Acorn–foraging activity and feeding behaviour by two species of freshwater crabs (Brachyura: Potamidae) from Okinawa Island, Ryukyu Islands, Japan

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Abstract.—Acorn foraging activity and feeding behaviour by two species of potamid freshwater crabs (Geothelphusa grandiovata and Candidiopotamon okinawense) were studied at Yanbaru forest, northern Okinawa Island, Ryukyu Islands, Japan. Adult females of the two species were observed to inhabit burrows that were filled with acorns of Castanopsis sieboldii and Quercus miyagii. The burrows with the crabs as well as gathered acorns were distributed relatively close to a stream (0.8–5 m) at slopes of the forest. Acorns were either eaten with a part of the lower part or seed coat remaining, or vertically broken up and only the inside consumed. Feeding experiments under laboratory conditions indicated that the acorns eaten by G. grandiovata had the same feeding scars as the ones found around crabs burrows, suggesting that the crabs were indeed feeding on acorns. There were 1–24 uneaten acorn(s) observed from all burrows with gathered acorns. Some of the uneaten acorns were even germinated at both around opening of and in the burrow. The accumulation of acorns by the crabs thus inadvertently helps the dispersal of C. sieboldii and Q. miyagii along the slopes of valleys, where the seeds cannot easily lodge and germinate.

Introduction

True freshwater crabs spend their entire life cycle in freshwater and/or semiterrestrial to even terrestrial environments as they lack planktonic phase and practice direct development (e.g. Ng, 1988; Kasai & Naruse, 2003). The area called “Yanbaru” is located at the northern part of Okinawa Island and hosts a Castanopsis sieboldii (acorn)–dominant evergreen broadleaf forest. The Yanbaru forest is also famous for several iconic and Yanbaru–endemic species, e.g. the Okinawa rail, Gallirallus okinawae (Yamashina & Mano) (Rallidae); Okinawa woodpecker, Sapheopipo noguchii (Seebohm) (Picidae); Yanbaru long–armed scarab beetle, Cheirotonus jambar Y. Kurosawa (Scarabaeidae), etc. Five species of true freshwater crabs are also distributed in the Yanbaru area; Geothelphusa sakamotoana (Rathbun, 1905); G. tenuimanus (Miyake & Minei, 1965); G. aramoto Minei, 1973; G. grandiovata Naruse, Shokita & Ng, 2006, and Candidiopotamon okinawense Minei, 1973 (Gima & Shokita, 1980; Naruse et al., 2006; Yeo & Naruse, 2007). Three of these species (G. tenuimanus, G. grandiovata and C. okinawense) are endemic to Okinawa Island (Suzuki & Naruse, 2011), and C. okinawense is restricted to the Yanbaru area.

In their general review of Ryukyuan freshwater crabs, Kasai & Naruse (2003) noted that they usually feed on attached algae, rotten fallen leaves, and aquatic insects in rivers, as well as fallen leaves and nuts, dead bodies (e.g., frogs and worms) etc. Recently, one of the authors (TS) found feeding signs on aggregations of fagaceous acorns around burrows of G. grandiovata and C. okinawense, which was briefly noted by Tsuchiya et al. (2013). Such aggregations have been observed from forests of Mts. Yona, Nishime, Ibu, and Yonaha, all in the Yanbaru area (T. Sasaki, unpublished data). The present study records in detail the foraging activities and feeding behaviour of the two crab species.

Materials and Methods

The field survey was conducted at Yona field, Subtropical Field Science Center, University of the Ryukyus, from 10th to
14th February 2004. The surveyed forest is about 220 m above sea level and located at almost the head of streams. The forest has not been clear-cut logged for more than 50 years (Saito, 2011). In this forest, the distribution of burrows of the freshwater crabs was surveyed for about 2 ha (about 200 m long along a stream, with about 100 m wide (Fig. 1). Locations of the burrows with and without aggregated fagaceous acorns were mapped (Fig. 1). For the burrows with aggregated acorns, major and minor axes of the opening were measured first, and then the burrow was slowly dug by a small scoop as deep as its end and burrow’s schematic figure was drawn. Number, species, presence or absence of feeding sign on aggregated acorns from both outside and inside the burrow were recorded and their locations were mapped onto the schematic figure. All those acorns were collected and studied in the laboratory. The species, sex, and size (carapace length
× width in millimeter) of resident crab were also recorded. To understand the fagaceous flora of the studied site, a cross section of the vegetation was drawn by mapping and measuring height of trees with the chest–height diameter of more than 10 cm for an area of 30 m (from bottom of valley toward the ridge) × 10 m from about the center of the studied site (Fig. 2).

Three female *G. grandiovata*, collected from burrows with aggregated acorns, were used to observe feeding behaviour in the laboratory. Since males were not collected from the study site, a male *G. grandiovata* was collected from upstream of Zatsun River to observe its feeding behaviour. The crabs were kept individually in a cage (73 cm length × 40 cm width × 44 cm height) with a layer of Kunigami Maaji (red residual soil; see Miyagi & Kondo, 1990) covered by leaf mold. After three days of starvation (only water was provided), 10 acorns of *Castanopsis sieboldii* were provided to each crab at 20:00 hours. Feeding behaviours were observed under the fluorescent light wrapped with a red cellophane sheet. The timing of feeding was recorded. Remains of acorns were then compared with those collected from the field.

Naruse et al. (2006: 761) provisionally defined the minimum adult size of female *G. grandiovata* as 27.1 × 33.8 mm based on the criterion that “the smallest individual whose fifth abdominal somite is equal to or wider than the third somite”. Based on this criterion, and the specimens of *C. okinawense* examined by Naruse et al. (2007), the minimum size of adult female *C. okinawense* is defined as 23.9 × 27.4 mm. The specimens examined are deposited in the National Museum of Nature and Science, Tokyo (NSMT); Ryukyu University

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*Fig. 2. A cross section of vegetation map in the study site. The section corresponds to a line between 7 and b in Fig. 1.*
Results

Burrows of crabs and aggregated acorns

A total of 26 burrows, including old ones, were found in the present study (Fig. 1). Among these burrows, aggregated acorns were observed at eight burrows (Fig. 3A), of which six were inhabited by a single individual each. Aggregations of acorns were found only around these burrows. These crabs include five females of *Geothelphusa grandiovata* (36 × 45 – 41 × 55 mm) and one female of *Candidiopotamon okinawense* (32 × 34 mm) (Table 1). The distance between the stream at the bottom of the valley and the opening of burrows varied between 0.8 to 4 m in *G. grandiovata*. The burrow of *C. okinawense* was located farthest from the stream (5 m), but the burrows with crabs were, in general, located at the lower part of the valley (Fig. 1).

Accumulated acorns were mostly of *Castanopsis sieboldii*, except for one *Quercus miyagii*. The number of aggregated acorns ranged from 6 to 168 at burrows of
ACORN-EATING FRESHWATER CRABS FROM THE RYUKYUS

G. grandiovata, of which 1 to 24 acorns were not eaten at the time of sampling. In the burrow of C. okinawense, 13 acorns out of 63 accumulated acorns were not eaten.

Figure 3 indicates examples of the distribution of acorns accumulated by the crabs. Acorns were accumulated around the opening of the burrow in that of G. grandiovata (Fig. 3B), whereas acorns were also seen in the burrow of C. okinawense (Fig. 3C). Some of the uneaten acorns had germinated around the opening of and in the burrow.

Acorns were either consumed entirely (including the seed coat) with the lower parts remaining, or broken up and only the inside was eaten.

Vegetation

The results of the vegetation survey are summarized in Table 2. The number of relatively arbor trees with a chest–height diameter of more than 10 cm are 41 trees belonging 11 species, including Castanopsis sieboldii (14 trees, 34%), followed by Meliosma squamulata (8 trees, 20%), Symplocus prunifolia (4 trees, 10%), Distylium racemosum and Syzygium buxifolium (3 trees each, 7%), Quercus miyagii, Diospyros morrisiana and Schefflera heptaphylla (2 trees each, 5%), and others. Among them, fagaceous species that produce acorns are C. sieboldii and Q. miyagii only. As the vertical section of vegetation shows (Fig. 2), C. sieboldii is more common from

Table 2. Vegetation table from the study area. Data were based on the trees with chest–height diameter of more than 10 cm from an area of 10 m × 30 m.

| Species                  | Number of trees | Percentage of tree numbers (%) | Mean chest–height diameter (cm) ± S.D. | Mean tree height (m) ± S.D. |
|--------------------------|-----------------|---------------------------------|---------------------------------------|-----------------------------|
| Castanopsis sieboldii    | 14              | 34                              | 31.4±11.5                             | 15.1±2.3                    |
| Meliosma squamulata      | 8               | 20                              | 14.3±4.4                              | 8.1±3.5                     |
| Symplocus prunifolia     | 4               | 10                              | 16.9±8.8                              | 9.0±5.1                     |
| Distylium racemosum      | 3               | 7                               | 24.2±13.7                             | 25.0±1.0                    |
| Syzygium buxifolium      | 3               | 7                               | 14.0±1.5                              | 9.2±1.6                     |
| Quercus miyagii          | 2               | 5                               | 22.0±10.6                             | 14.0±1.4                    |
| Diospyros morrisiana     | 2               | 5                               | 12.7±2.9                              | 11.0±1.4                    |
| Schefflera heptaphylla   | 2               | 5                               | 14.3±2.4                              | 9.0±1.4                     |
| Neolitsea sericea        | 1               | 2                               | 18.9                                  | 12.0                        |
| Daphniphyllum tejismannii| 1               | 2                               | 10.2                                  | 9.5                         |
| Meliosma rigida          | 1               | 2                               |                                       |                             |
Fig. 4. A male *Geothelphusa grandivata* eating an acorn (in laboratory). A, *G. graniovata* biting an acorn using its mandibles; B, part of the acorn bitten off. m, mandible; t, third maxilliped.
halfway of the valley to the ridge, while *Q. miyagii* is found in the lower part of the valley.

*Laboratory observations*

All four *G. grandiovata* individuals tested in this study consumed acorns of *C. sieboldii*. The most common method used by both a male and females is that they hold the acorns by their chela and third maxillipeds, bite the acorn (including the seed coat) with the mandibles; always starting from the upper part and leaving the lower areas uneaten (Fig. 4). Some individuals ate only the upper half of the acorn. They took 20, 36, and 40 minutes to finish consuming one acorn, respectively. The feeding marks and remnants of these acorns in the cages matched those collected from the field very well (Fig. 5).

**Discussion**

The Yanbaru forest at the northern part of Okinawa Island is covered by evergreen broadleaf forest that contains dominant *Castanopsis sieboldii, Quercus miyagii, Distylium racemosum* etc. Among these component species, fagaceous trees like *C. sieboldii*, *Lithocarpus edulis* and *Q. miyagii* are contributing to various kinds of animals in providing acorns as their food source (e.g., Teruya et al., 2010; Kotaka, 2011). The present study showed that aggregations of acorns of *C. sieboldii* and *Q. miyagii* occurred only around the burrows of adult female *Geothelphusa grandiovata* and *Candidiopotamon okinawense*, indicating that the freshwater crabs gather the acorns around their burrows. The feeding signs observed from the gathered acorns and those eaten by the crabs in laboratory conditions matched very well, confirming that the crabs are eating the acorns in the wild. Most of the acorns gathered by the crabs were *C. sieboldii* (99.8%), which makes sense as there are more trees of this species than *Q. miyagii* (Table 2). It is interesting that the crabs always started eating the acorn from the top (Fig. 4) and leave the lower parts uneaten in the laboratory condition. It may be easier for the crab to start biting from the top, as the upper half of the acorn is gently tapering toward the top. Also, it would appear that the crab does not eat the harder lower part, as observed both in the field and laboratory. The crabs did not break the acorn by their chelae in the laboratory, but this may have occurred in the wild as we found some acorns cut in half in the field (Figs. 3A, 5A).

The feeding habits of freshwater crabs are, in general, described as omnivorous. Fujita (2009) recorded that *Geothelphusa*...
miyakoensis Shokita, Naruse & Fujii, 2002, fed on plant (e.g., stems, branches and fallen leaves, fallen figs of Ficus microcarpa, F. superba var. japonica and green algae) as well as animal matter (e.g., land snails, larvae of dragonflies, carapace of G. miyakoensis etc.). Furthermore, during their ecological survey of G. dehaani (White, 1874), G. exigua Suzuki & Tsuda, 1994, and G. marmorata Suzuki & Okano, 2000, Okano et al. (2003) used traps baited with chicken, dog food and mashed spinach, and these have a higher catch–rate with just chicken–baited traps. It is not surprising that the freshwater crabs eat acorns. The present study showed that only adult females gathered acorns around their burrows. However, an adult male of G. grandiovata was also observed eating a fallen acorn of C. sieboldii on a forest road (T. Sasaki, unpublished data). In addition, laboratory experiments show that male also eat acorns. Further surveys will be needed to confirm that male crabs also gather acorns around its burrow.

Teruya et al. (2010) recorded that acorns of C. sieboldii fell between September and January, and the peak month of the acorn fall was November. This suggests that acorn–eating by crabs is seasonal. It is still difficult to assess how much the crabs depend on acorns as food sources. In any case, the ecologies and life histories of G. grandiovata and C. okinawense are understudied. Gima & Shokita (1980) recorded an individual (size unknown) was observed from a burrow with a depth of about 1 m with water in the bottom in the relatively cold winter season of December 1977 and January 1978. Naruse et al. (2006: 769) noted that “large individuals [of G. grandiovata] seem to prefer burrows which have at least some water in the bottom, but medium–sized individuals (e.g. a female, RUMF–ZC–143, CL 27.1 [× CW 33.8] mm; a male, RUMF–ZC–141, CL 29.7 [× CW 37.0] mm) have been obtained from totally dried burrows”. The “large individuals” mentioned above were, for example, ZRC 2006.0076 (44.8 × 55.4 mm) and NSMT–Cr 16851 (37.6 × 47.0 mm), collected by one of the authors (TN) in the relatively hot summer
season of July. In contrast, “medium–sized individuals” from dried burrows were collected from relatively cold periods (November and December) (Naruse et al., 2006). All the burrows observed by one of the authors (TN) did not have aggregated acorns around them. Among the burrows observed in the present study (February 2004, in winter), only the ones that were located very close to the stream contained water at the bottom of the burrows. The available data indicates that *G. grandiovata* appears to use a relatively wide range of habitats. *Candidiopotamon okinawense* is usually observed in shallow rivers near banks as well as terrestrial environments some distance from water sources (e.g. about 30–37 m from the Funn River; 120–200 m from the Aha River; cf. Gima & Shokita, 1980). Further ecological studies will be needed to evaluate the importance of acorns in the life history of freshwater crabs.

All six crabs collected from burrows with gathered acorns had uneaten ones at their burrows. It was also observed that some of the uneaten acorns of *C. sieboldii* had germinated around the opening of and in the burrow of *G. grandiovata* (Fig. 6). There are numerous studies on ecological and evolutionary interactions between seed trees and seed predators (e.g. Smith & Reichman, 1984; Kallander & Smith, 1990; Steele et al., 2005; Steele, 2008). For example in tree squirrels, while they primarily act as seed predators, they also function as a dispersal agent as they sometimes left cached acorns uneaten that later germinate (Smith & Reichman, 1984; Steele, 2008). It is possible that the accumulation of acorns by the crabs helps in seed dispersal, especially on the slopes of valleys where seeds cannot easily get lodged and germinate due to the steep gradient.

**Acknowledgments**

We express our thanks to Nobuhito Shimada, Issei Kawashima, Bunntaro Kusumoto, Misaki Kishaba, Hitomi Yara and Masayuki Hayashi who helped field survey of the present study. Prof. Shigemitsu Shokita encouraged us and kindly provided important literature. We also thank two anonymous reviewers who greatly improve our earlier version of the manuscript.

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Received: 8 April 2014.
Accepted: 1 October 2014.