

Influence of soil moisture on litter invertebrate community structure of pine forests of the steppe zone of Ukraine

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Abstract

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An analysis of litter invertebrate community structure of 141 pine forest ecosystems in the steppe zone of Ukraine in five moisture gradations has been carried out. The absolute number of macrofauna individuals in the pine forests of the steppe zone of Ukraine is on average 5 times lower than in the corresponding moisture conditions of deciduous forests. The average number of species and the Shannon-Weaver diversity index increases from mesoxerophilous to hygromesophilous conditions. The relative number of saprophages increases when the degree of moisture increases from mesoxerophilous through to mesohygrophilous conditions. Zoophages do not change their number with optimisation of moisture conditions; only the number of their species increases. The relative number of polyphages decreases as the soil humidity increases. It is possible to observe significant deviations in the size structure of pine forest macrofauna in comparison with that of steppe zone deciduous forests: the share of 4–7 mm size group increases and the number of individuals with >20 mm body length decreases in most moisture gradations. In pine forest litter, Formicidae occupy the first place among dominants, in hygromesophilous and mesohygrophilous forest types Porcellionidae make up more than a quarter of macrofauna, while Lycosidae and Carabidae dominate in all moisture gradations. The results of the studies allow us to assess the importance of pine forests in the steppe zone as low for preserving biological diversity of litter macrofauna.

Key words

biodiversity, litter invertebrate communities, moisture conditions, pine forests, structure of domination, trophic structure

Introduction

The Samarsky coniferous forest (the left-bank part of Dnipropetrovsk region) forms the southern limit of the natural range of *Pinus sylvestris* (Linnaeus, 1753) within the steppe zone of Ukraine (BELGARD, 1971). Only artificial plantations of this tree species can be found further to the south. An annual excess of the amount of precipitation over evapotranspiration by 200–400 mm is typical of natural pine forests in a forest zone. However, the reverse applies to the Samarasky coniferous forest, where the amount of precipitation is actually 150–250 mm lower than the amount of evapotranspiration. This causes certain specific features of the cycling of matter and the composition of animal population of this particular pine forest.

Natural communities of *P. sylvestris* L. and artificial plantations of this species in southern Ukraine are distributed on light-textured types of soil (sand and supersand). The low water-holding capacity of such soils causes rapid evaporation after rainfall, which results in the fact that microbiologically fallen needles do not have time to decompose to the same extent as in forest-steppe or forest zones (BELGARD, 1971). The accumulation of a thick layer of fresh litter and, below that, older litter prevents the development of herbaceous vegetation in pine forests, and the low crown closure is prone to overheat the soil surface and the litter during daylight hours (DOUGHERTY et al., 1994; KNIGHT et al., 1994). The compounds released during decomposition of needles (stilbene, various phenolics, lignin and its derivatives),

also adversely affect the passage of specific stages of ontogenesis of certain species of litter macrofauna (HÄNNINEN et al., 2011; PAN and LUNDGREN, 1996; SCHANZ et al., 1992).

Litter fauna of pine forests has been studied mostly in the north and in the centre of the range of *Pinus sylvestris* L. (ATLEGRIM and SJOBERG, 1995; HALME and NIEMELA, 1993; NIEMELA et al., 1988, 1989, 1992). Some families of litter invertebrates of these types of ecosystems have been studied better than others. For example, for Carabidae, indicative types and systems have been defined, that change their number in the gradient of certain environmental factors (JUKES et al., 2001; LUFF et al., 1989; POLLET and DESENDER, 1987; RAINIO and NIEMELA, 2003; SMALL et al., 2006), and for Lycosidae – trophic links to prey populations have been analysed (PERSONS et al., 2001).

The effect of anthropogenic factors on forest ecosystems in arid zones is much more significant in comparison with similar types of forests in the optimum moisture conditions of the forest zone (APIGIAN et al., 2006; DIDHAM, 1997; GUTIERREZ et al., 2004; HUHTA et al., 1967; MOROZ et al., 2011; SCHOWALTER, 1995). Pine forest ecosystems in the steppe zone of Ukraine have only received fragmentary attention from scientists (BRYGADYRENKO, 2003; BRYGADYRENKO and KOMAROV, 2008; FEDORCHENKO and BRYGADYRENKO, 2008; MOROZ et al., 2011). A general analysis of the litter macrofauna structure of these ecosystems has not been carried out so far.

In this connection, the aim of this paper is to assess the effect of moisture conditions on the main characteristics as well as the trophic, size and taxonomic structure of the litter macrofauna of the pine forests of southern Ukraine.

Material and methods

Invertebrates were collected with the help of soil traps (500 ml volume with 20% NaCl solution) during all the vegetation periods of 2001–2013. We examined 141 forest ecosystems with *P. sylvestris* L. as the dominant plant in the following moisture conditions: mesoxerophilous – 30, in xeromesophilous – 51, in mesophilous – 21, in hygromesophilous – 25, in mesohygrophilous – 14. Sample plots differed in the density of vegetation in the tree layer, the percentages of dominant tree and shrub species, the degree of plant litter accumulation, the texture of the soil, the salinity of the soil solution and other characteristics. When selecting sample areas, we tried to cover as fully as possible all the variety of ecological conditions typical for a certain moisture gradation. The ecosystems under examination were natural forests (50–200 years of age) as well as artificial plantations (20–80 years of age). Moisture gradations in the 141 ecosystems examined

by a standard scale (BELGARD, 1971) were using, first of all, the herbaceous plant community and correcting the results according to the data provided by the visual inspection of the test plot and the soil moisture analysis at the time of the inspection.

Collection was carried out on the territory of Dnipropetrovsk, Zaporizhzhya, Nikolayev, Donetsk and Kharkiv regions. Soil traps were checked every 5–7 days during 20–185 days (from 3 to 24 samples per every test plot). In order to compare the structure of the communities, 20-day time intervals were analyzed (mid-June), the precise timing varying slightly each year but being identical in each particular summer for each test plot.

The degree of diversity of macrofauna communities was assessed with the most widely used diversity indexes (PILOU, 1977; SHANNON and WEAVER, 1949). The groups that exceed 3% of the total number of the community were considered dominants in the taxonomic structure. Statistical processing of the results was performed in the software package Statistica 8.0. The diagrams show median, 25–75% quartiles and the selected outlier data points can (outliers – °, extremes – *). Only average values of the characteristics under discussion are given in the text due to the limited space of the paper. To compare the samples, the univariate analysis of variance was used, the differences between the values of the various moisture gradation characteristics being considered reliable at $P < 0.05$.

Results and discussion

Main characteristics of the communities

The number of invertebrates in the pine forest litter is on average 5 times lower than in the corresponding moisture conditions of deciduous forests (24.5 and 129.0 samples/100 trap-days accordingly). At the same time, certain test plots differ significantly due to the greatly increased number (up to 100–320 samples/100 trap-days) of Formicidae (*Formica cinerea* (Mayr, 1853), *F. fusca* (Linnaeus, 1758), *F. glauca* (Ruzsky, 1896) dominate). The change of moisture conditions in pine forests does not significantly affect the total number of litter invertebrates (Fig. 1a): the lowest numbers are present in minimal in mesohygrophilous moisture conditions (7.6 samples/100 trap-days), the maximum numbers – in xeromesophilous conditions (40.0 samples/100 trap-days).

The average number of species in the soil traps significantly increases during a 20-day period of their exposition from 10.3 in mesoxerophilous up to 20.4 in hygromesophilous conditions while not significantly decreasing up to 16.7 in mesohygrophilous moisture conditions of the soil (Fig. 1b). It is of interest that in natural deciduous forests of the region studied, the

number of species in similar moisture gradations varies within the range of 17.6–22.8, that is, a practically constant number of invertebrate species can be observed in the ecosystem of deciduous forests. Low pine crown closure causes significant daily fluctuations in temperature of pine forest leaf litter, which leads to the decrease of the species number in extreme conditions (in mesoxerophilous and xeromesophilous moisture conditions).

Shannon-Weaver diversity index (Fig. 1c) decreases significantly during the transition from mesoxerophilous (2.15 bits) to mesohygrophilous moisture conditions (2.96 bits). There are no significant changes in the Shannon-Weaver index (its average value does not differ from pine forests and is equal to 2.57 bits) in deciduous forests of southern Ukraine with similar moisture gradations. The evenness of the community structure – Pielou index (Fig. 1d) – does not change significantly: average values change within the range of 0.635–0.747 bits in various moisture gradations in the pine forests.

Trophic structure

The average share of phytophages in the trophic structure of litter macrofauna increases from 5.1% in mesoxerophilous to 10.6% in mesohygrophilous moisture conditions (Fig. 2a). There are far fewer phytophages than other groups of invertebrates in the litter fauna (maximum – 35.6% in one variant of hygromesophilous pine forests), the range of their number fluctuations for different moisture gradations is also much smaller. The number of phytophage species in the soil traps increases with the significant increase of moisture from 1–2 to 3–5.

The relative number of saprophages (Fig. 2b) significantly increases during the transition from mesoxerophilous (19.4%) to mesohygrophilous (29.4%) moisture conditions. A similar tendency can also be observed in natural deciduous forests of the steppe zone of Ukraine. The relative number of saprophages in the litter macrofauna of pine forests (21.6%) is significantly

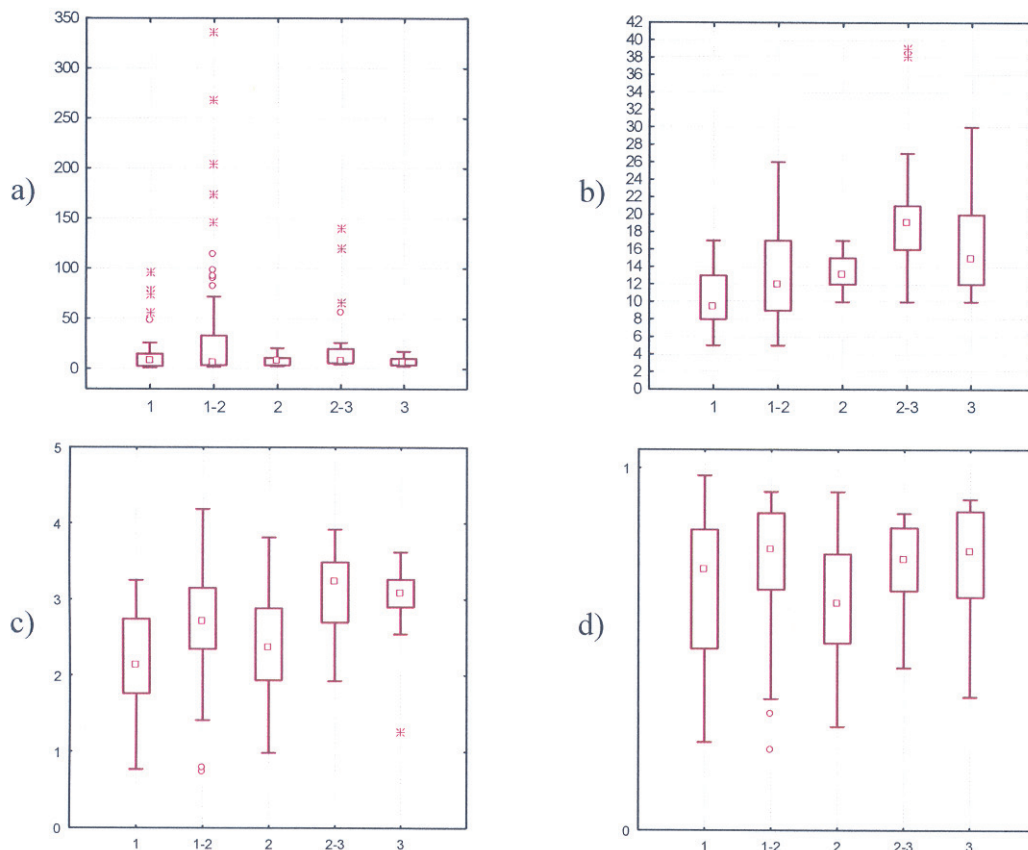


Fig. 1. Main characteristics of litter invertebrate communities of the pine forests of the steppe zone of Ukraine: a) total number (samples/100 trap-days), b) the number of species, c) Shannon index (bits), d) Pielou index (bits); abscissa – moisture conditions (1 – mesoxerophilous, 1–2 – xeromesophilous, 2 – mesophilous, 2–3 – hygromesophilous, 3 – mesohygrophilous), ordinates – values of characteristics.

lower than for deciduous forests (39.9%). The average number of saprophage species in one test area does not change in various moisture gradations, making up 2–4 species on average.

No significant change was registered in the relative number of zoophages (Fig. 2c) with increasing humidity in a pine forest (minimum share in hygromesophilous – 21.6%, maximum – in xeromesophilous conditions, 36.5%). In deciduous forests, the share of zoophages is significantly lower (16.2% compared with 28.7% for pine forests) ranging from 12.2% to 22.4% for different moisture gradations. The average number of zoophage species in pine forests increases from 3–5 species in mesoxerophilous to 7–10 species in hygromesophilous soils. Thus, the conditions of existence for the majority of predatory invertebrate species in the litter of drier pine forests are not favourable, but the absence of most species of this trophic group is made up for by increased number of the few remaining species of zoophages,

keeping their number in this trophic group at a stable level.

The relative number of polyphages decreases significantly (Fig. 2d) from 52.2% in mesoxerophilous and 61.4 in mesophilous to 25.9% in mesohygrophilous moisture conditions making up 43.3% on average of the litter macrofauna of pine forests in numbers. The average number of polyphage species increases from 2–3 to 3–5 with increasing moisture. In deciduous forests of similar gradations a similar tendency is observed: the relative number of polyphages in the litter decreases with increasing moisture, but the average number of species remains constant.

Size structure

In the extreme conditions of pine forests there is a simplification of the size structure of the litter macrofauna (Fig. 3). The dominant group of invertebrates,

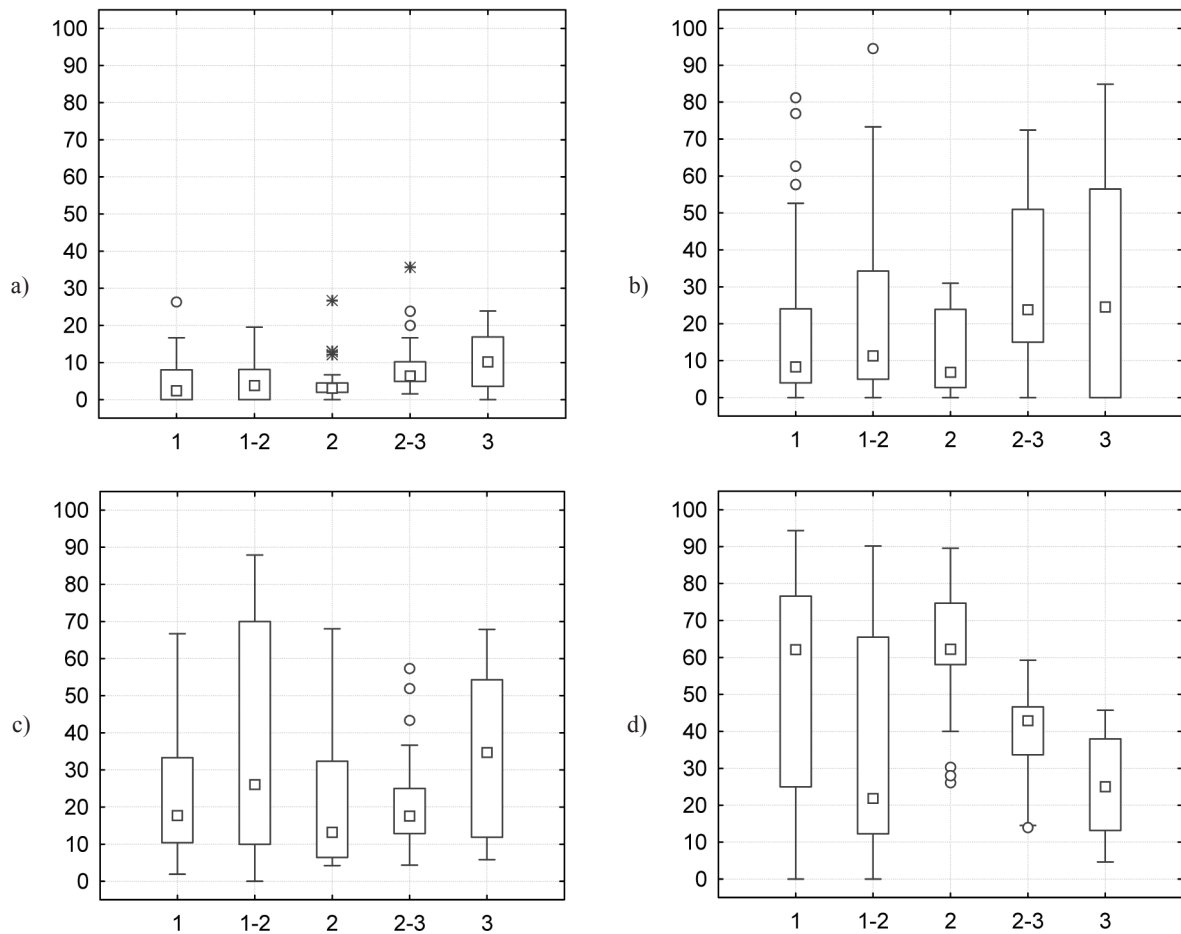


Fig. 2. Trophic structure of litter invertebrate communities of the pine forests of the steppe zone of Ukraine: a) phytophages, b) saprophages, c) zoophages, d) polyphages; abscissa – moisture conditions (1 – mesoxerophilous, 1–2 – xeromesophilous, 2 – mesophilous, 2–3 – hygromesophilous, 3 – mesohygrophilous), ordinates – share of the trophic group in numbers (%).

as in other forest types of the steppe zone, consists of invertebrates with the length of 4–7 mm. According to our observations, for different moisture gradations of natural deciduous forests the height of this peak

is within the range of 23.4–65.7% and for artificial deciduous plantations – 31.0–52.0%. The height of the peak for pine forests on the chart of the size structure is minimal for xeromesophilous forest variants (50.8%),

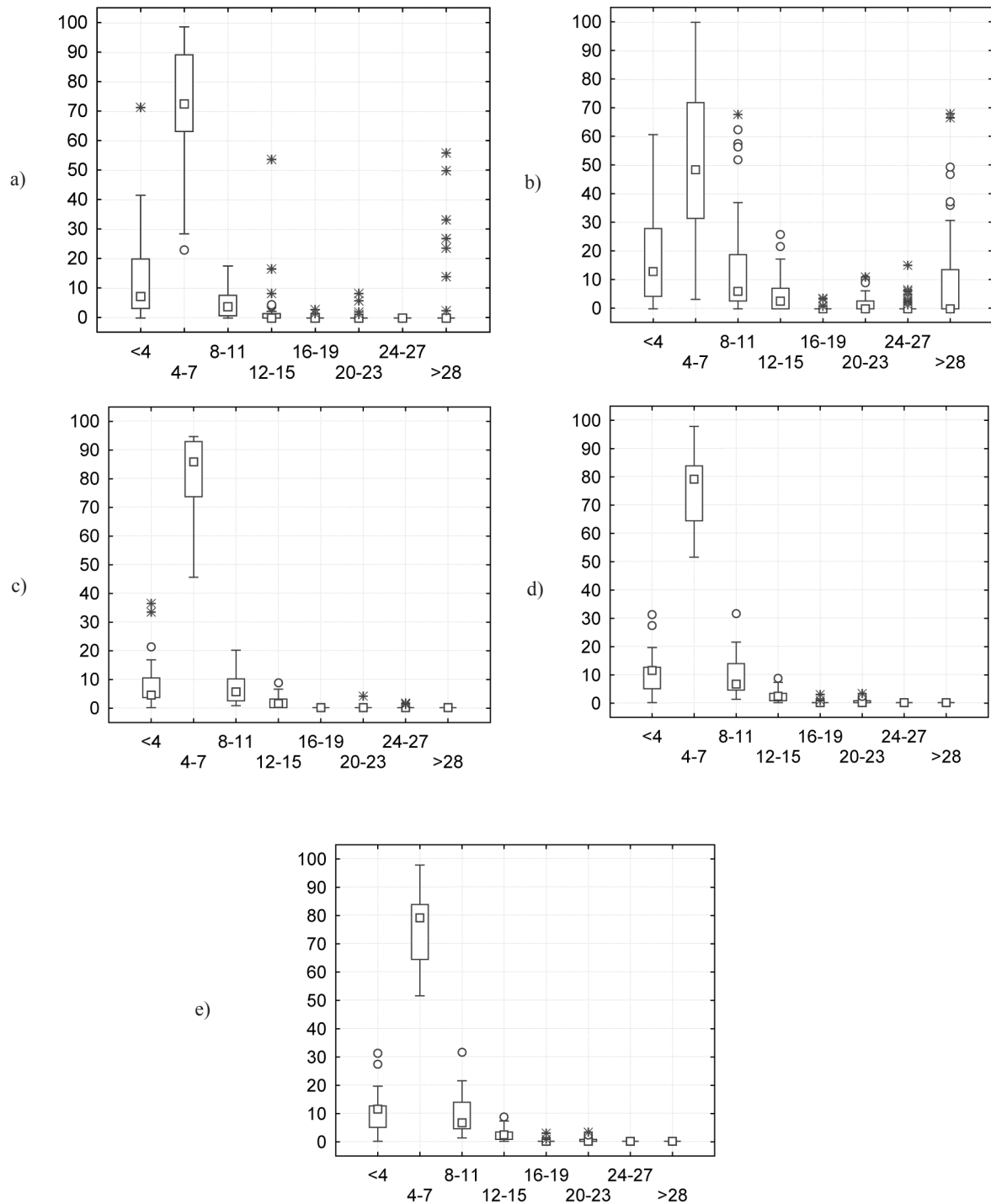


Fig. 3. Size structure of litter invertebrate communities of the pine forests of the steppe zone of Ukraine: a) mesoxerophilous, b) xeromesophilous, c) mesophilous, d) hygromesophilous, e) mesohygrophilous moisture conditions; abscissa – individual body length (mm), ordinates – share of this size group individuals in numbers (%).

and for other surveyed moisture gradations it fluctuates within the range of 71.1–80.4%.

The share in number of the size groups exceeding 20 mm of their body length reaches its maximum (13.0%) in xeromesophilous moisture conditions. It decreases sharply to 0.4–1.0% in mesophilous, hygromesophilous and mesohygrophilous moisture conditions. The low number of species exceeding 20 mm in body length is a characteristic feature of the pine forests of the steppe zone of Ukraine.

The average share of the smallest size group with the body length of less than 4 mm in the community of invertebrates does not exceed 20% of the total number in any of the pine forest humidity gradients (this varies from 9.2% in mesophilous to 17.6% in hygromesophilous moisture conditions). The share of this size group in deciduous forests of the steppe zone is significantly higher. This reduction in the number of invertebrates belonging to the group with the smallest body length is associated with violent fluctuations in hygrothermal conditions (this applies both at the seasonal and twenty-four-hour level) and the unfavourable chemical composition of the diet for many groups of saprophages (the presence in the needles of difficult to assimilate compounds and substances that affect the endocrine system of invertebrates).

Additional peaks for the size groups of 12–15 and 16–19 (as opposed to individual variants of deciduous forests) are absent in the diagram of the size structure.

The qualitative composition of the size structure (the size structure of the community calculated by the number of species) is characterized by the same features as the quantitative composition. Thus, significant deviations in comparison with deciduous forests of the steppe zone can be observed in the size structure of the macrofauna of the pine forests' litter: the relative number of 4–7 mm size group is significantly higher (50.8–80.4%), and the number of individuals with the body length of more than 20 mm decreases sharply in most humidity gradients.

Taxonomic structure

In the litter of mesoxerophilous pine forests of the steppe zone of Ukraine (Fig. 4a), Formicidae (average percentage of dominance in numbers – 49.9%), Lycosidae (13.2%), Julidae (6.9%), Lygaeidae (6.8%) and Carabidae (4.8%) are predominant.

In xeromesophilous variants of pine forests (Fig. 4b), the litter macrofauna is composed principally of Formicidae (34.6%), Lycosidae (13.3%), Carabidae (12.9%), Julidae (11.1%), Isopoda (4.3%) and Lithobiidae (3.0%).

Mesophilous moisture conditions (Fig. 4c) are characterized by the dominance of Formicidae (59.7%), Lycosidae (10.2%), Carabidae (9.0%), Tenebrionidae (5.3%) and Isopoda (4.4%).

In the pine forest communities of hygromesophilous moisture conditions (Fig. 4d), Formicidae (37.3%), Isopoda (25.8%), Lycosidae (9.9%), Carabidae (8.1%) and Lygaeidae (4.0%) predominate.

The complexes of mesohygrophilous variants of pine forests of the steppe zone of Ukraine are significantly different from those characterized above (Fig. 4e): Isopoda (26.9%), Formicidae (23.2%), Carabidae (16.5%), Lycosidae (9.1%), Phalangidae (6.2%) and Lygaeidae (3.6%).

Thus, in all moisture gradients of the pine forests studied, except for the most humid of the variants considered, the Formicidae family (23.2–59.7%) occupies the first place among the dominants. In hygromesophilous and mesohygrophilous variants of pine forests, the Porcellionidae family of Isopoda order makes up more than a quarter of the number of macrofauna. In all the moisture gradients studied, Lycosidae (9.1–13.3%) and Carabidae (4.8–16.5%) predominate, and the relative number of the latter increases with increasing humidity.

Conclusions

The specific composition of the leaf litter fauna of the *P. sylvestris* L. ecosystems studied, which differs dramatically from the litter fauna of deciduous forests of the steppe zone, may be explained by a combination of the extreme hygrothermal conditions and chemical composition of the litter. Pine forests are characterized by the dominance of invertebrates that are adapted to significant migrations by flight and by ground locomotion, species with hard (sclerotized) external skeleton, species that accumulate or synthesize toxic substances in the hemolymph. With the increase of humidity, the limiting impact of the lack of moisture decreases, and in the most humid of the considered moisture gradients, it is possible to observe a gradual approach of the litter community structure to that of zone types of deciduous forests. On the whole, ecosystems of pine forests are much poorer in species composition than deciduous forests of similar moisture gradients or areas of sand steppe or meadows.

Even optimum hygromesophilous moisture conditions, which allow the formation of a rich litter macrofauna in natural deciduous forests of the steppe zone, do not lead to the formation of a complex and diverse community in the pine forest, whose grass and shrub layer is represented by only a few species of flowering plants. The ecosystems of natural and artificial pine forests do not significantly differ according to the structure and the main characteristics of the litter macrofauna.

The present work is part of a comprehensive monitoring study of the litter macrofauna of forest ecosystems of the steppe zone of Ukraine. The main characteristics and features of the structure considered

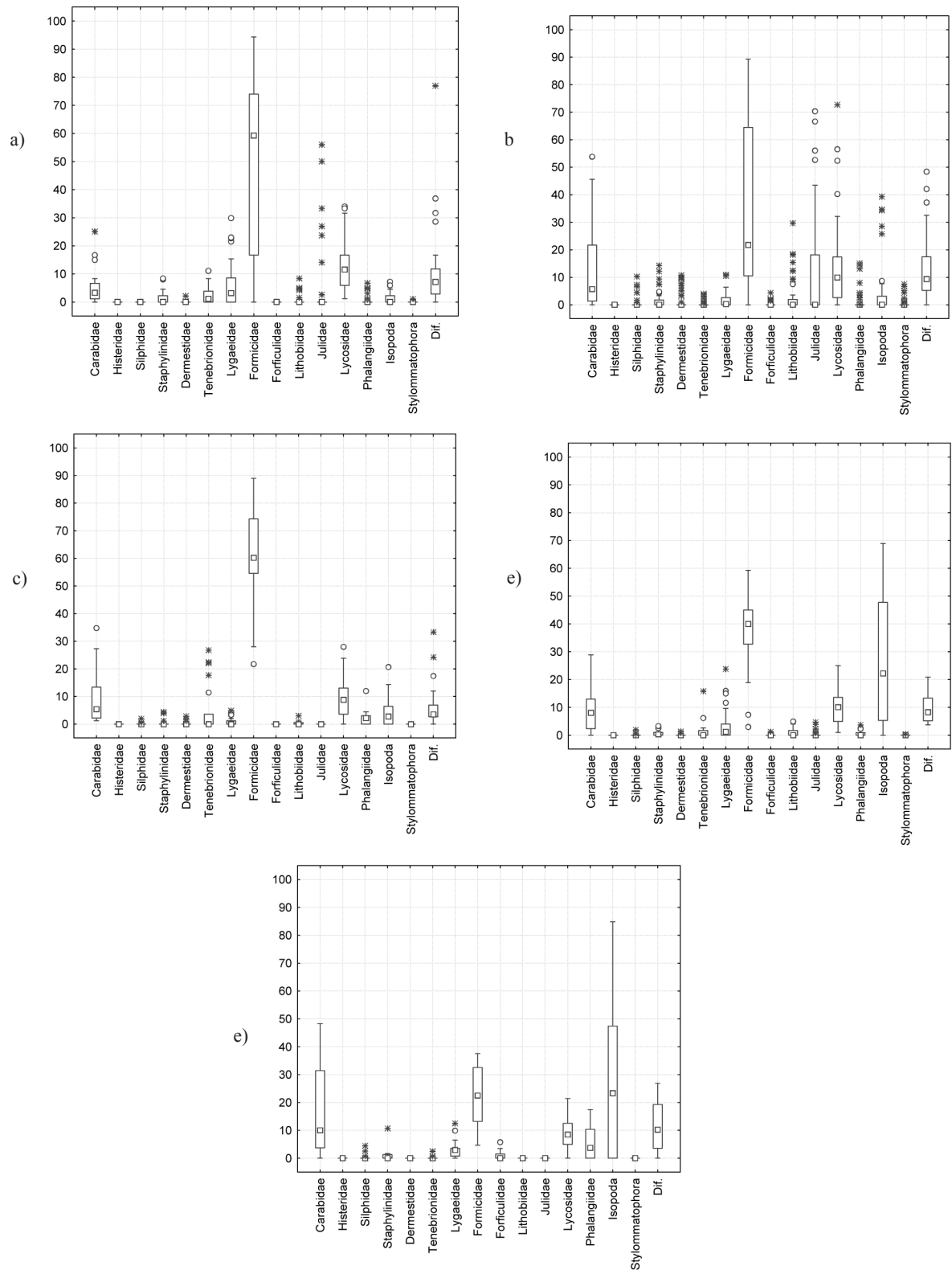


Fig. 4. Taxonomic structure of litter invertebrate communities of the pine forests of the steppe zone of Ukraine: a) mesoxerophilous, b) xeromesophilous, c) mesophilous, d) hygromesophilous, e) mesohygrophilous moisture conditions; abscissa – dominant taxonomic groups, ordinate – share of this taxonomic group in the community in numbers (%); Dif. – species of other taxonomic groups.

here compel us to assess the value of the steppe zone pine forests for the conservation of biological diversity of the litter macrofauna as low in comparison with other types of forest communities in the steppe zone.

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