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Community Structure of Litter Invertebrates of Forest Belt Ecosystems in the Ukrainian Steppe Zone

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ABSTRACT: Specific features of the structure of the ground litter invertebrate community in forest belt ecosystems in the Ukrainian steppe zone have been considered. For 14 years invertebrate fauna of the litter of 176 forest belt sites with different composition has been studied with the aid of soil traps. The main characteristics of litter invertebrate communities (total population, a number of species, Shannon-Wiener and Pielou indices of diversity) are not significantly different in various types of forest belt. The maximum number of saprophages is typical for *Robinia pseudoacacia* L., *Fraxinus excelsior* L. and *Betula pubescens* Ehrh stands. Zoophages and polyphages are dominant (20 and 50%, respectively, by numbers) in all forest belts of the steppe zone. There are more zoophages and fewer polyphages in *Acer tataricum* L. forest belts than in other types of forest belt. The most leveled size structure of the litter invertebrate community can be observed in the forest belts composed of *Gleditsia triacanthos* L., *A. tataricum* L., *R. pseudoacacia* L. and *F. excelsior* L. The average number of species with a body length less than 4 mm exceeds 20% of the litter invertebrate community composition only in *F. excelsior* L. and *R. pseudoacacia* L. forest belts indicating the presence of relatively stable temperature and moisture conditions throughout the season in these types of habitat. Compared with the natural forest types in the steppe zone of Ukraine, the same families of litter invertebrates dominate in forests belt but the numbers of Julidae, Isopoda, Silphidae and Staphylinidae are lower.

Key words: Forest ecosystems, Trophic structure, Size structure, Taxonomic structure, Diversity of litter invertebrates

INTRODUCTION

Using invertebrates communities for biological indication of environmental conditions is traditionally pursued to evaluate influences of selected environmental factors like burning of dry vegetation, habitat fragmentation (Thiele 1977, Ottesen 1996, Batiè *et al.*, 1999, Bohac 1999, Paoletti and Hassall 1999, Roslin and Koivunen 2001, Longcore 2003, Bogaert *et al.*, 2005, Apigian *et al.*, 2006, Buddle *et al.*, 2006, Major *et al.*, 2006) or their correlating complexes, for example, in the course of urbanization (Grandchamp *et al.*, 2000, Eyre *et al.*, 2004, Wolf and Gibbs 2004, Deichsel 2006). The effect of forest resource management on the community of soil and ground litter Arthropoda has been studied quite well (Greenberg and McGrane 1996, Magura 2002, Wardle *et al.*, 2003, Bouget and Duelli 2004, Jabin *et al.*, 2004, Vila *et al.*, 2004). Patterns of change in the soil and ground litter invertebrate communities have been studied for different kinds of agricultural practice on pasture, hay and arable lands (Frampton *et al.*, 1995, Wyss 1996, Bogya and Marko 1999, Irmler 2003, Pearce *et al.*, 2004, Cardenas *et al.*, 2006). Up to now the fauna of protective forest belts (henceforth, referred to in the text simply as forest belts) remains insufficiently studied (Fahy and Gormally 1998).

The steppe zone occupies about 40% of the total area of Ukraine. Annual precipitation is less (300–500 mm) than evaporation from water surface (700–900 mm): moisturizing factor varies from 0.90 in the north to 0.55 in the south of the steppe zone (Bachinsky 1962). Rainless periods (occurring between April and October) can last up to 50 days in the north and more than 90 days in the south of the steppe zone. It is this hot dry summer period that is critical for survival of the most litter invertebrates in forest belts. During the winter period, the number of days with snow cover is about 90 in the north but these decreases to less than 30 days in the south of the zone. This contributes to soil freezing to a considerable depth in those ecosystems where the litter horizon is fragmented or

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absent, which also reduces periodically the number of invertebrates species in forests of the region. The frost-free period in the north-east of the Ukrainian steppe zone lasts for 150 days while in the south this increases up to 220 days per year. Minimal winter temperatures reach –40ºC in the north-east of the steppe, and –20ºC – in the south. The annual total radiation in the north-east of the steppe zone is 107 kcal/cm^2, and in the south it rises to 125 kcal/cm^2 (Bachinsky 1962). All these features make the growth of natural forest vegetation in the steppe zone practically impossible (only fragments of it remain in the lower parts of the relief, typically along river valleys), and contribute to the depletion of the invertebrate fauna of forest ecosystems of the steppe zone.

In the middle of the XXth century, due to the prevalence of extensive methods of crop cultivation most land suitable for plowing in Ukraine was transformed into arable land. In view of this, in the 1950s–1960s, the intensity of dust storms rose sharply and the degradation of topsoil increased. In order to environmentally stabilize the newly created agroecosystems, the system of protective forest belts was created, which covers most of the territory of the steppe zone of the former SU until now. In accordance with site conditions (moisture, soil fertility, the exposure of the slope etc.), protective forest belts of complex species composition were planted, usually consisting of 1–5 woody and 2–3 shrub species. By the beginning of 1990s the condition of the forest belts had been monitored but under difficult conditions of the transition period in independent Ukraine, active state control and renewal of these forest belts have not been carried out. Thus, over the past 20 years, these ecosystems have often experienced sub-optimal growth conditions suffering a negative impact from the local population (grazing, cutting out trees for household needs, pollution with construction and household wastes etc.), and are still actually degrading. Particularly intense extinction of tree species in forest belts occurs in the south of the steppe zone, where natural forest vegetation is practically absent. Biodiversity preservation under the press of extremely strong man-made effect in transformed ecosystems of the steppe zone of Ukraine (in the majority of administrative units the percentage of the tilled area is 65–85% or more) is not possible without maintaining the diversity of the animal population in forest belts at a rather high level.

The study of the distribution patterns of invertebrates in these ecosystems is of significance both from a theoretical and practical point of view (Hietala-Koivu 2004). The litter invertebrate fauna of forest belts of the steppe zone of Ukraine have been studied since the time of their establishment (Volchaneckij and Medvedev 1950, Medvedev *et al.*, 1951, Gilyarov 1956, Gilyarov 1957, Perel 1958). These studies were focused primarily on the distribution of various species and particularly on the pests of crops and silviculture (Arnoldi *et al.*, 1950, Vasiliev 1974). Only in recent years have the features of the community structure of individual forest belt sites (the term sites is used here because forest belts in the region form a continuous mesh which has to be artificially divided up for the purpose of studies) in the steppe zone of Ukraine been analyzed (Brygadyrenko 2004, Brygadyrenko 2005, Brygadyrenko and Fedorchenko 2007, Brygadyrenko and Solovjov 2007, Brygadyrenko *et al.*, 2012, Moroz *et al.*, 2011).

Most of the litter invertebrates use forest belts for survival during unfavourable periods of the year (frosty winters without snow and long summer droughts) or when farm operations are conducted (like treatment with pesticides, burning of crop residues, deep plowing etc.). Therefore, the features of their fauna formation depending on the structure of plants, their species composition, development of the litter horizon, thickness of the canopy of grass and tree layers are of significant interest. The purpose of this paper is to characterize the structure of litter invertebrate communities in the forest belts of various species composition.

MATERIALS & METHODS

Litter fauna was studied during the growing seasons of 2001–2013. Sampling covered 176 forest belt sites of various species compositions, dominated by *Robinia pseudoacacia* L. (62 ecosystems), *Fraxinus excelsior* L. (48), *Gleditsia triacanthos* L. (18), *Quercus robur* L. (15), *Acer tataricum* L. (5), *Malus domestica* Borkh. (5) and *Betula pubescens* Ehrh. (4 ecosystems). The extent of tree species in the forest belts of steppe zones of Ukraine is correlated with the number of surveyed test areas: more than 70% of forest belts in the steppe zone of Ukraine are represented by the plantations of *F. excelsior* L. and *R. pseudoacacia* L., which are the most resistant to the conditions of insufficient humidity. When choosing test areas, we tried to cover areas with the most differing conditions of humidity and the texture of soils, on which the plantation forest belts of the given composition were grown.

Sampling was carried out on the territory of Dnipropetrovska, Zaporizska, Mykolaivska, Donetska and Kharkivska oblasts. Soil traps were exposed for 20–185 days (from 3 to 24 samples for each test area) by 10 traps on each plot. In order to compare community structures, the 20-day time periods (one for each test plot) are analyzed in this paper. Although sampling was often conducted on a particular test plot during the full growing season, only a 20-day period in mid-June was taken for the analysis conducted for this article. This period is the most typical one because it is characterized by maximal number of typical species (species with spring activity still persist, and species with summer-autumn activity are already present in the ecosystem) for the ecosystem. Minimal distance between the test areas with various species composition was 800 m, and between surveyed forest belts with similar composition was 4000 m. The same soil traps were used for different survey seasons (500 ml plastic beakers with 20% NaCl solution as a preservative).

Statistical processing of the results was carried out with the aid of Statistica 8.0 batch program: the diagrams show median, 25–75% quartiles and the selected outlier data points (outliers – º, extremes – *). The differences between numerical values of the characteristics of various types of plants were considered to be reliable at $p < 0.05$.

RESULTS & DISCUSSION

The main characteristics of litter invertebrate communities differ slightly. The number of species of invertebrates in the litter of *R. pseudoacacia* L. and *F. excelsior* L. plantations is significantly higher. On individual test plots the total quantity of litter mesofauna (Fig. 1a) is an order of magnitude more than average for this type of forest belt due to the dominance of one or two non-characteristic species for other types of forest belt. The average number of invertebrates of forest belts is similar to that in intact forest ecosystems (floodplain and gully deciduous forests) and is, of course, significantly lower in pine forests.

In most of the forest belts, which were all surveyed with the aid of soil traps, 8–18 invertebrate species were found during a 20-day time period (Fig. 1b). However, on several plots dominated by *G. triacanthos* L., *Q. robur* L., *R. pseudoacacia* L. and *F. excelsior* L. 30–56 species of invertebrates were caught over the same period.

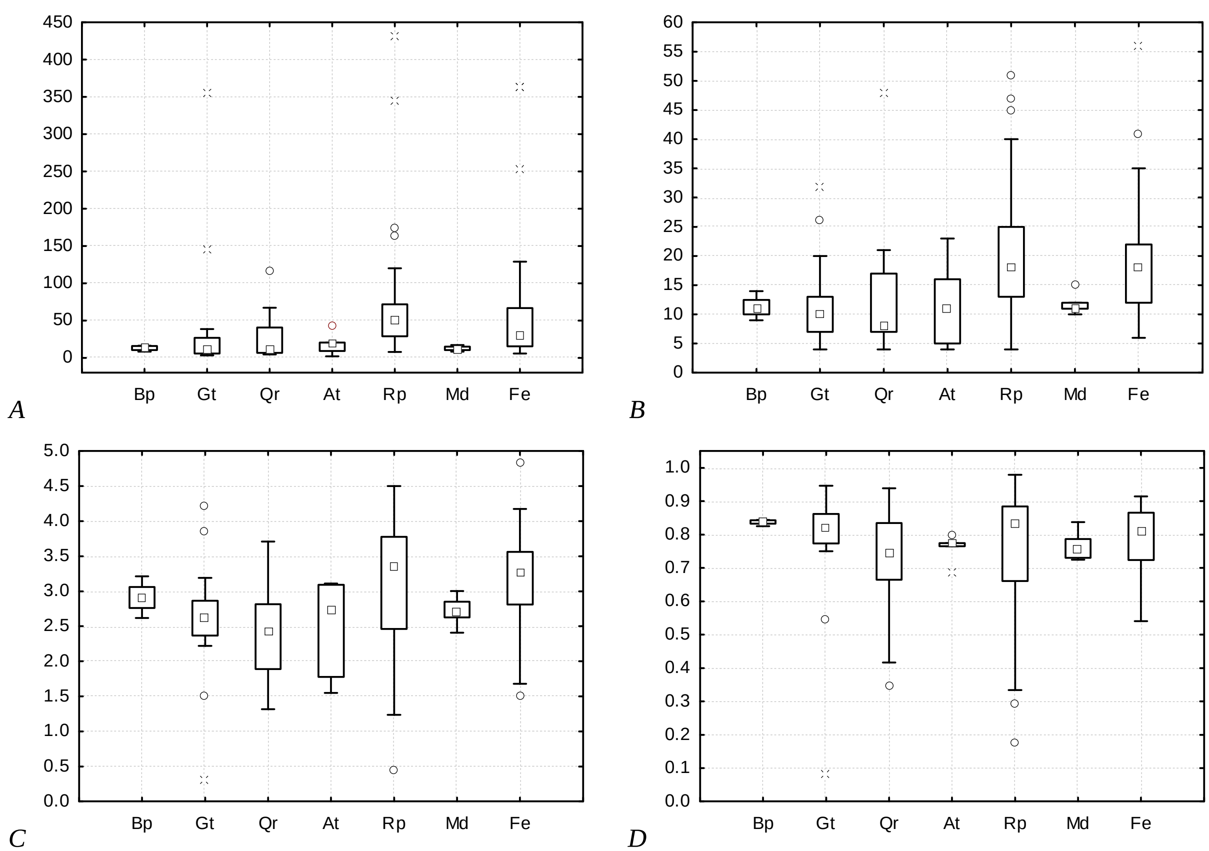

Fig. 1. Main characteristics of litter mesofauna of forest belts of the steppe zone of Ukraine: A is total number (samples/100 trap-days), B is number of species, C is Shannon-Wiener variety index (bit), D is Pielou variety index (bit); on the axis of abscissa is plotted abbreviated Latin names of tree species (Bp – ***Betula pubescens*** **Ehrh., Gt –** ***Gleditsia triacanthos*** **L., Qr –** ***Quercus robur*** **L., At –** ***Acer tataricum*** **L., Rp –** ***Robinia pseudoacacia*** **L., Md –** ***Malus domestica*** **Borkh., Fe –** ***Fraxinus excelsior*** **L.), on the axis of ordinate is plotted the scale of the corresponding characteristic**

Mean values of biological diversity indices (Shannon-Wiener (H') and Pielou (P) index of diversity) are minimal for the forest belts composed of *Q. robur* L. and *M. domestica* Borkh.and maximal for *R. pseudoacacia* L. and *F. excelsior* L. (Fig. 1c, d). The Pielou index unlike the Shannon-Wiener one (Shannon and Weaver 1949) does not account for the number of species on the test area but illustrates the degree of evenness of species population by numbers, and estimates absence of dominance (Pielou, 1977). In some cases, it reaches the lowest values on the plots where the dominance of ant species can be observed (primarily *Formica* spp. and *Myrmica* spp., more seldom *Lasius* spp.). Significant differences of diversity indices for the ecosystems of various tree species composition were not registered.

The trophic structure of the litter macrofauna in forest belts of the steppe zone is represented by phytophages (in those types of forest where herbaceous and shrub layers are pronounced), saprophages (with groups of phytosaprophages, zoosaprophages, coprophages and necrophages), zoophages (predators and parasites) and polyphages. The latter group is often named as pantophages (omnivorous species) but it would be more correct to define the trophic specialization of the given species as polyphage because they do not eat all kinds of food, and many of them (for example, they combine eating living plant and animal food or feed on dead and live plant tissue). In forest belts in the steppe zone, herbivores inhabit the upper layers of the ecosystem, and in the litter, they are only at certain stages of ontogeny or at extreme changes of the weather conditions. However, herbivores, on average, make up from 3 to 14% by number of the litter invertebrate fauna for various types of plants (Fig. 2a). These are mainly grassland and ubiquitous species of Chrysomelidae, Cicadellidae, Scutellaridae families and others. There are more phytophages in the ecosystems of *B. pubescens* Ehrh., *G. triacanthos* L. and *Q. robur* L. Saprophages in the steppe forests dominate in the soil and, quite often, in the litter. Saprophage percentage

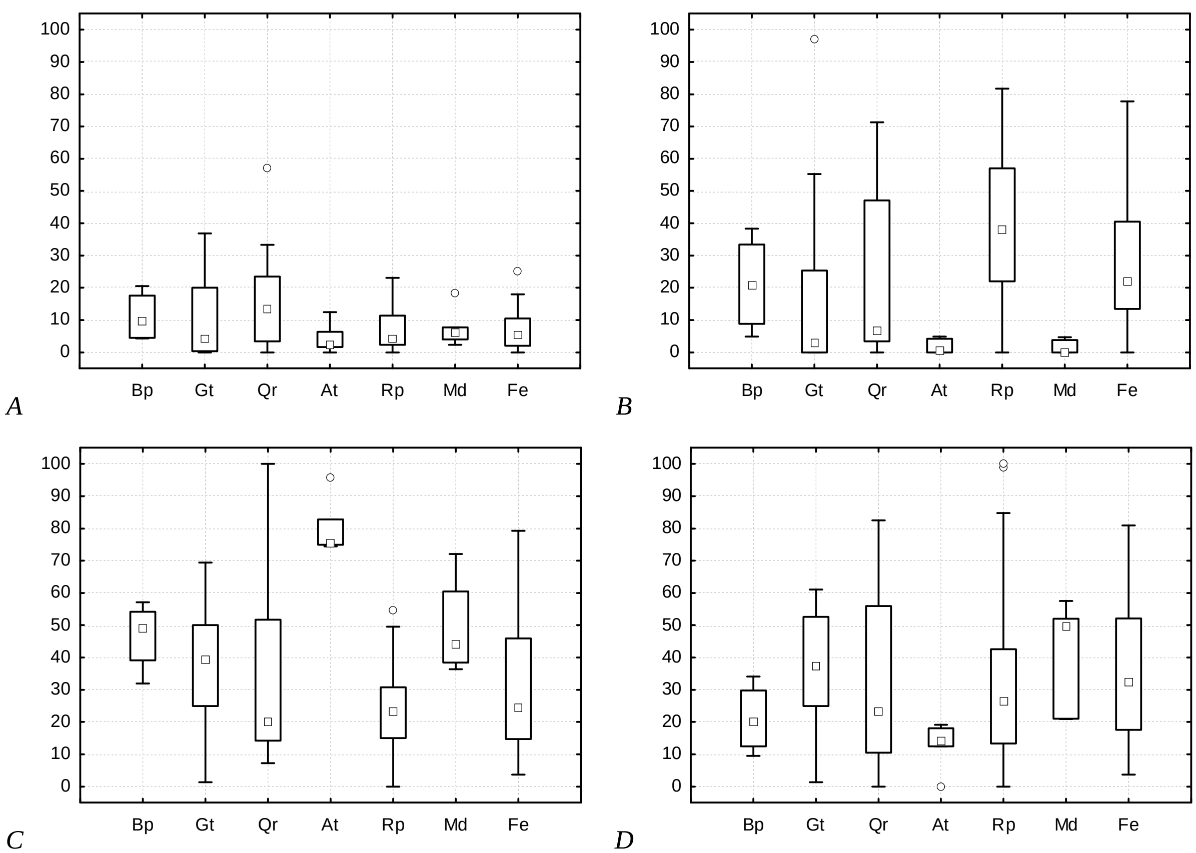

Fig. 2. Trophic structure of litter mesofauna of forest belts of the steppe zone of Ukraine: A is phytophages, B is saprophages, C is zoophages, D is polyphages; on the axis of abscissa is plotted names of tree species (Bp – *Betula pubescens* Ehrh., Gt – *Gleditsia triacanthos* L., Qr – *Quercus robur* L., At – *Acer tataricum* L., Rp – *Robinia pseudoacacia* L., Md – *Malus domestica* Borkh., Fe – *Fraxinus excelsior* L.), on the axis ordinates is plotted the share of the trophic group by numbers (%)

(Fig. 2b) varies greatly within forest belts composed of the same tree species. Its median maximum is observed for the ecosystems of *R. pseudoacacia* L., *F. excelsior* L. and *B. pubescens* Ehrh. Of saprophages, Diplopoda and Isopoda dominate in forest belts of the steppe zone. Zoophages (Fig. 2c) and polyphages (Fig. 2d) dominate (20–50% by number in average) in all forest belts. In *A. tataricum* L. ecosystems there are significantly more zoophages and fewer polyphages than in other types of forest belts.

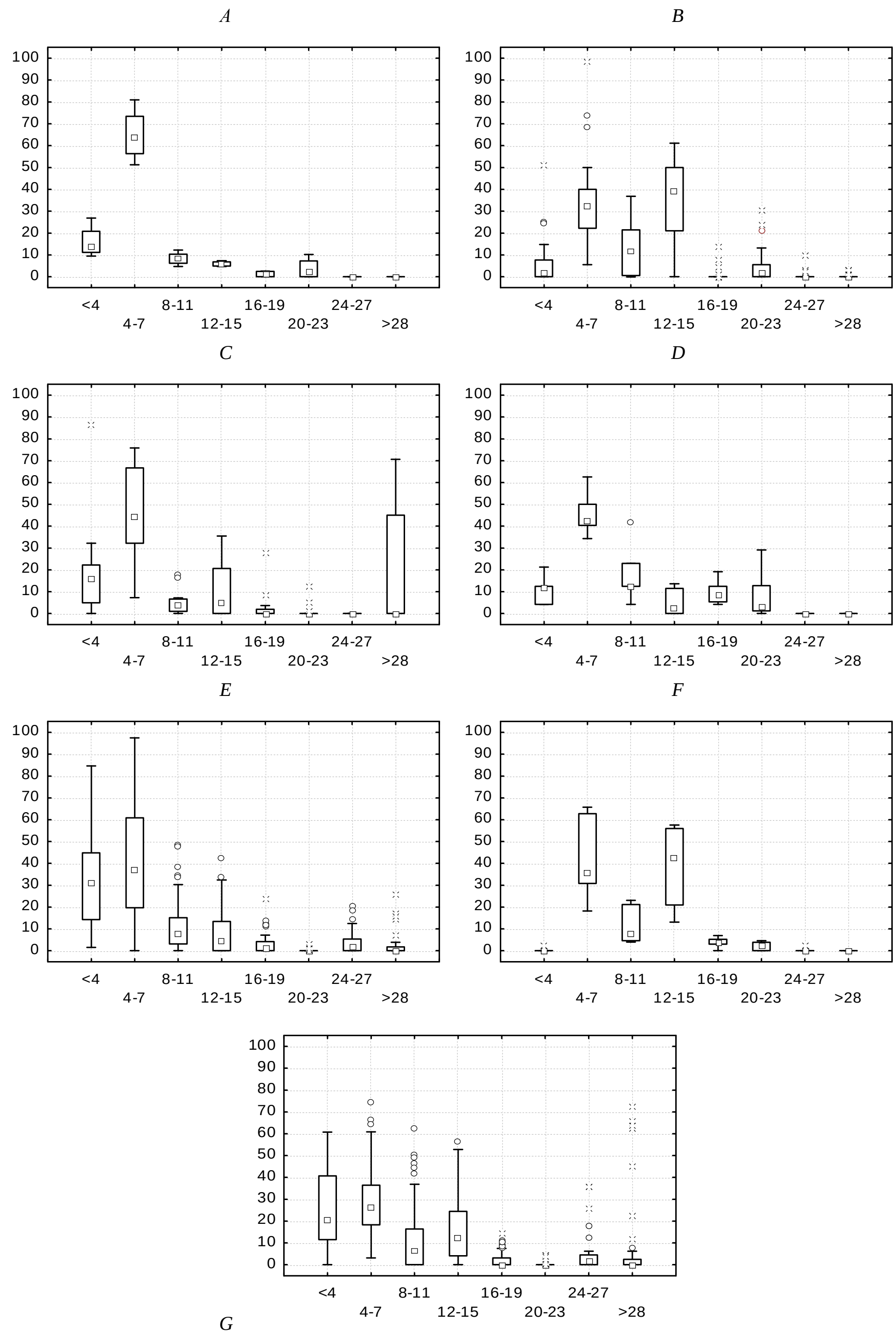

Fig. 3. Size structure of litter mesofauna of forest belts of the steppe zone of Ukraine: À – *Betula pubescens* Ehrh., B – *Gleditsia triacanthos* L., C – *Quercus robur* L., D – *Acer tataricum* L., E – *Robinia pseudoacacia* L., F – *Malus domestica* Borkh., G – *Fraxinus excelsior* L.; on the axis of abscissa is plotted specimen body length (mm), on the axis of ordinate is plotted the share of this group specimens by number (%)

It is interesting that in the number of invertebrate species in the trophic structure, dominants are practically not expressed: the median for each trophic group in various forest belt ecosystems varies from 4 to 8 species. When analyzing the trophic structure in the terms of number of species, it is seen that numerically uneven trophic structures are absent. There are no significant differences between forest belts of various tree species when analyzing the number of species of phytophages, zoophages and

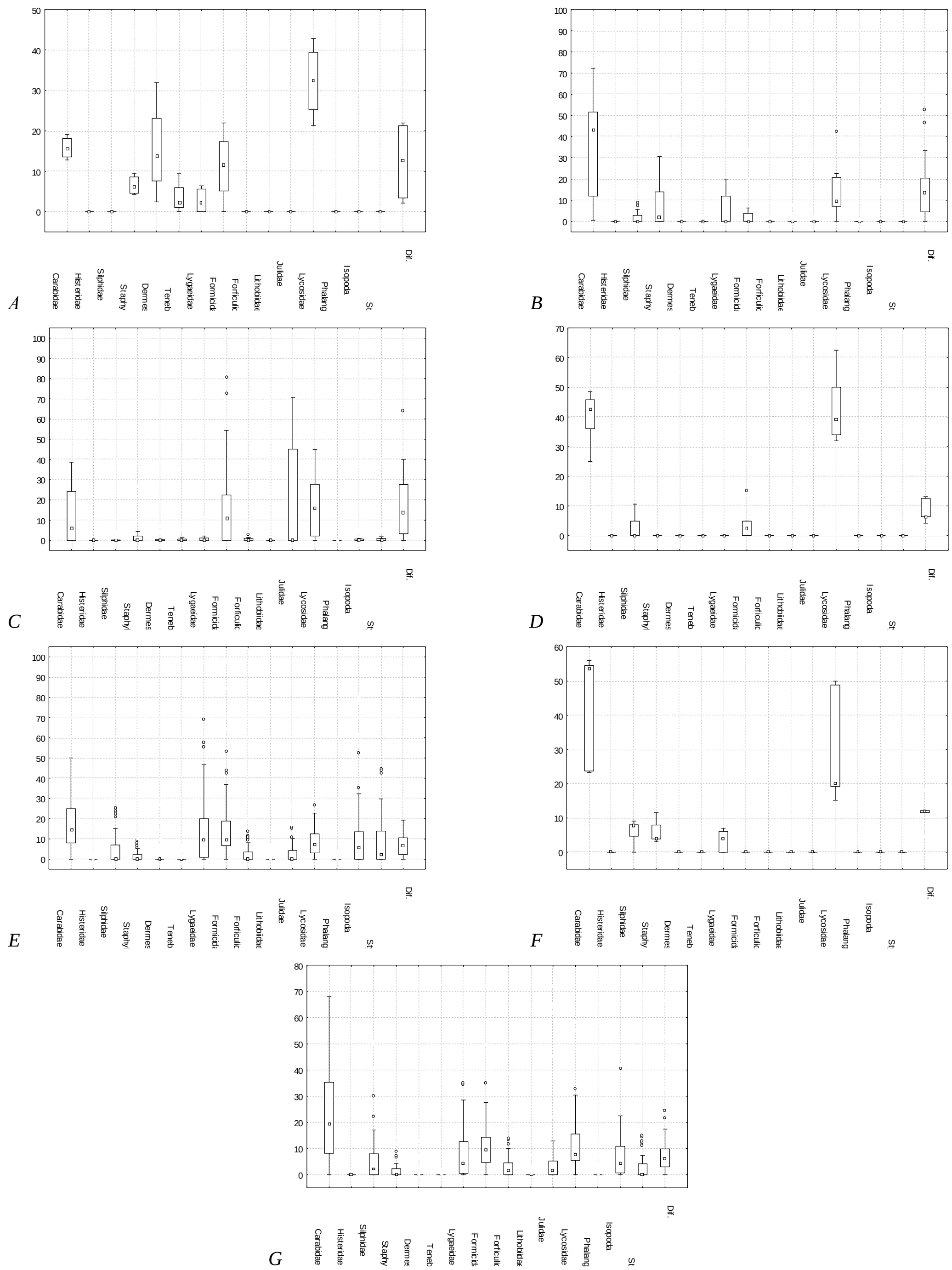

Fig. 4. Taxonomic structure of litter mesofauna of forest belts of the steppe zone of Ukraine: A– *Betula pubescens* Ehrh., B – *Gleditsia triacanthos* L., C – *Quercus robur* L., D – *Acer tataricum* L., E – *Robinia pseudoacacia* L., F – *Malus domestica* Borkh., G – *Fraxinus excelsior* L.; on the axis of abscissa is plotted dominant taxonomic groups, on the axis of ordinate is plotted the share of this group by number (%); Dif. – other taxonomic groups

polyphages; the number of species of saprophages was significantly higher in the ecosystems of *R. pseudoacacia* L. and *F. excelsior* L. The size structure of the litter invertebrate community characterizes the complete use of the ecosystem resources by the invertebrate community. The community, in which there are both small as for the body size species and medium size species as well as big forms, can be considered as more saturated, more stable and sustainable, and closer to the climax of natural forest ecosystems than a forest belt, in which individual size groups of invertebrates are absent. The most even community size structure can be observed in *G. triacanthos* L. (Fig. 3b), *A. tataricum* L. (Fig. 3d), *R. pseudoacacia* L. ecosystems (Fig. 3e) and in *F. excelsior* L. ecosystems (Fig. 3g).

Here, on the one hand, the number of large size classes is rather high (more than 16 mm body length), and on the other hand, fluctuations in the number of adjacent size classes are expressed not so much as with other types of plants. A valuable diagnostic feature is the relative quantity of the least, as for the body length, invertebrate group of the litter (body length of less than 4 mm). Their average number of less than 20% of the invertebrate community composition of the litter in *F. excelsior* L. (Fig. 3g) and *R. pseudoacacia* L. forest belts (Fig. 3e) indicates the presence of relatively stable temperature and humidity conditions throughout the season in these types of ecosystem. In the size structure of the communities, species with the body length of 4–7 mm dominate by the number of species. The greatest number of species of the smallest size class (4 mm) is typical for the forest belts dominated by *F. excelsior* L. and *R. pseudoacacia* L. No significant deviations in the size structure of the communities in their quantitative and qualitative analysis was observed. Analysis of taxonomic structure of communities of the forest belt litter showed that Carabidae and Lycosidae are the most numerous groups of invertebrates for most tree species (Fig. 4). Formicidae dominates in 5–6 of 7 types (relating to tree species) of forest belt. The number of Julidae, Isopoda, Silphidae and Staphylinidae, which are typical for natural forest types of the steppe zone, is not high in forest belts.

In forest belts dominated by *B. pubescens* Ehrh., the basic litter invertebrate communities are Lycosidae (average percentage of dominance by number is 32.3%), Carabidae (15.8%), Dermestidae (15.4%), Formicidae (11.2%), Staphylinidae (6.6%) and Tenebrionidae (3.5%).

In the forest belts dominated by *G. triacanthos* L. Carabidae (37.5%), Lycosidae (13.7%), Isopoda (9.9%), Staphylinidae (7.1%), Lygaeidae (5.1%), Formicidae (3.8%) and Silphidae (3.7%) dominate.

The ground litter of forest belts of *Q. robur* L. is mostly inhabited with Formicidae (20.1%), Julidae (17.8%), Lycosidae (17.2%), Carabidae (12.1%) and Staphylinidae (9.0%).

The community of *A. tataricum* L. is characterized by the dominance of Lycosidae (43.6%), Carabidae (39.6%), Formicidae (4.4%) and Silphidae (3.1%).

In the *R. pseudoacacia* L. ecosystems the most numerous groups are Stylommatophora (29.8%), Formicidae (17.4%), Carabidae (16.9%), Lygaeidae (14.0%), Isopoda (13.8%), Lycosidae (8.1%), Silphidae (4.2%) and Julidae (3.2%).

In the forest belts of *M. domestica* Borkh. Carabidae (42.3%), Lycosidae (30.6%), Staphylinidae (6.1%), Silphidae (5.9%), Lygaeidae (3.4%) dominate.

Forest belts composed of *F. excelsior* L. are the most polydominant ones among all analyzed community types, and they are dominated by Carabidae (22.8%), Lycosidae (12.5%), Formicidae (11.9%), Julidae (8.8%), Silphidae (8.0%), Lygaeidae (7.8%), Isopoda (7.3%), Forficulidae (3.9%) and Stylommatophora (3.0%).

The largest number of outlier data points (deviations from the mean values for a given type of plant) is characteristic for the most resilient plants in the steppe zone, *F. excelsior* L. (Fig. 4g), *R. pseudoacacia* L. (Fig. 4e) and *G. triacanthos* L. (Fig. 4b). The communities of these tree species are the most drought-resistant; they can survive in more elevated terrain and are more resistant to extreme conditions of the lack of humidity. The population of invertebrates of their litter approaches in the terms of taxonomic composition the species complexes which are typical for steppes. Polydominance (absence of at least one expressed dominant group, the median number of which exceeds 30% of the total composition of the community) is characteristic for *Q. robur* L., *F. excelsior* L. and *R. pseudoacacia* L. plantations. It is these types of forest belt that are the most stable in the conditions of low humidity.

Maximal numbers of a family or an order of invertebrates is usually combined with a low number of species characteristic of the test area, and conversely, if a specific family of invertebrates in a given type of forest belt is low in numbers, it is often represented by several competitive species. This pattern is typical for many pioneer communities surveyed (afforested sand dunes, abandoned agrocoenoses undergoing primary stages of plant succession, island ecosystems etc.) (Brygadyrenko and Solovjov 2007).

The variation of individual characteristics of the litter invertebrate fauna is defined most of all by the thickness and moisture of the litter. The thickness of the litter horizon determines the preservation of soil moisture from evaporating under geographic conditions and, often, ecological non-compatability of a forest ecosystem with the specific habitat conditions of its site and surrounding area (Belgard 1971). Insufficient moisture in the forest belts of the steppe zone of Ukraine obliges litter invertebrates to concentrate on limited plots with optimum moisture, and move to upper soil horizons and fall into a diapause during the periods of unfavourable temperature and hydrological conditions. Our studies of forest ecosystems of the forest-steppe zone, to the northwest of the area studied in this article, (Brygadyrenko and Komarov 2008) have not displayed similar features of seasonal dynamics in conditions of sufficient moisture of litter (more annual precipitation and less intensity of moisture evaporation).

Insufficient thickness of the litter determines significant fluctuations of the per diem soil surface temperature and the moisture conditions unfavourable for the evolution of microorganisms. Herbaceous plants which are not sheltered under the forest canopy have an advantage (more rainwater reaches the surface of the soil, more solar radiation is absorbed by their photosynthetic apparatus, less tree leaf litter prevents their seeds from moving into soil and germinating). Besides, the litter containing the matter of herbaceous plants is decomposed faster and more completely by microorganisms and invertebrates (Striganova, 1980). Thus, the forest ecosystem in the steppe zone is in a state of permanent conflict between forest and steppe cycling of matter and energy flows (Belgard 1971). The penetration of steppe species under the canopy of the forest community is observed in varying degrees in all types of forest ecosystems of the steppe zone of Ukraine. This is true for herbaceous plants and litter invertebrates. In plots with undeveloped litter horizon (up to 10 mm) ubiquitous and steppe species of invertebrates start to dominate.

CONCLUSIONS

It should be emphasized that the litter invertebrate communities of the forest ecosystems of the steppe zone of Ukraine are quite a complex and variable system, the structure of which is determined by external factors as regards the given plant community (the texture of the soil, its moisture, the type and intensity of anthropogenic pressure), the structure of the plant community (species composition, the density of woody and herbaceous layers, the thickness of the litter) as well as by the internal structure of the dominant taxonomic groups of invertebrates in the litter.

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