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Research Article

Life History of an Endangered Marine Insect *Halovelia septentrionalis* Esaki (Hemiptera: Veliidae)

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Halovelia septentrionalis Esaki is one of the endangered marine water striders found along the Japanese coast. It is of primary importance to investigate its life history in the field so as to develop conservation measures as well as to understand how this species has adapted to marine environments. We studied its life history in Misaki on the southern part of the Miura Peninsular near Tokyo, ca. 35°N, probably the northernmost locality not only for *H. septentrionalis* but also for any *Halovelia* species, most of which are found in warm tropical or subtropical waters. The southern part of the Miura Peninsular has jagged coastlines with deep inner bays. Adults and nymphs were found skating along the rocky shore of inner bays with overhanging vegetation nearby. This species appeared to have at least 2 generations a year and to overwinter in the adult stage. We discussed its overwintering strategy in comparison to those of two other Japanese marine water striders.

1. Introduction

Out of more than one million extant insect species, only a few thousand species are found in the marine environment [1, 2]. Water striders and their allies (Heteroptera: Gerromorpha) are probably the most successful insect group in colonizing in the marine habitats [3]. More than 150 species representing five families of Gerromorpha are marine, occupying the two-dimensional niche, that is, the sea surface, and most of them live in warm tropical or subtropical waters between 30°N and 30°S [3–5].

Along the Japanese coast, 6 species of marine Gerromorpha are known to live. All of them are now designated as endangered or nearly endangered by the national government and/or local authorities due to the population decrease caused by coastal developments and seawater pollution [6]. Two species of endangered marine Gerromorpha, *Halovelia septentrionalis* Esaki and *Halobates japonicus* Esaki, were recorded by Esaki [7–9] along the coast of Misaki on the Miura Peninsular near Tokyo, ca. 35°N, probably the northernmost localities for these two species. For the last several decades the coastlines around this area have been drastically developed and altered by the growth of big cities such as Tokyo. Surveys conducted in 2011 and 2013 for the two species in the southern part of the Miura Peninsular including Misaki revealed that *H. japonicus* was probably extinct [10]. As for *H. septentrionalis* (Figure 1(a)), they were found in a few inner bays. In most cases, a handful of individuals were found skating on the sea surface close to the shore. Considerably abundant populations were found only at a small number of sites that still to some extent retain the features of natural coasts, such as a cove conserved by citizen groups or some tiny coastal spots hardly accessible from the land due to bad road connections. Little is known about the ecology of *H. septentrionalis* in the natural habitat except for a brief account of its biology and behavior based on the observations by Esaki [7]. It is of primary importance to study its life history in the field so as to develop conservation measures as well as to understand how this species has adapted to marine environments. With the above in mind, we conducted a year-round survey of *H. septentrionalis* in one of the inner bays around Misaki. Most other *Halovelia* species inhabit areas among coral reefs in warm tropical or subtropical waters [11–13]. Therefore, it is quite intriguing how *H. septentrionalis* has

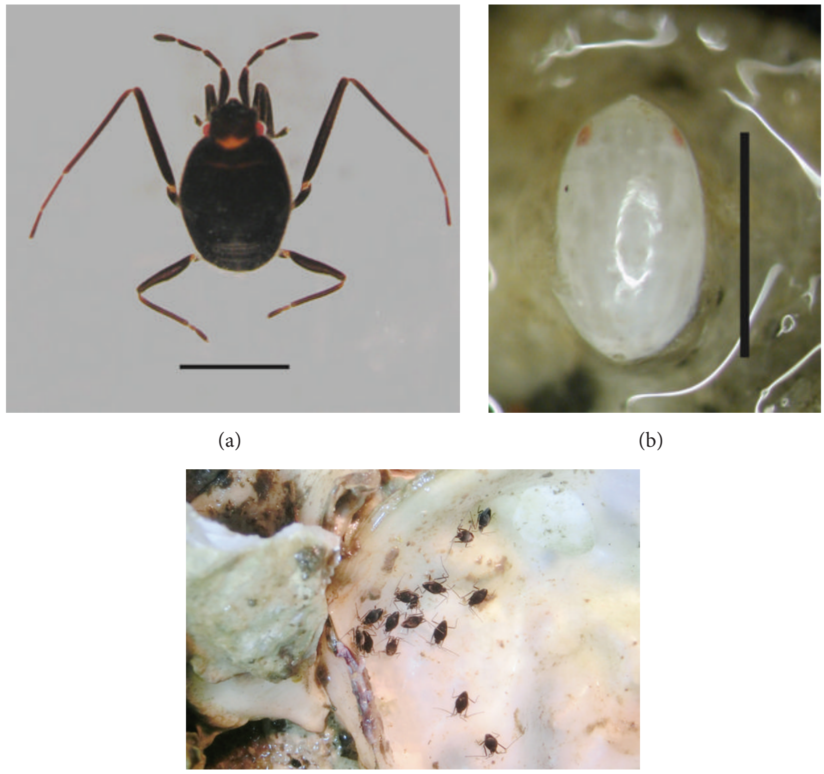

Figure 1: *H. septentrionalis*. (a) Male adult. Scale = 1 mm (Photo by T. Ikawa). (b) Developing egg with red eye-spots showing through. Scale = 0.5 mm (Photo by T. Ikawa). (c) Overwintering individuals in an oyster shell (Photo by H. Era).

Figure 2: Habitat of *H. septentrionalis*. This species is found along rocky shores with overhanging vegetation nearby (a), in a calm inner bay protected from strong winds and waves (b).

survived along the rocky shore of Misaki, in the temperate climate zone of Japan, where snow falls and the sea surface temperature drops below 15°C during winter.

2. Materials and Methods

2.1. Study Site. Our study was conducted along the shore of an inner bay in the Misaki area in the southern part of the Misaki Peninsular, Kanagawa, Japan (35°10′N 139°37′E). The southern part of the Miura Peninsular has jagged coastlines with deep inner bays as is seen in Figure 2(b). Some other marine water striders recorded in Japan, *Halobates matsumurai* Esaki and *Asclepios shiranui* (Esaki), are also found in such inner bays [14–18]. The study site was characterized by a rocky shore under a cliff with overhanging vegetation nearby (Figure 2(a)), difficult to access from the land. We visited the study site on vessels owned by Misaki Marine Biological Station, School of Science, The University of Tokyo, hereafter referred to as MMBS.

2.2. Surveys and Samplings. Once a month from March 2014 to April 2015 excluding April 2014, we made intensive surveys along the coast in the study site. We searched for eggs, nymphs, and adults of *H. septentrionalis* on the sea surface, on the rock surfaces, in the holes and crevices of rocks, and in empty oyster shells on the rocks. Most adults and nymphs were found skating on the sea surface. In order to examine seasonal changes in the composition of adults and nymphs, from the shore, we collected samples off the sea surface using insect nets with an opening of 25 cm in diameter. The survey dates in 2014 were March 7, May 15-16, June 12-13, July 24-25, August 13, September 10, October 10, November 5-6, and December 8. Survey dates in 2015 were January 7-8, February 6, March 5-6, and April 2-3. The sampling was conducted once during each survey if adults and/or nymphs were found.

All the specimens collected were preserved in 99% ethanol and kept at the University of Morioka for further studies in the laboratory. Under the stereomicroscope adults were sexed and nymphs were sorted into developmental stages by measuring representative leg segments. To examine seasonal changes in the egg load of females, we dissected 20 females from each month, counted mature eggs in the ovarioles, and measured the length and width of the largest mature egg from each female.

3. Results

3.1. Appearance of Adults and Nymphs. As is shown in Figure 3, adults were found from May to November 2014 and in April 2015. Nymphs were found from July to November 2014. During the spring and summer, many mating pairs were observed and during the autumn the number of mating pairs appeared to decrease. The proportion of females was higher than that of males in May, September, October, and November of 2014 and April of 2015. The majority of mating pairs and single adults were skating in sparse aggregations along the shore. Some adults were skating as singles. From July, nymphs appeared. Nymphs were aggregating with adults or skating singly. There were very few young nymphs found during the surveys. Occasionally, a few adults or nymphs were observed jumping on the rock. So far, no individuals were found in the holes and crevices of the rocks.

During the cold season, that is, in the month of March 2014 and during the period from December 2014 to March 2015, neither adults nor nymphs were found in the study site. However, a number of overwintering adults were found in an empty oyster shell on a rock along the shore in a bay near the study site around 11:30 p.m. on December 21, 2014 (H. Era, personal communication). According to Mr. Era, the empty oyster shell was opened with an abalone scraper because it was tightly closed except for a very narrow chasm between valves through which *H. septentrionalis* would barely be able to enter. They were alive but very inactive. Judging from the picture provided by Mr. Era (Figure 1(c)), there were 14 or 15 individuals of which, at least, 11 were female adults, probably 3 were male adults. There was one unidentifiable individual. The oyster shell was attached to the rock at around the lowest sea level which was underwater most of the day. Although several other empty oyster shells were opened and examined

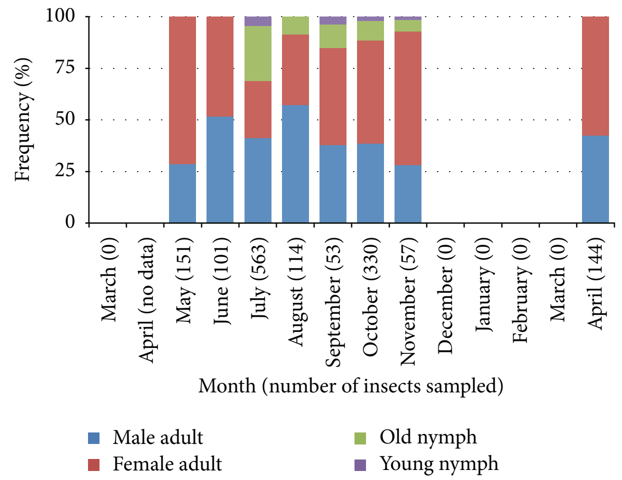

Figure 3: Seasonal changes in the composition of developmental stages of *H. septentrionalis* from March 2014 to April 2015.

on the same day, no other *H. septentrionalis* was found. The air temperature was 2°C and the sea surface temperature was 14°C. Since then, we have opened and examined numerous empty oyster shells at the study site but no overwintering individuals have yet been found.

3.2. Egg Load of Adult Females and the Search for Eggs in the Field. The egg loads of females of each month are shown in Figure 4. In late autumn (October and November 2014) and in early spring (April 2015), no females had mature eggs. In May 2014, 50% of females had mature eggs. In June 2014, all the females had mature eggs. From July to September 2014, 65%–100% of females had mature eggs. The number of mature eggs per female was at most 4.

Table 1 shows the average length and width (mm) of the largest mature egg of each female from May 2014 to September 2014. The length ranged from 0.676 mm to 0.703 mm and the width from 0.313 mm to 0.320 mm. Compared to the average size of adult females (body length = ca. 2 mm), the egg size was quite large and the body cavities of females were filled with eggs. The egg shells of *H. septentrionalis* were soft, different from the hard egg shells of other marine water strider *Halobates matsumurai* and *Asclepios shiranui* that overwinter in the egg stage.

In spite of an intensive search during the surveys we found no eggs in the study site. However, females kept in a tank with seawater and rocks in the laboratory laid eggs on a rock around the water surface (Ikawa and Miyata, unpublished observation; Figure 1(b)).

4. Discussion

4.1. Life Cycle of H. septentrionalis. Our study showed that (1) no individual was found at the study site during the winter; (2) only adults appeared in spring while nymphs did not appear until summer; (3) both adults and nymphs were observed until late autumn (Figure 3). These results and the fact that a number of overwintering adults were found in the

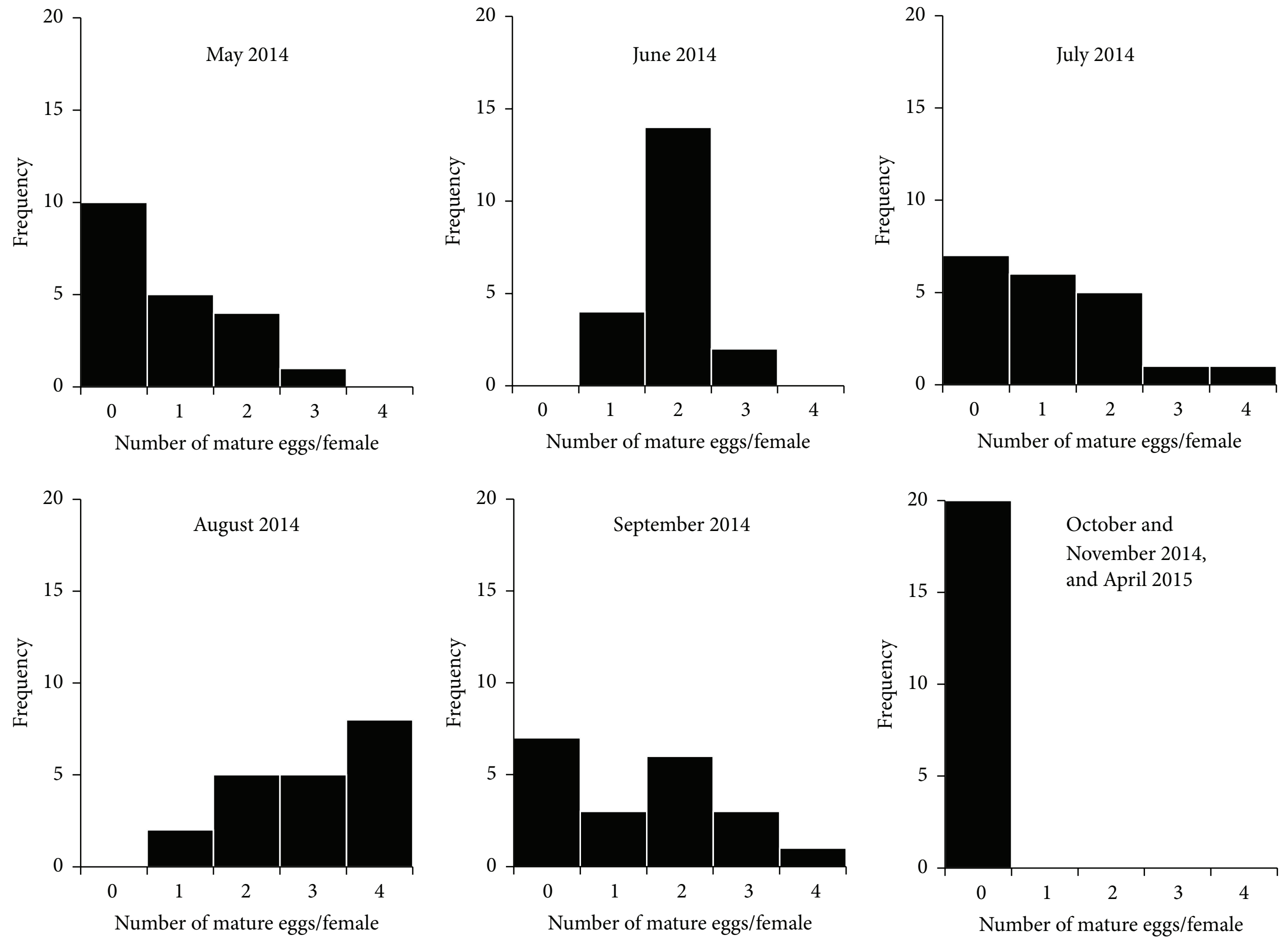

Figure 4: Histogram of number of mature eggs/female from May 2014 to April 2015.

Table 1: Average length and width (mm) of largest mature egg in a female collected in 2014.

Date of sampling	Number of eggs measured	Length and width (average ± SD) of mature egg	
		Length (mm)	Width (mm)
May 15	10	0.676 ± 0.0300	0.313 ± 0.0215
June 12	19	0.687 ± 0.0165	0.324 ± 0.0164
July 24	11	0.687 ± 0.0171	0.322 ± 0.0164
August 24	19	0.692 ± 0.0300	0.321 ± 0.0154
September 10	13	0.703 ± 0.0262	0.320 ± 0.0183

empty oyster shell in December (H. Era, personal communication) strongly suggest that *H. septentrionalis* overwinter in the adult stage. After overwintering, adults would have appeared on the sea surface and mated, at latest, by April. As shown in Figure 4, in April no adult females had mature eggs, in May 50% of females had mature eggs, and in June all the females had mature eggs. This suggests that the oviposition of females would have started in late April or early May and lasted for a few months. The nymphs that appeared in July would have been hatched from these eggs and have become adults in August or after. Nymphs observed in late autumn would have died before becoming adults. Mating pairs were observed until November. However, there were no eggs in females' ovarioles in late autumn. Thus, *H. septentrionalis* probably overwinter in the adult stage and there may be at least 2 generations a year.

4.2. Eggs in the Field. Esaki [7] found no eggs of *H. septentrionalis* during his survey along the coast. We also did not find eggs in the field. However, the fact that females kept in a tank laid eggs on a rock (Ikawa and Miyata, unpublished observation) suggests that the oviposition site of *H. septentrionalis* would be on the surface of the rocks in the field. Kellen [19] found no eggs of *H. bergrothi* Esaki in the coast of Samoa but, in the laboratory, females laid eggs in the holes of rocks in a tank.

4.3. Comparison of Overwintering Strategies among Three Marine Water Striders. Halobates matsumurai Esaki live along the southwestern coast of Japan [14, 20]. *H. matsumurai* lays eggs on the sandstones along the shore mostly above the average sea level and overwinters in the egg stage [17]. Overwintering eggs stay on the sandstones for more than 6 months from late autumn to spring. The eggs of *H. matsumurai* are covered with hard shells, presumably serving to protect them from desiccation, solar radiation, and storms. Laying eggs above the average sea level would serve to keep them from the damage of wave action and thus to survive a long overwintering period. *Asclepios shiranui* that often cooccurs with *H. matsumurai* also has eggs with hard shells and overwinters in the egg stage [17]. This species is suspected of having the same overwintering strategy. On the other hand, for *H. septentrionalis* natural selection has favored overwintering in the adult stage. Overwintering adults were found in an empty oyster shell around the lowest sea level which was underwater most of the day (H. Era, personal communication). It has not been proved yet if this is always the case with overwintering *H. septentrionalis*. Undoubtedly, however, overwintering underwater would be one of the best adaptive strategies to survive the cold season, because the seawater temperature is much warmer than the air temperature. It would be possible for *H. septentrionalis* to survive underwater for a long time through the use of air trapped among the thick hydrofuge hair which covers the body surface, especially because the metabolic rate of overwintering adults would be low thereby requiring little oxygen. Thus, each marine water strider appears to have developed its own adaptive strategy to survive the winter of the temperate climate zone.

5. Conclusion

This paper focuses on the life history of the endangered marine water strider *H. septentrionalis* found in Misaki, Japan, ca. 35°N, the northernmost locality of any extant *Halovelia*-species, most of which live in the tropical/subtropical waters. The results suggest that this species has at least two generations a year and overwinters in the adult stage, presumably staying in some sort of shelter such as an empty oyster shell which remains underwater most of the day. This overwintering strategy differs from those of the two other previously studied Japanese marine water striders.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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