

Population analysis of *Asarum europaeum* in the Northeast of Ukraine

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Article info

Received 14.06.2017

Received in revised form
27.07.2017

Accepted 30.07.2017

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Kovalenko, I. M., Klymenko, H. O., & Hozhenko, K. H. (2017). Population analysis of *Asarum europaeum* in the Northeast of Ukraine. *Biosystems Diversity*, 25(3), 210–215. doi:10.15421/011732

An analysis of the populations of *Asarum europaeum* L. in forest ecosystems of the North East of Ukraine during the growing periods of 2004–2015 was carried out. In carrying out field research we used standard methods of ecology, geobotany such as study plots of 400 m², and for detailed elaboration of the surface layer we used study plots of 100 m². According to the results of the examination of plots of the size 50 × 50 cm, we obtained data on the number and density of individuals within populations. We found that populations of this species often dominate in the lower tiers of broadleaf and mixed forests in the region under research. We identified the basic population characteristics of the species and described its growth and development in three subformations: Querceta roboris, Pineta sylvestris, Acereto (platanoiditis) – Querceta (roboris). It was found that according to the time gradient, depending on meteorological conditions, the projective cover and the average population density of the plants vary. Based on the average growth rate of the plants, the balance of morphogenesis in the course of the plants' ontogenesis was determined. We determined that the most optimal conditions for the growth and development of *A. europaeum* are provided in the North East of Ukraine in the subformation of Querceta roboris. The results of the analysis of ontogenetic state of partial bushes in populations of *A. europaeum* are described. It was found that populations in the subformation Querceta roboris and Pineta sylvestris were full-membered, while in the subformation Acereto (platanoiditis) – Querceta (roboris) it was unfully-membered with fallout of seedlings and juvenile plants. It was found that the population of *A. europaeum* in the Pineta sylvestris subformation, is left sided, with the peak number in pregenerative partial bushes – this was the youngest population with the highest Index innovation value and the lowest Index senilis value. The Index aetas of the youngest population is 0.14 while the Index generative is 45.0%. The population of *A. europaeum* in the subformation of Querceta roboris was more mature: Index aetas is equal to 0.19, the age range of the left-hand side with the peak on the partial bushes g₁, Index generative reaches 55.4%. In the population with the subformation Acereto (platanoiditis) – Querceta (roboris) Index aetas is significantly greater than one and equals 2.35. In the oldest population, the age spectrum is centered with the peak on generative partial bushes, the Index generative is high and equals 68.5%. This vital analysis of the population structure is based on a sample of more than 3,000 partial shrubs. The key signs of vitality were: total phytomass (W), leaf surface (A) and reproductive effort (RE₁). It has been established that two of the three populations studied *A. europaeum* are in equilibrium (from the subformations of Pineta sylvestris and Acereto (platanoiditis) – Querceta (roboris)) and one is flourishing.

Keywords: population analysis; vital structure; ontogenetic structure; growth parameters

Introduction

Forests perform a number of biosphere ecological functions, they are a biodiversity reserve and are considered as a necessary component of the landscape (Rogers and Runion, 1994; Gilvear and Bradley, 2000; Hryhora and Solomakha, 2005; Zhigalskiy, 2011; Saltyikov, 2014; Falk et al., 2006; Ma et al., 2017). For the North East of Ukraine, forests are the main ecological framework of the territory. A great deal of attention has been paid to their preservation: over the past 25 years a number of nature reserves have been created: national natural parks, nature reserves and others, in which the study of forest ecosystems is of particular importance (Onyshchenko et al., 2012).

Plants that are part of the grass-shrub tier of forest ecosystems differ in their peculiar and rather highly-specific biological characteristics. They have special environmental requirements for growth. The stability of the herbaceous-bush tier depends on the fulfilment of these conditions and on the mechanism of controlling the natural regeneration of tree species and the stability of the forest ecosystem in general. The above-ground live cover of forests serves as an important indicator of ecosystem status, and of biological integrity and its susceptibility to various kinds of natural and man-made

loads (Anenkhonov et al., 2015; Tessler et al., 2016). The concentration of nitrogen and phosphorus in the leaves of forest grasses is 30% higher than in the leaves of trees, the concentration of magnesium is 2 times higher, and potassium is 3 times higher than in the leaves of trees. More than 20% of biomass and a significant supply of nutrients are in the litter layer, which is most organically associated with the tier of forest herbs.

The plant cover of forest phytocoenoses has a complex organization. It is multi-tier, characterized by a clear parcel structure, dynamic and clearly responsive to anthropogenic actions. Human civilization entered the 21st century in the context of the growing global environmental crisis (Shackleton and Pandey, 2013; Matsuura et al., 2014; Kasper-Pakosz et al., 2016; Angelstama et al., 2017; Jürgens and Bischoff, 2017). One of the important components of the system of conservation measures for forests and the biosphere as a whole is the expansion of the area of natural protected areas, which in the long term should form a single planet-wide ecological network (Fontaine et al., 2011; Mapping, 2013; Poisot et al., 2016). Such a network is intended to stabilize the natural environment, maintain biodiversity (Albouy et al., 2014; Zhang et al., 2017) and provide comfortable living conditions for people in any region of the planet.

Species of plants of the herbaceous-shrub layer in forest ecosystems have a significant influence on the initial stages of the natural regeneration of all tree species (Sklyar, 2012; Thompson et al., 2012; Bozzano et al., 2014; Peralta et al., 2014). That is why long-term studies of the state and structure of populations of herbaceous plant species of forest ecosystems are a scientific problem of high priority.

Monitoring of the state of phytopopulations on the basis of a comprehensive concept of their sustainability can only be effective provided there is an assessment not only of the number but also the ontogenetic and vital structure of the population, and for a significant number of plant species a gender structure should be also assessed. Even having these data, monitoring of materials may not be reliable because of the absence of information on the nature of the relationship of this population with other types of ecosystem and information on hourly trends of dynamics (Burkle et al., 2013; Grzybowski and Juśkiewicz-Swaczyna, 2013; Higa et al., 2013; Bartomeus et al., 2016; Auffret et al., 2017).

The purpose of this study was to conduct a comprehensive monitoring of populations of *Asarum europaeum* L. in forest ecosystems of the North-East of Ukraine.

Materials and methods

The research covered populations of *A. europaeum* L. (European wild ginger), a species typical of the typical forest ecosystems of the North-East of Ukraine. Field studies were conducted during the growing seasons 2004–2015.

By the level of preservation of natural vegetation, the North East of Ukraine ranks first among the lowland regions of Ukraine, with one of the highest percentages of forested areas, up to 29%. This is a unique region for the representation of biodiversity, as well as a focal point for specific postglacial vegetation and flora, including glacial relics (Andriyenko et al., 2006).

Forest ecosystems of the North-East of Ukraine play an ecological and stabilizing role, and also have a high sociological value. In terms of Ukraine's geo-botanical zoning, its northeastern part is located in the Chernihiv-Novgorod-Siversky (Eastern Polesia) region and includes seven districts (Ripkin-Dobryansky, Horodnyansk, Shchorsko-Semenivsky, Novgorod-Siversky-Ponomirsky, Shostka, Chernihiv-Sosnitsky, Olishevsky-Koropsky) (Didukh and Shelyah-Sosonko, 2003).

A characteristic feature of the studied region is the high level of preservation of natural complexes and low level of cultivation of the territory (this does not exceed 39%) (Polyakov et al., 2005).

Currently, within the territory of the north-eastern part of Ukraine, about 65 thousand hectares are included to the nature reserve fund (including almost 19 thousand hectares of forests), where rare species of plants and rare phytocoenoses are protected. After the forest ecosystems were given environmental protection status, the issue of ensuring their sustainable existence was particularly acute.

Thus, in terms of conservation of natural vegetation, the territory of the North-East of Ukraine, the area of which is about 32,000 km², is the key territory within the left-bank part of Ukraine. In general, the region has a higher forested area, combined with a uniform distribution of forest cover.

For the characterization of forest ecosystems, standard methods of ecology, geobotany and forestry were used (Kovalenko, 2015). Also, we used study plots of 400 m², and for detailing of the condition of the living surface layer we used 100 m² trial plots.

According to the results of the survey of plots of the size of 50 x 50 cm we obtained data on the number and density of individuals in populations (Gorb and Gorb, 1999). Study plots were located within the territory of a particular association in random order.

In assessing plant growth, dynamic metric parameters were used. They show the rates of growth and accumulation of bioproducts over a period of time. In our study, we made repeated measurements of all static metric parameters which were needed to calculate dynamic, morphometric parameters at intervals of ten

days. This work was carried out three times during the growing season. The following formulae have been used:

$$AGR = (W2 - W1)/T$$

$$AGRA = (A2 - A1)/T$$

$$RGR = (Ln W2 - Ln W1)/T$$

$$RGRA = (Ln A2 - Ln A1)/T$$

where the indices 1 and 2 correspond to two time-related morphometric records, and T is the time interval between these records, which, as noted above, was taken in our studies for ten days.

The overall progress of the productive process of plants is calculated as net assimilation, or, as it is sometimes called – the net productivity of photosynthesis. It is based on the following formula:

$$NAR = [(W2 - W1)/T] * [(Ln A2 - Ln A1)/(A2 - A1)]$$

With this method of calculating of net assimilation, the main focus is made on the accumulation of dry matter in the process of photosynthetic apparatus.

The following indices were used to estimate the total ontogenetic status of populations: Index innovation – I_{inn} (Index of renewal), Index senilis – I_{sen} (Aging index) and Index generative – I_{gen} (Index of generativity) (Kovalenko, 2015). They were calculated using the following formulae:

I_{inn} – the ratio of pregenerative partial shrubs to their total number:

$$I_{inn} = \frac{\sum_{i=1}^p \sum_{j=1}^v \sum_{k=1}^s n_{ijk}}{\sum_{i=1}^p \sum_{j=1}^v \sum_{k=1}^s n_{ijk}} * 100,$$

where p , v , s are age states of partial bushes in standard notation. In the index of renewal, the proportion of the pre-generative ramets of the clone indicates its active growth, which occurs by capturing a new territory;

I_{sen} – the ratio of partial bushes of ontogenetic states g_3 , ss and s to their total number:

$$I_{sen} = \frac{\sum_{i=1}^p \sum_{j=1}^v \sum_{k=1}^s n_{ijk}}{\sum_{i=1}^p \sum_{j=1}^v \sum_{k=1}^s n_{ijk}} * 100;$$

I_{gen} – the ratio of the number of young generative partial shrubs (g_1 , g_2) to their total:

$$I_{gen} = \frac{\sum_{i=1}^p \sum_{j=1}^v \sum_{k=1}^s n_{ijk}}{\sum_{i=1}^p \sum_{j=1}^v \sum_{k=1}^s n_{ijk}} * 100;$$

I_{aet} – as a proportion of Index senilis to the Index of innovation of the population:

$$I_{aet} = I_{sen}/I_{inn}.$$

The proportion of generative ramets of a clone is its generativity. It is higher where the conditions of plant growth are optimal, and the ramets quickly go into the generative phase and retain the ability to grow annually for several years.

In calculating the statistical parameters of plant individuals and populations we used the ANOVA. The content analysis consisted of only statistically significant ($P < 0.05$) results.

Results

A. europaeum is a perennial grassy plant with a creeping rhizome and reaching 5–10 cm in height. The stalk is creeping, fluffy and short. The leaves are round and kidney-shaped. Flowers are single. The perianth is fine. The fruit is a six part capsule. One generative individual produces up to 100 seeds a year. The plant is characterized by various forms of zoochory (seed dispersal by animals). It blossoms in April – May, the seeds mature in June. It grows in shady broadleaf and mixed forests. It prefers fresh, moist, moderately humus, neutral or light-grained soils (Gorb et al., 2000; Marian et al., 2011).

Populations of this species often dominate in the lower tiers of broadleaf and mixed forests in the North-East of Ukraine. *A. europaeum* is a perennial polycarpic herb, a typical oak companion. In forests habitats the seeds of *A. europaeum* sprout in spring or autumn. Type of germination is above ground. The root system consists of adventitious roots, whose length is from 3 to 40 cm. The main root is well developed, but subsequently it dies. The roots have endotrophic mycorrhiza, in sod-podzolic and grey forest soils they penetrate to a depth of 10 cm. The rhizomes are plagiotropic, of brown colour, and grow from the axillary buds of monocyclic

shoots. Growth of rhizomes is sympodial. The bulk of the rhizomes lie at a depth of 1–2 cm. Shoots, which can be up to 15-years-old, are formed on rhizomes up to 5 cm long. Clones are formed from partial shrubs, which, in turn, are formed on the rhizomes of the axillary buds. The life span of a separate partial shrub is up to 9 years. Up to flowering, the aboveground shoot increases monopodially. Renal buds develop in the lower middle of the assimilation leaf (Steinhübel, 1972; Grimme, 1984). The number of lateral branches is 2–4. Formation of leaves in *A. europaeum* occurs on the basis of annual growth. Leaves of hoof buds are of the renal form, chapped, pubescent. In the forests of the region, there are usually formed two middle assimilating leaves with green, whole-length plates up to 5 cm long and up to 6 cm wide in *A. europaeum*. The length of the slightly curved lowered petioles reaches 10 cm. *A. europaeum* is a summer-winter plant. The leaves remain green in winter, the life span of a separate leaf is 14–16 months. The leaves

have two peaks of photosynthesis: in spring, it occurs until the leaves appear on the trees and in autumn it occurs at the end of the vegetation season. At 5–7 years of life of a partial bush *A. europaeum* begins flowering, which is more abundant in well-lit locations. Since then, the growth of plants becomes sympathetic. In the forests of the North East of Ukraine, *A. europaeum* blooms in late April – early May. Flowers are self-pollinating, but small insects also help in the pollination of flowers. The duration of flowering is about 20 days. The fruit of *A. europaeum* is a fleshy syncarpum box. In each nest, the ovary has 4 seeds. The fruit is cracked. Seeds are triangular-egg-shaped with appendage up to 4 mm in length and about 2 mm in width. Seeds ripen in June – July. *A. europaeum* is a mesophyte, shadow-tolerant.

On the basis of personal field geobotanical descriptions and literary data (Trass, 1976; Kovalenko, 2015) the stages of *A. europaeum* ontogeny are presented Fig. 1).



Fig. 1. Stages of ontogeny *A. europaeum*: *p* – seedling; *j* – juvenile; *im* – immature; *v* – virginal; *g*₁ – young generative; *g*₂ – average generative; *g*₃ – old generative; *s* – senile plant

The average indicators of projective cover and density of populations of the investigated species of herbaceous-shrub-tree plants of the North-East of Ukraine, as one of the most important population parameters, are given in Table 1. These data were obtained from the results of the survey of 50 x 50 cm plots. The study plots were located in the territory of a particular association in a random manner.

Table 1
Population parameters of *A. europaeum*

Forest phytocenoses (subformation)	Projective cover, %	Plant density, pcs/m ²
Querceta roboris	51.8 ± 3.14	28.6 ± 0.77
Pineta sylvestris	57.3 ± 2.84	30.9 ± 1.12
Acereto (platanoiditis) – Querceta (roboris)	51.4 ± 3.56	38.7 ± 1.23

According to the time gradient, depending on meteorological conditions, the projective cover and the average population density of the plants (to a lesser extent) vary. However, these variations are much smaller than in meadow groupings. Substantially, these factors are also influenced by anthropogenic factors.

To study the growth and productive process of plants, of course, the morphometric method is one of the most promising. (Radford, 1967; Květ et al., 1971; Hunt, 1978; Chiariello et al., 2000). Depending on the ecological-cenotic conditions, the morphometric parameters of the main vegetative and generative organs can vary with statistically significance, as the morphological struc-

ture of the forest herbs is variable and flexible. Average growth rates are well disclosed in such indicators as absolute growth rate (AGR), relative growth rate (RGR), absolute leaflet formation rate (AGRA) and net assimilation (NAR).

Growth and formulation were studied in three subformations: Querceta roboris, Pineta sylvestris, Acereto (platanoiditis) – Querceta (roboris): size of total overground phytomass of plants, phytomass and leaf area, height of the ramets of *A. europaeum* (Fig. 2). In parallel with the dying in the beginning of July of the previous year's leaves, which in the conditions of forest ecosystems are alive until the end of June – July, there was a decrease in the total aboveground phytomass, as well as phytomass and leaf area of *A. europaeum* individuals. In the period from May to November there was a natural increase of all parameters that were measured in the ramets. In the subformation of Acereto (platanoiditis) – Querceta (roboris), there was an earlier die-out of the previous year's leaves, which is associated with higher illumination of the herb-shrub tier compared with other subformations, in which the thickening of the *Corylus avellana* L. substrate contributes to shading. In the subformation of Acereto (platanoiditis) – Querceta (roboris) the measured morphological parameters of *A. europaeum* individuals were lower than in other subformations.

Average growth rates of *A. europaeum* in different subformations were similar. However, the absolute growth rate (AGR) and the absolute rate of formation of the leaf surface (AGRA) were higher in the subformation of Querceta roboris, which corresponds

to higher statistical parameters of *A. europaeum* in this subformation. Other morphological parameters showed practically no differences in the subformations under investigation, but the net assimilation index was somewhat higher in the subformation of *Querceta roboris*. The obtained results indicate that in the subformation *Querceta roboris* the most optimal conditions for the growth and

development of *A. europaeum* in the conditions of the North-East of Ukraine are formed. The study of the ontogenetic spectra of *A. europaeum* populations was carried out on the basis of a sample of more than 3 dozen partial shrubs and was carried out in three subformations: *Querceta roboris*, *Pineta sylvestris*, *Acereto (platanoiditis) – Querceta (roboris)*.

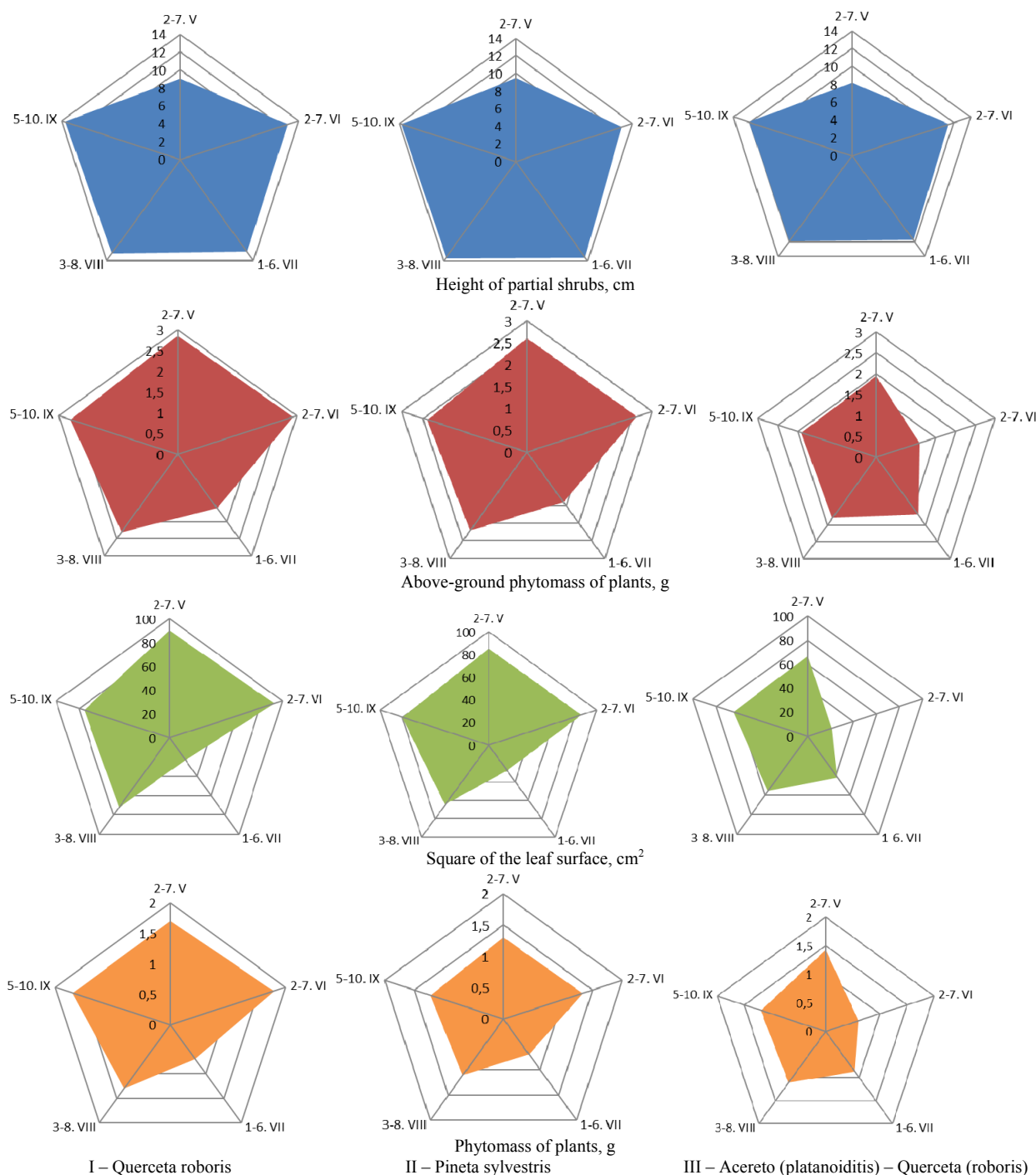


Fig. 2. Ecological condition of growth and formation of *A. europaeum* in the studied subformations

The populations in the subformation of *Querceta roboris* and *Pineta sylvestris* were fully-membered, and in the subformation *Acereto (platanoiditis) – Querceta (roboris)* were unfull with the fallout of seedlings and juvenile plants (Fig. 3). Senile bushes were absent. The population of *A. europaeum* in the subformation of *Pineta sylvestris* was left-sided with the peak of the number on pregenerative partial bushes. This is the youngest population of the three analyzed: it has the highest Index innovation value and the lowest Index senilis value. The index of the youngest population is

0.14 while the Index generative is 45.0% (Table 2). The population of *A. europaeum* in the subformation of *Querceta roboris* was more mature. Index aetas here is 0.19, the age range of the left-hand side with the peak on the partial bushes g₁. Index generative of this population is higher and reaches 55.4%. In the population with the subformation *Acereto (platanoiditis) – Querceta (roboris)* Index aetas is significantly greater than one and equals 2.35. Naturally, such a population has a high Index generative, which is 68.5%. The analysis of the vitality structure of *A. europaeum* populations

was carried out on the basis of a sample of more than 3,000 partial shrubs, in particular in subformations Querceta roboris, Pineta sylvestris, Acereto (platanoiditis) – Querceta (roboris). The key signs of vitality were: total phytomass (W), leaf area (A) and reproductive effort (RE₁).

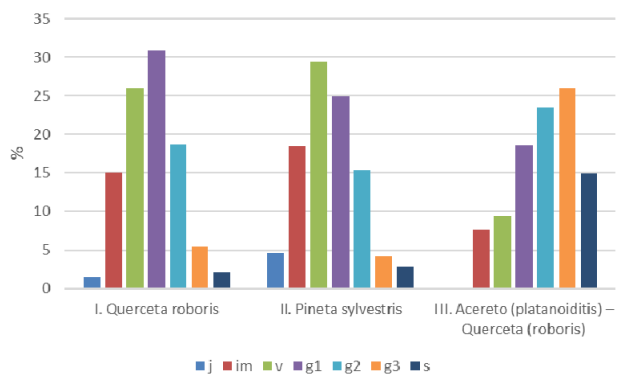


Fig. 3. Ontogenetic spectrum of populations of *A. europaeum* in subformations Querceta roboris, Pineta sylvestris and Acereto (platanoiditis) – Querceta (roboris)

Table 2
Ontogenetic indices of *A. europaeum* populations

Subformations	I _{inn}	I _{sen}	I _{gen}	I _{act}
Querceta roboris	43.4 ± 3.17	8.1 ± 0.45	55.4 ± 2.77	0.19 ± 0.009
Pineta sylvestris	53.2 ± 4.66	7.4 ± 0.37	45.0 ± 2.45	0.14 ± 0.003
Acereto (platanoiditis) – Querceta (roboris)	17.6 ± 1.88	41.3 ± 1.65	68.5 ± 2.25	2.35 ± 0.117

It turned out that of the three studied populations of *A. europaeum*, one of the subformations of Querceta roboris was flourishing with a quality factor Q equal to 0.35 and the other two were in equilibrium with Q values of 0.21 and 0.29, respectively. The statistical probability of the estimates obtained was in the range of 50.0% to 99.5% (Table 3).

Table 3
The vital structure of *A. europaeum* populations

Subformations	Percentage of individuals by class, %			Quality index Q	Type of the population	Level of statistical accuracy, %
	A	B	C			
Querceta roboris	31	38	31	0.35	flourishing	50.0
Pineta sylvestris	38	20	42	0.29	equilibrium	99.5
Acereto (platanoiditis) – Querceta (roboris)	24	17	59	0.21	equilibrium	70.0

It should be mentioned that the population of *A. europaeum* of the lower vitality in the subformation Acereto (platanoiditis) – Querceta (roboris) was the oldest in ontogenetic composition and had the highest generative index – 68.5%.

Apparently, the vital structure of the *A. europaeum* populations tends to decrease as the populations age.

Discussion

Based on the average growth rate of plants, for *A. europaeum*, the equilibrium of morphogenesis is determined during plant ontogenesis. This was previously noted by Zakamskaya and Zhukova (2000), with age the variability of the main features of the morphometry of the plants in the partial shoots of this species decreased. This pattern was also followed in our studies. Usually, the largest increments of length of shoots are characteristic of generative plants (Tetryuk, 2000).

There is a reason to believe that populations of *A. europaeum* with high values of Index innovation (subformation of Querceta roboris and Pineta sylvestris) will progressively develop in the study group of phytocoenoses.

In the oldest population (subformation Acereto (platanoiditis) – Querceta (roboris)), the age spectrum is centered with a peak on generative partial bushes. This is the population of *A. europaeum*, which is the longest established in the maple-oak forests of the region. Such populations may be characteristic of phytocoenoses close to the climax state. Thus, in the forests of the Altai, the populations of *A. europaeum* were of a normal type with a predominance of generative individuals. Such populations were stable, they had active vegetative and seed reproduction (Yablokova, 1984). As with the eggplant, the age of the population of *A. europaeum* is related to the history of the forest groups in the region. According to Shestakova et al. (1991), in birch forests populations of *A. europaeum* are, as a rule, fully-membered with a predominance of pregenerative and post-generative partial shrubs.

Populations of *A. europaeum* decrease in vitality in a number of subformations: A – Querceta roboris, B – Pineta sylvestris, B – Acereto (platanoiditis) – Querceta (roboris). Vitality decreased from 0.35 to 0.21. In this plant, the history of the decline in the population’s vitality was both a change in the composition of the tree stands and a decrease in its density value from 0.7 to 0.5. On the Landolt scale, *A. europaeum* is a shade loving plant with an optimum development in 10% illumination.

Conclusions

As a result of comprehensive monitoring surveys of populations of *A. europaeum* in forest ecosystems of the North-East of Ukraine, we elaborated the main parameters for determining the level of biodiversity of the population. These include the following: the number and density of individuals in the population, growth parameters, ontogenetic and vital structure, ontogenetic indices. It was established that the populations of *A. europaeum* are most characteristic for oak, pine and maple-oak subformations. By ontogenetic type, they are normal and vary from mature to aging. All three populations have a fairly high generative capacity. According to the vital type one population is flourishing, the other two are equilibrium.

References

Albouy, C., Velez, L., Coll, M., Colloca, F., Loc’h, F., & Mouillot, D. (2014). From projected species distribution to food-web structure under climate change. *Global Change Biology*, 20, 730–741.

Andriyenko, T. L. (2006). Fitoriznomanityta Ukrayins’koho Polissya ta yoho okhrona [Phylodiversity of Ukrainian Polissya and its protection]. Phytosociocenter, Kyiv (in Ukrainian).

Anenkhonov, O. A., Korolyuk, A. Y., Sandanov, D. V., Liu, H., Zverev, A. A., & Guo, D. (2015). Soil-moisture conditions indicated by field-layer plants help identify vulnerable forests in the forest-steppe of semi-arid Southern Siberia. *Ecological Indicators*, 57, 196–207.

Angelstam, P., Khaulyak, O., Yamelynets, T., Mozgerisd, G., Naumova, V., Chmielewski, T. J., Elbakidzea, M., & Manton, M. (2017). Green infrastructure development at European Union’s eastern border: Effects of road infrastructure and forest habitat loss. *Journal of Environmental Management*, 193, 300–311.

Auffret, A. G., Aggemyr, E., Plue, J., & Cousins, S. (2017). Spatial scale and specialization affect how biogeography and functional traits predict long-term patterns of community turnover. *Functional Ecology*, 31(2), 436–443.

Bartomeus, I., Gravel, D., Tylianakis, J. M., Aizen, M. A., Dickie, I. A., Bernard-Verdier, M. (2016). A common framework for identifying linkage rules across different types of interactions. *Functional Ecology*, 30, 1894–1903.

Bozzano, M., Jalonen, R., Thomas, E., Boshier, D., Gallo, L., Cavers, S., Bordacs, S., Smith, P., & Loo, J. (2014). The state pf the word’s forest genetic resources – thematic study. Food and Agriculture Organization of the United Nations, Rome.

Burkle, L. A., Marlin, J. C., & Knight, T. M. (2013). Plant-pollinator interactions over 120 years: Loss of species, co-occurrence, and function. *Science*, 339, 1611–1615.

Chiariello, N. R., Mooney, H. A., & Williams, K. (2000). *Plant physiological ecology*. Kluwer Academic Publishers, Dordrecht, Boston, London.

Didukh, Y. P., & Shelyah-Sosonko, Y. R. (2003). Heobotanichne rayonuvannya Ukrainy ta sumizhnykh terytoriy [Geobotanical zoning of Ukraine and adjacent land]. *Ukrainian Botanical Journal*, 60(1), 6–17 (in Ukrainian).

- Falk, D. A., Palmer, M., & Zedler, J. B. (2006). *Foundation of restoration ecology*. Island Press, Washington.
- Fontaine, C., Guimarães, P. R., Kefi, S., Loeuille, N., Memmott, J., Van der Putten, W. H., Van Veen, F. J. F., & Thébault, E. (2011) The ecological and evolutionary implications of merging different types of networks. *Ecology Letters*, 14, 1170–1181.
- Gilvear, D. J., & Bradley, C. (2000). Hydrological monitoring and surveillance for wetland conservation and management; A UK perspective. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere*, 25(7–8), 571–588.
- Gorb, S. N., & Gorb, E. V. (1999). Dropping rates of elaiosome-bearing seeds during transport by ants (*Formica polyctena* Foerst.): Implications for distance dispersal. *Acta Oecologica*, 20(5), 509–518.
- Gorb, S. N., Gorb, E. V., & Punttila, P. (2000). Effects of redispersal of seeds by ants on the vegetation pattern in a deciduous forest: A case study. *Acta Oecologica*, 21(4–5), 293–301.
- Grimme, D. K. (1984). Water relations of *Mercurialis perennis* and *Asarum europaeum* in their natural habitat. *Flora*, 175(4), 249–256.
- Grzybowski, M., & Juśkiewicz-Swaczyna, B. (2013). The structure of *Matteuccia struthiopteris* population in the nature reserve “Pióropusznikowy Jar”. *Polish Journal of Natural Sciences*, 28(2), 197–216.
- Higa, M., Nakao, K., Tsuyama, I., Nakazono, E., Yasuda, M., Matsui, T., & Tanaka, N. (2013). Indicator plant species selection for monitoring the impact of climate change based on prediction uncertainty. *Ecological Indicators*, 29, 307–315.
- Hryhora, I. M., & Solomakha, V. A. (2005). Roslynnist' Ukrayiny (Ekolohot-senotychyny, florystychyny ta heohrafichnyy narys) [Vegetation of Ukraine (Ecocoenotic, floristic and geographical essay)]. Phytosociocenter, Kyiv (in Ukrainian).
- Hunt, R. (1978). *Plant growth analysis*. E. Arnold, London.
- Jagodziński, M. A., Dyderski, M. K., Rawlik, K., & Kaźna, B. (2016). Seasonal variability of biomass, total leaf area and specific leaf area of forest understory herbs reflects their life strategies. *Forest Ecology and Management*, 374, 71–81.
- Jürgens, A., & Bischoff, M. (2017). Changing odour landscapes: The effect of anthropogenic volatile pollutants on plant – pollinator olfactory communication. *Functional Ecology*, 31, 56–64.
- Kasper-Pakosz, R., Pietras, M., & Luczajcorresponding, L. (2016). Wild and native plants and mushrooms sold in the open-air markets of South-Eastern Poland. *Journal of Ethnobiology and Ethnomedicine*, 12, 45.
- Kovalenko, I. M. (2015). Ekolohiya nyzhnikh yarusiv lisovykh ekosystem [Ecology of the lower tiers of forest ecosystems]. University Book, Sumy (in Ukrainian).
- Ma, J., Shugart, H. H., Yan, H., Cao, C., Wu, S., & Fang, J. (2017). Evaluating carbon fluxes of global forest ecosystems by using an individual tree-based model FORCCHN. *Science of the Total Environment*, 586, 939–951.
- Marian, M., Peter, A., Mihălescu, L., Vosgan, Z., & Matei, G. (2011). Allelopathic potential of *Asarum europaeum* toward *Lycopersicon esculentum*. *Analele Universității din Oradea - Fascicula Biologie*, 18(1), 39–44.
- Matsuura, T., Sugimura, K., Miyamoto, A., Tanaka, H., & Tanaka, N. (2014). Spatial characteristics of edible wild fern harvesting in mountainous villages in Northeastern Japan using GPS tracks. *Forests*, 5, 269–286.
- Onyshchenko, V. A., & Andriyenko, T. L. (2012). Fitoriznomanityta zapovidnykiv i natsional'nykh pryrodnykh parkiv Ukrayiny [Varieties of nature reserves and national natural parks of Ukraine]. Phytosociocenter, Kyiv (in Ukrainian).
- Peralta, G., Frost, C. M., Rand, T. A., Didham, R. K., & Tylianakis, J. M. (2014). Complementarity and redundancy of interactions enhance attack rates and spatial stability in host-parasitoid food webs. *Ecology*, 95, 1888–1896.
- Pfeiffer, T. (2007). Vegetative multiplication and patch colonisation of *Asarum europaeum* subsp. *europaeum* L. (Aristolochiaceae) inferred by a combined morphological and molecular study. *Flora – Morphology, Distribution, Functional Ecology of Plants*, 202(2), 89–97.
- Poisot, T., Stouffer, D. B., & Kéfi, S. (2016). Describe, understand and predict: Why do we need networks in ecology? *Functional Ecology*, 30, 1878–1882.
- Polyakov, M., & Teeter, L. (2005). The influence of regulatory forest policy tools on biodiversity measures for forests in Ukraine. *Forest Policy and Economics*, 7(6), 848–856.
- Radford, P. J. (1967). Growth analysis formulae – their use and abuse. *Crop Science*, 7(3), 171–175.
- Rogers, H. H., & Runion, G. B. (1994). Plant responses to atmospheric CO₂ enrichment with emphasis on roots and the rhizosphere. *Environmental Pollution*, 83(1–2), 155–189.
- Saltyikov, A. N. (2014). Strukturno-funktsionalnye osobennosti estestvennogo vozobnovleniya pridonetskih borov [Structural and functional features of the natural renewal of the Doneck forests]. Kharkov National Agrarian University, Kharkov (in Russian).
- Shackleton, C. M., & Pandey, A. K. (2013). Positioning non-timber forest products on the development agenda. *Forest Policy and Economics*, 38, 1–7.
- Sklyar, V. G. (2012). Tsenoticheskie svyazi podrosta klena ostrolistnogo i duba obyknovennogo v usloviyah Novgorod-Siverskogo Polesya [The cenotic relations of the young of a maple of acrylic and octopus in the conditions of the Novgorod-Siversky Polesye]. *Biological Bulletin of Bogdan Chmelnitskiy*, 3, 77–89 (in Russian).
- Steinhübel, G. (1972). K sezonnej dinamike hospodarenia asimilatmi u kopytnika európs-keho (*Asarum europaeum*). *Biologia (ČSSR)*, 27(7), 509–517.
- Tessier, N., Wittenberg, L., & Greenbaum, N. (2016). Vegetation cover and species richness after recurrent forest fires in the Eastern Mediterranean ecosystem of Mount Carmel, Israel. *Science of the Total Environment*, 572, 1395–1402.
- Teteryuk, L. V. (2000). Dinamika godichnykh prirostov kornevish *Asarum europaeum* L. na raznykh etapakh ontogeneza v podzone sredney taygi Respubliki Komi [Dynamics of annual growths of rhizomes *Asarum europaeum* L. at different stages of ontogenesis in the subzone of the middle taiga of the Komi Republic]. Program and theses of the reports of the All-Russian Council, 149–152 (in Russian).
- Thompson, R. M., Brose, U., Dunne, J. A., Hall, R. O. Jr, Hladysz, S., & Kitching, R. L. (2012). Food webs: Reconciling the structure and function of biodiversity. *Trends in Ecology and Evolution*, 27, 689–697.
- Trass, H. H. (1976). *Geobotanika* [Geobotany]. Science, Leningrad (in Russian).
- Yablokova, L. P. (1984). Vozrastnaya struktura tsenopopulyatsiy *Asarum europaeum* L. v chernykh lesakh Salairskogo kryazha [Age structure of the cenopopulations of *Asarum europaeum* L. in the black forests of the Salair ridge]. *Ecology*, 2, 43–47 (in Russian).
- Zakamskaya, E. S., & Zhukova, L. A. (2000). Osobennosti morfostruktury i morfologicheskaya izmenchivost kopyitnya evropeyskogo [Features morphostructure and morphological variability of the claw european]. Program and theses of the All-Russian Council, 84–86 (in Russian).
- Zhang, Y., Chen, H., & Taylor, A. (2017). Positive species diversity and above-ground biomass relationships are ubiquitous across forest strata despite interference from overstorey trees. *Functional Ecology*, 31(2), 419–426.
- Zhigalskiy, O. A. (2011). Otsenka biologicheskogo raznoobraziya lesnykh ekosistem Urala [Assessment of the biological diversity of forest ecosystems in the Urals]. *Bulletin of the Udmurt University, Series Biology*, 3, 13–22 (in Russian).