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Control of the Beet Armyworm in Open Fields with Sex Pheromone

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Abstract

The feasibility of synthetic sex pheromone as a communication disruption agent for the control of the beet armyworm, *Spodoptera exigua* (Hübner), was tested using a 7:3 mixture of (*Z,E*)-9,12-tetradecadienyl acetate and (*Z*)-9-tetradecen-1-ol. When dispersed into a 155-ha field, attraction of male moths to sex pheromone traps was completely inhibited and densities of egg masses and young larvae were reduced to 6 and 1%, respectively, relative to those in an untreated field about 9 km away. Follow-up studies enabled us to estimate that rate of mating inhibition in the treated field was about 97%. Pheromone treatment shows potential for reducing the population density in open fields. Evaluation techniques of the effects of sex pheromone treatment will be discussed.

Introduction

The beet armyworm (BAW), *Spodoptera exigua* (Hübner), (Lepidoptera: Pyralidae), is a serious pest of cabbage in Southeast Asia, especially in Thailand. This insect has also attacked Welsh onion (*Allium fistulosum* L.) fields in Kochi and Kagoshima Prefectures in Japan since the early 1980s (Horikiri 1986; Takai 1988a, 1989). The effectiveness of most of the insecticides used (including methomyl and EPN) has declined. Insecticides were certainly effective in the early 1980s (Takai 1988b), but this species appears to have the potential to rapidly acquire resistance (Takai 1988b; Meinke and Ware 1978). The development of a new technique other than insecticide spraying was necessary to control this insect. This prompted us to study the feasibility of disrupting communication using synthetic sex pheromone.

Brady and Ganyard (1972) identified one of the sex pheromone components of BAW as (*Z,E*)-9,12-tetradecadienyl acetate (Z9E12-14:Ac). Mitchell and Doolittle (1976), however, showed that this component had no attractant activity by itself. Tumlinson et al. (1981) reinvestigated the sex pheromone components, identified 11 compounds from virgin female secretions, and revealed that (*Z*)-9-tetradecen-1-ol (Z9-14:OH) was also an essential component for male attraction. Mitchell et al. (1983) reported an effective formulation: a mixture of 0.1 mg of Z9E12-14:Ac and 0.01 mg of Z9-14:OH on a rubber septum. In Japan and Taiwan, this formulation was demonstrated to be effective for male attraction (Wakamura 1987; Cheng et al. 1985), and to be useful for monitoring seasonal occurrence.

Communication Disruption in Open Fields

Experiments were conducted in two areas, Nii and Kitahara, Tosa City, Kochi Prefecture, Japan, in 1987. The treated area (Nii) was about 155 ha, of which Welsh onion plots comprised about 24 ha (Wakamura et al. 1989, 1990b). This area was regarded as isolated from other agricultural areas; the west side of this area faces forest and the northwest side faces a river bordered by forest. To the south of the field is a small residential area bordered by the ocean. The untreated area (Kitahara) was 9 km from the treated one.

Since no information was available on the dispersal distance of adult BAW, we assumed that it has flight potential equalling that of adult *S. litura*. *S. litura* males are able to fly more than 5 km during one night (Oyama and Wakamura 1976; Wakamura et al. 1990a). Females have equal flight potential (Noda and Kamano 1988). Sex pheromone permeation of a field certainly inhibited mating behavior, but often resulted only in a slight reduction of larval population, possibly because of immigration of fertilized females from outside the treated area (Oyama et al. 1978; Kitamura et al. 1985; Kitamura and Kobayashi 1985). We attempted to permeate as large an area as possible with the largest possible amount of synthetic sex pheromone.

The dispensers of synthetic sex pheromone were supplied by Shin'Etsu Chem. Co. Ltd.; a sealed polyethylene tube 20 cm long and containing 80 mg of a 7:3 mixture of Z9E12-14:Ac and Z9-14:OH and an aluminum wire. Twenty-four thousand dispensers were set evenly in the Welsh onion fields at the rate of 1000 dispensers/ha. In other parts of the treated area (about 130 ha) such as rice fields, greenhouses, orchards, home gardens and forests, about 42,000 dispensers were set at the rate of 320 dispensers/ha. In the open Welsh onion or rice fields, each release point had three dispensers attached to the top of a 60-cm plastic stick with vinyl adhesive tape. Trees and greenhouses had dispensers directly attached, at 1-1.5 m above the ground. The total number of dispensers was 66,000, and the total amount of sex pheromone used was about 5.3 kg.

In 1986, a large peak of trap catches of adult *S. exigua* was observed in September in sex pheromone and light traps. This peak was preceded by an increase in severe crop damage by larvae (Takai 1988a). In the present experiment, sex pheromone dispensers were set on 16-17 July 1987 to investigate the effect on the larval population from late August to early September; it was removed on 17 and 18 September to examine whether the population density would increase after the removal.

Effects of communication disruption

Water-pan type of sex pheromone traps (30 × 24 × 15 cm, Takeda Chem. Ind. Ltd.) were set 1 m above the ground at four locations in the treated area, and at two locations in the untreated area to evaluate the effect of communication disruption. Each trap was baited with a rubber septum impregnated with a 7:3 mixture of Z9E12-14:Ac and Z914:0H (Wakamura 1987). Each trap in the treated area was accompanied by an empty trap 10 m away to offset chance male catches (i.e. catches not by attraction). A light trap (lamp: FL-6) was set at the center of the treated area. Each trap was checked daily and captured BAW moths were stored in 70% ethanol. Females were dissected to investigate the spermatophore in the bursa copulatrix.

Two-day-old females were tethered and placed on tops of sticks arranged in the onion fields in treated and untreated areas as in Oyama (1974). On the evening of 27 August, 20 females were tethered in each of the two plots in the treated area, and 25 females in the untreated area. They were recovered the next morning and investigated for spermatophore.

BAW adults were captured with a light trap throughout the treatment period (Fig. 1). This indicates that adults were in the treated area throughout the experimental period. Conversely, mean trap catch of sex pheromone traps was as low as that of empty traps during the treatment period. These results showed that the effect of communication disruption certainly continued throughout the period.

The mating rate of the females caught with the light trap increased during the treatment period (Table 1): 40-60% in late July and early August, 70-80% in mid and late August, and 70-90% in early and mid September. After removal of the dispensers, the mating rate exceeded 90%. The mating rates of the tethered females were 0% [0/18 = (no. of females mated)/(no.

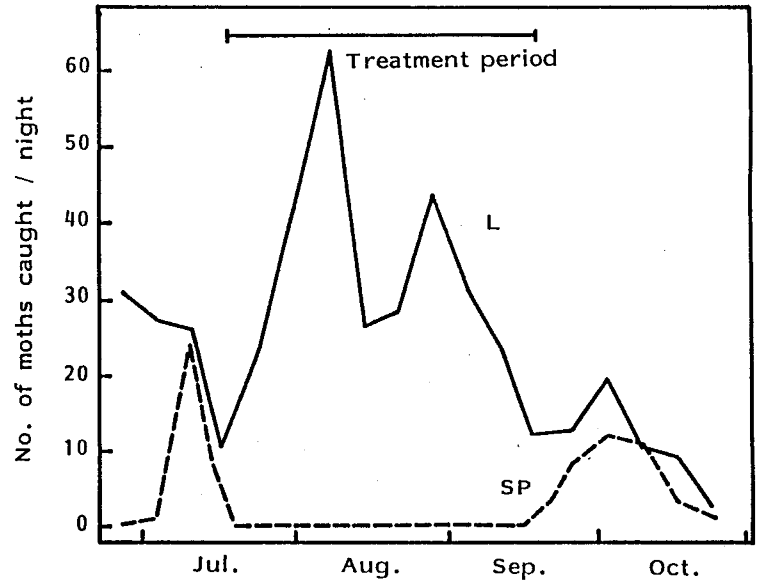

Fig. 1. Catches of BAW with sex pheromone traps (SP) and light trap (L) in the area treated with synthetic sex pheromone (1987, Nii).

Table 1. Catches of adult BAW with light trap in the treated area with synthetic sex pheromone (1987, Nii).

Date	No. of individuals caught				Mating ratio[b] (%)	Sex ratio[c] (%)
	Female		Male	Unknown[a]		
	Mated	Virgin				
7/24-7/30	16	24	134	9	40	23
7/31-8/6	59	43	97	8	58	51
8/7-8/13	28	7	79	2	80	69
8/14-8/20	21	7	77	2	75	27
8/21-8/27	35	15	33	2	70	60
8/29-9/3	93	36	121	7	72	52
9/4-9/10	35	5	62	3	88	39
9/11-9/17	27	11	47	6	71	45
------removal of pheromone dispenser------						
9/18-9/24	42	4	31	5	91	60
9/25-10/1	58	0	45	9	100	56

[a]destruction of abdomen. [b](no. of females mated)/(no. of females caught) × 100. [c](no. of females caught)/(no. of females) + (no. of males) × 100.

of females recovered alive)] and 17% (3/18) in the treated area, and 92% (23/25) in the untreated area. Therefore, some females were thought to be able to mate even in the treated area.

Effects on density of BAW eggs and larvae

Onions were planted on about 1 m wide ridges in the plots (0.05-0.1 ha) which were scattered in the experimental areas. Larval field density was surveyed in every 5 or 6 plots in the central and marginal parts of the treated area, and in the untreated area once a week from 3 weeks before the placement of dispensers (26 June) to 6 weeks after removal (30 October). Plot and ridge were arbitrarily selected where onion plants were 30-60 cm high.

Surveys were conducted on all of the 400 to 500 hills on 10 m of ridge of each plot. Most larvae were inside hollow leaves. Damaged leaves were collected and dissected to recognize the instar and to count the number of larvae. When the density became higher, fewer hills were sampled to save time and labor. Farmers sprayed insecticides such as methomyl, EPN, permethrin and fenvalerate-dimethoate against BAW, both in the treated and untreated areas, independently from the experiment. However, these insecticides were ineffective (Takai 1988b) and thus considered to have no effect on population density.

The mean densities of egg masses, 1st and 2nd instar larvae, and 4th and 5th instar larvae are shown in Fig. 2. In the treated area, the egg mass density was less than 0.5/100 hills,

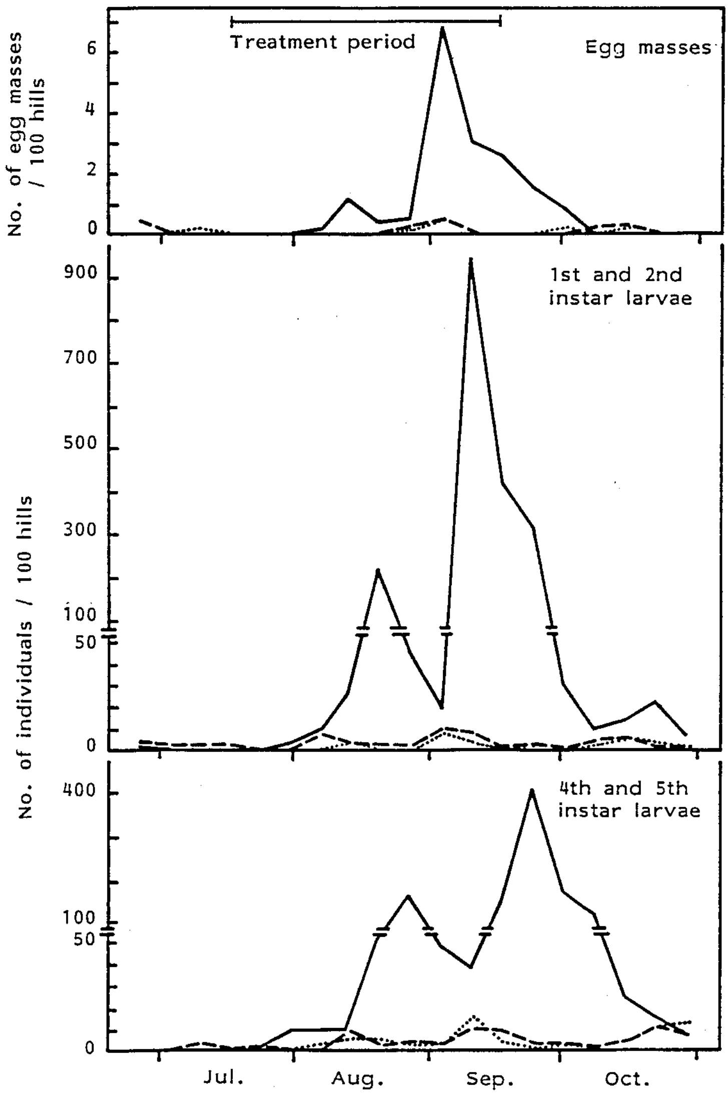

Fig. 2. Population densities of BAW egg masses and larvae in areas treated and not treated with synthetic sex pheromone in 1987. Broken and dotted lines indicate the densities in two survey areas. Solid line indicates densities in the untreated area.

both in the middle and peripheral plots throughout the period. Conversely, in the untreated area, mean egg mass density peaked twice. These peaks were followed by peaks of the 1st and 2nd instar larvae both in treated and untreated areas. They appeared 1 week after those of egg masses. In the treated area, the maximal density was about 10 individuals/100 hills compared with more than 900 individuals/100 hills in untreated areas. Egg mass density was considered to have been reduced in the treated area. However, all of the egg masses collected in both treated and untreated areas were observed to hatch normally. This suggests that hatchability was not reduced in the treated area. It is therefore apparent that the chance for the females to mate was reduced by the large amount of sex pheromone dispersed into the test area, which resulted in a decrease of density of egg masses and 4th and 5th instar larvae.

Communication disruption experiments were successful against several fruit tree and tea pests in Japan (Ohtaishi 1986; Furuno 1986; Sato 1986). Subsequently, some pest control agents have been commercially available. However, communication disruption experiments which aimed to control noctuid species have been reported for *S. litura* (Kitamura et al. 1985; Oyama et al. 1978), *S. littoralis* (Kehat et al. 1983, 1986), and *Heliothis virescens* (Tingle and Mitchell 1982). In these cases, even though the mating rate was certainly reduced, field density and crop damage was not significantly decreased. The present study, in which the field population of BAW was remarkably suppressed, is the first case of successful control of noctuid species using sex pheromone.

Effects of Z9E12-14:Ac on *S. litura* population

Spodoptera litura is also a severe pest on the Welsh onion. The major component of BAW sex pheromone, Z9E1214:Ac, is a minor but important component of *S. litura* sex pheromone (Tamaki et al. 1973). Although the mating of *S. litura* has been inhibited by the evaporation of Z9E12-14:Ac (Yushima et al. 1975; Oyama 1977), its effect on the field population was not clear (Oyama et al. 1978).

For the evaluation of the effect of the treatment against *S. litura*, two dry pheromone traps (box type, Takeda Chem. Ind., Ltd. Sato et al. 1978) were set in both treated and untreated areas. An empty trap with no lure was also set 10 m from each trap in the treated area. In order to evaluate the effect on the field population of *S. litura*, the number of egg masses and larvae of *S. litura* were also recorded during BAW field population surveys.

In the treated area, trap catches of *S. litura* males were apparently less than those in the untreated area: 1-15% from late July to early August and 13-30% from mid August to mid September. The field density of the larvae in the treated area seemed to be suppressed in late July and early August (Fig. 3). This suppression was possibly caused by the intensive spray of insecticide against BAW in the treated area. The field density of larvae in the treated area was not remarkably decreased in comparison with that of the untreated area. In the present experiment, the effect of communication disruption with Z9E12-14:Ac, a minor component of *S. litura* sex pheromone, is thought to have been insufficient for reduction of the *S. litura* field population.

Follow-up experiments in 1988

In 1988, we conducted follow-up experiments in which sex pheromone was released at higher rates into smaller areas than in 1987 to reconfirm the population suppression effect. Treated area was about 50 ha of which Welsh onion plots comprised about 24 ha. This area was the northern one-third of the experiment area in 1987. Untreated area was about 9 km from the treated area. Dispensers were set evenly in Welsh onion plots and other cultivated plots at the rate of 1500 and 600 tubes/ha, respectively. Sex pheromone dispensers were set in the plots on 6-8 July and removed on 30 September 1988.

Larval density was surveyed in every six plots in two survey areas in the treated area and in five plots in the untreated area. Surveys were conducted once a week from 13 July through

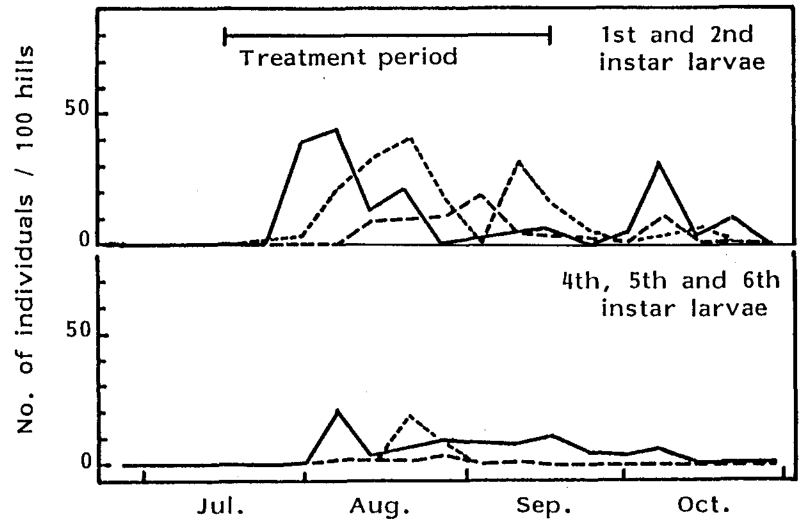

Fig. 3. Densities of *Spodoptera litura* larvae in Welsh onion fields. Broken and dotted lines indicate the densities in the curve areas A and B, respectively. The solid line indicates density in the untreated areas.

27 September. In each plot, the survey was stopped when the number of infested hills reached 25 or when the total number of hills surveyed reached 500.

In the untreated area, densities of egg masses and larvae increased gradually until late August, and rapidly increased in early September (Fig. 4); maximum density of 1st and 2nd instar larvae was more than 400 individuals/100 hills. The mean infestation rate of hills was more than 50% in mid September; in some plots, every hill was observed to be infested by the larvae.

Conversely, population density was low throughout the treatment period in the treated area. No egg mass was found during the treatment period. First instar larvae were found in one survey area on 20 September (0.9 larva/100 hills). No young larvae was found in the second survey area. Few 4th and 5th instar larvae (less than 0.2 individual/100 hills; Fig. 4) were found in both the first (mid-July and late August) and the second survey areas (early September). Infestation rate of hills was less than 0.2% throughout the treatment period.

In 1987, Welsh onion fields were treated with 990 dispensers/ha, and rice fields, greenhouses, orchards, home gardens, and forests were also treated with 320 dispensers/ha. In 1988, 50 ha fields were treated with larger amounts of dispensers than in 1987. The initial density in the treated area was considered to be much lower in 1988 than in 1987, which was indicated by the population survey (Fig. 2, 4) and the capture data with light trap; only a few males were captured throughout the experiment in 1988. Both increased concentration of synthetic sex pheromone and low initial density were thought to have resulted in approximately zero population during the test period. Low initial density was a possible effect of the sex pheromone treatment of the previous year.

It was confirmed again that permeation of the synthetic sex pheromone reduced the egg mass density and consequently reduced the field population of BAW larvae.

Influences Of Delayed Mating

In the open field experiment in 1987, we observed 50-80% of mating ratio in the females caught with the monitoring light trap in spite of drastic reduction in field population density (Table 1). Since the capturing efficiency of virgin females was about one-quarter of that for mated females (Wakamura and Takai 1990), the real mating rate in field population

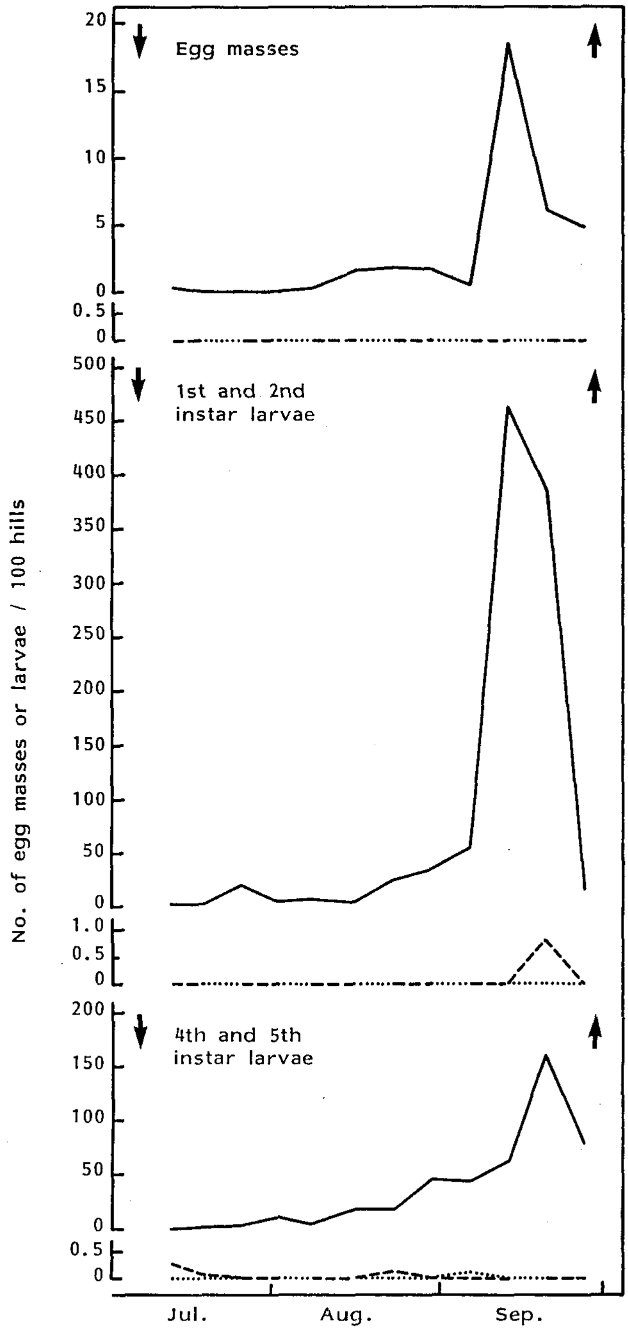

Fig. 4.
Population densities of BAW egg masses and larvae in areas treated and not treated with synthetic sex pheromone in 1988. Broken and dotted lines indicate the densities in two survey areas. Solid line indicates densities in the untreated area. Arrows show the times of setting and removing pheromone dispensers.

was tentatively estimated to be 20-50%. This estimated ratio seems too high to explain the reduction of field population density.

Wakamura et al. (1975) and Barrer (1976) suggested that delay in mating would result in reduction of fecundity in *Cadra cautella*. Kiritani and Kanoh (1984) simulated the expected effect by communication disruption in *Homona magnanima*, based on the reduction caused by delay in mating. In order to understand the effect of mating inhibition, effect of mating delay was investigated in the laboratory (Wakamura 1990).

Delay in mating and reproduction of BAW

One to 10-day-old BAW females were allowed to mate with 2-day-old males. Each pair was placed in a glass pot (9 cm diameter 6 cm high) with a piece of wet cotton. Eggs laid were collected and counted every 3 days and the number of eggs hatched were investigated 4 days after the collection. The insects used were of the 3rd and 4th generations collected from the fields. They were reared on an artificial diet in the laboratory (Wakamura 1988).

The numbers of eggs laid and hatched are shown in Table 2. Three-day-old or younger females laid more than 900 eggs and more than 85% of the eggs hatched. Females older than 4 days laid fewer eggs and their hatchability decreased markedly. The number of unfertilized eggs laid before pairing was increased in 4-day-old and older females. Mating ratios decreased in 8-day-old or older females. The longevity of unmated females was 9.9 days after emergence in a separate investigation.

Delayed mating apparently resulted in decreased reproduction of BAW. Similar phenomena were observed in *Cadra cautella* (Wakamura et al. 1975: Barrer 1976), *Adoxophyes* sp. (Noguchi 1981), *Homona magnanima* (Kiritani and Kanoh 1984) and *Pectinophora gossypiella* (Lingren et al. 1988).

Simulation of reproduction under mating disruption

According to Kiritani and Kanoh (1984), cumulative percentage of mated females and realized expected reproduction (RER) were calculated assuming 90% of mating inhibition. Similar simulation was conducted assuming different percentages of mating inhibition (Table 3). These results suggested that cumulative mating rate and realized expected reproduction would reduce 5 and 30% or less, respectively, when daily mating inhibition were less than 70%. More than 90% reduction of daily mating inhibition is necessary to expect more than 70% reduction of reproduction.

Table 2. Influence of delayed mating on reproduction of BAW female (mean ± SD).

Age (days)	Mating ratio (N)	No. of eggs laid	No. of eggs hatched	Hatchability	Relative fecundity
1	100(10)	991±323	899±372	0.910	92
2	90(10)	1165±248	981±433	0.850	100
3	100(10)	992±271	873±354	0.856	89
4	100(10)	655±217	465±258	0.714	47
6	90(10)	549±204	227±274	0.341	23
8	60(10)	342±252	97±167	0.171	10
10	30(10)	105±148	3±9	0.019	0

Each female of different age was paired with a 2-day-old male.

Table 3. Cumulative ratio of mated females and realized relative expected reproduction in a hypothetical population of BAW.

Daily mating inhibition	Cumulative ratio of mated females	Cumulative realized expected reproduction
0.00	1.00	92
0.20	1.00	93
0.40	1.00	90
0.60	0.99	80
0.70	0.95	71
0.80	0.85	56
0.90	0.59	33
0.95	0.33	18
0.98	0.15	8
0.99	0.08	4

In the 1987 experiment, although a marked reduction of BAW was observed, the mating ratio of females captured with a light trap was 50% or more. Real mating rate was estimated to be 20-50% considering the difference in the trapping efficiency between mated and virgin females (Wakamura and Takai 1990). Applying these estimates to the simulation shown in Table 6, daily inhibition of mating would have been more than 90% throughout the experiment period. In this simulation, removal of females caused by death or dispersal are not considered, which would result in overestimations for both daily inhibition and realized expected reproduction. We can estimate that mating of BAW should have been inhibited 95% or more in the 1987 experiment.

It is therefore concluded that the effect of communication disruption on field populations is the reduction of fecundity caused by mating delay resulting from the reduction of daily mating rate.

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