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Hibernation and Flight Ability of the Cabbage Webworm, *Hellula undalis* in Japan

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Abstract

The hibernation ecology and flight behavior of the cabbage webworm, *Hellula undalis* were studied from 1983 to 1987 in the field and by laboratory experiments. Overwintering of *H. undalis* was estimated to be successful in the southern parts of the Kanto district along the Pacific Ocean and of the Hokuriku district along the Sea of Japan; this species was able to hibernate in the last instar larval or pupal stages. *H. undalis* could not overwinter under adverse field conditions when exposed to a temperature below 0°C for more than 10 days during the winter. The flight ability was determined using a flight mill; the potential flight distance was 40 km for female and 50 km for male adult moths. However, on the basis of studies on the relationship between the flight behavior and reproductive success of females, and on the flight behavior in mark-recapture experiments with males, it was concluded that the flight characteristics of *H. undalis* were not adequate for long-distance overseas migration.

Discipline: Insect pest
Additional key words: flight mill, mark-recapture, migration, reproductive success

Introduction

The cabbage webworm, *Hellula undalis*, a serious lepidopterous pest of cruciferous vegetables, is widely distributed from the tropical to temperate regions. Japan is located in the northernmost distribution area of this species in Asia[3]. In the field, a low larval density can cause severe damage to many cruciferous crops (cabbage, radish, cauliflower, broccoli, etc.), because one or a few larvae infest the growing points or shoots of young plants.

In the southern part of Japan, the population of the webworm increases especially under hot and dry weather conditions[14]. It has been suggested that *H. undalis* may undertake long-distance overseas migration, as in the case of migratory pyralid moths such as the rice leafroller, *Cnaphalocrocis medinalis*, or the beet webworm, *Hymenia recurvalis*[14], since individuals of *H. undalis* have been caught at a weather ship stationed 500 km south of mainland Japan in the Pacific Ocean[2], and the adult population density in Japan increases rapidly from late summer to early autumn. To verify this possibility, extensive field investigations on the hibernation ecology were conducted from 1983 to 1987[4,9]. Some intensive studies on flight ecology were also carried out by measuring the flight ability using a flight mill and mark-recapture experiments[5,10,11].

This paper reviews the results from this series of studies, and refers briefly to a simple rearing method of *H. undalis* for laboratory experiments and to a method of monitoring

population density.

Simple rearing method

H. undalis is easily reared on a diet of germinating radish seed by the same method as that used for the diamondback moth, *Plutella xylostella*[15]. The rearing procedure is illustrated in Fig. 1. After emergence, about 50 pairs of females and males are placed in a mesh cage for 1 or 2 days, and the mated females are put into a plastic dish with germinating radish seed (② in Fig. 1). Following oviposition, the females are removed from the plastic dish to prevent the development of mold fungi (e.g. *Rhizopus* sp.) (③). To maintain appropriate humidity conditions, the larvae in the dish are transferred to a larger plastic container with one or two pieces of corrugated cardboard, when they reach the third or fourth (last) instar stages (④, ⑤). Larvae pupate in this cardboard, which facilitates a high rate of emergence.

Hibernation ecology

Detailed field surveys on the population density of male adults using virgin female traps, and of larvae by the visual counting method, were conducted in Mie Prefecture, central part of mainland Japan during 1985[4]. The numbers of generations per year and hibernating stages obtained from these surveys were in good agreement with the estimated values from both the developmental zero and the effective accumulative temperature for *H. undalis*[13]. Therefore, the data on the seasonal changes in male adult density recorded in various localities in Japan enabled us to determine in which localities the insect was able to overwinter and at which life stage(s) overwintering was successful. Based on data for developmental zero (egg: 12.5°C, larva: 13.1°C, pupa: 11.4°C, overall: 12.0°C), effective accumulative temperature (egg: 37, larva: 152, pupa: 87, total 303 day-degrees)[13] and the temperature in various localities, the theoretical date of emergence in the field was calculated when this species was able to hibernate in the larval or pupal stages[9]. If the first capture of a male adult in the trap was recorded within the period theoretically predicted, then the captured individual was defined as a moth that was able to hibernate in the larval or pupal stages in a given locality. On the other hand, if the first male adult was captured beyond the period theoretically predicted, then the individual was considered to be a moth which could not hibernate there and had immigrated from its original habitat. These analyses revealed that overwintering of *H. undalis* was successful in the southern parts of the Kanto district along the Pacific Ocean and of the Hokuriku district along the Sea of Japan, and that the moth was able to hibernate in the last instar larval or pupal stages (Fig. 2). Field observation of overwintering success of larvae in Mie Prefecture also showed that the moth could hibernate in the last instar

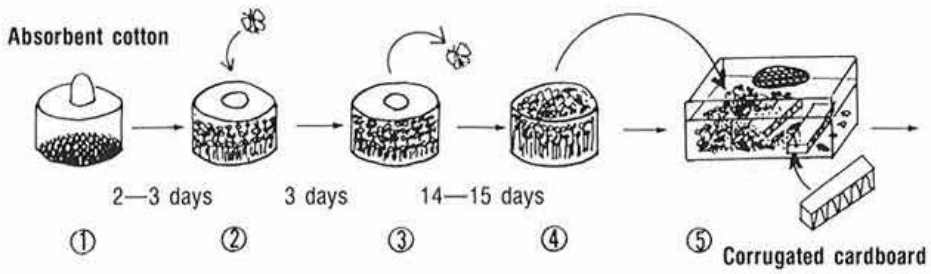

Fig. 1. A simple rearing method for *H. undalis*, using germinating radish seeds (rearing conditions: 23°C, 16L-8D)

larval or pupal stages, and that the overwintering success depended substantially on the environmental conditions of their hibernaculum in soil at a depth of ca. 2–10 cm. Overwintering under field conditions where exposure to rain or snow could be avoided was more successful than that under adverse conditions. Based on laboratory experiments on the resistance at the pupal stage, exposure to temperatures below 10°C for more than 10 days severely reduced pupal survival[9]. In the boundary zone of overwintering success (e.g. the inland area of mainland Japan) (Fig. 2.), success seemed to depend on environmental conditions such as micro-climatic factors in each locality, because the overwintering success varied during the three study years, 1985 to 1987[9].

Fig. 2. Overwintering success of *H. undalis* in Japan
○ : Area where overwintering was successful.
● : Area where overwintering was difficult.
◑ : Area where overwintering varied among the years.

Flight behavior

1) Flight ability determined using a flight mill

To understand the fundamental flight capacity and behavior of *H. undalis*, flight ability was determined using a flight mill device with an automatic data recorder linked to a personal computer[5]. The mean distance flown during the 3 days-measurement was 40.2 km for females and 52.6 km for males. However, no flight ability parameters (duration, velocity, distance and proportion of moths with long-term continuous flight) differed significantly between the sexes, because of the large variances observed (Table 1). The maximum flight distance and the longest continuous flight duration were 83.9 km and 24.5 hr, respectively. Flight velocity increased in proportion to temperature, but a high temperature of 30°C reduced continuous flight, suggesting that the optimum temperature for flight activity was about 20°C. Study of the flight ability of moths reared successively for 2 years (22–24 generations) revealed a slight decrease in the duration of continuous flight, but no significant difference in the flight velocity and distance when compared with those of wild moths[5].

2) Relationship between flight behavior and reproductive success in female moths

For studies on the relationship between reproductive success and flight behavior in females, mating and oviposition behavior were examined, combined with tethered flight assessment by flight mill[11]. There was no significant difference between any flight ability in virgin and mated females (Table 2). Following a one-day flight, the mated females were

Table 1. Flight ability of wild adult moths of *H. undalis*, determined using a flight mill

Flight ability[a,b] / Sex[c]	Days after the start of flight mill experiment		
	1	2	3
Flight duration (min)			
Female	924.5±120.6 (21)	351.0±151.9 (18)	102.9±86.9 (7)
Male	829.3±118.4 (19)	550.1±154.4 (16)	377.6±229.0 (6)
Flight velocity (m/min)			
Female	30.9±3.5 (21)	21.6±3.7 (18)	18.5±4.5 (7)
Male	29.7±3.5 (19)	27.0±3.1 (16)	25.7±3.7 (6)
Flight distance (km)			
Female	29.4±5.5 (21)	8.9±4.3 (18)	1.9±1.2 (7)
Male	26.3±6.7 (19)	15.7±4.8 (16)	10.6±7.2 (6)

a): Mean±95% confidence limits (No. of moths tested).
b): Flight ability was measured for 3 days under constant conditions (23°C and 16-L photophase).
c): For both sexes, unmated moths (1 day after emergence) were tested.

Table 2. Flight ability determined using a flight mill in virgin and mated females of *H. undalis*

Flight ability[a,b] / Condition of female[c]	Days after the start of flight experiment		
	1	2	3
Flight duration (min)			
Virgin	769.3±64.6 (62)	271.0±72.7 (52)	131.2±48.8 (24)
Mated	771.8±75.7 (52)	233.7±68.2 (45)	137.1±63.6 (19)
Flight velocity (m/min)			
Virgin	21.3±2.3 (62)	16.8±1.7 (52)	14.9±1.4 (24)
Mated	19.0±2.3 (52)	14.6±2.1 (45)	12.8±2.1 (19)
Flight distance (km)			
Virgin	16.9±2.9 (62)	5.1±1.8 (52)	2.1±0.8 (24)
Mated	15.0±2.6 (52)	3.5±1.4 (45)	1.7±0.8 (19)

a): Mean±95% confidence limits (No. of moths tested).
b): Flight ability was measured for 3 days under constant conditions (23°C in darkness).
c): The females reared for 3 or 4 successive generations (2 days after emergence) were tested.

able to lay a large number of fertilized eggs (118.1 on average), which did not differ significantly from the numbers produced by the non-flight mated females. On the other hand, virgin females after a one-day flight laid fewer eggs than non-flight virgin females, though the mating success after flight did not differ between the two groups (Table 3). Females of *H. undalis* are ready for mating immediately after emergence because of the rapid maturation of their ovaries[17]. The data in Tables 2 and 3 suggest that females are able to display either of the following two sequences of flight-oviposition behavior: "Emergence → Mating → Flight → Oviposition" or "Emergence → Flight → Mating → Oviposition". From the viewpoint of reproductive success, the former sequence, in which mated females lay eggs after flight, may be more favorable for reproduction of an emigrant population.

Table 3. Effect of flight experience on subsequent reproductive success in females of *H. undalis*

Condition of female	Flight experience	No. of moths tested	Proportion of mating success (%)	No. of eggs laid per female[a)]
Virgin female	one-day flight[b)]	30	46.7	86.9±31.2 (14) } *
	non-flight	40	67.5	199.7±36.7 (27) } *
Mated female	one-day flight[b)]	23	100.0	118.1±19.7 (23)
	non-flight	30	100.0	133.6±22.9 (30)

a): Mean±95% confidence limits (No. of females with mating success).
b): Tethered flight for 24 hr by flight mill.
* Significant difference at 5% level by *t*-test.

Table 4. Numbers of male moths recaptured in the mark and recapture experiment of *H. undalis*[a)]

Distance from the release point (km)	Days after release								
	1	2	3	4	5	6	7	8	Total
0 – 2	5	22	3	1	1	1	1	0	34
2 – 4	2	7	3	0	2	0	0	0	14
4 – 6	0	1	0	1	0	0	0	0	2
6 – 8	1	0	0	0	0	0	0	0	1
8 – 10	0	0	0	0	0	0	0	0	0
10 – 12	0	0	0	0	0	0	0	0	0
12 – 14	0	0	0	0	0	0	0	0	0
14 – 16	0	1	0	0	0	0	0	0	1
Total[b)]	8 (2.4)	31 (2.2)	6 (2.2)	2 (3.1)	3 (2.7)	1 (1.2)	1 (1.2)	0	52

a): 2,200 marked male moths were released from 28 Aug. to 5 Sept. 1986 in Ano, Mie Prefecture.
b): Mean flight distance between the release point and recapture points is indicated in parentheses.

3) Mark-recapture experiments with male moths

In late August and mid-October 1986, male moths marked with fluorescent dyes were released and recaptured in 50 virgin female traps placed 1–22 km from the release point[10]. In the first experiment, 52 individuals among 2,200 released moths were recaptured during the entire study period. One moth was recaptured 6.8 km from the release point on the next day after its release, and another was captured 15.9 km away on the second day after release. Most moths, however, were recaptured within 4 km and 3 days after their release, which did not suggest any distinct tendency of long-distance migration (Table 4). The flight direction of the recaptured moths was not correlated with the wind direction during the nights of the experimental period. In the second experiment, only 1 among 3,930 released moths was recaptured, because the flight activity of *H. undalis* was extremely reduced due to very low night temperatures, ranging from 6 to 15°C during the study period. This result was consistent with the flight study in the laboratory[5].

4) Possibility of long-distance migration

Based on the relationship between flight and reproduction[7], the laboratory studies on

females (Tables 2 and 3) did not provide any evidence that *H. undalis* was capable of long-distance flight. In addition, the mark-recapture experiments with the males did not reveal any tendency of long-distance dispersal flight[10]. Our series of studies showed that *H. undalis* was able to overwinter in the Kanto and Hokuriku districts of Japan, even though the overwintering success was very low[9], and that this moth had a potential capacity to fly 50–80 km for several days from summer to early autumn[5]. Only one observation of long-distance migration of this species has been reported[2], and no other indication of long-distance migration has been documented so far[16]. On the basis of our series of studies on *H. undalis*, it is concluded that the flight characteristics of this species are not adequate for long-distance migration, and that the moths rarely immigrate from overseas to Japan.

Control and monitoring of population density

Control of *H. undalis* is not difficult in Japan, because the larvae can be easily controlled by many types of synthetic organic insecticides. In recent years, in some areas of Southeast Asia (e.g. Thailand and Malaysia), damage by *H. undalis* to cruciferous crops has increased, although synthetic organic insecticides were routinely applied there[6,12]. Up to now, it has not been verified experimentally whether *H. undalis* has actually developed resistance to synthetic organic insecticides. Insecticide resistance should be tested, not only in the field but also in laboratory experiments. The simple rearing method described in Fig. 1 is applicable to laboratory experiments.

A large number of adult moths of *H. undalis* appear to fly commonly a considerable distance, ranging from 3 to 4 km for 1–2 days, as shown by the mark-recapture experiment (Table 4), and their flight activity in vegetable crop fields is estimated to be greatest during the high-temperature season. Monitoring the population density of *H. undalis* might be important for the effective implementation of a program of insecticide application. The population density of male adults can be correctly assessed only with the aid of virgin female trap because, while a major component of the sex pheromone of this species has already been identified[1], synthesis of the pheromone for use in monitoring has not yet been completed. In addition, the number of moths caught by a mercury-vapor lamp trap was significantly less than that of the moths present in the field[8], because few individuals of either sex were attracted to any light trap[14]. Therefore, monitoring of the larvae should be carried out at regular intervals in vegetable crop fields, in order to detect the occurrence of this species while the damage caused by larvae is not yet extensive.

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