Article

Structure and dynamics of *Lithocolletis ringoniella*-Parasitoids food web in apple orchards of Shaanxi, China

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Abstract
The formation and evolution of food web is a self-organizing process. A food web, *L. ringoniella*-Parasitoids food web, was proposed in present study. With the apple pest *Lithocolletis ringoniella* as the basic host, four parasitoids, *Apanteles theivorae*, *Sympiesis sericeicornis*, *Ageniaspis testaceipes*, and *Sympiesis Foerst* are included in the food web. In this food web, *A. theivorae* and *A. testaceipes* are primary parasitoids of *L. ringoniella*. *A. theivorae* mainly parasitizes apodous larva of *L. ringoniella* while *A. testaceipes* only chooses *L. ringoniella* egg to parasitize (egg-larva endoparasitization). *S. Foerst* and *S. sericeicornis* are facultative hyper-parasitoids. They can parasitize not only the larvae and pupae of *L. ringoniella*, but also *A. theivorae*. *S. sericeicornis* can be hyper-parasitized by *S. Foerst*. The occurrence mechanism and population dynamics of *L. ringoniella* and parasitoids, and parasitization effect of parasitoids in apple orchards of Shaanxi, China, were described in detail.

Keywords food web; *Lithocolletis ringoniella*; *Apanteles theivorae*; *Sympiesis sericeicornis*; *Ageniaspis testaceipes*; *Sympiesis Foerst*; structure; apple; China.

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1 Introduction

Lithocolletis ringoniella Mats. (Lepidoptera: Gracilariidae) is an important defoliator pest in the apple orchards of northern China, Japan and Korea (Zhang and Zhao, 1996; Zhang et al., 2001). The larvae of *L. ringoniella* usually live inside plant leaves and feed mesophyll, causing bubble-like cystics, reducing effective leaf area for photosynthesis, and causing earlier defoliation (Sun et al., 2001; Zhou et al., 2002). It will not only lead to the loss of organic nutrition but also affect the next year's fruit quality and production. Since its first serious outbreaks in 1992 and 1993, the pest has widely occurred in main apple-producing areas of northern China (Zhao, 1995). Its occurrence and damage are still increasing year by year and has become a predominant insect pest from the secondary pest over the past twenty years (Shi et al., 2003; Qiao and Hua, 2005).

Many control practices indicated that chemical insecticides were not quietly effective in the control of *L.*

ringoniella. Natural enemies are proved to be a major agent for natural equilibrium of *L. ringoniella*. Dominant natural enemies of *L. ringoniella* in Shaanxi, China, include *Ageniaspis testaceipes* Raz, *Apanteles theivorae, Sympiesis sericeicornis* Nees, etc (Sun et al., 1987). Some other insects, including ladybirds, lacewings, etc., are also in the list of natural enemies. Parasitic rate of these natural enemies may reach 30%-50% in the apple orchards without or few chemical pesticide sprayings.

The present study aimed to propose a *L. ringoniella*-Parasitoids food web and describe the structure and dynamics of the food web in apple orchards of Shaanxi, China, in order to understand self-organizing mechanism of the food web and to provide some knowledge for the biological control of *L. ringoniella*.

2 Materials and Methods

2.1 Sampling *L. ringoniella*

Apples trees were sampled from mid-April to early December 2008 in Yangling, Shaanxi, China. The sampling was conducted every 10 days. A total of 24 samplings were conducted. For each sampling, several leaves with cystics caused by *L. ringoniella* were randomly sampled and taken to laboratory for recording the number of larvae, pupae and puparium.

2.2 Sampling parasitoids of *L. ringoniella*

Apples trees were sampled from August to October 2007 and April to December 2008 in Yangling, Shaanxi, China. The sampling was conducted every 10 days. Five sites, with one tree in each site, were selected in the orchard. For a tree, four directions (East/South/West/North), three layers (upper/middle/lower) and two sides (inside/outside; only for middle and lower layers), in total of 20 sampling units (i.e., positions), were sampled. For each position, several leaves with cystics caused by *L. ringoniella* were randomly sampled and taken to laboratory for recording species and number of *L. ringoniella* parasitoids. All samples were combined for further analysis.

2.3 Hyperparasitism of parasitoids

In laboratory, parasitoids were dissected under microscopy to check hyperparasitism. Species and number of hyperparasitization were recorded.

2.4 Data treatment

The emergence rate of *L. ringoniella* adults from pupae was calculated as

(puparium/larvae+pupae+puparium)*100%

And the parasitic rate of parasitoids was recorded as

(parasitized hosts/total hosts)*100%

3 Results and Analysis

3.1 Structure of food web

3.1.1 Reported parasitoids of *L. ringoniella*

According to a report from Japan, there were 20 species of parasitoids for *L. ringoniella*, among which some are hyper-parasitoids (Han et al., 2004). The most occurred parasitoids included *Apanteles theivorae* (Genus: Apanteles), *Sympiesis* sp., *Sympiesis laevifrons* Kamijo and *Sympiesis sericeicornis* Nees (Genus: Sympiesis), *Ageniaspis testaceipes* Raz (Genus: *Ageniaspis*), *Pnigalio* sp. (Family: Eulophidae).

All of these parasitoids are mainly divided into two categories, i.e., the endoparasitoids that live and mature inside host body, such as *A. theivorae*, *A. testaceipes*, and the ectoparasitoids that live and mature outside host body, such as the species of genus Sympiesis, and *P*. sp.

In China, in total of 8 parasitoids belonging to 5 families of parasitoids of *L. ringoniella* have been recorded, in which *A. testaceipes*, *S. sericeicornis*, and *A. theivorae* are dominant species (Hou, 1987, 1989;

Zhang, 1991). Occurrence of the three species is almost synchronous to that of *L. ringoniella* (Sun et al., 1987). In Shaanxi, occurrence generations of *A. testaceipes* are almost the same as *L. ringoniella* and it has a stronger time-synchronity with *L. ringoniella*. Major occurrence period of other parasitoids, *S. sericeicornis*, and *A. theivorae*, is between May to August which corresponds to the first generation to the fourth generation of *L. ringoniella*. They are seldom found after September (Zhang, 1990).

3.1.2 Description of dominant parasitoids of *L. ringoniella* in Shaanxi

In present study we found 8 species of parasitoids of *L. ringoniella*. Among these the dominant parasitoids are *A. testaceipes*, *S. sericeicornis*, *Sympiesis Foerst*, and *A. theivorae*, which is similar to previous reports (Hou, 1987; Sun et al., 1987; Zhang, 1991; Chen et al., 2006). *A. theivorae* is an endoparasitoid (Askew and Shaw, 1986). Each host can only contain a parasitoid. *S. sericeicornis* and *S. Foerst* are ectoparasitoids and each host can contain one parasitoid only. *A. testaceipes* is an endoparasitoid but a host may breed several or many parasitoids. We found that in average 10 of *A. testaceipes* emerged from a body of *L. ringoniella*.

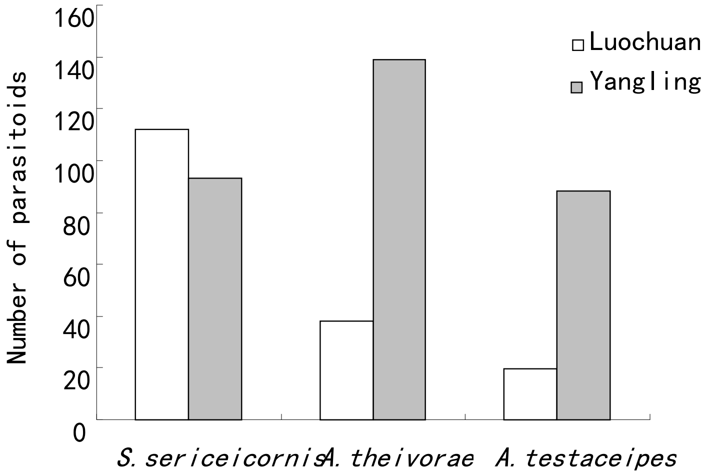

Fig. 1 Dominant parasitoids of *L. ringoniella* in apple orchards. In total of 500 cystics of *L. ringoniella* from different leaves were examined (Yangling and Luochuan, Shaanxi, China, 2008).

From the population comparison in Fig. 1, we can find that in a sense *S. sericeicornis* is the most dominant and stable parasitoids of *L. ringoniella* in Shaanxi.

(1) *A. theivorae*

A. theivorae (Apanteles, Microgastrinae, Braconidae) lays an egg inside the body of 1st to 3rd instar larva of *L. ringoniella*, and the egg hatches as a larva, and the larva lives and matures inside the host's body. The parasitoid breaks away from matured larva of host, leaves the host larva died (Sun et al., 1987) and pupates beside host body. With less than 10% only (in a few cases, greater than 10%), the parasitic rate of *A. theivorae* is less than the other two parasitoids. *A. theivorae* is a primary parasitoid. Thus it is a beneficial parasitoid. *A. theivorae* occurs 5 generations a year and the adult's emergency dates are almost the same with that of *L. ringoniella.*

In nature, the hyperparasitoids of *A. theivorae* include the species of Pteromalidae, Eurytomidae, Elasmidae, and Ichneumonidae, et al. Parasitic rate of these hyperparasitoids is in average 27%-72%, and sometimes reaches 41%-98%.

Our experiment showed that *A. theivorae* demonstrates different emergence rates at different times in a day. Emergence dynamics of *A. theivorae* are indicated in Table 1 and Table 2.

Table 1 Emergence rate of *A. theivorae* at different time intervals in a day (Yangling, Shaanxi, China, 2008).

Time	No. females	No. males	Total	Female (%)	Male (%)	Sex ratio
Before 6：00am	4.0	2.0	6.0	66.67	33.33	2.00
6：00am-8：00am	44.0	2.0	64.0	68.75	31.25	2.20
8：00am-10：00am	23.0	13.0	36.0	63.89	36.11	1.77
10：00am-12：00am	9.0	5.0	14.0	64.29	35.71	1.80
12：00am-14：00pm	9.0	6.0	15.0	60.00	40.00	1.50
14：00pm-16：00pm	5.0	5.0	10.0	50.00	50.00	1.00
16：00pm-18：00pm	2.0	1.0	3.0	66.67	33.33	2.00
18：00pm-20：00pm	2.0	1.0	3.0	66.67	33.33	2.00
20：00pm-22：00pm	5.0	1.0	6.0	83.33	16.67	5.00
22：00pm-24：00pm	4.0	2.0	6.0	66.67	33.33	2.00
Total	107.0	56.0	163.0	65.64	34.36	1.91

Table 2 Emergence rate of *A. theivorae* in different days (Yangling, Shaanxi, China, 2008).

Date (Day)	No. females	No. males	Total	Female (%)	Male (%)
1	5.00	0.00	5.00	4.67	0.00
2	8.00	1.00	9.00	7.48	1.79
3	10.00	2.00	12.00	9.35	3.57
4	13.00	3.00	16.00	12.15	5.36
5	14.00	15.00	29.00	13.08	26.79
6	14.00	11.00	25.00	13.08	19.64
7	17.00	12.00	29.00	15.89	21.43
8	16.00	7.00	23.00	14.95	12.50
9	7.00	5.00	12.00	6.54	8.93
10	3.00	0.00	3.00	2.80	0.00
11	0.00	0.00	0.00	0.00	0.00
Total	107.00	56.00	163.00	100.00	100.00

(2) *S. sericeicornis* and *S. Foerst*

S. sericeicornis or *S. Foerst* lays an egg (sometimes hyperparasitization is found) outside the body of the higher instar larva or pupa of *L. ringoniella*; the egg hatches as a larva, and then sucks body fluid of the host. The matured parasitoid finally leaves its host larva. They occur 5 generations in a year and the adult's emergency dates are slightly later than or similar to that of *L. ringoniella*. *S. sericeicornis* and *S. Foerst* parasitize not only the larvae and pupae of *L. ringoniella* but also *A. theivorae*. Moreover, *S. Foerst* can parasitize *S. sericeicornis*.

The parasitization and hyperparasitization of *S. sericeicornis* and *S. Foerst* is indicated in Table 3.

Table 3 Parasitization and hyperparasitization of *S. sericeicornis* and *S. Foerst* (Yangling, Shaanxi, China, 2008).

Host of *S. sericeicornis* and *S. Foerst*	Number	Percentage (%)	Female	Male	Sex ratio
A. theivorae	1522	93.09	945	577	1.64
Pupa of *L. ringoniella*	15	0.92	14	1	14.00
Larva of *L. ringoniella*	98	5.99	90	8	11.25
Total	1635	100.00	959	586	1.64

From Table 3, we conclude that even though *S. sericeicornis* and *S. Foerst* are hyper-parasitoids of *L. ringoniella*, the parasitization has been from their hyperparasitization to *A. theivorae*, which accounts for 93.09% of the total. Their parasitization to *L. ringoniella* pupae accounts for 0.92% only. In this sense, *S. sericeicornis* and *S. Foerst* are not of significance in the biological control of *L. ringoniella*.

Table 4 Emergence statistics of *A. testaceipes* from 110 of *L. ringoniella* hosts (Yangling, Shaanxi, China, 2008).

No. pupae of *A. testaceipes*	No. hosts for complete emergence	No. hosts for 1 non-emergenced	No. hosts for 2 non-emergenced	No. hosts for 3 non-emergenced	No. hosts for 4 non-emergenced
4	0	0	0	0	2
5	0	0	1	0	0
6	1	0	0	0	0
7	0	0	0	0	1
8	3	1	3	1	4
9	9	1	4	2	2
10	17	1	2	4	0
11	12	5	2	1	2
12	11	0	2	1	0
13	9	1	0	0	0
14	2	1	0	0	0
15	2	0	0	0	0
Total	66	10	14	9	11

(3) *A. testaceipes*

A. testaceipes is an important parasitoid of *L. ringoniella*. *A. testaceipes* lays an egg into the body of *L. ringoniella* larva and experiences a polyembryony. Larva of *A. testaceipes* cocoons and pupates inside the host body. Each host may emerge up to 15 of *A. testaceipes* adults (Sun et al., 2006). It occurs 5 generations in a year and the emergence dates of adults are basically coincident with that of *L. ringoniella*. In Shaanxi, it has a higher parasitic rate to *L. ringoniella* for the first generation and the fifth generation.

Table 4 shows the emergence statistics of *A. testaceipes* from 110 of *L. ringoniella* hosts.

3.1.3 Food web

From the past reports and our investigation, we may conclude that *A. theivorae* and *A. testaceipes* are primary parasitoids of *L. ringoniella*. *A. theivorae* mainly parasitizes apodous larva of *L. ringoniella* while *A. testaceipes* only chooses *L. ringoniella* egg to parasitize (egg-larva endoparasitization). *S. Foerst* and *S. sericeicornis* are facultative hyper-parasitoids. They can parasitize not only the larvae and pupae of *L. ringoniella*, but also *A. theivorae*. And *S. sericeicornis* can be hyper-parasitized by *S. Foerst*. Details of parasitic mechanism are indicated in Table 5.

Table 5 Parasitic mechanism of four dominant parasitoids of *L. ringoniella*.

Parasitoid	Parasitism type	Parasitism level	Parasitized host stage	Host stage for parasitoid's departure
Apanteles theivorae	Konobiont endoparasitism Monoparasitism	Primary parasitism	Apodous larva	Footed larva
Sympiesis sericeicornis	Idiobiont ectoparasitism Monoparasitism	Facultative hyperparasitism	Footed larva, pupa	Footed larva, pupa
Sympiesis Foerst	Idiobiont ectoparasitism Facultative polyparasitism	Facultative hyperparasitism	Footed larva, pupa	Footed larva, pupa
Ageniaspis testaceipes	Konobiont endoparasitism Polyembryony monoparasitism	Primary parasitism	Egg	Footed larva

Based on known knowledge and our investigation, we have constructed a *L. ringoniella*-Parasitoids food web in apple orchards of Shaanxi, China, as illustrated in Fig. 2.

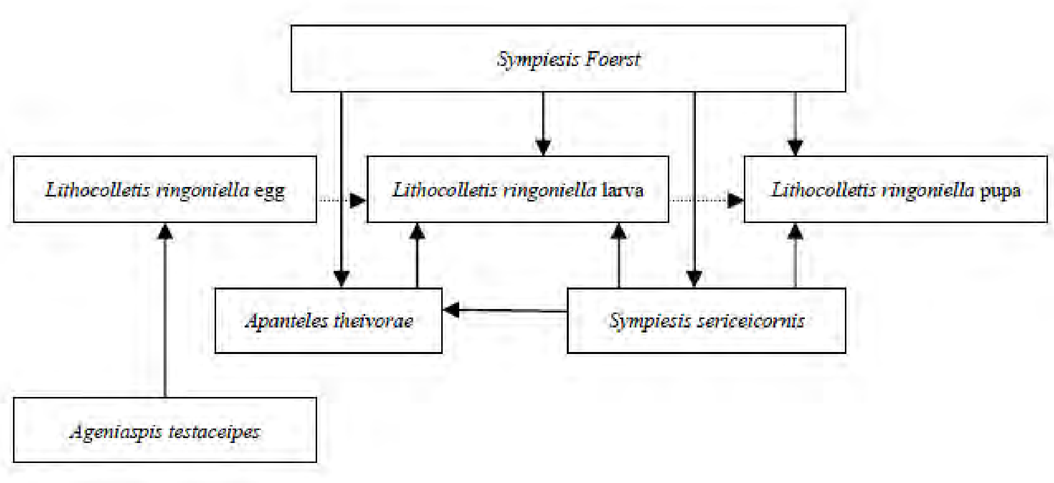

Fig. 2 *L. ringoniella*-Parasitoids food web in apple orchards of Shaanxi, China, constructed from known knowledge and our investigation.

3.2 Dynamics of food web

3.2.1 Dynamics of *L. ringoniella*

The investigated field dynamics of *L. ringoniella*, with different development stages, is shown in Fig. 3.

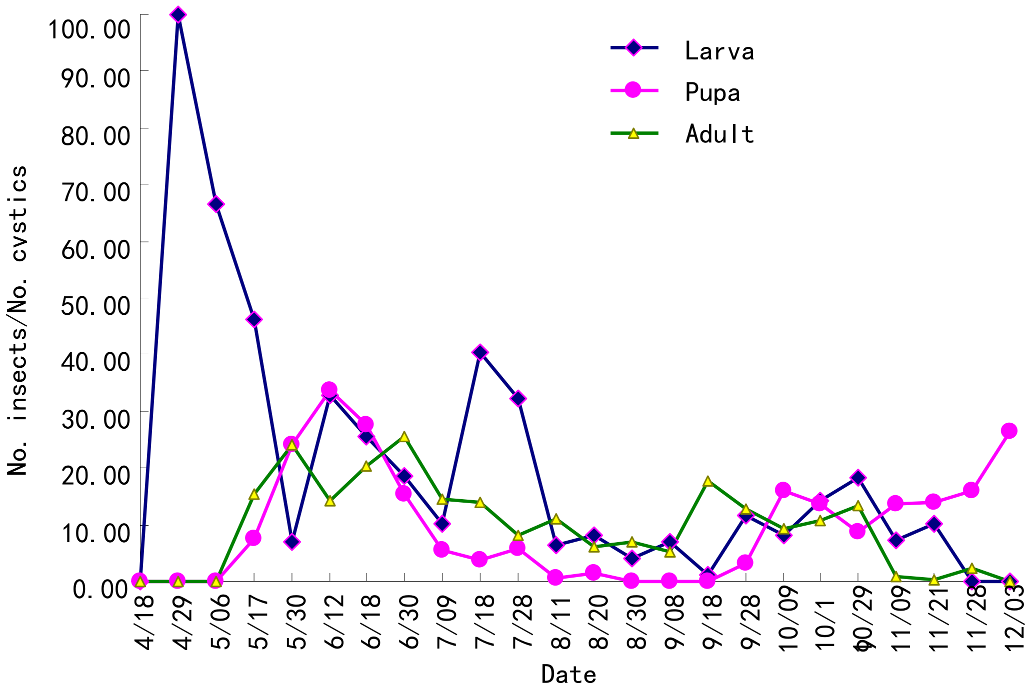

Fig. 3 Dynamics of *L. ringoniella* (Yangling, Shaanxi, China, 2008).

It can be concluded from Fig. 3 that in Yangling, Shaanxi, the larvae, pupae and adults of *L. ringoniella* occurs firstly in late April to early May. The larva population of *L. ringoniella* discontinuously declines from late April to early December. Pupa population has a peak in early and mid-June, and keeps at a very low level from July to September. Pupa population starts to grow since early October.

Starting from the overwinter generation, the adult population tends to show a significant peak in June, seconded by a weak peak during late September to late October.

3.2.2 Dynamics of four parasitoids

As an exception, *A. testaceipes* shows polyembryony in the reproduction. In average 10 individuals of *A. testaceipes* can emerge from a host body. The dynamics of four parasitoids of *L. ringoniella* is shown in Fig. 4.

From Fig. 4, it can be found that the parasitic rate of *A. testaceipes* reaches as high as 90%; for *S. sericeicornis*, *A. theivorae* and *S. Foerst*, it is 70%, 35% and 25% respectively. The dominancy rank of these parasitoids is coincident with previous reports (Sun et al., 1987; Chen et al., 2003).

A. theivorae occurs mainly between May to September, corresponding to the first generation to fourth generation of the host larvae, particularly between late May to early July, corresponding to the second generation to third generation of the host larvae. This is similar to the reported (Zhang, 1990). Overall it declines from late April to late December.

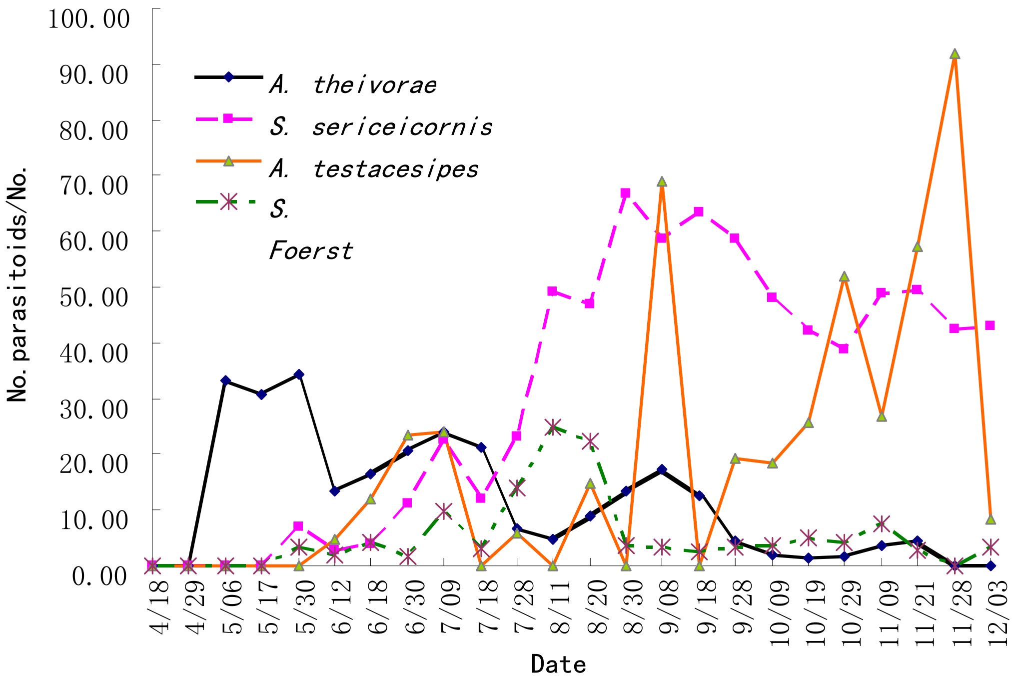

Fig. 4 Dynamics of four parasitoids of *L. ringoniella* (Yangling, Shaanxi, 2008).

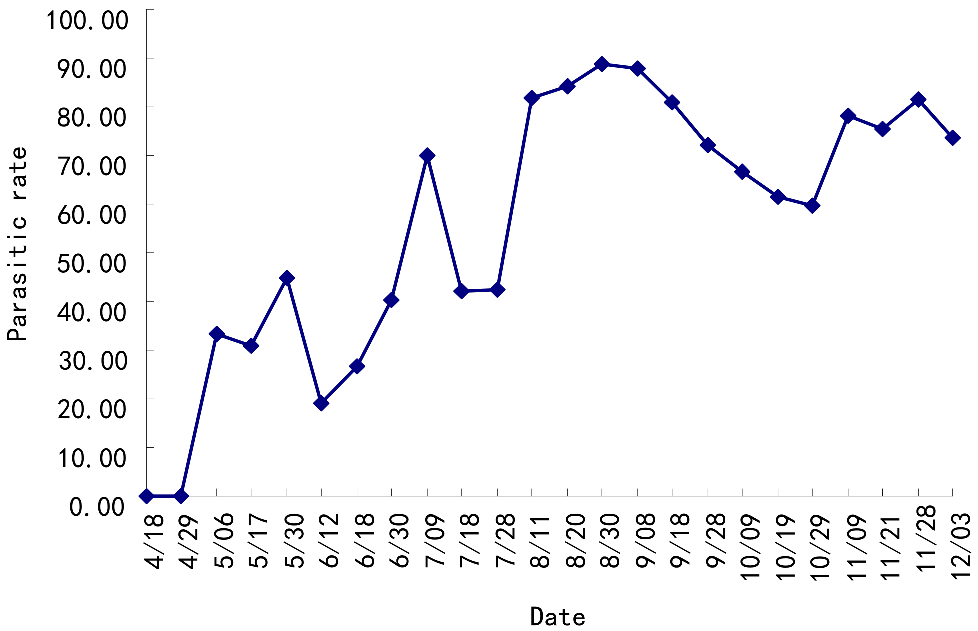

Fig. 5 Dynamics of parasitization effect to *L. ringoniella* (Yangling, Shaanxi, 2008).

S. sericeicornis starts to occur since late May and increases to reach a maximum in late August to mid-September, and keeps at a higher level thereafter. It thus mainly parasitizes the third generation, fourth generation and overwinter generation of the host.

A. testaceipes has two population peaks in early September and late November. Overall its population discontinuously grows from late May to December.

Table 6 shows emergence dynamics of *A. theivorae* and *S. sericeicornis*, investigated in Yangling, Shaanxi.

Table 6 Emergence dynamics of *A. theivorae* and *S. sericeicornis* (Yangling, Shaanxi, China, 2008).

Date (m/d)	No. cocoons	*A. theivorae*		*S. sericeicornis*		No. emergenced	Emergence rate (%)	Cocoon/cystics (%)
		Number	%	Number	%			
4/18	0	0	0	0	0	0	0.00	0.00
4/29	0	0	0	0	0	0	0.00	0.00
5/06	1	1	100.00	0	0	1	100.00	33.33
5/17	1	1	100.00	0	0	1	100.00	7.69
5/30	1	0	0.00	1	100.0	1	100.00	3.45
6/12	27	23	88.46	3	11.54	26	96.30	12.86
6/18	129	106	86.89	16	13.11	122	94.57	15.62
6/30	296	137	59.31	94	40.69	231	78.04	20.96
7/09	619	186	41.06	267	58.94	453	73.18	41.18
7/18	122	51	64.56	28	35.44	79	64.75	16.46
7/28	399	60	20.00	240	80.00	300	75.19	25.73
8/11	74	6	9.38	58	90.63	64	86.49	21.20
8/20	29	4	16.67	20	83.33	24	82.76	21.64
8/30	55	7	15.91	37	84.09	44	80.00	22.54
9/08	4	1	33.33	2	66.67	3	75.00	6.90
9/18	9	1	14.29	6	85.71	7	77.78	11.39
9/28	20	2	14.29	12	85.71	14	70.00	12.90
10/09	43	1	3.70	26	96.30	27	62.79	26.54
10/19	51	1	3.23	30	96.77	31	60.78	21.79
10/29	46	1	3.70	26	96.30	27	58.70	19.91
11/09	205	10	7.35	126	92.65	136	66.34	50.00
11/21	138	9	9.00	91	91.00	100	72.46	56.33
11/28	41	0	0.00	22	100.0	22	53.66	47.13
12/03	60	0	0.00	30	100.0	30	50.00	49.59

3.2.3 Dynamics of parasitization effect

Dynamics of parasitization effect of four parasitoids (*A. theivorae*, *S. sericeicornis*, *A. testaceipes*, *S. Foerst*) is illustrated in Fig. 5.

From Fig. 5 we know that parasitization starts to occur since late April; overall it grows and asymptotically reaches a maximum of 89% in late April to early September. Thereafter the parasitization keeps at a higher level. It is obvious that the parasitization effect of parasitoids to *L. ringoniella* is much significant.

4 Discussion

The conclusions in present study are drawn from comprehensive and complete analysis on previous reports and our investigation. Therefore, our conclusions are reliable. More experiments and investigations to overwinter generations of *L. ringoniella* and parasitoids are needed, which will help to further understand the dynamics and overwinter mechanism of these insects.

We constructed real food web and described its structure and dynamics. Further studies can be conducted on modeling of population and community dynamics (Ivanchikov and Nedorezov, 2011, 2012; Elsadany, 2012; Nedorezov, 2012; Zhang, 2012a, 2012b), topological analysis of food web (Dorman, 2011; Kuang and Zhang, 2011; Zhang, 2011), self-organizing process (Zhang, 2012a, 2012b, 2013), etc.

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