28.0                |                    |
| November 2 | 3      | 14:05  | Male  | —     | Hard shell (Stage C) | 25.3                | Under water/pool   |
|        |               | Female | Juvenile   | Adult | Hard shell (Stage C) | 18.1                |                    |
|        |               | 4      | 14:31       | Male  | —     | Hard shell (Stage C) | 23.7                | Under water/pool   |
|        |               | Female | —           | Adult | Soft shell (Stage B) | 25.7                |                    |
|        |               | 5      | 14:45       | Male  | —     | Hard shell (Stage C) | 24.8                | Under water/pool   |
|        |               | Female | —           | Adult | Hard shell (Stage C) | 24.8                |                    |

Fig. 1. Photographs of copulating pairs of *Geothelphusa dehaani*. a; pair No. 1, b; pair No. 4.
COPULATION OF POTAMID CRAB

(Fig. 1a) or female over male (Fig. 1b). Neither courtship behavior nor guarding behavior by males was observed, and no guarding behavior was observed after the copulation. They soon separated from each other. Carapace width and conditions were recorded (Table 1). One pair on 13 October unfortunately disappeared before their CW could be measured (pair No. 1). Females included both a juvenile (pair No. 3) and adults (pairs No. 1, 2, 4 and 5), and they were either in their hard-shell (Stage C, pairs No. 1, 2, 3 and 5) or soft-shell condition (Stage B, later post-molt, pair No. 4). Carapace width relationship between the sexes was not matched; there were three types, male ‘female (pair No. 2, 4), male ‘female (pair No. 5) and female ‘male (pair No. 3). They were all found exposed on the river’s substrate under the water in pools (Fig. 1).

Discussion

During the survey period, mating pairs were found only underwater, in the daytime and in mid- and late fall. It does not necessarily mean that the mating of G. dehaani is limited to this environmental condition only. However, there were neither observations nor records in other environments despite the frequent surveys, and certainly their mating can be observed with a higher probability in this timing and site.

In G. dehaani’s natural habitat, only copulation could be seen and guarding behavior was not observed. Among brachyuran crabs, pre- or post-copulatory guarding by males is accompanied with copulation in some species (Hartnoll, 1969; Christy, 1987; Diesel, 1991). Especially, pre-copulatory guarding by males is closely related with the receptability period in female crabs; which is limited to the short time when they are in their soft-shell condition just after molting (like some species of Portunidae and Cancridae). In contrast, post-copulatory guarding does not necessarily depend on the hardness of the female’s shell condition (some Grapsidae, Majidae and Ocypodidae). This type of guarding is related to fertilization and spawning; and males guard mates in order to block copulation from competing males until spawning (Edwards, 1966; Kobayashi, 1999). Furthermore, there is no guarding behavior in some species (Hartnoll, 1969). At least Geothelphusa dehaani does not perform post-copulatory guarding, and the female’s shell condition does not have any direct relations with their mating. This might be often observed among potamid crab species (Chua et al., 2014; Liu and Hartnoll, 2017).

Female juveniles still copulated in G. dehaani. They could not bear eggs as they were, because of their undeveloped abdomen; but their genital openings became receptive early and they might store semen within their seminal receptacles to some degree. Such a mating in the earlier developmental stage is not abnormal among potamid crabs, and a similar mating has been already reported in other species such as Johora singaporensis (Ng) and Candidipotentamon rathubunae (De Man) (Chua et al., 2014; Liu and Hartnoll, 2017). In these cases, there may be sometimes a time lag between the maturation of each female crab’s reproductive organ, and males cannot distinguish completely which are the mature females. If there are long gaps in the timing between copulation and ovulation, these females can successfully ovulate after a puberty molt between these events.

Size-assortative mating has been observed among some crustaceans, including brachyuran crabs (Crespi, 1989; Clark & Backwell, 2016; Fazhan et al., 2017). No evident tendencies may be present in the case of G. dehaani, and male crabs may randomly select mates irrespective of their body size.

Literature Cited

Araki, A., & Matsuura, S., 1995. Growth of a freshwater crab, Geothelphusa dehaani (White). Scientific Bulletin of Faculty of
Agriculture, Kyushu University, 49: 125–132. (in Japanese)

Christy, J. H., 1987. Competitive mating, mate choice and mating associations of brachyuran crabs. Bulletin of Marine Science, 41: 177–191.

Chua, K. W. J., Ng, D. J. J., & Yeo, D. C. J., 2014. In situ observations of behaviour of the Singapore freshwater crab Johora singaporensis (Crustacea: Brachyura: Potamidae) Nature in Singapore, 7: 117–120.

Clark, A. H. L., Backwell, P. R. Y., 2016. Assortative mating in a fiddler crab. Behaviour, 153, 175–185.

Crespi, B. J., 1989. Causes of assortative mating in arthropods. Animal Behaviour, 38: 980–1000.

Diesel, R., 1991. Sperm competition and the evolution of mating behavior in Brachyura, with special reference to spider crabs (Decapoda: Majidae). In: Bauer R. G. and Martin J. W. (eds.), Crustacean sexual biology. New York: Columbia University Press, pp. 145–163.

Edwards, E., 1966. Mating behavior in the European edible crab (Cancer pagurus L.). Crustacea, 10: 23–30.

Fazhan, H., Waiho, K., Wan Norfaizza, W. I., Megat F. H. & Ikhwanuddin, M., 2017. Assortative mating by size in three species of mud crabs, genus Scylla (Brachyura: Portunidae). The Journal of Crustacean Biology, 37: 654–660.

Gherardi, F., Messana, G., Ugolini, A. & Vannini, M., 1988a. Studies on the locomotive activity of the freshwater crab, Potamon fluviatile. Hydrobiologia, 169: 241–250.

Gherardi, F., Tarducci, F., & Vannini, M., 1988b. Locomotor activity in the freshwater crab Potamon fluviatile: the analysis of temporal patterns by radio-telemetry. Ethology, 77: 300–316.

Hartnoll, R. G., 1969. Mating in the Brachyura. Crustacea, 16: 161–181.

Koba, K., 1935. Preliminary notes on the distribution of Geothelphusa dehaami (White) in Japan. Bulletin of the Biogeographical Society of Japan, 6: 27–29.

Koba, K., 1936a. Preliminary notes on the development of Geothelphusa dehaami (White). Proceedings of the Imperial Academy 12: 105–107.

Koba, K., 1936b. Some observation on Geothelphusa dehaami (White) in Japan. Botany and Zoology 4: 529–536. (in Japanese)

Kobayashi, S., 1999. Mating behavior of the Japanese mitten crab Eriocheir japonica (de Haan). In: Okutani T., Ohta S. and Ueshima R. (eds.), Updated Progress in Aquatic Invertebrate Zoology. Tokyo: Tokai University Press, pp. 231–247. (In Japanese)

Liu, H. C., & Hartnoll, R. G., 2017. Precocious mating in the freshwater crab Candidipotamon rathubunae (De Man, 1984). Crustacea, 90: 225–233.

Micheli, M., Gherardi, F., & Vannini, M., 2006. Growth and reproduction in the freshwater crab, Potamon fluviatile (Decapoda, Brachyura). Freshwater Biology, 23: 491–503.

Okano, T., Suzuki, H., & Miura, T., 2000. Comparative biology of Japanese freshwater crabs Geothelphusa exusa and G. dehaami (Decapoda, Brachyura, Potamidae). Journal of the Crustacean Biology, 20: 299–308.

Okano, T., Suzuki, H., & Horie, M., 2003. Habitat use and activity patterns of three Japanese freshwater crabs Geothelphusa exusa and G. dehaami (Decapoda, Brachyura, Potamidae). Journal of the Crustacean Biology, 23: 308–317.

Sather, B. T., 1966. Observations on the molt cycle of the crab, Podophthalmus vigil (Fabricius) (Decapoda, Portunidae). Crustacea, 11: 185–197.

Shih, H. T., Yeo D. C., & Ng P. K. L., 2009. The collision of the Indian plate with Asia: molecular evidence for its impact on the phylogeny of freshwater crabs (Brachyura: Potamidae). Journal of Biogeography, 36: 703–719.

Shih, H. T., & Ng, P. K. L., 2011. Diversity and biogeography of freshwater crabs (Crusta-
COPULATION OF POTAMID CRAB

Vannini, M., Gherardi, F., & Pirillo, M., 1983. Aggressive communication in Potamon fluviatile (Herbst) (Decapoda, Brachyura): role of size, colour, and other visual cues. Crustaceana, 45: 203–209.

Yamaguchi, T., & Takamatsu, Y., 1980. Ecological and morphological studies on Japanese freshwater crab, Geothelphusa dehaani. Kumamoto Journal of Science, Biology, 15: 1–27.

Shimoji, H., & Wada, K., 1995. Distribution of the freshwater crab Geothelphusa dehaani in relation to season, sex and body size. Biology of Inland Waters, 10: 18–25. (in Japanese)

Suzuki, H., & Naruse, T., 2012. Freshwater Decapoda Crustaceans in Japan. In: Shrimps, Crabs and Crawfish—Conservation and Biology of Freshwater Crustaceans—. (eds Kawai, T., Nakata, K.). Seibutsu-kenkyusha, Tokyo, pp. 39–73. (in Japanese)

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