SHORT REPORT

Possible biological control of the armyworm by the harvest mouse

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Introduction

The harvest mouse, *Micromys minutus* Pallas (Rodentia: Muridae), is highly adept at climbing grass leaves and stems with its remarkably small body size (7–9 g in adults), grasping hands and feet and a prehensile tail; this fact reveals how effectively this species has adapted to inhabit the stalk zone of Gramineae communities (Ishiwaka & Mōri 1999). The harvest mouse is widely distributed in the temperate and humid climate zone between East Asia and West Europe (Harris & Trout 1991). In most of the regions in this zone, Gramineae communities progress to climax vegetation in which trees are dominant, unless disturbances such as burning, floods, grazing or harvesting occur. Despite such a wide distribution, the International Union for Conservation of Nature (IUCN) has listed this species in the "near threatened" category since 1996 (IUCN 2007).

The harvest mouse appears to be strongly associated with agricultural lands including their surrounding grass strips that are exposed to various disturbances (Harris & Trout 1991; Bence *et al*. 2003; Moore *et al*. 2003; Surmacki *et al*. 2005). Furthermore, in Japan, many harvest mice appear to inhabit some gramineous crop fields and their edges (i.e. grass strips); this has occurred following the conversion of many river banks into concrete walls. The unique spherical nests of the harvest mouse are often observed in rice (*Oryza sativa* L.) communities in paddy fields and in *Imperata cylindrica* (L.) Beauv. var. *koenigii* (Retz.) Durand et Schinz communities in paddy levees. However, rice farmers sometimes remove these nests to prevent damage to their crops. Compared with rice fields, the less intensive management of agricultural grasslands such as meadows and pastures allows the harvest mouse to maintain its population, even though machinery, chemical fertilizer and introduced crop plants are applied there (Tsukada *et al*. 2004; R. Ishiwaka, unpubl. data).

The armyworm, *Mythimna separata* Walker (Lepidoptera: Noctuidae), is a pest of several cereal and forage crops in Asia and Australia, specifically between a latitude of 45°N to 45°S, and a longitude of 60°E to beyond 170°W (Sharma & Davies 1983, cited by Sharma *et al*. 2002). Larvae of the armyworm feed on primarily leaves of gramineous plants and periodically causes serious damage to the following crops: sorghum (*Sorghum bicolor* [L.] Moench), pearl millet (*Pennisetum glaucum* [L.] R.Br.), *O. sativa*, maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and sugarcane (*Saccharum officinarum* L.) (Sharma *et al*. 2002). This pest affects the following forage plants as well: perennial ryegrass (*Lolium perenne* L.), orchardgrass (*Dactylis glomerata* L.), reed canarygrass (*Phalaris arundinacea* L.), redtop (*Agrostis alba* L.), and weeping lovegrass (*Eragrostis curvula* Nees) (Watanabe 1961; Koyama & Watanabe 1962; Kanda *et al*. 1977). Yield losses are influenced largely by the stage at which the damage occurs and the gregarious behavior of the larvae. Sometimes, an outbreak results in complete crop loss. Outbreaks of the armyworm in crop fields have been recorded many times in South Asia (Lin *et al*. 1964; Thakur *et al*. 1987; Sharma *et al*. 2002). In Japan, serious damages to rice and other gramineous crops have been reported frequently (Ohmori 1960; Koyama 1963, 1966, 1970; Oku & Kobayashi 1974; Oku *et al*. 1979; Hirai *et al*. 1985); in contrast, only sporadic outbreaks have occurred in agricultural grasslands such as meadows (Oku *et al*. 1976; Kanda *et al*. 1977; Kanda 1988).

The use of insecticides has depressed the populations of herbivorous insects to some extent, but their use is severely restricted, particularly in organic agriculture and forage crop fields. Therefore, the biocontrol of pest insects has been investigated in crop fields. Insectivorous birds, parasitic wasps as well as arthropod predators such as spiders, and pathogens have been studied in relation to the biocontrol of pest insects (e.g. Fowler *et al*. 1991; Bock *et al*. 1992; Donovan 2003; Hooks *et al*. 2003; Rosa and Simões 2004; Jones *et al*. 2005).

Forty-two parasitoids, 15 predators, four bacteria, five fungi, and three viral strains have been reported as natural control agents for the armyworm (Sharma & Davies 1983, cited by Sharma *et al*. 2002). The armyworm larvae tend to

remain hidden under the ground or in the sheath of the host plant during the day, and they feed at night (Kanda 1988). It is natural that the control agents for the armyworm should exclude bird species because most insectivorous ones are diurnal. Mammal species, on the other hand, usually become more active at night; therefore, they can potentially depress the populations of such nocturnal pest insects. However, to the best of our knowledge, studies on any omnivorous or insectivorous mammal as a natural control agent for pest insects have not been available to date, except for a study by Ellis *et al.* (2005), probably because mammal species, especially rodents, have been generally regarded as little more than pests.

Grassland scientists have generally discussed wildlife, especially wild mammal species, primarily as pests or in relation to biodiversity. We assumed that some omnivorous and insectivorous mammal species including the harvest mouse would have the potential to modify the interaction between gramineous forage plants and pest insects as well as other control agents in agricultural grasslands. If function of such a mammal as an extra biocontrol agent for pest insects is suggested, the establishment of integrated pest management in grasslands will be promoted. Moreover, with this study, conservation of a threatened species can directly link to agricultural profitability.

The aim of this study is to evaluate the effects of the harvest mouse on a gramineous forage plant infested by the armyworm. Because of the difficulty in establishment of authentic grassland from which only the harvest mouse is completely removed, we adopted cages, in which the harvest mouse, the armyworm and a forage grass were brought, on a crop field.

Materials and methods

Experimental condition

We used harvest mice from a colony established with five wild individuals captured in Saga, Kyushu, Japan in 1990. In May 2001, we built six cages sized 90 cm × 90 cm × 100 cm on the ground at a crop field in Fukuoka, Kyushu, Japan (5 m a.s.l.). The cages were made of wire mesh (5 mm × 5 mm) and wood. Guineagrass (*Panicum maximum* Jacq.), a kind of tropical forage grass, was seeded inside and outside the cages. The top of each cage was covered with a sheet of transparent vinyl chloride in order to keep the harvest mouse from dying and its artificial food (described later) from decay. Every sheet had holes through which rainwater fell in and all the guineagrass vegetations inside the cages were watered when needed, though neither fertilized nor harvested. We had transplanted some individuals from the outside at a low density to establish similar vegetations among the cages when the grass was still short. The cages were then left alone until the end of the experimental period.

On 13 October, when each cage was found to have a closed dense grass canopy, we placed six adult harvest mice into

three cages, with one pair in every cage as treated condition, prior to release of the armyworm. Eighteen days after the placing of the harvest mouse, we examined the guineagrass leaves in the cages with the harvest mouse to evaluate whether it can be a pest of this crop. The armyworm larvae in various instars were obtained from an infested sudangrass (*Sorghum sudanense* Piper [Stapf]) crop field located 4 km east. Thirty-eight to 40 individuals of the armyworm were placed inside each cage; they were transferred with similar instar composition to all the six cages on 1 November (19–21 individuals cage^{-1}), 3 November (4 individuals cage^{-1}) and 19 November (15 individuals cage^{-1}). In the armyworm, third instars can become pupae and no longer feed on leaves no earlier than 18 days at 20°C (Okuyama & Tomioka 1963). Therefore, the guineagrass communities would be exposed to infestation by the armyworm larvae at all times during the experiment. Water and food were available for the harvest mouse ad libitum; the diet consisted of commercial laboratory mouse chow NMF (Oriental Yeast, Tokyo, Japan) along with the following seeds: canary grass, Chinese, foxtail, common millet, flax, and sunflower.

Categorization of guineagrass leaves

Forty days after placing the first armyworm larvae into the cages, we sampled approximately 100 guineagrass leaves from each cage at random. Then, we classified each of the leaves into one of five categories based on the infestation stage; namely, the extent of consumption by the armyworm in terms of leaf area. The categories were as follows: intact leaves (no consumption detected); up to 25% of the leaf area consumed; between 25% and 50% of the leaf area consumed; between 50% and 75% of the leaf area consumed; and more than 75% of the leaf area consumed. The tendency of the armyworm to neglect midribs when feeding on grass leaves enabled us to estimate the damage it caused to the leaves in terms of dry weight. Based on the length of the midrib of a damaged leaf, we estimated the dry weight of the leaf before consumption; this was done by means of a relationship curve of the midrib length versus the dry weight of more than 500 intact leaves. The actual dry weight of the damaged leaves subtracted from the estimated dry weight before damage is equivalent to the yield loss caused by the armyworm.

Statistical analyses

We used a χ^2 analysis for comparison between the frequency distributions of the extent of leaf consumption by the armyworm. We replaced each category of intact to more than 75% with 0–4 as scores, respectively, and calculated a mean score of each cage. After Bartlett's test for homogeneity of variances of the mean scores, a two-tailed Student's *t*-test was used for comparison between the presence and the absence of the harvest mouse. We again adopted a Student's *t*-test for

comparison between the estimated yield losses in the presence and the absence of the mouse.

Results

No feeding sign of the harvest mouse was detected on guineagrass leaves. The frequency distribution of the extent of leaf consumption by the armyworm is shown in Figure 1. The frequency distributions of the extent of leaf consumption by the armyworm were significantly different between the presence and absence of the harvest mouse (χ^2 analysis, $P < 0.0001$). The mean proportion of the intact leaves from the cages in which the harvest mouse was present ($59.1 \pm 2.1\%$, mean $\pm$ standard error of the mean [SEM]) was greater than that in the cages in which the harvest mouse was absent ($35.0 \pm 2.4\%$). Conversely, the mean proportion of those in which the damage was between 50% and 75% of the leaf area and the mean proportion of the leaves in which the damage was more than 75% of the leaf area was lower in the cages with the mouse ($5.7 \pm 0.7\%$ and $4.9 \pm 1.6\%$, respectively) than those in the cages without it ($10.4 \pm 0.9\%$ and $13.2 \pm 1.1\%$, respectively). The mean proportion of the leaves in which the damage was up to 25% of the leaf area and the mean proportion of those in which the damage was between 25% and 50% of the leaf area increased from $21.0 \pm 3.6\%$ and $9.2 \pm 1.0\%$ in the presence of the harvest mouse, respectively, to $27.1 \pm 1.8\%$ and $14.2 \pm 2.2\%$ in its absence, respectively.

The mean score of infestation stages in the presence of the harvest mouse (0.76 ± 0.05, mean $\pm$ SEM) was significantly lower than that in the absence (1.40 ± 0.09; Student's t-test, $P = 0.004$). The mean estimated yield loss in terms of dry weight from the cages with the harvest mouse was 4.68 ± 0.45 g,

which was significantly less than the figure of 7.47 ± 0.77 g from the cages without the mouse ($P = 0.036$).

Discussion

The harvest mouse significantly reduced the damage of leaves by the armyworm, leading to a greater proportion of intact leaves (i.e. lower proportion of damaged leaves), and resulted in a significant lowering of the estimated yield loss caused by the armyworm. The results suggest that the harvest mouse has the potential to modify the interaction between gramineous forage plants and the armyworm through lessening the density of the armyworm. The harvest mouse can live temporarily at the density in this study, as some different individuals had been caught at one trap station during a few consecutive days (R. Ishiwaka, unpubl. data). The density of the armyworm in this study has been often observed in the time of outbreaks. Compared to gramineous crop fields under more intensive management, much fewer reports on outbreaks of the armyworm in agricultural grasslands have been published, in spite of the fact that gramineous plants are present in both. Structurally complex landscapes with substantial areas of woody habitats and a limited agricultural area hold the potential for sustainable pest control by natural enemies (Bianch *et al.* 2005), and agricultural intensification can have wide impacts on biodiversity (Robinson & Sutherland 2002). The less the intensification and the more complex the landscapes, and thus the more efficient the management of the habitat of some wildlife including the harvest mouse, may be associated with fewer outbreaks of the armyworm in the grasslands.

An analysis of fecal pellets from an urban environment revealed that seeds, fruit, monocotyledon and dicotyledon leaves, and insects were the primary dietary items of the harvest mouse; fungi, moss, roots and some other invertebrates were also found to be consumed (Dickman 1986). Although fecal analysis is currently one of the most commonly-used methods for understanding the diet of a mammal, this analysis suffers from some drawbacks (Ruetter *et al.* 2005). For example, highly digestible food items such as insect larvae cannot be effectively detected. In fact, the harvest mouse actively may prey on insects including larvae of the armyworm probably to meet its nutritional need for animal protein more often than reported in the published work; this has been suggested through a study of the harvest mouse under captivity with various food items (R. Ishiwaka, unpubl. data). It also supports our hypothesis that several carcasses of the adult armyworm remained in every cage without the harvest mouse when the experiment ceased, meanwhile no carcass was found in any of the cages with the mice. The lack of feeding signs of the harvest mouse detected on guineagrass leaves and significant reduction in crop yield loss in the cages with the harvest mouse suggest that the harvest mouse can function as a natural control agent for the armyworm rather than a pest, at

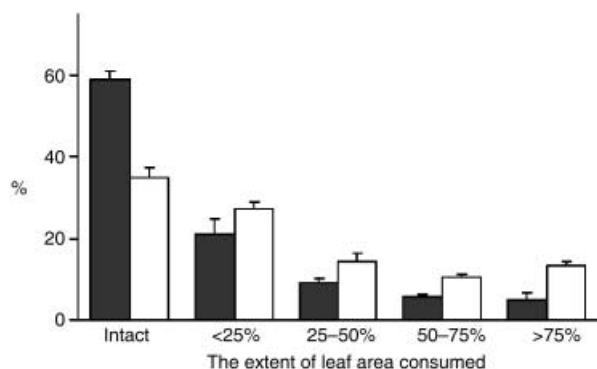**Figure 1** Proportions of guineagrass leaves that were classified into five categories based on the extent of the leaf area consumed by the armyworm; approximately 100 leaves were randomly sampled from the cages (■) with and (□) without the harvest mouse. The vertical bars indicate standard error of the mean. The frequency distributions of the extent of leaf consumption were significantly different between the presence and absence of the mouse (χ^2 analysis, $P < 0.0001$).

least in soiling forage crop fields and agricultural grasslands, in spite of a general impression of "mice" being a pest. Agricultural grasslands are the habitat or feeding places for several insectivorous and omnivorous mammal species. Among the omnivorous species, the harvest mouse may prefer insects on account of its small body size besides food items such as herbaceous plant seeds.

Cotesia kariyai Watanabe (Hymenoptera: Braconidae) is a specialist parasitoid of the armyworm larvae and thus well known as a major control agent of this pest insect. In a tritrophic system consisting of corn plants, the armyworm and *C. kariyai*, the infested corn plants attracted *C. kariyai* with herbivore-induced synomone only when the inflicting larvae were in the early instars (Takabayashi *et al.* 1995; Hou *et al.* 2005). The parasitization of young larvae resulted in a decrease in the damage caused by them, while the parasitization of old larvae did not affect the amount of damage caused. It appears that corn plants attract *C. kariyai* only when the recruitment is adaptive for the plants. In contrast, we observed that, while under captivity, the harvest mouse preyed on the armyworm larvae without any infested plants; that is, without any herbivore-induced synomone (R. Ishiwaka, unpubl. data). The predation by the harvest mouse on the armyworm larvae would occur without any infested plant attraction, and therefore regardless of the larvae instars in the field. Additionally, the accessibility of the harvest mouse to adequate food and water in our experiment and that no reproduction occurred in the two cages during the experiment suggest that this species can prey on the armyworm, irrespective of the dynamics of other food resources or the breeding condition; on the other hand, climate and breeding conditions determine the parasitic activity on the armyworm (Sharma *et al.* 2002).

Acknowledgments

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