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Relationship between the seasonal prevalence of the predacious coccinellid *Pseudoscymnus hareja* (Coleoptera: Coccinellidae) and the mulberry scale *Pseudaulacaspis pentagona* (Hemiptera: Diaspididae) in tea fields: Monitoring using sticky traps

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Abstract

The relationship between the seasonal prevalence of the predacious coccinellid *Pseudoscymnus hareja* and the mulberry scale *Pseudaulacaspis pentagona* in tea fields was investigated using sticky traps set inside tea bushes. Crawlers (newly-hatched larvae) and winged adult males of *P. pentagona* and adults of *P. hareja* were captured in large numbers. The number of trapped *P. hareja* adults reached a peak 0 to 15 days (average: 6.9 days) after the peak in the number of *P. pentagona* crawlers in each tea field. *P. hareja* adults captured in this period are considered to have visited tea fields to prey on *P. pentagona* larvae and to deposit their offspring (larvae), which primarily consume *P. pentagona* larvae. Another relatively lower peak in *P. hareja* adults was found 0 to 14 days (average: 6.6 days) after the peak in the number of *P. pentagona* adult males. *P. hareja* adults trapped in this period are suggested to be those that had spent their larval period feeding on *P. pentagona* larvae and male pupae in tea fields. Thus, the seasonal occurrence of *P. hareja* adults in tea fields is associated with that of *P. pentagona* larvae as the main prey of *P. hareja* larvae.

Key words: *Pseudoscymnus hareja*; *Pseudaulacaspis pentagona*; seasonal prevalence; tea tree; sticky trap

INTRODUCTION

The mulberry scale *Pseudaulacaspis pentagona* (Targioni) (Hemiptera: Diaspididae) is a harmful pest of various agricultural crops such as tea plants, mulberry plants, and kiwifruit plants (Kawai, 1980). Particularly on tea trees, *P. pentagona* densities occasionally reach high levels, thereby causing severe damage to the trees (Minamikawa and Osakabe, 1979). An outbreak of *P. pentagona* in tea fields was recorded from 1994 to 1996 in Japan (Kawai et al., 1997). Chemical control of *P. pentagona* is occasionally unsuccessful because it is difficult for tea plant growers to determine the optimum timing for insecticide application, which is limited to 2–5 days after the peak in the hatching of *P. pentagona* (Tatara, 1999).

Hatched first-instar larvae (called crawlers) of *P. pentagona* crawl to their settling sites and form relatively sparse aggregations on twigs and branches of host trees. Winged adult males emerge and mate with females approximately one month after hatching on tea trees in Shizuoka Prefecture (Minamikawa and Osakabe, 1979). Females remain at the settling site throughout life and produce a wax covering on their body. Approximately two months after hatching, adult females lay eggs beneath their coverings and then die. *P. pentagona* normally passes three discrete generations per year on tea trees in most areas in Shizuoka Prefecture (Minamikawa and Osakabe, 1979): crawlers are observed in mid- to late May (referred to as first generation), mid- to late July (second generation), and early to mid-September (third generation). Adult females overwinter on tea trees in Shizuoka Prefecture.

P. pentagona is attacked by many natural enemies, including parasitoids, predators, and fungi

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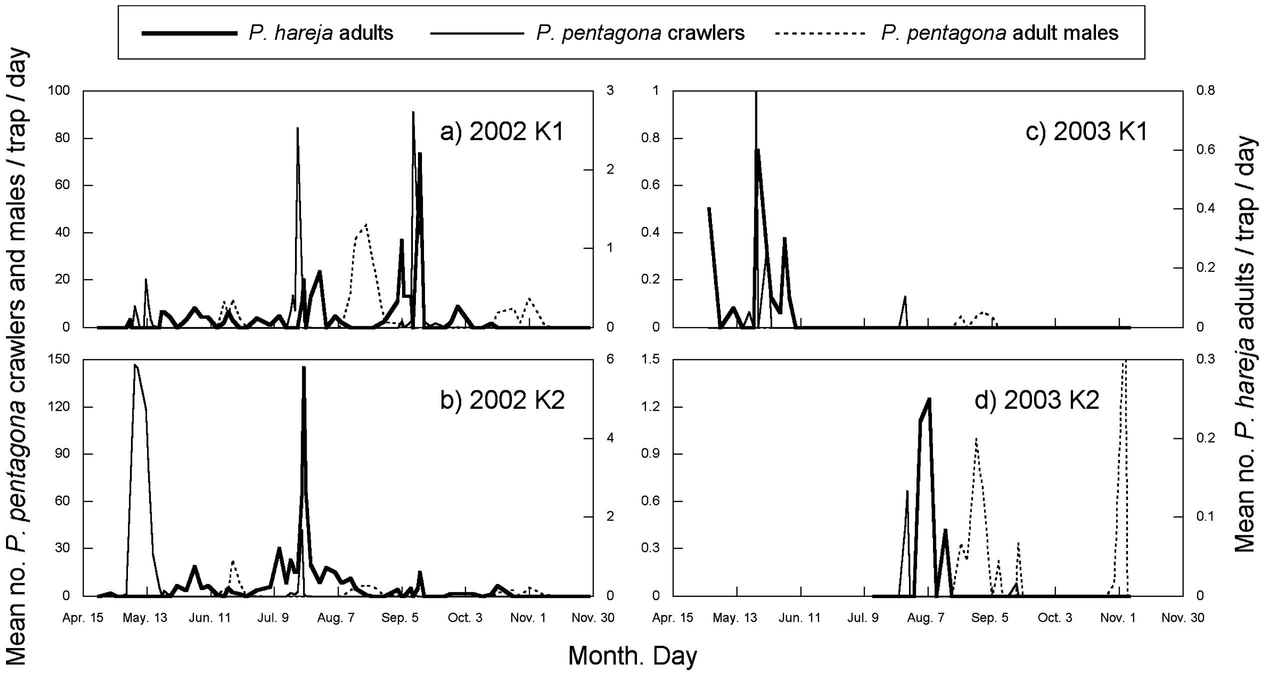

Fig. 1. Seasonal changes in the number of *P. hareja* adults and *P. pentagona* crawlers and adult males captured on sticky traps set in tea bushes in two tea fields in Kikugawa (K), Shizuoka Prefecture, in 2002 and 2003.

(e.g., Ishii, 1953; Tachikawa, 1958, 1959; Sato, 1978, 1986; Yasuda, 1981). The coccinellid *Pseudoscymnus hareja* (Weise) (Coleoptera: Coccinellidae) has been reported as a predator of *P. pentagona* (Miyatake, 1958; Tachikawa, 1959; Yasuda, 1981). *P. hareja* is a common species and widely distributed in Japan (except for the Ryukyu Islands) and Taiwan (Kurosawa et al., 1985). The adult body length ranges from 1.9 to 2.5 mm. The larval dorsum is densely covered with fleecy, waxy secretions. *P. hareja* is a predator of several species of diaspidid scales, including *P. pentagona*, the cryptomeria scale *Aspidiotus cryptomeriae* Kuwana and the arrowhead scale *Unaspis yanonensis* (Kuwana) (Tachikawa, 1983). Both adults and larvae of *P. hareja* feed on *P. pentagona*; they can consume *P. pentagona* adult females but preferentially prey on *P. pentagona* larvae and male pupae (Tachikawa, 1959). Therefore, *P. hareja* may be an important enemy contributing to the regulation of *P. pentagona* population in tea fields, but the biological and ecological characteristics of *P. hareja* are not well known.

Temporal synchronization with prey is considered an attribute of effective biological control agents (Dixon, 2000). The relationship between the seasonal prevalence of the predator *P. hareja* and *P. pentagona* as its prey in tea fields has not yet been examined. The occurrence of crawlers and winged adult males of *P. pentagona* can be monitored using small sticky card traps (100 mm×100 mm each) set inside tea bushes (Ozawa, 1994a). Sticky traps are applicable for estimating the seasonal prevalence of not only the adults of several parasitoid species exploiting *P. pentagona* (Ozawa, 1994b) but also the adults of *P. hareja* (Ozawa, 2005a). Therefore, the temporal relationship between the occurrence of *P. hareja* and *P. pentagona* can be investigated using sticky traps.

In this paper, we describe the results of monitoring the seasonal prevalence of *P. hareja* and *P. pentagona* using sticky traps in several tea fields in Shizuoka Prefecture and examine the temporal relationship between the occurrence of *P. hareja* adults and *P. pentagona* crawlers or adult males based on the results. We obtained information on the biology of *P. hareja*, which will help in assessing its effectiveness as a biological control agent of *P. pentagona*.

MATERIALS AND METHODS

Monitoring sites and methods. From 2002 to 2005, the seasonal occurrence of *P. hareja* and *P.*

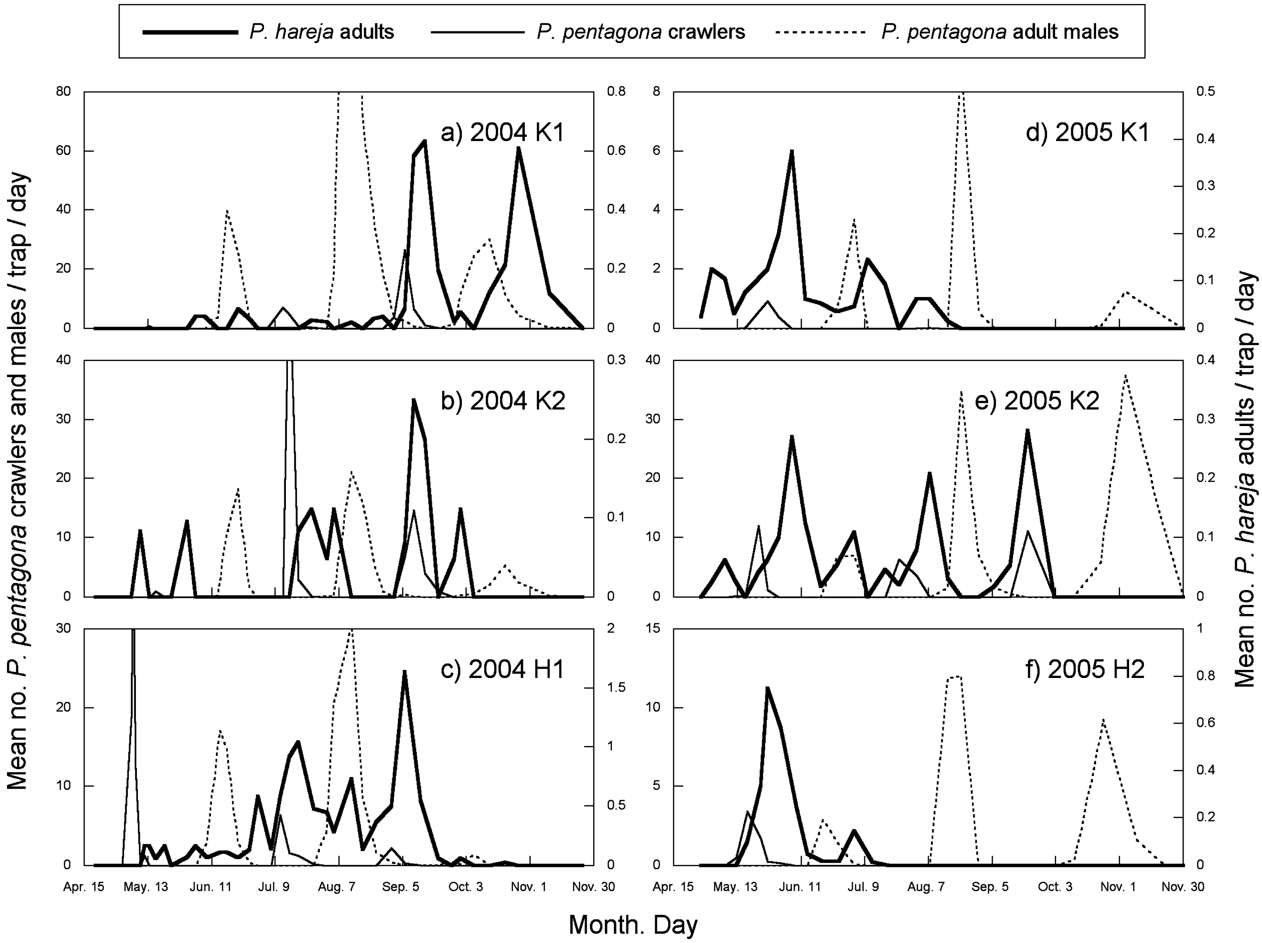

Fig. 2. Seasonal changes in the number of *P. hareja* adults and *P. pentagona* crawlers and adult males captured on sticky traps set in tea bushes in two tea fields in Kikugawa (K) and in two fields in Haibara (H), Shizuoka Prefecture, in 2004 and 2005.

pentagona was monitored in two experimental tea fields in Shizuoka Prefectural Tea Experiment Station in Kikugawa (500 m apart; hereafter, K1 and K2) and in two experimental tea fields in Haibara (300 m apart; hereafter, H1 and H2), both in Shizuoka Prefecture. Fertilizer and pesticide applications and other management practices in these fields followed local agricultural practices, but no insecticide was applied to control *P. pentagona*. In each field, three to eight sticky traps (100 mm×100 mm yellow acrylic cards with a clear adhesive sheet on each side) were set in a vertical position 0.1–0.2 m under the plucking surface of the tea bushes and the distance between the traps was approximately 5 m. We set five traps at K1 and K2 in 2002, five at K1 and three at K2 in 2003, six at K1 and H1 and three at K2 in 2004, and eight at K1, K2 and H2 in 2005. From mid-April to late November (with the exception of K2 in 2003), these traps were renewed at intervals of 3–7 days (generally 5 days); in K2 in 2003, this was done from mid-July through November. The number of *P. hareja* adults and *P. pentagona* crawlers and adult males captured on the collected traps was counted under a binocular microscope.

RESULTS

The seasonal prevalence of *P. hareja* adults captured on the sticky traps in each of the examined tea fields is represented together with the prevalence of *P. pentagona* crawlers and adult males in Figs. 1 and 2. The number of *P. hareja* adults peaked after (or at) the peak in the number of *P. pentagona* crawlers in each tea field (Fig. 1). Table 1 represents tea fields where a peak in *P. hareja* adults was detected after (or while) *P. pentagona* crawlers occurred in each *P. pentagona* generation.

Table 1. Date of peak number of *P. hareja* adults and *P. pentagona* crawlers captured on sticky traps set in tea bushes, number of *P. hareja* adults and *P. pentagona* crawlers at the peak, and difference in the date of peaks between *P. hareja* and *P. pentagona* in each tea field in each *P. pentagona* generation

P. pentagona generation	Year	Tea field	Date of peak number of *P. hareja* adults: (A)	Number of *P. hareja* adults at the peak: no./trap/day	Date of peak number of *P. pentagona* crawlers: (B)	Number of *P. pentagona* crawlers at the peak: no./trap/day	Difference in the date of the peaks: (A)–(B)
First	2003	K1	May 23	0.6	May 23	1.0	0
	2004	H1	May 12	0.2	May 7	35.5	5
	2005	K1	June 7	0.4	May 27	0.9	11
	2005	K2	June 7	0.3	May 23	12.0	15
	2005	H2	May 27	0.8	May 18	3.4	9
Second	2002	K1	July 30	0.7	July 20	84.4	10
	2002	K2	July 23	5.8	July 23	42.1	0
	2003	K2	Aug. 8	0.3	July 29	0.7	10
	2004	K2	July 26	0.1	July 16	55.2	10
	2004	H1	July 20	1.0	July 12	6.4	8
	2005	K2	Aug. 8	0.2	July 25	6.3	14
Third	2002	K1	Sep. 13	2.2	Sep. 10	91.2	3
	2004	K1	Sep. 15	0.6	Sep. 6	26.4	9
	2004	K2	Sep. 10	0.3	Sep. 10	14.6	0
	2005	K2	Sep. 21	0.3	Sep. 21	11.1	0

Table 2. Date of peak number of *P. hareja* adults and *P. pentagona* adult males captured on sticky traps set in tea bushes, number of *P. hareja* adults and *P. pentagona* males at the peak, and difference in the date of peaks between *P. hareja* and *P. pentagona* in each tea field in each *P. pentagona* generation

P. pentagona generation	Year	Tea field	Date of peak number of *P. hareja* adults: (A)	Number of *P. hareja* adults at the peak: no./trap/day	Date of peak number of *P. pentagona* males: (B)	Number of *P. pentagona* males at the peak: no./trap/day	Difference in the date of the peaks: (A)–(B)
First	2005	K1	July 11	0.2	July 5	3.7	6
	2005	K2	July 5	0.1	July 5	7.0	0
	2005	H2	July 5	0.1	June 21	2.9	14
Second	2004	H1	Aug. 13	0.7	Aug. 13	30.8	0
Third	2004	K1	Oct. 27	0.6	Oct. 14	30.2	13

The date of the peak number of *P. hareja* adults and *P. pentagona* crawlers and the number at the peak largely varied across the tea fields and study years. The number of *P. hareja* adults peaked 0 to 15 days (average: 6.9 days) after the peak number of *P. pentagona* crawlers. Thus, the seasonal prevalence of *P. hareja* adults in tea fields is associated with that of *P. pentagona* crawlers.

Another relatively lower peak in the number of *P. hareja* adults was detected after (or at) the peak number of *P. pentagona* adult males in each of the tea fields monitored in 2004 and 2005 (Fig. 2). Table 2 represents tea fields where a peak in *P. hareja* adults was found after (or while) *P. pentagona* males occurred in each *P. pentagona* generation. The number of *P. hareja* adults peaked 0 to 14 days (average: 6.6 days) after the peak number of *P. pentagona* males.

DISCUSSION

Synchronized seasonal prevalence between *P.*

pentagona and three hymenopterous parasitoids attacking *P. pentagona*, i.e., *Arrhenophagus chionaspidis* Aurivillius, *Pteroptrix orientalis* (Silvestri) and *Thomsonisca typica* Mercet (=*T. amathus* Walker), has been documented in tea fields (Takagi, 1974; Ozawa, 1994b, 2005a). Seasonal fluctuation in the number of adults of the coccinellid *P. hareja* preying on *P. pentagona* has been observed in mulberry fields (Yasuda, 1981) and tea fields (Ozawa, 2005a); however, these studies have not shown a temporal relationship between the occurrence of *P. hareja* and *P. pentagona*. Therefore, this is the first report indicating an association between the seasonal prevalence of *P. hareja* adults and *P. pentagona* crawlers (Table 1).

The timing of larval hatching in *P. pentagona* is primarily determined by temperature accumulation (Takeda, 2004; Ozawa and Kubota, 2006). On the other hand, the extent to which temperature affects the seasonal occurrence of *P. hareja* adults is unknown. Adults and larvae of *P. hareja* preferentially attack *P. pentagona* larvae and male pupae (Tachikawa, 1959), presumably because immature *P. pentagona* is not protected by a “hard” wax covering. In addition, *P. hareja* larvae were frequently found foraging on tea branches where *P. pentagona* larvae and male pupae were abundant (S. Kaneko, pers. obs.). This suggests that *P. hareja* adults trapped after the peak in the number of *P. pentagona* crawlers are those that visited tea fields to prey on *P. pentagona* larvae and to deposit their offspring (larvae), which primarily consume *P. pentagona* larvae and male pupae.

The observed numerical response of *P. hareja* adults to the occurrence of *P. pentagona* larvae may be ascribed to the aggregation of foraging *P. hareja* adults in tea fields where *P. pentagona* larvae occur by detecting their presence; the cues used by searching *P. hareja* adults need to be determined. This response suggests that *P. hareja* exploits *P. pentagona* as important prey in tea fields; therefore, *P. hareja* may play a significant role in regulating *P. pentagona* populations. The ability of *P. hareja* to decrease *P. pentagona* density needs to be assessed experimentally by releasing *P. hareja* larvae or adults into tea fields and then investigating the following population changes in *P. hareja* and *P. pentagona*.

This study also found a relatively lower peak in the number of *P. hareja* adults after the peak number of *P. pentagona* adult males in each tea field (Table 2). *P. hareja* larvae were primarily observed when *P. pentagona* larvae and male pupae were present on tea trees (S. Kaneko, pers. obs.); therefore, *P. hareja* adults captured during the abovementioned period would have consumed *P. pentagona* larvae and male pupae during the larval stage in the monitored tea fields. Monitoring in 2004 and 2005 suggests that *P. hareja* requires 4–5 weeks from egg deposition to adult emergence in tea fields (Fig. 2). The duration of the immature stages of *P. hareja* coincides with their rearing at a temperature of 20°C in the laboratory (S. Kaneko, pers. obs.).

Ozawa (2005b) documented that *P. hareja* was susceptible to several types of insecticides. Our study showed that the peak number of *P. hareja* adults occurs twice per generation of *P. pentagona* in tea fields, i.e., approximately one week after the peak in *P. pentagona* crawler number and one week after the peak in *P. pentagona* adult male number. Insecticides that are harmful to *P. hareja* should not be sprayed in tea fields when *P. hareja* adults occur in large numbers. Appropriate pesticide application would preserve *P. hareja* populations in tea fields, thereby improving the control of *P. pentagona* by *P. hareja*.

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