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Patterns in the horizontal structure of litter invertebrate communities in windbreak plantations in the steppe zone of the Ukraine

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Abstract: The article analyses the patterns in the horizontal structure of litter invertebrate communities in windbreak plantations in the Steppe zone of the Ukraine. The number of invertebrate species shows statistically insignificant changes depending on the extent of the litter horizon development. With an increase in litter mass from 300 to 900 g/m^2 the number of invertebrate species increases. An increase in the total number of macrofauna is observed in areas having a minimum and maximum thickness of the litter layer. Maximum values in the Shannon diversity index were observed in areas with sparse litter (50–150 g/m^2). An observed increase in the variety of macrofauna species were seen where there was sparse grass cover in windbreak planted areas. The total number of litter invertebrate individuals related to the percentage of projective cover of herbaceous plants shows a significant increase in plots with 20–28% cover, though this factor does not affect the number of Aranei, Carabidae, and Staphylinidae. There is a decrease in the number of litter invertebrate species in areas with higher numbers of *Lasius platythorax* Seifert, 1991, while there is an insignificant change in the overall numbers of macrofauna. The abundance of *Myrmica scabrinodis* Nylander, 1846 does not show a significant influence on the number of litter macrofauna species. The minimum values of the Shannon biodiversity index for macrofauna were registered in plots with maximum numbers of *M. scabrinodis*. With an increase in the abundance of ants, the abundance of litter saprophages and phytophages decreases. There are also significant changes in the dominance structure of other taxonomic groups. Biotic factors have greater significance for the horizontal structure of litter macrofauna of steppe plantations than abiotic factors.

Key words: distribution structure of populations, diversity, forest plantation ecosystems, litter invertebrates

Introduction

Maintaining biological diversity of anthropogenically transformed ecosystems in the Ukraine's steppe zone is not possible without a sufficiently high preservation level of the forest plantation animal populations. The communities of litter invertebrates of windbreak plantations are a highly complex and changeable system. The structure is defined by factors external to this community (texture and moisture of the soil, the type of plant community, intensity of anthropogenic pressure) and by the internal structure of the litter invertebrate communities (Bird *et al*. 2000; Jukes *et al*. 2001; Taboada *et al*. 2010; Brygadyrenko *et al*. 2012).

The priority in our research into the litter invertebrates of the Ukraine's steppe zone windbreak plantations was the distribution of certain species, particularly the pests of agricultural crops and forest plantations. The peculiarities of the trophic structure of forest plantation communities in the steppe zone have only been analysed in recent years (Komarov and Brygadyrenko 2011; Korolev and Brygadyrenko 2012). However, the distribution structure of litter macrofauna communities in most types of forest plantations in the Ukrainès steppe zone has been insufficiently studied.

The dominant tree species, as defined by distribution, in the windbreak plantations of the Ukraine's steppe zone are *Robinia pseudoacacia* L. and *Fraxinus excelsior* L. They are the best adapted to conditions of insufficient moisture. In forest plantations, various communities of litter invertebrates are formed which are not significantly different from communities in natural forests (Malaque *et al*. 2008). The study of invertebrate distribution regularities in the forest ecosystems of the Ukraine's steppe zone has not only scientific, but also practical value for controlling the numbers agricultural crop pests in areas adjacent to windbreak plantations (Bird *et al*. 2000; Brygadyrenko and Komarov 2008; Kozłowski and Kozłowska 2008; Meena *et al*. 2013; Trzciński and Piekarska-Boniecka 2013).

Each particular plantation has its own specific mosaic of humidity and light conditions, and mosaic distribution of plants and different food resources available to the macrofauna. This patchwork of ecological conditions permits the coexistence in a single site of a variety of species of invertebrates, including those competing for the same

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trophic resources, and also predators and their prey (Bonham *et al*. 2002; Ferguson and Berube 2004; Kozłowski and Kozłowska 2008; Barsoum *et al*. 2013). The litter of a forest plantation is a specific environment, to which the animal population is inextricably connected not only trophically, but also distributionally. Variations in the various characteristics of litter invertebrate communities depend upon edaphic factors (mass and humidity of the litter), which in turn provide the conditions for the food base for most groups of macrofauna (Fuller *et al*. 2008; Winter and Möller 2008; Sobek *et al.* 2009). The thickness of the litter horizon determines the degree of preservation of the soil moisture from evaporation in conditions when forest ecosystems geographically, and often ecologically, do not harmonise with the particular conditions of their localities.

Thus, it is interesting to research the peculiarities of litter macrofauna formation against the background of: anthropogenic factors of different intensity, the degree of influence of abiotic, and mediated biotic environmental factors (spatial structure of plantations, degree of development of the litter horizon, density of the grass stand and tree layer, and the influence of dominant groups of predatory invertebrates, for example Formicidae) on the distribution of different functional litter-macrofauna groups.

The first objective of our research was to determine the distribution regularities of litter invertebrates in forest plantation plots in the Ukraine's steppe zone. The second objective was to determine the influence of the thickness of the litter layer in the herbaceous layer. The third objective was to determine the abundance of the commonest species of ants on the basic characteristics of litter macrofauna communities.

Materials and Methods

The collection was carried out 10.08.2013, on the territory of a windbreak plantation located 5 km to the south of Dnipropetrovsk (Ukraine). In the studied plantation the dominant trees were *Acer negundo* L., *A. tataricum* L., *Fraxinus lanceolata* Borkh., and *F. excelsior* L. The shrub layer in the studied community was not significantly represented (density of cover 15%): *Euonymus verrucosus* Scop., *Swida* sp. In the herbaceous layer the dominant plants were *Impatiens parviflora* L., *Viola odorata* L., *Geum urbanum* L., *Torilis japonica* (Houtt.), *Anthriscus sylvestris* (L.) Hoffm., *Ballota nigra* L., and *Urtica dioica* L. The plantation was about 65 years old.

The method of manual investigation of the litter was used to count the invertebrates. An overall plot of 60 m^2 (5 × 12 m) was divided into quadrats of 1 × 1 m using twine and stakes. The plots to be counted were subjected to minimal interference, and this only on the periphery. The 1 m^2 plots were dissimilar in: litter mass (75–865 g/m^2), the number of species (3–11), density of the herbaceous layer (1–28%), and cover percentage of juvenile and immature trees and bushes (0–17%).

Before collecting litter, we measured the plant cover of each 1 m^2 plot, including the percentage of cover for each of 17 species of herbaceous plants and of the juvenile and immature stages of six species of bushes and four species of trees. Before investigating the litter, the above-ground parts of herbaceous plants were carefully removed using pruning shears, taking care to disturb the litter horizon as little as possible to avoid causing vertical or horizontal migrations of the litter macrofauna.

The litter together with the aerial parts of plants were hand collected and placed on polythene sheets. Then, half a minute to one minute later they were transferred to a table equipped for sifting, making sure that no invertebrate individual was lost because all would be used for further analysis. The litter samples were sifted through a sieve 60 × 60 cm with openings 2 cm in diameter, to extract the greater part of the larger plant fragments. After this, the larger plant fragments were rechecked for any remaining invertebrates, put in plastic bags and air dried in the laboratory.

The sifted litter, composed of finer fragments, was collected in plastic bags, carefully transferred to the laboratory, where on the same day all the macrofauna individuals were taken out and put into test tubes with 70% ethanol. Over a period of one week, this finer grained part of the litter was air dried, recombined with the coarser grained part which had been collected on the same 1 m^2 plot, and was weighed to an accuracy of 1 g.

For the evaluation of litter invertebrate diversity, the most commonly applied indexes (Shannon and Weaver 1949; Pielou 1977) were used. The statistical analysis of the results was conducted through the Statistica 7.0 programme package. The differences between selections were estimated using analysis of variance (ANOVA), they were considered accurate at $p < 0.05$. The diagrams show the median, 25–75% quartiles, maximum and minimum values, and in exceptional cases extremes.

Results

The dominant block in the trophic structure of litter communities in forest plantations in the Ukraine's steppe zone is formed by predatory groups of invertebrates. The most numerous in the studied area were Carabidae, Lycosidae, and Formicidae. The numbers of Julidae, Isopoda, Silphidae, and Staphylinidae, which are typical for natural forests on the Ukraine's steppe zone, are not as high in artificial windbreaks.

The number of invertebrate species changes insignificantly in relation to the extent of the litter horizon development (Fig. 1A). In the areas with low litter mass (50–150, 151–300 g/m^2), the number of litter macrofauna species varies between 3 to 12 species/m^2. The insignificant increase in the number of species in the areas with poorly developed litter is explained by an increase in the share of species which inhabit grassy areas: in areas with poorly developed litter the projective grass coverage also increases. Lack of moisture in the plantation forests of the Ukraine's steppe zone makes litter invertebrates migrate to limited areas with optimal humidity. These are usually depressions in the microrelief which have a denser layer of litter (Fig 1A). There is a gradual increase in the number of invertebrate species as the litter mass rises from 300 to 900 g/m^2. Typical saprophage species dominate:

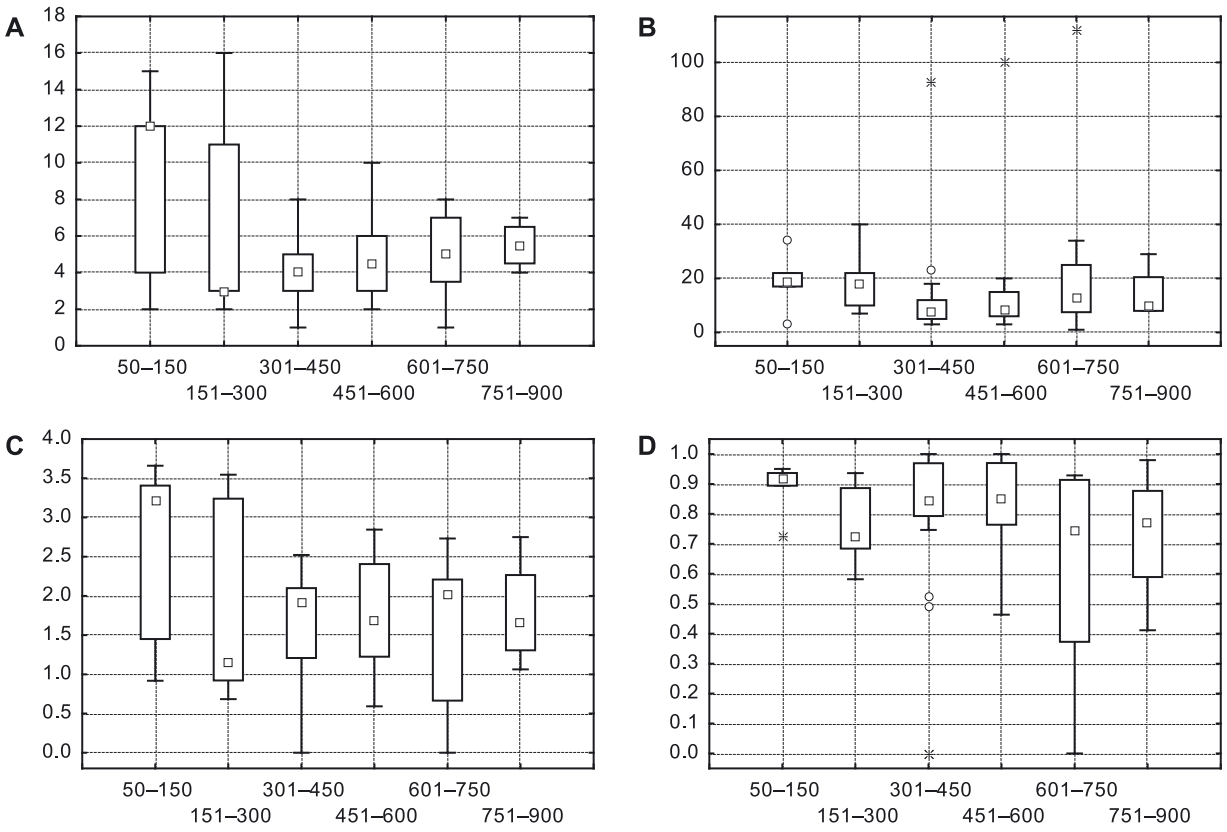

Fig. 1. Basic characteristics of litter invertebrate communities of plantation forest ecosystems in the steppe zone of the Ukraine in relation to the thickness of the litter: A – number of species, B – total number of invertebrates (individuals/m²), C – Shannon index (bits), D – Pielou index (bits); abscissa – dry mass of litter (g/m²), ordinate – value of the characteristic

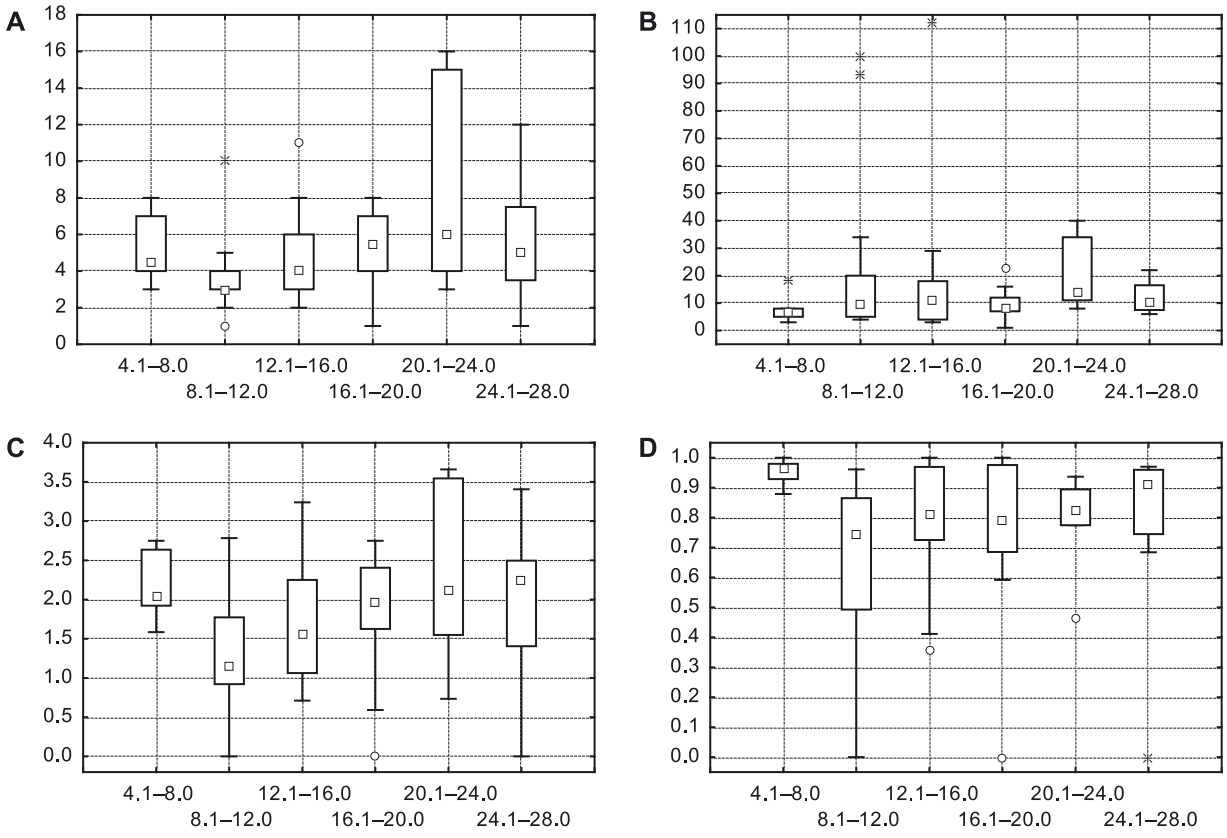

Fig. 2. Basic characteristics of litter invertebrate communities of plantation forest ecosystems in the steppe zone of the Ukraine in relation to the density of the herbaceous layer: A – number of species, B – total number of invertebrates (individuals/m²), C – Shannon index (bits), D – Pielou index (bits); abscissa – density of herbaceous layer (%), ordinate – value of the characteristic

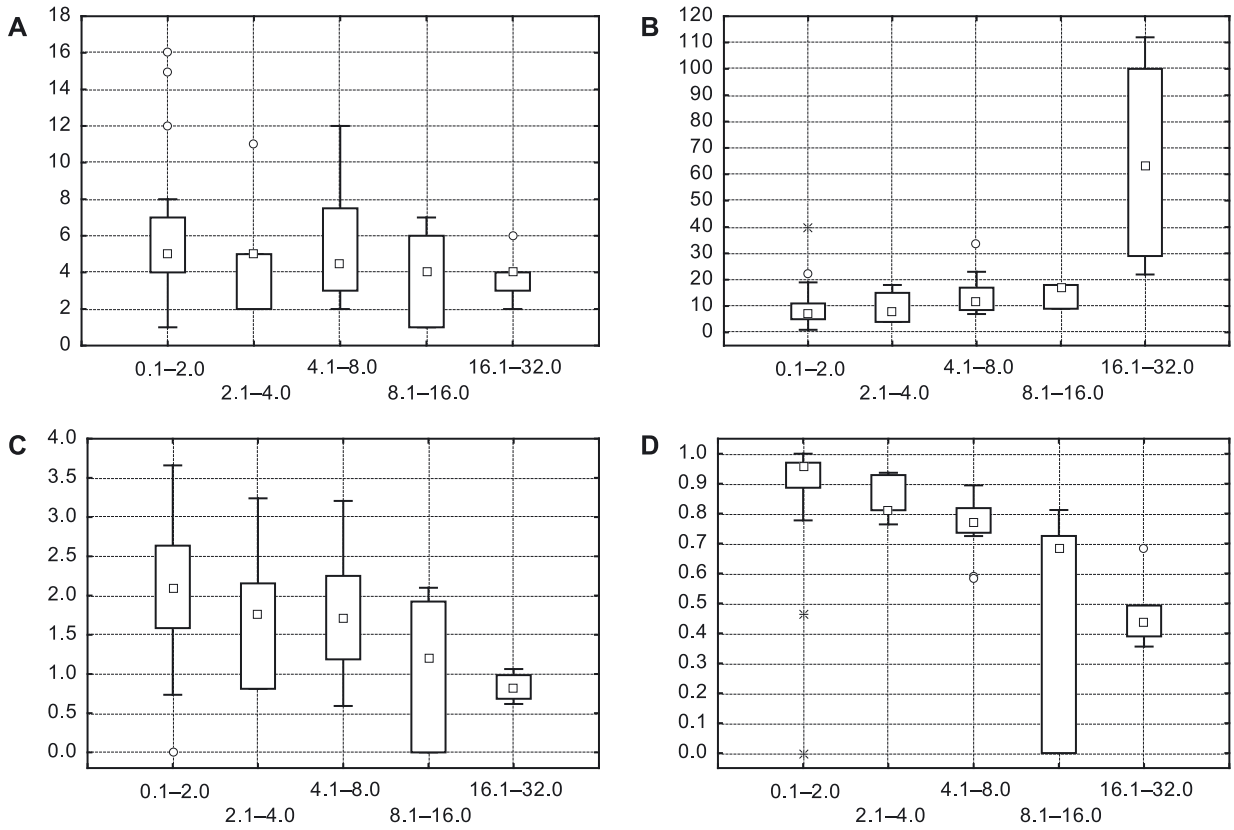

Fig. 3. Basic characteristics of litter invertebrate communities of plantation forest ecosystems in the steppe zone of the Ukraine in relation to the abundance of *Lasius platythorax* Seifert: A – number of species, B – total number of invertebrates (individuals/$/m^2$), C – Shannon index (bits), D – Pielou index (bits); abscissa – abundance of *L. platythorax* (individuals/m^2), ordinate – value of the characteristic

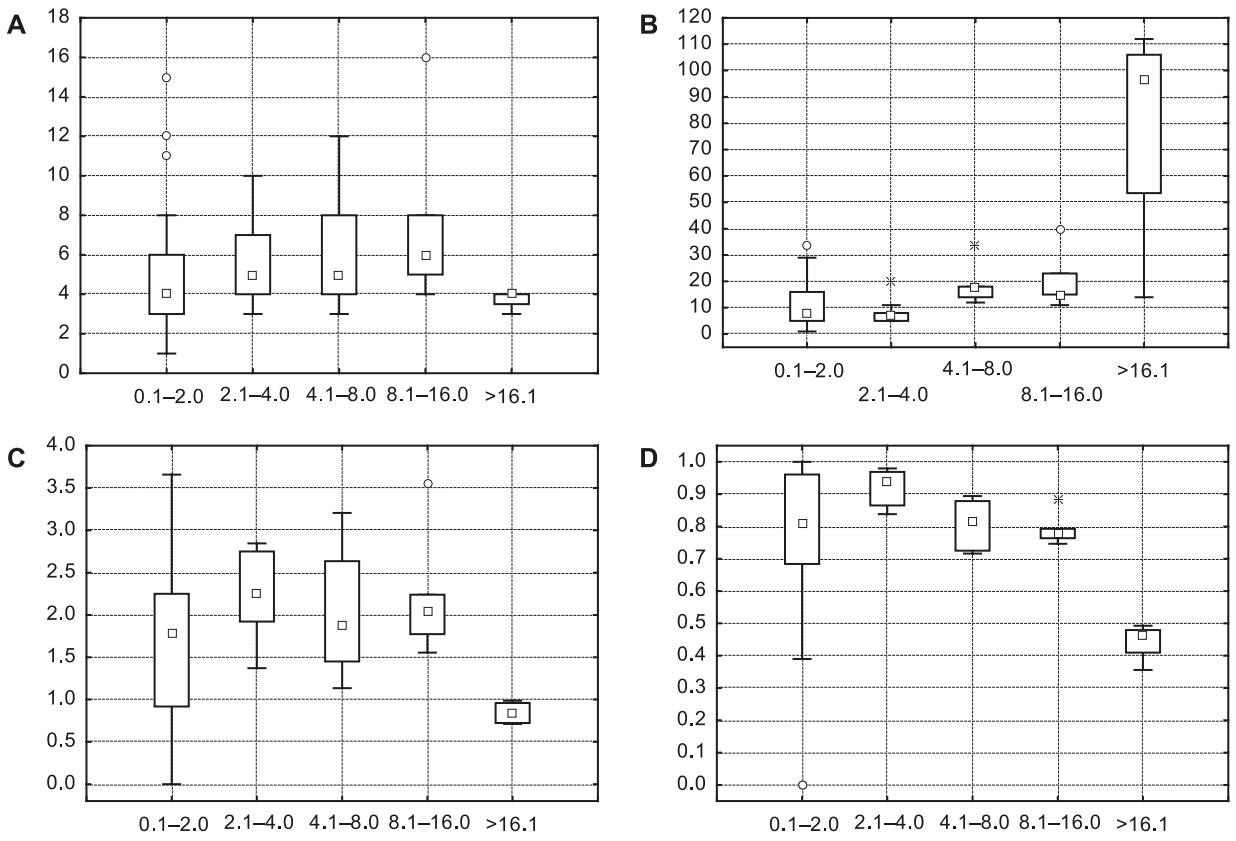

Fig. 4. Basic characteristics of litter invertebrate communities of plantation forest ecosystems in the steppe zone of the Ukraine in relation to the abundance of *Myrmica scabrinodis* Nylander: A – number of species, B – total number of invertebrates (individuals/$/m^2$), C – Shannon index (bits), D – Pielou index (bits); abscissa – abundance of *M. scabrinodis* (individuals/m^2), ordinate – value of the characteristic

Armadillidium vulgare (Latreille, 1804), *Porcellio scaber* Latreille, 1804, *Rossiulus kessleri* (Lohmander, 1927), *Turanodesmus dmitriewi* (Timopheev, 1897), and *Lumbricus* sp.

Statistically significant increases in the total number of invertebrates (df1 = 5, df2 = 54, F = 2.59, $F_{0.05}$ = 2.37, p = 0.04) were observed in areas with minimum and maximum litter thickness (Fig. 1B). The dominance structure of a multispecies community is presented using biological diversity indexes, which are expressed in bits. The Shannon diversity index measures the relative abundance of species in the litter macrofauna as well as the overall number of species for each 1 m^2 plot. Maximum values for this indicator (3.2 bits), showing an absence of dominants among the litter invertebrates, were obtained in areas with low-litter mass (50–150 g/m^2). With an increase in litter mass, the values on the Shannon and Pielou indexes did not show a significant change (Fig. 1C, D).

The herbaceous layer is just as important a factor affecting the distribution of litter macrofauna. Where there was sparse grass cover in a windbreak plantation, we observed a statistically unreliable increase in species diversity. Absence of the required shade and humidity together with an impoverished food base, causes horizontal (to adjoining areas with a higher level of humidity and a thicker litter layer) and vertical (through cracks in the upper soil horizon) migrations of invertebrates. With an increase in the grass stand density, the number of species shows a statistically unreliable increase on account of the presence of grassland specialists (*Coccinella septempunctata* (Linnaeus, 1758), *Adalia bipunctata* (Linnaeus, 1758), *Chrysolina fastuosa* (Scopoli, 1763), *Cassida nebulosa* Linnaeus, 1758, *Nabis ferus* (Linnaeus, 1758), *Pentatoma rufipes* (Linnaeus, 1758), *Graphosoma italicum* (Müller, 1766), and *Cicadellidae* sp.)) (Fig. 2A). The total number of litter invertebrates when related to the percentage of projective cover of herbaceous plants, showed a statistically significant increase in plots with 20–28% density (df1 = 5, df2 = = 54, F = 3.07, $F_{0.05}$ = 2.39, p = 0.02) (Fig. 2B). However, this factor does not affect the abundance of certain groups of zoophages (Aranei, Carabidae, Staphylinidae).

The Shannon diversity index reaches its maximum values in the plots with the highest number of macrofauna species (Fig. 2C). The increase in density of the herbaceous layer did not significantly influence the diversity of macrofauna. The median of the Pielou index (Fig. 2D) also showed a statistically insignificant increase (from 0.76 to 0.94 bits) as the density of the herbaceous layer increased from 8 to 28%.

The degree that ants influence particular functional and taxonomical groups of macrofauna in certain forest plantations is conditioned by the species affiliation and numbers of Formicidae. Litter invertebrates of different taxa in the forests of the Ukraine's steppe zone do not react identically to changes in the abundance of ants. The influence of Formicidae is at its greatest with the distribution of generalist zoophage groups (Carabidae and Lycosidae). Certain saprophage groups (Juliae and Lygaeidae) are resistant to the influence of ants. Some species of ground beetles easily tolerate high numbers of ants (Brygadyrenko 2005) or even increase their populations in the proximity of ant-hills (*Amara similata* (Gyllenhal, 1810), *Harpalus rufipes* (De Geer, 1774)).

As classified by type of diet, the ants belonging to the *Lasius* family are zoonecrophages (their source of protein is dead insects, their source of carbohydrate is the faeces of aphids). The biology of most of these species has been insufficiently studied. *Lasius platythorax* Seifert, 1991 is a litter invertebrate, its nests are hemispherical in form, the passageways are 10 cm deep. The number of inhabitants of the nest is comparatively low. This species which is typical for steppe forests in the Ukraine is not uncommon in urbanised areas.

The number of litter invertebrate species in areas with a higher number of *L. platythorax* showed an insignificant decrease (df1 = 4, df2 = 55, F = 19.99, $F_{0.05}$ = 2.54, p = 3.29 × × 10^{-10}) (Fig. 3A). The data showing changes in the total number of macrofauna is statistically significant (Fig. 3B). Maximum indicators (median – 2.1 bits) in the Shannon index are registered in plots with the highest number of macrofauna species, which corresponds to minimum numbers of *L. platythorax* (df1 = 4, df2 = 55, F = 4.80, $F_{0.05}$ = = 2.54, p = 0.01) (Fig. 2C). The Pielou index showed a significant decrease (df1 = 4, df2 = 55, F = 10.41, $F_{0.05}$ = 2.54, p = = 2.38 × 10^{-6}) in forest plantation plots where this Formicidae species dominated (Fig. 3D).

Myrmica scabrinodis Nylander, 1846 is an ant grassland specialist, whose workers generally forage in the herbaceous layer. They are found in moderately humid habitats. Their nests are made in the soil, in remains of trees, under the bark, and at the bases of bushes and trees. In the Ukraine's steppe zone their numbers are often high.

During our studies we did not receive significant data on the influence of *M. scabrinodis* on the number of litter macrofauna species. The overall number of invertebrates showed a significant increase only on plots with a maximum concentration of this ant species (Fig. 4A, B). A significant change in the Shannon and Pielou indexes (df1 = 4, df2 = 55, $F_{0.05}$ = 2.54, F = 2.70, p = 0.04; F = 3.20, p = = 0.02, correspondingly). Minimum readings on the biodiversity indexes (0.90 and 0.44 bits) were taken from test plots where the numbers of *M. scabrinodis* exceeded 16.1 individuals/m^2 (Fig. 4C, D).

With an increase in the number of ants, the number of litter saprophages and phytophages decreases, and significant changes in the dominance structure of other taxonomical groups were also observed.

Discussion and Conclusions

Litter macrofauna communities are more closely tied to the density and humidity of the litter horizon than to the age and species composition of a plantation. Research has been done with an aim an determining the connection between the extent of the development of the litter horizon and macrofauna species diversity in forest plantations (Pearce and Venier 2006; Cameron and Leather 2012; Oxbrough *et al*. 2005, 2010, 2012). In most cases, this research has shown significant changes in the basic characteristics of the structure of litter invertebrate communities in plots with different litter humidity, litter thickness, and species composition in the plantations. According to our re-

search, the number of litter invertebrate species and their abundance in the litter of steppe forests, increases with litter mass (ranging from 300–900 g/m^2). An insignificant increase in species diversity was observed for conditions of significantly thinned-out herbaceous cover in forest plots. With an increase in grass-stand density, the total number of litter invertebrates showed a reliable increase. The result of our study upheld the conclusions of other researchers about the heterogeneity of the litter macrofauna in conditions of varying herbaceous and tree layer densities (Reynolds *et al*. 2003; Halaj *et al*. 2008; Schuldt *et al*. 2008).

The influence of ants on certain functional and taxonomical groups of macrofauna in forest plantations is conditioned by the species structure and abundance of Formicidae (Dlussky 2001; Włodarczyk *et al*. 2009; Slipinski *et al*. 2012). The interspecific hierarchy in ant communities causes the formation of a mosaic structure in the locations of nests of the dominant species. As a result of these changes, the nests of subordinate species are also relocated. In multispecies ant communities, the morphological polymorphism of individuals within a family also increases (Dlussky 2001; Marko *et al*. 2004; Moron *et al*. 2008). It was only on six out of the 60 plots studied in our research (10%) that high numbers of *M. scabrinodis* and *L. platythorax* were observed simultaneously (more than 15 individuals/m^2 for each species). Ants played a significant role in dispersion of the seeds of herbaceous plants and trees on the study plots, which greatly accentuates irregularities in the abundance of herbaceous plants in windbreak study plots (O'Grady *et al*. 2013).

The species of ground beetles which have been studied in laboratory conditions, often eat ants of the *Formica*, *Lasius* and *Myrmica* families (Komarov and Brygadyrenko 2011; Korolev and Brygadyrenko 2012). Despite this fact, these beetles turned out to be much more scarce near the ant-hills than in areas with average populations of Formicidae. This can be explained by competition and by the occasional consumption of ground beetles by the ants (Hawes *et al*. 2013), but also by the disturbance experienced by the beetles as a result of frequent encounters with ants. In the course of our laboratory experiments, large species of ground beetle species of the *Pterostichus* family could eat more than 10 ants of the *Lasius* and *Myrmica* families in 24 h, yet the ants cannot be considered as the staple diet of the beetles (Komarov and Brygadyrenko 2011; Korolev and Brygadyrenko 2012). The elimination by ants of the food base of ground beetles, the continuous disturbance the ants cause, and the effect of formic acid on the integument of many predatory invertebrate species cause the decrease in beetle abundance near ant hills.

In the forest community analysed in this research, the number of species of litter invertebrates significantly decreased as the numbers of *L. platythorax* increased. In areas with high populations of *L. platythorax* and *M. scabrinodis*, the readings on the Shannon and Pielou indexes significantly decreased.

The horizontal structure of the studied windbreak plots is characterised through the aggregate distribution of litter invertebrates. The irregularity of the distribution of animal populations, conditioned by the mosaic structure of the environment, contributes to a rise in the resilience of the forest ecosystems. As a result of the research, regularities were again proved; the structure of the litter macrofauna structure is conditioned more strongly by biotic factors than by abiotic. The domination of ants determines the changes in the basic characteristics of litter invertebrate communities in forest plantations in the Ukraine's steppe zone.

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