Timing of Oviposition and Nymphal Diapause under the Natural Daylengths in *Carbula humerigera* (Heteroptera: Pentatomidae)¹

Yukio KIRITANI²

Laboratory of Entomology, Faculty of Agriculture, Hirosaki University, Hirosaki 036, Japan

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Nymphs of *Carbula humerigera* collected in the field at Hirosaki matured synchronously as adults from late June to early July. Females did not lay eggs before the summer solstice. Rearing under natural daylengths at 25°C indicated that increasing daylengths suppressed oviposition and decreasing ones promoted it. Nymphal diapause was induced in the third to fifth instars by short photoperiod, apparently maintained by decreasing photoperiod, and terminated near the time of the winter solstice.

INTRODUCTION

Carbula humerigera is a rice paddy pest and occurs throughout the northern parts of Japan and around the margins of the mountainous regions in southern Japan. In Tottori Prefecture, this bug is univoltine and overwinters as a nymph (FUKUDA and CHIYONISHIO, 1981). Since most heteropterans such as *Riptortus clavatus* (KIDOKORO, 1978; NUMATA and HIDAKA, 1982), *Aelia acuminata* (HODEK, 1971) and *Eysarcoris ventralis* (NODA and ISHII, 1981) have adult diapause, the life cycle of this species is an interesting subject for comparison.

Generally, insects detect seasonal changes by means of environmental stimuli, such as photoperiod, temperature, food, etc. (DANILEVSKII, 1961; BECK, 1968). Of all these environmental factors, photoperiod is the most accurate seasonal cue. To assess the significance of daylength in the annual life cycle of an insect, observation of development in natural daylengths at a constant temperature is important.

In this paper, the author describes the life cycle of *C. humerigera* and examine the effects of photoperiod on the induction and termination of nymphal diapause and adult oviposition.

MATERIALS AND METHODS

Nymphs and adults were collected at Nakatomarizawa and Shinzansawa near Hirosaki in the summer of 1981 and 1982. They were reared under natural daylengths at 25°C. Adults laid eggs on pieces of cotton wool and these eggs were used for the experiments. Bugs were usually reared in plastic containers (7 cm high and 13 cm in diameter). The bottom was lined with sheets of filter paper and the top was covered

¹ Contribution No. 97 from the Laboratory of Entomology, Faculty of Agriculture, Hirosaki University.

² Present address: 1-35-12, Komatsu, Tsuchiura, Ibaraki 300, Japan

with a ventilated lid. Water was provided in vials with cotton plugs and changed about once a week. Bugs were fed on dry soybeans and foxtail millet seeds, *Setaria italica*. The number of eggs laid on the cotton wool was counted. The newly hatched nymphs were provided with rice seedlings (*Oryza sativa*), because the first and second instars could not feed on dry soybean or foxtail millet. When adults emerged, each pair of male and female was kept separately.

RESULTS

Adult emergence

Nymphs were collected in the field from late June to early July and kept under natural daylengths at 25°C in 1981 and again in 1982. As shown in Fig. 1, most of these nymphs matured in early July. In the field, adults were observed to emerge from late June to early July.

Oviposition

The sequence of oviposition in three groups of adults were observed in natural daylengths at 25°C (Fig. 2). Group A (early) was composed of male and female pairs that had emerged as adults from early to mid-June, group B (average) from late June to early July and group C (late) from mid-August to early September. The early females did not lay eggs before the summer solstice. Few of them laid eggs in late June, but their ovipositing activity extended mainly from early July through September. The average pre-oviposition period after the adult emergence was about 30 days. Each female usually laid a mass of 14 eggs every two days until death. Most of the average females laid their first eggs within 25 days after adult emergence and continued to lay

Fig. 1. Adult emergence of *Carbula humerigera* collected in the field at Shinzansawa, Hirosaki from late June to early July in 1981 and 1982 and reared under the natural daylengths at 25°C.

Fig. 2. Oviposition of *C. humerigera* under natural daylengths at 25°C. Group A: adults that had emerged from June 1 to 10. Group B: adults that had emerged from June 24 to July 10. Group C: adults that had emerged from August 10 to September 16. Dotted line: number of adults survived. Histogram: number of eggs deposited.

Fig. 3. Seasonal succession of developmental stages in *C. humerigera* under natural day-lengths at 25°C. Closed triangle indicates hatching.

eggs from early August to mid-October. The late females oviposited by day 20 of their adult life. This pre-oviposition period was the shortest among the three groups. The females started to oviposit in early September and stopped by November. The number of eggs laid was small and the females laid eggs irregularly. Few bugs were still surviving in early December.

These results suggest that females might not be able to oviposit before the summer solstice, since the early females delayed oviposition and the average females that had emerged after the summer solstice laid eggs without delay. Prompt but not highly active oviposition was observed in the late group. In the field, oviposition probably starts around early August. The date of adult emergence in the average group might be similar to that in the field, and these females started oviposition in late July to early August.

Nymphal development

Newly hatched nymphs were reared in natural daylengths at 25°C. The seasonal progression of their development is shown in Fig. 3. All nymphs that had hatched before mid-July matured to adults within 60 days after hatching. About 50 percent of nymphs that had hatched on July 25 became adults by day 65, but the rest delayed development at the fourth or fifth instar. Some of these nymphs survived until late November. The nymphs that had hatched from eggs after early August entered diapause. In the later groups that had hatched after early August and entered diapause at third or fourth instar, nymphs resumed development in mid-November and emerged

as adults at about the winter solstice (Fig. 3). The nymphs that had hatched later entered diapause at younger stages than those that had hatched earlier.

The field collected nymphs that matured in early July began to oviposit in early August. All nymphs that had hatched after early August in the laboratory did not emerge as adults and entered diapause. Therefore, it is inferred that the nymphs usually enter diapause in the field.

DISCUSSION

In the laboratory, nymphs and adults of *C. humerigera* were reared at 25°C and provided with the standard food. Therefore, the natural daylength was the only factor affecting the life cycle. Overwintering nymphs collected in the field emerged as adults synchronously in early July (Fig. 1). These adults laid eggs within 40 days and continued to do so from early August to early October. The females emerging as adults in early to mid-June were suppressed to oviposit till the summer solstice. Those that had emerged from mid-August to early September showed the shortest pre-oviposition period among the three groups. All surviving nymphs that had hatched before mid-July emerged as adults. Half of the nymphs that had hatched on July 25 became adults in mid-September and the rest entered diapause and emerged as adults at about the winter solstice.

Under such conditions, females emerging before the summer solstice delayed oviposition as compared with those emerging after early July (Fig. 2). They might enter a short reproductive diapause and began to oviposit just after the summer solstice. The daylength before the summer solstice increases and thereafter decrease. Therefore, the increasing photoperiod might suppress and the decreasing one might promote oviposition. Few females surviving at 25°C stopped oviposition in early November (Fig. 2) and the adults maturing in the short daylength from mid-December to mid-January did not oviposit until early April. Therefore, the short photoperiod may also suppress oviposition. There seem to be two different types of reproductive diapause in this species, occurring in summer and winter, respectively at 25°C under the natural conditions of photoperiod, although the winter reproductive diapause would not be manifested in the field.

In Hirosaki, the summer reproductive diapause is also very rare, since overwintering nymphs emerge as adults in early July when the daylength is decreasing. So that the summer diapause would not be induced. In Tottori Prefecture, however, the adults emerge from mid-May to mid-June but their oviposition does not begin until late August to mid-September (FUKUDA and CHIYONISHIO, 1981). Despite the earlier emergence of the adults, oviposition occurs later than in Hirosaki. It is possible that the adults in Tottori Prefecture enter a reproductive summer diapause in response to the long and increasing daylength in early summer.

The critical date of hatching for the induction of nymphal diapause was July 25. About half of the nymphs hatching on this day became adults in mid-September and the rest entered diapause at the fifth instar. The daylength including twilight decreased from 15 to 13.5 hr during their development from late July to mid-September. It is inferred that the critical daylength lies between 13.5 and 15 hr. Nymphs are able to enter diapause in the third, fourth or fifth instar. The nymphs that had hatched in the early season entered diapause at older stages than that had hatched later. FUKUDA

and CHIYONISHIO (1981) reported that the overwinterers in the field were in the second, third or fourth instar.

When continuously kept at 25°C in the natural light conditions, diapause nymphs in the third or fourth instar resumed development after mid-November and became adults at around the winter solstice (Fig. 3). The nymphs that had reached the fifth instar early in the year at 25°C emerged as adults only after the winter solstice when the daylength was still close to the shortest level. Therefore, it may well be that the reduced rate of decrease in daylength or the shortest range of daylength just before the winter solstice tends to terminate the nymphal diapause. In the field, the effect of decreasing photoperiod on the maintenance of diapause would disappear under the influence of low temperatures, and the diapause would be terminated at moderate temperatures in the spring.

In the life cycle of this insect, the timing of reproductive activity is most important. If females lay eggs in the early season, offspring nymphs do not enter diapause and emerge as adults. If they do so later, the offspring can enter diapause as nymphs. For this seasonal regulation, adults have to respond to the change in photoperiod around the summer solstice.

Most univoltine heteropteran bugs enter diapause in the adult stage and reproduce from early summer to fall. While *C. humerigera* begins to reproduce only after the summer solstice. This special timing of reproduction may be adaptation to avoid the long-day season for nymphal development and thus to ensure diapause in the offspring.

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