Effects of exotic plants and insects on the ladybird beetle communities in Japan

Yuko TODA and Yasuyuki SAKURATANI
Laboratory of Environmental Ecology, Faculty of Agriculture, Kinki University, Nara 631-8505, Japan

Introduction

Many species of plants and insects invaded into Japan in the last one hundred years (The Ecological Society of Japan, 2002). Some of them expanded their geographical distribution throughout Japan and became dominant species in the community (The Ecological Society of Japan, 2002).

For example, *Solidago altissima* invaded into Japan in the early 1900s from North America, and became dominant plant in most regions in Japan (Hattori, 2002). The species of aphid infesting this plant were not recorded from Japan, however, one species of exotic aphid (*Uroleucon nigrotuberculatum*) was recorded on *S. altissima* in fifteen years ago(Tanaka & Sorin, 1999). The distribution of this aphid expanded rapidly. Some species of ladybird beetle preying on this aphid were observed recently, and most of them were native ladybird beetle species. Another example is an exotic plant, *Oenothera biennis*, invaded in Meiji Era (Shimizu, 2003), and an exotic aphid species (*Aphis oenotherae*) was recorded several years ago from Japan. The distribution of this aphid also expanded rapidly in Japan. Some species of ladybird beetle preying on this aphid were recorded shortly, and most of them were native ladybird beetles. An exotic tree, *Leucaena leucocephala*, is distributed widely in the South –West Islands of Japan (Yamamura, 2002), and this tree is infested by psylla, *Heteropsylla cubana*, which is also exotic insect (Kiritani, 2002). An exotic ladybird beetle, *Olla v-nigrum* preys on only this psylla (Uneno & Sasaji, 1989; Omomo & Sasaji,1989). This food chain consists of all exotic species in Japan. *Adalia bipunctata* is also exotic predacious ladybird beetle recorded in 1993 from Japan (Sakuratani, 1994). This species preys on native aphid on *Acer buergerianum*, *Rhaphiolepis umbellata* and other trees in Japan. And this ladybird beetle has inter-specific relationships with native ladybird beetle (Sakuratani et al., 2000).

Thus, the food chain including exotic plants and insects forms some types of food chain in the ecosystem of Japan. There was only one type of food chain prior to invasion of exotic plants and insects. However, if an exotic species entered into at least one trophic level of the food chain consisting of three trophic levels (producer, first consumer and second consumer), the number of type of food chain in the three trophic levels increases to eight times (Sakuratani, 2000) (Fig.1). Thus, many effects of exotic species may occur in those communities including predacious ladybird beetles. And the effects of exotic species in the communities may differ from the position (niche) of exotic species in each trophic level.

In this paper, we show some cases of food chain including exotic plants, herbivorous insects and predacious ladybird beetles in Japan, and discuss the effects of these species on the communities.

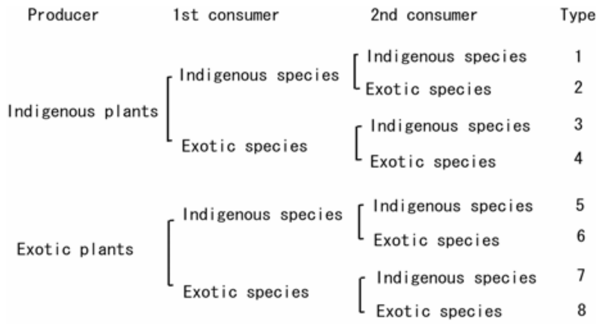

Fig. 1. Type of food chain consisting of three trophic levels including exotic species

Materials and Methods

1. Field investigation

The investigations were carried out in some fields invaded exotic producer (plants), first consumer (aphids and psyllas) and second consumer (predacious ladybird beetles). The number of ladybird beetles were counted on each plant or shoot of tree chosen at random. The aphid density was recorded at five or six density level (0:nothong –5:very high in grass, 1:nothing or very low –5: very high in tree). The investigation schedule is shown in Table 1.

2. Survival rate of ladybird beetles fed on various native and exotic preys

Some species of ladybird beetle (native: *Coccinella septempunctata* and *Harmonia axyridis*, exotic: *Adalia bipunctata* and *O. v-nigrum*) were reared at 20 ℃ (*C. septempunctata* and *H. axyridis*), 22.5 ℃ (*A. bipunctata* and *O. v-nigrum*), 14L:10D feeding on some species of exotic and native preys, and examined the survival rate.

Table 1. Schedule of investigation of food chain including exotic species. Type1, 2, 6, 7, 8, see Fig. 1.

Schedule no.	Producer	1st consumer	2nd consumer	Type	Searching points and year (Japan)
1	*Vicia angustifolia*	*Aphis craccivora* *Acyrthosiphon pisum*	*Coccinella septempunctata* *Harmonia axyridis* *Propylea japonica*	1	Nara campus of Kinki University, Nara Pref. 2002
2	*Artemisia princeps*	Aphid A Aphid B Aphid C	*Coccinella septempunctata* *Harmonia axyridis* *Propylea japonica*	1	Nara campus of Kinki University, Nara Pref. 2002
3	***Solidago altissima***	***Uroleucon nigrotuberculatum***	*Coccinella septempunctata* *Harmonia axyridis* *Propylea japonica* *Menochilus sexmaculatus* ***Adalia bipunctata***	7	Nara campus of Kinki University, Nara Pref. 2001, 2002
4	***Oenothera biennis***	***Aphis oenotherae***	*Coccinella septempunctata* *Harmonia axyridis* *Propylea japonica* *Menochilus sexmaculatus* ***Adalia bipunctata*** *Scymnus hoffmanni*	7	Nara campus of Kinki University, Nara Pref. 2001, 2002
5	***Acer buergerianum***	*Periphyllus viridis*	***Adalia bipunctata*** *Harmonia axyridis* *Menochilus sexmaculatus* *Coccinella septempunctata*	6	Osaka Nanko Central Park Osaka Pref. 2000
6	*Rhaphiolepis umbellata*	*Nippolachnus piri* *Psylla satsumensis*	***Adalia bipunctata*** *Harmonia axyridis* *Menochilus sexmaculatus* *Coccinella septempunctata*	2	Osaka Nanko Central Park Osaka Pref. 2004
7	***Leucaena leucocephala***	***Heteropsylla cubana***	***Olla v-nigrum*** *Menochilus sexmaculatus* *Coccinella septempunctata*	8	Okinawa Pref. 2004-2005

Bold：exotic species

Results

Results obtained in the investigation are as given below. Type 1, 2, 6, 7 and 8, see Fig.1, and Schedule 1- 7 see Table 1.

1. Community in food chain of all native species (Type 1, Schedule 1)

The aphid density level peaked in late April, and declined in late May when *Vicia angustifolia* died (Fig. 2). The number of *C. septempunctata* peaked in late April, and this ladybird beetle disappeared in late May on *V. angustifolia*. *H. axyridis* and *Propylea japonica* were very scarce throughout the investigation.. The dominant species of ladybird beetle on *V. angustifolia* was *C. septempunctata.*

2. Community in food chain of all native species (Type 1, Schedule 2)

The aphid density level peaked in June and July, but the density of aphid was comparatively low throughout the season (Fig. 3). The number of *C. septempunctata* peaked in late April and early October, and disappeared in summer on *A. princeps.* The numbers of *H. axyridis* and *P. japonica* were very low on *A. princeps* throughout the investigation. The dominant species of ladybird beetles on *A. princeps* was *C. septempunctata* as well as on *V. angustifolia*.

3. Community in food chain of exotic host plant (*S. altissima*) and exotic aphid (*U. nigrotuberculatum*) (Type 7, Schedule 3)

The aphid density level peaked in early June and mid November in 2001 (Fig.4a), and late June in 2002 (Fig.4b). The number of *C. septempunctata* peaked in early June and showed small peak in mid Novenber on *S. altissima*. A few individuals of *H. axyridis* and *P. japonica* were found in June in 2001, but they were scarce in 2002.The dominant species of ladybird beetle on *S. altissima* was also *C. septempunctata.*

4. Community in food chain of exotic host plant (*O. biennis*) and exotic aphid (*A. oenotherae*) (Type 7, Schedule 4)

The aphid density level peaked in early June and early September in 2001 (Fig.5a), and occurrence of aphids continued throughout investigation in 2002 (Fig.5b). The number of *C. septempunctata* peaked in late June and July in 2002 on *O. biennis*. Some individuals of *H. axyridis* were found on *O. biennis* in early July in 2001, but they were scarce in 2002. The number of *P. japonica* was very low both 2001 and 2002. The dominant species of ladybird beetle on *O. biennis* was *C. septempunctata*, and in 2001 second dominant one was *H. axyridis*.

5. Community in food chain of exotic host plant (*A. buergerianum*), native aphid and exotic ladybird beetle (*Adalia bipunctata*) (Type 6, Schedule 5)

The aphid density level peaked in early May in 2000, and the number of *A. bipunctata* peaked in mid May on. *A. buergerianum* (Fig.6). The peak of *H. axyridis* was late May, though the density was far lower than *A. bipunctata*. The density of *Menochilus sexmaculatus* was low throughout the investigation. Other species of ladybird beetle were not observed.

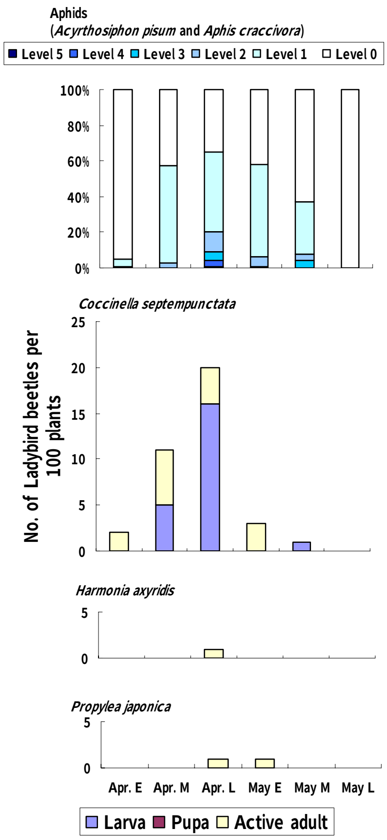

Fig. 2. Community on Vicia angustifolia (2002)

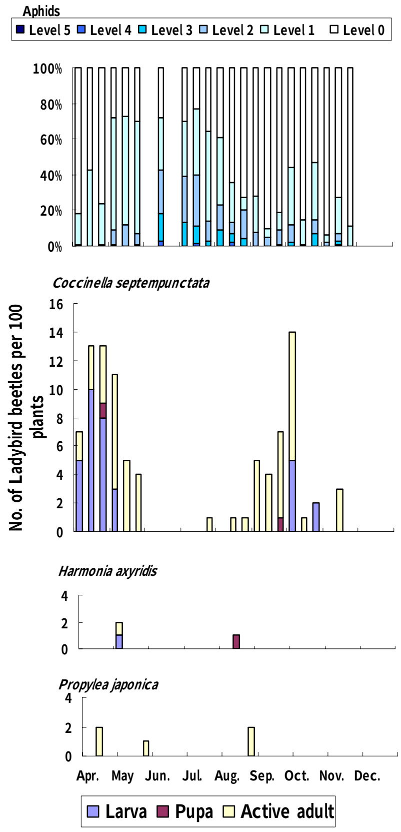

Fig. 3. Community on Artemisia princeps (2002)

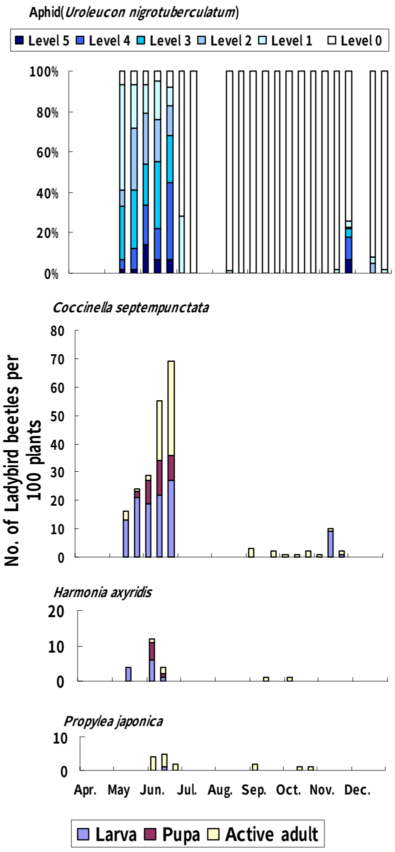

Fig. 4a. Community on Solodago altissima (2001)

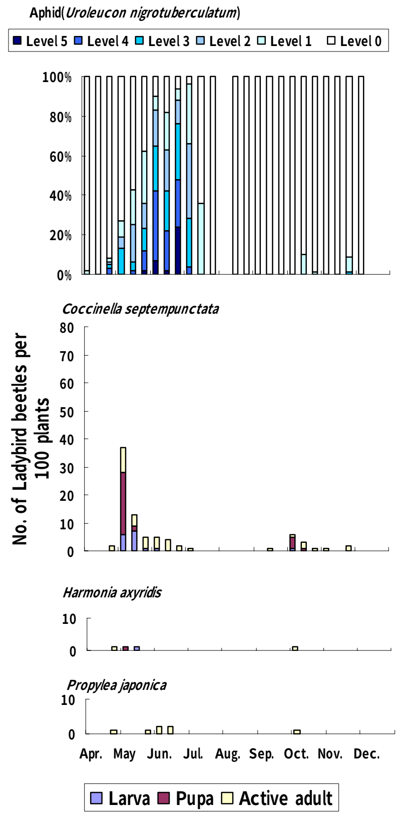

Fig. 4b. Community on Solodago altissima (2002)

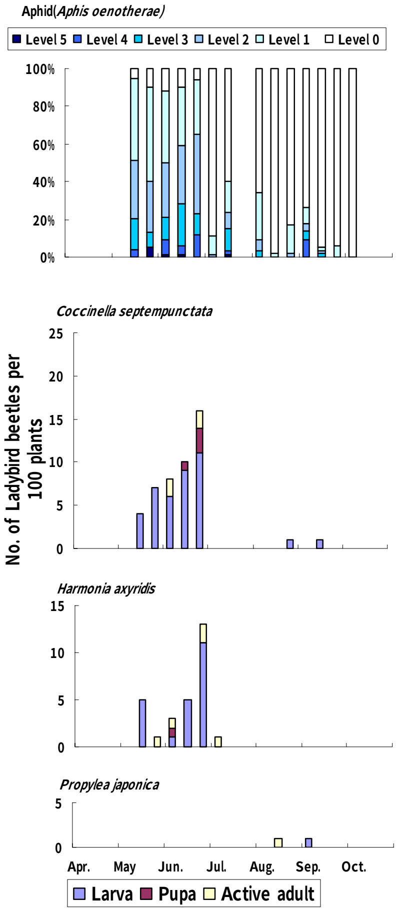

Fig. 5a. Community on Oenothera biennis (2001)

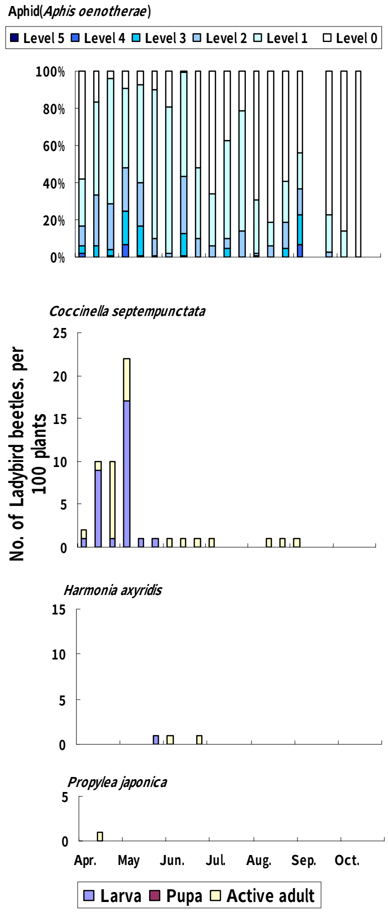

Fig. 5b. Community on Oenothera biennis (2002)

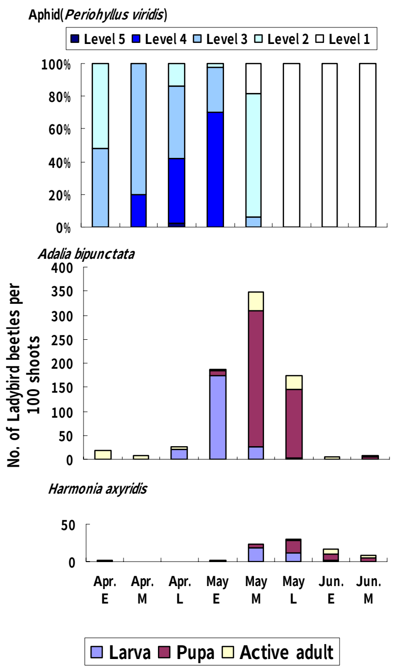

Fig. 6. Community on Acer buergerianum (2000)

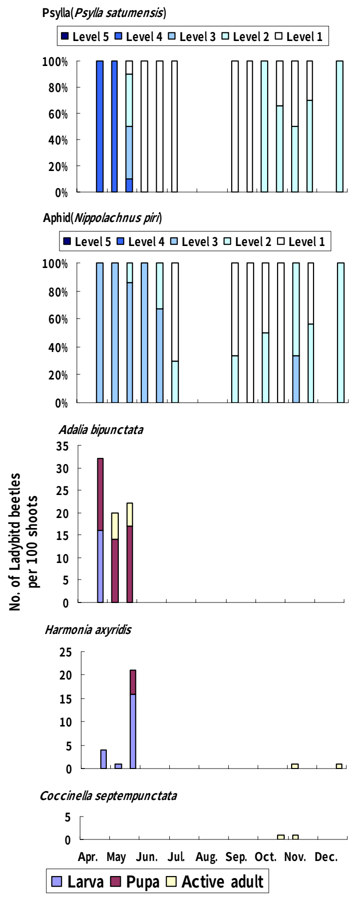

Fig. 7. Community on Rhaphiolepis umbellata (2004)

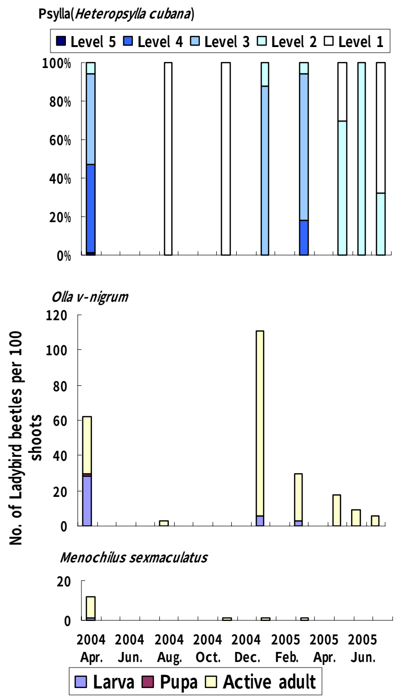

Fig. 8. Community on Leucaena leucocephala (2004-2005)

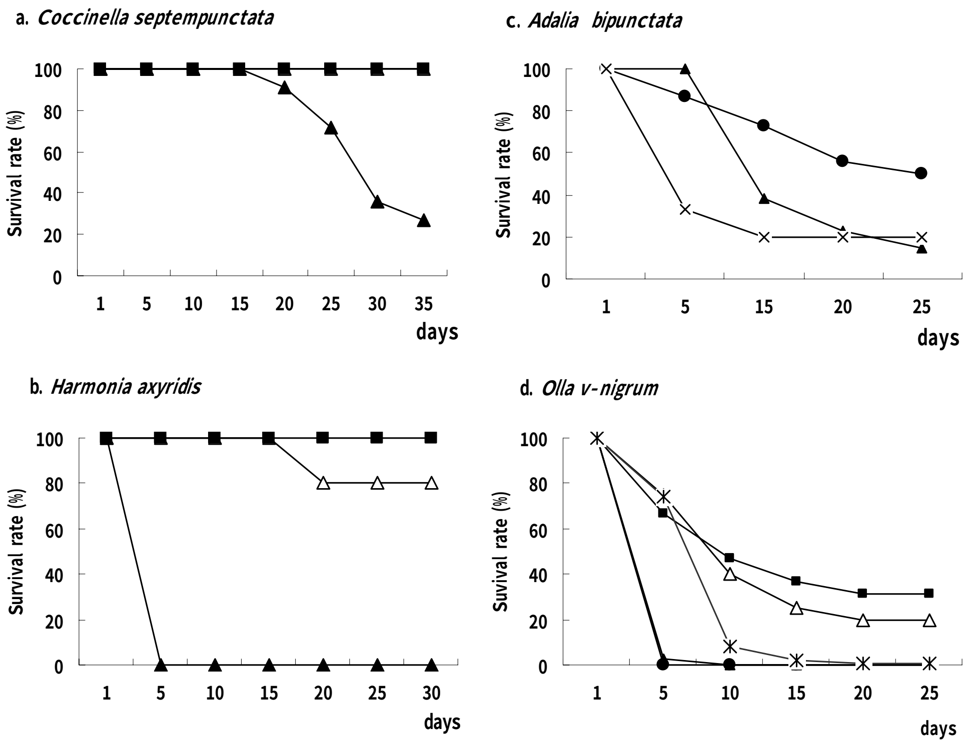

Fig. 9. Suvival rate of Ladybird beetles fed on various aphids.
Day 1：Hatching, Day 20-35：Adult emergence
Coccinella septempunctata and Harmonia axyridis △：Aphis craccivora
■：Aphis oenotherae ▲：Uroleucon nigrotuberculatum
Adalia bipunctata and Olla v-nigrum △：Psylla satsumensis ▲：Aphis rumicis
■：Accizia jamatonica ●：Nippolachnus piri ×：Aphis spiraecola *：Aphis craccivora
Bold：exotic species

6. Community in food chain of native host plant, native aphid and psylla, and exotic ladybird beetle (*Adalia bipunctata*) (Type 2, Schedule 6)

The density of aphid and psylla peaked in late April in 2004, and the number of *A. bipunctata* reached peak in late April on *Rhaphiolepis umbellata* (Fig.7). However, the peak of *H. axyridis* was late May. The density of *C. septempunctata* was low throughout the observation.

7. Community in food chain of exotic host plant, *Leucaena leucocephala*, exotic psylla and exotic ladybird beetle (*Olla v-nigrum*) (Type 8, Schedule 7)

The density of psylla, *H. incisa*, was abundant in winter and spring(Fig.8). The number of *O. v-nigrum* peaked in January. The density of native ladybird beetle, *M. sexmaculatus* was lower than that of *O. v-nigrum*. *L. leucocephala* was distributed widely in Okinawa, the psylla was also dominant insect on *L. leucocephala*, and *O. v-nigrum* was dominant predacious ladybird beetle on *L. leucocephala*.

8. Survival rate of ladybird beetles fed on various foods

The survival rate of *C. septempunctata* was highest in the case of native aphid , *Aphis craccivora* , and exotic aphids, *Aphis oenotherae*, but low in exotic aphid, *U. nigrotuberculatum* (Fig. 9a). The survival rate of *H. axyridis* was highest in the case of exotic aphis, *A. oenotherae*, and native aphid, *A. craccivora*, but all individuals fed on *U. nigrotuberculatum* died during larval stage (Fig. 9b). The survival rate of *A. bipunctata* was higher in *Nippolachnus piri* than the two species aphids, *A. spiraecola* and *A. craccivora* (Fig. 9c). The survival rate of *O. v-nigrum* was low in any aphids, especially, in the cases of *N. piri* and *A. spiraecola*, all individuals died during larval stage (Fig. 9d).

Discussion

The growing season of native grass, *V. angustifolia*, is restricted during spring and died in June. The aphid population increased from early spring, and peaked in April. The occurrence of native ladybird beetle, *C. septempunctata*, synchronized with the life history of *V. angustifolia* (Fig.2). On another native grass, *A. princeps*, the occurrence of *C. septempunctata* was in spring and autumn. The adults of *C. septempunctata* aestivate at the base of weed such as *Miscanthus sinensis* (Sakurai et al. 1981; Sakuratani and Kubo,1985). However, on the two exotic species of grass, *S. altissima* and *O. biennis*, *C. septempunctata* occurred till June or July. Thus, the life history of *C. septempunctata* may be shifted by the exotic plants and the exotic aphids having long-term occurrence.

The food chain consisting of all exotic species as *L. leucocephala*, *H. cubana* and *O. v-nigrum* was observed in this study in Okinawa Island (Fig.8). The distribution of *L. leucocephala* was widely throughout the island (Yamamura, 2002). A large number of *H. cubana* (the first consumer,, an exotic insect) infesting on *L. leucocephala* tree severely was found, and some trees were killed by this psylla (Kiritani, 2002). The larvae, pupae and active adults of *O. v-nigrum* were observed on *L. leucocephala*, in winter and spring. They preyed on this psylla and this ladybird beetle may be specialist, though some individuals feeding on the aphids on the pine tree, *Pinus luchuensis*, and hibiscus, *Hibiscus rosa-sinensis*, were observed. In ecosystem of Okinawa Island, *L. leucocephala* is an invader occupying large area in the island. The distribution of *H. cubana* expanded with the distribution of the tree. Hence, this insect utilized the vacant niche successfully like piggybacking. The distribution of *O. v-nigrum* may also expand with the dispersion of psylla, and this ladybird beetle may utilize the vacant niche or guild successfully. On the other hand, some native species of ladybird beetle such as, *M. sexmaculatus*, were found on *L. leucocephala* and they utilized the psylla newly in the three exotic trophic levels within Japan. Some inter-specific relationships occurred and formed a new guild of predacious ladybird beetles on *L. leucocephala*.

In the case of *S. altissima*, this plant is also very widely distributed in Japan at this time (Hattori, 2002). Though the aphid invaded after about 100 years invading this plant, this aphid dispersed very rapidly in Japan. The abundance of the aphid increased in most areas where *S. altissima*. was distributed (Tanaka & Sorin, 1999). There were no exotic ladybird beetles on this plant in Japan, and the species of ladybird beetle preying on this aphid were all native species. Thus, these native ladybird beetles utilized the exotic aphid as well as the native aphids. New guilds of aphids and ladybird beetles are forming on this exotic plant.

In the case of anther exotic plant, *O. biennis*, similar results as *S. altissima* were obtained in this field investigation (Fig. 5). However, the number of individuals and growing area of *O. biennis* were far small than *S. altissima.* Thus, the effect of this plant on the community may be small, but the occurrence of aphid was observed throughout three seasons and may affect to the life history and population density of native ladybird beetles. No exotic ladybird beetles were recorded on *O. biennis*. These native ladybird beetles can utilize the exotic aphids successfully.

A.bipunctata is an intruder because this species invaded into native aphid communities. The member of guild on *A. buergerianum* and *R. umbellate* increased newly with addition of this ladybird beetle (Sakuratani et al., 2000). The competition about prey and habitat (aestivating site and over-wintering site) among native ladybird beetle intensified (Sakuratani et al., 2000). Recently, the kind of prey of this species tended to increase (Toda & Sakuratani, 2005), and the competition intensified on many native and exotic plants. *A. bipunctata* is univoltinism unlike some native species of ladybird beetle. *A. bipunctata* occurs in spring and the competition with other native ladybird beetle occur in this season. Thus, this life history may avoid intense competition. The speed of distribution of *A. bipunctata* is very slow (Sakuratani et al., 2000) in contrast to *O. v-nigrum*. This slow expansion of distribution of *A. bipunctata* may due to the resistance of native ladybird beetles such as *H. axyridis* on each tree.

The preys and/or plants through the medium of prey affect the survivorship and development of ladybird beetle (Blackman, 1967; Birch et al., 1999; Francis et al., 2000; Okamoto, 1978). Though *H. axyridis* appeared on *S. altissima*, all larvae fed on *U. nigrotuberculatum* died (Fig.9).This aphid was also not so suitable for *C. septempunctata*. On the other hand, *A. oenantherae* which was recorded and expanded recently in Japan was very suitable for *H. axyridis* and *C. septempunctata*.

Thus, the effect of exotic plants and exotic insects varied in the position of each species in the trophic level of food chain. Generally, native ecosystem is saturated with native first and second consumer. The invader such as *A. bipunctata* suffered to intrude into this ecosystem. In the food chain consisting of all exotic species, there may be many vacant niches and guilds. When the exotic insect invade into such a food chain, this species can establish and expand the distribution, if the environmental and trophic (prey) conditions are suitable. On the other hand, in the case of invasion of exotic insect (first consumer or second consumer) in the native food chain, the establishment and the expansion of distribution may be not easy.

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