ASSOCIATION BETWEEN PATTERNS IN AGRICULTURAL LANDSCAPES AND THE ABUNDANCE OF WHEAT APHIDS AND THEIR NATURAL ENEMIES

JUN-HE LIU[1,*], MING-FU YU[1], WEN-YI CUI[1], LI SONG[1], ZI-HUA ZHAO[2], and ABID ALI[3]

[1] Department of Biological Engineering, Huanghuai University, Zhumadian, Henan 463000, P.R. China
[2] State Key CAS Laboratory of Integrated Management of Pest Insects and Rodents, Institute of Zoology, Chinese Academy of Sciences, Beijing 100101, China
[3] State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing 100193, P.R. China
* Corresponding author: liujunhe79@126.com

ABSTRACT
Effect of different landscape patterns on insect distribution and diversity was determined by studying wheat fields in complex and simple agricultural landscapes. We studied the influence of simple and complex agricultural landscapes on wheat aphids and their natural enemies in terms of the time of migration, abundance, population growth rate of the aphids and parasitoid abundance. The results indicate that the diversity of natural enemies is greater in the complex agricultural landscape and the effect of natural enemies on the abundance of wheat aphids was greater in the complex non-crop habitat. Wheat aphid hyperparasitoid populations differed in different agricultural landscapes with a greater number of parasites in complex agricultural landscapes. Resident times of predatory natural enemies differ in simple and complex agricultural landscapes. The number and types of predatory natural enemies are higher in complex than simple agricultural landscapes. Aphid population growth rates and the maximum population densities of wheat aphids differed significantly in simple and complex landscapes. Maximum population densities of different wheat aphids were very different in simple and complex landscape structures. The population growth rates and maximum population densities of the different predatory natural enemies and hyperparasitoids differed greatly.

Keywords: landscape pattern, natural enemy, population dynamics, wheat aphid

Introduction

Landscapes are composed of various types of habitats that could potentially determine the abundance of natural enemies (Bianchi et al. 2008). Natural enemies have the potential to control many insect pests and prevent outbreaks of insects in forests and agro-ecosystems (DeBach and Rosen 1991) and ultimately contribute to a reduction in the use of pesticides and their adverse effects on the environment (Naylor and Ehrlich 1997). In all agricultural landscapes, there are habitats that provide alternative food sources, hibernation sites and hosts or prey for natural enemies (Landis et al. 2000) and therefore the composition of landscapes has strong effect on the numerical responses of natural enemies (predators and parasitoids) (Elliott et al. 2001). The mechanism that results in species responding differently to landscapes composition is not the same for all species. In order to understand the ecology of landscape one needs to understand the spatial and temporal dynamics of organism (Wu and Hobbs 2002). Activity of insect pests can be affected by many aspects of landscape composition (Tscharntke and Brandl 2004; Hassan et al. 2012) and movement of species in landscapes is determined by habitat specificity and dispersal capacity (Roland and Taylor 1997; Wanger and Edwards 2001). Thus, the composition of landscapes is important in determining the movement of insect pests and natural enemies in a landscape.

The pattern of agricultural landscapes greatly influences insects and their relationship to predators and parasites. There is little research on the effect landscape patterns on insect communities and interspecies relationships (Vollhardt et al. 2008) but recently it has become an important topic for ecologists (Andrén 1994; Boutin et al. 2002; Haila 2002; Baguette et al. 2003; Dauber et al. 2003). This study included both heterogeneous and homogeneous landscapes with a gradient from simple agricultural landscapes in which most of the land was cultivated (89.3% arable) to complex agricultural landscapes in which a high percentage of the land was covered with non-crop habitats (39.6% arable). In order to determine the relationships between wheat aphids and their natural enemies in simple and complex agricultural landscapes on the Yinchuang plain, we studied the distribution of the natural enemies of wheat aphids in different agricultural landscapes (Table 1). We propose to test the following hypotheses: 1) the complexity of the structure of a landscape and diversity of natural enemies of wheat aphids are positively correlated – the more complex the structure of the landscape, the greater the diversity of natural enemies. 2) structure of the landscape affects migration of winged wheat aphids and the numbers of parasites and predators recorded in different agricultural landscapes. This paper explores the effect of landscape on the numbers of natural enemies of wheat aphids.

Table 1 Species composition of wheat aphids, parasitoids, hyperparasitoids and predators collected in spring wheat fields and reared in the laboratory.

Pest group	Species	Complex agricultural landscape (CAL)	Simple agricultural landscape (SAL)
Insects	*Macrosiphum avenae*	1757 ± 235	2376 ± 428
	Schizaphis graminum	1318 ± 152	1790 ± 192
	Rhopalosiphum padii	416 ± 75	598 ± 83
Parasitoids	*Aphidius avenae*	311 ± 36	447 ± 51
	A. gifuensis	147 ± 35	214 ± 44
	A. sichuanensis	15 ± 4	8 ± 3
	Trioxys asiaticus	7 ± 2	8 ± 3
	Lysiphlebus confusus	4 ± 2	9 ± 3
	Praon volucre	6 ± 3	9 ± 4
	P. rhopalosiphum	3 ± 1	6 ± 2
	Tetrastichus sp.	2 ± 1	8 ± 3
Hyperparasitoids	*Asaphes vulgaris*	49 ± 17	35 ± 13
	Asaphes suspensus	78 ± 28	68 ± 23
	Pachyneuron aphidis	170 ± 39	119 ± 34
	Aphidencyrtus aphidivorus	13 ± 2	7 ± 3
	Dendrocecrus carpenter	9 ± 3	8 ± 3
	Alloxysta sp. 1	175 ± 42	131 ± 36
Predators	*Hippodamia tredecimpunctata*	8 ± 3	5 ± 2
	Hippodamia variegata	6 ± 2	11 ± 4
	Coccinella septempunctata	2 ± 1	5 ± 2
	Harmonia axyridis	3 ± 1	4 ± 2
	Propylea japonica	12 ± 4	7 ± 3
	Chrysopa sinica	7 ± 3	8 ± 3
	C. formosa	4 ± 1	6 ± 2
	Sympetrum croceolum	3 ± 1	2 ± 1
	Chlaenius pallipes	19 ± 8	59 ± 15
	Pterostichus gebleri	4 ± 1	13 ± 3
	Cymindis binotata	3 ± 1	21 ± 6
	Cymindis daimio	4 ± 1	19 ± 5
	Calosma maderae	5 ± 2	13 ± 4
	Scarites terricola	6 ± 1	18 ± 3
	Harpalus crates	9 ± 2	6 ± 4
	Harpalus salinus	7 ± 1	4 ± 2
	Staphylinus maxillosus	17 ± 5	21 ± 7
	Erigonidium graminicolum	19 ± 6	27 ± 8
	Pardosa astrigera	23 ± 8	39 ± 12
	Lycisa coelestris	10 ± 3	13 ± 4
	Theridionocto macutatum	5 ± 2	9 ± 3
	Misumenops tricuspidatus	11 ± 3	19 ± 5
	Pardosa laura	8 ± 3	5 ± 2
	Tetragnatha shikokiana	9 ± 3	7 ± 2
	Xysticus ephippiatus	18 ± 5	12 ± 4
	Erigone prominens	14 ± 5	11 ± 2
	Agelena opulenta	8 ± 2	3 ± 1
	Scaeva selenitica	3 ± 1	5 ± 2
	Syrphus corollae	9 ± 3	21 ± 4
	Syrphus nitens	8 ± 3	19 ± 5

Materials and Methods

Study region and experimental design

The study was conducted in Yinchuan (38°26′05N, 106°22′04E) in Ningxia Province, PR China. The areas studied were assigned to the following categories of landscape: (1) complex agriculture (CAL hereafter) or highly heterogeneous agricultural areas, (2) simple agriculture (SAL hereafter) or homogenous agricultural areas (Zhao Zihua 2010). There were three study areas: I – Xixia army horse ranch in Yinchuan, Ningxia (complex landscape); II – Zhangzheng Bridge in Xingqing district (complex landscape); III – Zhangzheng town in Xingqing district (simple landscape). In all the regions studied no pesticides were applied and they were managed according to the recommended production technology for that area and crop. They were studied from May to July in 2009, 2010 and 2011. Wheat aphids generally tend to stay and increase in numbers in a field before flying away. A five-point (East, South, West, North and Center) sampling grid was established, depending on the local characteristics. A total of 70 wheat fields of different sizes in different landscapes were studied.

Wheat aphid populations recorded in different periods

Three important factors in the population dynamics of aphids were recorded on different dates throughout the sampling period in 2009, 2010 and 2011: (1) appearance in the fields (10 April – 15 May), (2) period of population growth (16–30 May), and (3) peak numbers (30 May – 20 June). The aphids and natural enemies were counted at intervals of 10 days from 15th April to 20th June.

Monitoring of arthropods / Insect Sampling

Method used to survey wheat aphids: At each point on the grid 100 representative wheat plants were randomly selected. Each of these plants was examined over a period of 15–20 min and any *M. avenae, S. graminum* or *R. padi* and wingless aphids present on the plants were recorded thereby generating five sets of data for the grid (Table 2).

Method used to survey parasitoids: Using the grid described above, 100 wheat plants were randomly selected and visually examined for 15–20 min. The number of mummified aphids, *S. graminum* and *R. padi* and wingless aphids were counted. Mummified aphids were taken to the laboratory and placed in a Petri dish labeled with the date of collection and a sample code number and kept under the following conditions (16 : 8 L : D, 20 ± 1 °C, RH = 65 ± 3%) in an incubator. Over a period of more than 40 days we recorded whether parasitoids had emerged from mummies every day at 5:00 PM. These parasitoids and the aphid mummies were stored in 90% alcohol prior to identification.

Net method: Predators were surveyed using the same checkerboard 5 point random sampling grid described above. Each position on the grid was swept 10 times. Ten adult insects from each sweep of the net were collected and together with debris placed in a poison bottle, with a total of five bottles collected at each position. All adult

Table 2 Sampling parameters used in agricultural landscape patterns.

Sample parameters	Order	Family	Species
Aphids	Homoptera	Aphidinea	*Macrosiphum avenae* (F.)
	Homoptera	Aphidinea	*Schizaphis graminum* (Rond)
	Homoptera	Aphidinea	*Rhopalosiphum padi* (L.)
Primary Parasitoids	Hymenoptera	Aphididae	*Aphidius avenae*
	Hymenoptera	Aphididae	*A. sichuanensis*
	Hymenoptera	Braconidae	*A. gifuensis*
	Hymenoptera	Aphididae	*Lysiphlebus confusus*
	Hymenoptera	Aphididae	*Praon volucre*
Secondary Parasitoids	Hymenoptera	Charipidae	*Alloxysta* sp.
	Hymenoptera	Pteromalidae	*Pachyneuron aphidis* (Bouche)
	Hymenoptera	Pteromalidae	*Asaphes suspensus* Nees
	Hymenoptera	Pteromalidae	*Asaphes vulgaris* Walker
	Hymenoptera	Megaspilidae	*Dendrocerus carpenteri* (Curtis)
Predators	Coleoptera	Coccinellidae	*Hippodamia tredecimpunctata* (Say)
	Coleoptera	Coccinellidae	*Hippodamia variegata* (Goeze)
	Diptera	Syrphidae	*Metasyrphus corollae* Matsumura
	Coleoptera	Carabidae	*Chlaenius pallipes* Gebler
	Neuroptera	Chrysopidae	*Chrysopa intima*
	Araneae	Lycosidae	*Pardosa astrigera* Koch
	Hemiptera	Miridae	*Deraeocoris punctulatus* (Fallen)

specimens brought back to the laboratory were identified to species. Any nymphs collected were taken back to the laboratory and reared to the adult stage and identified, and the numbers of each of the species noted.

Trap method: Beetles and spiders in the wheat fields were captured on the ground and in the soil. Disposable plastic cups (height 9 cm diameter 7.5 cm) were used as traps. Five sampling points were established in each plot and 5 cups placed at each sampling point so that in each plot there were 25 cups. The attractant placed in the cups was a 2 : 1 : 1 : 20 mixture of vinegar, sugar, methanol and water by weight. Each cup contained 40~60 ml of this mixture. The cups were inspected every six days when all the arthropods were removed and taken back to the laboratory for identification and the attractant in the cup was replaced and the trap reset.

The large soil animals were hand-sorted and placed in 75% alcohol. Small soil animals were extracted from the soil using a Tullgren funnel (2 mm standard sieve) and the specimens collected and sorted using a zoom microscope and preserved in 75% alcohol prior to identification.

Statistical analysis

The numbers of cereal aphids and their natural enemies were subjected to one way analysis of variance (ANOVA) using statistical software (SAS institute Inc., 2006). Means of numbers of cereal aphids and their natural enemies were compared using LSD and a 5% level of significance.

Results

The effect of agricultural landscape on the time of the colonization of wheat field by aphids and their natural enemies

Parasitoids: The parasitoids were first recorded in the different agricultural landscape at about the same time. The first record of *A. avenae* in fields in the complex agricultural landscape was 26 April and 10 days later in the simple agricultural landscape (Table 3). The other parasitic wasps also occurred later in the simple landscape except for *L. confusus,* which occurred there earlier. Significantly more parasitic wasps were recorded in the complex agricultural landscape and only *L. confusus* was more abundant in the simple landscape. The total number of parasitoids in the complex landscape was significantly greater than in the simple landscape (Table 3).

Hyperparasitoids: All species of hyperparasitoids were recorded a few days earlier in the complex landscape (Table 4). The number of individuals of each hyperparasitoid recorded varied. The numbers of *P. aphidis*, *A. suspensus* and *A. vulgaris* were significantly greater in the complex landscape. But the number of *D. carpenteri* was significantly higher in the simple landscape and that of *Alloxysta* sp was not significantly different in the two landscapes (Table 4). The total number of hyperparasitoids was significantly higher in the complex landscape.

Predators: The first predators were recorded at different times in the two agricultural landscapes. The predators were all first recorded during the period when the aphids first arrived in the fields (10 April to 15 May). Predators were first recorded later in the simple landscape, except for *H. tredecimpunctata* (Table 5). *C. pallipes*, *P. astrigera* and aphids were all recorded on the first day the fields were sampled in both the complex and simple landscapes and it is possible that they overwintered in the wheat fields.

The numbers of all the species of predators were significantly greater in the complex landscape (Table 5). The total number of species of predators was significantly greater in the complex landscape.

Table 3 Effects of different agricultural landscapes on the time of the appearance and numbers of parasitoids in wheat fields. The aphids were first recorded 10 April – 15 May.

Parasitoid species		Complex agricultural landscape (CAL) ± SE	Simple agricultural landscape(SAL) ± SE
Aphidius avenae	Time of appearance	26 April	16 April
	Numbers	0.46 ± 0.28a	0.32 ± 0.22b
A. gifuensis	Time of appearance	10 May	5 May
	Numbers	0.56 ± 0.27a	0.36 ± 0.18b
A. sichuanensis	Time of appearance	13 May	10 May
	Numbers	0.23 ± 0.11a	0.16 ± 0.17b
Lysiphlebus confusus	Time of appearance	30 April	8 May
	Numbers	0.08 ± 0.05a	0.11 ± 0.08b
Praon volucre	Time of appearance	13 May	8 May
	Numbers	0.14 ± 0.07a	0.12 ± 0.14b
Total parasitoids	Time of appearance	26 April	16 April
	Numbers	1.47 ± 0.53a	1.07 ± 0.42b

Table 4 Effects of different agricultural landscapes on the time of the appearance and numbers of hyperparasitoids in wheat fields. Hyperparasitoids were first recorded 10 April – 15 May.

Hyperparasitoid species		Complex agricultural landscape (CAL) ± SE	Simple agricultural landscape(SAL) ± SE
Alloxysta sp.	Time of appearance	8 May	15 May
	Numbers	0.59 ± 0.24a	0.33 ± 0.18a
Pachyneuron aphidis	Time of appearance	2 May	10 May
	Numbers	0.88 ± 0.25a	0.46 ± 0.16b
Asaphes suspensus	Time of appearance	2 May	10 May
	Numbers	0.51 ± 0.13a	0.29 ± 0.07b
Asaphes vulgaris	Time of appearance	10 May	15 May
	Numbers	0.26 ± 0.11a	0.19 ± 0.07b
Dendrocerus carpenteri	Time of appearance	15 May	20 May
	Numbers	0.11 ± 0.06a	0.28 ± 0.10b
Total hyperparasitoids	Time of appearance	2 May	10 May
	Numbers	2.35 ± 0.41a	1.55 ± 0.32b

Effects of the structure of the landscape on the population growth rate and maximum population density of wheat aphids and their natural enemies

Aphids: The population growth rate and maximum population density of *M. avenae* was 6 and 2 times greater, respectively, in the simple than in the complex landscape (Table 6). For *S. graminum* the population growth rates were significantly greater in the complex landscape, but the maximum population density they achieved was significantly greater in the simple landscape. *R. padi* achieved significantly higher population growth rates and maximum population densities in the complex landscape. The averages of the population growth rates and maximum population densities of all the species of aphids were significantly higher in the complex landscape.

Parasitoids: There were no significant differences in population growth rates or maximum population densities of parasitoids in the complex and simple landscapes (Table 7) except for *A. avenae*, which achieved significantly higher population densities ($F = 36.26$, df = 14, $p = 0.0001$) in the complex landscape and *P. volucre* with significantly higher population growth rates ($F = 28.86$, the df = 14, $p = 0.0001$) in the simple landscape. Total population growth rates were not significantly different in the two landscapes but the maximum population density was significantly greater ($F = 18.62$, df = 14, $p = 0.026$) in the complex landscape.

Table 5 Effects of different agricultural landscapes on the time of the appearance time and numbers of predators in wheat fields. Aphids first recorded, 10 April – 15 May.

Predator species		Complex agricultural landscape (CAL) ± SE	Simple agricultural landscape(SAL) ± SE
Hippodamia tredecimpunctata	Time of appearance	26 April	16 April
	Numbers	0.93 ± 0.41a	0.41 ± 0.26b
Hippodamia variegata	Time of appearance	2 May	10 May
	Numbers	0.41 ± 0.19a	0.33 ± 0.19a
Metasyrphus corollae	Time of appearance	2 May	10 May
	Numbers	0.79 ± 0.26a	0.31 ± 0.14b
Chlaenius pallipes	Time of appearance	10 April	10 April
	Numbers	5.62 ± 3.19a	1.62 ± 1.27b
Chrysopa intima	Time of appearance	30 April	8 May
	Numbers	0.52 ± 0.37a	0.23 ± 0.12a
Pardosa astrigera	Time of appearance	10 April	10 April
	Numbers	3.18 ± 0.93a	1.86 ± 0.53b
Deraeocoris punctulatus	Time of appearance	26 April	5 May
	Numbers	1.09 ± 0.61a	0.88 ± 0.37a
Total predators	Time of appearance	10 May	10 May
	Numbers	11.54 ± 3.62a	5.64 ± 1.21b

Table 6 Effects of the structure of the landscape on the population growth rate and maximum population density of wheat aphids.

Aphid species		Complex agricultural landscape (CAL) ± SE	Simple agricultural landscape(SAL) ± SE
Macrosiphum avenae	Growth rate	29.13 ± 4.76b	4.845 ± 0.95a
	Max population density	286.42 ± 49.32b	144.82 ± 26.33a
Schizaphis graminum	Growth rate	53.25 ± 15.32b	30.21 ± 16.42a
	Max population density	319.32 ± 57.32a	396.54 ± 36.91b
Rhopalosiphum padi	Growth rate	43.43 ± 25.32a	25.62 ± 9.35a
	Max population density	252.83 ± 45.32b	136.56 ± 28.32a
Total wheat aphids	Growth rate	39.43 ± 11.84b	13.73 ± 7.49a
	Max population density	821.65 ± 66.56b	677.81 ± 32.98a

Table 7 Effects of different agricultural landscapes on the population growth rate and maximum population density of parasitoids in wheat fields.

Parasitoid species		Complex agricultural landscape (CAL) ± SE	Simple agricultural landscape(SAL) ± SE
Aphidius avenae	Growth rate	18.63 ± 3.62	21.65 ± 6.93
	Max population density	139.62 ± 32.63a	96.83 ± 21.83b
A. gifuensis	Growth rate	11.26 ± 2.93	13.52 ± 4.83
	Max population density	62.53 ± 18.63	46.83 ± 15.81
A. sichuanensis	Growth rate	9.63 ± 2.83	7.82 ± 1.99
	Max population density	1.26 ± 0.28	1.13 ± 0.19
Lysiphlebus confusus	Growth rate	7.26 ± 2.92	9.36 ± 3.62
	Max population density	0.92 ± 0.19	0.83 ± 0.21
Praon volucre	Growth rate	3.25 ± 1.16b	5.36 ± 1.83a
	Max population density	1.08 ± 0.31	1.24 ± 0.418
Total parasitoids	Growth rate	10.01 ± 3.63	11.71 ± 4.82
	Max population density	205.41 ± 43.26a	146.86 ± 31.63b

Table 8 Effects of different agricultural landscapes on the population growth rate and maximum population density of hyperparasitoids in wheat fields.

Hyperparasitoid species		Complex agricultural landscape (CAL) ± SE	Simple agricultural landscape(SAL) ± SE
Alloxysta sp.	Growth rate	21.38 ± 6.83	16.89 ± 5.88
	Max population density	42.29 ± 15.62	35.09 ± 11.24
Pachyneuron aphidis	Growth rate	13.62 ± 4.26	9.39 ± 3.19
	Max population density	39.95 ± 14.59	35.26 ± 16.93
Asaphes suspensus	Growth rate	11.22 ± 3.13	8.92 ± 2.12
	Max population density	26.38 ± 8.69	22.83 ± 7.93
Asaphes vulgaris	Growth rate	7.26 ± 2.92	9.36 ± 3.62
	Max population density	18.62 ± 5.93	26.83 ± 7.63
Dendrocerus carpenteri	Growth rate	9.63 ± 3.61	8.92 ± 4.62
	Max population density	4.68 ± 1.36	3.26 ± 1.06
Total hyperparasitoids	Growth rate	12.62 ± 4.12	10.68 ± 3.99
	Max population density	132.92 ± 49.83	122.27 ± 38.89

Hyperparasitoids: There were no significant differences in population growth rates or maximum population densities of hyperparasitoids in the complex and simple landscapes (Table 8). In total there were five main species of hyper–parasitoids the population growth rates and the maximum population densities of which were greater in the complex than the simple agricultural landscape. They were: *Alloxysta sp.* (21.38 ± 6.83 vs. 16.89 ± 5.88, 42.29 ± 15.62 vs. 35.09 ± 11.24), *Pachyneuron aphidis* (13.62 ± 4.26 vs. 9.39 ± 3.19, 39.95 ± 14.59 vs. 35.26 ± 16.93), *Asaphes suspensus* (11.22 ± 3.13 vs. 8.92 ± 2.12, 26.38 ± 8.69 vs. 22.83 ± 7.93), *Dendrocerus carpenteri* (9.63 ± 3.61 vs. 8.92 ± 4.62, 4.68 ± 1.36 vs. 3.26 ± 1.06), but the differences are not significant. Only the population growth rates (7.26 ± 2.92 vs. 9.36 ± 3.62) and max population density (18.62 ± 5.93 vs. 26.83 ± 7.63) of *Pachyneuron* were greater in the complex landscape, but the differences ($F = 5.19$, df = 14, $p = 0.062$, table 9) are not significant.

Table 9 Effects of different agricultural landscapes on the population growth rate and maximum population density of predators in wheat fields.

Predator species		Complex agricultural landscape (CAL) ± SE	Simple agricultural landscape(SAL) ± SE
Hippodamia tredecimpunctata	Growth rate	7.26 ± 2.39	5.36 ± 2.03
	Max population density	10.67 ± 3.60	6.91 ± 2.38
Hippodamia variegata	Growth rate	6.45 ± 2.31	5.26 ± 1.96
	Max population density	13.83 ± 3.66	11.22 ± 4.06
Metasyrphus corollae	Growth rate	8.63 ± 4.26a	3.19 ± 1.01b
	Max population density	1.31 ± 0.34a	0.68 ± 0.14b
Chlaenius pallipes	Growth rate	0.87 ± 0.22a	0.43 ± 0.11b
	Max population density	4.38 ± 1.09a	1.01 ± 0.16b
Chrysopa intima	Growth rate	14.09 ± 5.21a	8.67 ± 2.34b
	Max population density	7.63 ± 2.26a	5.29 ± 3.01b
Pardosa astrigera	Growth rate	1.26 ± 0.41	1.52 ± 0.71
	Max population density	5.66 ± 2.36	6.29 ± 3.21
Deraeocoris punctulatus	Growth rate	3.62 ± 1.21	2.38 ± 0.92
	Max population density	2.69 ± 0.88	2.37 ± 0.79
Total predators	Growth rate	5.88 ± 1.88a	3.83 ± 1.36b
	Max population density	46.17 ± 15.26	33.77 ± 10.89

Predators: The population growth rates and maximum population densities of the 7 species of predators differed in the complex and simple landscapes (Table 9). In the cases of *H. tredecimpunctata*, *H. variegata*, *P. astrigera* and *D. punctulatus*, however, the differences were not significant, but for the other three species both the population growth rates and maximum population densities differed significantly. For *M. corollae*, *C. pallipes* and *C. intima* the population growth rates (F = 19.69, df = 14, p = 0.029; F = 16.82, df = 14, p = 0.034; F = 13.62, df = 14, p = 0.038) and population densities (F = 23.92 df = 14, p = 0.021; F = 39.95, df = 14, p = 0.001; F = 12.66, df = 14, p = 0.041) were both significantly greater in the complex landscape.. Both the total population growth rate and the maximum population density of predators was significantly higher in the complex than in the simple landscape (F = 22.69, df = 14, p = 0.23; F = 28.91, df = 14, p = 0.018).

Discussion

Population dynamics of wheat aphids in different landscapes

There is no need to control wheat aphids in northern China, because the wheat aphid populations that occur there are relatively low. The number of alatae recorded in the two landscapes differed. Although the numbers of alatae recorded in the complex landscape was significantly lower than the simple landscape, the population growth rate of the aphids was considerably different possibly because of the high degree of fragmentation of the complex landscape, which makes it more difficult for natural enemies to find prey. But wheat aphids need to be controlled in the south of China. Wheat aphid abundance was not affected by the structure of the landscape, which is consistent with the findings of Costamagna et al.'s (2004) study on *Pseudaletia unipuncta.* Here we think it is likely that wheat aphid abundance is not affected by the complexity of the structure of the landscape but by the degree of fragmentation of host plant habitats in the landscape.

Percentage parasitism

The difference in percentage parasitism recorded in complex and simple landscapes was very slight. This may be attributable to the following: (1) landscape structure affects the richness and diversity of parasitic wasps but not in the area studied. (2) non-crop habitats limits the richness and transfer of parasitic wasps. (3) difference in the population dynamics of the parasitic wasps and aphids. The little difference in the percentage parasitism in the two landscapes may because the population density of the host in the two landscapes is as Costamagna et al. (2004) and Zhao et al. (2012) have shown very similar and host density is usually the main factor determining percentage parasitism. The richness and diversity of parasitic wasps increased with host density with a higher diversity in the simple landscape, which is what theory predicts. A high percentage of grassland in a landscape is associated with an increased number of predatory natural enemies and increase in the control of the wheat aphid population. An increase in the complexity of the structure of the landscape is also associated with an increase in the diversity of predatory natural enemies. Therefore, the design of agricultural landscapes should take into consideration the need to maintain species diversity. At the landscape scale, increasing the proportion of grassland in an agricultural landscape can also strengthen the role of the natural enemies in biological control by maintaining a higher diversity of natural enemies. Designing landscapes that facilitate biological control by increasing the efficiency of natural enemies and reducing the colonization of crops by pests is ultimately a reasonable use of resources. Mosaic landscapes should include grassland, woodland, wetland, buildings, roads etc. We should make full use of these resources to enhance biological control and the value of ecosystem services. Landscape planning may be the most effective means of increasing the numbers of natural enemies, especially in agricultural landscapes.

The diversity of parasitoids and variation in percentage parasitism

The diversity parasitoids and percentage parasitism of aphids in a complex landscape were lower than those in a simple landscape. In the complex landscape the habitat fragmentation index was 1.54 times greater than in the simple landscape. Habitat fragmentation reduces the effectiveness of the foraging behaviour of natural enemies of pests (Landis et al. 2000). It also affects the searching behaviour of the pests and determines to some extent when and the numbers of aphids that colonize the fields. There are many predators and parasitoids of aphids in wheat fields. In the complex landscape the rapid growth of the wheat aphid populations may be because the habitat fragmentation there reduced the efficiency with which the natural enemies were able to find and consume aphids. In the complex landscape studied the population growth rates of the three species of wheat aphids were higher than in the simple landscape.

Conclusion

In order to determine the effect of landscape structure on the population dynamics of wheat aphids we need to study in greater detail the following aspects: (1) the relationship between the complexity of the landscape and the ability of wheat aphids to locate their host plants and their subsequent population growth rate, (2) the question, whether the greater habitat fragmentation of complex landscapes adversely affects the foraging for aphids of predators and parasitoids and (3) which structures of complex landscapes affect the foraging for aphids by predators and parasitoids.

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Disclosure

J-H L, M-F Y, W-Y C and L S designed and performed the experiments. A A and Z-H Z analyzed the data and wrote the manuscript.

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