Efficiency of the sterile insect release method as an eradication measure for the sweet potato weevil, *Cylas formicarius* (Fabricius) (Coleoptera: Brentidae) in the field

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Abstract
A small scale experiment was carried out to eradicate the sweet potato weevil, *Cylas formicarius* (Fabricius) by the sterile weevil release method from 1994 to 1996 on the islet, Kiyamajima, 35 ha, of the Amami Islands, Kagoshima Prefecture, Japan. Weevils were mass-reared with fresh sweet potato roots at 27°C and roots filled with the weevils were irradiated with gamma ray, 80 Gy on the 27th to 28th days after oviposition (newly eclosed adult). Sterile weevils were stained with fluorescent dyes and released by hand on host plant foliages. Monitoring was done by both pheromone traps and root traps throughout the experimental period. From 11 January, 1994 to 19 July, 1994, ca. 32,000 sterile weevils were released every 10 d as a rule all over the island. This trial suggested the necessity of a denser release of sterile weevils for successful eradication. Thus, for intensive release ca. 16,000 sterile weevils were released every 10 d as a rule from 29 July, 1994 to 5 September, 1995 in a restricted area, 13 ha, as the release zone. The wild population in the release zone was controlled to zero or at least nearly to zero after summer in 1995. Only a few unmarked males were captured by pheromone traps for one year after the final release of sterile weevils on 5 September, 1995, which was probably immigrants from outside of the release zone. No weevils were found in the reexamination of root traps and dissection of wild host plants carried out in September in 1996.

Key words: *Cylas formicarius*, sweet potato, eradication, sterile insect release

INTRODUCTION

In Japan, the sweet potato weevil, *Cylas formicarius* (Fabricius) is distributed only in the Nansei Archipelago (Southwestern islands) and causes destructive damage to sweet potato crops. It has been prohibited by the plant quarantine regulation to transport sweet potato crops from this area to other non-distributed areas in Japan. However, *C. formicarius* was frequently brought into non-distributed areas of Japan during the last 50 years by accident (Setokuchi et al., 1996). In these invaded areas, *C. formicarius* was eradicated by applying many chemical insecticides and uprooting host plants, which caused large damage to the nearby ecosystem. Thus, development of sustainable techniques for eradicating this weevil has been anticipated not only from invaded areas but also from all areas of the Nansei Archipelago in Japan.

Male annihilation (Steiner et al., 1965) using sex pheromone traps proved to be ineffective as an eradication measure for this weevil (Yasuda, 1995; Setokuchi et al., 1996). Some studies on the sterilization of this weevil using gamma irradiation (Walker, 1966; Dawes et al., 1987; Hayashi et al., 1994) have suggested the possibility of using this technique as an eradication method for *C. formicarius*. Thus, with the support of the Japanese Government, we undertook in 1988 to develop the sterile insect release method (Knipling, 1955) to...
eradicate this weevil. In this paper, we report the hopeful results of a study to control *C. formicarius* by the sterile insect release technique which was carried out from 1994 to 1996 on a small island in Japan.

**MATERIALS AND METHODS**

**Locality (Kiyamajima Is.).** Field experiments were conducted in Kiyamajima Island, 35 ha, adjacent to Amami-Oshima Island of Kagoshima Prefecture (Fig. 1). The island is 500 m distant from the nearest island, Ukejima, to the southwest. A long and steep rocky hill (150 m high) runs from northwest to southeast in the central part of this island and forms its watershed. There are sandy beaches and shrub zones in the northeastern and northwestern parts. The island is uninhabited, and sweet potato crops have never been cultivated there. The wild host plants of this weevil, *Ipomoea pes-caprae* R.Br. grew along the beaches and *Pandanus odoratissimus* L.f. around the skirt of the hill. On the hill, *Pinus luchuensis* Mayr., *Rhaphiolepis umbellata* Makino and other plants grew, but host plants were very rare.

**Sterilization.** The weevils were mass-reared by the method developed by Kamikado et al. (1993), namely, the adults were given fresh roots of sweet potato as a diet and an oviposition site under 27°C, 70% RH and 16L8D. The roots filled with weevils were irradiated with 80 Gy of the gamma ray on the 27th or 28th d after oviposition (newly eclosed adult) as an optimal dosage (Tokunaga, personal communication).

**Marking.** The adult weevils emerging from irradiated roots were put into a vinyl bag with fluorescent dye and were stained by shaking the bag, so as to allow them to be easily distinguished from the wild weevils when recaptured by monitoring traps in the field. Fluorescent dye attached on females was detected by the emission of luminescence from a cryshed body under a fluorescent light.

**Release of sterile weevils.** The sterile weevils were released at 10-d intervals as a rule, though this interval often had to be changed due to weather conditions, etc. Sterile weevils (31,674 ± 12,589, mean ± SD) consisting of both sexes were released at every release by hand on the foliage of host plants all over the island from 11 January to 19 July in 1994. This is referred to as 'the exten-

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**Fig. 1.** Distribution of pheromone traps (circle) and the sterile weevil release zone in the intensive release (shaded area) in Kiyamajima island in Amami Islands, Nansei Archipelago, Japan. Solid circles represent the traps which captured many weevils during the extensive release.
sive release' hereafter. From 29 July, 1994 to 5 September, 1995 15,916±8,336 sterile weevils were released only in ‘the release zone’ which covers 13 ha of the northeastern part of the island (shaded area in Fig. 1), and the remaining area of the island was adopted as ‘the control zone’ with no release. This restricted release is referred to ‘the intensive release,’ hereafter.

In the extensive release, more sterile weevils were released on the foliage of wild host plants with a higher weevil density corresponding to precedent data of nearby traps. The total number of sterile weevils released varied widely at every release due to our limited ability for weevil production (Fig. 2).

**Monitoring method.** Pheromone traps: Plastic box pheromone traps (Setokuchi et al., 1991) were used to monitor the wild male population. A fiberboard formulation impregnated with 100 μg of synthetic sex pheromone and an insecticide, MEP (Setokuchi et al., 1991) was set in the trap. Thirty traps were continually placed all over the island in the extensive release. In the intensive release, 13 traps and 25 traps were continually placed in the sterile weevil release zone and in the control zone, respectively, throughout the experiment (Fig. 1). The Fiberboard formulations set in the traps were exchanged for once a month. The males captured were recovered from the traps every 10 d as a rule and the ratios of the numbers of sterile marked males released to that of wild unmarked males were examined in the laboratory. The values of the ratios obtained through the surveys are shown as the fractions of marked individuals per unmarked ones (M/U).

Root traps: Root traps (Sugimoto et al., 1994a) were used to monitor females attracted to and eggs deposited on them. In each trap, 3 roots were placed into a plastic mesh basket (25 cm ht.×27 cm dia.), through which weevils could move in and out freely. Ten root traps in the release zone and five traps in the control zone were continually placed around the foliage of wild host plants from 13 December, 1994 to 14 September, 1995. The roots were exchanged for new ones every 10 d. The roots recovered from the field were incubated in the container at 27°C for 1 month, and weevils emerged from them were counted.

Host plants: The samples, 1 m long vines of the wild host plant, *Ipomoea pes-caprae*, were sampled on 5, 14, 26 and 27 September in 1995 after stopping the sterile weevil release in both release and control zones, and dissected in the laboratory to monitor wild weevils.

**Verification of the effect of sterile weevil release.** To verify the effect of sterile weevil release in the release zone, 13 pheromone traps were continually placed in the release zone and 25 traps in the control zone from 14 December, 1995 to 11 September, 1996. Five surveys by pheromone traps were conducted during January to September in 1996. Ten and five root traps were placed in these two zones, respectively, on 11 September, 1996. These root traps were recovered on 26 September, 1996, and the adults emerged from the roots were counted on 19 December, 1996, after incubation at 27°C. The stems of wild host plants were sampled on 26 September, 1996, from as many points as possible in the release zone and dissected to count the number of weevils in them.

**RESULTS**

**Extensive release of sterile weevil**

In Fig. 2 the number of males captured by the pheromone traps placed all over the island is shown separately for the northeastern part of the island, the intensive release zone, and the control zone. The wild populations in both zones gradually decreased until May in 1994, but increased rapidly again from July to August that year. This seasonal change of the population was like that of the wild population (Yasuda, 1995), so the effect of sterile weevil release on the inhibition of wild population was thought to be negligible. More weevils tended to be captured by traps placed along the beach (Fig. 1). The number of males captured by 6 traps, which captured many males during June and July 1994 and that by the remaining 24 traps are shown separately in Fig. 3. The partial population monitored by the latter 24 traps was controlled to nearly zero after May, probably due to its initial low density. However, the other partial populations monitored by 6 traps could not be controlled by sterile weevil release probably due to the initial high density. These facts suggested the possibility of successful eradication by a denser release of sterile weevils. Thus, the northeastern part of the island was established as the denser release zone because of a limited ability to produce sterile weevils. This
restricted area for intensive release is isolated geographically by the watershed, and the weevil population in this area was smaller than that in the control zone.

**Intensive release of sterile weevils**

*Pheromone traps*

In the intensive release all sterile weevils were released only in the release zone (Fig. 1) for a denser release after 29 July, 1994. In the release zone the wild population decreased gradually with some slight rises and dropped to nearly zero after June in 1995, though it increased rapidly during this period in the control zone (Fig. 2). Sterile weevil release was stopped on 14 September, 1995.

With regard to the males captured by the pheromone traps, the ratio M/U for the number of marked males to that of unmarked ones became more than 50 in many cases after 7 September, 1994 (Fig. 2). Low values of this ratio on 7 Febru-
ary and 21 April, 1995 might be due to low captivity as a result of frequent rainfall and to a chance no-release on 12 April, respectively. After December in 1994 this ratio frequently varied very widely due to small catches. After stopping the release, two low ratios were derived from 12 marked males to 1 unmarked one on 26 September and from 1 marked male to 6 unmarked ones on 9 November.

**Root traps**

The number of unmarked females captured by the root traps was maximal from late April to mid May in 1995 in the control zone (Fig. 2). However, this does not indicate the peak of the seasonal abundance of the wild population, because the captivity efficiency of the tuber trap tends to fall with the thick growth of host plants around them (Sugimoto et al., 1994a). Namely, wild host plants grew thickest during summer to autumn, and so the captivity efficiency of the trap fell during this season in spite of the peak of the wild population (Yasuda, 1995). In fact, in the control zone many adult weevils emerged from root traps placed during the summer (Fig. 2). On the other hand, in the release zone a few unmarked females were continually captured after spring, especially in summer in 1995. However, few adult weevils emerged from these root traps. Only seven weevils emerged from two of the traps placed during mid April to mid May in 1995. After late May, only four weevils emerged from the same trap placed during mid August. No weevils emerged from traps placed after late August.

**Examination of wild host plants**

Dissection of wild host plants revealed as many dead weevils in the release zone as in the control zone (Table 1). Such dead weevils were usually found within the stems of host plants in the field, the mortality factors of which consisted of parasitoids, diseases and others. However, it is notable that no living weevils were found in the release zone, unlike in the control zone.

**Reexamination of the effect of sterile weevil release**

**Pheromone traps**

The wild population in the release zone fell to zero or nearly to zero in autumn, 1995 (Fig. 2). Thus, the effect of sterile weevil release was examined again in 1996 in the release zone. All pheromone traps were continually placed in both zones after 14 December, 1995 and the males captured were recovered six times by 11 September, 1996. Only eight males were captured after late May in 1996 in the release zone (Table 2).

**Root traps**

No adult weevils emerged from any root traps placed in the release zone, though those traps were in place for about 2 wk in September in 1996, corresponding to the most abundant season of the wild population (Table 3).

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**Table 1. Weevils found in the wild host plant, Ipomoea pes-caprae, in the release and the control zones after stopping sterile weevil release**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Total length of vines dissected (m)</th>
<th>No. of living individuals</th>
<th>No. of dead individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Larvae</td>
<td>Pupae</td>
</tr>
<tr>
<td>Release zone</td>
<td>927.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Control zone</td>
<td>1,717.4</td>
<td>121</td>
<td>81</td>
</tr>
</tbody>
</table>

*a Four surveys were carried out during September in 1995 after final release.
Host plants

One hundred seventy five stems of the host plants were sampled from five points in the release zone on September 26, 1996. No weevils was found in these plant stems.

DISCUSSION

In the extensive release, the number of unmarked males captured varied widely among pheromone traps (Figs. 1 and 3), and this indicates the contagious distribution of the wild population of *C. formicarius*. Foliage of host plants was spatially distributed in patch and distribution of the weevil populations followed that of the host plants. From the fact that the population monitored by 24 traps was controlled to nearly zero, while that monitored by 6 traps failed to be controled after June (Fig. 3), we determined that sterile weevil release controlled wild weevils to nearly zero in patches with a low weevil density (poor patches), but failed to control them in patches with a high weevil density (rich patches). This difference in the effect of sterile weevil release among patches would be mainly related to the low dispersal ability of this weevil, especially in the presence of host plant foliage (Sugimoto et al., 1994a).

However, by the intensive release, unmarked males captured by the pheromone traps decreased to nearly zero, the M/U ratios gradually increased and few adult weevils emerged from root traps (Fig. 2). In the reexamination no sweet potato weevils were found in either root traps or host plants in 1996 (Table 3). These facts may indicate that the wild population in the release zone was eradicated by the sterile weevil release, or at least controlled to nearly zero.

The results obtained above indicate that, to achieve eradication, the release level of sterile weevils should be determined based upon weevil abundance in rich patches. Hence, for efficient eradication, partial preliminary suppression of wild populations prior to sterile weevil release may be necessary under high wild population density. We should suppress not simply the average density of the wild population but more heavily the partial populations in rich patches, because it is difficult in a large-scale sterile insect release program to release sterile weevils proportionally to the abundance of partial populations inhabiting host plant patches. Therefore, a preliminary census of the spacial distribution of the wild population is necessary for the efficient control of insect pests by the sterile insect release technique, especially in the case of insects with low dispersal ability.

In the intensive release zone, most of the unmarked females captured by the root traps in the release zone were probably not wild, but had lost their marks before being recovered by the traps after release, because fewer progenies emerged from these traps (Fig. 2). This should be true for males as well. According to the surveys on detection rate of fluorescent dye in August and September in 1995, more than 10% of unmarked males captured by pheromone traps would have lost their marks.

But, most of the remainder were likely to have been immigrants from the control zone. Males are

<table>
<thead>
<tr>
<th>Zone</th>
<th>No. of traps placed(^a)</th>
<th>Total no. of males captured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jan. 25</td>
<td>Mar. 6</td>
</tr>
<tr>
<td>Release zone</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Control zone</td>
<td>25</td>
<td>54</td>
</tr>
</tbody>
</table>

\(^a\) All traps were continually placed in both zones after 14 December in 1995.

<table>
<thead>
<tr>
<th>Zone</th>
<th>No. of traps placed(^a)</th>
<th>No. of adults emerged(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release zone</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Control zone</td>
<td>5</td>
<td>127</td>
</tr>
</tbody>
</table>

\(^a\) All traps were continually placed from 11 to 26 September in 1996.

\(^b\) Adults emerged by 19 December in 1996.

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**Table 2.** Number of males captured by pheromone traps in the release and the control zones in 1996

**Table 3.** Number of adult weevils emerged from root traps in the release and the control zones
more active than females, and moved more than 50 m in 1 d on the average, sometimes more than 2 km in 1 d under poor host plant conditions (Sugimoto et al., 1994a; Moriya, 1995; Miyatake et al., 1997). In this experiment, one year after the final release only eight males and no females were captured by the pheromone traps in the release zone (Table 2), and 44 of 1,076 males captured during August to September in 1994 were marked in the control zone. These probably had immigrated over the top of the hill from the release zone on the southern wind. Such migration will occur equally between the release zone and the control zone, though it will depend upon wind direction.

In this study, one pheromone trap was placed per ha all throughout the island. This means that most areas of the island were within the effective ranges of a pheromone trap (Sugimoto et al., 1994b). Thus, it is notable that the results obtained in this study should include not only the effect of the sterile weevil release but also those of male annihilation (Steiner et al., 1965) and communication disruption (Shorey et al., 1974) by the pheromone traps placed densely throughout the experimental period.

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