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Geographical distribution of three oceanic *Halobates* spp. and an account of the behaviour of *H. sericeus* (Heteroptera: Gerridae)

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Abstract. *Halobates* spp. are the only insects inhabiting the open sea. One sea skater species, *Halobates sericeus*, was collected at 18 locations in the East China Sea area (27°10′N– 33°24′N, 124°57′E–129°30′E), and *H. micans* and/or *H. germanus* at only 8 locations in the area south of 29°47′N, where water temperatures were more than 25°C. At three locations, where the water temperature was less than 23°C, neither *H. micans* nor *H. germanus* were caught. The effect of photoperiod on the aggregation and mating behaviour of the sea skater, *H. sericeus*, was studied under laboratory conditions during a one-month cruise. Adults and 5th instar larvae of *H. sericeus*, collected between 29°02′N and 30°29′N, were kept under long (14.5L : 9.5D) or short-day (10.5L : 13.5D) conditions at 23 ± 2°C for 20 days. Aggregation and mating behaviour of these sea skaters were recorded over a period of 150 min during the daytime. To analyze the data, the observation period of 150 min was divided into 50 intervals of 3 min. Aggregation was observed more under short than long-days. Duration of a group was much longer under the short (mean ± SD : 43.0 ± 108.1 sec) than long-days (7.6 ± 3.1 sec).

INTRODUCTION

The only insects that inhabit the open sea are five species of sea skaters: *Halobates micans*, *H. sericeus*, *H. germanus*, *H. splendens*, and *H. sobrinus* (Cheng, 1985). Three species, *Halobates sericeus*, *H. micans* and *H. germanus* inhabit tropical and temperate areas of the Pacific Ocean in the northern hemisphere, including The Kuroshio Current and the East China Sea (Andersen & Polhemus, 1976; Cheng, 1985). *Halobates sericeus*, *H. micans* and *H. germanus* are reported from a latitudes of 13°N–40°N, 0°N–35°N and 0°N–37°N, respectively, in the Pacific Ocean (Miyamoto & Senta, 1960; Andersen & Polhemus, 1976; Ikawa et al., 2002). However, this information was collected on different cruises and different times of the years. That is, there has not been ecological study based on samples collected in a specific area in a particular season.

Halobates sericeus could use day-length as a seasonal cue and anticipate seasonal variations in the environment. However, there are no experimental studies on the photoperiodic regulation of life-history traits, including reproduction and several other kinds of behaviour in this species, although the photoperiodic regulation of life history traits of many species of terrestrial Gerridae is well studied (Vepsäläinen, 1971, 1978; Spence, 1989; Harada & Numata, 1993; Spence & Andersen, 1994; Harada et al., 2000; Harada, 2003).

This paper presents information on the geographical distribution of three species of *Halobates* in the eastern region of the East China Sea at a specific period in spring and reports the change induced in its life history traits, including mating and other kinds of behaviour, in response to photoperiod.

MATERIAL AND METHODS

Samples (15 min at 3.0–3.5 knots) were collected from 9–20 May, 2002 using a NEUSTON NET (rectangular parallel pipes, width of the opening: 112 cm) or ORI NET (round-shaped opening with a diameter of 150 cm) trailed along on sea water surface 2–3 m from the side of the Hakuhomaru (3900 t), which is owned by the Ocean Research Institute, University of Tokyo. Samples were taken at 18 locations (16 using a NEUSTON and 2 a ORI net) in the area 27°10′N–33°24′N and 124°57′E–129°30′E (Fig. 1).

Adults and 5th instar larvae were collected for an experiment at 3 locations: 29°02′N–127°23′E, 30°29′N–128°40′E and 29°89′N–129°00′E, in the East-China Sea. They were placed in a round plastic aquarium (30 cm in diameter, 15 cm in height) filled with sea water, and kept at a photoperiod of 14.5L: 9.5D or 10.5L : 13.5D and 23 ± 2°C. These sea skaters were fed on adult flies of *Lucilia illustris*, which were replaced every 12 h, when the sea water was also changed. During the 3-week rearing period, longevity and oviposition were monitored. Mating and aggregation behavior were observed and recorded at the end of the 3 weeks. Aggregation behaviour is characteristic of sea skaters and similar to that of a "skydiving team" (Fig. 2). Two to six adults are attached to one another by their legs and do not move. This behavior was observed with the naked eye over a period of 150 min from 14:00 to 16:30. The sea skaters were observed through a 3 mm diameter pinhole, which was pierced in the top of the box (70 × 70 × 70 cm^3), placed over the top of the aquarium to cut out light from outside. Frequency of mating attempts and duration of copulations were recorded. The observation period of 150 min was divided into 50 sets of 3 min interval and the results obtained in these intervals were used to analyze the aggregation and the mating behaviour. Statistical analysis of the results was performed using software for PC of "SPSS Base 9.0J" (SPSS Inc. North Michigan Avenue, Chicago, IL 60611).

RESULTS

Distribution

Halobates sericeus were caught at all 18 locations, while *H. micans* and *H. germanus* were caught at only 8 locations in the area south of 29°47′N. (Table 1) (Fig. 1). At 7 of the 8 locations, where all three species were caught, the water temperature was higher than 25°C. The temperature at location E8 (29°41′N), on the warm Kuroshio Current was relatively high, 27.0°C. Number of individuals collected tended to be weakly

TABLE 1. Number of *Halobates* collected at 18 locations in the eastern region of the East China Sea, 9–20.v.2002. N – total number of individuals collected; *H.m. – Halobates micans*; *H.g. – Halobates germanus*; *H.s. – Halobates sericeus*; Stat – station number; WT – water temperature; SS – area of water surface over which the NEUSTON or ORI nets were trailed by the ship; ○ – caught; × – not caught.

Latitude	N	*H.m.*	*H.g.*	*H.s.*	Stat	WT (°C)	Time of day	S.S. (m^2)
27°10′	82	○	○	○	M6	26.1	21:37	15803
28°19′	161	○	○	○	I 1	26.1	22.37	15693
28°40′	19	○	○	○	H1	26.1	17:38	17852
29°11′	6	○	○	○	A8	25.1	1:45	23036
29°11′	74	○	○	○	A8	25.8	23:30	14869
29°12′	23	×	○	○	M	25.0	10:05	13630
29°12′	2	×	×	○	M3	25.0	10:35	12100
29°12′	6	×	×	○	M3	25.0	10:55	13028
29°30′	16	○	○	○	F1	25.8	14:25	19970
29°41′	65	○	○	○	E8	27.0	21:45	17501
29°47′	58	○	○	○	F4	23.5	20:00	14764
30°31′	13	×	×	○	B3	25.1	22:57	24870
30°31′	31	×	○	○	B3	24.9	2:18	12100
31°20′	7	×	○	○	E3	23.3	8:57	19237
31°28′	2	×	×	○	C6	22.1	6:00	18862
31°28′	37	○	×	○	C4	22.1	1:45	18231
31°30′	7	×	×	○	C10	22.5	9:45	19710
33°24′	57	×	○	○	A7	25.2	23:33	34602

positively correlated with water temperature (Pearson's coefficient = 0.44, P = 0.067).

Laboratory experiment

Fifty seven individuals of *Halobates sericeus* collected in the East China Sea were kept under long (13 females, 8 males, 9 larvae of 5th instar) or short-day conditions (11 females, 8 males, 8 larvae of 5th instar). Five of the 30 individuals (16.7%) survived 20 days under long days and 29.6% of the 27 individuals under short days (χ^2 test: χ^2 value = 1.356, fd = 1, P = 0.244). There was no significant difference in the survival of the adults over the 20 days in the long (23.8% of 21 adults) and short days (42.1% of 19 adults) (χ^2 test: χ^2 value = 1.522, fd = 1, P = 0.217) (Fig. 3). Most insects in the sample kept at each photoperiod (5 individuals under long-days, 6 under short-days) were observed for 150 min. For those kept under the short-day conditions, aggregation was recorded more frequently than for those under the long-days (χ^2 test: χ^2 value = 16.513, fd = 1, P = 0.001) (Fig. 4a). Duration of a group was much longer under short than long-days (Mann-Whitney U-test: z = –3.554, P < 0.001) (Fig. 4b). At both photoperiods the adult *Halobates sericeus* skated very rapidly without interruption on the sea water surface in the aquarium. If females and males met by chance during the skating, males sometimes tried to grasp, ride on the

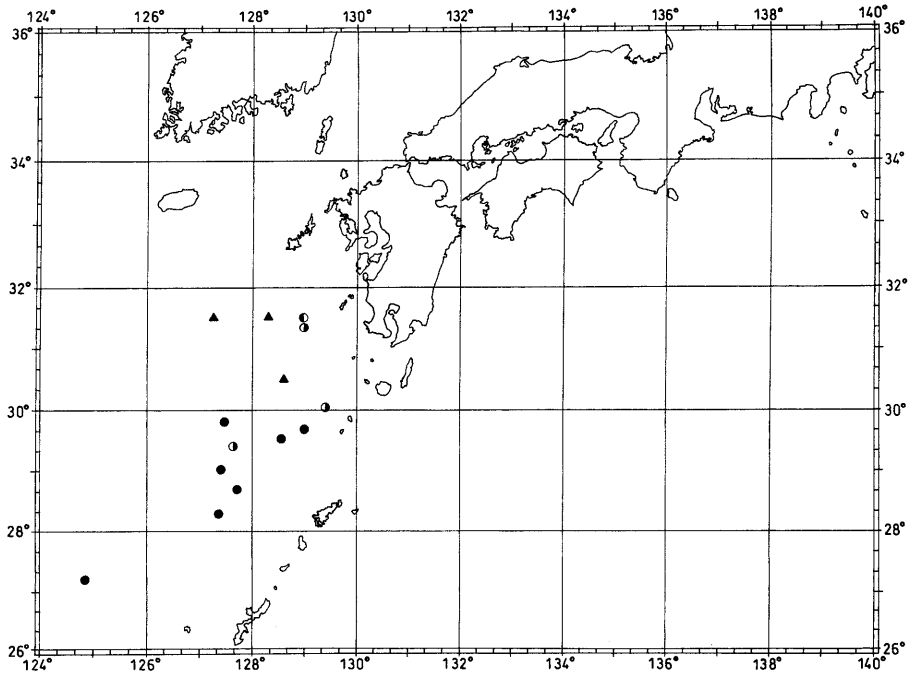

Fig. 1. Sampling locations: triangles – only *Halobates sericeus* collected, left-half-solid circles – *H. sericeus* and *H. micans*, right-half-solid circles – *H. sericeus* and *H. germanus*, and solid circles – all the three species.

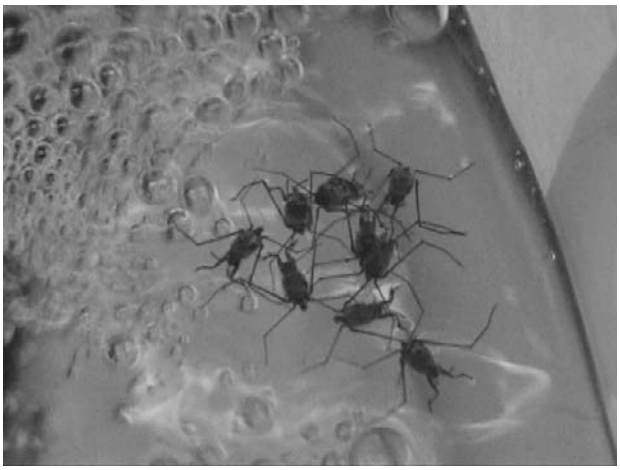

Fig. 2. An aggregation consisting of males and females.

back and mate with females (mating attempt). During a mating attempt the couple rotated at one point on the water surface for 1–10 sec. If successful, copulation lasted for 8–10 min after the rotation ceased. If unsuccessful, the male and female separated and again skated rapidly on the water surface. Mating behaviour was recorded in 58% of the 50 intervals under short and 42% of those under long-days (χ^2 test: χ^2 value = 2.56, fd = 1, P = 0.11). Mating behaviour was recorded 51 times in total in 150 min under the short and 25 times under long-days. Only one mating was successful (duration of copulation: 9 min 40 sec) of the 25 mating attempts observed under long-days and only two (7 min 58 sec, 8 min 20 sec) of the 51 under short-days. This low success rate may be due to the relatively low temperature (23 ± 2°C) in the laboratory. Eggs were laid by females at both photoperiods.

DISCUSSION

Three species, *Halobates sericeus*, *H. micans* and *H. germanus* are reported to inhabit the western area of the Pacific ocean (Cheng, 1985). However, whether the three species coexist in certain seasons is unknown. In the East-China Sea, the three species of *Halobates* show clear differences in the northern limits of their distributions. Miyamoto & Senta (1960) report *Halobates sericeus*, *H. micans* and *H. germanus* at many locations where the water surface temperatures were 21–23°C, 24–30°C, 27–30°C, respectively. Higher resistance to lower temperatures in *Halobates sericeus* than in the other two *Halobates* species might account for its northern distribution

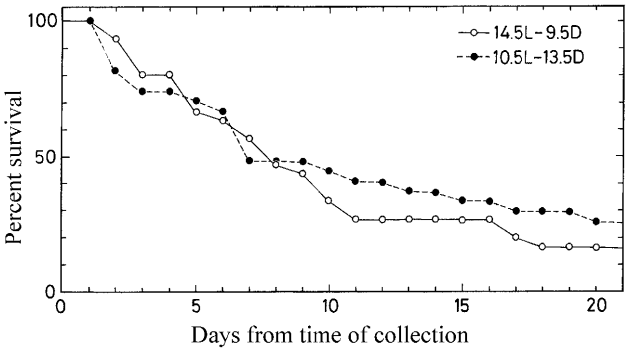

Fig. 3. Survival of adults of *Halobates sericeus* collected from East China Sea (29°02′N–30°29′N) kept under long (○) (14.5L : 9.5D) or short (●) (10.5L : 13.5D) days, at 23 ± 2°C.

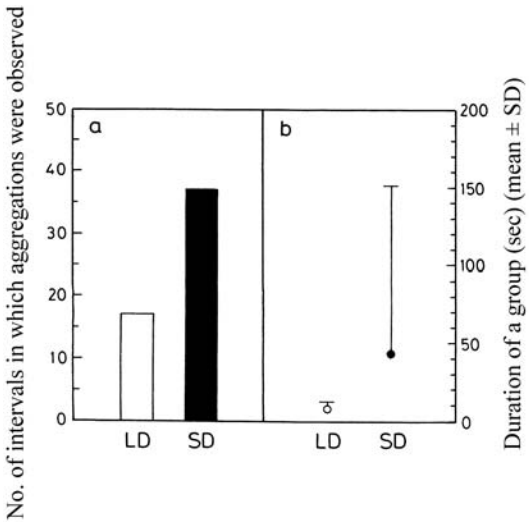

Fig. 4. The effect of short (10.5L : 13.5D – SD) and long-day (14.5L : 9.5D – LD) photoperiods on (a) the incidence of aggregation behaviour (no. of intervals in which it was observed) and (b) the duration of an aggregate (mean ± SD) in the sea skater, *Halobates sericeus*.

reaching 33°24′N in sea, although other environmental parameters may affect the distribution of this species.

In some terrestrial insects, reproductive diapause is linked to crowding (Tauber et al., 1986; Danks, 1987), which is advantageous for finding mates the following spring (eg. Coccinellidae beetles, Hodek & Honěk, 1996). Crowding may be one component of the so-called diapause syndrome (Danks, 1987). However, this was not the case for the sea water strider, *Halobates sericeus*, because although aggregations were observed more frequently under short-days (Fig. 4), reproductive diapause was not induced by these conditions. A relative to *Halobates*, *Metrocoris histrio*, which is included in the sub-family Halobatinae, lives in fresh-water habitats. Embryos of this species enter a facultative diapause (Harada & Wada, 2000). There is no evidence that *Halobates sericeus* undergoes embryonic diapause.

Short-day condition, 10.5L : 13.5D, promoted more frequent and longer boats of aggregation than long-days of 14.5L : 9.5D (Fig. 4a,b). Aggregations seem to be observed frequently in fall and winter outdoors, and sometimes may lead to the formation of a large and immobile aggregations. How important is this behaviour in fall and winter? Grouping in winter might be advantageous for *H. sericeus*, because there is likely to be little prey (eg. zooplankton: Chen, 1985) floating on the water surface in winter and any items caught by chance can be shared by more individuals in an aggregation.

Mating behaviour was promoted more by short than long-days. In some terrestrial insects inhabiting warm-temperate or subtropical zones, aestivation is induced by long-days, thus avoiding reproduction in hot and dry seasons (Masaki, 1980). However, this may not be the case in *H. sericeus* because water temperature in the open sea can be less than 30°C, even in mid summer. Alternatively, *H. sericeus* might reproduce throughout the year, because even in autumn and winter water temperatures are moderate in warm currents such as The Kuroshio (eg. 24°C in the middle of the current in December) (Harada, 2001) at relatively high latitudes, 30–40°N.

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