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GROUND BEETLES (COLEOPTERA: CARABIDAE) IN DIFFERENT AGROECOSYSTEMS OF SOUTHEAST KAZAKHSTAN

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SUMMARY

The recent study on ground beetles (Carabidae) was carried out in 2020 over five different agroecosystems, i.e., alfalfa, barley, corn, soybean, and triticale, at the Kaskelen Experimental Farm, Southeast Kazakhstan. Overall, 38 species of ground beetles related to 24 genera were identified. From these, the *Harpalus rufipes*, *Poecilus cupreus*, and *P. versicolor* were the dominant ones in the different agroecosystems. Most of the ground beetles are general predators and useful as entomophages. These beetles and their larvae exterminate various agricultural pests. However, the presence of *P. versicolor*and *P. cupreus* suggests a threat to the crops. Those species have a mixed diet and are also known as economically significant pests, of which the most famous is the ground beetle *Zabrus morio*. Different agroecosystems have shown different distributions of ground beetle species, indicating the influence of cultivated crops on the formation of the ground beetle community. Findings from the study could provide the basis for designing crop management programs after promoting the presence of ground beetles that can contribute to the prevention and control of agricultural pests.

Keywords: Ground beetles diversity, species distribution, crop management, pests, agro-ecosystems

Key findings: The data obtained can be used in the development of various pest control measures and the implementation of measures to ensure the timely elimination of pest foci. This quantitative study can provide the basis for managing the strategies that take advantage of the ecosystem services (bio-control) provided by the ground beetles community.

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INTRODUCTION

Beetles (Coleoptera) are one of the largest orders of insects (Ślipiński *et al.*, 2011) and play a vital role in various agroecosystems (Eyre *et al.*, 2013). Past studies highlighted the importance of many species of agricultural pests, that are also agents of biological control (Purchart and Kula, 2005; Bukejs and Balalaikins, 2008; Khomitskiy *et al.*, 2020). In summary, agricultural management determines ground beetle species distributions, size, dispersal ability, and life history (Ribera *et al.*, 2001; Bukejs, 2009; Nuzhnykh, 2009). Consequently, the management differences between crops are likely to influence the

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ground beetles' community structure. The dynamics of the interactions between generalist predators and their many pests and non-pest prey reviewed in the past studies (Symondson *et al.,* 2002; Babayan, 2022). They concluded that generalist predators, either alone or in assemblages, significantly reduced prey numbers. Carabid predation of pests in crops has been suggested as slowing early-season population increase and thereby, facilitating control by later-arriving specific predators and parasitoids (Scheller, 1984; Lestari *et al*., 2015). For example, carabid assemblages are considered important agents in the control of aphid populations in cereals in England (Lövei and Sunderland, 1996). The phenology of individual carabid species can influence their ability to colonize fields and contribute to the control of pest populations.

In addition, studying the dynamics of the number and distribution of the species composition of ground beetles within the community is necessary for a deeper understanding of the mechanisms of natural regulation (Medvid and Gavrilyuk, 2020). These regulatory mechanisms are crucial tools for the sustainability of crops, and the development of biological methods of pest control. In modern plant protection measures, the use of natural enemies and predators to suppress the number of pests is one of the most promising directions. Consequently, the study of their species composition is not only of practical importance but also a scientific necessity (Kazlauskaitė *et al.*, 2015; Halimov, 2020).

Ground beetle distribution in the wider environment is influenced by site productivity and disturbances in their natural ecosystem (Eyre, 2006). Indices reflecting these basic drivers were generated for the sample sites on the split management of the farm. Those farms were also surveyed to investigate an overall approach contrasting with the more usual work where efforts are concentrated on assessing limited and specific effects on ground beetles.

Investigations on the multiplication of Carabidae in the agroecosystems were performed in the Moscow Region and the Kuban Plane of Russia (Afonina *et al.*, 2001, 2010; Tshernyshev *et al.*, 2001, 2010; Timokhova, 2001; Bokhovko, 2006). An interesting review of this context was made by Gongalsky and Cividanes (2008) and focused on the questions of how the spatial heterogeneity of landscape influences carabid biodiversity, and what are the main factors causing this biodiversity across spatial scales. They found that soil factors, e.g.. litter depth, microclimate, and vegetation composition are the main factors within the biotopes.

Five different crops (alfalfa, barley, corn, soybean, and triticale) provided an opportunity to evaluate how different crops influence the diversity and distribution of the ground beetles. The main aim of the research work was to investigate the ecology of ground beetles in different agroecosystem. To do so, the ground beetles were sampled from the five different crop systems at the Kaskelen Experimental Farm, Southeast Kazakhstan. The research objectives were to determine the ground beetle's dominant species and their distribution under the environmental conditions of different agroecosystems in Southeast Kazakhstan.

MATERIALS AND METHODS

Study area and sampling

The recent study was based upon the observations carried out in 2020 at the Kaskelen Experimental Farm, District Karasai, Almaty region, Southeast Kazakhstan. Five different crops, i.e., alfalfa, barley, corn, soybean, and triticale were selected. All the selected crops represent grain plantings, fodder, and industrial importance for the economy of Kazakhstan. The collection of material and its processing were carried out using standard entomological methods, i.e., standard pitfall traps, light traps, and manual methods (Paliy, 1970). The data regarding the collection of ground beetles were gathered starting from the second day of May to September 2020 using Barber pitfall traps (Barber, 1931; Prisny, 1989). Taking into account the mobile part of the ground beetle population, the effectiveness of the pitfall traps method depends on the size of the traps (Waage, 1985; Koivula *et al.*, 2003), methods of their installation (Korczycski and Sienkiewicz, 2006), and the presence or absence of a fastener (Karpova and Matalin, 1992). Each trap was made of 0.5 l plastic cups with a mouth of 9 cm in diameter. The cup was filled to 1/4 capacity with 4% solution of formalin. In each culture, 10 trapping glasses were installed in one line. The distance between adjacent trapping containers was 2.5 m from each other. Various baits were used in the Barber's traps. Traps were exposed every seven days from first May till 30 September. Insects caught in the Barber's traps were selected from trapping containers using tweezers (Barber, 1931). Sampling with an 8

Table 1. The caught and species composition of Carabidae in the studied agroecosystems.

Taxon	Crops				
	Corn	Soybean	Triticale	Alfalfa	Barley
Acupalpis elegans	2	1	-	-	-
Agonum gracilipes	2	2	-	-	-
Agonum lugens	2	2	-	-	-
Agonum sexpunctatum	1	1	-	-	-
Amara aenea	6	6	2	5	-
Anchomenus dorsalis	3	1	-	4	-
Brachinus crepitans	2	1	1	4	-
Brachinus ejaculans	1	4		2	-
Broscus declivis	2	2	5	2	-
Calathus erraticus	-	6	-	2	-
Calathus halensis	2	1	1	5	-
Callistus lanatus	-	2	-	-	-
Calosoma auropunctatum	2	1	1	4	-
Calosoma denticolle	3	1	1	4	-
Carabus cicatricosus	2	1	1	4	-
Carabus cumanus	2	1	1	6	-
Carabus nemoralis	1	-	1	7	-
Chlaenius spoliatus	5	3	1	4	-
Cymindis picta	-	3	-	-	-
Ditomus calydonius oriens	2	-	-	3	-
Elaphrus cupreus	1	2	-	2	-
Elaphrus riparius	3	2	-	3	-
Harpalus smaragdinus	-	-	5	-	2
Harpalus rufipes	2	2	1	5	-
Lebia cruxminor	1	-	-	2	-
Loricera pilicornis	-	3	-	-	-
Nebria aenea splendida	5	9	-	7	-
Nebria psammophila	-	5	-	2	-
Notiophilus aquaticus	2	-	-	3	-
Poecilus cupreus	1	4	-	9	-
Poecilus versicolor	2	1	1	4	-
Pogonus punctulatus	-	-	-	5	-
Pterostichus niger	3	2	1	3	-
Pterostichus planicola	2	1	1	4	-
Scarites terricola	1	4	-	4	-
Tachys bistriatus	2	1	-	-	-
Zabrus morio	2	1	1	4	-
Total	67	76	25	113	2

W ultraviolet lamp was carried out from 15 May to 30 September; the hand sampling and sweeping with an entomological net were performed every day. The 283 specimens were caught (Table 1). Only images were taken into account during the identification of the material.

Data analysis

For statistical analysis, the quantitative data (total and relative abundances) on the distribution of the different species and genera of the ground beetles in the different crops were used. Total catch data for most of the common species were corrected and compiled and later subjected to linear models and multiple comparisons adjusted for variance heterogeneity. This approach allowed us to detect the differences in the average abundance and richness for each crop system. Statistical comparisons for the differences in ground beetle communities were restricted to crops where sufficient ground beetles were collected during the trapping window between May to September 2020, and all the treatments were sampled consistently. According to the commonly accepted system (Southwood, 1978), a taxon is considered dominant if it is represented by more than 5%

of the total: subdominants (5.1%–10.0%), dominants (10.1%–25.0%), and superdominant (>25%).

The data were processed using R version 4.0.2 (R Core Team, 2021). The data transformations and distance matrices were produced with the decostand and vegdist functions from the vegan package (Oksanen *et al.*, 2019). Heatmap was used to highlight the differences in community structure in the different crop systems using the gplots package (Goslee and Urban, 2007). Hierarchical clustering was performed with hclust (function Ward. D2) from core R package stats. For determining the significance of the different clusters, approximately unbiased (AU) p-values were obtained for the nodes of hierarchical clustering dendrogram using the R package 'pvclust' (Suzuki and Shimodaira, 2006).

Lastly, species abundance distribution (SAD) models were selected based on the species-rank curves for each crop system by ranking all species from the most to the least abundant (Magurran, 2013; Alroy, 2015; Matthews and Whittaker, 2015). The tested SAD models were, i.e., niche-preemption, lognormal, Zipf, Mandelbrot, and neutral-theory (null hypothesis). The Akaike information criterion (AIC) method was adopted to compare the different models, and the best model was indicated by the lowest AIC value and by the goodness-of-fit of curves as performed with the 'vegan' package (Oksanen *et al.*, 2019).

RESULTS

The analysis of the collected material revealed that in the different crops, the ground beetle community was mainly dominated by nine genera (Table 1). Those nine genera responded to more than 60% of the total abundance recorded, i.e., *Amara, Carabus*, *Poecilus*, *Nebriaaenea*, *Calathus*, *Calosoma*, *Harpalus*, *Pterostichus*, and *Brachinus* (Figure 1). Overall, the agroecosystem with alfalfa was observed with the highest number of ground beetles (Table 1). In the areas with alfalfa, the ground

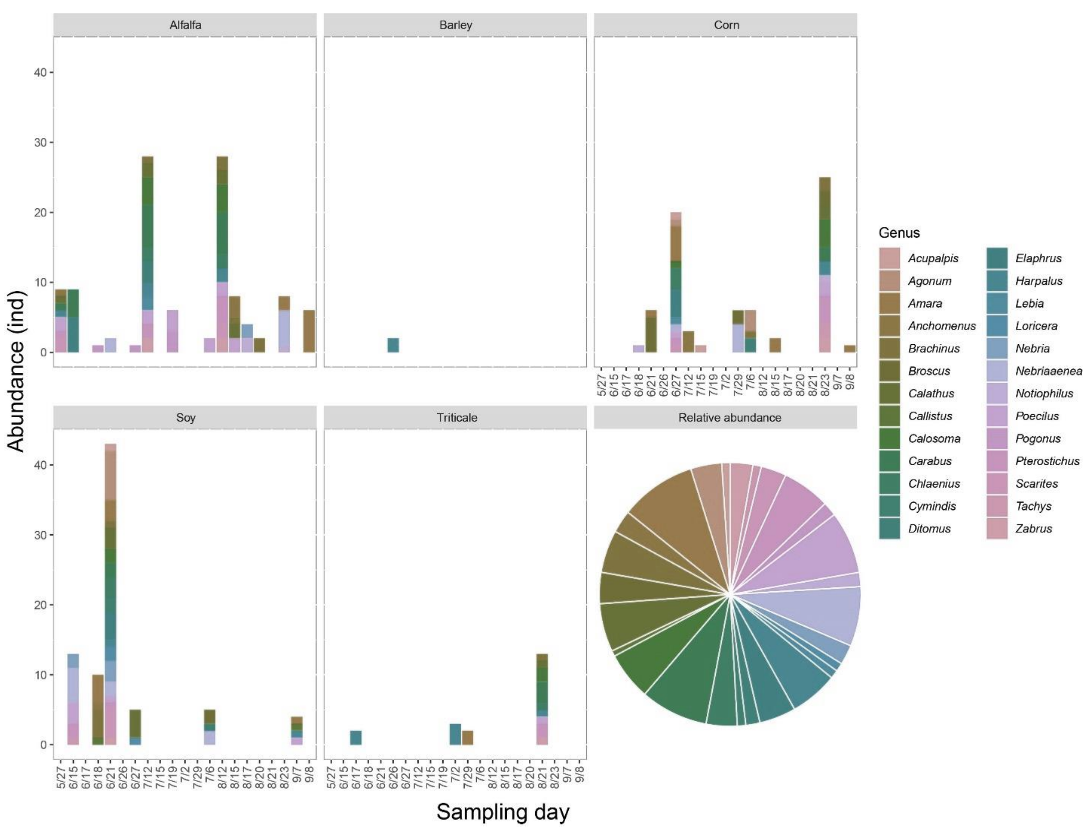

Figure 1. The abundance of different genera of ground beetles along the sampling period (a – e) and the abundance of the total sampling period under the different crops (f) at the Kaskelen Experimental Farm, Almaty, Kazakhstan.

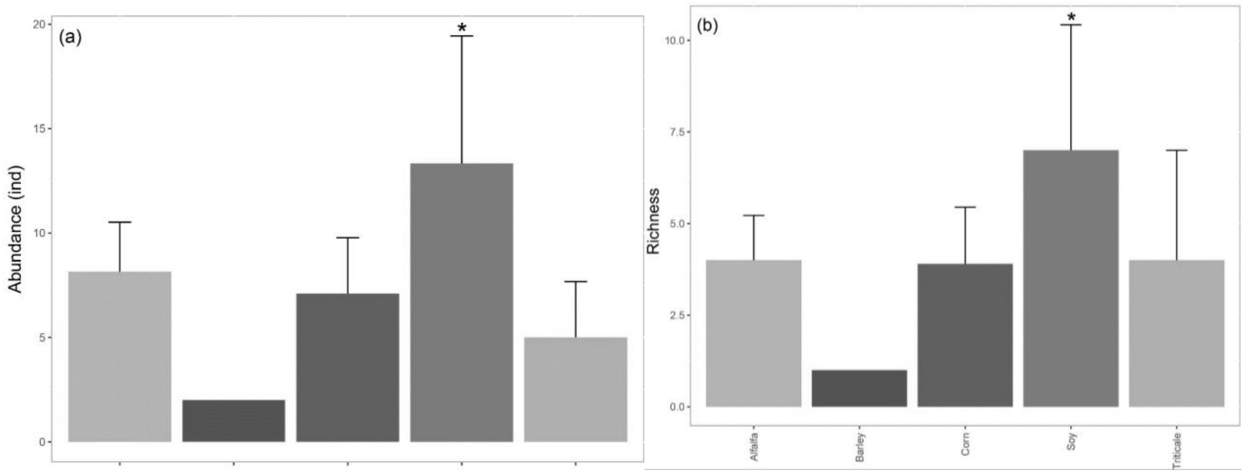

Figure 2. Average abundance (a) and species richness (b) of the different species of ground beetles (Carabidae) under the different crops at the Kaskelen Experimental Farm, Almaty, Kazakhstan. Average followed by a * differed significantly from the other systems according to the Tukey test at 5% probability.

beetles were found more often and the same was also authenticated by the different number of sampling days in which those organisms were collected.

The second ecosystem with a high number of ground beetles was the soybean (80 individuals in total (Table 1), however, here, more than half of these beetles were collected in a single day. In third place, the corn plantation presented a total of 71 ground beetles, however, they were more evenly distributed along the sampling period similarly as in the alfalfa system. In the triticale plot, a total of 20 ground beetles were collected, and more than half of them were observed in a single sampling day. Lastly, in the barley system, only two ground beetles of the genus *Harpalus* (*H*) were recorded throughout the whole sampling period. By recording so low abundance of ground beetles in the barley system, it was also kept out of all the other analyses. In total, as a result of the studies carried out in 2020 on the grain, fodder, and industrial field crops of the Kaskelen Experimental Farm, Almaty, Kazakhstan, the 38 species of ground beetles belonging to 24 genera were identified. Among the ground beetles, *H. rufipes*, *P. cupreus*, and *P. versicolor* were the dominant species in the different agroecosystems. The impact of different crops on the abundance and species richness of ground beetles (Carabidae) was also recorded (Figure 2). Overall, the soybean system presented the highest average for both abundance (Figure 2a) and species richness (Figure 2b). These findings are likely a consequence of the peak in abundance and diversity observed in a single day of our sampling interval.

Interestingly, the different species of ground beetles shared similar responses to the changes in crop systems. The clustering analysis of the species response identified seven different clusters with statistically significant support that allowed us to identify the ground beetles that responded similarly to the different agroecosystems at the Experimental station. The first cluster (C1) contained the different ground beetle species. i.e., *Amara aenea*, *Brachinus crepitans, Calathus halensis, Calosoma denticolle*, *C. auropunctatum*, *Carabus cicatricosus*, *Chlaenius spoliatus, Harpalus rufipes, Poecilus versicolor*, *Pterostichus planicola*, *P. niger*, and *Zabrus morio*. The second cluster contained the beetle species. i.e., *Scarites terricola, Brachinus ejaculans*, and *Elaphrus cupreus*. Cluster C3 contained only two species of ground beetles (*Anchomenus dorsalis* and *Elaphrus riparius*). Cluster C4 contained six species, three from the same genus (*Agonum gracilipes, A. lugens*, and *A. sexpunctatum*) and the other three belonged to different genera (*Acupalpis elegans, Tachys bistriatus*, and *Amara equestris*). For cluster C5, the two species of ground beetles were observed from the same genus (*Carabus nemoralis* and *C. cumanus*), along with a mixture of species from distinct genera (*Pogonus punctulatus*, *Lebia crux−minor, Ditomus calydonius*, and

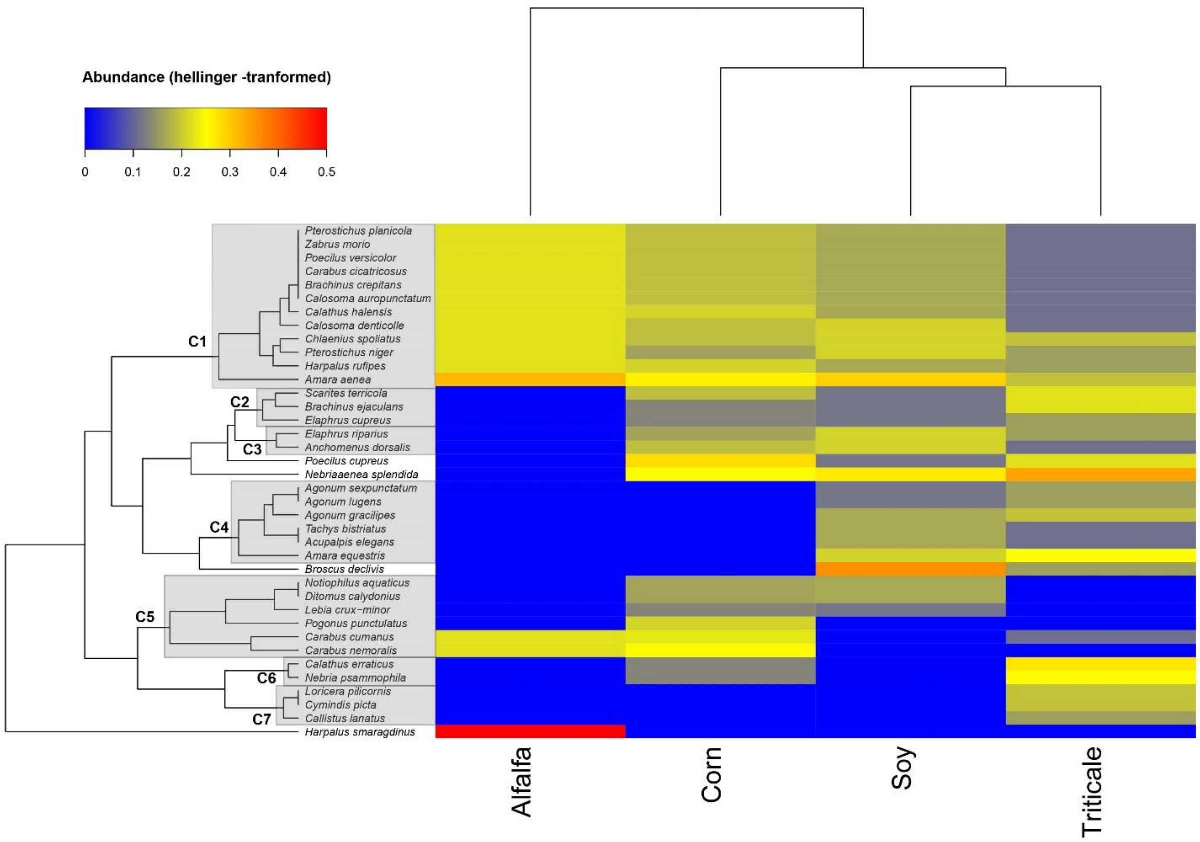

Figure 3. Heatmap showing the dissimilarity between the communities of ground beetles (Carabidae) according to the different crops at the Kaskelen Experimental Farm, Almaty, Kazakhstan. Species with a similar response to the different crops were also grouped (left cluster). Clusters with AU>95 are shaded in gray.

Notiophilus aquaticus). The last two clusters (C6 and C7) were small containing only two species (*Nebria psammophila* and *Calathus erraticus*) and three species (*Callistus lanatus, Cymindis picta*, and *Loricera pilicornis*), respectively. Therefore, the co-occurrence of certain groups of ground beetles is determined by the crop system.

The community structure and population of ground beetles also differed according to the different crops (Figure 3). The cropping system with the most distinct community was the alfalfa characterized by high dominance of *Harpalus smaragdinus*. This crop also presented a high abundance of the ground beetle species, i.e., *Amara aenea, Brachinus crepitans, Calathus halensis, Calosoma denticolle, C. auropunctatum, Carabus cicatricosus, Chlaenius spoliatus, Harpalus rufipes, Poecilus versicolor, Pterostichus planicola, P. niger*, and *Zabrus morio*. Soybean and triticale crops shared some similarities in the community structure of ground beetles.

These two agricultural systems presented a low population of *Harpalus smaragdinus*, however, only an ample population was also found in the alfalfa system. Additionally, in both the soybean and triticale systems, the species *Carabus nomoralis* and *C. cumanus* were not observed, however, the highest population of such species was found in both the alfalfa and corn systems. Similarly, the alfalfa and corn systems also presented a higher abundance of the species. i.e., *Acupalpis elegans*, *Agonum lugens*, *A. sexpunctatum*, *A. gracilipes*, *Amara equestris,* and *Tachys bistriatus*. However, these ground beetle species were not present in either the corn or the alfalfa systems. Ground beetle species *H. rufipes* and *Poecilus cupreus* prefer fields with cereal crops and perennial grasses. These species determine the high dynamic density of ground beetles in the indicated fields. The most dominant species of ground beetle in the fields of winter grain crops and alfalfa was *P. cupreus*, while *H. rufipes* occupied first place in terms of prevalence in these fields.

Different agroecosystems differed not only in the species diversity of beetles, but also in the characteristic quantitative distribution of species (Figure 4). In the alfalfa system, the community of ground beetles followed a lognormal distribution, whereas, in corn and triticale plantations, their abundances followed a Zipf distribution. No distribution model was found fit and suitable for the barley system due to the absence of ground beetles. The soybean also followed a distinct distribution as compared to other systems (Preemption). Therefore, it is concluded that different crop systems interfere in the assemblage of the ground beetles community.

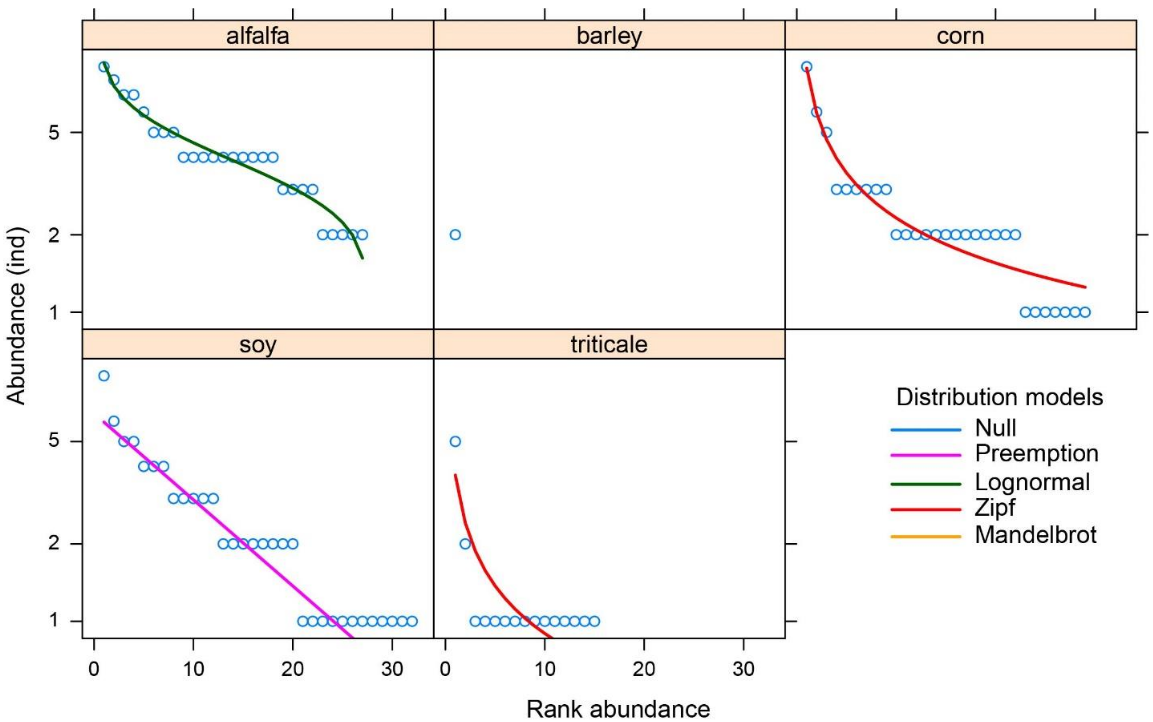

Figure 4. Distribution models that explain the rank abundance of the different ground beetle species (Carabidae) under the different crops at the Kaskelen Experimental Farm, Almaty, Kazakhstan. Distribution models were selected based on the smaller value of AIC.

DISCUSSION

Ground beetles are biologically very diverse (zoophages, phytophages, saprophages, and necrophages) and are small (1.5–5 mm) to large (up to 5 cm) size insects (Kryzhanovsky, 1983; Lera and Nauka, 1989). These insects belong to a large order of coleopteran, numbering about 2,500 species in the fauna of the former USSR, 1,000 species in Kazakhstan, and about 525 species in the Almaty region of Kazakhstan. Most of the species are predators, however, there are species with mixed feeding and phytophages. Among them, there are many entomophages, few species are agricultural pests (Kryzhanovsky, 1974; Erwin et al., 2005; Arndt *et al.*, 2016).

Being the most important component of the soil mesofauna, ground beetles form integral complexes that depend on soil-plant and microclimatic conditions and their vital role as regulators of the soil invertebrates in agroecosystems. In the recent study, the number of beetles captured changed over time and was associated with the climatic conditions and irrigation technology used in the fields of the Kaskelen Experimental Farm, Almaty, Kazakhstan. Another reason for the large changes in species composition, diversity, and the highest number of ground beetles in the studied districts might be the farming management without the use of insecticides. This factor contributes significantly to the preservation of both the entomofauna, in general, and the ground beetles, in particular (Fasulati, 1971).

The study noted most of the ground beetles were omnivore predators, i.e., *Anchomenus dorsalis*, *Brachinus crepitans*, *B. ejaculans*, *Calathus halensis*, *C. erratus.*, *Calosoma auropunctatum*, *C. denticolle*, *Carabus cicatricosus*, *C. cumanus*, *C. nemoralis*, and *Chlaenius spoliatus*. These beetles and their larvae are useful entomophages. Therefore, their presence in the different agroecosystems suggested potential protection against various pests of agriculture.

The study also observed the presence of *Harpalus rufipes* was observed in four crops (alfalfa, corn, soybean, and triticale), and *H. smaragdinus* was the most dominant species in alfalfa. *H. rufipes* has a mixed feeding, sometimes harms plants and also eats unripe grains of wheat and other cereals. The small harm caused is largely regained by the fact that this ground beetle eats nodule weevils, the larvae of owlet moths, and many other pests. On the other hand, *H. smaragdinus* feeds mainly on plant food and can harm cereals by gnawing seeds at the germination stage. *H. smaragdinus* eats inactive development stages of small and medium-sized species of insect pest eggs, larvae, and pupae. This suggests a potential for managing these two ground beetles species to promote the biocontrol of agricultural pests in the four crops (Saypulaeva, 2015).

Poecilus versicolor and *P. cupreus* have a mixed feeding, sometimes harming various cultivated plants, mainly in spring during dry weather, when beetles gnaw succulent shoots to restore the body's water balance. Among phytophagous and mixophagous ground beetles, there are economically significant pests in which the most famous is the carabid beetle, *Zabrus morio*. It feeds on seeds of wild and cultivated cereals. Beetles can seriously harm crops and pastures by eating grains from the spikes. They also feed on seeds of cereals of milky and waxy ripeness. Consequently, the presence of *Z. morio* in alfalfa, corn, and soybean systems poses a threat to their productivity.

Pterostichus niger and *P. splanicola* are entomophages. They feed on worms, older larvae, and pupae, as well as, other invertebrates. Studies showed their potential application as biocontrol agents due to their capacity to exterminate a large number of agriculture and forestry pests (Fasulati, 1971). The study results also suggested that in the grain, fodder, and industrial field crops at the Kaskelen Experimental Farm, Almaty, Kazakhstan,the predatory insects may be able to regulate pests. Species abundance distribution (SAD) is a simple and powerful approach for describing the variation among the individuals of the species within a given ecological community (McGill et al., 2007; Magurran, 2013; Alroy, 2015).

The niche preemption model was found as best suited to explain the ground beetle species abundance distribution in soybean fields. The niche preemption distribution appears when there is a larger proportion of common species and a lower proportion of rare species (non-uniform distribution) (Magurran, 2013; Villa *et al*., 2018). For two crops (corn and triticale), the Zipf model was identified as the best model to explain the ground beetle's distribution. According to Gibb *et al*. (2013), the Zipf model was best suited when the frequency of any species is inversely proportional to its ranking. The Zipf model is the descriptive model and suggests that neutral mechanisms were responsible for the assemblage of ground beetles in these two crops (Tokeshi, 1993). However, multiple mechanisms can also result in the same distribution (McGill *et al.*, 2007). Lastly, the ground beetle community in the alfalfa field followed a log-normal distribution, thus, suggesting that most of the species were relatively rare and only some of them were common (McGill *et al.*, 2007; Borda-de-Água *et al.*, 2012; Matthews and Whittaker, 2015). The observed SAD patterns corroborated with the idea that the different crop systems shaped the ground beetle's community diversity and structure, and suggest an impact on niche resource distributions (McGill *et al.*, 2007).

Crop type had the most influence on ground beetle assemblage composition and richness on the Kaskelen Experimental Farm, Almaty, Kazakhstan. Improvements in the generation of rankings based on factors such as disturbance and productivity may be one way of understanding underlying influences in structurally different crops, sown at different times, and in adjacent non-crop habitats. This approach may also be of use in explaining invertebrate distribution and activity at larger scales (Gabriel *et al.*, 2010), where landscape complexity indices could be simplified, leading to a greater understanding of the provision of ecosystem services by predators, given the restricted knowledge of the efficacy of invertebrate predation on crop pests (Firbank *et al.*, 2013).

CONCLUSIONS

Ground beetles are important components of agroecosystems and play a significant role in the control of insect pests. The species composition and importance of predators in the regulation of the agroecosystems main pest number in Kazakhstan have not been sufficiently studied. Therefore, the data obtained can be used in the development of pest control measures and in the implementation of measures to ensure the timely elimination of pest foci. The approach used in the recent study demonstrated a basis for species abundance distribution in crops, which can be used for the identification of key species (e.g., common and rare) that work as biocontrol agents. This study concluded that the higher species abundance in soybean fields responded to the niche preemption models of SAD. Subsequently, the species abundance distribution tends to have a more uniform distribution, fitting the lognormal model. Thus, the research determined the variation in species abundance distribution throughout the different crops. The said quantitative study can provide the basis for management strategies that take advantage of the ecosystem services (e.g., bio-control) provided by the ground beetles community.

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