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Density Estimation of Ground-Dwelling Predators in Wheat Fields of Northwest China

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JL, MY, AA and JL designed the field experiments. JL, MY and JL conducted the field experiments. JL, AA, KL and NK analyzed the data. All authors participated in writing the article.

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Biological control, cereal aphids, ground-dwelling predators, species diversity

A B S T R A C T

High abundance and species diversity of natural enemies is the basis for biological pest control in wheat fields. However, population densities of ground-dwelling predators are less known, despite their potential to reduce cereal aphid population. In the present study, the role of natural enemies dwelling in the soil limiting the densities of wheat aphids has been focused. The population abundance of ground-dwelling predators and cereal aphids were sampled weekly from 2009-2012 in Ningxia Province, China. Results showed that natural enemies abundance was negatively correlated with aphid densities, indicating predator did not exhibit a numerical response to cereal aphids. Nine species of ground-dwelling predators accented for 78% of all predators collected. Species richness of collected predators varied significantly, depended on the geographical positions. Two species of the predators namely, *Chlaenius pallies* and *Pterostichus gebler* were dominant at all selected locations. These findings could be helpful for management of cereal aphids by exploiting ground-dwelling predators as biological agent in wheat fields.

INTRODUCTION

In agro-ecosystem, agricultural landscapes contain a diverse community of ground-dwelling predators, dominated by species of Carabidae beetle and spiders (Elliott *et al*., 2006; Gardiner *et al*., 2010; Sherawat *et al*., 2015). Wheat is an important crop and agricultural landscape in Northwest China. Cereal aphids including two species (*Sitobion avenae* (Fabricius), *Schizaphis graminum* (Rondani) are the most serious juice-sucking pest of wheat in Yinchuan plain, Ningxia Hui Autonomous Region, Northwest China (Zhao *et al*., 2012, 2013a). Wheat fields are also inhabited by numerous species of ground-dwelling predators, which feed primarily at the soil surface and below ground and prey on numerous insect and other invertebrate species, including cereal aphids (Schmidt *et al*., 2005). It has been observed in Europe that ground-dwelling predators feed on cereal aphids which often occur on the soil surface as the result of intentional dispersal among plants or unintentional dislodgment from plants caused by wind, rain, agricultural practice, activity of natural enemies, and many other factors. More than 60 species of ground-dwelling predators could be found in wheat growing areas in Europe (Elliott *et al*., 2006). These species differ widely in body size, abundance, feeding, habitat, and seasonal activity pattern.

Pitfall trapping methods have been widely used to collect ground-dwelling predators (Schmidt *et al*., 2005), which also has some limitations (Roschewitz *et al*., 2005; Perdikis *et al*., 2011), because this method has drawback of collection data, as it is affected by a wide variety of abiotic and biotic factors. In order to know the species richness and composition of ground-dwelling predators within the field and its surroundings, accurate estimation is of paramount importance in spring wheat fields (Anjum-Zubair *et al*., 2010; Zhao *et al*., 2013b).

In addition, it would be helpful to know if density of ground-dwelling predators was correlated to cereal aphid density in wheat aphids (Tscharntke *et al*., 2005, 2007; Melnychuk*et al*., 2003; Naranjo and Ellsworth, 2009). The numerical response between ground-dwelling predators and cereal aphids is important and poorly known. Predators which exhibit a strong numerical response to their prey could play an important role for the management of noxious pests. It is believed that for ground-dwelling predators, which are mostly generalist predators, a strong numerical response to cereal aphids would not be expected. However, few studies conducted in Europe in wheat fields, suggesting that such relationship is possible (Macfadyen *et al*., 2009; Melnychuk *et al*., 2003).

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Hammond (1997) reviewed the methods which are appropriate for sampling ground-dwelling predators. He pointed out that all the available sampling methods for collection of ground dwelling predators have some drawback. However, there are some other methods that provide more exact population density than pitfall trapping method. For example, D-vac suction sampling within enclosures followed by hand collection of the plants and soil provides accurate estimates of density for most ground-dwelling predators (Schmidt *et al*., 2003, 2004). We used D-vac suction sampling within enclosures followed by hand collection to sample ground-dwelling predators in spring wheat fields in the six major wheat growing regions for four years between April to June of each season. Our objective was to gain real information on abundance and species richness of ground-dwelling predators in spring wheat fields. In particular, we tried to assess the extent to which ground-dwelling predator species assemblages varied yearly, season-wise and in different geographic locations. In addition, we determined if density of ground-dwelling predator could correlate with abundance of cereal aphids.

MATERIALS AND METHODS

Adult ground-dwelling predators were collected from individual wheat fields (0.6 ha) located in the six major wheat growing regions of Ningxia Hui Autonomous Region in Northwest China: Helan, Wuzhong, Guyuan, Yongning, Yanchi, and Huinong Region. An adapted spring wheat cultivar "Ning 43" at Helan and "Ning 45" at the other regions was planted in these fields in early-March of 2009-2012. Sampling was carried out at beginning of the wheat tillering growth stage. During this period, ground-dwelling predators and cereal aphids were collected after every 7-14 d unless weather conditions precluded sampling. Agricultural practices in all studied fields were typically the same. Moreover, no insecticide and herbicide were applied.

Ten equal sizes sub-sample were designed randomly in each experimental location. A single sample was taken within each sub-sample on each sampling occasion. D-vac suction (Rincon-Vitova Insectaries, Ventura, California, USA) sampling was used to collect ground-dwelling predators. Sampling each sub-sample was accomplished within 20 cm deep, 1 m^2 circular toothed sampling frame. The frame was placed at a random position in each sub-sample, toothed side down, and inserted into the soil to block adult ground-dwelling predators from escaping. The area within the frame was sampled using a D-vac fitted with a ventilated 60 cm long cylindrical metal extension. After suction sampling within the frame for approximately 10 min, the interior of the frame was searched for adult ground-dwelling predators. Hand collection was continued within the frame for 10 min, with plants, the soil surface, and underneath loose soil thoroughly inspected for collection of predators, using hand-held container. Samples were brought back to the laboratory and all adult predators were stored in polyethylene vials filled with 80% ethyl alcohol until their fixation with insect pins and afterward they were identified up to species level. Aphids were sampled in all respective fields by inspecting 100 tillers / sub-plot. Five sub plots were selected from each site. In case of lower population aphid density100 wheat tillers were-inspected while, in higher densities 50 wheat tillers were inspected. Tillers were collected by walking 10 m distance in u-shaped transects, and individual tiller were removed from ground level.

Ordination of species densities with potential explanatory variables (density of cereal aphid, year, location, and season) was accomplished by canonical correspondence analysis (CCA) using CANOCO version 4.5. Data used in CCA were means for each species for the 10 sub-samples from respective field in single collection. Climatic factors (fall, winter, or spring) were based on calendar date as normally defined. Species abundance data were transformed by taking their square roots prior to CCA. Explanatory environment variables were entered into CCA using the forward stepwise selection option in CANOCO. Using the forward selection method, explanatory variables were entered in the CCA in order of their contribution to explains the greatest percentage of variation is added first, and other variable were entered consecutively according to the percentage of remaining variation accounted for, with the restriction that only statistically significant variables (a = 0.05) entered. F-statistics based on Monte Carlo randomization (500 random permutations) of the reduced model were used to test the significance of the relationship between species density and each explanatory variable. Results of CCA indicated that geographic position was the only factor related to ground-dwelling predator community structure (species composition and density). Therefore, the mean and standard error of the density of each of the most abundant ground-dwelling predator species were calculated for data pooled across the 10 sub-samples for each field and all collection occasions using the means procedure.

RESULTS

The number of times a spring wheat field was collected varied among location. But the differences did not make significance among different locations. The weather was so dry that the rain was rare in all regions except Guyuan and Helan.

Table I.- **Result of Forward Stepwise of Explanatory Environment Variable in the CCA of ground-dwelling predator communities in wheat field during 2009-2012 in Ningxia Hui Autonomous Region of northwest China.**

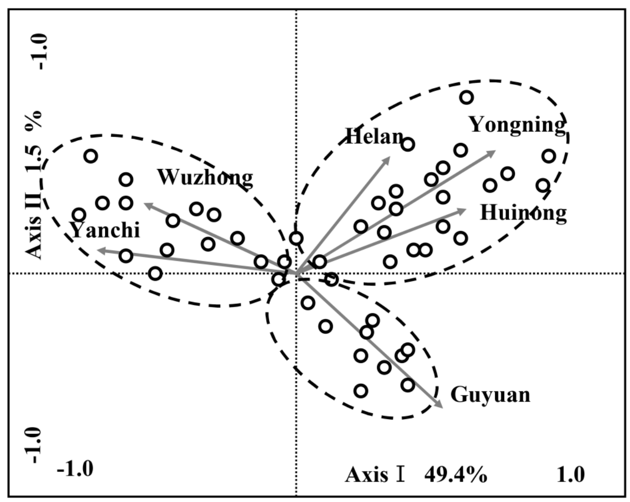
Explanatory variable	F-ratio	P>F
Location and field position	2.79	0.02
Month and season	1.13	0.23
Wheat growth stage	1.02	0.29
Year	0.93	0.35
Prey density	0.84	0.47

The CCA eigen values for axes 1 through 3 were 0.613, 0.381 and 0.309. Axis 1 explained 47% of the variation; whereas, axes 1-3 combined accounted for 79% of the variation in the species density-environment relationship. Forward stepwise selection of explanatory environment variables in the CCA demonstrated that only the wheat field's geographic position had a statistically significant effect on predator community structure (Table I), indicating that predators did not exhibit a numerical response to cereal aphid populations at within-field scale.

Adults of a total of 49 species of ground-dwelling predators were collected in field at the six locations in Ningxia Hui Autonomous Regions. The density of the eight most abundant species, other species, and total ground-dwelling predators are listed in Table II. Mean density of predators per m^2 varied markedly among locations from at Huinong (13^{th} May) to 27^{th} August at Guyuan.

Nine species, *Calosma maderae*, *Chlaenius pallipes*, *Dolichus halensis*, *Scarites terricola*, *Pterostichus gebleri*, *Harpalus crates*, *Pardosa astrigera*, *Erigonidium graminicolum*, and *Erigone prominens* accounted for 76% of all ground-dwelling predators occurring in samples. In all locations, *P. astrigera* was the most abundant species, followed by *S. terricola* and *E. graminicolum*. Overall species relative abundances were similar to those in the four-year study of ground-dwelling predators in wheat field while in our study, these ranked fourth with respect to relative abundance. *P. astrigera* was the most abundant species at Helan, Huinong and Yongning, while *E. graminicolum*, was the most abundant species at Guyuan. However, *S. terricola* was the most abundant at Wuzhong.

Although ground-dwelling predators can occasionally be found up to 15 cm soil depth, the estimates confirmed that ground-dwelling predator density in wheat field is relatively high. The density of particular species varied among different locations. For example, a biplot of field location and species density score is illustrated in Figure 1. Where, vectors represent spring wheat fields and specie density scores are represented by abbreviations of the first three letters of the generic name followed by the first four letters of the species name of ground-dwelling predators. Vectors that are long and close to a particular axis in the biplot have a strong association with the axis. Examination of Fig. 1 indicated that the field at Helan is strongly associated with axis 2, while field at other locations are associated with both axes. The community of ground-dwelling predator at the wheat field ordinates in a distinctive quadrant of the biplot indicating that it differed from those at the other locations likewise the Guyuan field was distinctive. The Huinong and Wuzhong wheat field ordinated near each other, indicating greater similarity of the predator communities at those locations.



Variables are listed in their order of selection based on overall variance in the species-environment relationship accounted for by the variable.

Fig. 1. Redundancy analysis (RDA) of wheat growing regions and insect sampling sites.

Species of ground-dwelling predator located near the origin of the biplot axes are species that were associated with wheat fields at all locations; whereas, those located close to the end of a particular vector were strongly associated with the wheat fields at that location. *Pardosa astrigera*, *S. terricola* and *E. graminicolum* were recorded from all studied locations, but most of the species were recorded only from one or two locations. For example, *C. daimio* and *P. mongolicus* were strongly associated with Guyuan, while *Clubiona japonnicola* and *Trachelas japonica* investigated at Yanchi only.

Table II.- Species composition and diversity of wheat aphids, parasitoids, hyperparasitoids and predators in spring wheat fields collected during 2009-2012 in Ningxia Hui Autonomous Region, China.

Nutrition	Family	Gene	Species	Frequency
Parasitoids	Aphidae	*Aphidius*	*Aphidius avenae*	*****
			Aphidius gifuensis	***
			Aphidius sichuanensis	**
			Aphidius ervi	*
			Aphidius rapae	*
		Toxares	*Toxares* sp.	*
		Ephedrus	*Ephedrus persicae*	*
		Lysiphlebus	*Lysiphlebus confuses*	*
		Trioxys	*Trioxys asiaticus*	*
			Trioxys pallidus	*
		Praon	*Praon orientale*	*
			Praon volucre	**
			Praon rhopalosiphum	*
	Eulophidae	*Tetrastichus*	*Tetrastichus* sp.	**
	Aphelinidae	*Aphelinusal*	*Aphelinusal bipodus*	*
			Aphelinusal sp.	*
Specialist predators	Coccinellidae	*Hippodamia*	*Hippodamia variegata*	****
			Hippodamia tredecimpunctata	**
		Harmonia	*Harmonia axyridis*	****
		Coccinella	*Coccinella septempunctata*	**
			Coccinella transversoguttata	*
			Coccinella trifasciata	*
		Oenopia	*Oenopia conglobata*	*
		Coccinula	*Coccinula undecimpunctata*	*
			Coccinula quatuordecimpustulata	*
		Propylea	*Propylea japonica*	**
		Scymnus	*Scymnus bipunctatus*	*
	Syphidae	*Syphus*	*Syphus corollae*	**
			Syrphus nitens	**
		Episyrphus	*Episyrphus balteatus*	****
		Sphaerphoria	*Sphaerphoria cylindrica*	***
		Melanostoma	*Melanostoma scalare*	**
		Scaeva	*Scaeva selenitica*	*
			Scaeva pyrastri	*
	Chrysopidae	*Chrysopa*	*Chrysopa formosa*	**
			Chrysopa phyllochroma	*
			Chrysopa sinica	*
		Sympetrum	*Sympetrum Croceolum*	***
	Cecidomyoodae	*Aphidoletes*	*Aphidoletes abietis*	*
Generalist predators	Libellulidae	*Pantala*	*Pantala flayescenx*	**
		Sympetrum	*Sympetrum frequens*	*
	Aeschnidae	*Epophthaimia*	*Epophthaimia elegans*	*
	Asilidae	*Neomochtherus*	*Neomochtherus kozlovi*	*
		Promachus	*Promachus yesonicus*	*
	Nabinae	*Nabis*	*Nabis ferus*	*
			Nabis sinoferus	*
	Miridae	*Deraeocoris*	*Deraeocoris punctulatus*	**
	Lygaeidae	*Geocoris*	*Geocoris grylloides*	*
	Reduviidae	*Oncocephalus*	*Oncocephalus* sp.	*
	Anthocoridae	*Oris*	*Oris minutus*	**

Continued

Nutrition	Family	Gene	Species	Frequency
Omnivorous predators	Staphylinidae	*Staphylinus*	*Staphylinus maxillosus*	***
		Stenus	*Stenus tenuipes*	*
	Carabidae	*Calosma*	*Calosma maderae*	**
		Chlaenius	*Chlaenius pallipes*	****
			Chlaenius circumdatus	*
		Pterostichus	*Pterostichus gebleri*	*
		Scarites	*Scarites terricola*	***
		Dolichus	*Dolichus halensis*	**
			Dolichus halensis	*
		Pesudotaphoxenus	*Pesudotaphoxenus brevipennis*	*
		Corsyra	*Corsyra fusula*	*
		Nebria	*Nebria livida*	**
		Carabus	*Carabus* sp.	*
		Harpalus	*Harpalus crates*	***
			Harpalus calceatus	*
			Harpalus salinus	**
			Harpalus griseus	**
		Cymindis	*Cymindis binotata*	*
			Cymindis daimio	*
	Cicindelidae	*Cicindela*	*Cicindela elidae*	*
			Cicindela hybrida	**
			Cicindela raleea	*
	Lycosidae	*Pardosa*	*Pardosa astrigera*	****
			Pardosa laura	**
		Lycisa	*Lycisa coelestris*	***
			Lycisa sinensisi	**
			Lycisa erudita	*
			Lycisa pesudannulata	*
	Tetragnathidae	*Tetragnatha*	*Tetragnatha shikokiana*	*
	Agelenidae	*Agelena*	*Agelena opulenta*	**
	Gnaphosidae	*Gnaphosa*	*Gnaphosa kompirensis*	*
	Theridiidae	*Enoplognatha*	*Enoplognatha japonic*	*
		Theridionocto	*Theridionocto macutatum*	*
	Linypiidae	*Erigonidium*	*Erigonidium graminicolum*	****
		Erigone	*Erigone prominens*	****
	Araneidae	*Neoscona*	*Neoscona doenitzi*	*
		Argiope	*Argiope bruennichi*	**
		Araneus	*Araneus ventricosus*	**
		Singa	*Singa pygmaea*	**
			Singa hamata	**
	Clubionidae	*Clubiona*	*Clubiona japonnicola*	*
		Trachelas	*Trachelas japonica*	*
	Thomisidae	*Misumenops*	*Misumenops tricuspidatus*	***
		Philodromus	*Philodromus cespitum*	**
		Xysticus	*Xysticus ephippiatus*	***
			Xysticus striatipes	*
			Xysticus mongolicus	**

Note: ***** stands for the density of respective species with numbers >100; **** stands for the density of respective species with numbers >20, but ≤100; *** stands for the density of respective species with numbers >10, but ≤20; ** stands for the density of respective species with numbers >5, but ≤10; * stands for the density of respective species with numbers >1, but ≤5.

DISCUSSION

The density of ground-dwelling predators was relative high and ranged from 5.13 individuals per m^2 to 8.27 individuals per m^2 compared to Europe (Elliott *et al*., 2006; Garratt *et al.*, 2010). Ground-dwelling predator species were not uniformly distributed across the widely geographically separated spring wheat fields we studied in Ningxia Hui Autonomous Region. Particular species were associated more strongly with one or two locations. Whether the distribution of predators occurrence reflects the influence of regional differences in abiotic or biotic factors, or whether local factors are unknown (Elliott *et al*., 2002; Gardiner *et al*., 2010). Overall, our study indicated that there are differences in ground-dwelling predator communities in wheat fields, but did not confirm whether these differences were related to within-fields or surrounding habitats in the agro-environment.

Ground-dwelling predator densities in wheat field were variable among locations but were always high, averaging more than 5 individual per m^2 during the growing season (Lee *et al*., 2005; Leslie *et al*., 2009). Such high densities bring into question the extent to which ground-dwelling predators contribute to the biological control of cereal aphids and other pests in wheat field in Ningxia Hui Autonomous Region. In Europe, where ground-dwelling predator densities are typically lower, also observed in Ningxia, although densities as low as reported from America (Elliott *et al*., 2006; Zhao *et al*., 2013b). However, further research is required to evaluate the field performance of the recorded predators in wheat field of Ningxia and its neighboring provinces in biological control.

In the past a few decades, the landscape simplification caused by agricultural intensification has resulted in significant shift of ground-dwelling predators in agroecosystem (Zhao *et al*., 2015a). The changes of community structure have resulted in decreasing biocontrol services with biodiversity loss, which appear to have significant negative impacts on sustainable pest management. Our results suggest that ground-dwelling predators with a decreasing agro-chemical could sustain biodiversity of ground-dwelling predators, thereby contributing to biocontrol of pests in agroecosystem (Zhao *et al*., 2015b; Bianchi *et al*., 2010).

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