Distributions of land hermit crabs (Decapoda: Coenobitidae) on the coast of the tidal lagoon, Nagura Amparu, on Ishigakijima Island, Japan.

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Katsuyuki Hamasaki, Shunsuke Fujikawa, Tetsuya Sanda, Takuma Tsuru and Shuichi Kitada

Department of Marine Biosciences, Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato, Tokyo 108-8477, Japan

Abstract. We investigated the distributions of land hermit crabs on the coast of the tidal lagoon, Nagura Amparu, on Ishigakijima Island, Japan, through six surveys conducted during the period from October 2011 to September 2013. Nagura Amparu is a brackish estuary system with a tidal flat and mangrove tree area separated from the outer sea bay by a sandbank. Land hermit crabs were captured using bait traps at three sites along the shoreline of the sandbank facing the inner tidal flat and at one site in the coastal forest on the sandbank. Four land hermit crab species, *Coenobita brevimanus*, *C. cavipes*, *C. rugosus*, and *C. violascens*, were collected. Almost all collected crabs were *C. violascens*, and a few *C. rugosus* were collected on the shoreline. On the other hand, *C. cavipes* was dominant, followed by *C. violascens*, and a few *C. brevimanus* were captured in the coastal forest. *Coenobita violascens* were juveniles and adults, and they widely inhabited the shoreline and coastal forest. All *C. cavipes* were juveniles, suggesting that this species utilizes the coastal forest as a nursery ground. Our results highlight the importance of the Nagura Amparu as habitat for juveniles and adults of *C. violascens* and juveniles of *C. cavipes*.

Key words: biogeography, *Coenobita cavipes*, *Coenobita violascens*, juvenile, terrestrial hermit crab

Introduction

Land hermit crabs are mainly distributed in subtropical and tropical coastal regions (Hartnoll, 1988). In Japan, five land hermit crab species, including *Coenobita brevimanus* Dana, 1852, *C. cavipes* Stimpson, 1858, *C. purpureus* Stimpson, 1858, *C. rugosus* H. Milne-Edwards, 1837, and *C. violascens* Heller, 1862, are commonly found in the Ryukyu Archipelago and the Bonin Islands (Nakasone, 1988; Asakura, 2004). Land hermit crabs have been a Natural Monument Animal since 1970 in Japan, and some species have been listed as "near threatened" on the Red Lists by the Ministry of the Environment of Japan. In Okinawa Prefecture, however, land hermit crabs have been traditionally collected as fishing bait and/or ornamental animals, so that even now some traders are collecting land hermit crabs on Okinawajima Island for trade as ornamental animals throughout the entire country under permission of the Agency for Culture Affairs, Ministry of Education, Culture, Sports, Science and Technology of Japan.

Knowledge on the distributions of land hermit crab species on the islands is indispensable for the in situ conservation of these animals. We investigated the distributional characteristics of land hermit crabs along the coasts of Ishigakijima Island and Iriomotejima Island in the Ryukyu Archipelago and revealed that the distribution of *C. violascens* was restricted to the vicinity of the river, mainly in the mangrove estuaries (Fujikawa *et al*., 2017; Hamasaki *et al*., in

*Corresponding author: hamak@kaiyodai.ac.jp

press). Thus, our previous surveys highlighted the importance of protecting mangrove estuaries to conserve the *C. violascens* populations.

On Ishigakijima Island, the largest mangrove area extends from the mouth of Naguragawa River on the western island; this area is a brackish estuary system called "Nagura Amparu", with a tidal flat and mangrove tree area separated from the outer bay by a sandbank (Fig. 1). *Coenobita violascens* is abundant along the shoreline of the sandbank facing the inner tidal flat (Fujikawa *et al*., 2017; Hamasaki *et al*., in press). However, surveys of land hermit crab distributions have been limited to the shoreline of the sandbank in the Nagura Amparu. In the present study, as a basis for further understanding the importance of the Nagura Amparu for the in situ conservation of land hermit crabs, we examined the distributions of land hermit crabs in the coastal forest as well as along shoreline of the sandbank in the Nagura Amparu.

Materials and Methods

Field study

Fujikawa *et al*. (2017) investigated the distributions of land hermit crabs along the coast of Iriomotejima Island through visual surveys during daytime and nighttime and using bait traps overnight. They showed that the number of species of collected crabs was similar between visual and bait-trap surveys although the species diversity index (Shannon-Wiener Index H') was high during visual surveys at night. They also showed that bait traps could collect crabs with various body sizes. It was difficult to conduct effective visual surveys in the coastal forest; therefore, we used bait traps for collecting crabs in the present study.

Land hermit crabs were collected at three sites along the shoreline of the sandbank facing the inner tidal flat and one site in the coastal forest on the sandbank in the Nagura Amparu (Fig. 1). The shoreline sites were set in the survey area in our previous study (station no. 13 by Fujikawa *et al*. (2017)). The coastal forest site is the only location where investigators could easily access the interior forest through a small road crossing the sandbank toward the inner tidal flat. The field surveys were conducted six times from October 2011 to September 2013

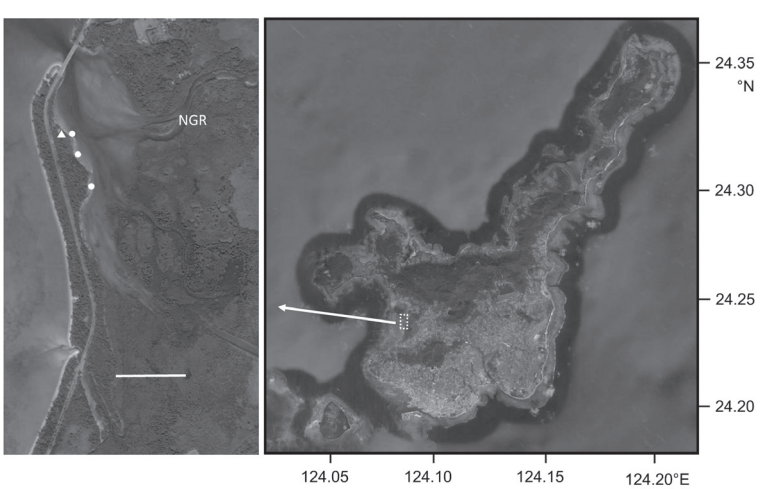

Fig. 1. Google Earth photographs showing Ishigakijima Island (right panel) and the tidal lagoon, Nagura Amparu, extending from the river mouth of the Naguragawa River (NGR) (left panel). Land hermit crabs were captured using bait traps at three sites along the shoreline of the sandbank facing the inner tidal flat (white circles) and at one site in the coastal forest on the sandbank (white triangle). A white scale bar in the left panel indicates 250 m.

(October 29–30, 2011; June 29–30, 2012; August 25–26, 2012; October 3–4, 2012; June 22–23, 2013; and September 15–16, 2013). One plastic bucket (20 cm depth, 24.5 cm upper diameter, and 18.5 cm lower diameter; 6 L volume) containing poultry feed was buried at the ground level at each site in the evening of the first day of each survey period. In the following morning, the buckets were harvested, and the collected crabs were counted and morphologically identified in accordance with Nakasone (1988), Asakura (2004) and Hamasaki *et al*. (2017). The shield length (SL) of collected crabs was measured using Vernier calipers to the nearest 0.1 mm according to Fujikawa *et al*. (2017). When a crab could not be removed from the mollusk shell to identify the anterior carapace, the dactylus length of the left third pereiopod was measured and converted into the SL value using a formula established for each *Coenobita* species according to Fujikawa *et al*. (2017). The collected crabs were released on-site after the body size measurements.

The mean values of air temperature and relative humidity measured in the afternoon and the morning during the survey period were as follows: October 29–30, 2011 (28.0°C, 59.0%); June 29–30, 2012 (30.9°C, 74.0%); August 25–26, 2012 (32.5°C, 71.0%); October 3–4, 2012 (29.0°C, 60.5%); June 22–23, 2013 (27.0°C, 78.3%); and September 15–16, 2013 (31.7°C, 63.6%).

Statistical analysis

All statistical analyses were performed using the R statistical software (R3.3.1; R Core Team 2016) with a 5% significance level. A Pearson's chi-squared test was performed to determine whether the species compositions differed between the shoreline and coastal forest using the numbers of *C. cavipes* and those of other species. The intraspecific variation in SL values in *C. violascens* and *C. cavipes* collected at the shoreline and/or coastal forest sites in the six surveys were evaluated with the Kruskal-Wallis test. The SL values of *C. violascens* collected at the shoreline and coastal forest sites were compared with the Wilcoxon rank-sum test.

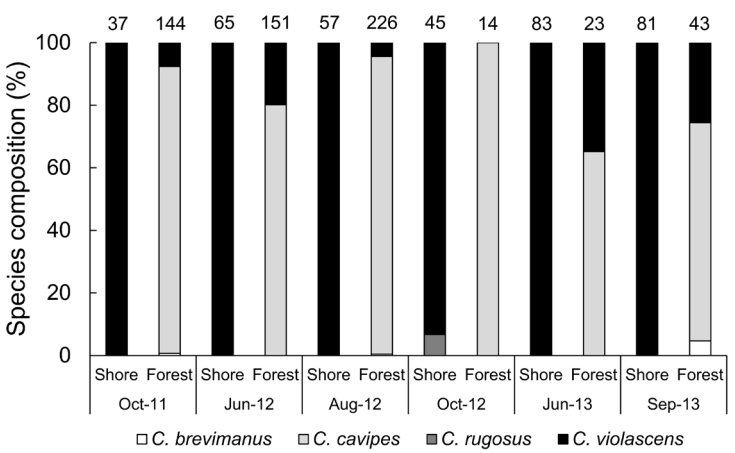

Fig. 2. Species compositions of land hermit crabs collected at three sites on the shoreline and one site in the coastal forest from 29 to 30 October 2011, 29 to 30 June 2012, 25 to 26 August 2012, 3 to 4 October 2012, 22 to 23 June 2013, and 15 to 16 September 2013. The numbers of crabs collected at three sites on the shoreline were pooled for each survey period. Values on the bars indicate the total number of crabs collected.

Results

The species compositions of land hermit crabs collected at the shoreline and coastal forest sites in the six surveys are shown in Fig. 2. On the shoreline, almost all collected crabs were *C. violascens*, and only three individuals of *C. rugosus* were captured in the survey in October 2012. Therefore, the numbers of crabs collected at the three shoreline sites were pooled. In contrast, three land hermit crab species were collected in the coastal forest; *C. cavipes* was dominant, at 65–95% of the total number of collected crabs, in each survey (mean, 84%), followed by *C. violascens* at 0–35% (15%), and one individual of *C. brevimanus* was collected in the surveys of October 2011 and August 2012, while two individuals of this species were collected in the survey in September 2013. Thus, the species compositions of land hermit crabs collected by bait traps differed significantly between the shoreline and coastal forest (χ^2 = 53.604–240.49, df = 1, $P < 0.0001$ in all surveys). The number of crabs collected per bait trap in the six

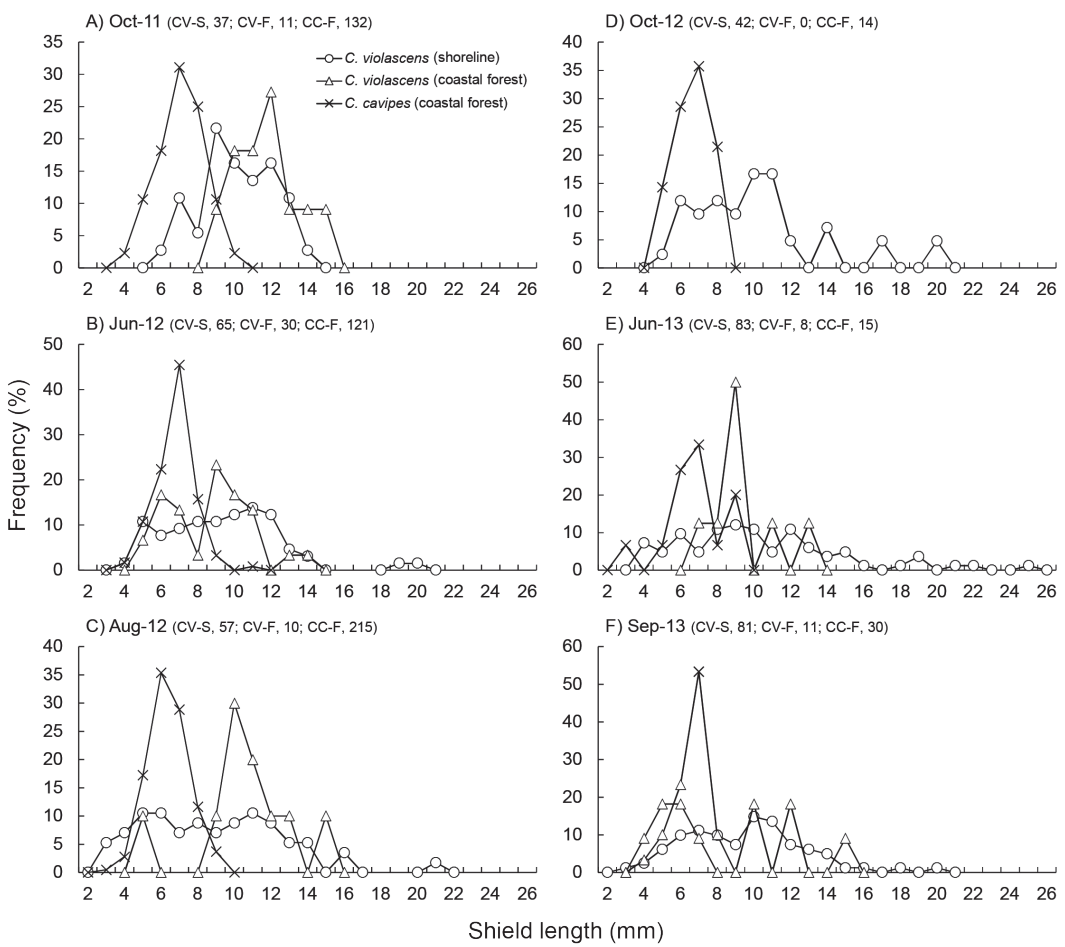

Fig. 3. Size-frequency distributions of *C. violascens* collected along the shoreline, *C. violascens* collected in the coastal forest, and *C. cavipes* collected in the coastal forest from 29 to 30 October 2011 (A), 29 to 30 June 2012 (B), 25 to 26 August 2012 (C), 3 to 4 October 2012 (D), 22 to 23 June 2013 (E), and 15 to 16 September 2013 (F). Numbers of individuals of *C. violascens* at the shoreline sites (CV-S) and coastal forest site (CV-F) and *C. cavipes* at the coastal forest site (CC-F) are shown in parentheses in each graph.

surveys was 12, 22, 19, 14, 28, and 27 for *C. violascens* on the shoreline, 11, 30, 10, 0, 8, and 11 for *C. violascens* in the coastal forest, and 132, 121, 215, 14, 15, and 30 for *C. cavipes* in the coastal forest, respectively.

The size-frequency distributions of *C. violascens* collected on the shoreline and those of *C. violascens* and *C. cavipes* collected in the coastal forest are shown for the six surveys in Fig. 3. *Coenobita violascens* captured on the shoreline mainly occurred in the size class of less than 16 mm SL and within the range of 2–25 mm, and a significant difference was not found in the SL values among the six surveys (χ^2 = 6.3783, df = 5, P = 0.2711). Although the SL values of *C. violascens* collected in the coastal forest differed significantly among the six surveys (χ^2 = 14.664, df = 4, P = 0.0055), a significant difference was not found in the SL values of *C. violascens* between the shoreline and coastal forest (W = 12793, P = 0.9855). Although a significant difference was also detected in the SL values of *C. cavipes* collected in the coastal forest among the six surveys (χ^2 = 34.044, df = 5, P < 0.0001), similar unimodal size-frequency distributions with a modal value of 6–7 mm SL were observed throughout the survey periods. The SL values of the three *C. rugosus* were 2.5 mm, 5.3 mm, and 6.5 mm, and those of the four *C. brevimanus* were 6.0 mm, 7.1 mm, 9.6 mm, and 11.1 mm.

Of the collected *C. violascens*, we found small crabs (< around 8–9 mm SL) showing the body color

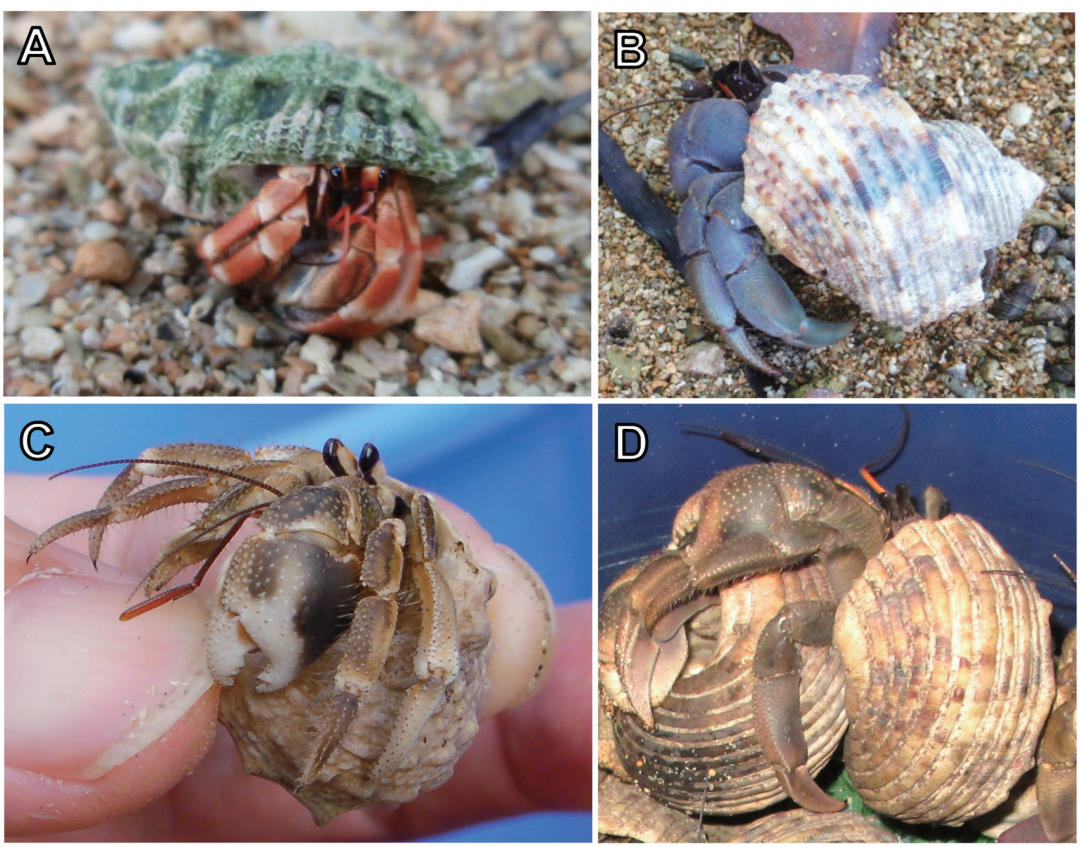

Fig. 4. Juvenile (A) and adult (B) of *C. violascens* and juvenile of *C. cavipes* (C) collected in the present study and adult of *C. cavipes* (D) collected by one of the authors on Ishigakijima Island.

pattern that is specific to the juvenile stage (Hamasaki *et al*., 2017), i.e., brownish-red pereiopods with white rings at the boundaries between segments (Fig. 4A), and large crabs (> around 8–9 mm SL) showing a grayish-violet body color (Fig. 4B). On the other hand, all individuals of collected *C. cavipes* showed the juvenile body color pattern (Hamasaki *et al*., 2017), i.e., brown pereiopods with white rings at the boundaries between segments (Fig. 4C), and large crabs showing a grayish-brown body color were not found (Fig. 4D).

Discussion

In our previous studies, we collected land hermit crabs by hand during the daytime and nighttime via visual surveys along the shoreline of the sandbank facing the inner tidal flat in the Nagura Amparu; three species, *C. violascens*, *C. cavipes*, and *C. rugosus*, were captured, and *C. violascens* was the dominant species, comprising > 90% of the total number of crabs collected in the surveys (Fujikawa *et al*., 2017; Hamasaki *et al*., in press). In the present study, we collected land hermit crabs using bait traps in the same area in the Nagura Amparu as in our previous studies (Fujikawa *et al*., 2017; Hamasaki *et al*., in press); almost all captured crabs were identified as *C. violascens*, and a few individuals of *C. rugosus* were collected. Thus, the present study confirmed that *C. violascens* was the dominant species along the shore area in the Nagura Amparu. On the other hand, three land hermit crab species, *C. cavipes*, *C. violascens*, and *C. brevimanus*, were captured in the coastal forest, and *C. cavipes* was abundant among the collected crabs (mean proportion, 84%), followed by *C. violascens* (15%). Our results demonstrated that the species composition of the land hermit crabs inhabiting the coastal forest was different from that in the shore area in the Nagura Amparu.

The number of crabs collected per bait trap was similar for *C. violascens* between the shoreline (12–28 individuals) and coastal forest (8–30 individuals, except for the survey in October 2012, when this species was not collected). Additionally, the body size of *C. violascens* was not significantly different between the shoreline and coastal forest, and juvenile and large-size crabs ranging from 2–25 mm SL were collected. Although we did not examine whether the crab was ovigerous or not in the present study, it is known that ovigerous females have been observed in *C. violascens* with > ~8 mm SL on Ishigakijima Island, including the Nagura Amparu (Fujikawa *et al*., 2017). It has also been reported that early juveniles of *C. violascens* (< 2 mm SL) commonly inhabit the shore area of the sandbank facing the inner tidal flat in the Nagura Amparu (Hamasaki *et al*., in press). Consequently, it is thought that megalopae of *C. violascens* migrate to the Nagura Amparu; then, they settle and acquire empty mollusk shells and emigrate from the lagoon onto the land of the sandbank. After migrating onto the land, *C. violascens* widely inhabit the shore and coastal forest areas of the sandbank and grow to reproduce there. In contrast, *C. cavipes* was only collected in the coastal forest, and all captured crabs had juvenile body color patterns and showed unimodal size frequency distributions with a modal value of 6–7 mm SL. It has been reported that ovigerous females of *C. cavipes* were commonly observed with > ~7 mm SL on Ishigakijima Island (Fujikawa *et al*., 2017). Additionally, early juveniles (< 2 mm SL) of *C. cavipes* were found in the shore area of the sandbank facing the inner tidal flat in the Nagura Amparu (Hamasaki *et al*., in press). Therefore, it is thought that after emigrating from the lagoon onto the land, *C. cavipes* migrate into the costal forest and utilize this area as a nursery ground. Thus, the Nagura Amparu functions as an important habitat for a whole life history of *C. violascens* and serves as a nursery for *C. cavipes* after migrating onto the land. Additionally, it has been

reported that *C. rugosus* is abundant and spends its whole life history after landing on the shoreline of the sandbank facing the outer sea bay in the Nagura Amparu (Fujikawa *et al*., 2017; Hamasaki *et al*., in press). Consequently, the Nagura Amparu is a crucial habitat for the in situ conservation of the land hermit crab species.

The number of *C. cavipes* and *C. violascens* collected per bait trap ranged from 121 to 215 (mean, 156) and 10 to 30 (mean, 17), respectively, in the surveys conducted from October 2011 to August 2012, and from 14 to 30 (mean, 20) and 0 to 11 (mean, 6), respectively, in the surveys conducted from October 2012 to September 2013. Thus, the number of collected crabs decreased in these survey periods in both species, and the reduction rate in the mean number of crabs captured was higher in *C. cavipes* (87%) than in *C. violascens* (65%). It has been suggested that *C. cavipes* is the most inland dweller (Okinawa Prefecture Board Education, 1987, 2006). Consequently, the decreased number of *C. cavipes* collected in the coastal forest might be because of the migration of crabs into the inland habitats. The sandbank of the Nagura Amparu is, however, isolated by the river mouths at the northern and southern parts of the lagoon (Fig. 1). Therefore, *C. cavipes* that land on the sandbank of the Nagura Amparu might be isolated as a juvenile population there. Further study is needed to investigate the distributions of land hermit crabs along the entire sandbank as well as in the inland areas adjacent to the Nagura Amparu.

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