

# Ecology of the Land Hermit Crab *Coenobita purpureus* on Kikaijima Island.

## I. Breeding Site, Breeding Season and Migration

MICHIO IMAFUKU

Department of Zoology, Graduate School of Science, Kyoto University,  
Sakyo, Kyoto, 606-8502 Japan  
(Received December 5, 2001)

**Abstract** The breeding ecology of the land hermit crab, *Coenobita purpureus*, on Kikaijima Island was investigated. The hermit crabs were observed to gather to a particular site on the coast of the island to release larvae in summer. Fifteen gathering sites were identified on the island, and categorized into 4 types according to topography, including a calm inlet and a rough rocky shore exposed to the open sea. A detailed survey on the coast revealed that their distribution was rather restricted to a limited area. Aggregation near the zoea-release site was observed from the end of June to the end of August. Marking and telemetric surveys revealed that crabs migrated towards the zoea-release site prior to aggregation formation, frequently moved between the coast and the upper part in the breeding season, and that crabs artificially transferred to a new coast could immediately orient to the particular site of the coast.

**Key words** Land hermit crab, *Coenobita purpureus*, Breeding, Zoea release, Migration

### Introduction

Hermit crabs belonging to genus *Coenobita* are all terrestrial hermit crabs that occupy snail shells, and comprise Family Coenobitidae together with the coconut crab, *Birgus latro*, that does not carry a shell (Miyake 1982). There are 13 known species of land hermit crabs in the world. Four species have been recorded, respectively, from the east coast of America, Atlantic, the west coast of Africa, and Red Sea to Pakistan, and the remaining 9 species are mainly distributed in the Indo-West Pacific (Hartnoll 1988; Nakanose 1987a), and thus, genus *Coenobita* is thought to be a group that speciated in East Asia.

In Japan, 6 species are known; *Coenobita brevimanus* Dana, *C. rugosus* H. Milne Edwards, *C. purpureus* Stimpson, *C. perlatus* H. Milne Edwards, *C. cavipes* Stimpson and *C. violascens* Heller. Among them, *C. purpureus* is a temperate to subtropical species, and distributed from the northern limit of the Kii Peninsula to Sakishima-shoto, especially rich in Amami-Oshima and the Okinawa main island (Zeze & Suzuki 1986; Shimamura 1987; Kuniyoshi & Nishihira 1987; Kurozumi *et al.* 1987). They are rich also in Ogasawara Islands (Board of Education, Tokyo 1987).

Many studies have been carried out on land hermit crabs. Distributional works have been made for *C. clypeatus* (Herbst) in Curaçao of Carribean Sea (DeWilde 1973), 4 species including *C. perlatus* in Enewetok Atoll (Page & Willason 1982), 3 species in-

cluding *C. rugosus* in Formosa (Takahashi 1934), and the Japanese species in Kagoshima (Zeze & Suzuki 1986), Okinawa (Yamashiro 1987; Nakasone 1987b; Shimamura 1987; Kuniyoshi & Nishihira 1987; Kurozumi *et al.* 1987) and Ogasawara (Board of Education, Tokyo 1987). The adaptation of land hermit crabs to the terrestrial environment has been studied in *C. clypeatus* on Curaçao (DeWilde 1973) and *C. scaevola* (Forsk.) on the Sinai Peninsula (Achituv & Ziskind 1985). The feeding ecology and behavior of 3 species including *C. perlatus* (Page & Willason 1983), and *C. compressus* H. Milne Edwards (Thacker 1996) have been investigated. Concerning shell utilization and acquisition, several investigators have dealt with shell fighting (Hazlett 1966; Radinovsky & Henderson 1974), an effect of introduction of a single shell into a population on other individuals (Chase *et al.* 1988), chemical orientation to shell acquisition sites (Thacker 1994) and fossil shell utilization in Bermuda (Walker 1994).

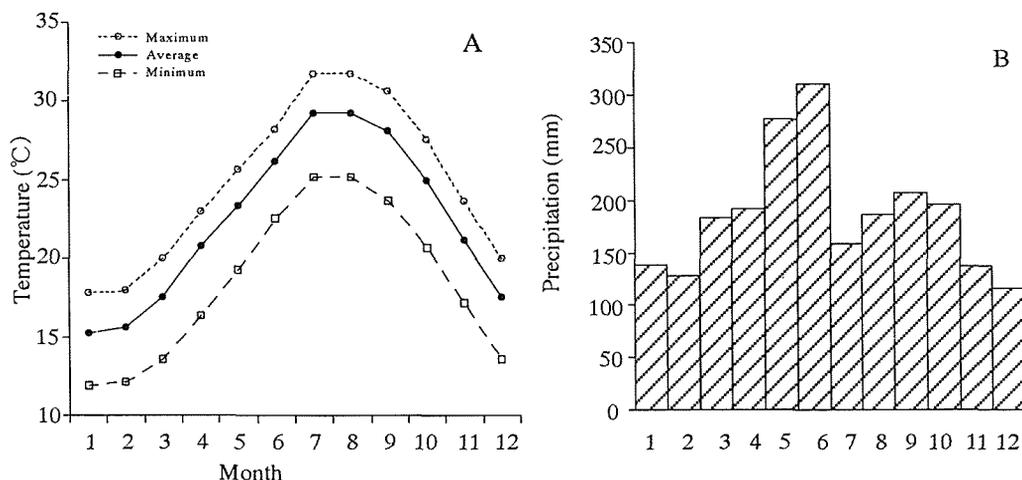
As sensory and physiological works, Kinoshita & Okajima (1968) studied the shell recognition behavior, and Dunham & Schöne (1984) examined the slope recognition. Herreid & Full (1986) studied the energy physiology of crabs by comparing oxygen consumption between crabs with and without shells. Imafuku & Ikeda (1990) investigated the sounds produced by land hermit crabs. There are also some works on larval morphology and development (Yamaguchi 1938; Shokita & Yamashiro 1986; Nakasone 1987c).

Concerning the breeding ecology of land hermit crabs, some investigators estimated the breeding season from confirmation of berried females (Zeze & Suzuki 1986; Kuniyoshi & Nishihira 1987; Board of Education, Tokyo 1987), but there are few works dealing with such aspects as male-female encounter, copulation and release of zoeal larvae.

In 1998, I received a letter from Mr. Dôsuke Tanaka of Kikaijima Island informing me of a site where countless numbers of land hermit crabs gathered at night and urging me to study them on the island. In 1990 and in 1994-1996, I visited the island and investigated the breeding ecology and some related behavior of the land hermit crab distributed there. As for the land hermit crabs on Kikaijima Island, Yamaguchi (1938) have already reported a brief observation at a breeding site and on larval development. In the present paper, I report the breeding sites newly found on the island, the characteristics of those sites, a detailed survey at Sômani coast a long been known breeding site, the period of breeding-aggregation formation, and migration of crabs to the site.

### **Kikaijima Island**

Kikaijima Island (130°00' East, 28°20' North) is located 300 km south of Kagoshima City, 25 km east of Amami-Oshima, and extends over an area of 56 km<sup>2</sup> (ref. Fig. 3). The island is fringed by a very rough rocky reef made of limestone, with some sandy beaches scattered in small bays or in the recesses of narrow channels. The average temperature is 29.3°C in summer (July and August), and above 15° even in winter (Fig. 1A). The annual precipitation is 2,230 mm (average of 1966 to 1995, data from Seiwa Togyo Co.), lower than 2,871 mm (average of 1961 to 1990, Chronological Science Tables, ed. by National Astronomical Observatory) at Naze in Amami-Oshima. Rain fall is most frequent in the



**Fig. 1.** Monthly temperature (A) and precipitation (B) in Kikaijima Island.

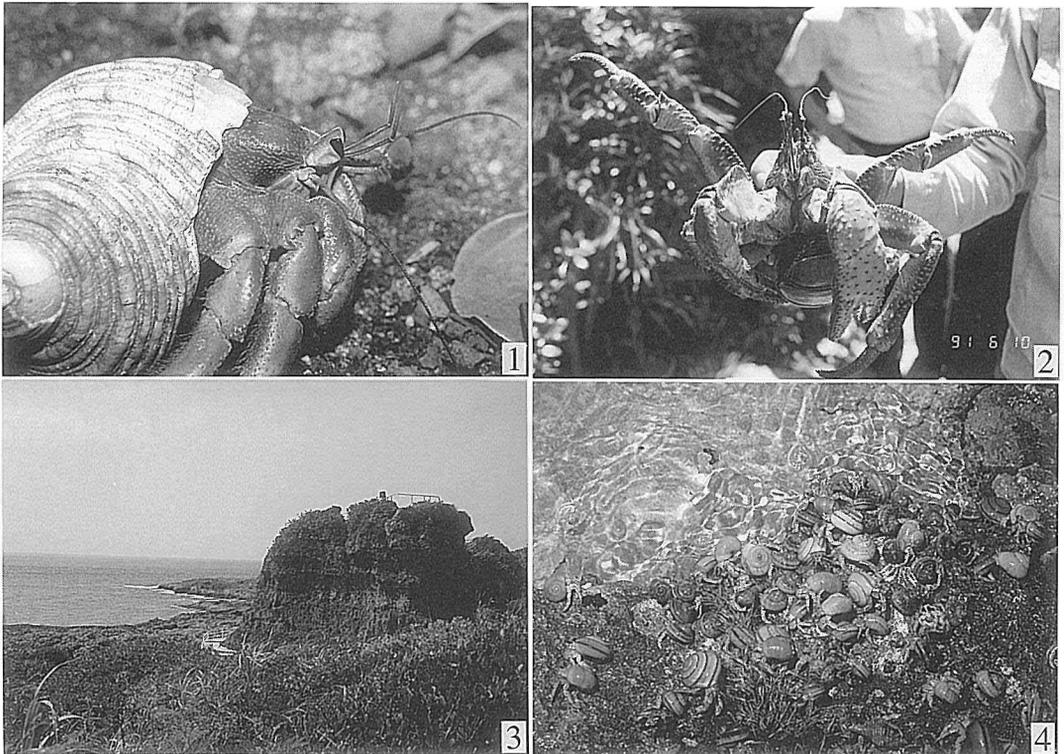
rainy season from May to June, with a second peak in autumn due to frequent typhoon attacks (Fig. 1B). No rivers run on the island, and occasional springs are important water sources for the islanders. Most of the flat area has been changed to sugarcane fields, but natural forests remain, especially around steep cliffs near the east coast of the island. There are many natural coasts without port piers or breakwater around the island, except for village areas.

### Land Hermit Crabs on the Island

*Coenobita purpureus* (Fig. 2-1) is a land hermit crab that was the most commonly seen in the present investigation. It inhabited most places near the coastline, and was found to gather at particular sites at night in the summer season. Not many individuals of another species *C. rugosus* were found among stranded matter such as algae around the high water mark. According to Yamaguchi (1938), *C. cavipe* were also distributed on the island, but I could not confirm this in the present study.

The coconut crab, *Birgus latro*, was recorded on this island; Fig. 2-2 shows a photo of this crab captured near the promenade passing through the west part of the island on July 10, 1991, courtesy of staff of the Project and Sightseeing Section of the Kikai Town Government. According to Mr. D. Tanaka, there are also a few records of capture or observation of the coconut crab on this island. However, it is not clear whether this crab is really breeding in the island or not.

Thus, 3 species of *Coenobita* and 1 species of *Birgus* are known on Kikaijima Island.

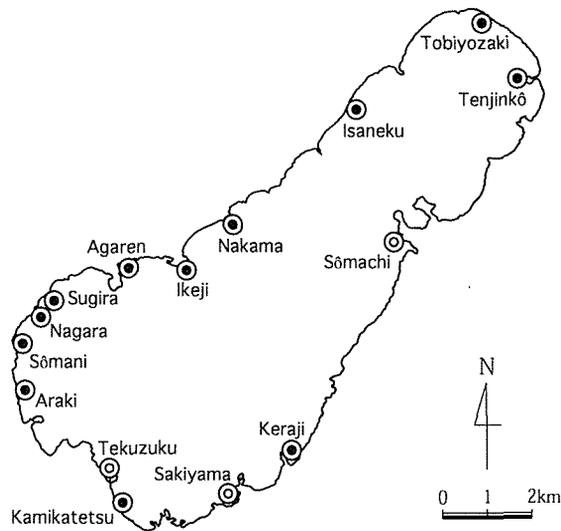


**Fig. 2.** Coenobitid crabs and the breeding site on Kikaijima Island. 1: The land hermit crab, *Coenobita purpureus*, the species most commonly found in the island (July 1, 1995, Tekuzuku). 2: The coconut crab, *Birgus latro*, captured in the island (a photo taken by staff of the Kikai Town Government). 3: The huge rock called Sômani. The place is known for a long time as a breeding site of the land hermit crab, *C. purpureus*. The breeding site on this coast is located at the point where the water deeply invades the land (July 22, 1994). 4: Crabs swarming on the water edge to release zoeal larvae (June 9, 1990, Sakiyama).

### Breeding Sites on the Island

Yamaguchi (1938) described that in the breeding season in summer, “males and females of land hermit crabs all over the island migrate toward the sea coast” to gather at particular sites, and “the most conspicuous site is found near the huge rock called Sômani on the west coast of a village of Araki that is located in the southwest of the island” (Fig. 2-3). Another site found by Mr. D. Tanaka and the other 13 sites based on information from islanders are shown and summarized in Fig. 3 and Table 1.

At all sites shown in Fig. 3, hermit crabs were found hiding themselves in assemblage in such bush as *Scaevola frutesces* Krause trees, under stones, logs or plastic during the daytime, and those sites were confirmed as breeding sites by the direct observation of larval release (Table 1). The 15 coasts, in most cases named after the village nearby,

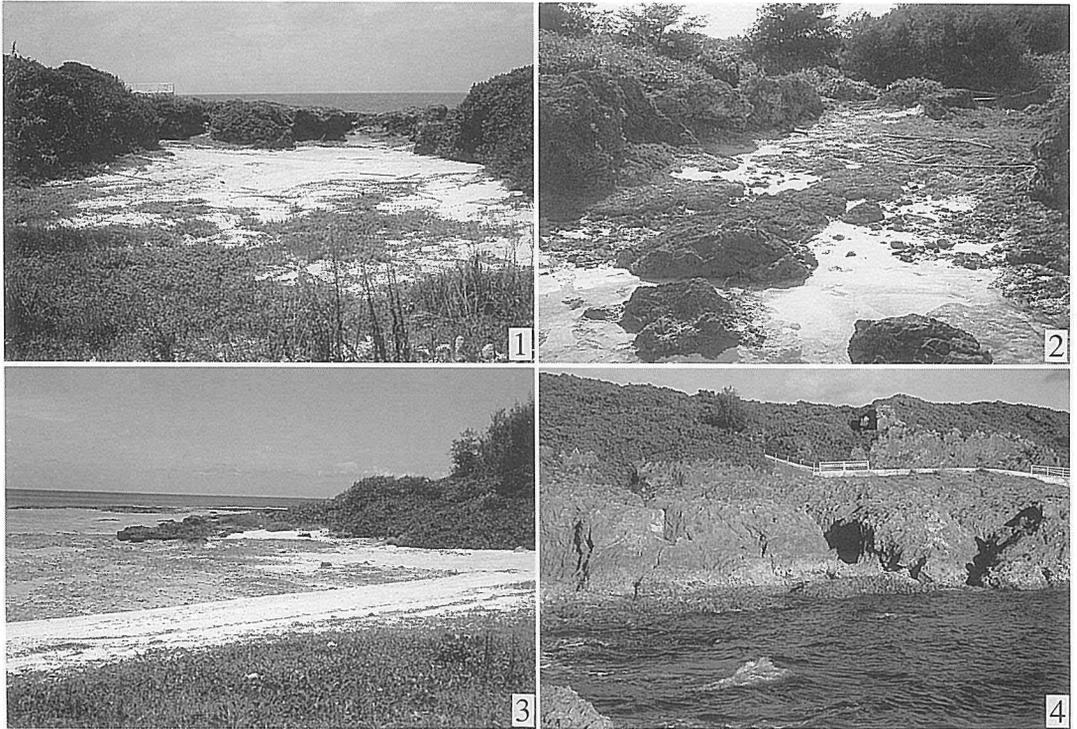


**Fig. 3.** Fifteen places found as breeding sites of *C. purpureus* on Kikaijima Island. Double circles with an open inner circle indicate the site that was changed due to development.

**Table 1.** Breeding sites of *Coenobita purpureus* on Kikaijima Island.

Site name	Position	Type of coast	Confirmation day of zoea-release
Sakiyama	East of village of Sakiyama	B	'90-7-9
Kamatetsu	South of Daini Junior High School	A	'96-7-20
Tekuzuku	Right of the port	A	'94-6-22
Araki	Near the left end of the promenade	D	'96-7-4
Sômani	Right below from the huge rock	D	'94-7-8
Nagara	Left of Sugira beach	A	'95-7-12
Sugira	Nakazato Bathing Place	A	'95-7-21
Agaren	Below the housings for school staff	A	'96-7-4
Ikeji (left)	The left end of the bathing place	C	'95-7-21
(right)	The right end of the bathing place	C	'96-7-4
Nakama	In the middle of village of Nakama	C	'96-7-4
Isaneku	Between Isaneku and Onotsu	A	'95-7-21
Tobiyozaki	Right of the cape	A	'96-7-4
Tenjinkô	Left of the port	A	'96-7-20
Sômachî	Right of the port	C	'96-7-20
Keraji	Inlet embayed on the left of the bay	B	'96-7-20

Type of coast: A=inlet connected to the open sea through a narrow channel, B=inlet embayed from a bay, C=sandy beach widely open to the sea, D=rocky coast exposed to the open sea.



**Fig. 4.** Landscapes of 4 types of coasts confirmed as the breeding site of *C. purpureus*. 1: An inlet of Isaneku (type A). 2: An inlet of Sakiyama (type B). 3: Sandy beach of Ikeji (type C). 4: Rocky coast of Sômani (type D).

are as follows.

**Sakiyama** (Figs. 4-2 & 6): a tiny sandy beach on an inlet from the bay in the east of the village of Sakiyama. It was surrounded by rocky walls. Land hermit crabs were found hiding in crevices of rocks during the daytime, and appeared in such large numbers at night that one could not move without stepping on them. Crabs were seen swarming at the water edge to release larvae at night (Fig. 2-4). However, a road was constructed through the center of the inlet from 1991 to 1992, which had greatly reduced the number of crabs when observed in 1995.

**Kamikatetus:** the site was on an inlet located to the south of Kikai Daini Junior High School. It was a small sandy beach in the recesses of the inlet connected to the open sea through a narrow channel. The number of crabs was not so large.

**Tekuzuku:** the site was a tiny sandy beach on a small bay just before a small hill covered with *Scaevola frutesces* bush. In the evening, countless numbers of crabs were observed to move down to the beach where they released larvae, and some of them showed copulation behavior. According to an aerial photograph taken in 1991 (Kikai Town Gov-

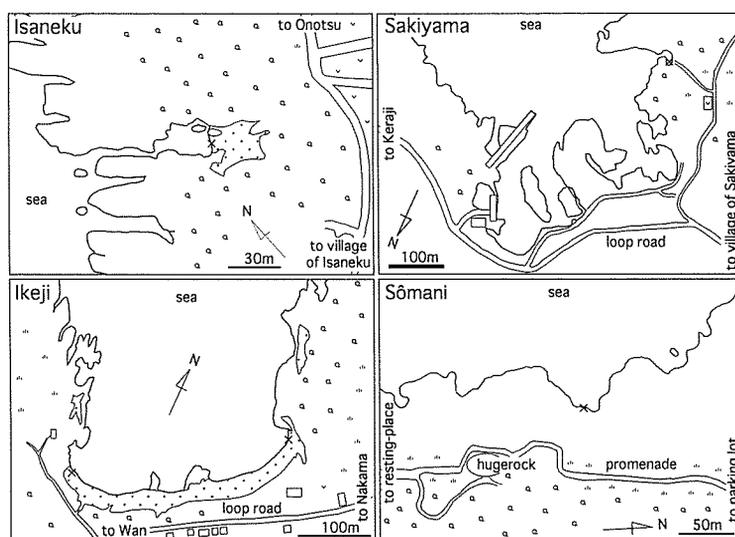


**Fig. 5.** Behavior of crabs observed at the breeding site of the island. 1: Crabs clinging to the vertical surface of the rock washed by violent waves to release larvae (Sômani, a photo taken by N. Kaki in August, 1997). 2: Crabs releasing larvae in a pool of the Sômani coast. The crab in the center is just releasing zoeae which can be seen as a dark cloud on the frontal left side of the crab (July 10, 1994). 3: A crab carrying a cleanser bottle cap instead of a snail shell (June 9, 1990, Sugira). 4: Crabs moving from the daytime hiding place to the sandy beach of Isaneku to breed after dark (July 20, 1995).

ernment 1992), the bay was connected to the open sea with a rather wide straight-edged ditch, suggesting that a previously narrow channel had been enlarged in need of a shipping lane. Thus, the bay was probably calmer than at the time the photo was taken. The port pier was further extended in 1994 over the natural breeding site of the land hermit crab. In 1995, many individuals were seen clinging to the vertical surface of the concrete.

Araki: the site was on a rocky coast facing the open sea, exposed to rough waves. It was located on the south side of the promenade that passed through the west part of the island. In the evening, countless numbers of crabs were seen crossing the promenade to go down to the breeding site. Some of them were observed to release larvae on the surface of a large rock and others in tide pools in the evening. During the daytime, many crabs were seen concealing themselves in crevices and hollows of rocks nearby.

Sômani (Figs. 4-4 & 6): the place is named after a huge rock (ref. Fig. 2-3) located about 100 m from the site. The site was also near the parking lot at the north end of the



**Fig. 6.** Examples of 4 types of coasts for *C. purpureus* breeding sites. The zoea-release site is shown with ×. Top left: an inlet of Isaneku, connected to the open sea with narrow channels (type A). Top right: an inlet of Sakiyama, embayed from a bay (type B). Bottom left: sandy beach of Ikeji, directly facing the open sea (type C). Bottom right: rocky coast of Sōmani, exposed to rough waves of the open sea (type D).

promenade. It was a breeding site for a long time. The site is a rocky coast directly facing the open sea. In the evening, many crabs were seen migrating from the daytime hiding places to the water edge to release larvae on the surface of rocks exposed to rough waves (Fig. 5-1) and in tide pools nearby (Fig. 5-2). Countless numbers of larvae were found swimming in small pools at night, and in the next morning, reddish clouds of dead larvae that could not return to the sea were seen on the bottom of pools, especially at higher levels.

Nagara: this beach was located on the left of the following “Sugira” beach. It was a small sandy beach at the deep end of a channel, thus very calm. On June 27, 1995, a survey was carried out to estimate the number of crabs appearing on the beach. The whole beach area was visually divided into several sections depending on crab density, and the numbers of crabs in quadrates settled in each section were counted. The total number of crabs was estimated to be 2,500 over an area of 160 m<sup>2</sup>.

Sugira: another name Nakazato Bathing Place. A wide sandy beach extending about 500 m of shoreline with a rocky reef projecting from both ends of the beach toward the center of the bay, making the water calm. At night, crabs appeared from the grass area on the left, especially abundantly near the water edge crossing the rocky reef. On the same day when Nagara beach was surveyed, the number of crabs on this beach was also estimated, in the same way, to be 58,000 individuals. A crab carrying the cap of a cleanser bottle was found on this beach (Fig. 5-3). Such crabs were occasionally found on other beaches, as well.

Agaren: an inlet with a small sandy beach in the recesses, just on the right of the port

of Wan, a center of the island. There was a drain in the middle of the beach and also a lot of trash scattered. Thus, this site was under the strong influence of human activities. In spite of such circumstances, some crabs were seen gathering on the sand surface, and a few of them were confirmed to release larvae.

Ikeji (Figs. 4-3 & 6): a wide sandy beach facing the open sea, just aside the loop road of the island. Many crabs were found on the sand surface near both ends of the beach, whereas there were no crabs around the middle part of the beach with pure sand substratum.

Nakama: this was a wide sandy beach facing the open sea, situated just alongside the loop road. Many crabs were found near the rocky area projecting in the middle of the beach from the land side, whereas almost no crabs were found on the rocky reef near the left end of the beach, suggesting that the gathering site of the crabs was rather restricted.

Isaneku (Figs. 4-1 & 6): located in the middle of the villages named Isaneku and Onotsu. It was a small sandy beach on an inlet connected to the open sea through a very narrow channel. Crabs hid themselves in crevices and hollows of the rocky reef or under bush of *Scaevole frutesces* during the daytime. In the evening, they appeared on an open beach in such a great number that the beach was covered with them, one crab over another (Fig. 5-4).

Tobiyozaki: a small inlet with a sandy beach, on the right of the Tobiyozaki (or Tombizaki) Cape, the northernmost tip of the island. Some crabs were found gathering at night.

Tenjinkô: another name Shito-oke Bathing Place. It was a calm small bay with a wide sandy beach, connected to the open sea with a narrow mouth. Crabs were seen on the left half of the rocky area at night. There were not so many crabs, but they were large.

Sômachi: situated on the right of the large port. The site has long been known as a crab gathering place. One islander said that he had frequently run over many crabs that crossed the loop road moving down to the water edge in the season. On July 22, 1996, after the construction of concrete facilities, some crabs were found on the road and also on the beach where some were seen releasing larvae, clinging to the vertical surface of the construction.

Keraji: a small sandy beach on an inlet embayed from the left side of a bay, with a long breakwater on the back of the beach. Not many crabs were found at night, and some crabs were observed attempting to cross over the breakwater.

In summary, 4 types (A to D) of coasts were categorized as the breeding site of the land hermit crab, *Coenobita purpureus*. Type A is a sandy beach on an inlet that is connected to the open sea with a narrow channel (8 coasts). Type B is a sandy beach on an inlet embayed from a larger bay (2 coasts). Type C is a wider sandy beach directly facing the open sea (3 coasts). Type D is a rocky shore directly facing the open sea (2 coasts). Coasts of types A and B are relatively calm with sand substratum, whereas that of type C is an open sandy beach washed by relatively rough waves, and that of type D is a rocky shore exposed to violent waves. Coasts representative for respective types are shown in Figs. 4 & 6.

It is known from observations made in Okinawa that land hermit crabs including

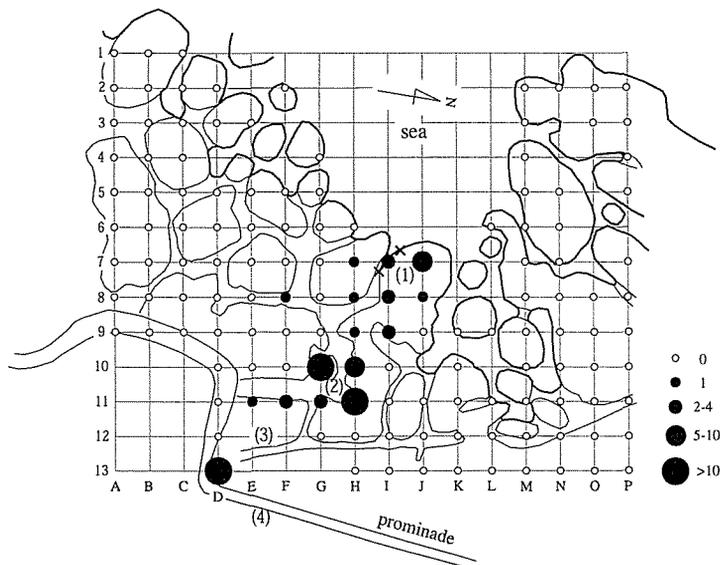
*Coenobita purpureus*, release larvae on a calm sandy beach (Nakasone 1987b), but there seems to be no report that describes the zoeal release on the rocky shore exposed to violent waves such as were seen in the present study.

### Distribution on the Sômani Coast

Fifteen points were revealed as breeding sites of the land hermit crab, *Coenobita purpureus*, on Kikaijima Island. Among them, wide coasts open to the sea, such as Sômani and Ikeji, were involved (Figs. 4 & 6). Even on such wide coasts, land hermit crabs were found in a restricted area, but not widely scattered over the substratum. To clarify the detailed distribution of crabs on a wide coast, a survey was carried out on the Sômani coast.

The breeding site on the Sômani coast was located 100 m northwest from the Sômani huge rock, and separated from the rock by the promenade (Fig. 6). The circumstance around the zoea-releasing site was a rocky reef made of large rocks which were bare near the coastline, gradually scattered with weeds such as grasses and the memorial rose, *Rosa wichuraiana* Crép, according to elevation, and finally covered with bush of *Scaevola*.

A detailed map of this coast was made by direct measurements, referring to the aerial photograph of this island. The survey was carried out in an area of 100 m × 80 m centering the zoea-release site (Fig. 7). Transects were settled parallel and perpendicular to the



**Fig. 7.** Detailed distribution of *C. purpureus* on the Sômani coast. Solid circles indicate points where the crab was found. The number of individuals is shown on the right. The mesh size is 6.56 m. Crosses (X) indicate the zoea-release sites. The numbers in parentheses are the stations investigated for the aggregation formation period.

coastline at an interval of 6.56 m, and the cross points were checked for numbers of crabs. This survey was made briefly to cover all the area for a short time: the numbers of crabs found within a circular area of 1 m diameter, when viewed from the center of the point, were recorded. When the area was on a vertical plane, such as the side of a rock, it was regarded as horizontal. When the area was covered with stranded logs or a piece of styrene foam, they were removed. The survey was made, excluding upper areas with thick vegetation and lower areas under water. This survey was made from 15:00 to 16:00 on June 20 and from 10:00 to 12:00 on June 21, 1996.

Of 135 points surveyed, hermit crabs were found inhabiting 16 points that were distributed on a line from the zoea-release site (indicated with ×) toward inland (Fig. 7). In this survey, dense aggregations of crabs were found in the ditch near the release site (I7-J7). In this ditch, innumerable numbers of crabs were observed hidden piled one over another (ref. Fig. 10-2).

These results indicate that the land hermit crabs were distributed in a relatively limited area of a wide coast.

### Aggregation Formation Period

According to Mr. Tanaka who has been observing the land hermit crabs on the island for a long time, aggregation of crabs was seen from the beginning of the rainy season in June to the end of it in July, and almost no crabs were found in the other seasons. The occurrence of the land hermit crab on the coast of Sômani was checked at 4 stations on the coast, as shown in Fig. 7, and observed at intervals of several days to one month, from July to September 1995 and May to July 1996, to confirm this. The survey was completed with the help of Mr. Tanaka.

The 4 stations were; (1) a ditch near the zoea-release site, (2) a crevice between rocks some distance from the water edge, (3) the inside of a cave about 3 m deep, and (4) under the *Hibiscus tiliaceus* L. tree in the *Scaevola* bush just on the land side of the promenade. Positions and photos of these stations are shown in Figs. 7 & 8, respectively.

The results are shown in Table 2. In the ditch near the release site (1), hermit crabs were seen till the end of August, but not in September. They started to appear in the end of June. In the crevice of rocks located above this (2), crabs disappeared earlier and appeared later than in the lower station. In the cave (3), crabs could be seen till August and gathered earlier in May than in the lower rocky stations. Under the *Hibiscus tiliaceus* tree (4), crabs could be seen latest and appeared already in May of the next year.

Among the 4 stations, those under the *Hibiscus* (4) and in the cave (3) were covered with *Scaevola* bush, whereas stations located near the coastline (1) and (2) were exposed without plants. Under such dry conditions, the aggregation formation period was from the end of June to the end of August. It is, however, unclear whether this period exactly corresponds to the real breeding period of the crabs. It needs to be verified by confirmation of zoea release or observations of berried females. Further, it is also necessary to clarify whether or not crabs continuously exist all the year round in the uppermost point



**Fig. 8.** Landscapes of the 4 stations for the survey of aggregation formation period in the Sômani coast. 1: The ditch near the zoea-release site. 2: The crevice of rocks slightly above the ditch. 3: The cave surrounded by *Scaevola* bush. 4: The *Hibiscus* tree on the upper side of the promenade. For the position of the respective stations, see Fig. 7.

under thick vegetation of the examined stations. Winter observations are needed on this problem.

In Okinawa, zoea release of this species, *Coenobita purpureus*, was observed from the end of June to the end of August (Nakasone 1987b), well coinciding with the results of the present study. However, ovigerous females were collected from the end of May to the middle of September (Nakasone 1987b), suggesting that the breeding period determined by observation of larval release seems to appear in a shorter period. The breeding season of the Yaeyama population of this species is known from May to August (Shimamura 1987). In *C. rugosus*, the zoea release was observed from July to October, and the ovigerous females were obtained from June to November (Nakasone 1987b). In *C. clypeatus* on Curaçao Island, the breeding season is described as summer and autumn (DeWirde 1973).

### Migration to the Breeding Site.

From the above survey, it is clear that the zoea-release site is restricted to a relatively

**Table 2.** Occurrence of *Coenobita purpureus* at the 4 stations on the Sômani coast.

Date	In the ditch (1) in Fig. 7	In the crevice (2)	In the cave (3)	Under the <i>Hibiscus</i> (4)
'95-7-20	⊙	○	⊙	⊙
8-26	⊙	×	⊙	×
9-26	×	×	×	○
'96-5-21	×	×	×	○
26	×	×	○	○
31	×	×	×	×
6-4	×	×	×	○
5	×	×	×	○
7	×	×	○	○
11	×	×	×	○
13	×	×	×	○
17	×	×	○	○
21	×	×	×	○
23	×	×	×	⊙
25	⊙	×	○	⊙
26	⊙	×	○	○
27	⊙	○	○	⊙
7-1	⊙	○	×	⊙
23	⊙	○	⊙	⊙

⊙ : found immediately, ○ : found after an intensive search, × : not found.

narrow area on the coast, and that the time when aggregation is formed was also limited to the summer season. From these findings, it is expected that the land hermit crabs, *Coenobita purpureus*, start to migrate to a particular site for breeding in early summer and to disperse or to return to the inland by the end of summer. Investigations were carried out by individual marking and by telemetry in a wide area including Sônami and Araki coasts to reveal the migration behavior of the land hermit crab.

### Marking survey

With an adhesive, small disks (6 mm in diameter) made of reflective plastic tape were attached to the shells of crabs found at higher points along the promenade in Sômani (ref. Fig. 10-1). The shells were also numbered with a black felt pen (Paint Marker PX-20, Mitsubishi). They were released where they had been collected. A different color of plastic tape was used for each collection site, but as the number of colors was limited, red was used for 2 sites with different numbers. Reflective tape was expected to be useful to find the marked individuals at night, but it was not.

As shown in Fig. 9, a total of 242 individuals were marked and released in June 3, 1994, and 3 of them were recaptured. One individual (green No. 9) was found at the base of a *Crinum asiaticum* L. shoot on the south of the Sômani huge rock on June 29, about 1 month after the release, and 2 individuals No. 8 marked yellow (see Fig. 10-1) and No. 7 marked red were recaptured at the zoea-release site on July 22 and 25, respectively. All the individuals found were thought to have moved along the course to the zoea-release

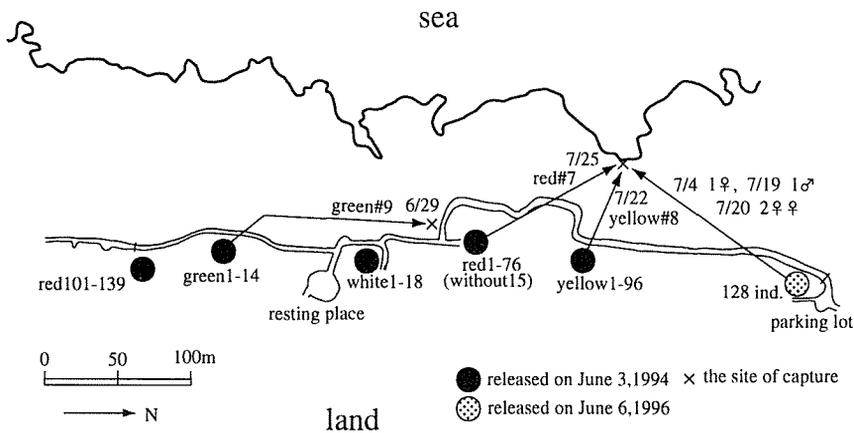


Fig. 9. The results of the marking survey on the Sômani coast.

site.

On July 12 the next year, a shell attached with a red mark was accidentally found on the sandy beach of Nagara by a primary school pupil. On this finding, there were 3 possibilities: (1) the crab that was marked at Sômani coast moved to the Nagara beach the next year and only the shell was left there for an unknown reason, (2) the marked crab drowned or slipped out of the shell when releasing larvae on the coast of Sômani and only the shell drifted to Nagara beach, or (3) the shell was artificially moved. Among these possibilities, (2) is hardly probable, because the shell would have had to drift over 1 km without sinking. In a trial, a shell of the same species, *Satsuma oshimae* (Pilsbry), put on the surface of water in a washbowl, was found to sink within 3 minutes due to the perturbation of the water. (1) and (3) are both probable. Especially, as land hermit crabs were frequently used for bait, (3) is highly probable. However, if (1) were the case, it follows that one crab visits different coasts for releasing larvae year to year, as far as shell exchange between crabs is not involved. This possibility should be checked in future studies.

To clarify the dispersion process from the aggregation site, 510 crabs in the ditch near the release site of Sômani were marked on the shell spire with a pink felt pen and released from July 19 to 20 in 1995 (Fig. 10-2). From September 26 to 27 when the aggregation had perfectly disappeared from the ditch, crabs were searched for around the promenade, and only 102 individuals were found, but all without marks. In the next year, however, 2 crabs (male, 12.0 mm in shield length and ovigerous female, 5.5 mm) were found on June 29 and July 1, respectively, at the zoea-release site, suggesting that the same crab comes to the same breeding site in successive years.

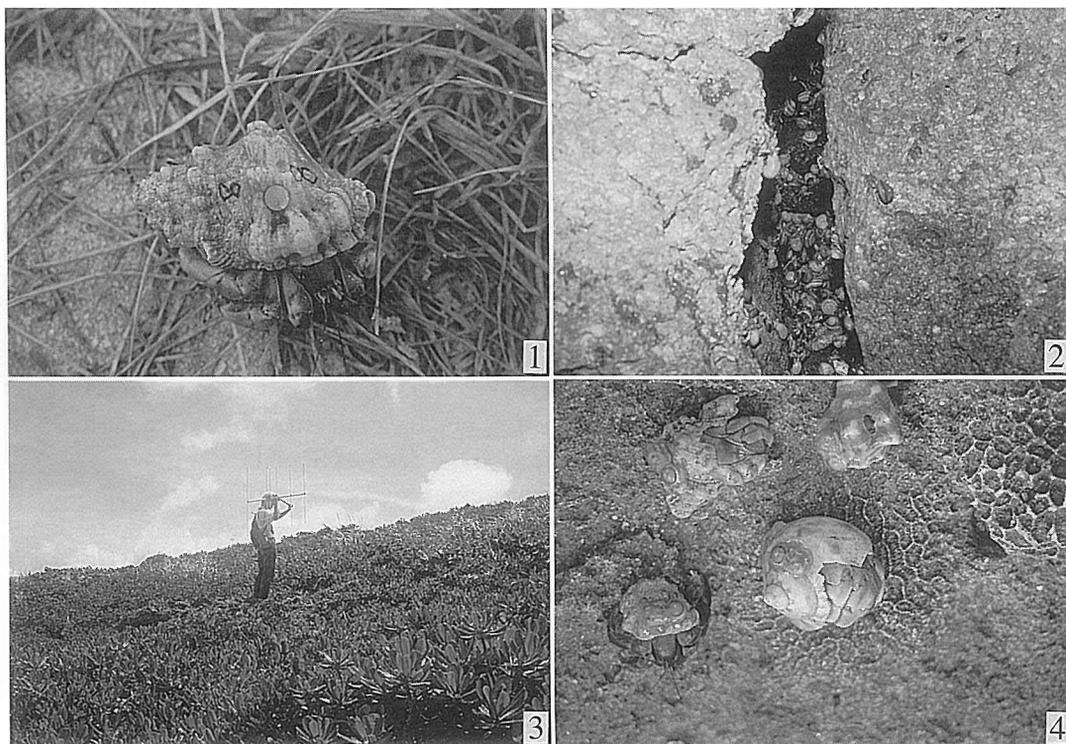
In 1996, a marking survey was carried out over a wider range. On July 6, 128 crabs collected near the parking lot of Sômani were marked with a pink paint marker and released. On June 6 and 7, 260 crabs on the coast of Araki were released, and were released 41 crabs at the middle of Sômani and Araki on June 7. In order to discriminate crabs marked the previous year, those of the current year were marked on the first whirl of the

shell, instead of the shell apex. The pattern of the mark was also changed according to the release point.

One male (8.2 mm, recaptured on July 19), 1 female (5.5 mm, July 4) and 2 ovigerous females (4.6 mm & 6.0 mm, both July 20) released near the parking lot of Sômani were found at the zoea-release site of Sômani (Fig. 9), and no more crabs could be recaptured. From this result it is inferred that crabs within a 200 m range from the zoea-release site gather to that site.

### Telemetry survey

Because the recapture rate by means of the mark-recapture method was rather low, with little information about the detailed route of the crab migration, the telemetry method was introduced in 1996. Transmitters were SMT-392-RS (150-151 MHz, 1.2 g, battery life=ca. 4 weeks) made by Urbana (USA), and the receiver was FT-290mkII made by Yaesu (Japan), with an antenna Maspro WF144 (Fig. 10-3). The detection distance was about 100 m in a clear area and about 30 m in the forest. The transmitter was attached on



**Fig. 10.** The migration survey. 1: Crab no. 8 recaptured on July 22, 1994, at Sômani. 2: Crabs lurking in the ditch near the zoea-release site of Sômani during the daytime. Many crabs show the mark painted the previous day (July 20, 1995). 3: Telemetry survey in which the crab position was located with a directional antenna (July 5, 1996, Sômani). 4: Crabs attached with transmitters (July 1, 1996).

the shell with an adhesive (Fig. 10-4), and the attached crabs were also marked with a paint marker both on the shell and the cheliped or the ambulatory leg.

On July 1, transmitters were attached to 4 crabs captured in the ditch near the zoea-release site of Sômani. They were released near the parking lot (S4), near the station (4) under the *Hibiscus* tree (S1), on the left side of the huge rock (S8), and the upper part of the Araki coast (S6). On the same day, transmitters were attached to 2 crabs in the zoea-release site of Araki. These crabs were then released in the upper part of Araki (A9) and near the station (4) of Sômani (A2). After that, they were located every day for 4 days to July 5 and also from July 19 to the end of oscillation. Hidero Tofuku of Kikai High School and Naoki Kaki of Shito-oke Primary School took part in this survey. The results are shown in Fig. 11.

Crab S1 that was released at station (4) moved toward the zoea-release site, but stopped on the way and stayed nearby for 4 days. On July 19, it had moved to the inland forest where it was darker even in the daytime. Crab S4 released near the parking lot moved toward the zoea-release site on the first day, and then moved into the forest. Finally, this crab retreated to the recesses of the forest about 1 month later. Crab S8 brought near the huge rock stayed there for 2 days, and then moved in parallel to the coastline toward the upper part of the zoea-release site, where it stayed for a long time. Crab A2 that transferred from Araki to Sômani approached the zoea-release site of Sômani on the next day. Some freshly exuded eggs were found attached to the cheliped surface on that day, suggesting that this crab had released zoeae and copulated the previous night. After that, it walked around in the *Scaevola* bush. Accidentally, it was found walking on the promenade and recovered on July 22.

On the other hand, crab S6 that was collected in Sômani and released in Araki immediately moved toward the zoea-release site of the new coast, and stayed near the site for 4 days. It was relocated in the upper part of the coast thickly covered with *Scaevola* on July 21 after which it stayed in the bush for a long time.

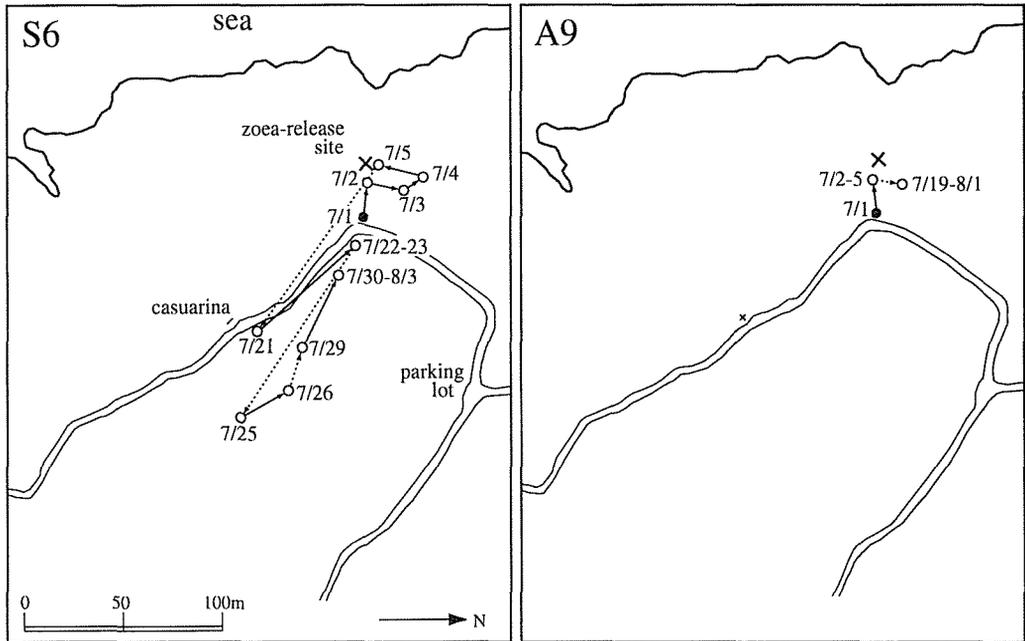
On July 19, 2 crabs (S3 and S5) captured in the ditch of Sômani were released at the site of capture after being loaded with transmitters. Transmitters were attached to 2 other crabs captured in the forest of Sômani. One (S7) was then released at the collection site, and the other (S10) transferred to the crevice near the ditch of Sômani.

Crab S3 captured and released in the ditch near the zoea-release site moved landward on the next day and stayed in the *Scaevola* bush for 10 days. It gradually moved further inland to the depths of the forest. Another crab (S5) moved toward the land one day later, and it again appeared near the coast. Crab S10 that was transferred from the upper forest to the shore returned to the forest in 2 days, and then moved around widely in the forest. Crab S7 that was collected in the forest and released there, once moved toward the coast, but moved into the depth of the forest thereafter.

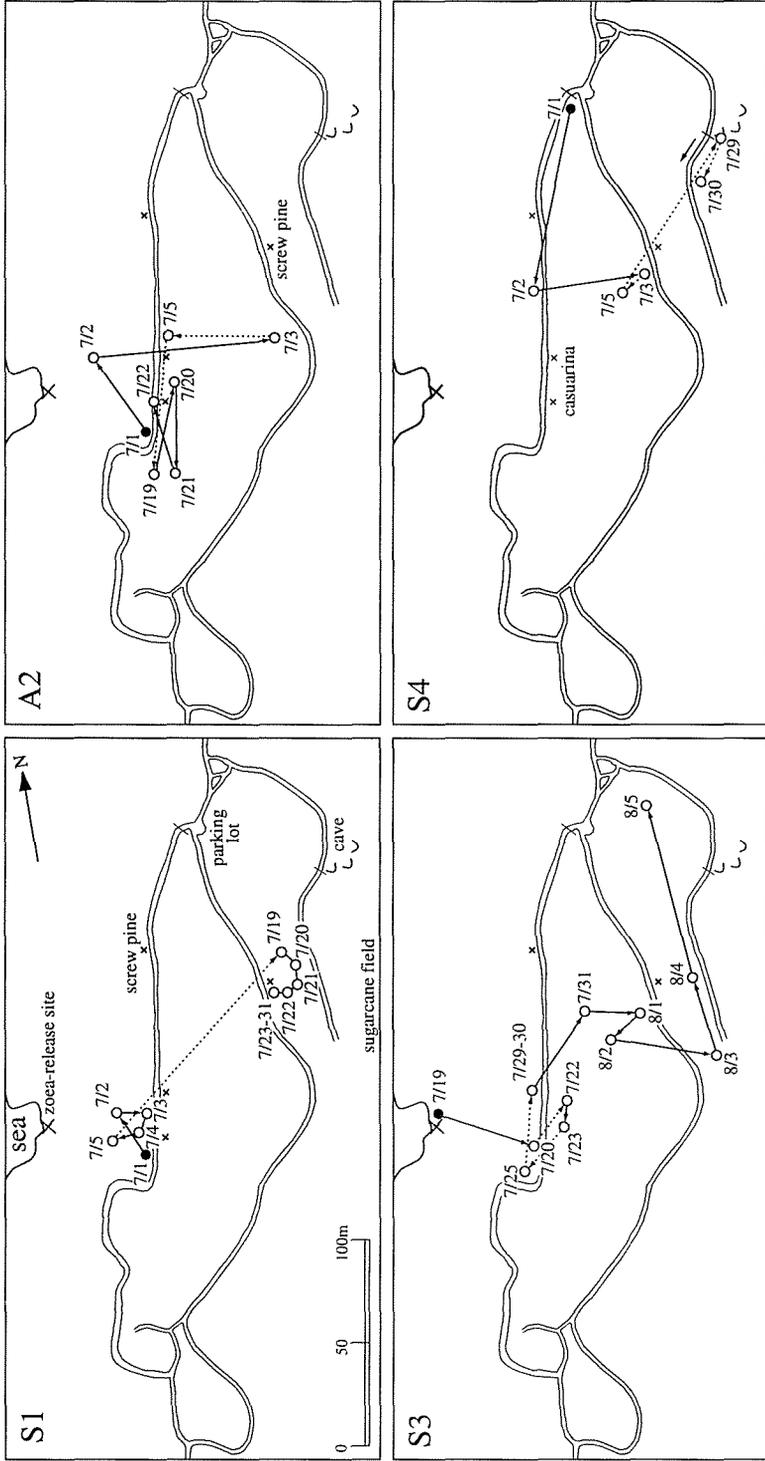
In summary, (1) 3 (S1, S4 & A9) of the 4 crabs that were collected near the zoea-release site and transferred to an upper part of the coast, immediately moved toward the zoea-release site, whereas one crab (S8) started toward the shore line after a few days. Thus, crabs seem to have knowledge about the direction of the zoea-release site even when they were transferred to a new place. (2) Two crabs (A2 & S6) that were transferred

to a new coast immediately moved toward the zoea-release site of the new coast, indicating that they were able to orient to the zoea-release site by means of some environmental cues but not by memory of a route they had once taken. As such cues, some olfactory factor specific to the zoea-release site may take part, or an olfactory agent formed by aggregation of many crabs may play a role. (3) Among some crabs released in the upper part of the coast, one (A9) reached the zoea-release site and stayed there, but many (S1, A2, S4 & S6) moved inland after once approaching the release site. Some crabs (S3, S5 & S10) moved to the forest without staying near the coastline. Thus, crabs seem not to stay near the coastline for a long time during the breeding season. (4) The moving ability of the land hermit crabs was large and could move about 100 m in a night (A2, S3 & S4), frequently going up and down between the coast and the forest. Thus, aggregation seen during the breeding season seems to change its members continuously.

As mentioned above, some aspects of migration of the land hermit crabs were clarified, but there remain some unsolved problems. Firstly, the place where they go after the aggregation breaks up is unknown. The behavior seen on crabs S1 and S7 may suggest that they retreat to the recesses of the forest after breeding, but it was not clear whether they have really finished breeding for that season. This problem is related to a possibility of individual variation in the breeding period; that is, some crabs start and end breeding



**Fig. 11.** The results of the telemetry survey. Solid and open circles indicate the point of release and the point where the crab was detected, respectively. Arrows with dotted line show including days when location was not made. The number at the top left corner indicates the individual code with "S" and "A" meaning the collection site of the crab in Sômani and Araki, respectively.



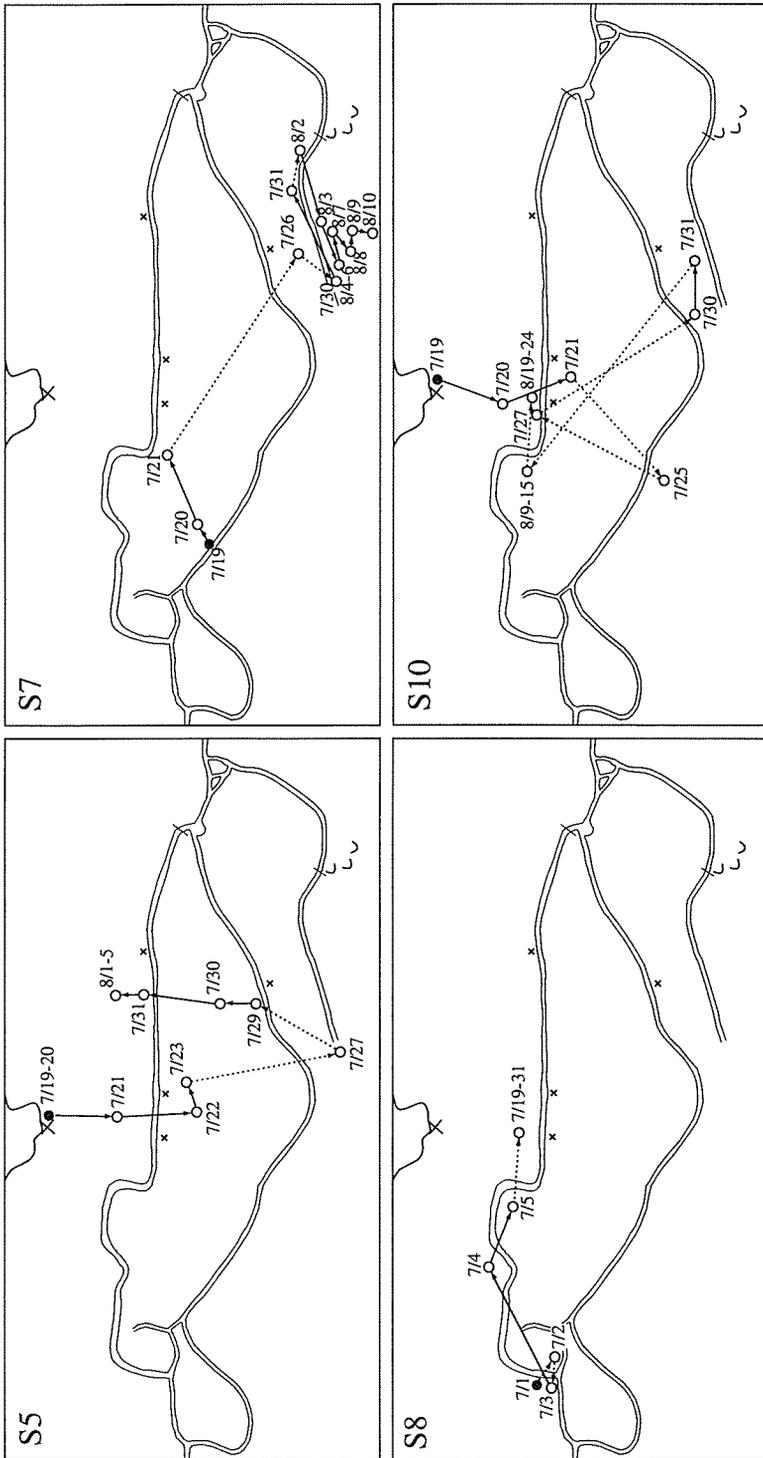


Fig.11. (continued)

earlier than the others. There may also be some difference in movement, or appearance frequencies at the aggregation site among individuals such as males, ovigerous and non-ovigerous females, or among crabs of different sizes. Future studies are needed for these problems. Contrary to the present study, De Wirde (1973) performed a large-scaled survey of migration that revealed that crabs migrated more than 3 km from the inland to the coastline in Curaçao Island.

### Acknowledgements

I thank Mr. Dôsuke Tanaka who provided me with a clue to the present study, helped gather information about the breeding sites of crabs and took part in the survey of the aggregation formation period, Hidero Tofuku of Kikai High School and Naoki Kaki of Shito-oke Primary School for assisting in telemetry work and providing meteorological data of the island and valuable photos, Ikutaro Ide of NHK for helping in the marking survey, Chihiro Aoshi of Sakamine Primary School who found a marked shell on the coast. I also thank staff of the Kikai Town Government and many islanders for invaluable information of crabs on the island. This study was partly supported by grants from MIKIMOTO FUND for Marine Ecology.

### References

- Achituv, Y. & M. Ziskind 1985 Adaptation of *Coenobita scaevola* (Forsk.) (Crustacea, Anomura) to terrestrial life in desert-bordered shore line. *Mar. Ecol. Prog. Ser.* 25: 189-197.
- Board of Education, Tokyo 1987 A survey report on the distribution of land hermit crabs in Ogasawara-shoto. The City of Tokyo. (In Japanese)
- Chase, I.D., M. Weissburg & T.H. Dewitt 1988 The vacancy chain process: a new mechanism of resource distribution in animals with application to hermit crabs. *Anim. Behav.* 36: 1265-1274.
- De Wilde, P.A.W.J. 1973 On the ecology of *Coenobita clypeatus* in Curaçao with references to reproduction, water economy and osmoregulation in terrestrial crabs. *Stud. Fauna Curaçao* 44:1-138.
- Dunham, W.D. & H. Schöne 1984 Substrate slope and orientation in a land hermit crab, *Coenobita clypeatus* (Decapoda, Coenobitidae). *J. Comp. Physiol. A* 154: 511-513.
- Hartnoll, R.G. 1988 Evolution, systematics, and geographical distribution. In: W.W. Burggren & B.R. McMahon (eds.) *Biology of the Land Crabs*. pp.6-54. Cambridge Univ. Press, New York, New Rochelle, Melbourne, Sydney.
- Hazlett, B.A. 1966 Observations on the social behavior of the land hermit crab, *Coenobita clypeatus* (Herbst). *Ecology* 47: 316-317.
- Herreid, C.F., II & R.J. Full 1986 Energetics of hermit crabs during locomotion: the cost of carrying a shell. *J. exp. Biol.* 120: 297-308.
- Imafuku, M. & H. Ikeda 1990 Sound production in the land hermit crab *Coenobita*

- purpureus* Stimpson, 1858 (Decapoda, Coenobitidae). *Crustaceana* 58: 168-174.
- Kikai Town Government 1992 Our town viewed from the sky, an album of aerial photographs of Kikaijima. Project and Sightseeing Section, Kikai Town Government. (In Japanese)
- Kinosita, H. & A. Okajima 1968 Analysis of shell-searching behavior of the land hermit-crab, *Coenobita rugosus* H. Milne Edwards. *J. Fac. Sci. Univ. Tokyo, sect. IV* 11: 293-358.
- Kuniyoshi, M. & M. Nishihira. 1987 On the land hermit crab in Bengatake, Shuri, Naha City. In: *Aman - A Report of Distribution of Land Hermit Crabs*. pp.119-132. Board of Education, Okinawa Prefecture. (In Japanese)
- Kurozumi, T., M. Toyama & K. Shimamura 1987 Ecological observations on land hermit crabs on Min-najima, Okinawa Prefecture. In: *Aman - A Report of Distribution of Land Hermit Crabs*. pp.133-151. Board of Education, Okinawa Prefecture. (In Japanese)
- Miyake, S. 1982 Japanese crustacean decapods and stomatopods in color. Vol. 1. Hoikusha, Osaka. (In Japanese)
- Nakasone, Y. 1987a Taxonomy of genus *Coenobita* in Okinawa Prefecture. In: *Aman - A Report of Distribution of Land Hermit Crabs*. pp.3-15. Board of Education, Okinawa Prefecture. (In Japanese)
- Nakasone, Y. 1987b Ecological research on land hermit crabs in the south part of Okinawajima and Kudakajima. In: *Aman - A Report of Distribution of Land Hermit Crabs*. pp.16-60. Board of Education, Okinawa Prefecture. (In Japanese)
- Nakasone, Y. 1987c On the development of larvae of some species. In: *Aman - A Report of Distribution of Land Hermit Crabs*. pp.152-176. Board of Education, Okinawa Prefecture. (In Japanese)
- Page, H.M. & S.W. Willason 1982 Distribution patterns of terrestrial hermit crabs at Enewetak Atoll, Marshall Islands. *Pac. Sci.* 36: 107-117.
- Page, H.M. & S.W. Willason 1983 Feeding activity patterns and carrion removal by terrestrial hermit crabs at Enewetak Atoll, Marshall Islands. *Pac. Sci.* 37: 151-155.
- Radinovsky, S. & A. Henderson 1974 The shell game. *Nat. Hist.* 83: 22-29.
- Shimamura, K. 1987 Ecological research on land hermit crabs in Yaeyama-shoto. In: *Aman - A Report of Distribution of Land Hermit Crabs*. pp.61-118. Board of Education, Okinawa Prefecture. (In Japanese)
- Shokita, S. & A. Yamashiro 1986 Larval development of the land hermit crab, *Coenobita rugosus* H. Milne Edwards and *C. cavipes* Stimpson reared in the laboratory. *Galaxea* 5: 267-282.
- Takahashi, S. 1934 On the land-hermits (Coenobitidae) in Formosa. *Trans. Nat. Hist. Soc. Formosa* 33: 506-517. (In Japanese)
- Thacker, R.W. 1994 Volatile shell-investigation cues of land hermit crabs: Effect of shell fit, detection of cues from other hermit crab species, and cue isolation. *J. Chem. Ecol.* 20: 1457-1482.
- Thacker, R.W. 1996 Food choices of land hermit crabs (*Coenobita compressus* H. Milne Edwards) depend on past experience. *J. exp. mar. Biol. Ecol.* 199: 179-191.

- Walker, S.E. 1994 Biological remanence: Gastropod fossils used by the living terrestrial hermit crab, *Coenobita clypeatus*, on Bermuda. *Palaos* 9: 403-412.
- Yamaguchi, S. 1938 Larval release and development of the land hermit crab, *Coenobita rugosus*. *Gakujutsu-zasshi* 8: 163-177. (In Japanese)
- Yamashiro, J. 1987 Distribution and shell utilization of land hermit crabs on Sesoko Island of Okinawa Group, the Ryukyus. *Biol. Mag. Okinawa* 25: 35-42. (In Japanese)
- Zeze, T. & H. Suzuki 1986 Genus *Coenobita* in Kagoshima Prefecture — a report of urgency on the distribution. Board of Education, Kagoshima Prefecture. (In Japanese)