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STRUCTURE ANALYSIS OF A LOWLAND GRAZED *QUERCUS PUBESCENS* – *QUERCUS FRAINETTO* FOREST IN NORTHEASTERN GREECE

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Abstract

The aim of this study was to analyze the diameter structure of a *Quercus pubescens*-*Quercus frainetto* remnant forest in Northeastern Greece. The main disturbances acting in the study area are illegal cuttings and grazing. Two site types are found in the studied forest as a result of different grazing pressure. In site type A, where the grazing pressure is not as intense as in site type B, there are *Q. pubescens*-*Q. frainetto* degraded stands. Site type B is covered by *Q. pubescens* degraded stands. In each site type, a square plot of 100×100 m was established. Each plot was divided into four square subplots of 50×50 m (I, II, III and IV subplots), where the breast height diameter of all trees having a diameter equal and over 4 cm was measured. For I, II, III and IV subplots, I+II subplot and I+II+III+IV plot Anderson-Darling statistic was used in order to examine in which typical distribution their diameter distribution fits better. This procedure took place for the investigation of diameter structure spatial heterogeneity. Both species, in all plots, present low basal area and do not exhibit large diameters. The main conclusion of this study is that there is a significant spatial heterogeneity in the tree diameter structure. This heterogeneity is a combination of different forms of diameter distributions as well as of differences in basal area in the different plots. In site type B the spatial heterogeneity is more intense than in site type A if the form of the diameter distributions is considered as the main criterion for the heterogeneity assessment. On the other hand, the heterogeneity is higher in site type A if only the differences among the basal areas of subplots of 50×50 m are taken into account. The understanding of the structure of these rare for Greece stands will contribute to the protection and sustainable management of them as well as of analogous ecosystems.

Key words: degraded forest, oak forest, overgrazing, remnant forest, stand heterogeneity.

Introduction

Grazing can degrade a forest ecosystem (Evans 1998, FAO 2011). Anthropogenic disturbances such as grazing and illegal cuttings have affected the stand structures and dynamics of many forests in Greece.

According to Milios and Smiris (2001), illegal cuttings and grazing determined the structure of *Fagus sylvatica*-*Quercus dalechampii* sub-mountainous stands in the Rhodope Mountains of Northeastern Greece. Illegal cuttings and grazing shaped the structure of *Juniperus excelsa*

stands in the central part of Nestos valley in Northeastern Greece (Milios et al. 2007). The same disturbances influenced the structure and regeneration of *Juniperus excelsa* stands in Prespa National Park in Greece (Stampoulidis and Milios 2010, Stampoulidis et al. 2013).

In Greece, oak forests are grazed (Bergmeier and Dimopoulos 2008, Papanastasis et al. 2009). In an open coppice oak forest of Northeastern Greece, species composition is strongly influenced by different intensities of grazing. In addition, the contribution of woody species was significantly increased when there was a protection from grazing (Kyriazopoulos et al. 2010). Goats affect negatively the growth of young oak shoots (Papachristou and Platis 2011). Chaideftou et al. (2009) found that grazing decreased the species' richness in the vegetation of a sub-Mediterranean oak forest. Tsitsoni (2003) reported that overgrazing combined with repeated fires can convert oak forests to barren land. However, grazing also affects oak ecosystems in other Mediterranean areas (Pulido et al. 2001, Plieninger 2007, Pardini 2009, Alias et al. 2010).

Quercus frainetto and *Q. pubescens* are common oak species of Greece growing in various elevations in pure and mixed formations (Boratynski et al. 1992, Christensen 1997). However, such lowland forests are very rare in Greece. According to Theodoropoulos (1996), *Q. pubescens* lowland forests in Greece are rare due to the conversion of forests to agricultural land, overgrazing, and illegal cuttings.

One of these rare forests is a degraded grazed *Q. pubescens*-*Q. frainetto* remnant forest found in Northeastern Greece. Milios et al. (2014) analyzed the regeneration of this forest in the context of grazing and referred that its stand structure is heterogeneous without having analyzed

diameter structure data.

The aim of this study is to analyze the stand diameter structure as well as to investigate the spatial heterogeneity of diameter structure in this rare forest that is under grazing pressure of domesticated animals. The understanding of the structure will contribute to the protection and sustainable management of them as well as of analogous ecosystems.

Materials and Methods

Study area

The study area is comprised of the remnants of a lowland *Quercus pubescens* Willd.-*Quercus frainetto* Ten. forest located in the southern part of Xanthi region, a few kilometers away from the seashore in Northeastern Greece (41°00' N, 24°55' E). It covers an area of approximately 284 ha with a low slope and an altitudinal range of approximately 27 to 70 m (Milios et al. 2014). Around the studied forest there is agricultural land (Batziou et al. 2017). The substratum is tertiary deposits (Schinas et al. 1995). The mean annual air temperature is 15.5 °C and the average annual precipitation is 675 mm (Papaioannou 2008).

The main disturbances acting in the study area are illegal cuttings and grazing. Two thousand one hundred thirty six sheep, 87 goats and 68 horses graze periodically in the area (data from regional district of Xanthi archives).

Two site types are found in the studied forest as a result of different grazing pressure. In site type A, where the grazing pressure is not as intense as in site type B, there are *Q. pubescens*-*Q. frainetto* degraded stands and the soil texture is sandy clay to loam. The trees of the

two species, in most cases, are mixed. Site type B is covered by *Q. pubescens* degraded stands. The soil texture in site type B is sandy loam to clay. Moreover, in the area of site type B there is an animal stockyard (Milios et al. 2014).

According to Milios et al. (2014) the stand structure in the studied forest appears heterogeneous. There are areas having sparsely scattered trees, places with rather dense groups of trees, locations covered by *Erica manipuliflora* Salisb., almost bare or bare of vegetation areas, as well as areas covered by grazed ground vegetation. They also mention that the basal area in site type A is about 6.3 m²/ha while in site type B is approximately 3.8 m²/ha.

Research Method

In 2006, in each site type, a square plot of 100×100 m was randomly established. Each plot was divided into four square subplots of 50×50 m (I, II, III and IV subplots), where the breast height diameter of all the trees having a diameter equal and over 4 cm was measured. This was made in order to examine the diameter distribution in adjacent areas. For all subplots including the I+II subplot and the I+II+III+IV plot (the sum of the four subplots of 50×50 m creates the plot of 100×100 m) Anderson-Darling statistic was used in order to examine in which typical distribution (triangular, Weibull, gamma, normal, lognormal, exponential, empirical, beta, uniform) their diameter distribution fits better. We used the I+II subplot and the I+II+III+IV plot since the first covers a double area than each of the I, II, III and IV subplots (and integrates I and II subplots), and the later covers a double area than the I+II subplot (and integrates it as well as the I, II, III and IV subplots). This approach

was used since we wanted to investigate whether the diameter distribution changes as the area of a subplot is doubled. Saghheb-Talebi and Schutz (2002) have also used subplots which were successively doubled in size in order to study the stand structure of beech stands in Iran. Moreover, the tree basal area was calculated for each subplot of 50×50 m in the two site types. For continuous distributions, Anderson-Darling test can be used to find the distribution that most closely fits the data. The distribution with the smallest value of Anderson-Darling statistic is the one that provides the closest fit (Anderson and Darling 1954). When examining fit statistics for distributions, larger *p*-values indicate higher statistical significance. As a general rule, *p*-values less than 0.05 indicate that the distribution may not provide a close fit to the data. However, a *p*-value is not always available for all tested distributions – taking this into account, we based our decision regarding the best fitted distribution on the value of Anderson-Darling statistic only. This procedure took place for the investigation of diameter structure spatial heterogeneity. In the present study the heterogeneity is considered as a combination of different forms of diameter distributions (resulting in differences in the distributions that fit better to them), with differences in basal area in the different subplots.

Results and Discussion

In total 221 trees were measured in the 100×100 m plot of site type A and 368 trees in the 100×100 m plot of site type B. In figures 1 and 2 the diameter distribution of the subplots and the plot in site type A is presented. In all subplots in *Q. pubescens* and in I, II, I+II subplots and I+II+III+IV

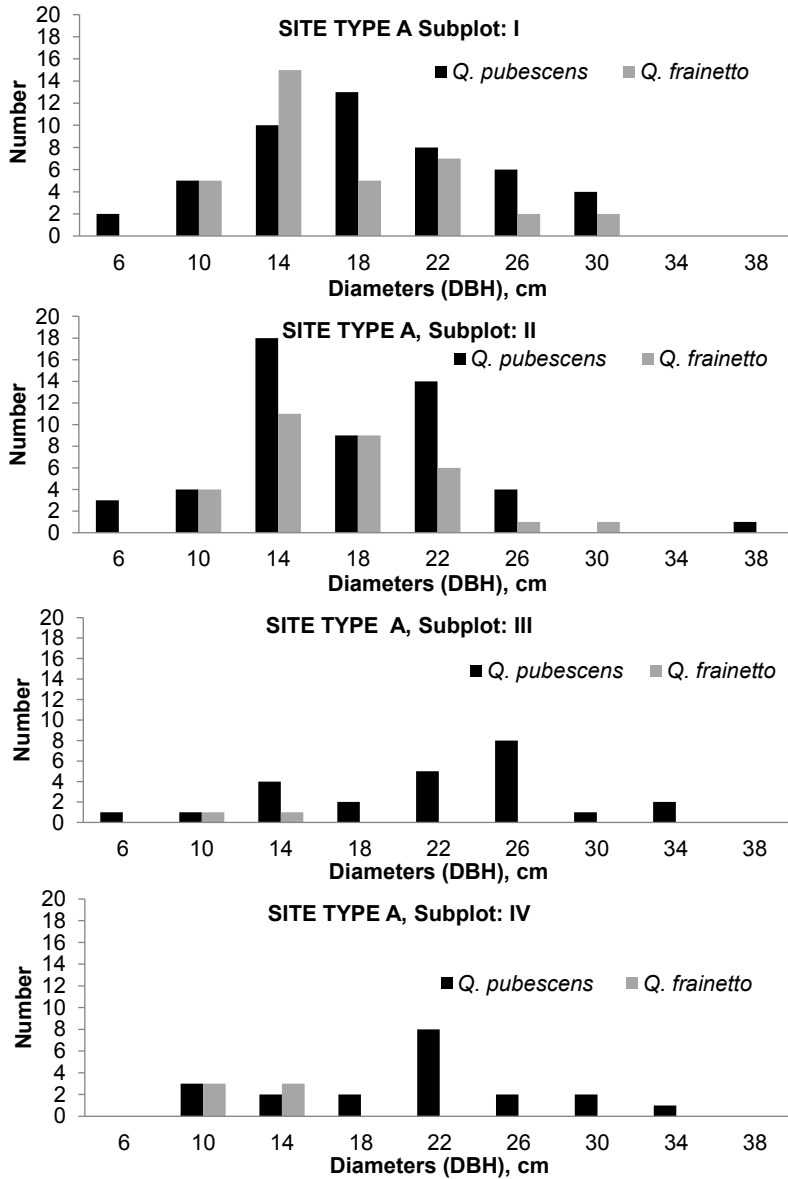


Fig. 1. Diameter distribution of *Q. frainetto* and *Q. pubescens* in subplots I–IV in site type A.

plot in *Q. frainetto*, the most trees appear between the classes of 14 and 26 cm. *Q. pubescens* is the dominant species in all subplots. In III and IV plots the participa-

tion of *Q. frainetto* is very small. On the other hand, in the subplots of site type B almost all trees are found up to the class of 14 cm (figs 3 and 4). In site type A, the

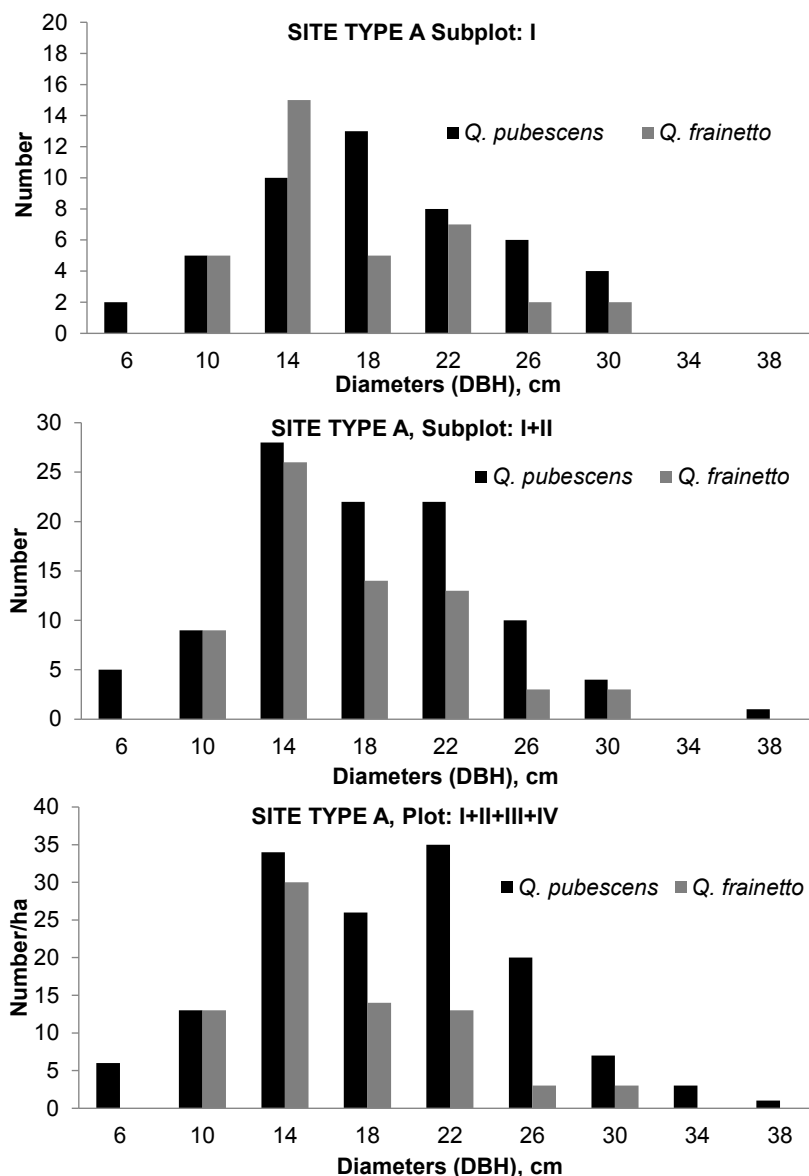


Fig. 2. Diameter distribution of *Q. frainetto* and *Q. pubescens* in subplots I, I+II and in plot I+II+III+IV in site type A.

larger trees of *Q. pubescens* appear in greater diameter classes compared to the largest trees of the species in site type B (figs 1 and 3). Moreover, a multi-stemmed

form of adult *Q. pubescens* trees is mainly observed in site type B (Batziou et al. 2017). This was not the result of a coppice silvicultural system. Milios et al. (2014)

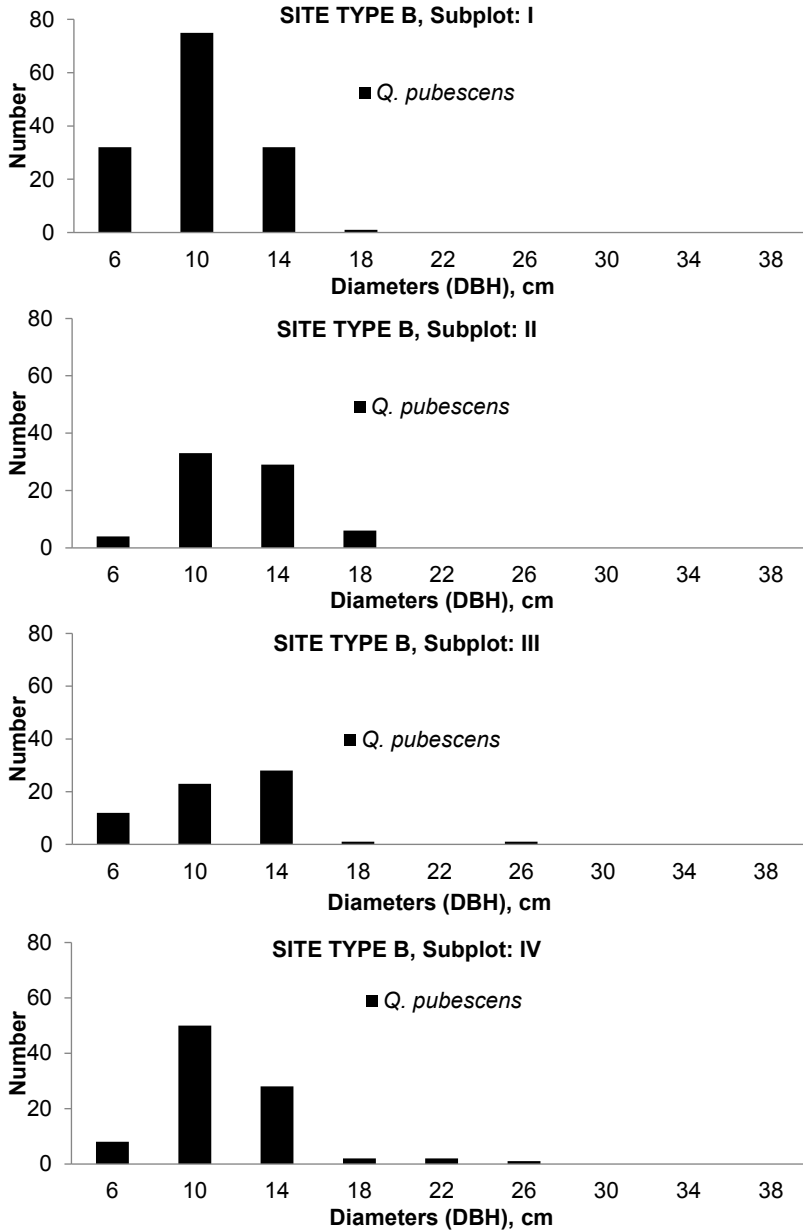


Fig. 3. Diameter distribution of *Q. pubescens* in subplots I–IV in site type B.

reported that in the study area, all examined regeneration plants of the two species with a height equal to or over 20 cm were sprouts. Most of them were multi-

stemmed (Batziou et al. 2017). It seems that this multi-stemmed form was retained mainly in the trees of site type B. Moreover, in some trees this form possibly is

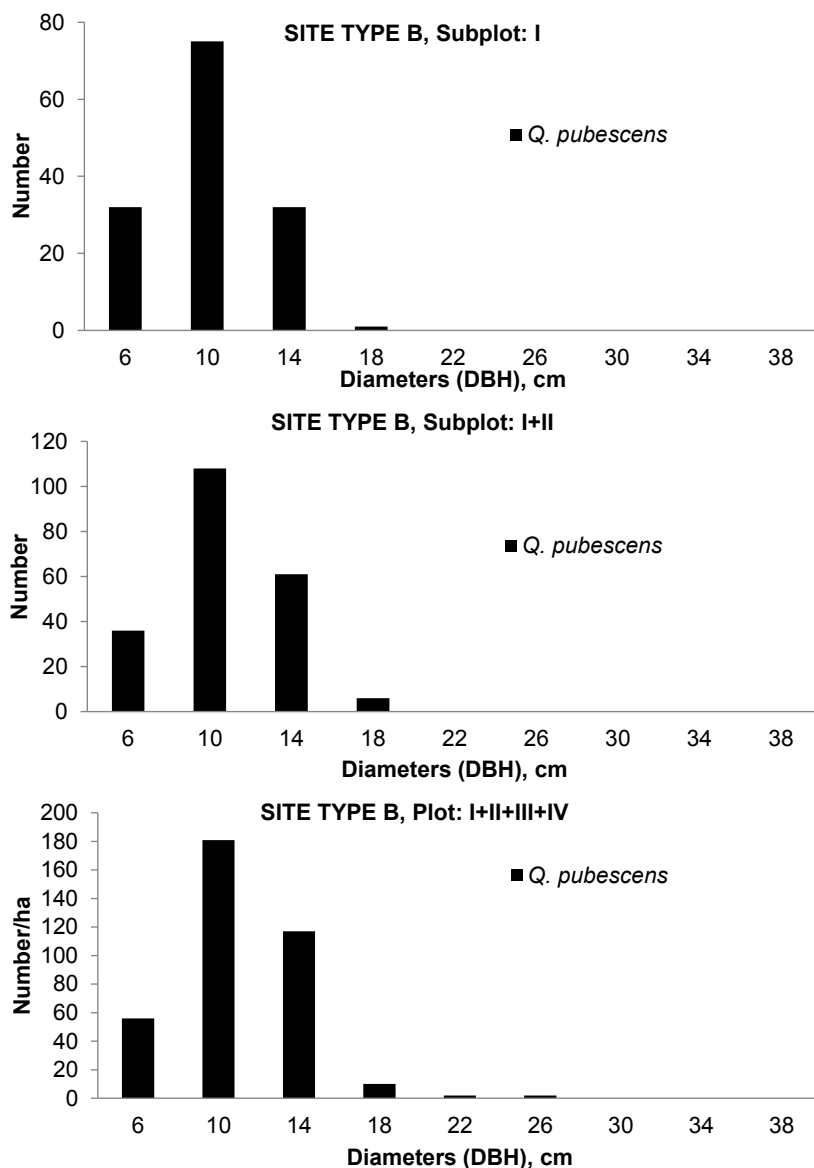


Fig. 4. Diameter distribution of *Q. pubescens* in subplots I, I+II and in plot I+II+III+IV in site type B.

the result of illegal cuttings.

In site type A, in all plots, the basal area is low and *Q. pubescens* exhibits higher basal area than *Q. frainetto*.

In site type A, in two of the subplots

(III and IV) triangular distribution fits better in *Q. pubescens* diameter distribution than the others. Moreover, regarding *Q. frainetto* in both subplots, Anderson-Darling statistic could not be applied, since

trees of the species appeared only in two classes (of 10 and 14 cm) (Fig. 1). On the other hand, in plot I uniform for *Q. pubescens* and triangular for *Q. frainetto* diameter distribution fit better than the others (Table 1). The corresponding distributions for plot II are exponential and uniform. In addition, there are differences among

the basal areas of I, II, III and IV subplots that range from rather significant to strong (Fig. 5). Finally, the distributions that fit better to the diameter distributions of I+II subplot and I+II+III+IV plot are exponential and uniform correspondingly for *Q. pubescens* and triangular in both of them for *Q. frainetto*.

Table 1. Typical distribution that fits better in the diameter distributions in site type A using Anderson-Darling statistic.

Subplots and plot	Species	Typical distribution	A (Anderson-Darling statistic)	p-value
I	<i>Q. pubescens</i>	Uniform	-0.75	0.999
II	<i>Q. pubescens</i>	Exponential	-1.02	0.430
III	<i>Q. pubescens</i>	Triangular	-2.52	Not available
IV	<i>Q. pubescens</i>	Triangular	0.37	Not available
I	<i>Q. frainetto</i>	Triangular	-1.96	Not available
II	<i>Q. frainetto</i>	Uniform	-2.05	0.870
III	<i>Q. frainetto</i>	-	-	-
IV	<i>Q. frainetto</i>	-	-	-
I+II	<i>Q. pubescens</i>	Exponential	-0.12	0.240
I+II+III+IV	<i>Q. pubescens</i>	Uniform	0.16	0.660
I+II	<i>Q. frainetto</i>	Triangular	-2.13	Not available
I+II+III+IV	<i>Q. frainetto</i>	Triangular	-1.99	Not available

In the case of site type B in each of I, II, III and IV subplots the distribution that fits better to their diameter distribution is different. In subplot I, it fits the triangular distribution, in subplot II the uniform, in subplot III the normal, and in the subplot IV fits the log-normal distribution. Moreover, in the diameter distributions of I+II

subplot and I+II+III+IV plot (Fig. 4) the distributions that fit better are uniform and triangular respectively (Table 2). Additionally, there are basal area differences among I, II, III and IV subplots. However, the total basal area in the subplots of site type B is in the most subplots lower than in site type A (in three of the four subplots) (Fig. 5).

Table 2. Typical distribution that fits better in the diameter distributions in site type B using Anderson-Darling statistic.

Subplots and plot	Species	Typical distribution	A (Anderson-Darling statistic)	p-value
I	<i>Q. pubescens</i>	Triangular	-1.21	Not available
II	<i>Q. pubescens</i>	Uniform	-0.23	0.150
III	<i>Q. pubescens</i>	Normal	0.57	0.800
IV	<i>Q. pubescens</i>	Lognormal	0.39	0.260
I+II	<i>Q. pubescens</i>	Uniform	-1.29	0.926
I+II+III+IV	<i>Q. pubescens</i>	Triangular	-1.25	Not available

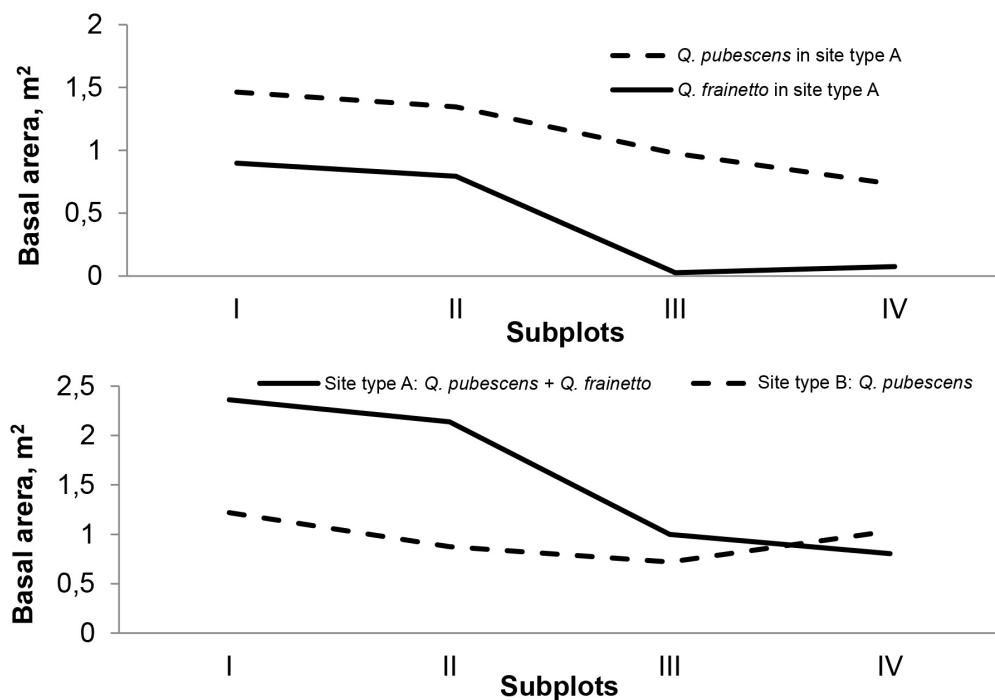


Fig. 5. Total basal area in subplots I–IV in both site types and basal area for *Q. frainetto* and *Q. pubescens* in site type A.

Both site types exhibit diameter structure heterogeneity. In site type B the spatial diameter heterogeneity is more intense than in site type A if the form of the distributions is considered as the main criterion for the heterogeneity assessment, since in all subplots of 50×50 m the distributions that fit better in their diameter distributions differ between each other. On the other hand, the heterogeneity is higher in site type A if only the differences among the basal areas of subplots are taken into account. The differences in basal area between the (sequential) adjacent subplots are greater compared to those of site type B (Fig. 5).

The different intensity of grazing and illegal cuttings led to the observed difference in stand structure heterogeneity. In site type B the intense disturbances

resulted in lower basal area and greater differences in the spatial arrangement of trees among the subplots of 50×50 m compared to site type A. Another reason for these differences might have been the rather worse site conditions that possibly exist in site type B than in site type A. Batziou et al. (2017) mentioned that in site type B possibly there is a different soil compaction compared to site type A. On the other hand the greater differences in the basal area between the (sequential) adjacent subplots in site type A compared to that of site type B are probably the result of greater differences in the intensity of illegal cuttings (which reduce the basal area of an area) between adjacent areas in site type A compared to that of site type B. Milios (2000a) referred that the different intensity of grazing and illegal cuttings

led to different development patterns and structures in *Ostrya carpinifolia* Scop. stands in the central part of Nestos valley in Northeastern Greece. Similarly, in the same wider area, different timing and (or) intensity of disturbances (like grazing and illegal cuttings) influenced development patterns and structures of mixed stands in the central part of the Rhodope Mountains (Milios 2000b). Smiris (1995) reported that in the northern part of Olympus Mountain in Greece grazing and illegal felling affected development patterns of mixed stands. Even though structural heterogeneity promotes biodiversity (Barnes et al. 1998, Lindenmayer and Franklin 2002), in the present study heterogeneity is so strong that there is a significant forest fragmentation which, in combination with the low basal area of the stands, constitutes a clear picture of degradation. If grazing and illegal cuttings stop the stand diameter structure will differentiate and the forest area will expand. According to Milios et al. (2014) in the studied forest, in the open areas (almost bare or bare of vegetation areas that alternate with areas covered by grazed ground vegetation) the oak regeneration density was 6917 plants/ha in site type A and 2667 plants/ha in site type B. As a result after the stop of grazing the open areas of the forest will be covered by trees (Milios et al. 2014) and the spatial heterogeneity will gradually decrease.

Conclusions

Both site types exhibit diameter structure heterogeneity. This heterogeneity is a combination of different shapes of diameter distributions resulting in differences in the distributions that fit better to them, with differences in basal area in the different subplots. In site type B the spatial hetero-

geneity is more intense than in site type A if the form of the distributions is considered as the main criterion for the heterogeneity assessment. On the other hand, the heterogeneity is higher in site type A if only the differences among the basal areas of subplots are taken into account.

In the present study structure heterogeneity is so strong that there is a forest fragmentation which, in combination with the low basal area of the stands, constitutes a clear picture of degradation.

The Forest service has to restore this forest.

Acknowledgments

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THE EFFECTS OF ALTITUDE ON MACRONUTRIENT CONCENTRATION IN BIRCH LEAVES (*BETULA PUBESCENS* EHRH. AND *B. PENDULA* ROTH) ALONG HIGH-ALTITUDE GRADIENT IN NORTHERN URALS

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Abstract

Latitude and altitude affect the geographical distribution of plant communities on Earth from the equator to the poles. While latitude has influence on the horizontal distribution, the altitude confines the vertical range of plant communities, shaping the floral composition and their eco-physiological features such as macronutrients that control the growth. In this research, the effects of different altitude gradients on plant macronutrients (N, P, K, Mg, Ca, Na) content in leaves of two different birch species (*Betula pubescens* Ehrh. and *B. pendula* Roth) distributed in the Northern Urals region were investigated for two years. Tree leaves were collected in growing seasons in 2006 and 2008, and all measured macronutrients concentration levels were compared according to altitude and year, respectively. As a result, leaf concentration of N and P were increased by altitude in Downy birch (*B. pubescens*), while the macronutrient concentration levels were decreased in Silver birch (*B. pendula*) species. In addition, although concentration of N, P, and K levels changed in both species, the N concentration level was not significantly changed in two years. Moreover, N, P, K, and Mg concentration levels in the leaves of Silver birch increased from 2006 to 2008. This reason was likely due to the later start of the growing season and higher percentage of humidity in 2006. Consequently, altitude gradients played a significant role on macronutrient contents of birch species' leaves.

Key words: ecological chemistry, highlands, micronutrients, nitrogen, plant productivity.

Introduction

Development of the plants and their ability to adapt to certain environment are very important for physiology, agronomy and forestry studies, because plant productivity mainly relies on the adaptability to specific soil and climatic conditions. The most important adaptation mechanism

of woody plants in extreme environmental conditions is related to evolution of many transformation ways of the plants. Physiological and biochemical studies allow a comprehensive analysis in terms of assessing resilience to adverse environmental conditions for woody plants (Pavlov 2006, Marakaev et al. 2006).

Nitrogen (N), phosphorus (P) and po-

tassium (K) are the macronutrients that are commonly studied for plant growth relations. Fluctuations in the content of these three elements in plants most strongly affect their growth and productivity. In addition, these three elements usually limit trees' radial increment. They are also considered as one of the indicators for site index in forestry. It is known that the ability of plants to absorb, accumulate and use chemical elements is genetically determined (Zhurbitsky and Lavrichenko 1982). Therefore, nutrient concentration level is mainly related to genus, as well as to species properties. However, within one genotype form, the pattern of plant absorption under the influence of external conditions can markedly vary. The concentration of elements in the substrate, and the associated ratio of chemical elements in the environment play a crucial role in productivity (Barsukova 1997).

Representatives of the genus *Betula* are one of the main forests forming species in Russia, which cover more than half of the total area among the deciduous forests (Drozdov et al. 2014). Silver birch and Downy birch are two important tree species for timber production in Russia. Due to their wide distribution in the country, birch species appeared as a good object to study the influence of environmental factors, such as soil and air temperature and humidity on the chemical composition of leaves. Downy birch is better adapted to drained peatlands, and it is a more common species than Silver birch. Especially on peatlands, these tree species are usually exposed to several nutritional problems including deficiencies of the main macronutrients (i.e., P and K) (Sarjala and Kaunisto 2002).

Doing investigation on variability of biochemical and physiological parameters

within the altitude gradients may be one of the approaches for identifying mechanisms of adaptation to environmental conditions. The altitude parameter, which is one of the ecological factors in forest ecosystems, may adversely affect plant growth due to the decrease in soil temperature and shortening of growing period by varying altitude (Coomes and Allen 2007). Previous studies show that nitrogen concentration in the leaves of Downy birch is increased by high-altitude gradient (Karls-son and Nordel 1988). It is assumed that the increased nitrogen concentration in leaves of high-mountain birch seedlings is genetically determined, and it has an adaptive value in a cold environment (Weihs and Karlsson 1999). Thus, nutrient concentration in leaves may be used as an important parameter to recognize nutrient cycling at ecosystem level which act as regulators of plant productivity, biomass accumulation, and decomposition processes (Rossato et al. 2015). However, our knowledge related to chemical variations among the adults that naturally regenerated birch trees in native populations has been limited.

The harsh climatic conditions put mountain ecosystems on a par with such 'extreme for life' coenoses as zonal tundra and arctic deserts contributed to the formation of similar features of high-latitude and highland biota. In terms of understanding the response of arctic/sub-arctic vegetation to climate change, the boreal forest-tundra ecotone represents a particularly important region. Because in this area, tree species are growing at a limited environmental condition (Hustich 1953).

The complex mutual relations among climatic, geochemical, and biotic factors determine the variability of the chemical

composition in plants (organic compounds and the chemical elements), and they may be defined by species properties (Mitrofanov 1977). Studies have shown a strong relationship between soil nutrient content and leaf nutrient concentration level. In a study, Rossatto et al. (2015) found significant positive relationships between soil P and plant leaf P concentration, as well as between soil Ca and plant leaf Ca concentration. However, the same study reported that there were not significant relations between soil and leaf K and Mg concentrations (Rossatto et al. 2015). In addition, the nitrogen condition in the soil limits the growth conditions by affecting the physiological activity of the plants (Da Silva et al. 2014). It is reported that soil nutrient content can be reflected in leaf nutrient concentration (Kimmins 2003).

Macronutrients (N, P, K, Mg, Ca, Na) considered to be particularly important for the tree growth and their life cycle. Therefore, in this research, we examined how the macronutrients concentration in the leaves of two different birch species changed over two years according to the altitudinal variations. We also observed the changing of macronutrient concentration levels annually depending on the zone in the highlands of the Northern Urals.

In this research, the effects of different altitude gradients on plant macronutrients (N, P, K, Mg, Ca, Na) concentration in leaves of two different birch species (*Betula pubescens* Ehrh. and *B. pendula* Roth) distributed in the Northern Urals region were investigated in 2006 and 2008. In other words, macroelement levels in leaves, i.e. plant productivity of two birch species in different mountain belts on sites with relatively severe climate and soil conditions have been observed.

Materials and Methods

The investigation area and species

Mount Konzhakovsky Kamen (59°37'9" N, 59°8'11" E) is the highest point of the southern part of the Northern Urals (1569 m). The climate of the region is cold, excessively humid and characterized by short and moderately warm summers, long and cold winters, and very early snow cover starting in the end of September. The vegetation period in the highland region of the Urals is significantly shorter than in the taiga zone (Gorchakovsky 1975). Downy birch widespread in mountain forests is replaced by a closely related mountain birch in the mountain-tundra belt (*Betula pubescens* var. *pumila* (L.) Govaerts) (Moiseyev 2008). The average wind speed during the year ranges from 2.4 to 4.5 m/s, and increases with altitude up to 8–9 m/s in the barren land. The warmth of the soil is very small. In summer, in the mountain tundra, only the most superficial layer of soil (5–8 cm) heats up to 12–15 °C. The air temperature decreases with increasing absolute height by 0.5°C, for every 100 m of height (Gorchakovsky 1975).

Description of the five study sites:

- The control site (207 m a.s.l.): thickness of the snow cover – 60 cm, annual precipitation – 600–700 mm/y, forest type: pine forests, dark-coniferous and birch forests.

- The lower (423 m a.s.l.) and upper boundaries (555 m a.s.l.) of the mountain forest belt: thickness of the snow cover – 70–80 cm, annual precipitation – 500–700 mm/y, forest type: dark coniferous taiga, birch forests.

- Subgoltsy (830 m a.s.l.): thickness of the snow cover – 200 cm, annual precipi-

tation – 1200 mm/y, forest type: larch woodlands, fir-spruce forests, cedar forests.

- Mountain-tundra (1117 m a.s.l.): thickness of the snow cover – 20 cm, annual precipitation – 1200 mm/y, forest type:

rocky, moss, grass-moss tundra.

For the research, meteorological data recorded at Serov meteorological stations (Fig. 1) were used. Serov station is located 78 km east of the investigation

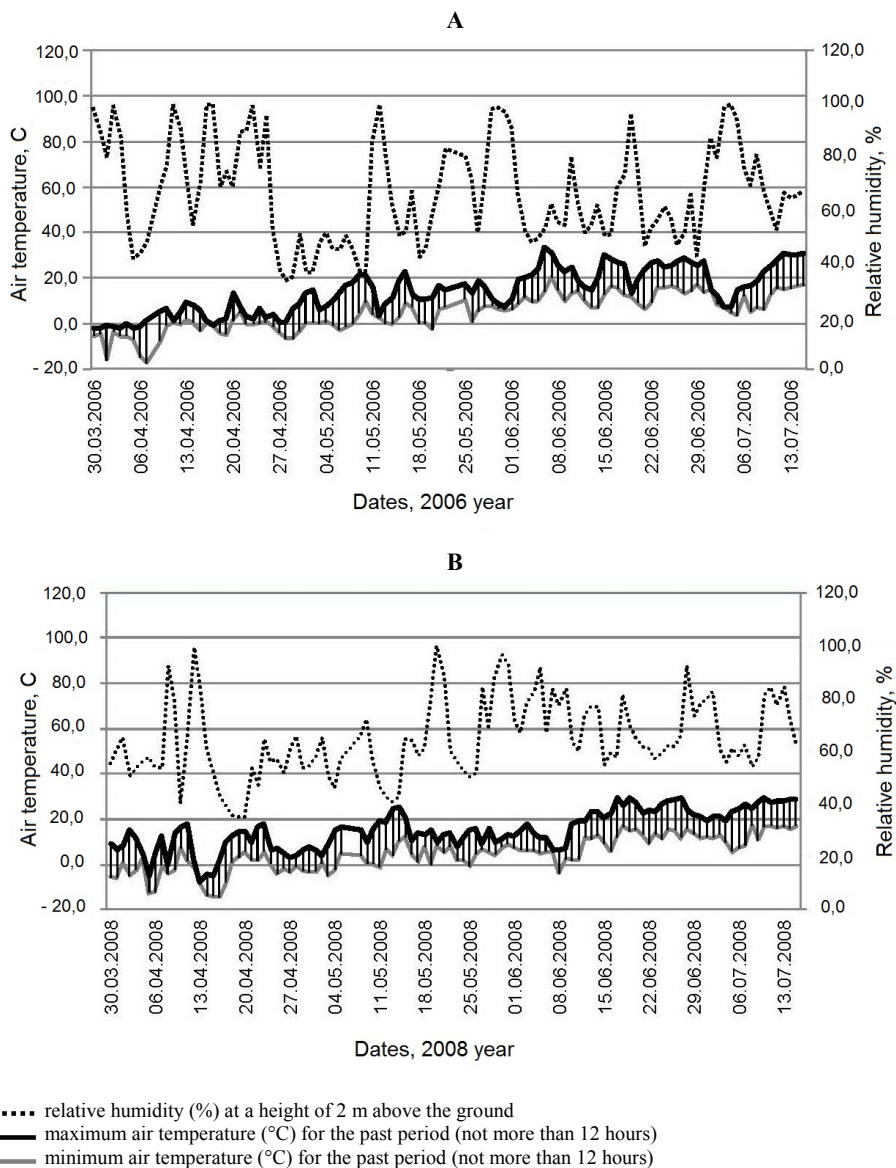


Fig. 1. Average daily air temperatures (°C), and daily relative humidity (%) near Serov city from 30 March to 15 July, years 2006 (A) and 2008 (B).

Note: the distance from Mount Konzhakovsky Kamen – 78 km; the Meteorological Station of Serov city provided data.

area at an elevation of 134 m a.s.l. The average temperatures from 30 March to 15 July were 9.9 °C in 2006 and 10.1 °C in 2008, while the relative humidity was 66.5 % and 65.5 % in 2006 and in 2008, respectively.

Leaf sampling

The studies were carried out in 2006 and 2008 in all mountain belts of Mount Konzhakovsky Kamen, and the control site (the most typical type of forest for this area). The forests selected for this research are naturally regenerated, mixed Silver birch and Downy birch. The trees of Downy birch were selected in the control site, and at the lower and upper boundaries of the mountain forest belt, in the subgoltsy and tundra belts. Silver birch trees were selected at the control site at the lower and upper limits of the mountain forest belt, because Silver birch does not grow in the upper belts. Leaves were collected in 2006 and 2008 in the second half of July.

To investigate individual variability, 15 trees of both species were marked at each mountain belts; leaf samples were taken from each of the 15 selected trees. Because the chemical composition of leaves is influenced by leaf development, we used leaves from short shoots to ensure that they were of the same age. A total of 240 leaf samples were analysed. From each tree, leaves were collected from the top third of the canopy. The leaves were first dried at room temperature (23–25 °C), then at 60 °C for 24 h and ground and corrected on dry weight basis by drying at 105 °C for 24 h, placed individually into paper bags.

Total N was analysed by the Kjeldahl method (Kjeldahl nitrogen analyser UDK 152 – Velp scientifica). The analysis of

phosphorus was made spectrophotometrically from dry-ashed material with molybdenum blue (Anonymous 1990). The analyses of potassium, calcium, magnesium, sodium were performed using a flame atomic spectrophotometer (AA-300). The results were recalculated in the ratio of elements.

The resulting data was analysed using the method of statistical analysis in the program (Statistica 10 for Windows 10.0). Differences between species and between 2006 and 2008 were tested by Student's t-tests. Changes between mountain forest belts in the concentrations of macronutrients were tested by one-way ANOVA followed by Fisher's test ($p < 0.05$). The influence of climatic factors on the plant N, P, K, Ca, Mg, Na concentration of Downy birch and on the N: P: K ratio were analysed using an ANOVA model with year and altitude as factors.

Results and Discussion

The concentration of nutrients in the leaves of birch trees along the high-altitude gradient of the Northern Urals

The features of the accumulation of the macronutrients in the leaves of birch trees, the individual variability of macronutrients concentration along the altitude gradient of Mount Konzhakovsky Kamen, as well as interspecific differences are revealed. The foliar macronutrients concentrations of silver and Downy birch in different years and altitude belts were different. Distinctions between the species in the altitudinal gradient were identified. Our results show that the concentration of individual birch leaf macronutrients follows different patterns. The differences of the two birch species appear in the opposite direction

of accumulation of macro-elements along the altitudinal gradient.

The most significant trends were associated with changes in the content of nitrogen, phosphorus and potassium. In the nitrogen concentrations of Downy birch leaves, there were highly significant differences between the years, and between the mountain belts ($p < 0.05$). The nitrogen concentration in the leaves of Downy birch increased along the altitude gradient from control to tundra for both years (Fig. 2a). Despite significant between-year variability, trends were stable in 2006 and 2008. In 2006, the nitrogen concentration in the leaves of Downy birch increased along the altitude gradient from 22.04 ± 0.78 mg/g in the control, to 30.7 ± 1.5 mg/g in the tundra where it reached its maximum value (Fig. 2a). In 2008, the maximum nitrogen concentration found in the tundra belt was 39.1 ± 1.0 mg/g, which was significantly different from the other belts in the high-altitude series. At the lower boundary of the mountain forest belt, the lowest nitrogen concentration in the leaves was 27.7 ± 0.6 mg/g, indicating that no significant differences between this point and the control were found.

Unlike Downy birch, Silver birch showed a tendency to decrease of the macronutrients concentration in the leaves with increasing altitude. In both years, the nitrogen concentration in the leaves of Silver birch decreased along the altitude gradient from the control to the upper boundary of the mountain forest belt (Fig. 2a). The maximum nitrogen concentration in the leaves of Silver birch in 2006 found in the control was 24 ± 0.5 mg/g, which is not significantly different from the Downy birch ($p > 0.05$), the lowest – at the top (19.7 ± 0.6 mg/g) and lower (20.3 ± 0.4 mg/g) boundaries of the mountain forest belt. Nitrogen concentra-

tion in 2008 was 27.2 ± 0.7 mg/g in the control, and decreased to 25.7 ± 0.8 mg/g at the lower boundary of the mountain forest belt and to 24.0 ± 0.5 mg/g at the upper boundary of the mountain forest belt. The N concentrations in 2008 were higher than in 2006 for both species ($p < 0.05$). The nitrogen concentration in the tundra zone compared with the control increased by 26 % in 2006, and by 21 % in 2008 for Downy birch.

In contrast to the nitrogen concentration, the phosphorus concentration in the leaves of Downy birch showed no definite trends. In 2006, no significant differences between the belts were found, while in 2008 the phosphorus concentration fluctuated, and the differences of this indicator among the mountain belts were revealed (Fig. 2b). The maximum phosphorus concentration was found in the tundra belt (11.9 ± 0.4 mg/g), which is significantly different from the control (9.1 ± 0.4 mg/g), lower (10.6 ± 0.3 mg/g) and upper (6.8 ± 0.2 mg/g) of the boundaries of the mountain forest belt and the subgoltsy belt (9.5 ± 0.3 mg/g). The between-year comparisons showed the significant differences in phosphorus concentration at all points of the altitude range. In all cases, the phosphorus concentration in 2008 was significantly higher ($p < 0.05$) than 2006.

Silver birch has a tendency to decrease the phosphorus concentration with an increasing of the altitude, in contrast to the Downy birch (Fig. 2b). In 2006, in Silver birch, the phosphorus concentration decreased from control (8.4 ± 0.3 mg/g) to the upper limit of the mountain forest belt (5.8 ± 0.2 mg/g), and significantly differed between the mountain belts. In 2008, the phosphorus concentration also decreased to the upper boundary of the mountain forest belt and amounted to 6.5 ± 0.3 mg/g, which was significantly different from the

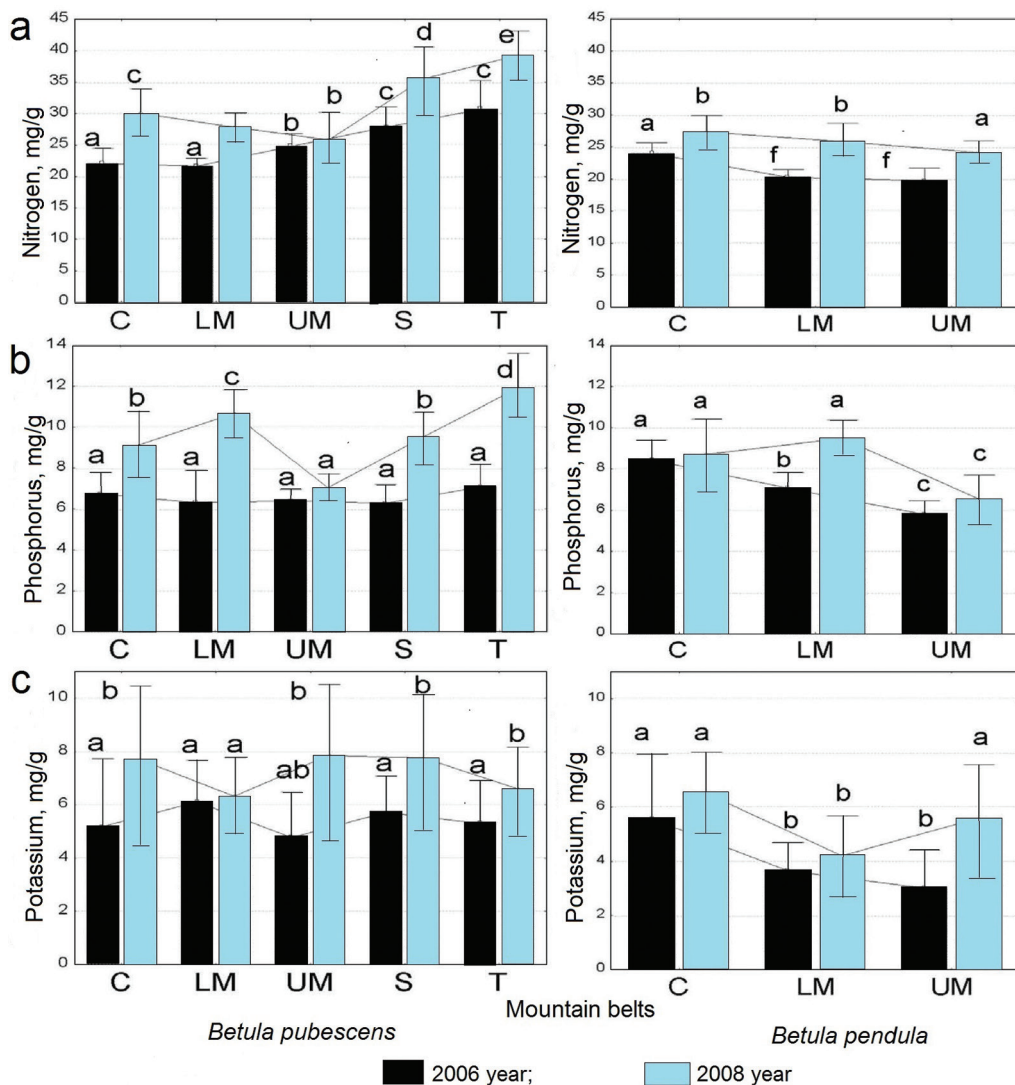


Fig. 2. The total N, P, K concentration in the leaves of Downy birch and Silver birch:
a – itrogen, mg/g; b – phosphorus, mg/g; c – potassium, mg/g.

Note: C – control, LM – the lower boundary of the mountain forest belt, UM – the upper boundary of the mountain forest belt, S – subgoltsy, T – tundra. Similar letters above the columns mean no statistically significant differences, distinct letters above the columns mean statistically significant differences between mountain belts and years ($p < 0.05$), based on a Fisher-test, $n=15$. Values are the means. Bars represent the standard deviation, SD. Bars indicate tree-to-tree variation, represents the mean value of 15 trees.

other belts. Changes over two years were found only in the lower boundary of the mountain forest belt, where in 2008 the phosphorus concentration was significantly higher than in 2006, while the differences between the years were not reliable at other points.

Changes in the concentration of potassium in the leaves of both species were the same as phosphorus. The potassium concentration of Downy birch leaves was stable at the altitude belts for both years, while the level of potassium in 2008 exceeded 2006 at almost all points, which also repeats the phosphorus concentration (Fig. 2c). Although the level of individual variability of potassium was significantly higher (more than 28 %), it was less than 11 % compared with phosphorus.

In the leaves of Silver birch there is a tendency to decrease potassium concentration from the control to the upper boundary of the mountain forest belt (Fig. 2c). There was a high level of individual variability from 29 % to 43 %. In 2006, the control was significantly higher than the upper and lower limits of the mountain forest belt. In the control site, there were no significant differences between the species ($p > 0.05$), and between the years. In the potassium concentrations, there were no statistically significant differences between the species in the control.

In the calcium concentration, there was a tendency to a decrease in the leaves of Downy birch along the altitude gradient for both years (Fig. 3a). The significant differences ($p < 0.05$) between the lower and upper points of the altitude belts were found. Significant differences between the years were found in all belts, with the exception of the subgoltsy and tundra. The calcium concentration in the leaves of

Silver birch also significantly decreased with increasing altitude, which follows the trend of Downy birch (Fig. 3a).

At the same time, for both years, the control was significantly different from the upper and lower limits of the mountain forest belt. Calcium concentration decreased by 38.6 % and 45.5 % for Downy birch, and by 19.2 % and 31.7 % for Silver birch in 2006 and 2008, respectively. The level of individual variability varies from 11 % to 17 % for Downy birch, and from 9 % to 17 % for Silver birch in 2006, while it changed from 11 % to 24 % for Downy birch, and from 15 % to 30 % for Silver birch in 2008. For both years, the magnesium concentration in the control was significantly reduced comparing with the upper belt for Downy birch. The between-year comparisons showed significant differences between the years, and the concentrations in 2008 were higher than in 2006 for both species. There was no significant difference between mountain belts for Silver birch (Fig. 3b).

The individual variability of the sodium content was the highest among the macronutrients – from 35 % to 71 %; it is characterized by a high level. No significant differences were found either between mountain belts, or between investigation years for both species (Fig. 3c).

Table 1 shows the results of two-factor analysis of variance of the macronutrients concentration in the leaves of Downy birch. The concentrations of nitrogen, phosphorus, calcium was closely related to climatic conditions of the current year and the altitude belt, while the content of magnesium and potassium depended only on the year of investigation, and did not depend on altitude. The sodium content did not depend on either the year or altitude.

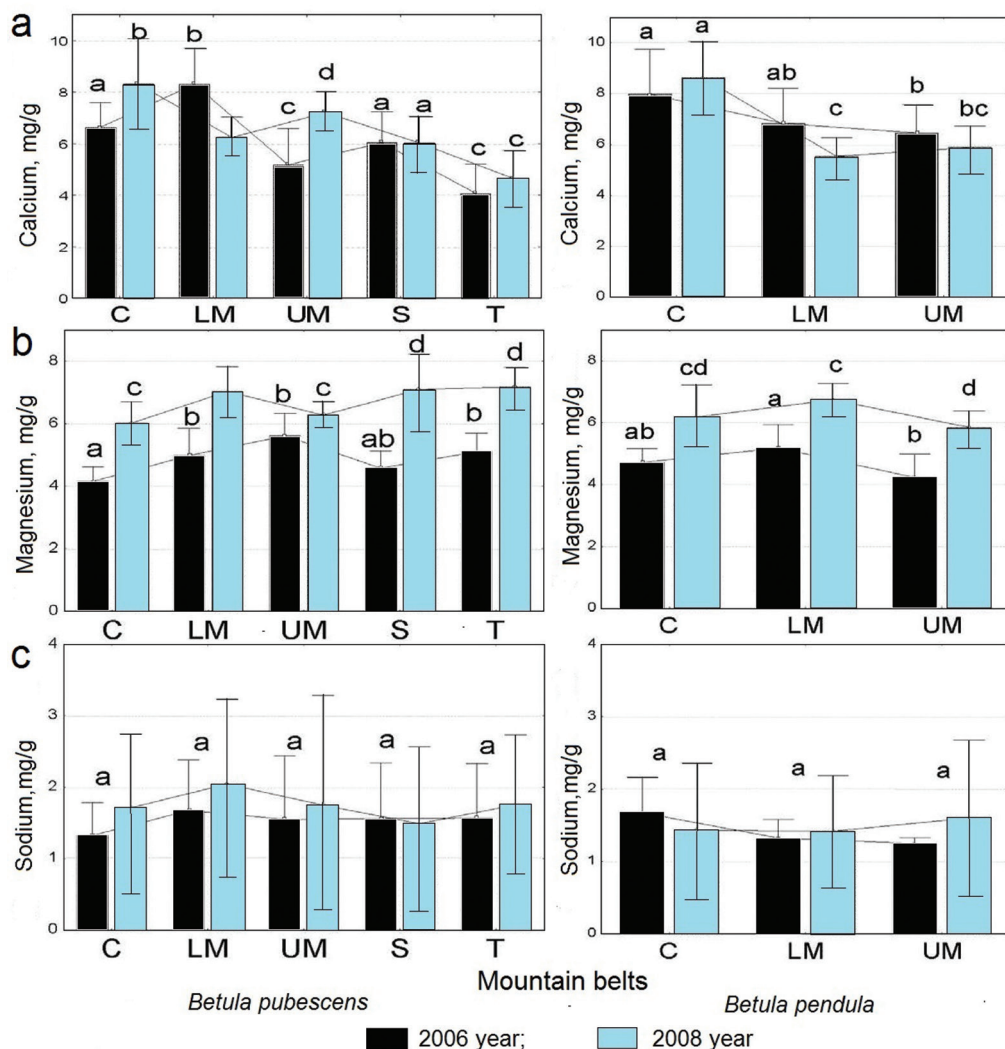


Fig. 3. The total Ca, Mg, Na concentration in the leaves of Downy birch and Silver birch: a – calcium, mg/g; b – magnesium, mg/g; c – sodium, mg/g.

Note: C – control, LM – the lower boundary of the mountain forest belt, UM – the upper boundary of the mountain forest belt, S – subgoltsy, T – tundra. Similar letters above the columns mean no statistically significant differences between mountain belts and years, ($p < 0.05$) based on a Fisher-test, $n=15$. Values are the means. Bars represent the standard deviation, SD. Bars indicate tree-to-tree variation, represents the mean value of 15 trees.

Table 1. Analysis of variance results for effects of year and altitude on the plant N, P, K, Ca, Mg, Na concentration of Downy birch.

Factors	Nitrogen	Phosphorus	Calcium	Magnesium	Sodium	Potassium
Year	***	***	*	***	NS	***
Altitude	***	***	***	NS	NS	NS
Interaction of year X altitude factors	**	***	*	***	NS	NS

Note: According to the results of two-factor analysis of variance. Two-order interactions were suppressed in the ANOVA model. NS – F-criterion is not significant ($p > 0.05$), * – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$.

The ratio of nutrients in the leaves of birch trees along the altitudinal gradient of the Northern Urals

NPK ratio was calculated as the proportion of nitrogen, phosphorus and potassium in the total amount of elements. The ratio of nitrogen increased with the altitude for both species, while the ratio of phosphorus and potassium in the leaves decreased. Despite the detected tendency of Silver birch to decrease the total nitrogen concentration in leaves with altitude, the ratio of nitrogen to phosphorus and potassium increases for Downy birch.

The percentage ratio of nitrogen increased with the altitude, and this tendency was found for both species. The significant differences between the highest and lowest points of the mountain boundary were found. Comparing Downy birch and Silver birch, there was no differences between the two species in terms of the percentage ratio of nitrogen (Fig. 4). There were also no significant differences between two years at each point of the altitude belts.

In general, although in 2008 positive air temperatures were noted at the end of March, they were accompanied by short frosts until the beginning of May, and also frosts in early June. In 2006, the average positive air temperatures over +5 °C be-

gan on May 1, and did not drop to below zero by mid-July, while the air humidity was lower than in 2008, if we take into account the period from the end of April. The number of rainy days was higher in 2006. It is likely that the beginning of the growing season was delayed in 2006 compared to in 2008. Probably, the later start of the growing season in 2006, accompanied by higher humidity, had an impact on the decrease of the concentration of nutrients in birch leaves. The percentage ratio of nitrogen was a fairly stable parameter, which did not change over the years (Table 2), despite the significant difference in the total N concentration between the years, where 2008 was significantly higher than 2006. At the same time, a significant increasing in this parameter at the highest mountain belts shows stability only within one ecotope, which indicates the presence of zonal variability, while the variability between years is not expressed. That conclusion is also confirmed by the data of two-factor analysis of variance (Table 2). The influence of altitude and year on the N: P: K ratio is shown in Table 2. The percentage ratio of N, P and K was not affected by the weather conditions of both years, and the ratio of NPK was influenced by the altitude belts.

The obtained trends in the concentrations of macronutrients in the leaves of

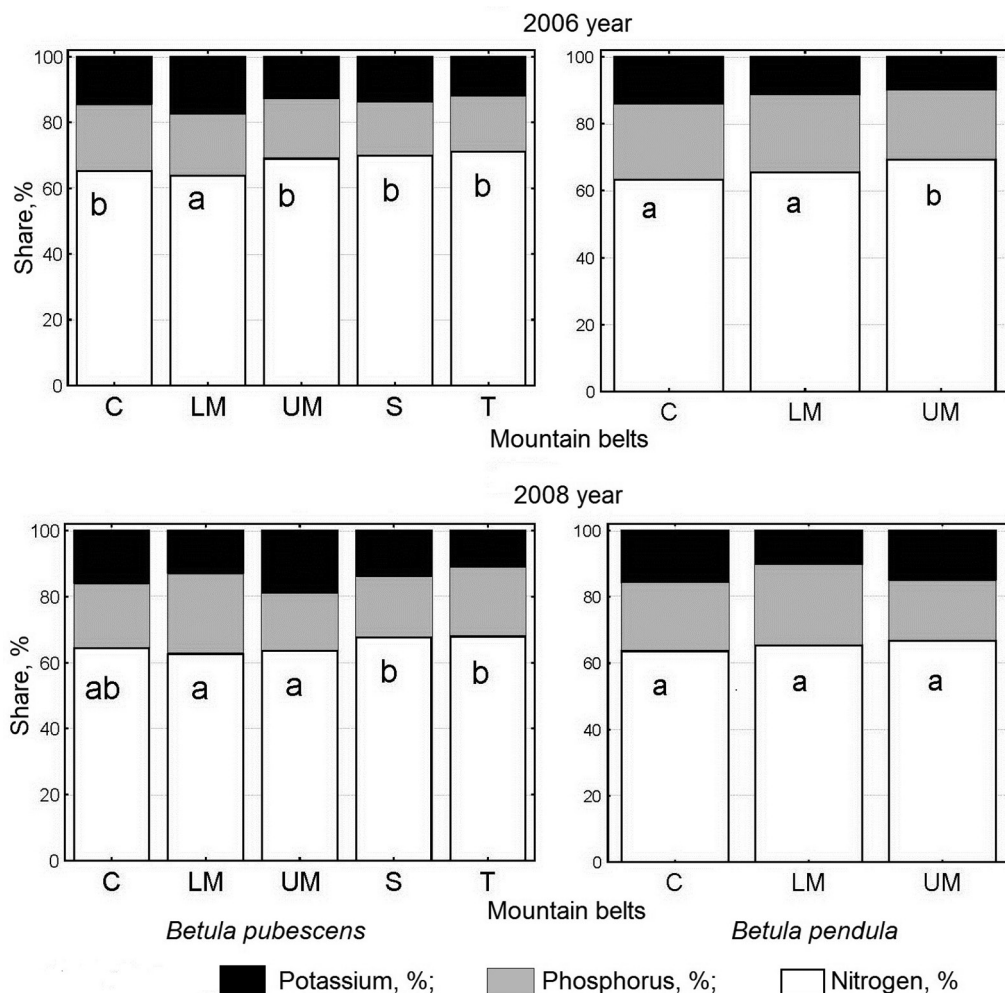


Fig. 4. The ratio of N: P: K (%) in the leaves of *Betula pubescens* and *B. pendula* along the high-altitude gradient of the Mt Konzhakovsky Stone in 2006 and 2008.

Note: C – control, LM – the lower boundary of the mountain forest belt, UM – the upper boundary of the mountain forest belt, S – subgoltsy, T – tundra. Similar letters above the columns mean no statistically significant differences, distinct letters above the columns mean statistically significant differences between mountain belts and years, ($p < 0.05$) based on a Fisher-test, $n = 15$. Values are the means.

Downy birch and Silver birch are probably associated with different physiological mechanisms of plant adaptation to extreme environmental factors. The chemical compounds of leaves reflect the characteristics of adaptation to environmental

conditions, and the direction of metabolic processes. It is known that due to low temperatures, the perception of water from plants with dissolved mineral salts is very difficult (Gorchakovskiy 1975). A decrease in the temperature of the root

Table 2. Analysis of variance results for effects of year and altitude on the ratio of NPK of Downy birch.

Factors	Nitrogen, %	Phosphorus, %	Potassium, %	Total NPK, mg/g
Year	NS	NS	NS	***
Mountain belts	**	***	**	***
Interaction of year X altitude factors	***	NS	***	**

Note: According to the results of two-factor analysis of variance. Two-order interactions were suppressed in the ANOVA model. NS – F-criterion is not significant ($p > 0.05$), * – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$.

space delays the absorption of ash elements, phosphorus and nitrogen (Korovin et al. 1964), while the absorption of P and its inclusion in organic compounds are most of all delayed.

According to Belyaev and Shcheglov (2012), a decrease in the productivity of tree species is accompanied by a decrease in the proportion of nitrogen in the leaves or needles with some increase (decrease) in phosphorus and potassium (Belyaev and Shcheglov 2012). Thus, an increase in the proportion of nitrogen in the leaves of both species may indicate an increase in the productivity of both species in the high-altitude gradient, despite a significant decrease in the total nitrogen content of Silver birch. However, we found that the concentration of nitrogen and phosphorus in the leaves of Downy birch increased along the altitude, while the contents of macronutrients in the leaves of Silver birch decreased along the altitudinal gradient. A high concentration of nitrogen in the leaves is explained by the tendency of high-altitude plants to store nutrients (Chapin et al. 1990). A similar strategy is proposed as a way of adapting plants to a nutrient-deficient environment (Chapin et al. 1990). A high rate of development of the photosynthesis in high altitude conditions is probably necessary for survival

and distribution during a shorter growing season in the mountain-tundra zone. It is also assumed that the high nitrogen concentration of the high mountain populations of Downy birch is genetically determined, and has an adaptive value to the cold climate (Weih and Karlsson 1999).

According to the previous research, a positive correlation between the concentration of nitrogen in the leaves and the rate of net photosynthesis (observed photosynthesis) is expected (Evans 1989). In a study on Silver birch seedlings (Alhalo and Lehto 1997), it was concluded that the accumulation and distribution of dry mass and nitrogen depend strongly on the mode of supply of nutrients. It is suggested that the lack of nitrogen and phosphorus reduce the formation of shoots and leaves. Reduction in the availability of phosphorus leads to a decrease in the export of sugars from chloroplasts to the cytosol (Ericsson 1995), and a lack of potassium leads to a decrease in photosynthesis (Ingestad and Agreen 1991).

In this research, we found that the decrease in the content of macronutrients in the leaves of *B. pendula* with increasing altitude can be associated with the ecological features of the species. Probably, the lowered temperature of the soil inhibits the entry of macronutrients into plants,

which is manifested in a decrease of N, P, K and Ca concentration in the leaves of *B. pendula* with increasing altitude. Because the Silver birch does not grow in the subgoltzy and tundra belt, due to the ecological characteristics of species, we assume that it is also expressed in the characteristics of chemical composition of leaves. Probably, lowered soil temperature does not affect the absorptivity of *B. pubescens*, since the N concentration increases, while P and K do not change, and Ca decreases. *B. pubescens* is less heat and light demanding species than *B. pendula* (Kurets and Drozdov 2006). It can be assumed that the adaptive capabilities of *B. pubescens* are also in sufficient absorption of soil minerals under adverse conditions of high mountains, which allows this species to spread to higher zones, compared with *B. pendula*.

Despite the differences in the amount of N, P, K following two years of research, the percentage of nitrogen in birch leaves remained at the same level, and did not significantly differ. However, according to some researchers, the N: P: K ratio in plants of this species under adaptation conditions is a species genotypic signs and does not depend on geographical and soil-climatic conditions (Lavrichenko and Zhurbitsky 1976). Belyaev and Shcheglov (2012) showed the interrelation of the productivity of tree species and concentration of biophile element in plant assimilating organs, the most indicative of which is not the total concentration of elements, but their ratio (Belyaev and Shcheglov 2012). It was also shown that the N:P:K ratio is not only an indicator of the level of mineral nutrition, but also characterizes the functional state of plants (Vakhmistrov and Vorontsov 1997).

Conclusion

In this research, we found that significant increase in the concentration of N, P, K, Mg in the leaves of Downy birch in 2008 were higher than in 2006. N, P and Mg in Silver birch were also higher in 2008. Changes in the chemical composition of two birch species with increasing elevation were revealed. The main nutrients in the leaves of the two species ranged in order of decreasing of concentration: $N > P = Ca = K > Na$. The differences between the two species are in an increase in the N content and certain tendencies in the increase in the P concentration in the leaves of the birch leaves, with a decrease in these elements in Silver birch leaves with an increase of the altitude. The similarity of the two types is in the tendency to decrease the Ca concentration with altitude, although the total element concentration was significantly different, as well as in a wide range of individual variability of Na and the absence of differences between the types and belts.

The results confirm that woody species can develop many physiological and chemical mechanisms to adapt to adverse environmental conditions. In addition, these results are very valuable as a basis for practical silvicultural processes to be applied in extreme areas and also allow a comprehensive analysis in terms of assessing ecological resilience of woody plants.

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WATER-CONSERVATION AND PROTECTIVE FUNCTIONS OF UKRAINIAN FORESTS IN CATCHMENT AREAS

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Abstract

The objects of the study were the forests in different natural zones in Ukraine. The aim was to reveal the relations between forest cover of water catchments of about 50 rivers of Dnipro, South Bug, Desna, and Siversky Donets basins in different natural zones and the components of water balance, atmospheric precipitations, surface, subsurface and total runoff and evapotranspiration. It was revealed that due to the increase in forest cover up to 20–25 % there was an increase in precipitation up to 95 % in all natural zones of Ukraine. However, further increase in the forest cover did not significantly affect it. The maximum amount of surface runoff (up to 90 %) absorbed by forests was detected when an increase in forest cover was up to 20 % in the steppe part of Ukraine and up to 50 % in Polissya zone. The highest increase in total evaporation – up to 60 % – can be observed if the forest cover increases up to 20–25 % in the Steppe zone and up to 50 % in Polissya and Forest-Steppe zones. Water conservation functions of catchment forest ecosystems are closely related to their spatial distribution and vegetation development as well as the specificities of economic activities within catchments. Significant improvement of Ukrainian rivers is impossible without sustainable management of the territory and increasing its forest cover to certain – optimal or minimum required – level. In this case, a small river catchment is to be the primary territorial unit for land and forest management. Water system sustainability and floodplain agricultural land improvement require complete afforestation of the meandering zones of rivers, as well as meander bars, dead stream branches, coasts of lakes, and scrublands.

Key words: commercial forests, forest cover percent, protective forests, recreational forests, water catchment.

Introduction

Forests are the natural base of the biosphere and play a key role in the conservation of natural resources and in supporting biogeochemical cycles in ecosystems, including climate mitigation targets (Grassi et al. 2017, Ferrara et al. 2016). They form an integral part of the natural environment and are able to improve substantially the environmental conditions, including water

balance of the areas where the role of forests takes on particular importance due to the intensive increase of fresh water deficiency. At the same time, too little attention has been given to moisture exchange in landscapes by means of forests as a powerful self-regulating ecosystem (Madrigal-González et al. 2017). In particular, climate and biota are likely seemed to be the primary determinants of carbon fluxes mainly through interacting carbon quantity

and quality inputs and through soil water and temperature (Chapin et al. 2012).

Forests on the catchments of rivers and their tributaries are the most powerful factor in stabilizing, at a certain level, the functional organization of natural ecosystems and enhancing their resilience to anthropogenic pressure and climate change (Bonan 2008, Tkach 2012, Kulchytskyi-Zhyhaylo 2018). The forests play important water conservation functions and act as constant natural biological barriers, positively affecting water quality and thus reliably protecting water bodies from silting and pollution (Mikhovych et al. 1986, Olijnyk 2014). One of the main goals of Ukraine's forest policy at present is to increase the forest cover to the optimum level in all natural zones. It is one of the strategic areas of activity that can not only increase the timber resources but also stabilize the environmental situation, make a significant contribution to mitigating the climate change and greenhouse effects, restore and preserve biological and landscape diversity, and create favourable conditions for harmonious and sustainable development (Tkach 1999, Olijnyk and Rak 2018).

The results of many years of research show (Mikhovych et al. 1986, Tkach 1999) that the water conservation functions of forests are closely related to their location within catchments. For example, according to Mikhovych et al. (1986), the increase in the forest cover of the catchment areas in Polissya zone to the optimal water-conservation level (23–40 %) will increase the subsurface component of the river runoff by 50–73 mm (the weighted average increase will be 65 mm). It will, on average, exceed the initial value of the subsurface runoff by 500 %. Therefore, under the optimal water-conservation forest cover, the subsurface recharge of rivers and springs

will increase by six times compared to that in the treeless catchment areas. The total runoff will increase by an average of 33 mm, or 41 %.

In the Steppe zone, the rise in the forest cover of the catchments up to the optimal water-conservation level will increase the subsurface component of the river runoff by 6–30 mm (by an average of 14 mm), or by 318 %, compared to the initial value of the subsurface runoff in the treeless catchments – i.e. subsurface water recharge of the rivers and springs will increase by 4 times (Mikhovych et al. 1986).

Tkach (1999) has determined the optimal forest cover for the floodplain forests within the Left-Bank Ukraine, which is 60.3 % for Siversky Donets floodplain, 35.4 % for Psel floodplain, and 40.4 % for Vorskla floodplain. The minimum necessary forest cover of treeless lands of the floodplains, however, should reach 15–20 %. These values of optimal forest cover should be taken into account when designing and planting new forests in floodplain areas within river catchments.

Tkach et al. (2008) calculated the optimal water-conservation forest cover, based on the analysis of the structure of catchments of the midstream of Siversky Donets River and its tributaries within Kharkiv Region. The estimated optimal forest cover varied from 18 to 23 % depending on river catchments.

The formation and distribution of forests in river catchments depends on the geomorphological structure, soil conditions, surface relief, and climatic characteristics (Mikhovych et al. 1986; Tkach 1999, 2012; Tkach et al. 2008; Olijnyk 2014). These specificities should be considered in forest management. It is necessary to ensure maximum diversity and differentiation of the catchment landscape,

that is, the mosaic of its structural units, to maintain the natural potential. This enables natural resilience, high productivity and aesthetics of the landscape (Tkach 1999).

At the catchment area, the optimal ratio of field, meadow and forest lands is necessary, which provides a stable natural balance and conservation of arable land and its fertility, as well as water resources and other components of the natural complex (Tkach 2012). The ratio of different lands, that is, the landscape balance of the catchment area should match the heat and water balances of a particular region. Field-protective, water-regulating, anti-erosion, roadside, backyard, and other forest belts and tree groups, in addition to their basic protective functions, significantly increase the aerodynamic roughness of the land surface and cause a significant, several hundred meters, rise in airflows, their cooling, and additional precipitation. At the same time, these plantings slow down the surface runoff and change it into subsurface one, especially if combined with other anti-erosion activities (agrotechnical, hydrotechnical, etc.). In this case, forest stands should be placed to fully absorb surface runoff – on watersheds and upper slopes, i. e. in places of its initial formation. Such placement is necessary not only to prevent soil erosion and to improve the water regime of the territory but also to provide effective water protection by the forests. Locating forest shelterbelts in a certain catchment area across the northwestern direction of humid winds is the most rational for water conservation, maximally contributing to the precipitation. The increase in the aerodynamic roughness of the earth's surface and the additional atmospheric precipitation largely depends not only on the area of forest stands per unit area

but also on their height. Therefore, preference to tall and, at the same time, few transpiring species should be given when selecting them for planting, taking into account soil and hydrological conditions. Due to the decrease of forest cover below the level required and plowing of large areas, intensive water and wind erosion of the soil begins. Subsequently, much of the arable land loses its fertility and becomes unsuitable for agricultural use, and water bodies become unsuitable even for technical water supply due to siltation and pollution. Therefore, it is necessary to clearly identify which lands in the catchment area should be afforested and not plowed under any conditions (Tkach et al. 1997, Tkach 1999).

Forest stands and farmland form complex forest agrarian coenoses within the catchment area, which are the single paragenetic system. Optimization of agricultural landscapes with forest-reclamation measures is a system of activities aimed at achieving high productivity of the complex while reducing erosion processes, preventing pollution and silting of water bodies, and ensuring the normal hydrological regime of rivers (Tkach 1999). A prerequisite is that the protective plantings in the terrain should form a single biological reclamation system and occupy the area of separate catchments. The role of single plantings is negligible in preventing water pollution.

If it is impossible to increase the forest cover due to the historically formed ratio of different lands, the insufficient forest cover can be compensated by planting protective stands on the treeless banks of the hydrographic network and erosion sensitive open areas.

Another important way to preserve and enhance sustainability and protective properties is to improve forest manage-

ment.

Tkach (1999, 2012) considered the change in management to the water catchment scale to be carried out in several phases. The first phase establishes standards that allow identifying a minimum catchment area depending on the geographical zone, topography, geomorphological features, etc., as well as the spatial organization and structure of the catchment area. The second stage defines the strategy for optimizing the structure of the catchment, including forest cover, and develops a plan for the transformation of land, taking into account the farm development prospects and the need to gradually achieve an ecological balance of the catchment. In the third stage, management systems should be introduced considering the specificities of the catchment.

The organization of forestry should take into account the location specifics for different purpose forests (both forested areas and shelterbelts). Also, the age structure and species composition of forests should be optimized and appropriate felling should be designed in the catchment area.

The aim of the study was to estimate the impact of forests on water balance components, namely precipitation, surface runoff, total evaporation, and subsurface runoff, as well as its change within Ukraine by natural zones depending on the forest cover of river catchments.

Materials and Methods

Both the materials of our studies and 50-year scientific researches of other authors for about 50 rivers of Dnieper, Southern Bug, Desna, Siversky Donets basins (Fig. 1) in different natural zones of Ukraine were used for analysis and syn-

thesis. The studies were conducted by establishing ecological profiles on the catchments of the investigated rivers (Forest inventory ... 2006).

MapInfo Professional 12.5 software and vector map of Ukraine were used to demarcate the boundaries of water catchments. They were determined by divide lines, which passed through the points from which the slopes split off in different directions. Such points are located in the places where the bends in the isohypses are the greatest. Catchment divides follow the ridge lines through the peaks and saddles.

An actual forest cover percent was defined as the ratio of the area covered by forest vegetation to the total area of river catchment (Tkach 2012).

Ecological profiles of the terrain along the slopes were established perpendicular to the terraces of the rivers to study the characteristics of forest formation on river catchments. If the relief allowed, the direction of lines was straightforward. The land navigation was carried out following a compass and map-boards of stands in state forestry enterprises (scale 1:10,000 or 1:25,000).

In selecting the study objects, we analyzed forest inventory data, plantation plans, soil, topographic, geomorphological, geological, landscape, hydrologic, climatic and vegetation maps, and scientific publications regarding this region.

We classified catchments of rivers by part of the area covered with forest vegetation by the method of Grodzynsky (1993) as follows: well-forested – 75–100 %, relatively forested – 50–75 %, medium-forested – 25–50 %, less-forested – 5–25 %, almost treeless – up to 5 %.

The methodology for determining the standard values for optimal water conservation forest cover in the catchment are-

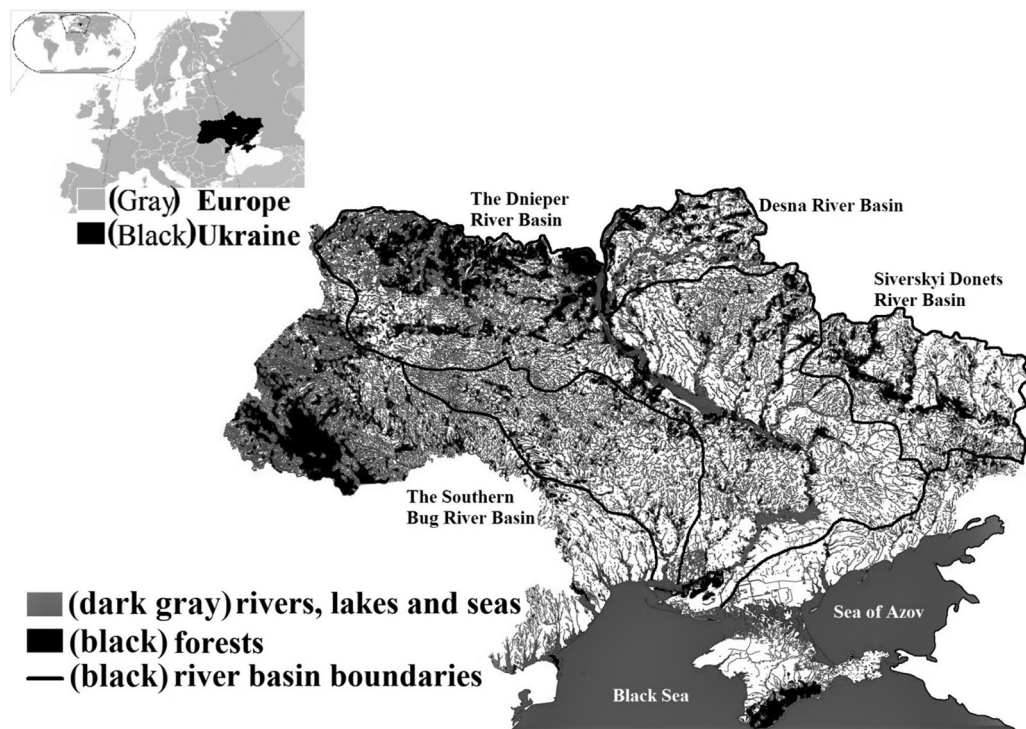


Fig. 1. Location of forests.

as of small and medium-sized rivers, and the quantitative assessment of expected changes in the main components of water balance and river runoff under the optimal water conservation forest cover, with different spacing of forest stands on the catchment area (even and uneven), is based on mathematical modeling of the impact of forest stands on atmospheric precipitation, surface runoff and total evaporation with estimating subsurface runoff change.

The methodology for quantitative estimation of the water-regulating role of a forest is based on a mathematical formula derived from the general formula (1) of the water balance of the land.

$$P = SR + SSR + E, \quad (1)$$

where: P is atmospheric precipitation, SR is a surface runoff, SSR is a subsurface

runoff, and E is total evaporation.

Atmospheric precipitation P , surface runoff SR , total evaporation E , and subsurface runoff SSR are the main components of the water balance. The value of SSR remains unknown and could be found by solving the equation with one variable.

The change in subsurface runoff – ΔSSR – is taken as the total indicator of forest water-regulating role. Change in SSR under the influence of forest can also have different effects in different conditions. If ΔSSR value is greater than zero, the forest fulfils a moistening role and, if less than zero, the forest exercises a draining function.

The impact of forest on each component of water balance is obtained by comparing the forested and treeless lands by formula (2) (Mikhovych et al. 1986).

$$\Delta SSR = \Delta P - \Delta SR - \Delta E, \quad (2)$$

where: ΔP is a change in atmospheric precipitation, ΔSR is a change in surface runoff, ΔE is a change in total evaporation under the influence of forest.

To determine the optimal forest cover for water conservation on the water catchment areas, we used multi-year data on the water balance, rainfall, and index of SR in the studied area. For this, observations of gauging stations between 1975 and 2015 were used.

By the method of Mikhovych et al. (1986), mathematical models for changes in the components of water balance and river runoff were calculated for different forest cover percentage, from 1 to 100 %. These calculations showed how the forest stands influenced the river runoff at a full and partial forest cover of the catchment areas and in which specific forest cover the greatest increase in SSR can be obtained. The percentage of forest cover, in which there is a maximum increase in SSR , is the optimal one for water conservation. Changes in annual runoff under the influence of forest cover were estimated using graphs developed by Mikhovych et al. (1986).

The objects of the study were the forests in Polissya, Forest-Steppe and Steppe natural zones in Ukraine.

Results

The present study shows that forest biocoenoses perform important water-conservation and protective functions. They positively influence on the increase of precipitation amount, total and subsurface runoff and on the whole water balance of landscapes. Due to the SR transformation into SSR , they substantially improve the quality of water resources, their chemical,

physical, bacteriological, thermal properties as well as prevent erosion processes and increase soil fertility. The forests perform also bank-protecting, river-bed-regulating, and anti-meandering functions, reduce the negative impact of floods and mudflows and even positively influence the water balance and climatic parameters on open areas bordered on them.

Summarizing experimental materials obtained during past few decades (Mikhovich 1969; Mikhovych et al. 1986; Tkach 1999, 2012; Tkach et al. 2008; Goroshko et al. 2015) gave an opportunity to get the system of mathematical relationships between the forest cover of water catchments of about 50 rivers of Dnipro, South Bug, Desna, and Siversky Donets basins in different natural zones of Ukraine and the components of water balance, atmospheric precipitations, surface, subsurface and total runoff and evapotranspiration. Change in SSR under the influence of forest cover and a specific forest location on a water catchment was taken as the index of water-regulating role of the forests, the value of which determines water content of rivers in a summer low streamflow period when the water deficiency problem is acutest.

It was determined that the rise of precipitation amount (up to 95 %) is observed with the forest cover increasing up to 20–25 % in all natural zones, but its further increase does not substantially influence the precipitation increase. The highest amount (up to 90 %) of the SR taken up by the forests is found under forest cover to increase up to 20 % in steppe part of Ukraine and up to 50 %, in Polissya. The largest increment of evapotranspiration (up to 60 %) will be observed at the increase of forest cover up to 20–25 % in Steppe and up to 50 % in Polissya and Forest-Steppe (Table 1).

Table 1. Dependence of change of water balance components, percent from the maximal change value at 100 % forest cover.

Forest cover, %	Precipitation increment change	Surface runoff change		Total evaporation increment change	
		Polissya	Steppe	Polissya, Forest-Steppe	Steppe
81–100	100	98.8–100.0	99.2–100.0	96.6–100.0	96.6–100.0
61–80	99.5–100.0	95.7–98.8	98.1–99.2	86.1–96.6	86.1–96.6
41–60	99.0–99.5	82.9–95.7	95.3–98.1	52.1–86.1	62.1–86.1
21–40	93.0–99.0	53.8–82.9	88.9–95.3	35.3–52.1	52.0–62.1
1–20	3.0–92.0	3.0–51.6	15.0–87.9	1.7–33.4	5.0–50.7

The forests positively influence on all components of water balance. However, this effect is the most evident in the forest *SR*. During its transformation into *SSR*, not only the qualitative characteristics of river runoff (to be recharged by ground waters purged from eroded material and pollutants) will be improved, but also erosion processes will be slow down substantially. This is particularly significant for planning forestry measures for land improving for water catchments with steep slopes.

An optimal water-conservation forest cover will result not only in the maximal increase in the *SSR* but also in improvement of other water balance components: the ratio of *SR* will decrease and the precipitations amount will increase.

The results of the study (Table 2, Fig. 2) indicate that in Polissya, on water catchment of Mena River, for example, *P* influenced by the forest plantations will increase by 47 mm, *SR* will increase by 45 mm, and evapotranspiration will grow by 51 mm, according to territorial norms and for the case of continuous afforestation of the territory. As a result of this, the underground recharge of Mena River will grow due to the increase of *SSR* by 41 mm. However, the maximal increase in underground recharge of the river will be observed not at 100 % of forest cover but at 28 % and the increase of *SSR* will be 51 mm. This is the water-conservation forest cover that will be the optimal one.

Table 2. Changes in water balance under different forest cover of water catchments.

Forest cover, %	Change in precipitation, mm	Change in surface runoff, mm	Change in evapotranspiration, mm	Change in subsurface runoff, mm	Sum of surface runoff and subsurface runoff changes, mm
Polissya, Mena river to the mouth (catchment area 775 km ² , actual forest cover 2 %, <i>P</i> 618 mm, <i>SR</i> 66 mm, evapotranspiration 508 mm, <i>SSR</i> 44 mm)					
100	+47.0	-44.9	+51.0	+40.9	-4.0
60	+46.7	-43.0	+43.9	+45.8	+2.8
28*	+45.8	-30.1	+24.8	+51.1	+21.0
20	+43.2	-23.2	+17.0	+49.3	+26.1
1	+1.4	-1.4	+0.9	+1.9	+0.5
Forest-Steppe, Vorsklytsya river to the mouth (catchment area 1490 km ² , actual forest cover 8 %, <i>P</i> 628 mm, <i>SR</i> 48 mm, evapotranspiration 568 mm, <i>SSR</i> 12 mm)					
100	+38.9	-36.0	+68.0	+6.9	-29.1
60	+38.7	-34.9	+58.5	+15.1	-19.8

Forest cover, %	Change in precipitation, mm	Change in surface runoff, mm	Change in evapotranspiration, mm	Change in subsurface runoff, mm	Sum of surface runoff and subsurface runoff changes, mm
20	+35.8	-25.1	+22.7	+38.2	+13.1
19*	+35.2	-24.6	+21.4	+38.4	+13.8
1	+1.2	-3.2	+1.1	+3.3	+0.1
Steppe, Yevsuh river to the mouth (catchment area – 1190 km ² , actual forest cover – 2 %, <i>P</i> 536 mm, <i>SR</i> 37 mm, evapotranspiration 429 mm, <i>SSR</i> 7 mm)					
100	+17.2	-29.6	+58.9	-12.1	-41.7
60	+17.1	-29.0	+50.7	-4.6	-33.6
20	+15.9	-26.0	+30.0	+11.9	-14.1
17*	+14.9	-25.0	+27.5	+12.4	-12.6
1	+0.5	-4.4	+2.9	+2.0	-2.4

Note: * – Optimal forest cover.

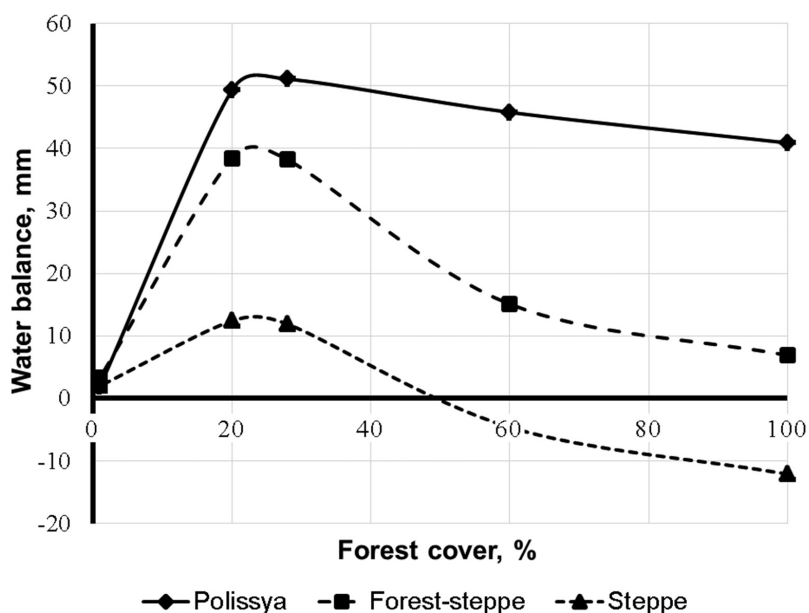


Fig. 2. Impact of forests on change in the water balance (*SSR*) of natural zones.

Toward the south of Ukraine, the changes in water balance characteristics, influenced by the change in forest cover of catchment areas, have certain specific distinctions. At Forest-Steppe (water catchment of Vorsklytsya River), as compared with Polissya, at forest cover of 100 %, an increase in *P* is less and *E* is

greater. In such a case, a *SR* is decreased and an increase in the *SSR* is insignificant. At the same time, in the case of the optimal water-conservation forest cover, the increase in the *SSR* will be 38 mm that exceeds considerably the actual water yield accounted for 12 mm.

In the Steppe zone (water catchment

of Yevsuh River), there is even a reduction in the SSR at calculated forest cover of 100 %, and in the case of the optimal water-conservation forest cover, its increase will be 12 mm that is almost 2 times exceeds the initial value (7 mm).

On the basis of the calculations performed, the limits of water-conservation forest cover percentage for water catchments of the main Ukrainian rivers were determined (Fig. 3). It is characteristic that the forest cover varies widely within the boundaries of administrative districts of many regions in Dnipro basin, in particular: from 6.7 % to 53.9 % in Volyn Region, from 6.3 % to 65 % in Zhytomyr Region, from 2.4 % to 42.1 % in Kyiv Region.

These results of the research must be taken into account at planning works concerning new forests planting in the administrative districts of the regions. Figure 4 presents the limits of water-conservation forest cover percentage by administrative

areas.

Note that, for most regions of Ukraine, the optimal limits of forest cover coincide with the limits of optimal forest cover percentage calculated by Sayko (2008).

The results of the study indicate that the forest cover of Ukrainian regions, including mountain part, should be substantially increased. To get the optimal water-conservation forest cover, at least additional 2.5 million ha of forests need to be created (Tkach 2012).

It is important to take into account the forests placement on water catchments. Results of the fundamental studies testify that the even placing of forest plantations of all kinds along the water catchment area is the most rational in point of water conservation. Performing basic protective functions (field-protecting, water-regulating, erosion-preventive, etc.) they enhance the aerodynamic roughness of earth surface and cause the considera-

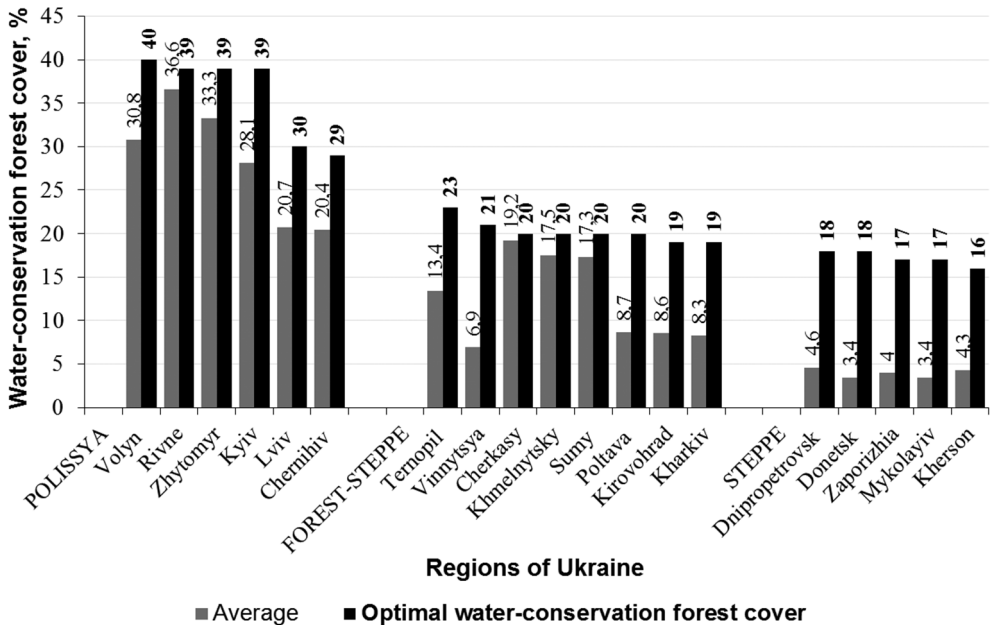


Fig. 3. Average and optimal water-conservation forest cover.

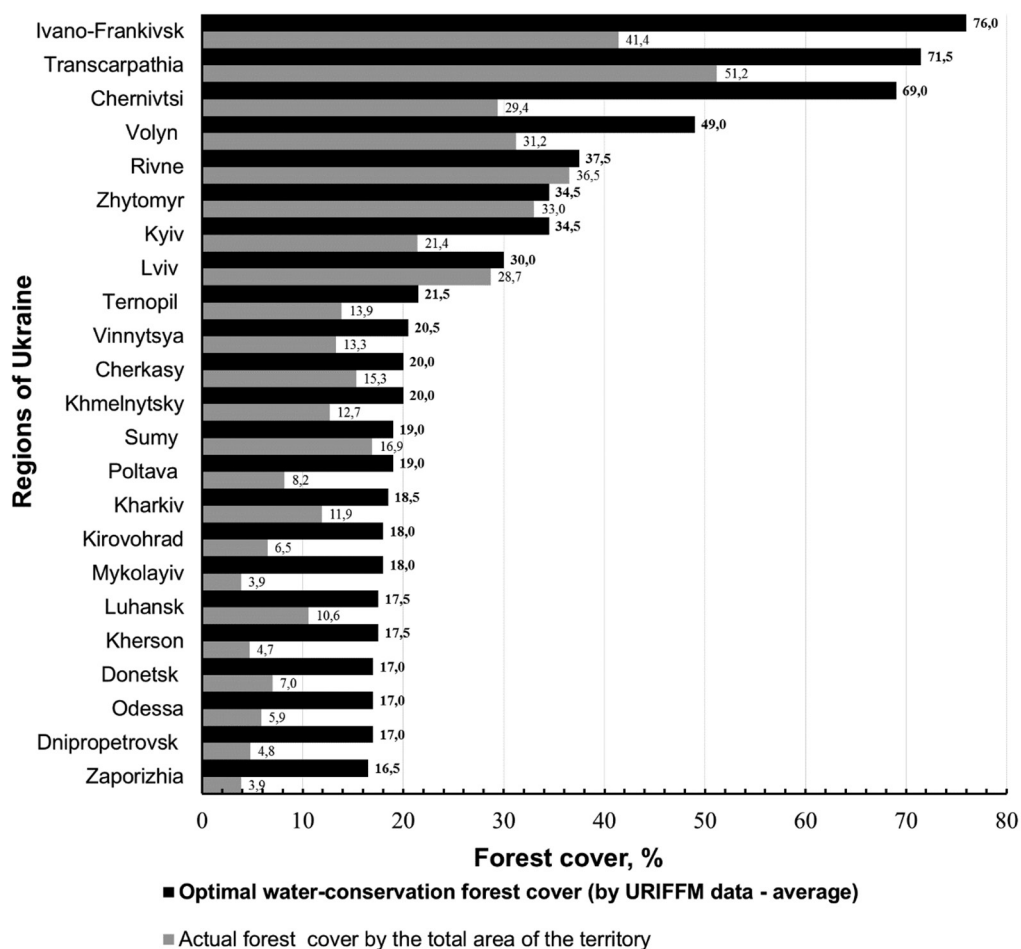


Fig. 4. Actual and optimal water-conservation forest cover percentage.

Note: URIFFM – Ukrainian Research Institute of Forestry and Forest Melioration.

ble (by several hundred meters) raising of air streams, their cooling, and additional precipitation. These plantations, especially when they affect as a whole with other erosion-preventive measures (land treatment, hydroengineering and others like that), entrap *SF* and transform it into *SSR*. Thus, they need to be placed in such a manner as to provide better absorption of the *SR* – on watersheds and heads of slopes – including the places of its initial forming, not only to prevent soil erosion

but also to improve the water regime of the territory.

In different parts of water catchments, the water-conservation functions of the forests have certain features. Thus, the riverside forests slow down river meandering processes and destruction of coastlines. The direction and intensity of this influence are determined by the geomorphological features of the valley, the bed-formation water flow rate, the value of forest cover of the floodplain and

near river part, and also by species composition of the stands grown in the river-side.

Biological features of the species determine deep root developing that allows

holding tightly the upper 2-meter soil layer.

River meandering zone, meander development coefficient, and turning angle are decreased with the increase of forest cover of the floodplain (Table 3).

Table 3. Dependence of morphometric indexes of river-beds on the pattern of riverside afforestation.

Pattern of riverside afforestation	Meander development coefficient	Meandering zone, m	Turning angle, degree
Vorskla River			
Non-afforested	1.44 $\pm$ 0.05	508 $\pm$ 38	144 $\pm$ 7
Afforested from one side of the river-bed	1.13 $\pm$ 0.03	338 $\pm$ 40	113 $\pm$ 14
Afforested from the both sides of the river-bed	1.13 $\pm$ 0.04	324 $\pm$ 62	109 $\pm$ 13
Psel River			
Non-afforested	1.87 $\pm$ 0.11	804 $\pm$ 61	152 $\pm$ 5
Afforested from one side of the river-bed	1.45 $\pm$ 0.09	613 $\pm$ 77	149 $\pm$ 6
Afforested from the both sides of the river-bed	1.39 $\pm$ 0.06	588 $\pm$ 48	132 $\pm$ 7
Siversky Donets River			
Non-afforested	1.71 $\pm$ 0.27	613 $\pm$ 107	156 $\pm$ 14
Afforested from one side of the river-bed	1.60 $\pm$ 0.21	515 $\pm$ 70	146 $\pm$ 11
Afforested from the both sides of the river-bed	1.46 $\pm$ 0.17	446 $\pm$ 40	137 $\pm$ 10

In floodplains of the largest rivers of left-bank part of Ukraine, anti-meandering and river-bed-stabilizing functions are peculiar not only to forest stands directly contacted with a river-bed but also to those growing on the distant floodplain sites. The forest stands significantly slow down the bank eroding velocity on adjacent woodless areas of the rivers. Thus, if in the case of continuous afforestation of the floodplain site near a river but only partial afforestation of all floodplain the calculated meandering zone of Siversky Donets is 446 m, then assuming continuous afforestation of all floodplain the meandering zone will be increased up to 229 m. Herein, a new type of out-of-boundary influence of a forest appears.

Discussion

As the result of the study shows, the forests of the left-bank part of a floodplain influence more significantly on the meander morphometric parameters and meandering processes as compared with the forests of the right-bank floodplain. This aspect should be taken into account when establishing forest shelterbelts in floodplains.

Economic activity in floodplains should be aimed at the maximal afforestation of meandering zone. The average width of this zone will determine the width of bank-protecting forest strips, which belong to the number of especially valuable areas of the forest resource. In particular,

the width of such strips must be 150 m for Vorskla River, 200 m for Siversky Donets River, and 250 m for Psel River (Tkach 1999).

Agricultural part of floodplains should consist exceptionally of meadows, haylands, and pastures. Water system sustainability and floodplain land improvement require complete afforestation of the meandering zones of the rivers, as well as meander bars, dead stream branches, coasts of lakes, and scrubland as agricultural part of floodplains.

A maximal effect is possible to be achieved by the creation of forest hydro-engineering complexes. Proof of that is the high efficiency of functioning of Kaniv, Norynsk and Rzhyshev forest hydro-engineering reclamative systems. Thus, only at Kaniv system, 1,820 ravines were stabilized. As a result of it, about 22 thousand ha of fertile croplands have been prevented from disturbance, 10 thousand ha have been restored for agricultural use, and the additional amount of wood has been got, the annual increment of which on the afforested areas is about 40,000 m³.

However, the current state of hydro-engineering constructions deteriorates steadily; their considerable part became out of action. It reduces the efficiency of reclamative influence of the protective forest planting substantially. The state of many water-regulating plantations is also unsatisfactory. At a rough estimate, the forest stands perform reclamative functions effectively only on the one-third of the area, and about 40 % of water-regulating forest strips need a complete or partial reconstruction. On large areas, forest strips had been created without considering scientifically reasonable standards and requirements.

A complete use of forest reclamative functions is possible only if the related

systems of protective forest plantations and strips having the certain purposes are created in accordance with natural zones and types of Ukrainian landscapes. It is clearly defined on the well-known objects of Dokuchaev's expedition, Starobilsk and Velykoanadolsk areas, where scientists from Mariupol and Luhansk Forest Melioration Research Stations of URIFFM carry out investigations during many decades. The results are unrivaled throughout the world agroforestry science. They testify that the system-based placing of forested areas and forest strips in hard steppe conditions brings a vast improvement of the microclimate: the air humidity rises, the range of extreme values of air and soil temperatures is reduced. During vegetation period, nonproductive moisture evaporation is decreased by 20–30 % and transpiration ratio, by 30–35 %. In the systems of strips, the amount of the trapped snow rise by 30–50 %, the conditions of winter crops overwintering is improved, the soil is supplied additionally by 10–20 % of water and waterborne soil movement is decreased by 1.5–2 times.

In the forest strips systems, the spring water tables rise more moderately, and the summer lowering of the soil water table is slow down. That, therefore, creates the best conditions for water vapor condensation on the soil, thereby dew is falling in a greater amount and remain for a longer period here, and moisture enriched air removing is decreased noteworthy. Moreover, it is currently thought that water balance and temperature might be one of the most important factors for determining soil carbon fluxes and storage (Chapin et al. 2012).

Lately, the discussions continue on the practicability of the creation of new forests in Steppe, as an increase of forest cover percentage in this natural zone, apparent-

ly, will result in loss of faunal and floristic diversity and will have a detrimental effect on Red List species. Related to this issue, it is worth noticing that in past centuries the forest cover percent of Steppe was several times higher. However, the forests grew here not everywhere, but only on certain areas: mainly in river valleys, effectively protecting them from a silting-up, and also in ravines and lower reaches. Considering extremely large plough-disturbance of the lands, the steady decrease of soil fertility, many small rivers ending and effective reclamative influence of the forests, it is necessary to study and clarify the regional standards of forest cover percentage and determine the structure of the forests and protective forest strips. Only those lands should be afforested that are suitable for the regeneration and are not in the list of such objects as valuable faunal and floristic complexes that are the subject or can be the subject of protection.

For planting new forests in Steppe, it is necessary to follow landscape-ecological principles on that new strategy of afforestation on sands of Lower Dnipro valleys was developed. It provides the following:

- Forest cover should not exceed 75 % of the area on hilly sands (50 % on burnt areas) and 50 % on flatly and hummock lands (40 % on burnt areas);
- Afforestation of lowlands of 0.5 ha between hills as well as tops of hills and sandy terraces is not advisable;
- Hills of up to 5 m height and their slopes must be afforested. Such areas should be classified as 'Reclamation areas';
- It is necessary to protect the areas with natural regeneration of forest species and to implement measures on natural regeneration assistance.

The optimal forest cover comprises not only the optimal area of the forests but also

their optimal structure that is a balance of the massive and linear plantations of the certain functional uses that will provide an equilibrium between the productivity of landscapes and quality parameters of the environment (Tkach et al. 2008, Goroshko et al. 2015).

Depending on the ecological and socio-economic role of the forests it is reasonable to distinguish the systems of the massive plantations (merchantable, protective, recreational forests, and plantations of environmental, scientific, historical and cultural purposes) and systems of the linear plantations (field-protective, ravine, growing along watercourses, etc.) (Bondar et al. 2016).

During the creation of new forests and protective forest strips of different designated use, which have an optimal structure, it is important not to disturb the natural meadow and bog coenoses and the natural integrity of all of the components of ecosystems: animal and plant kingdom and microorganisms (Tkach et al. 2016).

Therefore, further research is necessary to study the typification of territory of Ukraine by the qualitative characteristics of ecological disturbances of cultivated lands and to develop, selectively to the types of landscapes, the zonal systems of forest improvement measures, as well as the technologies of the creation of special-purpose forests for the effective land protection against water erosion and soil retirement, of the water resources improvement, desertification prevention and biodiversity conservation.

The conducted studies allow us to formulate problems to be solved in agricultural afforestation as follows.

Scientific:

- To ground the optimized systems of protective forest plantations of different uses selectively to the types of land-

scapes, taking into account the developed limits of protective forest cover;

- To improve the ecological and economic evaluation of reclamative functions of the special purpose protective forest stands.

Legislative and regulatory:

- To develop the way to change the economic management principles to catchment-landscape ones;

- To practice a mechanism of a simplified land cession for the creation of protective plantations and to legitimate it.

Organizational:

- To inventory the areas covered by protective forest strips and other plantations on reserve land;

- To develop land management plans in economies, which should include planning of forest strips of the certain functional uses;

- To transfer, at no additional charge, the protective forest strips and protective forest plantations into ownership or for the use (by lease or on a permanent basis) to natural and legal persons and to conduct forest management there;

- To draft proposals on making corresponding changes and additions regarding the legal status of the protective forest strips and plantations;

- To resume the activity of State Service of Agroforestry.

A water catchment should be an elementary territory economic unit during planning and implementation of economic measures. Within the boundaries of certain water catchment, one should determine the balance and the areas of massive and linear plantations. These are forest cover optimization principles on which forest management strategy and forest reclamation should be based in Ukraine.

The solution of the problem will be also facilitated by the implementation of meas-

ures documented in 'Concept of agroforestry in Ukraine', authorized by Cabinet of Ministers of Ukraine (in 2013).

It is necessary also to provide the implementation of top-priority business measures for maintenance of protective forest strips and forests on reserve land. Primarily, an inventory should be made for such plantations, and then land management plans should be developed concerning the allocation of the areas on the reserve lands under the forests and protective strips for the further assignment for charge-free ownership, use by lease or sustained use. Furthermore, according to Forest Code, it is reasonable to transfer the closed land plots covered with forest vegetation, of more than 5 ha in area, being a part of lands of farms and other economies, into natural or legal people's charge-free ownership. Land plots covered with forest vegetation, including forest strips, of more than 5 ha in area, being a part of lands of farms and other economies, should be transferred for natural or legal people's use by lease with a minimum land charge. Woodlands bordering forest areas should be transferred for the sustained use of forestry enterprises, establishing in such a case the corresponding land servitude for joint owners and land users for unimpeded access to protective forest strips and plantations (for the proper protection and forest tending). After that, an inventory should be made for these plantations. For the maintenance and creation of new protective forest strips and forests, it is expedient to resume the activity of State Service of Agroforestry and also to make corresponding changes and additions in laws and regulations in relation to the legal status of such plantations.

In the past, the protective planting projects were the component part of inner

land-utilization system of former collective and state farms; the targeted financing of protective strips creation had been provided, including publicity-funding. A similar approach would be applied even today when developing plans for land management, inventory, and territorial planning projects of different levels. Projecting for the creation of new forest plantations should be also carried out during national ecological network forming.

The history of successful farming in many developed economies of the world indicates the importance of the use of forest land-reclamations as an integral component of modern soil management. In these countries, the protective planting creation programs are adopted at a state level and budgeted; such measures encourage owners to implement the programs on their territories.

The successful solution of the stated problems will improve not only the water regime of landscapes but also the efficiency of agribusiness.

The presented results are of prime importance as they determine strategic sector of optimization of forest cover in Ukraine. Creation of the new forests, in Steppe and Forest-Steppe as a priority, will substantially improve the hydrological regime of the landscapes.

Conclusions

Forests have a positive effect on all components of water balance, especially on the surface runoff. By changing surface runoff into subsurface one, not only the quality indicators of river runoff will be improved, but also erosion processes will be slowed down. It must be given due attention when designing forest reclamation works for water catchment areas with

steep slopes.

It was revealed that due to the increase in forest cover up to 20–25 % there was an increase in precipitation up to 95 % in all natural zones of Ukraine. However, further increase in the forest cover did not significantly affect the increase in precipitation. The maximum amount of surface runoff (up to 90 %) absorbed by forests was seen when an increase in forest cover was up to 20 % in the steppe part of Ukraine and up to 50 % in Polissya zone. The highest increase in total evaporation – up to 60 % – can be observed if the forest cover increases up to 20–25 % in the Steppe zone and up to 50 % in Polissya and Forest-Steppe zones of Ukraine. The estimations can be used to determine the limits for water-conservation forest cover within the catchments of the main Ukrainian rivers.

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BODY MORPHOMETRICS OF GOLDEN JACKAL IN BULGARIA

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Abstract

The expansion of golden jackal (*Canis aureus* Linnaeus, 1758) in Europe in the last decades has triggered research interest. Many aspects of jackal's ecology, diet, population density, genetics, legal implications of range expansion and management have been studied thoroughly. However, very few studies have focused on body morphometrics. Bulgarian territory is considered the core area of golden jackal distribution in Europe with the highest population density, but morphometric studies including data about Bulgarian population were very scarce and local so far. The present study proposes the first comprehensive analysis of golden jackal morphometrics in Bulgaria, trying to clarify body shape and size related variability and differentiation. Morphometric data were analysed by applying recently developed statistical tools to respond to the following questions: (i) is there geographic variation in body size and shape among golden jackal population in Bulgaria, (ii) are there age-related differences and at what age jackals reach full growth of the body, and (iii) how pronounced is the sexual dimorphism in body shape and size among adult jackals? The body measurements of 87 golden jackals, collected all over the country were subjected to univariate and multivariate analyses. Body size and shape of golden jackal in Bulgaria show considerable individual variability, but weak intrapopulation differentiation. The differences in shape and size of the jackal body, as far as they exist, are age-related, but only 5–6 months old animals could be easily distinguished. Body growth ends at 10 months of age, but even 7–9 months old jackals are difficult to distinguish from the adults in the field. Sexual dimorphism in jackal's body is weakly pronounced, with older males a little bit larger than females. The results are consistent with recent genetic and morphological studies and give further insights on patterns in variability and population structure of golden jackal in Bulgaria.

Key words: body size, body shape, *Canis aureus*, sex dimorphism, geographic variation.

Introduction

Golden jackal (*Canis aureus* Linnaeus, 1758) is one of the most widely distributed canid species and is found in many areas of Europe, Asia and Africa (Jhala and Moehlman 2004, Arnold et al. 2012, Hoffmann et al. 2018, Moehlman and Hayssen 2018, Spassov and Acosta-Pankov 2019).

Since 1980s jackals have increased in their distribution and abundance in what is arguably the most dramatic recent expansion in Europe among native predators on the continent and today it is widespread species throughout southern Asia, the Middle East and south-eastern and central Europe, where jackals inhabit a wide variety of habitats, from semi-deserts and

grasslands to forested, agricultural, and semi-urban habitats (Jhala and Moehlman 2004; Šálek et al. 2014; Koepfli et al. 2015; Trouwborst et al. 2015). The jackal expansion in the last two decades was rapid and still ongoing. Jackals have expanded into Switzerland, Lichtenstein, Germany, Denmark, Poland, France, Netherlands, Baltic states, Belarus, and, in 2019, also Finland (Pyšková et al. 2016, Krofel et al. 2017, Potočník et al. 2019). The ongoing expansion of the species in Europe has caused concerns regarding possible negative effects its presence could exert, due to excessive predation of other wildlife species or livestock, and the transmission of pathogens (Rutkowski et al. 2015; Čirović et al. 2016). In addition, there are several uncertainties regarding jackal management and policies, often in association with the unknown origins of jackal populations (Trouwborst et al. 2015). Jackal expansion in the last decades has triggered research interest in Europe. Many aspects of golden jackal's ecology, diet, population density, genetics, legal implications of range expansion and management have been studied thoroughly in Europe. However, very few studies have focused on morphometric variability of golden jackal in Europe (Kryštufek and Tvrtković 1990, Boskovic et al. 2015). Morphometric data could be found in some books and monographs (Heptner et al. 1967, Demeter and Spassov 1993, Angelescu 2004, Jhala and Moehlman 2004, Sillero-Zubiri 2009). The most comprehensive is data set about jackal population in the Caucasus and Central Asia (Aliev 1968, Reimov and Nuratdinov 1970, Taryannikov 1974). Most of the morphometric studies focus on sexual dimorphism in jackals (Kryštufek and Tvrtković 1990, Angelescu 2004, Boskovic et al. 2015, Raichev et al. 2017).

Sexual dimorphism has been described

for many carnivore species in Europe (Petrov et al. 1992, Gittleman and Valkenburgh 1997, Milenković et al. 2010). Sexual size dimorphism is common among vertebrates, males usually being the larger sex (Ralls 1977). In the end of the last century, the extreme dimorphism in Mustelidae (Moors 1980, Wiig 1986), Felidae (Wiig and Andersen 1986) and Pinnipedia (Stirling 1975), and the reversed dimorphism in predatory birds (Andersson and Norberg 1981, Pleasants 1988) attracted particular interest, and new theories were proposed, associating the sexual dimorphism with divergent selection pressures on males and females (Moors 1980, Wiig 1986, Wiig and Andersen 1986). Sexual dimorphism in Canidae, when present at all, is usually minimal, with males slightly larger than females (Jolicoeur 1959, Hell et al. 1989, Simonsen et al. 2003, Schutz et al. 2009, Sillero-Zubiri 2009). Sexual dimorphism varies in African jackal species among regions and is not as pronounced as is typical of canids (Van Valkenburgh and Wayne 1994).

Bulgarian territory is considered the core area of golden jackal distribution in Europe with the highest population density (Stoyanov 2013, Spassov and Acosta-Pankov 2019), but morphometric studies including data about Bulgarian population were very scarce and local so far (e.g. Atanasov 1953, Raichev et al. 2017). Despite numerous studies of sexual dimorphism in carnivore body size, no studies have attempted to study dimorphism in overall body shape. The present study proposes the first comprehensive analysis of golden jackal morphometrics in Bulgaria, trying to clarify body shape and size related variability and differentiation. Morphometric data were analysed by applying recently developed statistical tools to respond to the following questions:

(i) is there geographic variation in body size and shape among golden jackal population in Bulgaria, (ii) are there age-related differences and at what age jackals reach full growth of the body, and (iii) how pronounced is the sexual dimorphism in body shape and size among adult jackals? Although modern genetic methods have been applied recently in phylogeny and taxonomy, understanding patterns in morphometric variability of golden jackal still provides very valuable insights on population structure. Furthermore, it is not only crucial for understanding the phylogeny, but also for management and conservation. Moreover, integration of genetic techniques and morphometrics represent a valuable tool in the resolution of taxonomic uncertainty.

Material and Methods

The body measurements of 87 jackals, 45 males and 42 females, collected in the period 1998–2007, originating from 20 sites in Bulgaria, were analysed. The main part of the sample was collected in three main regions with the highest jackal's population density: Yambol, Veliko Tarnovo and Burgas. The age of jackals was determined in consideration of upper incisive teeth wear (Lombaard 1971) and for some individuals also by counting the annual cementum layers in canines (Klevezal and Kleinenberg 1967). Both methods are reliable enough for the purposes of the study and provide accurate results, with precision up to one year for the first one (Harris et al. 1992, Raichev 2002). The animals were assigned to three age groups: juveniles, subadults and adults. Juvenile specimens were defined as individuals with fully developed second dentition, but less than 10 months of age, subadults as individuals

more than 10 months, when they reach sexual maturity, but less than two years of age, and adults as two years and older. Studies on the reproduction of golden jackal in Bulgaria have shown that jackals give birth from 10 April till 5 May in Southern Bulgaria, and from 25 April till 20 May in Northern Bulgaria (Vassilev and Genov 2002). Timing of births coincides with abundance of food supply and depends on weather conditions. However, it can be assumed that pups are born in the second half of April and early May. Knowing the age in years and the exact shooting date of each jackal in our sample, we determined the age of the animal with precision up to one month. Estimating the exact age in months allowed following the growth in first stages of ontogenetic development. According to growth stages, jackals in their first year were divided further to three age groups: 5–6 months old (6 individuals), 7–9 months old (7 individuals), and 10 months and older (2 individuals). Joint group of subadult and adult jackals included 72 animals, 42 males and 30 females.

For each individual 18 body measurements were taken (see Table 1) by using a metal measuring tape to the nearest 1 mm, following adopted standard techniques for carnivores (Heptner et al. 1967, Foresman 2012). Body weight was measured on lab scales with precision up to 50 g.

Statistical methods

All measurements were tested for normality by QQ plots and Shapiro-Wilk test. Homogeneity in variance was examined by Fligner–Killeen test. Differences in body size between age groups were tested by one-way analysis of variance (ANOVA) and visualized by applying Tukey's Honestly Significant Difference test (Tukey's

HSD). The dependence of body mass on season and month of the year was examined by one-way ANOVA. Kruskal-Wallis test was applied for testing the differences in body measurements that deviated from normal distribution. Statistical significance of the difference in means between males and females for each body measurement was examined by Wilcoxon–Mann–Whitney test.

Multivariate analyses were employed in order to explore the most significant variation in body size and shape. Shape in general tends to provide more reliable information than size on the morphology of organisms (Jolicoeur and Mosimann 1960). Size is often considered as a nuisance because it is strongly dependent on ecological factors (McCoy et al. 2006), but separation of size and shape in multivariate studies of morphological data is problematic (Claude 2008). This problem was addressed by using principal component analysis (PCA). Baur and Leuenberger (2011) have developed new methods allowing interpretation of principal components in terms of ratios and clear separation of size and shape. The authors defined an isometric size axis, called ‘isosize’, as the geometric mean of the original measurements and thus comprising only differences in scaling. For the exact definition of ‘isosize’, see Baur and Leuenberger (2011). Allometry free shape variables could be obtained by projecting the measurements orthogonal to isosize. A PCA calculated on the covariance matrix of these shape variables then accounts solely for differences in proportions. Baur and Leuenberger (2011) suggested to plot the isosize against each significant shape component in order to assess the amount of allometry in the data. Hence, for clear separation of shape and size, the PCA was applied on the standardized (dividing

each measurement by geometric mean) and log-transformed ratios of the original measurements (Claude 2008, Baur and Leuenberger 2011).

Geometric interpretation of PCA was made by using graphical tools developed by Baur and Leuenberger (2011). The ‘PCA ratio spectrum’ was applied for the interpretation of principal components in shape space. The amount of allometry in the data was assessed by the ‘allometry ratio spectrum’. For detailed mathematical description and statistical framework of the applied methods see Claude (2008) and Baur and Leuenberger (2011).

All statistical and graphical analyses were performed with R, version 3.6.1 (R Core Team 2019). Slightly modified versions of the R-scripts provided by Baur and Leuenberger (2011) and Claude (2008) were employed for calculations. PCA was performed by using the MASS software package (Venables and Ripley 2002).

Ethics statement

The body measurements used in the analyses were taken from individuals that died in vehicle collisions, due to natural causes or as a result of legal hunting. No animal was killed for the purpose of this study.

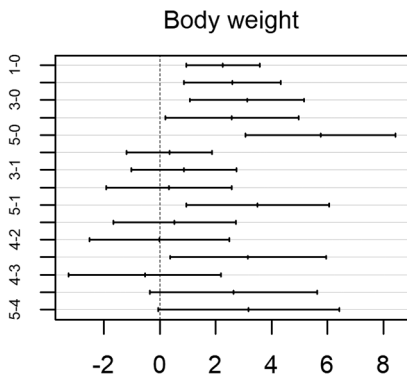
Results

Shapiro-Wilk tests and QQ plots showed that half of all measurements did not deviate significantly from normal distribution: weight, tail length, trunk length, withers height, sacral height, neck girth, chest girth, and belly girth. This allowed applying one-way ANOVA for exploring age-related differences in body size. Kruskal-Wallis

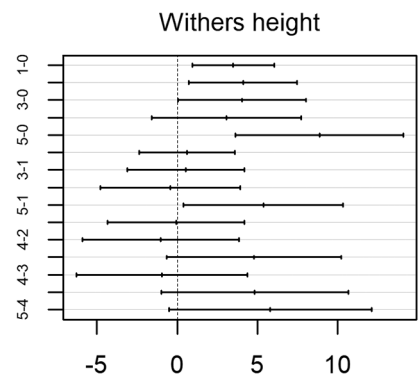
test was applied for testing the differences in body measurements that deviated from normal distribution. However, for most of the following statistical methods the assumption of normally distributed data is not strongly suggested. The results from Tuckey's HSD test showed that jackals up to one year old differ from the older animals only in few body measurements: weight,

withers height, sacral height, neck girth, chest girth, and hind paw width (Fig. 1). Estimating the exact age in months allowed following the growth of body in first stages of ontogenetic development. The most pronounced are differences in body weight (Fig. 2). Males have bigger size, but with large overlap, both between sexes, and between juvenile, subadult and

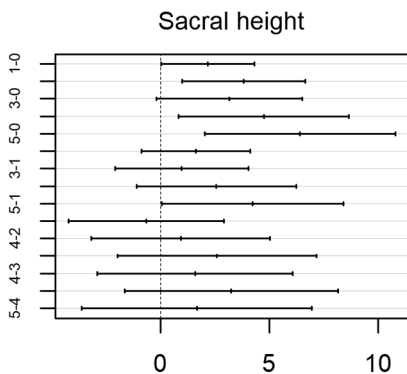
95% family-wise confidence level



95% family-wise confidence level



95% family-wise confidence level



95% family-wise confidence level

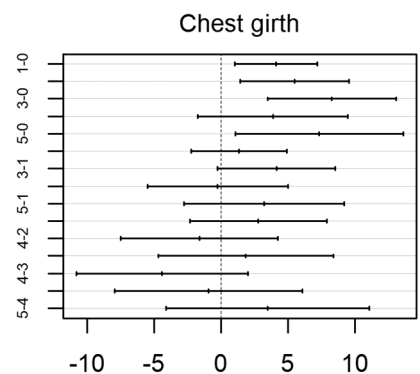


Fig. 1. Differences by age in some basic body measurements.

Note: Results from Tukey's Honestly Significant Difference test.

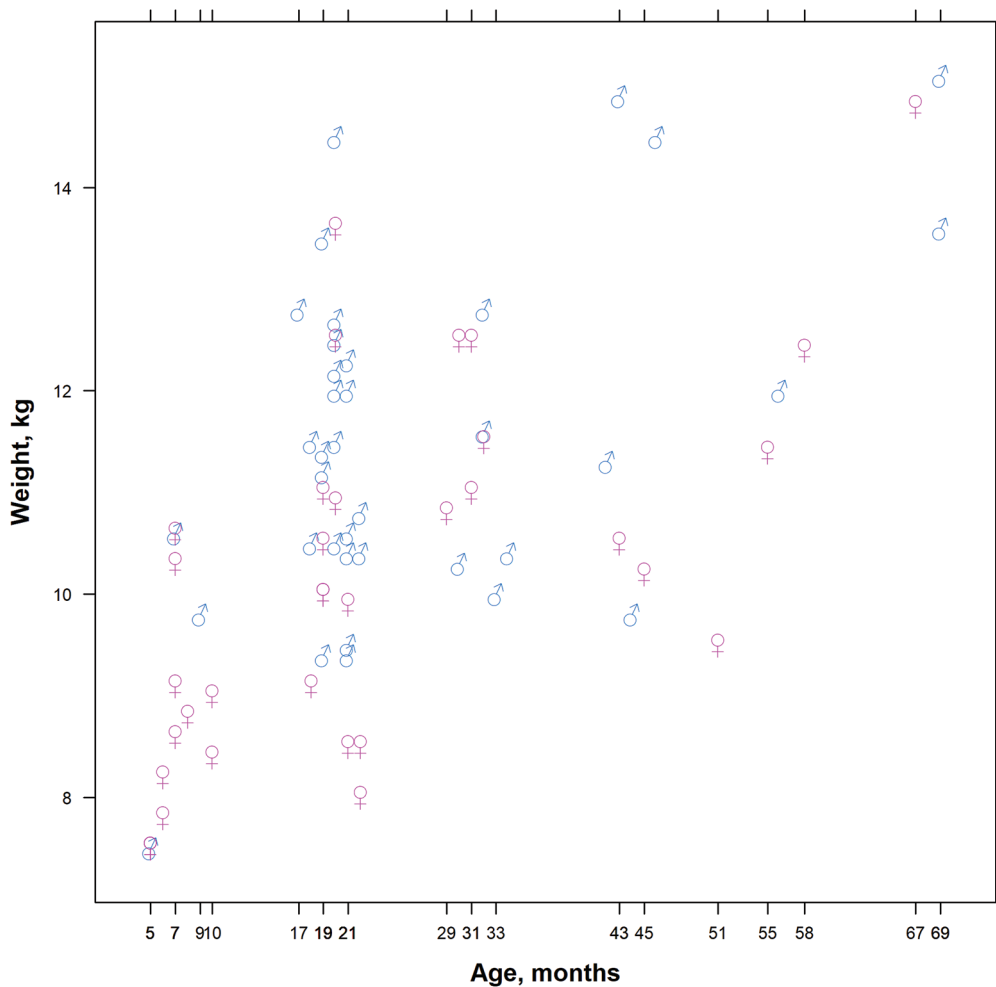


Fig. 2. Body weight of jackals by age and sex.

adult jackals. Despite the small number of individuals in the sample who are below 10 months of age, some of these animals almost reach the adult body mass. The same applies to other body measurements. In October and November, when they are 5–6 months old, the young jackals still differ in size. In winter, at 7–9 months, they are already almost reaching the size of adults and are difficult to distinguish (Fig. 3). We can assume that at the

age of 10 months, at the end of winter, the juvenile jackals grow fully and reach adult body size. In some measurements, such as body length, tail length, neck girth, and leg length, even animals at 5–6 months of age do not show significant differences from adult jackals. However, summary statistics of body measurements were calculated for joint group of subadult and adult jackals, i.e. animals older than 10 months.

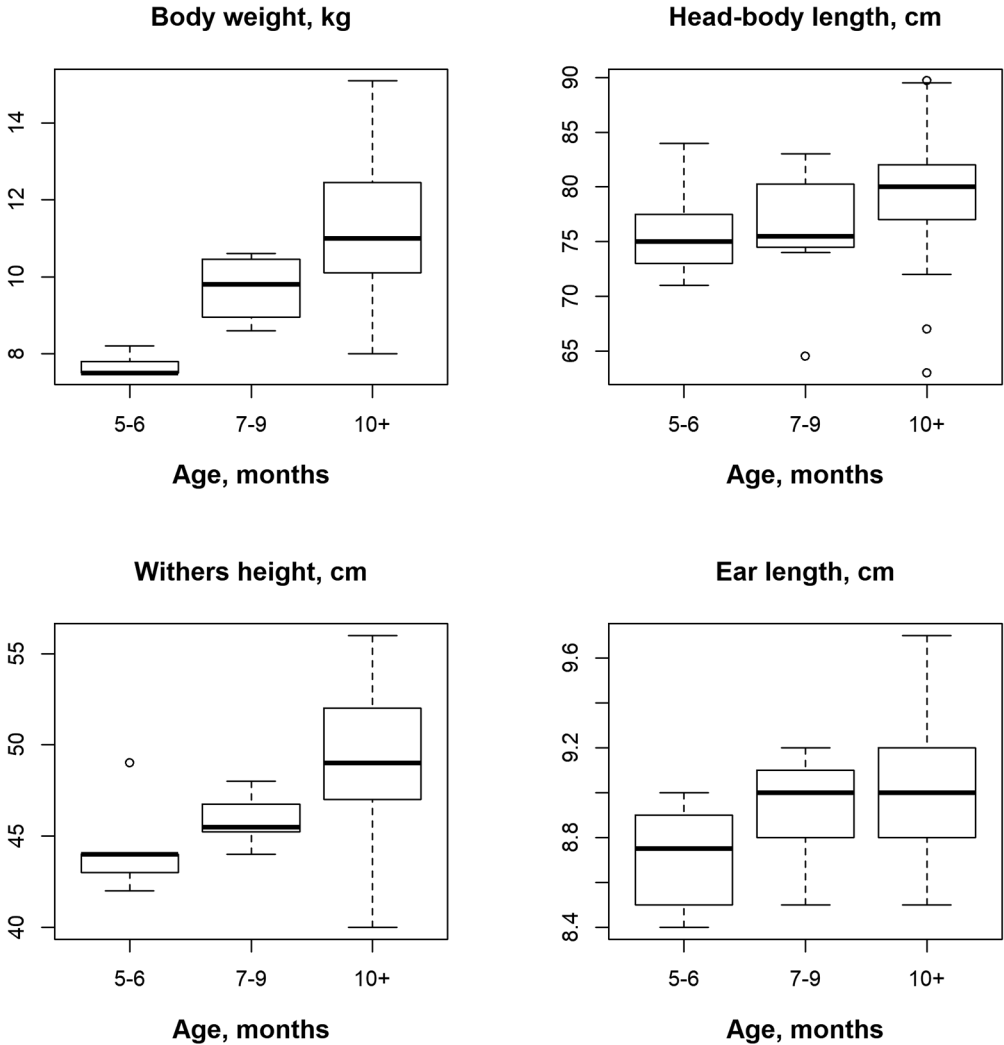


Fig. 3. Comparison of some basic body measurements between jackals in their first year and older animals.

Sexual dimorphism in body size was examined by Wilcoxon–Mann–Whitney test (Table 1). In half of all body measurements differences in means between males and females are statistically significant.

However, there is a large overlap in all measurements, and the sexes could not be separated by body size. As a rule, males are bigger with mean body mass about 8 % higher than females.

Table 1. Descriptive statistics of body measurements and statistical significance of the differences examined by Wilcoxon–Mann–Whitney test.

Measurements	Abbreviation	Males (n=42)				Females (n=30)				p
		min	max	$\bar{x}$	s	min	max	$\bar{x}$	s	
Weight, kg	Wt	9.4	15.1	11.8	1.5	8.0	14.8	10.9	1.5	0.031*
Head-body length, cm	HBL	73.0	90.7	81.5	4.1	63.0	85.0	77.4	4.8	0.0004***
Tail length, cm	TL	20.0	30.0	24.8	2.1	19.0	30.0	23.8	2.2	0.040*
Trunk length, cm	TrL	46.0	61.0	51.5	3.1	46.0	58.0	50.3	2.6	0.042*
Withers height, cm	WH	41.0	55.0	49.8	3.0	40.0	56.0	48.4	3.1	0.023*
Sacral height, cm	SH	46.0	56.0	51.2	2.6	46.0	56.0	50.0	2.4	0.022*
Neck girth, cm	NG	21.8	30.0	25.7	2.1	22.0	29.0	25.3	1.4	0.490
Chest girth, cm	CG	35.5	54.0	43.3	3.3	36.0	49.0	43.5	3.5	0.689
Belly girth, cm	BG	26.0	46.0	34.5	4.8	26.5	43.5	35.0	3.8	0.623
Hand length, cm	HL	9.5	14.0	12.4	0.9	11.0	13.5	12.3	0.5	0.197
Forearm length, cm	FAL	15.0	19.0	17.2	0.9	14.7	18.0	16.6	0.7	0.004**
Foot length, cm	FL	14.0	17.5	15.9	0.8	13.9	17.0	15.6	0.8	0.137
Leg length, cm	LL	16.0	22.0	18.6	1.6	15.7	20.5	18.1	1.1	0.192
Ear length, cm	EL	8.5	9.7	9.1	0.3	8.5	9.4	8.9	0.2	0.100
Front paw length, cm	FPL	5.0	6.8	5.8	0.4	4.8	6.5	5.6	0.4	0.038*
Front paw width, cm	FPW	3.4	4.5	3.9	0.2	3.3	4.6	3.8	0.3	0.271
Hind paw length, cm	HPL	4.5	6.2	5.4	0.4	4.3	6.3	5.2	0.4	0.015*
Hind paw width, cm	HPW	3.0	4.0	3.5	0.2	3.2	4.0	3.5	0.2	0.179

Note: Level of statistical significance: * – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$. $\bar{x}$ – mean, s – standard deviation.

The PCA was applied including specimens from all age groups. The first principal component in shape space accounted for 34.23 % of the variance. Projecting the data along isosize and first principal component in shape space did not reveal any specific patterns in distribution or clustering of the individuals (Fig. 4). Only the cluster of 5–6 months old jackals is well separated from older animals as it is shown by the ellipses enclosing 95 % of the confidence interval for each age group. Juvenile jackals above 6 months of age have the same body shape and size as subadults and two years old animals. The sex dimorphism in body shape and size is not pronounced and there is a large overlap between males and females. Differences are mainly in size, but not in

shape. Some males above three years old are bigger, but this does not depend on their exact age.

The first two principal components in shape space accounted for 50.93 % of the variance (Fig. 5). Projecting the data along first and second principal components reveals only differences in body shape. The group of 5–6 months old jackals could be distinguished clearly by shape from subadult and adult males but overlap with females. There are no differences in body shape between males and females. Projecting individuals along isosize and first principal component (Fig. 6) and along the first two principal components in shape space (Fig. 7) did not reveal any clustering depending on the collection site as well. Jackals from Northern and Southern

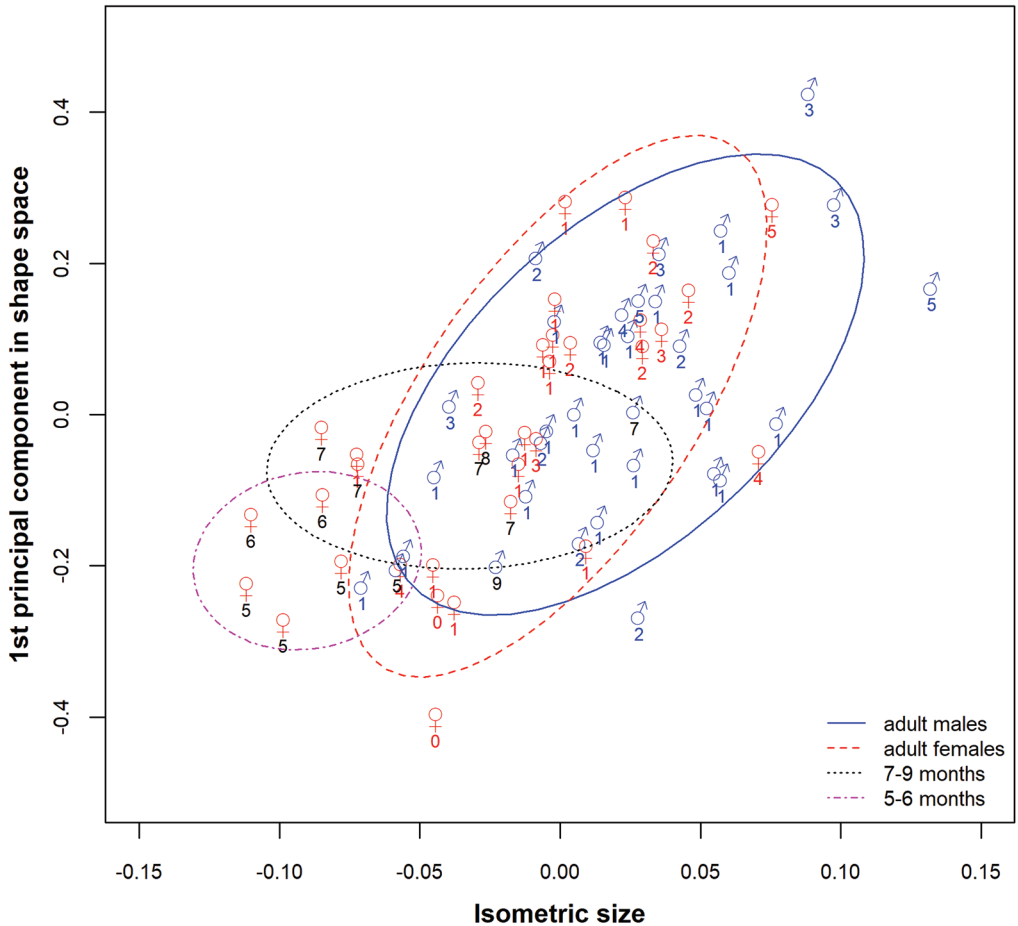


Fig. 4. Projection of individuals along isometric size and first principal component in shape space.

Note: Ellipses enclose 95 % confidence interval for each group. Sex and age of each individual are shown. Numbers in blue and red represent age in years for males and females respectively. Numbers in black correspond to age in months for juvenile individuals.

Bulgaria could not be clearly separated by their body size and shape.

The 'PCA ratio spectrum' allows the interpretation of principal components in shape space (Fig. 8). Considering factor loadings, ratios between body weight (Wt), belly girth (BG), chest girth (CG), leg length (LL), on the one side, and remaining body measurements, on the other side, explained a large proportion of the

variance of the first and second shape principal components. The same ratios, however, showed the most distinctive allometric behaviour as could be seen from the 'allometry ratio spectrum' (Fig. 9). Presence of allometry could be assessed as well, while projecting the first shape principal component orthogonal to the isometric size (Fig. 4). Judging from the graph, there is only a very moderate cor-

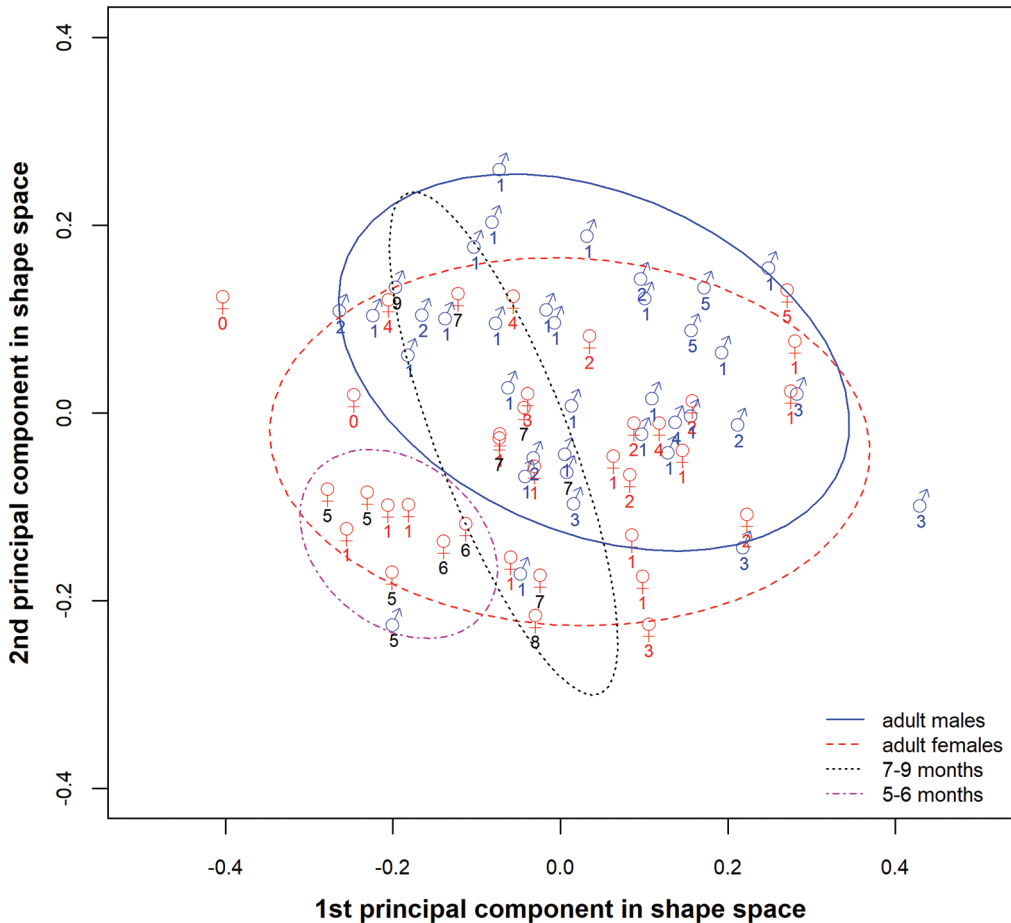


Fig. 5. Projection of individuals along first two principal components in shape space.

Note: Ellipses enclose 95 % confidence interval for each group. Sex and age of each individual are shown. Numbers in blue and red represent age in years for males and females respectively. Numbers in black correspond to age in months for juvenile individuals.

relation between shape and size. Hence, allometric variation was of marginal importance concerning our data set.

Body weight highly determines the morphometric differences between jackals, as far as they exist. Furthermore, this measurement showed the most distinctive allometric behaviour. Many factors could influence the weight of jackals, even the time of measurement. However, no dependence of body weight on the season

and even on the month of the year was found in both sexes ($F=0.963$, $df=5, 34$, $p=0.454$ for males and $F=1.652$, $df=5, 20$, $p=0.192$ for females).

Discussion

The results suggest that the differences in body size and shape of jackals, as far as they exist, are age-related. However,

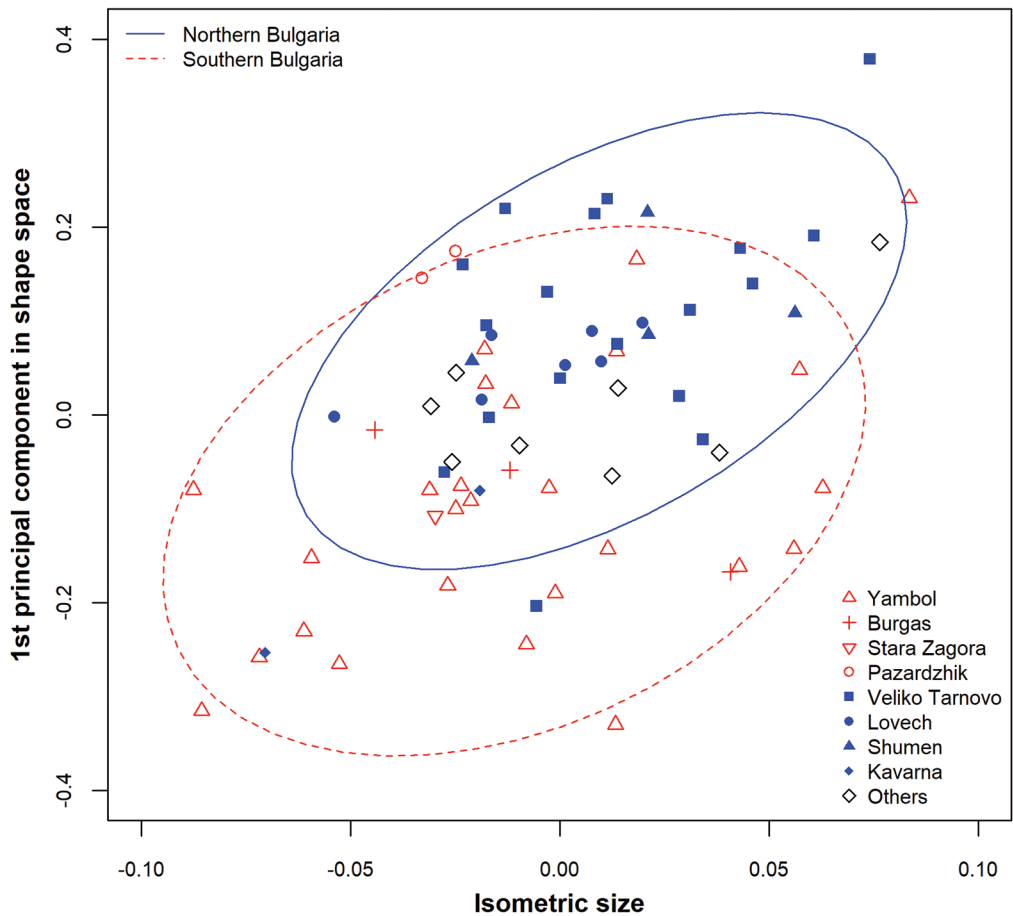


Fig. 6. Projection of individuals along isometric size and first principal component in shape space, according to collection site.

Note: Ellipses enclose 95 % confidence interval for each group, Northern Bulgaria and Southern Bulgaria correspondingly.

there is no clear differentiation between subadult and adult animals. Only 5–6 months old juvenile individuals could be separated by shape and size of the body. In winter, at 7–9 months, they are already almost reaching the size of the adults and are difficult to distinguish. At the end of winter, at the age of 10 months the juvenile jackals grow fully and reach adult body size. Univariate analyses showed that in all body traits juveniles, i.e. jackals below 10 months of age, differ from

the older jackals. The results of other studies for the growth rate of jackals are similar. The jackals grow rapidly during the first 5–6 months of their lives, after which the growth rate slows down, and after 10 months of age they almost reach the size of the adults (Taryannikov 1974). Studies in Uzbekistan show that by the end of October, at 6–7 months of age, the young jackals are almost indistinguishable from the adults in overall body size, but their weight is almost two times less

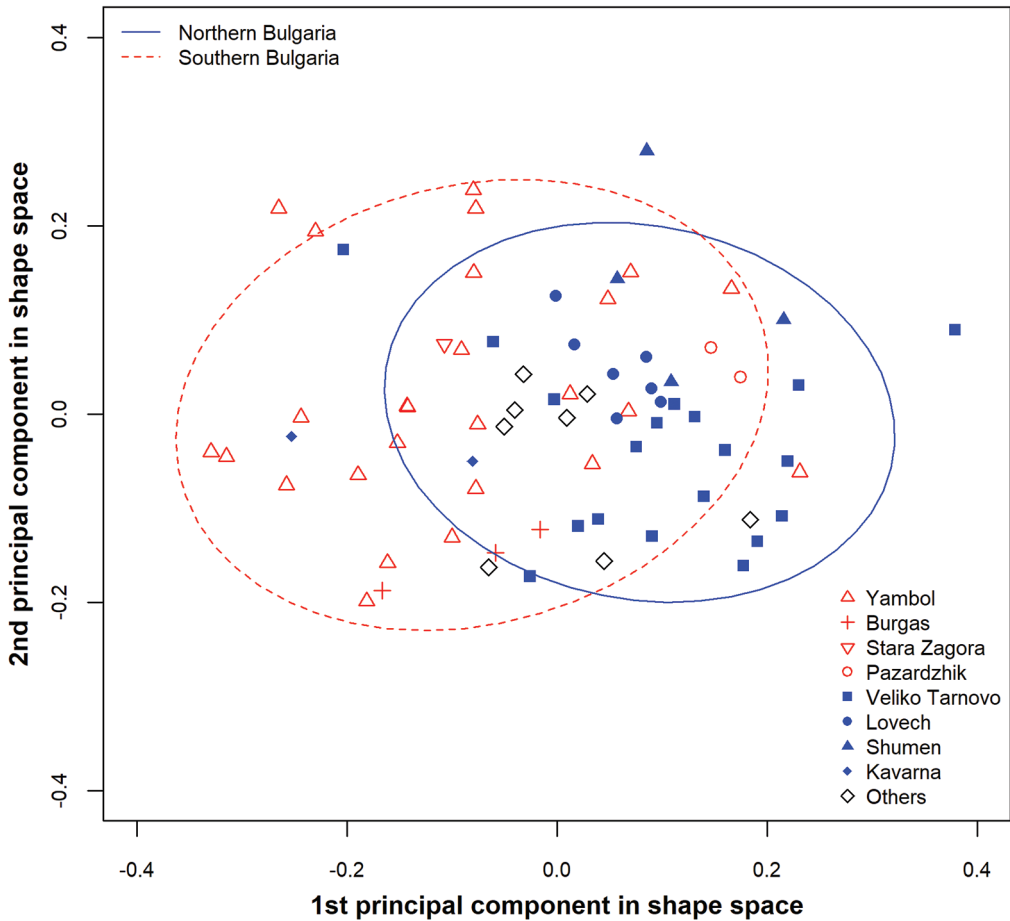


Fig. 7. Projection of individuals along first two principal components in shape space, according to collection site.

Note: Ellipses enclose 95 % confidence interval for each group, Northern Bulgaria and Southern Bulgaria correspondingly.

(Taryannikov 1976). Hence, jackals can be divided into two age groups in terms of body size, juveniles (up to 10 months) and adults (older than 10 months). Dividing the whole sample to three age groups was based on population demography of golden jackal and differences in the reproductive value of subadult and adult individuals (Stoyanov 2013). Golden jackals reach sexual maturity at the age of 10–11 months (Taryannikov 1976), but they rarely

reproduce at this age. In Tanzania 70 % of known surviving pups were observed helping with the next year's litter and thus didn't rear their own offspring (Moehlman 1987). According to the same author, retaining helpers potentially increases the parents' reproductive success, that is, it increases the parents' chances of passing on their genes to future generations. Our results showed that the jackals in reproductive age reach full body size. All infe-

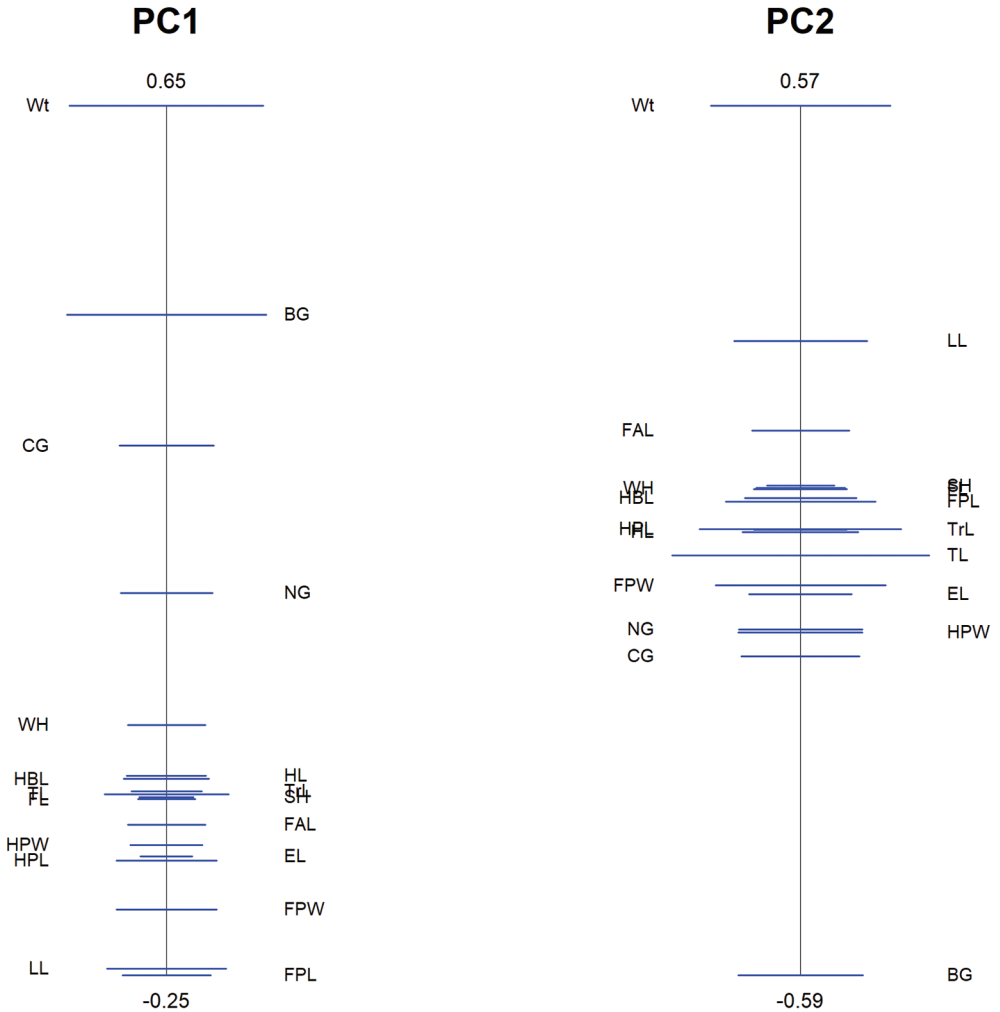


Fig. 8. PCA ratio spectrum for the first and second principal component in shape space.

Note: Bars represent 68 % confidence intervals based on 500 bootstrap replicates.

rences about growth of the body, based on such studies, however, should be treated cautiously. The data did not allow following the ontogenetic development of jackals because we compared different individuals. Usually more viable and healthy individuals reach senescence, while weaker and smaller animals die earlier and do not reach more than 2–3 years of age. Stu-

dies on population demography of golden jackal in Bulgaria showed that about 10 % of jackals from one cohort could reach up to 5 years and over, and jackals above 3 years comprise only 6 % of the population (Stoyanov 2013). Thus, post mortal comparison of body measurements leads to biased data. The best way to address this problem is to measure animals kept in

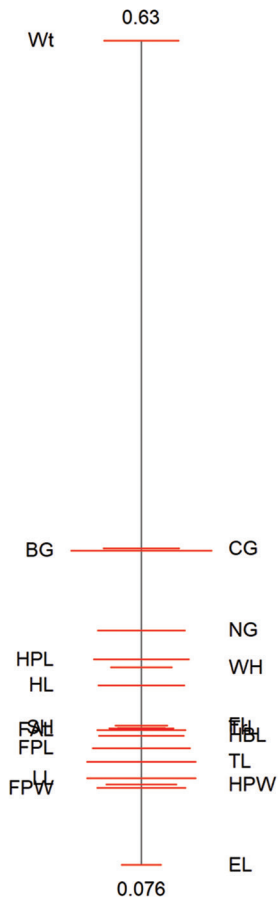


Fig. 9. Allometry ratio spectrum.

Note: Bars represent 68 % confidence intervals based on 500 bootstrap replicates.

captivity or by applying capture-mark-recapture approach. However, animals kept in captivity show different growth rate due to limited space and artificial feeding.

Sexual dimorphism in body size and shape is not clearly expressed, despite the statistical significance of differences in mean values between males and females in half of all measurements. The high level of statistical significance, as demonstrated by Wilcoxon–Mann–Whitney test, was due to the large sample size, and could

be misleading. However, there is large overlap between males and females in all traits, and they could be hardly differentiated only by body size. Furthermore, principal component analysis did not reveal any differentiation in body size and shape between males and females. The males are bigger with mean body mass about 8 % higher than females. The same results were confirmed by other studies as well (Atanassov 1953, Heptner et al. 1967, Aliev 1968, Reimov and Nuratdinov 1970, Taryannikov 1974, Jhala and Moehlman 2004, Sillero-Zubiri 2009, Raichev et al. 2017). In India male jackals have 12 % higher body mass than females (Jhala and Moehlman 2004, Sillero-Zubiri 2009). However, in the latter study the sample size was too small for making general conclusions.

Sexual dimorphism in Canidae, when present at all, is usually minimal, with males slightly larger than females (Sillero-Zubiri 2009), although studies on wolves from the Balkans show significant sexual dimorphism in adult individuals (Trbojević and Ćirović 2016). Such sexual dimorphism of golden jackal, with males a little bit larger than females, could be explained with monogamous reproductive system and the presence of male parental care (Kleiman 1977, Bekoff et al. 1981, Moore 1981, Moehlman 1987). Dimorphism is negatively correlated with age at independence or dispersal and age at first breeding (Bekoff et al. 1981). Furthermore, delayed dispersal and delayed breeding also are associated with monogamy (Kleiman 1977). Golden jackals form pair-bonds that are characterized by friendly behaviour and last the 6 to 8 years of their usual lifespans, there is little sexual dimorphism, either physically or behaviourally, and they share equally in most activities, such as marking and

defending their territory, foraging and resting (Moehlman 1987). Small to moderate sexual dimorphism in size may also be related to the fact that there does not appear to be intense competition for mates among male canids (Bekoff et al. 1981). Such degree of sexual dimorphism in Canidae was confirmed by other studies as well (Jolicœur 1959, Hell et al. 1989, Simonsen et al. 2003, Schutz et al. 2009).

Bulgarian jackals measured in our study do not differ from jackals in Romania, the Caucasus, Central Asia, Tajikistan and Uzbekistan compared to data published by other studies (Heptner et al. 1967, Aliev 1968, Taryannikov 1974, Angelescu 2004). Comparison of some basic body measurements from different parts of the range (Heptner et al. 1967, Jhala and Moehlman 2004) shows that the jackals in Europe, including our Bulgarian sample, and Central Asia are larger than the African and Indian jackals. Recent genetic analyses revealed that *Canis aureus* from North Africa should be considered as separate species (Koepfli et al. 2015). Moreover, Indian jackals (*Canis aureus indicus* Hodgson, 1833) belong to different subspecies (Moehlman and Hayssen 2018), and such differences in size are expected.

The body mass of jackals in Bulgaria did not depend on season and habitat. Males are on average 8 % heavier than females but with large overlap between sexes. Although some male animals weigh above 15 kg, body weight of an adult jackal is usually between 10 and 14 kg (Fig. 2). Most of juveniles and sub-adults weigh below 10 kg. Recent study in Sredna Gora Mountain and Thracian Plain reported similar results (Raichev et al. 2017). The body mass of jackals is usually overestimated by hunters. However, the body weight depends on habitat

quality and in areas with improved nutrition jackals in good condition could have increased their weight. In Bulgaria in the last decades jackals have flourished due to low sanitation and wide availability of easily accessible carcasses and other food resources in garbage dumps around villages. In Israel in the last 50 years an increase in body weight and length was found due to improved nutrition owing to a substantial increase in the amount of garbage and agricultural crops available (Yom-Tov 2003).

There could be hardly seen any differences in body shape between jackals from different regions of Bulgaria. The amount of geographical variation in Bulgarian population is comparable with sex and age differences. Although the sample size included in the analyses was not small, the projected data form a homogenous cluster, but with large individual variability. There are no morphologic differences in body size and shape between Northern and Southern Bulgaria. The lack of intrapopulation differentiation could be expected for such mobile, opportunistic and highly adaptable mesocarnivore as golden jackal. The jackals can easily expand their range and colonize new habitats. The recent colonization of the Baltic States is most likely a case of long-distance dispersal. It is not uncommon for golden jackals to disperse over several hundred kilometers in human-dominated landscapes (Rutkowski et al. 2015). This could explain the speed of jackal expansion in Europe that has been observed in the last decades (Trouwborst et al. 2015). Golden jackal has appeared in high mountains above 1000 m a.s.l. and Stara planina Mountain couldn't be considered a physical barrier. The results are consistent with recent genetic and morphological studies as well (Raichev et al. 2017, Rezić et al. 2017). Genetic studies

focused on jackals in Bulgaria, Serbia, Croatia and Italy suggested a low level of genetic diversity and weakly pronounced genetic structure, with only the coastal population from Dalmatia clearly differentiated from other Balkan samples (Zachos et al. 2009, Fabbri et al. 2014, Rutkowski et al. 2015).

Conclusion

Body size and shape of golden jackal in Bulgaria show considerable individual variability, but weak intrapopulation differentiation. The differences in shape and size of the jackal body, as far as they exist, are age-related, but only 5–6 months old animals could be easily distinguished. Body growth ends at 10 months of age, but even 7–9 months old jackals are difficult to distinguish from adults in the field. However, their body weight is smaller. Subadult and adult jackals largely overlap in body size and shape. Sexual dimorphism in jackal's body is weakly pronounced, with older males a little bit larger than females. The results are consistent with recent genetic and morphological studies suggesting little morphological variation, low level of genetic diversity and weakly pronounced genetic structure in European population of golden jackal.

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EVALUATION INDICATORS FOR SUSTAINABLE URBAN FOREST IN TABRIZ CITY, IRAN

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Abstract

The main goal of this study was to achieve a set of the main key to sustainable urban forest indicators by using Fuzzy Delphi method – Iran perspective. The questionnaires were developed based on the ecological (sub-criteria including urban trees biodiversity, trees canopy coverage, flood control, species habitat provision, carbon storage and greenhouse gases sequestration), social (sub-criteria including physical assess to nature, visual assess to nature, increasing growing space in the city, air quality improvement and danger probability of urban trees) and economic criteria (sub-criteria including energy conservation and increase property value) and 13 experts in the field of forest sciences were chosen to sit on the panel of experts. The results of this study showed that carbon storage and greenhouse gases sequestration (final weight = 0.25) in ecological sub-criteria, air quality improvement (final weight = 0.24) in social and energy conservation (final weight = 0.66) in economic criterion has the first level of importance in each criterion. The results demonstrate that urban forests not only beautify the landscape, they even play a major role in ecological, social and economic values. The results of this study will be implemented in urban forests developing projects by helping in suggesting proper tree species to maximize all of the indicators factors investigated in this study.

Key words: criteria and indicators, landscape, Iran, sustainable urban forestry.

Introduction

Urban forests are located in or around dense urban areas and include trees that grow in roadsides, parks, gardens, and remnant forest patches. Urban forest provides sustainable public health and public environmental benefits to urban residents (Gerrish and Lea Watkins 2018, Song et al. 2018, Vujcic and Dubljevic 2018) and offer urban dwellers a higher quality of life by delivering a wide range of benefits including ecological (moderating climate, air quality improvement and reduction

in noise levels), economical (providing shade cover and reducing energy costs and increasing property values) and psychological (provide a great potential perceiving general health by reducing stress and making positive emotions) benefits (Wilde and Maxwell 2018).

Recent studies demonstrate that urban forests provide visitors opportunities to various activities such as social interactions, physical activities, outdoor recreation, multiple health benefits, etc. Visitors have diverse motivations for visiting urban forests in every country such as taking

a walk in Denmark, barbequing and picnicking in Australia, walking and jogging in Austria and Germany (Zhai et al. 2018, Chen et al. 2018).

Over the past few decades, there have been intensive efforts to green cities because healthy urban forests can produce ecosystem functions and provide goods and services to benefit humans and the environment (McPherson et al. 2017, Song et al. 2018).

The presence of urban forests is constrained by urbanization. The urbanization has many challenges to urban dwellers and creates many problems that can affect human wellbeing and associated air pollution emission with consequent detrimental health effects. Therefore, the evaluation of sustainable urban forest indicators has become an essential need for overcoming these problems and help to create a healthy living environment (Chen et al. 2018, Selmi et al. 2016).

There are many scientific methods to achieve this purpose. The Delphi method is a well-established method that uses experts' consultation and contribute their opinion to obviate a structured problem and develop improves solutions in an urban forest situation (Barron et al. 2016, Ocampo et al. 2018) and generate a majority agreement around the most efficient criteria for improving urban forest planning framework (Toumbourou 2018).

Delphi method has been recognized as a social and policy technique and a valid instrument for assisting decision-making processes on various issues. The selection of a suitability qualified and knowledgeable panel is critical to the success, validity and accuracy results of a Delphi study (Toumbourou 2018). The Fuzzy Delphi method is the modified and improved version of the classical Delphi technique (Amira et al. 2016) that is an analytical

hierarchy approach for ranking of effective material section criteria (Kazemi et al. 2015).

The Fuzzy Delphi method established in this study is a highly objective, adaptive assistive decision-making tool that can facilitate subsequent maintenance and applications (Fig. 1) (Hsueh 2015). Fuzzy Delphi as an analytical method used probability theory (instead of absolute mathematical concepts) to address the fuzziness numbers of experts prediction interval values in order to achieve a better conclusion of the expert judgments and decision making (Sensuse et al. 2018, Ho and Wang 2008).

The natural environment and urban

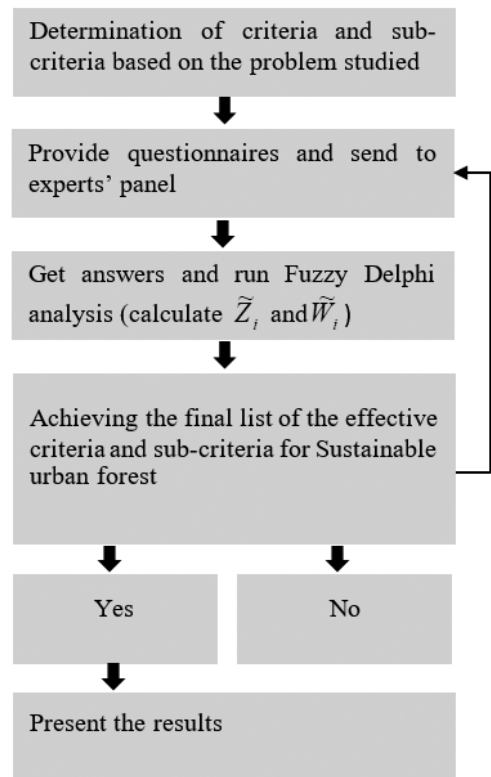


Fig 1. A summary of steps to run the Fuzzy Delphi method.

forests scientific studies by the Fuzzy Delphi approach have been a debate in many publications that attempted to qualify the benefits of urban forests. Filyushkina et al. (2018) applied the Delphi method to identify the impacts of five forest management alternatives and several forest characteristics on the preservation of biodiversity and habitats in the boreal zone of the Nordic countries. Ocampo et al. (2018) studied the sustainable ecotourism indicators with the Fuzzy Delphi method in Philippine. Toumbourou (2018) used the Delphi approach to identify the most efficacious interventions to improve Indonesia's forest and land governance. Barron et al. (2016) use a Delphi approach to develop a set of key indicators for healthy urban forest planning and designing future forests. Barzekar et al. (2011) studied criteria and indicators in monitoring ecotourism sustainability in the Northern forests of Iran by the Delphi technique.

Considering the strong concerns of increasing the urbanization and reducing green space in industrial big cities in the last decade, this study was conducted to explore the most important criteria to achieve the better scientific understanding of ecological, social and economic benefits of urban forests from the perspective of forestry experts by Fuzzy Delphi method and to provide the clear and

scientific express to urban forest planners and urban green space decision-makers to use the most effective criteria to expand green spaces and forest parks.

Materials and Methods

Study area

The study was performed in Tabriz city as the fifth largest and one of the important industrial cities located in the capital of Azarbaijan province, northwest of Iran (Fig. 2) with population of 1,558,693 (Based on the results of the 2016 census), at an altitude of 1361 m a.s.l and in 38°5' N and 46°16' E geographical coordinates. The mean annual precipitation is approx-



Fig 2. Location of the study area.

imately 290 mm, the mean temperature is 12.5 °C and classified in the Semi-Arid region according to the De Martonne aridity index. (Zarghami and Akbariyeh 2012, Hami and Tarashkar 2018, Sharafkhani et al. 2018).

Data analysis

Design questionnaire: This study used

a Fuzzy Delphi method to identify criteria and highlight the importance of understandings in the field of urban forestry, and therefore, first to establish a set of criteria and sub-criteria. A questionnaire was developed based on the main criteria introduced in works of literature (Tyrvaäinen 2001, McPherson and Simpson 2003, Nowak et al. 2013, Barron et al. 2016, McPherson et al. 2017) (Table 1).

Table 1. Set of key urban forest indicators used in this study.

Criteria	Sub-criteria	Descriptions
Ecological	Urban trees biodiversity	An urban forest with a variety of species is more adaptable and resistant to the factors of change, such as climate change, pests and diseases. This diversity includes age, species, genus and family. Diversity guarantees the long-term sustainability of the forest.
	Trees canopy coverage	Crown coverage is the most common criterion used to estimate the characteristics of an urban forest in cities because it is both easy to measure and publicly available.
	Flood control	Trees help the water penetration into the soil and purify the water and reduce the amount of surface runoff volume in an appropriate system.
	Species habitat provision	Urban forests can help protect biodiversity by creating a high-quality habitat for Fauna and Flora. A forest park can well provide the needs for the nature of a city.
	Carbon storage and Greenhouse gases sequestration	Carbon sequestration refers to the amount of carbon dioxide absorbed by leaves of trees and stored in the wood and soil texture. Carbon dioxide is the most abundant greenhouse gas that is achieved by using fossil fuels. Calculating the amount of carbon storage indicates the contributing of urban forests to reduce the impacts of global warming and climate change.
Social	Physical Assess to nature	Access to the natural area leads to an increase in physical activities in nature, such as hiking and outdoor recreation, therefore there are the important aspects of physical, mental and psychological well-being for citizens.
	Visual Assess to nature	There is scientific evidence that access to nature will reduce stress and increase physical and mental health, even with watching a beautiful view from the window.
	Increasing growing space in the city	The amount of natural space in the urban forest is an indicator of the potential of the community to increase the protection of urban forests. Without suitable space and soil, the urban forests will face to the problem in developing and managing.
	Air quality improvement	Trees are very useful to improve air quality and human health. Trees promote health and social well-being by removing air pollution, reducing stress, encouraging physical activity, and promoting social ties and community.

Criteria	Sub-criteria	Descriptions
Economical	Danger probability of urban trees	The fall of the trees' trunks and branches due to storm or uproot the trees and vulnerability to pests, pathogens of diseases are potentially concerned for urban forest dangers that may result in irreparable damages. But, these risks will be reduced easily by taking measures to protect the health of the trees, the age, and the proper species at the right places in urban forests.
	Energy conservation	This criterion is used to calculate the contribution of urban forests to reducing energy consumption in the community, which can be achieved by reducing the energy consumption of buildings by trees shade on buildings over warm summers or using cool and fresh air during warm hours.
	Increase property value	Estate close to urban forests is more expensive and thus affects people's economies. There are economic indicators that can easily calculate this value.

Then, three ecological, social and economic criteria and sub-criteria were determined by interval weights among 1 to 9 (Table 2). At the second step, a total of 13 experts and academic lecturers in the field

of forest sciences were chosen (Linstone 1978, Tsaur et al. 2006, Skulmoski et al. 2007) to sit on the panel of experts based on more than 6 to 10 years' experience (Hasan et al. 2017).

Table 2. Importance of the sub-criteria weights.

Weights of sub-criteria	Code	Descriptions (with triangular fuzzy numbers)
Quite unimportant	1	The sub-criteria has no significant effects in the urban forest (1,1,3)
Partly important	3	The sub-criteria has a partly significant effect in the urban forest (1,3,5)
Moderate important	5	The sub-criteria has a moderately significant effect in the urban forest (3,5,7)
Important	7	The sub-criteria has a significant effect in the urban forest (5,7,9)
Very important	9	The sub-criteria has a very significant effect in the urban forest (7,9,9)

Note: the numbers in brackets mean triangular fuzzy numbers.

Steps of data analysis: in the end, data analysis of the Fuzzy Delphi technique was performed by paired comparison matrix for sub-criteria according to participant opinions. The analysis steps included Fuzzy numbers definition based on the membership function of the triangle, paired fuzzy comparing between sub-criteria, the fuzzy relative weight of criteria calculating and finally the most effective factors determination to evaluate

key urban forest indicators (Hasan et al. 2017, Toumbourou 2018), as follows:

The basic steps of the Fuzzy Delphi process:

- Surveying experts: At first, it is surveying experts about effective factors.
- Calculation of fuzzy numbers: To calculate fuzzy numbers ($\tilde{a}_i$) the opinion of experts was used directly. Fuzzy numbers calculated based on the membership function of the triangle. The fuzzy numbers

defined as the following functions (1–4):

Function (1): $a_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij})$, where a_{ij} are triangular fuzzy numbers.

Function (2): $\alpha_{ij} = \min(\beta_{ijk}), k = 1, \dots, n$, where α_{ij} is the lower limit of expert's opinion; β_{ijk} is relative importance of i to j from k th expert.

Function (3): $\delta_{ij} = \left(\prod_{k=1}^n \beta_{ijk}\right)^{1/n}, k = 1, \dots, n$, where δ_{ij} is the geometric mean of experts' opinion.

Function (4): $\gamma_{ij} = \max(\beta_{ijk}), k = 1, \dots, n$, where γ_{ij} is the higher limit of expert's opinion.

The fuzzy opinion for the survey can be denoted as $\alpha_{ij} \leq \delta_{ij} \leq \gamma_{ij}$. In addition, the components change from intervals of $\left[\frac{1}{9}, 9\right]$.

- Fuzzy inverse matrix ($\tilde{A}$): Paired fuzzy comparing between sub-criteria was done based on the following function (5):

Function (5): $\tilde{A} = [\tilde{a}_{ij}]_{n \times n}, \tilde{a}_{ij} \times \tilde{a}_{ji} \approx 1, i, j = 1, 2, \dots, n$

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (\alpha_{1j}, \delta_{1j}, \gamma_{1j}) & (\alpha_{1n}, \delta_{1n}, \gamma_{1n}) \\ \left(\frac{1}{\gamma_{1j}}, \frac{1}{\delta_{1j}}, \frac{1}{\alpha_{1j}}\right) & (1,1,1) & (\alpha_{2n}, \delta_{2n}, \gamma_{2n}) \\ \left(\frac{1}{\gamma_{1j}}, \frac{1}{\delta_{1n}}, \frac{1}{\alpha_{1n}}\right) & \left(\frac{1}{\gamma_{2n}}, \frac{1}{\delta_{2n}}, \frac{1}{\alpha_{2n}}\right) & (1,1,1) \end{bmatrix}$$

- Calculation of fuzzy relative weight of criteria – functions (6) and (7):

Function (6): $\tilde{Z}_i = [\tilde{a}_{ij} \dots \tilde{a}_{in}]^{1/n}$.

Function (7): $\tilde{W}_i = \tilde{Z}_i / (\tilde{Z}_1 \oplus \dots \oplus \tilde{Z}_n)$, where: $\tilde{a}_1 \otimes \tilde{a}_2 = (\alpha_1 \times \alpha_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2)$ and sign $\otimes$ show multiple of fuzzy numbers and $\oplus$ show the addition of fuzzy numbers. $\tilde{Z}_i$ is the total relative fuzzy weights of the criteria $\tilde{W}_i$ is a row vector and shows fuzzy weighting of criteria i .

- None fuzzy weighting of criteria: The geometric mean of the fuzzy number of

the weight of criteria and sub-criteria calculated according to Function (8). Thus, the weight of criteria and sub-criteria explain as a certain number:

$$\text{Function (8): } W_i = \left(\prod_{j=1}^3 w_{ij} \right)^{1/3}.$$

Finally, the effective factors were determined (Abedi and Ganji 2015, Kazemi et al. 2015, Ocampo et al. 2018). Sometimes, this method requires multiple replications for asking experts' opinions that must continue until they get a consensus. In this study, the data from the first round survey reached an appropriate consensus, and there was no need to require multiple rounds.

Results

Eventually, final weighs of criteria ($\tilde{W}_i$) were calculated to evaluating and rat a set of important indicators in creating a framework for designing and planning sustainable urban forests in the future. According to the results, five ecological sub-criteria were classified into three categories. The carbon storage and greenhouse gases sequestration (0.25) sub-criteria were the most important ecological criteria, followed by trees canopy coverage (0.21), floodwater control, species habitat provision and urban trees biodiversity (0.18), respectively (Fig. 3).

The final weights of social criterion showed that air quality improvement (0.24) sub-criteria were the most important criterion, followed by physical access to nature (0.21), visual access to nature (0.21), increasing growing space in the city (0.19) and danger probability of urban trees (0.12), respectively, therefore five sub-criteria were classified into five categories (Fig. 4).

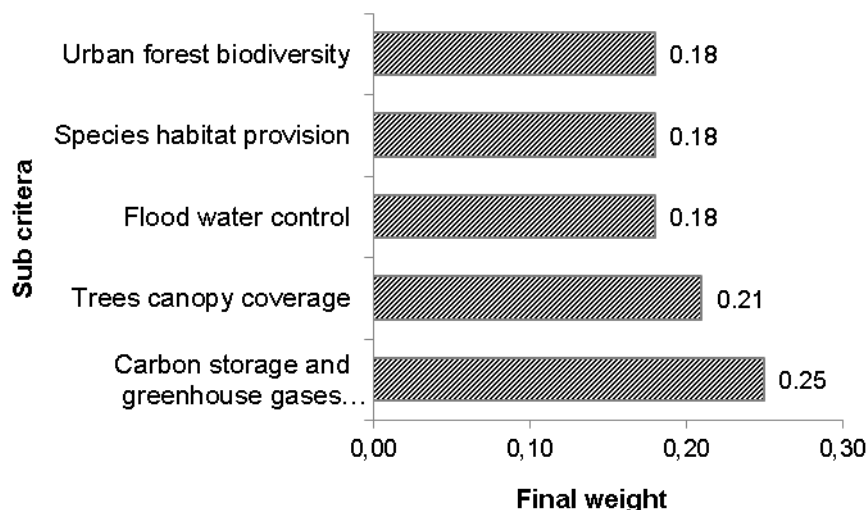


Fig 3. Final weights of Fuzzy Delphi sub-criteria for ecological criterion.

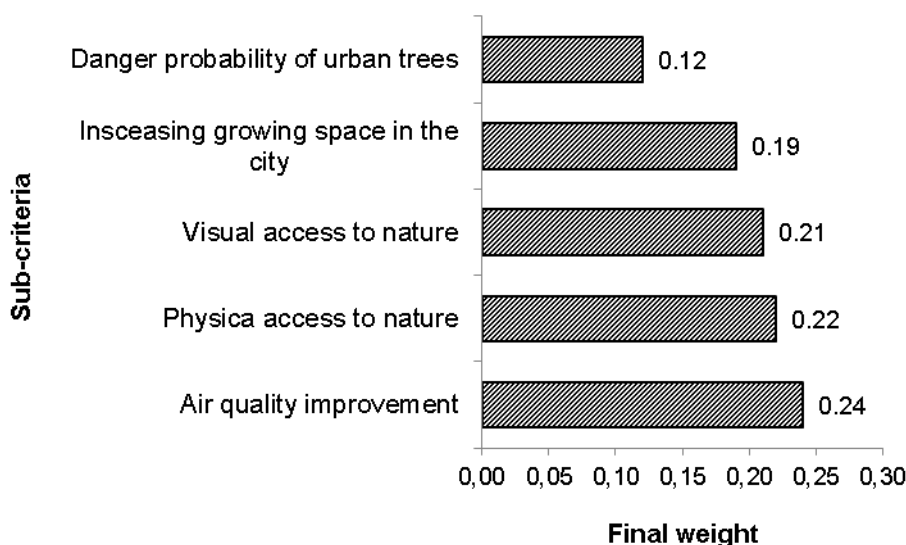


Fig 4. Final weights of Fuzzy Delphi sub-criteria for social criterion.

The sub-criteria of economic criterion were classified into two categories to evaluate indicators for the sustainable urban forest. Energy conservation has the first level of importance (0.66) and increase property value was the second (0.33) (Fig. 5).

Results of Fuzzy Delphi mean rating

matrixes of all participants' consensus ($\tilde{z}_i$) were formed for ecological, social and economic criterion (Table 3).

In addition, the average fuzzy vs. non-fuzzy weights of all criteria resulted from all participants were calculated and shown in Table 4.

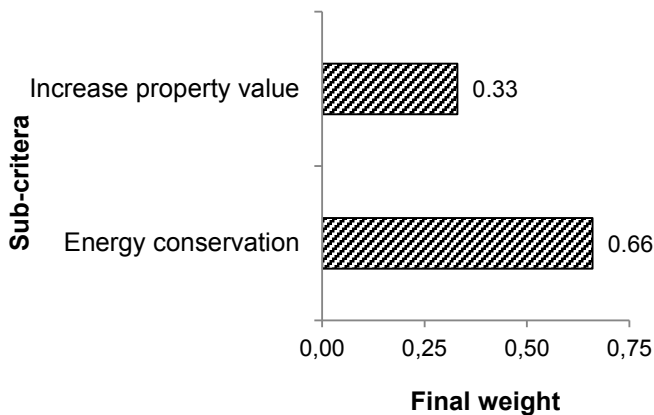


Fig 5. Final weights of Fuzzy Delphi sub-criteria for economic criterion.

Table 3. Total relative fuzzy weights of the criteria.

Criteria	Subcriteria	$\tilde{z}_i$		
		z_1	z_2	z_3
Ecological	1	0.51	0.87	1.58
	2	0.62	1.02	1.87
	3	0.48	1.00	1.58
	4	0.53	0.95	1.50
	5	0.89	1.19	1.97
	Total	3.04	5.03	8.49
Social	1	0.83	1.15	1.58
	2	0.78	1.14	1.50
	3	0.70	1.00	1.40
	4	0.95	1.23	1.69
	5	0.42	0.61	1.00
	Total	3.68	5.14	7.16
Economical	1	0.75	1.26	3.00
	2	0.33	0.79	1.34
	Total	1.08	2.05	4.34

Table 4. Average fuzzy and non-fuzzy weights of first, second and third criteria.

No	Criteria	Subcriteria	Fuzzy weights			Non-fuzzy weights
			w_3	w_2	w_1	
1	Ecological	1	0.06	0.17	0.52	0.18
		2	0.07	0.20	0.61	0.21
		3	0.06	0.20	0.52	0.18
		4	0.06	0.19	0.49	0.18
		5	0.10	0.24	0.65	0.25
		Mean	0.07	0.20	0.56	0.20

No	Criteria	Subcriteria	Fuzzy weights			Non-fuzzy weights
			w_3	w_2	w_1	
2	Social	1	0.43	0.22	0.12	0.22
		2	0.41	0.22	0.11	0.21
		3	0.38	0.20	0.10	0.19
		4	0.46	0.24	0.13	0.24
		5	0.27	0.12	0.06	0.12
		Mean	0.39	0.20	0.10	0.20
3	Economical	1	2.78	0.61	0.17	0.66
		2	1.24	0.39	0.08	0.33
		Mean	2.01	0.50	0.12	0.50

Discussion

One important aspect of a city environmental function is the urban forests affects included social, ecological and economic benefits, which is measurable by implementing questionnaires programs to design the best fit to achieve values and increasing awareness of the role of the urban forest in enriching human health and well-being (Barron et al. 2016).

The carbon storage and sequestration is the concept of carbon dioxide absorption by trees in wood and soil texture during photosynthesis and carbon as biomass. Carbon dioxide is the most abundant greenhouse gas resulting from the use of fossil fuels. Calculating the amount of carbon storage reflects on the high contribution of urban forests to reducing climate change. Nowak et al. (2013) showed that an average of $7.69 \text{ kg} \cdot \text{cm}^{-1}$ of tree cover density and average $0.28 \text{ kg} \cdot \text{cm}^{-1}$ carbon sequestrations of tree cover per year were store by urban trees in the USA. In addition, they emphasise that analysis of urban forest carbon sequestration capacity can improve people's knowledge level for forest ecological benefits and values, it can also provide a scientific basis for tackling regional climate change and develop planning and development of forest carbon sink market to build a healthy

ecological urban environment. Yu et al. (2017) founded that forest area and tree cover percentage are the major factors influencing regional carbon sequestration capacity in cities. Although, tree average carbon storage ability per square meter varies in different cities and states (Nowak et al. 2013). An analysis of forest ecosystem carbon sequestration capacity can provide scientific references for urban forest management strategies. Before the 1990s, people paid little attention to urban forest carbon storage (Yu et al. 2017). Nevertheless, the results of our study showed that this awareness has increased significantly.

The importance of trees to improve air quality in urban environments is a very clear issue. Trees are able to absorb a variety of air pollution with different amounts, depending on the species, age, location and health of the trees (Beljan et al. 2015). The reviewing of the literatures identified that mitigation pollution and carbon dioxide sequestration are the main urban forest services (Nowak et al. 2013, Yu et al. 2017). Environmental quality strategies make it possible to maximize people's overall life quality in a city. Urban forests are the sum of all urban trees, shrubs and lawns located in highly altered and extremely complex urban areas characterized by a high amount of population

densities and pollution (Escobedo et al. 2011).

Escobedo et al. (2011) introduce fuel conservation as an energy-saving service of urban trees shading. Energy conservation measures the amount of urban forest use to reduce energy consumption in the community and achieved by reducing energy consumption by shade on buildings over warm summers or using cool and fresh air in hot weather. McPherson et al. (2017) stated that the extent of urban residents benefit from these goods and services depends on their location relative to the urban tree canopy and canopy health. McPherson and Simpson (2003) estimate that existing trees in California reduce annual air conditioning energy use by 2.5 % with a wholesale value of \$ 485.8 million. The location of trees near the buildings to shade and the regional climate influence on the difference in potential energy saving.

McPherson et al. (2017) introduce the term 'Eco services' (ecosystem services) for urban forest services including energy conservation, air quality improvement, carbon storage, stormwater runoff reduction, wildlife habitat and raise property values and produce goods such as food and wood products and provide social, economic, aesthetic and health benefits. Song et al. (2018) reported that the most frequently studies to quantify the benefits of urban forests are related to environmental regulation, property values, carbon reduction and air quality.

Conclusions

This study attempted to understand main criteria and sub-criteria required to plan urban forests – Iran perspective and focused on an academic expert's opinion

by the Fuzzy Delphi method. The results demonstrate that urban forests not only beautify the landscape, they even play a major role in ecological, social and economic values. In this case, the main sub-criteria were evaluated: carbon storage and sequestration greenhouse gases emission, air quality improvement and energy conservation, respectively. The results of this study will be implemented in urban forests developing projects by helping in suggesting proper tree species to maximize carbon sequestration and qualify air condition and other main factors investigated in this study.

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ECOLOGICAL, FAUNISTIC AND ZOOGEOGRAPHICAL NOTES ON THE GROUND BEETLES (COLEOPTERA: CARABIDAE) FROM THE EASTERN RHODOPE MTS. OF BULGARIA

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Abstract

The present study adds new data to the list of Carabidae species from the Eastern Rhodope Mts. of Bulgaria, and reveals some patterns of the species composition from zoogeographic, ecological and conservation point of view. A total of 5915 specimens of 138 species belonging to 50 genera and 19 tribes are found, including 13 endemic species and subspecies, one relict and some rare and stenotopic species. This represents, respectively, 18.5 % of all established for the Bulgarian carabid fauna species and 40 % of the genera. Eleven genera (*Acupalpus* Latreille, 1829, *Anchomenus* Bonelli, 1810, *Anisodactylus* Dejean, 1829, *Carterus* Dejean & Boisduval, 1829, *Demetrias* Bonelli, 1810, *Elaphrus* Fabricius, 1775, *Gynandromorphus* Dejean, 1829, *Olisthopus* Dejean, 1828, *Parophonus* Ganglbauer, 1891, *Tachys* Dejean, 1821 and *Tachyura* Motschulsky, 1862) are new for the Eastern Rhodope Mts. Two of the genera (*Carterus* and *Gynandromorphus*) are also new for the whole Rhodope Mts. The subgenus *Philochthus* Stephens, 1828 is new for the Eastern Rhodopes and subgenus *Phyla* Motschulsky, 1844 is new for the whole Rhodope Mts. Among the species, 60 species are new for the Eastern Rhodopes, and 24 species of them are new for the whole Rhodope Mts. The richest tribes are Harpalini (46 species), Amarini (14 species), Lebiini (11 species) and Carabini and Sphodrini (10 species each). Pterostichini and Bembidiini are represented with nine species each. Zoogeographical analysis shows that the Mediterranean faunal type prevailed. In relation to their life forms, zoophagous carabids predominate, presented by 78 species (56.5 %). Mixophytophagous are 60 species (43.5 %). Most of the ground beetles are mesoxerophilous (51 species, 37 %).

Key words: carabids, endemism, life forms, zoogeography, new data.

Introduction

From the beginning of the 20th century until now, about 40 studies concerning the carabid fauna of the Eastern Rhodope Mountains have been published. According to the latest survey of the carabid fauna on

the territory of the mountain (Guéorguiev 2004), 146 species (20 % of all Bulgarian Carabidae species) occur in the Bulgarian part of the Eastern Rhodopes. So far, 156 species (21 % of all Bulgarian Carabidae species) are surely known, 54 species are likely to be found there and another

seven species are probably doubtfully established for that region (Teofilova and Guéorguiev unpublished results). Considering the degree of research, dimensions of the region and the habitat diversity, which it suggests, it can be argued that the expected real number of carabid species is about 250, or one-third of those known from Bulgaria (Guéorguiev 2004, Teofilova and Guéorguiev unpublished results).

The Eastern Rhodopes occupy the lower part of the Rhodope Mts. A variety of habitats occur on their territory: oak forests, beech forests (limited to the southernmost parts of the mountain), coniferous and broadleaved plantations, bushes, riparian woods and bushes, grasslands, pastures, rocky habitats, inland standing and running surface waters, as well as many artificial landscapes – villages, chalets, huts, etc. This fact is a prerequisite for the occurrence of species from different faunistic complexes, which are more or less attached to a particular setting of natural conditions.

The Eastern Rhodope Mts. are among the sites of highest biodiversity in Bulgaria. Within its territory fall several protected areas with different designation – ‘Valchi Dol’ Nature Reserve, four Managed Reserves (‘Zhenda’, ‘Chamlaka’, ‘Boraka’, ‘Borovets’), 20 protected sites and several natural monuments. The mountain overlaps with some Natura 2000 zones: seven SPA (BG0002012, BG0002013, BG0002014, BG0002019, BG0002071, BG0002073, BG0002106), included in EU Directive 79/409, and three SAC (BG0000372, BG0001031, BG0001032) of Directive 92/43. In 1998, the territory of the Arda Valley was determined as a CORINE site, due to its European significance in protection of rare and endangered habitats, plants and animals. In 1997, BirdLife International pronounced

the valley of the Krumovitsa River as an Important Bird Area.

The aim of the present study is to add new data to the list of Carabidae species from the Eastern Rhodope Mts. of Bulgaria, and to reveal some patterns of the species composition from zoogeographic, ecological and conservation point of view.

Material and Methods

Field work was carried out in two periods: 2005–2006 and 2019, in parallel with the conduction of monitoring researches in some target areas. Ground beetles were collected by hand picking, and terrestrial ‘pitfall’ traps made of plastic bottles, buried at the level of the ground surface. Table 1 contains detailed information about the individual localities, periods and collectors of the material.

Collected material was deposited in the Carabidae collection of the Institute of Biodiversity and Ecosystem Research (Bulgarian Academy of Sciences, Sofia).

According to their zoogeographical belonging, the ground beetles were separated in zoogeographical categories and complexes according to Kryzhanovskij (1965, 1983, 2002), Vigna Taglianti et al. (1999) and Kodzhabashev and Penev (2006), with some changes and adjustments, made by the authors of the present study.

According to their ecological requirements in terms of humidity, established carabid species were divided into six categories: hygrophilous, mesohygrophilous, mesophilous, mesoxerophilous, xerophilous and eurybionts.

Categorization of the species in respect of their life forms follows the classification of Sharova (1981). The following codes were used: Life form class 1. Zoo-

Table 1. List, average altitude and description of the sampling sites, methods and dates of visiting.

Code	Locality	Altitude, m a.s.l.	GPS coordinates	Habitat	Traps [number of traps, fixative, collector(s)]	Hand picking
2005–2006						
AT_A	S Krumovgrad, Ada Tepe Hill	270	N 41°26'24" E 25°39'14"	Black locust (<i>Robinia pseudoacacia</i> L.) plantation	25.IV–6.VI, 6.VI–7.VII, 7.VII–12.VIII, 12.VIII–18.IX, 18.IX–20.X.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–VII.2006 [6, formaldehyde, NK]	
AT_O	S Krumovgrad, Ada Tepe Hill	390	N 41°26'18" E 25°39'15"	Xerothermic oak (<i>Quercus</i> sp.) forest	25.IV–6.VI, 6.VI–7.VII, 7.VII–12.VIII.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–VIII.2006 [6, formaldehyde, NK]	
AT_O1	Ada Tepe Hill, near the top	480	N 41°26'14" E 25°39'13"	Xerothermic oak forest	6.IX–21.X.2005; 21.X.2005–14.IV.2006; 15.IV–17.VI.2006 [5, formaldehyde, DC&ML]	
AT_Pn	S Krumovgrad, Ada Tepe Hill	480	N 41°25'59" E 25°39'27"	Black pine (<i>Pinus nigra</i> J.F.Arnold) plantation, probably mixed with natural black pine forest	25.IV–6.VI, 13.VIII–20.IX, 20.IX–20.X.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–20.VIII, 20.VIII–18.IX.2006 [12, formaldehyde, NK]	
AT_M	S Krumovgrad, Ada Tepe Hill	280	N 41°26'15" E 25°38'39"	Actively grazed pasture near Pobeda vill. in the vicinity of the Kayadzhik Dere Site	25.IV–6.VI, 6.VI–7.VII, 7.VII–12.VIII, 12.VIII–21.IX, 21.IX–20.X.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–VII.2006 [6, formaldehyde, NK]	
AT_Ps	S Krumovgrad, Ada Tepe Hill	290	N 41°26'13" E 25°38'41"	Scots pine (<i>Pinus sylvestris</i> L.) plantation	5.VI–7.VII, 7.VII–12.VIII, 12.VIII–18.IX, 18.IX–20.X.2005; 15.IV–18.VI, 18.VI–VII.2006 [6, formaldehyde, NK]	
KD_R	S Krumovgrad, Ada Tepe	280	N 41°26'21" E 25°38'46"	Kayadzhik Dere river, riverbank forest Hill near Pobeda vill.	13.VIII–6.IX.2005 [5, formaldehyde, DC&ML] 15.IV–17.VI.2006 [5 tree traps DC&ML]	
P_O	W Potocharka vill., near Stari Chal vill.	395	N 41°35'52" E 25°38'32"	Xerothermic oak forest at the eastern border of the Valchi Dol Reserve	25.IV–6.VI, 6.VI–7.VII, 7.VII–13.VIII, 13.VIII–21.IX, 21.IX–20.X.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–20.VIII, 20.VIII–18.XII.2006 [12, formaldehyde, NK]	6.VI.2005 NK
P_O1	above Potoch-nitsa vill., near Kechi Kaya Peak	410	N 41°35'46" E 25°38'30"	Xerothermic oak forest and actively grazed pasture	23.IV–5.VI, 4.VI–3.VII, 6.XI–21.X.2005; 16.IV–17.VI.2006 [10, formaldehyde, DC&ML] 23.IV–5.VI, 14.VIII–6.IX.2005; 16.IV.2006 [10 tree traps, DC&ML]	

Code	Locality	Altitude, m a.s.l.	GPS coordinates	Habitat	Traps [number of traps, fixative, collector(s)]	Hand picking
P_SK	near Studen Kladenets vill.	195	N 41°36'31" E 25°38'15"	Xerothermic scrub near gully with waterfall (Kodzha dere)	4.VI–3.VII, 3.VII–14.VIII, 6.IX–21.X.2005; 16.IV–19.VI.2006 [5, formaldehyde, DC&ML] 6.IX.2005–16.IV.2006 [5 tree traps, DC&ML]	
SK_R	E Studen Kladenets vill.	165	N 41°36'28" E 25°38'33"	Grouping of poplars (<i>Populus</i> spp.), willows (<i>Salix</i> sp.) and epiphytes on the Arda River coast	25.IV–6.VI, 7.VII–12.VIII.2005 [6, formaldehyde, NK]	6.VI.2005 NK
SK_R1	NE Studen Kladenets vill.	162	N 41°36'35" E 25°38'38"	Riverbank forest near Arda river	23.IV–5.VI, 5.VI–3.VII, 3.VII–14.VIII, 14.VIII–6.IX.2005 [5, formaldehyde, DC&ML] 6.IX.2005–16.IV.2006 [5 tree traps DC&ML]	
M_R	NW Madzharovo vill.	135	N 41°38'22" E 25°51'18"	Arda River coast with natural riverine vegetation on sandy silt	25.IV–6.VI, 6.VI–7.VII, 7.VII–12.VIII, 12.VIII–18.IX, 18.IX–20.X.2005; 15.IV–18.VI, 20.VIII–18.XII.2006 [6, formaldehyde, NK]	
M_R1	2 km NE Madzharovo vill.	135	N 41°39'09" E 25°52'19"	Arda River coast, riverbank forest	22.IV–5.VI, 5.VI–3.VII, 3.VII–15.VIII, 7.IX–22.X.2005; 14.IV–19.VI.2006 [5, formaldehyde, DC&ML]	
M_O	NE Madzharovo vill.	200	N 41°38'34" E 25°52'22"	Xerothermic oak forest near dry pasture	25.IV–6.VI, 6.VI–7.VII, 7.VII–12.VIII, 12.VIII–21.IX, 21.IX–20.X.2005, 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–20.VIII, 20.VIII–18.XII.2006 [12, formaldehyde, NK]	
M_O1	NE Madzharovo vill.	220	N 41°38'33" E 25°52'26"	Xerothermic oak forest	6.IX–21.X.2005 [5, formaldehyde, DC&ML]	
M_O2	2 km NE Madzharovo vill.	145	N 41°39'01" E 25°52'20"	Xerothermic oak forest	22.IV–6.VI, 6.IX–21.X.2005 [11, formaldehyde, DC&ML]	
M_O3	2 km NE Madzharovo vill.	190	N 41°38'34" E 25°52'22"	Xerothermic oak forest	5.VI–4.VII, 4.VII–15.VIII, 15.VIII–7.IX.2005 [10, formaldehyde, DC&ML]	
M_Ps	SE Madzharovo vill.	210	N 41°36'55" E 25°52'40"	Scots pine (<i>Pinus sylvestris</i> L.) plantation mixed with sprout linden (<i>Tilia</i> sp.) forest	7.VII–12.VIII, 12.VIII–18.IX, 18.IX–20.X.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–20.VIII, 20.VIII–18.XII.2006 [12, formaldehyde, NK]	
M_M	SE Madzharovo vill.	420	N 41°35'56" E 25°52'51"	Very old mixed mesophyllous forest near never failing brook	13.VIII–21.IX, 21.IX–20.X.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–20.VIII, 20.VIII–18.XII.2006 [12, formaldehyde, NK]	

Code	Locality	Altitude, m a.s.l.	GPS coordinates	Habitat	Traps [number of traps, fixative, collector(s)]	Hand picking
M_D	SE Madzharovo vill.	210	N 41°37'38" E 25°52'18"	Lawn at the place of a recycled slag-depot	5.VII–15.VIII, 15.VIII–7.IX, 7.IX–22.X.2005 [5, formaldehyde, DC&ML] 5.VII–15.VIII, 7.IX–22.X.2005; 22.X.2005–14.IV.2006, 14.IV–19.VI.2006 [5 tree traps DC&ML]	
B_S	SW Borislavtsi vill.	180	N 41°39'27" E 25°55'24"	Abandoned pasture with Jerusalem thorn (<i>Paliurus spina-christi</i> Mill.) on well drained eroded terrain	15.IV–18.VI, 18.VI–20.VIII, 20.VIII–18.XII.2006 [12, formaldehyde, NK]	
B_DG	SE Dolni Glavanak	320	N 41°40'45" E 25°49'33"	Pasture with shrubs, grazed in summer and autumn, near xerophilous oak forest	25.IV–5.VI, 5.VI–7.VII, 7.VII–13.VIII, 13.VIII–21.IX, 21.IX–20.X.2005; 20.X.2005–15.IV.2006; 15.IV–18.VI, 18.VI–20.VIII, 20.VIII–18.XII.2006 [12, formaldehyde, NK]	
B_DG1	1 km S Dolni Glavanak vill.	350	N 41°40'43" E 25°49'28"	Xerothermic woods	25.IV–6.VI, 6.VI–3.VII, 3.VII–14.VIII, 14.VIII–7.IX, 7.IX–22.X.2005 [5, formaldehyde, DC&ML]	
O_P	NW Obichnik vill.	612	N 41°30'17" E 25°28'36"	Actively grazed pasture with scattered groups of oak trees and bushes of Jerusalem thorn, hawthorn (<i>Crataegus</i> spp.) and dog rose (<i>Rosa canina</i> L.)	17.VI–29.VII.2019 [5, salt-vinegar saturated solution, TT&KD]	17.VI., TT
O_O	NW Obichnik vill.	570	N 41°30'07" E 25°28'43"	Sparse pubescent oak (<i>Quercus pubescens</i> Willd.) forest with grazed glades	17.VI–29.VII.2019 [5, salt-vinegar saturated solution, TT&KD]	17.VI., TT
O_m	N Obichnik vill.	600	N 41°30'04" E 25°29'12"	Forest habitat with Hungarian oak (<i>Quercus frainetto</i> Ten.), black pine and smoke tree (<i>Cotinus coggygia</i> Scop.)	15.VI–31.VII.2019 [8, salt-vinegar saturated solution, TT&KD]	15.VI., TT
Ru_R	W Ribino vill.	430	N 41°24'43" E 25°31'02"	Vast meadow with bushes and single trees and adjoining pond, and oak and pine forests	16.VI–30.VII.2019 [10, salt-vinegar saturated solution, TT&KD]	
R_AY	SE Rozino vill.	286	N 41°26'13" E 25°55'04"	Along the Arpa Dere River (full-water river with rich vegetation) and Yuren Dere River (almost dry gully with puddles and rich vegetation), and the adjoining well preserved oak forests	18.VI–30.VII.2019 [12, salt-vinegar saturated solution, TT&KD]	18.VI., TT

Code	Locality	Altitude, m a.s.l.	GPS coordinates	Habitat	Traps [number of traps, fixative, collector(s)]	Hand picking
R_RF	SW Rozino vill.	365	N 41°26'00" E 25°53'33"	Rocks near mesoxerophilic oak forest and pseudomaquis with Jerusalem thorn, ashes (<i>Fraxinus</i> spp.), <i>Pistacia terebinthus</i> L., etc.	19.VI–30.VII.2019 [6, salt-vinegar saturated solution, TT&KD]	19.VI., TT
B_BR	NW Byalgradets vill.	197	N 41°25'34" E 25°54'02"	Dry stony riverbed of the Byala Reka River branch with tamarisk (<i>Tamarix</i> sp.) and surrounding poplar–willow stands	19.VI–31.VII.2019 [6, salt-vinegar saturated solution, TT&KD]	
Kr	Krumovgrad	265	N 41°28'15" E 25°39'41"	House yard near densely vegetated shore of a tributary of the river of Krumovitsa		18.VI., TT
Mo	Momchilgrad	263	N 41°31'50" E 25°24'16"	City park		31.VI., TT

Note: Collectors: DC – Dragan Chobanov, ML – Mario Langourov, NK – Nikolay Kodzhabashev, TT – Teodora Teofilova, KD – Krasimir Donchev.

phagous. Life form subclass: 1.1 – Phytobios; 1.2 – Epigeobios; 1.3 – Stratobios; 1.4 – Geobios. Life form groups: 1.1.2 – stem-dwelling hortobionts; 1.1.3 – leaf-dwelling dendrohortobionts; 1.2.2 – large walking epigeobionts; 1.2.2(1) – large walking dendroepigeobionts; 1.2.3 – running epigeobionts; 1.2.4 – flying epigeobionts; 1.3(1) – series crevice-dwelling stratobionts; 1.3(1).1 – surface & litter-dwelling; 1.3(1).2 – litter-dwelling; 1.3(1).3 – litter & crevice-dwelling; 1.3(1).4 – endogeobionts; 1.3(1).5 – litter & bark-dwelling; 1.3(1).6 – bothrobionts; 1.3(2) – series digging stratobionts; 1.3(2).1 – litter & soil-dwelling; 1.3(2).2 – litter & crevice-dwelling; 1.4.2(1) – small digging geobionts. Life form class 2. Mixophytophagous. Life form subclass: 2.1 – Stratobios; 2.2 – Stratohortobios; 2.3 – Geohortobios. Life form groups: 2.1.1 – crevice-dwelling stratobionts; 2.2.1 – stratohortobionts; 2.3.1 – harpaloid geohortobionts; 2.3.1(1) – crevice-dwelling harpaloid geohortobionts; 2.3.2 – zabroid geohortobionts; 2.3.3 – dytomeoid geohortobionts. The first figure in the index shows the class of life form, the second – the subclass, the third – the life form group. In brackets after the subclass the series is shown, when it exists.

The systematic list follows Kryzhanovskij et al. (1995).

Results and Discussion

During the field work were captured 5915 specimens of 138 species belonging to 50 genera and 19 tribes of ground beetles. This represents, respectively, 18.5 % of all established for Bulgarian carabid fauna species and 40 % of the genera (Teofilova and Guéorguiev un-

published results). During the first study (2005–2006) were captured 120 species (5688 specimens), and another 18 species (227 specimens) were added with the recent samplings (2019). The complete check-list of the established species with zoogeographic category, life form and ecological group in relation of the humidity is given in the Appendix.

Our study presents eleven new genera for the Eastern Rhodopes (*Acupalpus*, *Anchomenus*, *Anisodactylus*, *Carterus*, *Demetrias*, *Elaphrus*, *Gynandromorphus*, *Olisthopus*, *Parophonus*, *Tachys* and *Tachyura*). Two of the genera (*Carterus* and *Gynandromorphus*) are also new for the whole Rhodope Mts. The subgenera *Philochthus* and *Phyla* (both from the genus *Bembidion* Latreille, 1802) are new for the Eastern Rhodopes, and *Phyla* is also new to the whole Rhodope Mts. Sixty species are new for the Eastern Rhodopes; 24 species of them are new for the whole Rhodope Mts. The record of *Clivina fossor* (Linnaeus, 1758) gives confirmation for the presence of this species in this part of the mountain. All new species are marked in the Appendix.

The richest tribes were Harpalini (46 species), Amarini (14 species), Lebiini (11 species) and Carabini and Sphodrini (10 species each). Pterostichini and Bembidiini tribes were represented with nine species each. Harpalini and Amarini tribes include mostly ecologically plastic carabids. Carabini and Pterostichini are typical forest dwellers; most of them are stenotopic and any impact on the forest habitats where they occur, also affects the structure of their communities. Sphodrini tribe includes both forest dwellers and open living species. The increased richness of the tribes Lebiini and Bembidiini could be resulting from the fact that a significant

part of the material was collected by hand and with tree traps, since most of these beetles are rarely found in the pitfall traps.

Genera most rich in species were *Harpalus* Latreille, 1802 (25 species), *Amara* Bonelli, 1810 (11 species) and *Carabus* Linnaeus, 1758 (eight species). Genera *Ophonus* Dejean, 1821, *Calathus* Bonelli, 1810 and *Bembidion* were represented by six species each.

New highest altitudes were found in the distribution of five species: *Amara parvicollis* Gebler, 1833 – so far known only from the Black Sea coast and Eastern Danube Plain under 50 m a.s.l., now found in localities M_R and M_R1 (for locality codes see Table 1), at 135 m; *Anisodactylus intermedius* Dejean, 1829 – so far known only under 300 m a.s.l., now found in locality P_O1, at 410 m; *Brachinus brevicollis* Motschulsky, 1844 – so far known only under 300 m a.s.l., now found in locality B_DG, at 320 m; *Calathus cinctus* Motschulsky, 1850 – so far known only under 300 m a.s.l., now found in locality AT_O, at 390 m; *Poecilus anatolicus* (Chaudoir, 1850) – so far known only under 400 m a.s.l., now found in locality Ru_R, at 430 m. It is hard to claim if these new findings are evidences for the real movement of the species in height. They are probably resulting of the less knowledge about the ecology of these species and their distribution in Bulgaria.

We found some species with conservation value. Our study reports one Tertiary relict (*Myas chalybaeus* (Palliard, 1825)) and 14 endemic species and subspecies, of which Balkan endemics are 10 taxa (two species and eight subspecies), Bulgarian endemics are two taxa (one species and one subspecies), and one species and one subspecies are subendemic (Table 2).

Table 2. List of the endemic ground beetles found in the Eastern Rhodope Mts. in 2005–2006 and 2019.

Species/subspecies	Level
<i>Tapinopterus balcanicus balcanicus</i> Ganglbauer, 1891	Bulgarian
<i>Zabrus balcanicus</i> Heyden, 1883	Bulgarian
<i>Carabus scabriusculus bulgarus</i> Lapouge, 1908	Balkan
<i>Carabus montivagus montivagus</i> Palliardi, 1825	Balkan
<i>Carabus wiedemanni wiedemanni</i> Ménétries, 1836	Balkan
<i>Carabus scabrosus scabrosus</i> Olivier, 1790	Balkan
<i>Cychrus semigranosus balcanicus</i> Hopffgarten, 1881	Balkan
<i>Trechus subnotatus subnotatus</i> Dejean, 1831	Balkan
<i>Molops dilatatus</i> Chaudoir, 1868	Balkan
<i>Laemostenus cimmerius weiratheri</i> J. Müller, 1932	Balkan
<i>Zabrus graecus subtilis</i> Schaum, 1862	Balkan
<i>Licinus graecus</i> Apfelbeck, 1901	Balkan
<i>Myas chalybaeus</i> (Palliardi, 1825)	Balkan subendemic
<i>Platynus scrobiculatus purkynei</i> Obenberger, 1917	Balkan subendemic

Carabus intricatus Linnaeus, 1760 is included in the IUCN Red List as 'Near Threatened'. Along with *Calosoma sycophanta* (Linnaeus, 1758), it is included in the Annexes of CORINE and ESC Red List. *Carabus scabrosus* Olivier 1790, is enlisted in the Red Data Book of Bulgaria as 'Vulnerable' (Golemanski et al. 2015).

Some rare and stenotopic species occur in the studied region: *Amara saphyrea* Dejean, 1828, *Calathus micropterus* (Duftschmid, 1812), *Calosoma sycophanta*, *Lebia marginata* (Geoffroy, 1785), *Pedius inquinatus* (Sturm, 1824), *Platynus scrobiculatus* (Fabricius, 1801), *Zabrus graecus* Dejean, 1828, most of the endemites. Some of the species (e.g. *Carabus intricatus* and *Carabus scabrosus*) have become rare under the influence of anthropogenic pressures and changes in their primary habitats. *Calosoma inquisitor* (Linnaeus, 1758), *Calosoma sycophanta* and some of the *Carabus* species are usually highly sensitive to chemical agents, which affects their ranges and numbers (Huusela-Veistola 2000).

Zoogeographical analysis showed that

the Mediterranean (*sensu lato*) complex prevailed (47 species, 34 %). It was followed by the European-Asiatic (35 species, 25 %) and Northern Holarctic and European-Siberian complexes (31 species, 23 %). European complex consisted of 17 species (12 %) and Endemic complex – eight species (6 %) (Fig. 1). Mediterranean species are distributed in the so-called region of the 'Ancient Mediterranean' (Popov 1927, Kryzhanovskij 1965, 1983, 2002). European-Asiatic species ranges lie between the Eurosiberian and Mediterranean zones. Northern Holarctic and European-Siberian complex includes species distributed mainly in the northern regions of the Holarctic, mostly in Europe and Siberia. European complex includes mostly forest dwelling species connected to the middle and southern part of Europe.

Greatest number of species had the European-Central Asian, European-Near-eastern, Palaearctic, Balkan-Neareastern and Northmediterranean zoogeographic categories (Table 3). The predominance of the Mediterranean species is not typi-

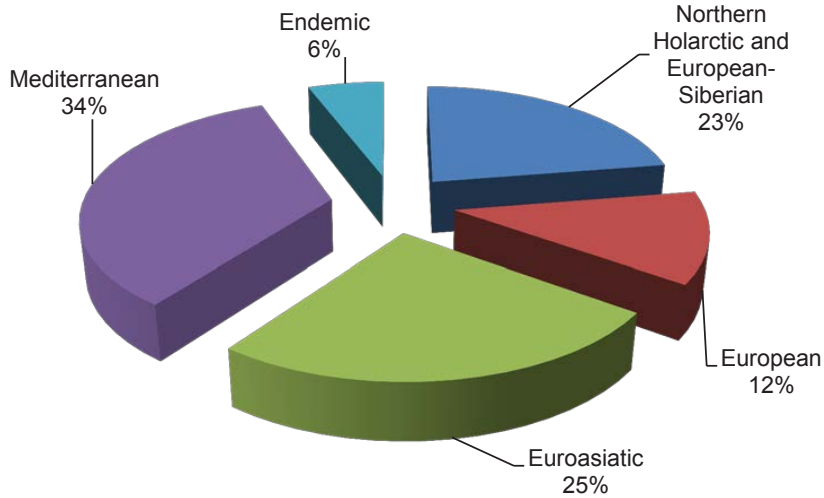


Fig. 1. Distribution of the carabid species among the zoogeographical complexes.

cal for the other mountain regions in Bulgaria (e.g. Kostova 2009, Teofilova 2016, Teofilova 2019b), but it is common for the habitats near the Black Sea coast (Popov and Krusteva 1999, Teofilova et al. 2015).

The specific geographic position and climatic conditions are a precondition for the development of respective vegetation and habitat types, determining the composition of the carabid coenoses.

Table 3. Zoogeographical categories of the ground beetles in the Eastern Rhodope Mts. (on species level).

Zoogeographical complex	Code	Zoogeographical element	Species, No	Species, %
Northern Holarctic and European-Siberian	OLA	Holarctic	5	4
	PAL	Palearctic	14	10
	WPAL	Western Palearctic	6	4
	E-SI	European-Siberian	5	4
	E-WSI	European and West Siberian	1	1
European	EUR	European	5	4
	CE-PAS	Central European and Neareastern	6	4
	CEE-PA	Central and Eastern European and Neareastern	3	2
	CE-E	Central and Eastern European	3	2
Euroasiatic	E-AS	Euroasiatic steppe and forest-steppe complex	2	1
	E-CAS	European and Central Asian	16	12
	E-PAS	European-Neareastern	15	11
	B-CAS	Balkan and Central Asian	2	1

Zoogeographical complex	Code	Zoogeographical element	Species, No	Species, %
Mediterranean	E-CA-M	European-Central Asian-Mediterranean	9	7
	E-PA-M	European-Neareastern-Mediterranean	9	7
	MED-PA	Mediterranean-Neareastern	2	1
	MED	Mediterranean	3	2
	EMED	Eastmediterranean	1	1
	NM-CAS	Northmediterranean-Central Asian	1	1
	NMED	Northmediterranean	10	7
	P-SMED	Pontic-Submediterranean	1	1
	B-PAS	Balkan-Neareastern	11	8
Endemic	BAL-K	Balkan subendemic (+ Balkan-Carpathian)	3	2
	BAL	Balkan endemic	4	3
	BGE	Bulgarian endemic	1	1

The ground beetles established during the study related to two classes of life forms proposed by Sharova (1981), with a predominance of class Zoophagous, presented by 78 species (56.5 %). Mixophytophagous were 60 species (43.5 %). This ratio is most similar to that in the meadow steppes from the Forest-steppe zone of Eurasia (Sharova 1981), habitats near Cape Emine at the Black Sea coast (Teofilova et al. 2015) and unvegetated, sparsely vegetated, and bryophyte- or lichen-vegetated cliffs, rock faces and rock pavements in the inland areas in Bulgaria (Teofilova 2019c), and differs from the established in other mountain regions in Bulgaria (e.g. Teofilova 2016, Teofilova 2018, Teofilova 2019b).

There were 21 life forms of ground beetles – 15 zoophagous and six mixophytophagous. Zoophagous life form groups are normally more numerous, especially in stable ecosystems (Sharova 1981) and in forest regions, as it was found in 'Leshnitsa' Reserve (Teofilova 2016), Vrachanska Planina Mts. (Teofilova 2019b) and in the Western Rhodope Mts. (Teofilova 2018, Teofilova 2019a). The largest share of the species belonged to the specialised

phytophagous harpaloid geohortobionts from Class Mixophytophagous (32 species, 23 %), followed by the crevice-dwelling surface & litter stratobionts (20 species, 14 %) from Class Zoophagous (figs 2 and 3).

The harpaloid geohortobionts were also dominating in the Western Rhodope Mts. (Teofilova 2018, Teofilova 2019a) and Vrachanska Planina Mts. (Teofilova 2019b). Surface & litter dwelling stratobionts are most of the *Bembidion* and *Agonum* Bonelli, 1810 species, *Notiophilus* Duméril, 1806, *Chlaenius* Bonelli, 1810. They were also found as the most species rich zoophagous category in the Western Rhodope Mts. (Teofilova 2018, Teofilova 2019a) and Vrachanska Planina Mts. (Teofilova 2019b).

In the studied part of the mountain, according to their ecological preferences, mesoxerophilous (51 species, 36 %) ground beetles prevailed (Fig. 4). Mesophilous were 37 species (27 %), hygrophilous were 18 species (13 %), mesohygrophilous were 15 species (11 %), 12 species were xerophilous (9 %), and only five species (4 %) were eurytopic.

These results showed the predom-

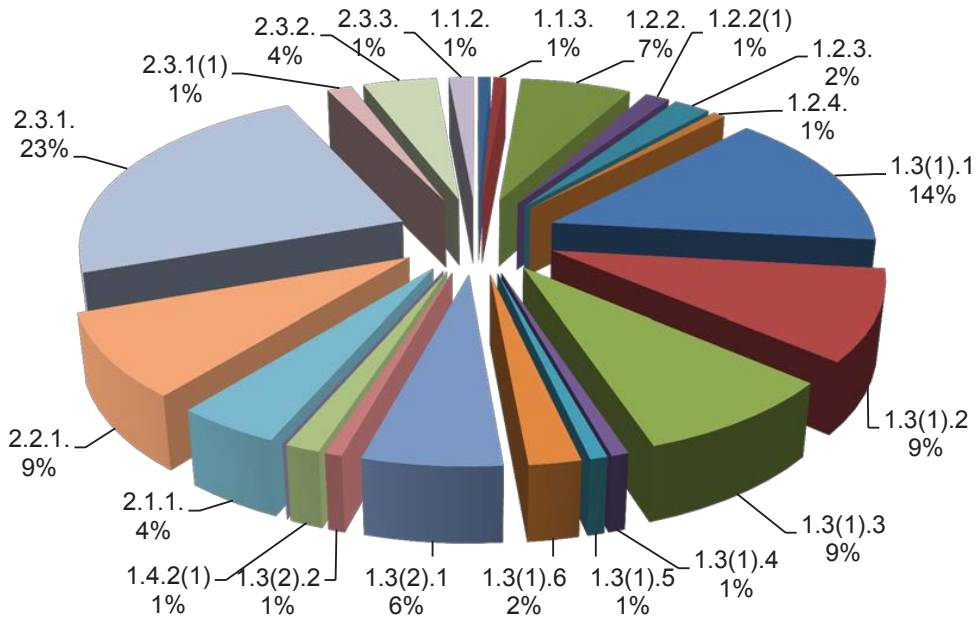


Fig. 2. Life forms of the ground beetles from the Eastern Rhodope Mts.
 Note: Explanations of the codes are given in the Material and Methods section.

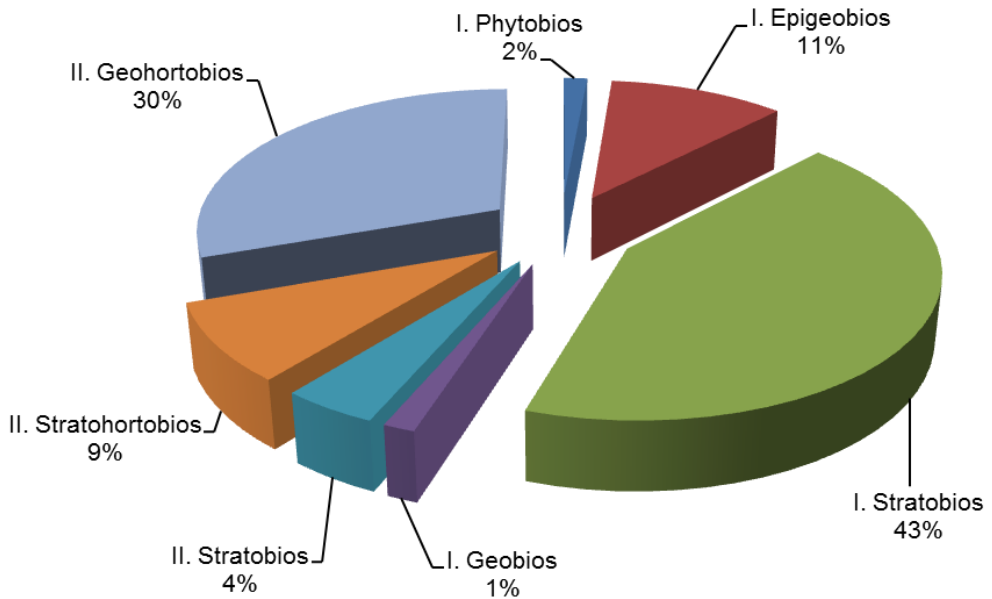


Fig. 3. Proportions of the subclasses of life forms in the carabid complex.
 Note: I – class Zoophaga, II – class Mixophytophaga.

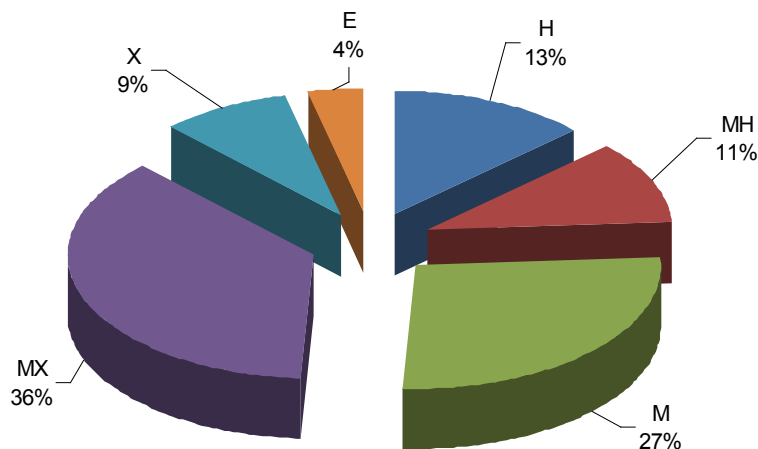


Fig. 4. Humidity preferences of the carabids from the Eastern Rhodope Mts. (number of species).

Note: H – hygrophilous, MH – mesohygrophilous; M – mesophilous, MX – mesoxerophilous, X – xerophilous, E – eurybiont.

inantly mesoxerophilous nature of the habitats, in contrast of the predominantly mesophilous conditions in the Western part of the Rhodope Mts. (Teofilova 2018, Teofilova 2019a) and Vrachanska Planina Mts. (Teofilova 2019b), probably resulting from the typical forest-mountain condition in those territories.

Conclusions

The large number of the found new species shows the great variety of the ground beetle fauna in the Eastern Rhodope Mts. As the studied area provides various and diverse habitats, and considering the general richness of the carabids and the lack of targeted methodical studies, it is quite possible that the carabid fauna is even more diverse. For general conclusions, however, more localities have to be examined systematically.

Zoogeographical analysis shows a predominantly Mediterranean nature of the established carabid fauna, which is in

accordance with the life forms structure, and the preference of the carabids for more mesoxerophilous habitats.

The region of the Eastern Rhodope Mts. is treasuring specific assemblages and species with conservation significance, and the preserving of their characteristic habitats is a keystone for their conservation, especially in that favoured mining prospecting region.

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Table A1. Systematic list of the ground beetles found in the Eastern Rhodopes in 2005–2006 and 2019.

No	Species	ZC	LF	HP	Locality code, material
1.	<i>*Cicindela</i> (s.str.) <i>sylicola</i> Dejean, 1822	CE-PAS	1.2.4	MX	R_RF, 1ex.[h]
2.	<i>Leistus</i> (<i>Pogonophorus</i>) <i>rufomarginatus</i> (Duftschmid, 1812)	EUR	1.3(1).1	M	AT_O, 3♂; AT_O1, 1♂; AT_Pn, 2♀1♂; AT_M, 1♂; AT_Ps, 2♂; M_O, 1ex.; B_DG, 1♂; B_DG1, 1♀; NA 1♂
3.	<i>Nebria</i> (s.str.) <i>brevicollis</i> (Fabricius, 1792)	E-PAS	1.3(1).1	MH	Ru_R, 2♀; B_BR, 1♀; AT_A, 4♀11♂; AT_O, 10♀17♂; AT_O1, 1♀; AT_Pn, 1♂; AT_M, 8♀6♂3ex.; AT_Ps, 1♀1♂; P_O, 3♀1♂[h]; SK_R, 3♂2♀[h]; SK_R1, 4♀5♂; M_R, 4♀7♂; M_R1, 1♀; M_O, 1♀; B_DG, 167♀154♂5ex.; B_DG1, 1♀
4.	<i>*Notophilus biguttatus</i> (Fabricius, 1779)	WPAL	1.3(1).1	M	P_O, 1♀
5.	<i>*N. substriatus</i> G. R. Waterhouse, 1833	E-PA-M	1.3(1).1	M	O_m, 1♀; AT_O, 1♀; NA 1♀
6.	<i>N. rufipes</i> Curtis, 1829	E-PAS	1.3(1).1	M	R_AY, 1♂; AT_A, 3♀3♂; AT_O, 1♂; AT_Pn, 2♀; AT_M, 1♂; M_O, 2♀; B_DG, 1♀1♂; B_DG1, 1♀3♂
7.	<i>Calosoma</i> (s.str.) <i>sycophanta</i> (Linnaeus, 1758)	PAL	1.2.2(1)	M	O_O, 1ex.[h]; P_O, 1♀; P_O1, 1♂[h]; M_O, 1♂
8.	<i>C. (s.str.) inquisitor</i> (Linnaeus, 1758)	PAL	1.2.2(1)	MX	O_m, 1♂[h]; O_O, 1ex.[h]; AT_O, 1♀2♂; AT_O1, 1♀; P_O, 1♀; P_O1, 1♀; M_O1, 1♀1♂; M_R, 2♀2♂; B_DG1, 1♂
9.	<i>Carabus</i> (<i>Trachycarabus</i>) <i>scabriusculus</i> Olivier, 1795	CE-PAS	1.2.2	X	P_SK, 3♀2♂
10.	<i>C. (Archicarabus) montivagus</i> Palliardi, 1825	CE-E	1.2.2	M	AT_O, 1♀; M_M, 2♀1♂
11.	<i>C. (Archicarabus) wiedemanni</i> Ménétrés, 1836	B-PAS	1.2.2	MX	O_O, 1ex.[h]; Ru_R, 3♀1♂; R_AY, 3♀4♂; R_RF, 1♂; B_BR, 3♂; AT_A, 12♀19♂5ex.; AT_O, 10♀3♂1ex.; AT_Pn, 143♀125♂16ex.; AT_M, 1♀3♂; AT_Ps, 41♀32♂10ex.; P_O, 15♀15♂3ex.; P_O1, 12♀7♂; P_SK, 3♀2♂; M_Ps, 6♀6♂; B_S, 3♀; B_DG, 1♀4♂; B_DG1, 3♀5♂; KD_R, 1♂; NA 7♀2♂
12.	<i>C. (Tomocarabus) convexus</i> Fabricius, 1775	E-PAS	1.2.2	MX	Ru_R, 1♀; R_AY, 12♀9♂3ex.; O_m, 1♀1♂; P_SK, 1♂; P_O, 9♀9♂; P_O1, 2♀3♂; M_R, 2♂; M_R1, 1♀; M_O, 1♀1♂; M_O1, 3♀3♂; M_Ps, 2♀4♂; M_M, 3♀2♂; B_S, 1♀1♂; B_DG, 1♀4♂; B_DG1, 18♀13♂; NA 1♀1♂
13.	<i>C. (Chaetocarabus) intricatus</i> Linnaeus, 1760	EUR	1.2.2	MH	O_O, 1ex.[h]; R_RF, 1ex.[h]; R_AY, 1ex
14.	<i>C. (Pachystus) morio</i> Mannerheim, 1830	B-PAS	1.2.2	MX	P_SK, 2♀; AT_A, 3♀1♂6ex.; AT_O, 1♀1♂; AT_Pn, 1♂; P_O, 2♀; 1♀[h]; P_O1, 1♀2♂; P_SK, 2♀; M_R1, 1♀; M_O, 15♀6♂2ex.; M_O1, 9♀4♂; M_D, 2♀1♂; B_DG, 2♂1ex.; NA 1♀5♂

No	Species	ZC	LF	HP	Locality code, material
15.	<i>C. (Procrustes) coriaceus</i> Linnaeus, 1758	E-PAS	1.2.2	E	R_AY, 1♀[h]; R_AY, 3♀3♂; P_SK, 4♀2♂; AT_A, 30♀24♂6ex.; AT_O, 19♀16♂6ex.; AT_O1, 1♀1♂; AT_Pn, 67♀73♂9ex.; AT_M, 32♀25♂17ex.; AT_Ps, 35♀43♂17ex.; P_O, 91♀69♂9ex., 1♂[h]; P_O1, 25♀17♂; P_SK, 2♀4♂; SK_R, 3♀; M_R, 2♀1♂1ex.; M_R1, 1♀1♂; M_O, 8♀5♂1ex.; M_Ps, 79♀119♂14ex.; M_M, 8♀7♂9ex.; B_S, 2♀3♂; B_DG, 22♀23♂5ex.; B_DG1, 3♀1♂; NA 7♀6♂1ex.
16.	<i>C. (Procerus) scabrosus</i> Olivier, 1789	B-PAS	1.2.2	M	Kr, 1ex.[h]; M_O, 1♂; M_Ps, 1♂; M_M, 6♂; B_DG, 1♀4♂
17.	<i>Cychrus semigranosus</i> Palliardi, 1825	BAL-K	1.2.2	M	M_Ps, 5♀7♂9ex.; M_M, 3♀3♂6ex.
18.	<i>*Elaphrus (Elaphroterus) aureus</i> P. W. J. Müller, 1821	EUR	1.2.3	H	M_R, 2♂
19.	<i>Clivina</i> (s.str.) <i>fossor</i> (Linnaeus, 1758)	PAL	1.4.2(1)	MH	B_BR, 2♀
20.	<i>*C. (s.str.) collaris</i> (Herbst, 1784)	E-PAS	1.4.2(1)	MH	M_R, 1♀; M_R1, 3ex
21.	<i>Trechus</i> (s.str.) <i>quadristriatus</i> (Schränk, 1781)	E-CA-M	1.3(1).2	MX	O_O, 1♂; O_m, 1♀1♂; P_SK, 1♂; AT_O, 1ex.; AT_O1, 1♀1♂; AT_M, 1♀1♂; P_O, 2♂; P_O1, 1♂; P_SK, 1♀[h]; M_M, 1♀2♂; M_D, 4♀1♂, 1♀[h]; B_DG, 2♀3♂
22.	<i>Tr. (s.str.) crucifer</i> Plochard de la Brûlerie, 1876	B-PAS	1.3(1).2	M	AT_A, 1♂; AT_O, 2♂; AT_Pn, 2♀
23.	<i>Tr. (s.str.) subnotatus</i> Dejean, 1831	NMED	1.3(1).2	M	R_AY, 1♂
24.	<i>**Tachys (Paratachys) bistriatus</i> (Duftschmid, 1812)	E-PA-M	1.3(1).4	H	P_SK, 1♀
25.	<i>*Tachyura</i> (s.str.) <i>quadrisignata</i> (Duftschmid, 1812)	E-PA-M	1.3(1).1	H	SK_R, 1♀1♂
26.	<i>*Asaphidion flavipes</i> (Linnaeus, 1760)	WPAL	1.2.3	MH	M_R, 5♀2♂; M_R1, 1♀
27.	<i>**A. flavicorne</i> (Solisky, 1874)	B-CAS	1.2.3	MH	M_R, 1♂
28.	<i>*Bembidion (Metallina) properans</i> (Stephens, 1828)	E-WSI	1.3(1).2	M	B_DG, 1♀
29.	<i>*B. (Phylla) tethys</i> Netolitzky, 1926	MED	1.3(1).1	H	B_BR, 6♀6♂
30.	<i>*B. (Philocnthus) guttula</i> (Fabricius, 1792)	PAL	1.3(1).1	H	B_BR, 2♀1♂; B_DG, 1♂
31.	<i>*B. (Peryphus) subcostatum</i> (Motschulsky, 1850)	B-PAS	1.3(1).1	H	B_BR, 2♀3♂; M_R, 2♀2♂; M_R1, 3♀1♂
32.	<i>*B. (Peryphanes) deletum</i> Audinet-Serville, 1821	E-PA-M	1.3(1).1	H	R_AY, 1♀[h]
33.	<i>*B. (Peryphanes) stephensii</i> Crotch, 1866	EUR	1.3(1).1	MH	R_AY, 1♂[h]
34.	<i>Sinechostictus</i> (s.str.) <i>effluviarium</i> Peyron, 1858	CEE-PA	1.3(1).2	H	B_BR, 3♀1♂

No	Species	ZC	LF	HP	Locality code, material
35.	<i>Myas</i> (s.str.) <i>chalybaeus</i> (Paliardi, 1825)	BAL-K	1.3(2).1	M	O_O, 1ex.[h]; O_O, 1♀; O_m, 1♂; P_O, 1ex.; M_R, 1♀; M_O, 3♀♂♂3ex.; M_O1, 3♀; M_Ps, 61♀66♂19ex.; M_M, 11♀17♂5ex.; B_DG, 8♀14♂2ex.; B_DG1, 16♀6♂
36.	** <i>Poecilus</i> (s.str.) <i>anatolicus</i> (Chaudoir, 1850)	B-PAS	1.3(2).1	MX	Ru_R, 2♀9♂
37.	<i>Pedius inquinatus</i> (Sturm, 1824)	B-PAS	1.3(2).1	MX	Ru_R, 1♂
38.	* <i>Pterostichus</i> (<i>Argutor</i>) <i>leonisi</i> Apfelbeck, 1904	CE-E	1.3(2).1	H	B_BR, 3♀
39.	<i>Pt. (Platysma)</i> <i>niger</i> (Schaller, 1783)	E-AS	1.3(2).1	MH	M_R, 1♀
40.	<i>Pt. (Pseudomaseus)</i> <i>nigrita</i> (Paykull, 1790)	E-SI	1.3(2).1	H	SK_R, 1♂[h]; B_BR, 1♀1♂
41.	** <i>Pt. (Phonias)</i> <i>ovoideus</i> (Sturm, 1824)	E-SI	1.3(2).1	MH	M_M, 1♀1♂
42.	* <i>Molops</i> (s.str.) <i>dilatatus</i> Chaudoir, 1868	BAL	1.3(2).1	M	P_O, 9♀11♂, 2♀2♂[h]; P_O1, 2♀6♂; M_O, 1♂; M_M, 4♀9♂
43.	<i>Tapinopterus</i> (s.str.) <i>balkanicus</i> Ganglbauer, 1891	BAL	1.3(2).2	M	M_M, 2♀
44.	* <i>Calathus</i> (s.str.) <i>distinguendus</i> Chaudoir, 1846	B-PAS	1.3(1).2	MX	O_P, 1♂; P_O, 1♂; P_O1, 5♀1♂
45.	<i>C.</i> (s.str.) <i>fuscipes</i> (Goeze, 1777)	PAL	1.3(1).2	E	O_P, 1♀1♂; Ru_R, 1♀6♂; B_BR, 4♀3♂; AT_A, 4♀1♂4ex.; AT_O, 2♀1ex.; AT_Pn, 2♀1♂; AT_M, 33♀50♂47ex.; AT_Ps, 1♀2♂2ex.; P_O, 1♀9ex.; P_O1, 4♀, 1♂[t]; SK_R, 1♀1♂; SK_R1, 1♂; M_R, 8♀3♂7ex.; M_R1, 1♂; M_O, 1♀; M_Ps, 1♀2♂; M_D, 1♀1♂[t]; B_S, 4♀1♂4ex.; B_DG, 93♀85♂52ex.; B_DG1, 5♀; KD_R, 1♀, 1♂[t]; NA 2♀2♂
46.	<i>C. (Neocalathus)</i> <i>ambiguus</i> (Paykull, 1790)	E-CAS	1.3(1).2	MX	M_D, 25♀10♂, 2♀[t]
47.	<i>C. (Neocalathus)</i> <i>melanocephalus</i> (Linnaeus, 1758)	PAL	1.3(1).2	M	M_R, 1♀; NA 1♀1♂
48.	** <i>C. (Neocalathus)</i> <i>cinctus</i> Motschulsky, 1850	E-PAS	1.3(1).2	MX	AT_O, 1♂; P_SK, 1♀1♂; M_D, 1♂
49.	** <i>C. (Neocalathus)</i> <i>micropterus</i> (Dufschmid, 1812)	E-SI	1.3(1).2	MX	AT_M, 1♀1♂
50.	** <i>Laemostenus</i> (s.str.) <i>venustus</i> (Dejean, 1828)	NMED	1.3(1).6	M	B_DG1, 1♀
51.	<i>L. (Pristonychus)</i> <i>ferricola</i> (Herbst, 1784)	WPAL	1.3(1).6	M	P_O, 9♀1♂; M_R, 1♀; M_Ps, 4♀1♂1ex.; M_M, 1♂2ex.; B_DG, 1♀
52.	<i>L. (Pristonychus)</i> <i>cimmerius</i> (Fischer von Waldheim, 1823)	P-SMED	1.3(1).6	M	O_P, 1♀; Ru_R, 1♂; O_m, 1♀; AT_A, 1♂; P_O, 12♀13♂22ex.; P_O1, 1♂4♂, 1♀[t]; M_R, 1♂; M_O, 8♀6♂12ex.; M_O1, 3♀2♂; M_Ps, 163♀74♂11ex.; M_M, 6♀1♂8ex.; B_S, 1♀2♂; B_DG, 12♀8♂5ex.; B_DG1, 5♀2♀; NA 1♀
53.	<i>Synuchus</i> (s.str.) <i>vivalis</i> (Illiger, 1798)	E-SI	1.3(1).2	M	M_R, 1♂
54.	** <i>Agonum</i> (<i>Olisares</i>) <i>dufschmidii</i> J. Schmidt, 1994	E-SI	1.3(1).1	H	B_BR, 7♀9♂

No	Species	ZC	LF	HP	Locality code, material
55.	<i>Platynus (Batenus) scrobiculatus</i> (Fabricius, 1801)	BAL-K	1.3(1), 1	M	M_M, 1♂
56.	* <i>Anchomenus dorsalis</i> (Pontoppidan, 1763)	PAL	1.3(1), 1	E	M_R, 4♀3♂; B_DG, 33♀43♂
57.	** <i>Olisthopus glabricollis</i> (Germar, 1817)	NMED	1.3(1), 2	M	P_O, 3♂[h]
58.	* <i>Amara (Zezea) tricuspidata</i> Dejean, 1831	E-CA-M	2.2, 1	M	P_O, 1ex.
59.	A. (s.str.) <i>aenea</i> (De Geer, 1774)	OLA	2.3, 1	MX	AT_A, 1♀; AT_M, 2♀4♂; P_O, 3♀1♂[h]; SK_R, 1♀1♂[h]; SK_R1, 1♀; M_R, 11♀2♂1ex.; M_D, 1♂[t]; B_DG, 4♀2♂
60.	*A. (s.str.) <i>anthobia</i> A. Villa et G. B. Villa, 1833	E-PAS	2.1, 1	MX	AT_A, 27♀26♂; AT_M, 3♀2♂; AT_Ps, 1♂; P_O, 1♀; SK_R, 3♀2♂; M_R, 3♀9♂; M_R1, 2♀2♂; B_DG, 17♀27♂
61.	*A. (s.str.) <i>eurynota</i> (Panzer, 1796)	OLA	2.3, 1	M	M_Ps, 1♀
62.	A. (s.str.) <i>lucida</i> (Dufschmid, 1812)	E-PA-M	2.3, 1	MH	AT_M, 1♀; B_DG, 1♀2♂
63.	*A. (s.str.) <i>ovata</i> (Fabricius, 1792)	PAL	2.3, 1	M	AT_A, 2♀2♂; AT_O, 2♀; B_DG, 1♀1♂
64.	A. (s.str.) <i>saphyrea</i> Dejean, 1828	CE-E	2.3, 1	MX	AT_A, 9♀8♂; AT_O, 1♂; AT_O1, 1♀2♂; P_O, 5♀1♂2ex.; P_O1, 1♀; 2♀2♂; M_R, 2♂; M_R1, 1♀1♂; B_DG, 17♀10♂; B_DG1, 1♂; NA
65.	A. (s.str.) <i>similata</i> (Gyllenhal, 1810)	E-CA-M	2.3, 1	MH	AT_A, 1♀
66.	*A. (<i>Paracelia</i>) <i>serdicana</i> Apfelbeck, 1904	B-PAS	2.3, 1	X	P_O, 2♀[h]; M_D, 1♀
67.	A. (<i>Bradytus</i>) <i>apricaria</i> (Paykull, 1790)	OLA	2.3, 1(1)	MX	M_D, 1♀, 1♀[t]
68.	A. (<i>Amathitis</i>) <i>parvicollis</i> Gebler, 1833	E-CAS	2.3, 1(1)	M	M_R, 1♀1♂; M_R1, 1♀
69.	<i>Zabrus</i> (s.str.) <i>tenebroides</i> (Goeze, 1777)	E-CAS	2.3, 2	MX	M_D, 1♂[t]
70.	Z. (<i>Pelor</i>) <i>graecus</i> Dejean, 1828	BAL	2.3, 2	M	M_R, 1♀; M_O, 1♂
71.	Z. (<i>Pelor</i>) <i>balkanicus</i> Heyden, 1883	BGE	2.3, 2	M	P_O1, 1♂; B_DG, 1♂
72.	** <i>Anisodactylus (Pseudodichirius) intermedius</i> Dejean, 1829	MED-PA	2.3, 1	H	P_O1, 2♀
73.	** <i>Gynandromorphus errusculus</i> (Quensel en Schönherr, 1806)	NMED	2.2, 1	MX	P_O, 1♂[h]
74.	<i>Stenolophus</i> (s.str.) <i>teutonius</i> (Schränk, 1781)	EMED	2.1, 1	MH	SK_R, 5♂[h]
75.	St. (s.str.) <i>discophorus</i> (Fischer von Waldheim, 1823)	CE-PAS	2.1, 1	H	M_R, 2♂
76.	* <i>Acupalpus</i> (s.str.) <i>flavicornis</i> (Sturm, 1825)	E-CAS	2.1, 1	MH	B_BR, 1♀
77.	**A. (s.str.) <i>meridianus</i> (Linnaeus, 1760)	E-PAS	2.1, 1	H	SK_R1, 1♀[t]
78.	**A. (s.str.) <i>exiguus</i> Dejean, 1829	E-CAS	2.1, 1	H	B_BR, 1♀
79.	** <i>Parophonus</i> (s.str.) <i>maculicornis</i> (Dufschmid, 1812)	E-PAS	2.2, 1	M	AT_M, 6♀2♂; M_R, 2♀3♂; B_DG, 2♀1♂

No	Species	ZC	LF	HP	Locality code, material
80.	<i>**P. (s.str.) planicollis</i> (Dejean, 1829)	NMED	2.2.1	M	AT_A, 1♂
81.	<i>**P. (s.str.) laeviceps</i> (Ménétriés, 1832)	B-PAS	2.2.1	M	SK_R, 1♀1♂[h]; B_S, 1♂
82.	<i>*Harpalus (Semiothorus) signaticornis</i> (Dufschmid, 1812)	PAL	2.2.1	MX	AT_M, 2♀11♂; SK_R1, 1♂
83.	<i>H. (Pseudophonus) rufipes</i> (De Geer, 1774)	PAL	2.3.1	E	AT_A, 3♀2♂; AT_M, 2♂; AT_Ps, 1♀; P_O, 1♂; SK_R1, 1♀; M_R, 2♀1♂; M_D, 1♂[f]; B_DG, 2♂
84.	<i>*H. (Pseudophonus) griseus</i> (Panzer, 1796)	PAL	2.3.1	MX	AT_M, 1♂; SK_R, 1♂
85.	<i>*H. (Pseudophonus) calceatus</i> (Dufschmid, 1812)	PAL	2.3.1	X	M_D, 1♀
86.	<i>*H. (Cryptophonus) tenebrosus</i> Dejean, 1829	E-CA-M	2.3.1	MX	Mo, 1♀[h]; B_DG, 1♀
87.	<i>H. (s.str.) honestus</i> (Dufschmid, 1812)	E-PAS	2.3.1	MX	AT_A, 4♀10♂; AT_M, 1♀; P_O, 2♀; M_O, 1♂; B_DG, 1♂
88.	<i>H. (s.str.) sulphuripes</i> Germar, 1823	CEE-PA	2.3.1	M	O_O, 1♀; O_m, 1♂; P_SK, 1♀; AT_A, 1♀1♂; SK_R, 1♀1♂; SK_R1, 1♀; M_O, 1♂; M_O1, 1♀; NA, 1♂
89.	<i>H. (s.str.) rubripes</i> (Dufschmid, 1812)	OLA	2.3.1	MX	O_P, 1ex[h]; AT_A, 4♀8♂; AT_O, 1♂; AT_M, 4♀1♂; P_O, 1♀2♂; P_O1, 1♂; B_DG, 3♀2♂
90.	<i>H. (s.str.) attenuatus</i> Stephens, 1828	E-PA-M	2.3.1	MX	O_m, 1♂[h]; Ru_R, 1♂; AT_M, 1♂; P_O, 1♀; P_SK, 1♀; M_R, 1♀; M_O, 1♂; B_S, 1♀2♂; B_DG, 1♂
91.	<i>H. (s.str.) atratus</i> Latreille, 1804	E-CAS	2.3.1	MX	Ru_R, 1♂; AT_A, 1♀1♂; AT_O, 7♂; AT_Pn, 1♀; P_O, 3♀2♂; P_O1, 1♀; M_O, 1ex; M_Ps, 1♂; M_M, 1♀6♂; B_DG, 1♂
92.	<i>H. (s.str.) serripes</i> (Quensel, 1806)	WPAL	2.3.1	MX	Ru_R, 1♀[h]; AT_A, 9♀17♂; AT_M, 18♀39♂; SK_R, 3♀8♂[h]; M_R, 21♀27♂; B_DG, 13♀12♂
93.	<i>*H. (s.str.) flavicornis</i> Dejean, 1829	CE-PAS	2.3.1	MX	P_SK, 1♀; AT_A, 1♀2♂; AT_M, 3♀6♂2ex.; P_O, 1♀2♂; SK_R, 1♀3♀[h]; M_R, 1♀; B_S, 3♀9♂; B_DG, 32♀43♂
94.	<i>H. (s.str.) pumilus</i> Sturm, 1818	E-CAS	2.3.1	MX	AT_M, 2♂; M_R1, 1♂; B_DG, 1♀
95.	<i>H. (s.str.) subcylindricus</i> Dejean, 1829	E-CAS	2.3.1	X	AT_A, 1♀1♂1ex.; AT_M, 1♀; SK_R, 1♂[h]; B_S, 1♀ Kr, 1ex[h]; O_P, 1♀[h]; B_BR, 1♂; O_m, 2♀1♂; P_SK, 1♀; AT_A, 10♀316♂; AT_O, 12♀18♂; AT_O1, 4♀1♂; AT_M, 18♀39♂; P_O, 5♀5♂2ex.; P_O1, 3♀3♂; M_R, 2♀2♂; M_R1, 1♀; M_O, 1♀2♂; M_O1, 2♀; M_M, 7♀3♂; B_S, 1♀5♂; B_DG, 22♀18♂8ex.; B_DG1, 4♀2♂; NA, 1♂
96.	<i>H. (s.str.) tardus</i> (Panzer, 1796)	E-CAS	2.3.1	MX	
97.	<i>*H. (s.str.) albanicus</i> Reitter, 1900	E-PAS	2.3.1	X	AT_A, 6♀9♂1ex.; AT_M, 3♂; P_O, 1♂; B_S, 2♀; B_DG, 2♀1♂1ex.
98.	<i>*H. (s.str.) smaragdinus</i> (Dufschmid, 1812)	E-AS	2.3.1	X	M_D, 1♀1♂
99.	<i>H. (s.str.) autumnalis</i> (Dufschmid, 1812)	E-CAS	2.3.1	MX	B_BR, 5♀4♂; AT_M, 1♂; M_R, 8♀19♂1ex.; M_R1, 1♀2♂
100.	<i>*H. (s.str.) cupreus</i> Dejean, 1829	NMED	2.3.1	MX	Ru_R, 1♀

No	Species	ZC	LF	HP	Locality code, material
101.	<i>H. (s.str.) dimidiatus</i> (P. Rossi, 1790)	E-PAS	2.3.1	MX	O_O, 1♂; Ru_R, 6♀18♂2ex.; B_BR, 1♂; AT_Pn, 1♀1♂; AT_M, 26♀83♂2ex.; AT_Ps, 1♀3♂; P_O, 3♀6♂1ex., 1♀[h]; P_O1, 4♀3♂; SK_R, 1♀5♂[h]; M_R, 1♂; M_O, 2♀1♂; B_S, 1♀1♂; B_DG, 25♀43♂3ex.
102.	<i>H. (s.str.) pygmaeus</i> Dejean, 1829	NMED	2.3.1	MX	AT_M, 1♀1♂
103.	<i>H. (s.str.) hospes</i> Sturm, 1818	CE-PAS	2.3.1	X	P_O1, 1♂
104.	<i>H. (s.str.) affinis</i> (Schrank, 1781)	E-CAS	2.3.1	MX	P_O, 1♀7♂[h]; SK_R1, 2♂
105.	<i>H. (s.str.) distinguendus</i> (Duftschmid, 1812)	PAL	2.3.1	E	SK_R, 1♀[h]
106.	<i>H. (s.str.) saxicola</i> Dejean, 1829	CEE-PA	2.3.1	MX	B_DG, 1♂
107.	<i>*Ophonus (Metoponhus) laticollis</i> Mannerheim, 1825	E-CAS	2.2.1	MX	Ru_R, 2♀1♂; O_m, 1♀; AT_A, 20♀19♂; AT_O, 1♀; AT_O1, 1♀; AT_M, 1♂; P_O, 1♀; M_R, 1♂; M_R1, 1♂; M_O, 2♀9♂; M_O1, 2♀3♂; M_M, 2♂; B_S, 1♀1♂; B_DG, 16♀34♂2ex.; B_DG1, 1♂
108.	<i>*O. (Metoponhus) rufibarbis</i> (Fabricius, 1792)	WPAL	2.2.1	M	B_DG, 6♀3♂
109.	<i>O. (Metoponhus) parallelus</i> (Dejean, 1829)	EUR	2.2.1	MX	AT_M, 1♀
110.	<i>O. (Hesperophonus) azureus</i> (Fabricius, 1775)	E-CA-M	2.2.1	MX	AT_M, 2♀2♂; AT_Ps, 1ex.; P_O, 1♀; P_O1, 1♂; P_SK, 1♂; M_D, 1♂[h]; B_S, 1♀; B_DG, 4♀3♂
111.	<i>O. (Hesperophonus) subquadratus</i> (Dejean, 1829)	E-PA-M	2.2.1	MX	M_R, 1♀1♂; M_R1, 1♀
112.	<i>O. (Hesperophonus) cribricollis</i> (Dejean, 1829)	E-CAS	2.2.1	MX	AT_A, 2♀; AT_M, 2♀2♂; P_O, 1♀; M_O, 1♀1♂; B_DG, 1♀1♂; NA 1♀
113.	<i>Acinopus (s.str.) picipes</i> (Olivier, 1795)	NMED	2.3.2	MX	Ru_R, 1♂; AT_M, 1♀4♂; P_O1, 1♀, 1♂[h]; M_D, 4♀3♂2ex. [h]; SK_R1, 1♀; B_DG, 2♀1♂
114.	<i>A. (Osimus) amophilus</i> Dejean, 1829	CE-PAS	2.3.2	X	M_D, 1♂[h]
115.	<i>**A. (Oedematicus) megacephalus</i> (P. Rossi, 1794)	NMED	2.3.2	MX	AT_M, 1♂; M_D, 2♂[h]
116.	<i>**Carterus (s.str.) dama</i> (P. Rossi, 1792)	MED	2.3.3	X	AT_M, 1♀
117.	<i>Dixus obscurus</i> (Dejean, 1825)	NM-	2.3.3	X	AT_A, 12♀3♂5ex.; AT_M, 4♀1♂6ex.; P_O, 1ex.; M_R, 3ex.; M_O, 3♀1♂5ex.; B_DG, 4♂3ex.; KD_R, 1ex.
118.	<i>Chlaenius (s.str.) festivus</i> (Panzer, 1796)	E-CAS	1.3(1), 1	H	SK_R, 2♂[h]
119.	<i>Chi. (Chlaenellus) vestitus</i> (Paykull, 1790)	WPAL	1.3(1), 1	H	B_BR, 1♀; SK_R, 2♀[h]
120.	<i>Chi. (Trichochlaenius) aeneocephalus</i> Dejean, 1826	B-PAS	1.3(1), 1	M	Ru_R, 1♀; B_DG, 1♀
121.	<i>Licinus (s.str.) graecus</i> Apfelbeck, 1901	BAL	1.3(1), 1	X	P_O, 1♂

No	Species	ZC	LF	HP	Locality code, material
122.	<i>L. (s.str.) silphoides</i> (P. Rossi, 1790)	NMED	1.3(1).1	MX AT_M, 1ex.	
123.	<i>*Lebia (s.str.) marginata</i> (Geoffroy, 1785)	E-PAS	1.1.3	X SK_R1, 1♂	
124.	<i>*Demetrius (s.str.) atricapillus</i> (Linnaeus, 1758)	E-CA-M	1.1.2	MH B_DG, 1ex.	
125.	<i>Paradromius (Manodromius) linearis</i> (Olivier, 1759)	E-PAS	1.3(1).5	MH P_O, 1♂[h]	
126.	<i>Syntomus obscuriguttatus</i> (Duftschmid, 1812)	E-PA-M	1.3(1).3	M Ru_R, 1♂; R_AY, 1♂; AT_M, 2♀3♂; M_R, 1♂; M_R1, 1♀; B_DG, 4♀3♂	
127.	<i>*S. pallipes</i> (Dejean, 1825)	E-CA-M	1.3(1).3	MX Ru_R, 2♀1♂; AT_A, 3♀6♂; AT_M, 3♀3♂; SK_R, 2♀1♂; SK_R1, 1♀; M_R, 1♂; B_DG, 6♀4♂	
128.	<i>*S. impressus</i> (Dejean, 1825)	MED	1.3(1).3	M B_BR, 1♂; AT_M, 1♀	
129.	<i>*Microlestes fissuralis</i> (Reitter, 1901)	E-CAS	1.3(1).3	M O_P, 1♂; B_S, 1♀; M_D, 1♂	
130.	<i>*M. minutulus</i> (Goeze, 1777)	OLA	1.3(1).3	MX Ru_R, 1♀1♂; AT_A, 1♂; AT_M, 1♀2♂; P_O, 1♀[h]; P_O1, 2♀; B_DG, 1♀1♂6ex.	
131.	<i>Microlestes negrita</i> (Wollaston, 1854)	MED-PA	1.3(1).3	MX B_DG, 2♂	
132.	<i>Lionychus (s.str.) quadrillum</i> (Duftschmid, 1812)	E-PAS	1.3(1).1	H B_BR, 4♀; AT_M, 1♀; M_R, 1♂	
133.	<i>Cymindis (s.str.) axillaris</i> (Fabricius, 1794)	E-PA-M	1.3(1).3	MX O_P, 1♀	
134.	<i>Brachinus (s.str.) crepitans</i> (Linnaeus, 1758)	PAL	1.3(1).3	MX AT_A, 4♀4♂; AT_M, 1♀; P_O, 1♂; SK_R, 1♀[h]; M_M, 1♀1♂1ex.	
135.	<i>*Br. (s.str.) psophia</i> Audinet-Serville, 1821	E-CA-M	1.3(1).3	MX B_DG, 82♀30♂	
136.	<i>*Br. (Brachynidius) brevicollis</i> Motschulsky, 1844	B-CAS	1.3(1).3	MX B_DG, 1♀1♂	
137.	<i>*Br. (Brachynidius) bodemeyeri</i> Apfelbeck, 1904	E-CA-M	1.3(1).3	M Ru_R, 1♀	
138.	<i>Br. (Brachynidius) explodens</i> Duftschmid, 1812	E-CAS	1.3(1).3	MX AT_A, 34♀, 32♂; AT_M, 5♀4♂; P_O, 4♀2♂[h]; P_O1, 1♀, 1♂[t]; SK_R, 5♀4♂[h]; M_R, 1♀; B_S, 2♀2♂6ex.; B_DG, 18♀12♂	

Note: * – new species for the Eastern Rhodope Mts.; ** – new species for the whole Rhodope Mts. ZC – zoogeographic category (explanations are given in Table 3 the Results section of the main paper); LF – life form (explanations are given in the Material and Methods section of the main paper); HP – humidity preference (H – hygrophilous, MH – mesohygrophilous; M – mesophilous, MX – mesoxerophilous, X – xerophilous, E – eurybiont); ♀ – female, ♂ – male, ex. – not determined; [h] – hand collection; [t] – tree trap; NA – label destroyed, material collected in 2005–2006. Locality codes are given in Table 1.

TRUNK DIAMETER GROWTH DYNAMICS OF WOODY PLANTS IN SIBERIAN INDUSTRIAL CITY GREENING

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Abstract

The research undertaken focused on trunk diameter growth dynamics of seven woody species widely used in urban community gardening in Siberian cities: *Picea pungens*, *Betula pendula*, *Ulmus pumila*, *Populus balsamifera*, *Sorbus aucuparia*, *Padus maackii*, *Malus baccata*. Diameter growth rate was used as indirect indicator of the extent to which industrial pollutions may affect woody species in community gardening. Greening of large industrial city Krasnoyarsk was under study. Five sample sites differing in content of industrial pollutions were established within the districts of the city. It was revealed that in the Downtown greenings being under heavy recreation and vehicle-caused pollutions *S. aucuparia*, *P. maackii*, *P. pungens*, *B. pendula* and *P. balsamifera* could be successfully used rather than *U. pumila* and *M. baccata*. Greenings heavily polluted by nonferrous metallurgy enterprises should be composed with tolerant *M. baccata*, *B. pendula*, *U. pumila* and *P. maackii*, and; at that time *P. pungens*, *S. aucuparia* and *P. balsamifera* could not be recommended for planting there. In greenings heavily polluted by heat power plants and chemical (pulp and paper) enterprises should be composed with tolerant *P. pungens*, *S. aucuparia*, *P. maackii*, *B. pendula*, *U. pumila*, *P. balsamifera*, *M. baccata* could not be recommended for planting there. Greenings, if planted in accordance with this recommendations, can be highly effective in fulfilling environmental, protective, sanitary, and esthetic functions in industrial cities. It should be taken into account in the implementation of management programs and development strategies for Siberian urban greenings.

Key words: diameter growth rate, industrial air pollution, urban community gardening, woody species.

Introduction

Continuous urgent problem in the world lies in estimation of the effect of industrial environment on woody plants against the backgrounds of urbanization, fast progressing in the last decades (Kulagin

1974, Avdeyeva and Kuzmichev 1997, McGovern and Pasher 2016). In the frame of this problem, assessments of urban trees provide total picture of urban gardening status in environmental, sanitary, and esthetic meaning in the implementation of management programs for urban

resources (Nowak et al. 2014, Lisotova et al. 2018). Assessments of industrial pollutions impact on urban greening are usually carried out by phyto-indication, applying morphometric characteristics of trunks and crowns, architectonics, foliage biometric and biochemical parameters, etc. (Nikolayevsky 1979; Artemiev 2003; Neverova 2009; Skripal'shchikova et al. 2009a, 2009b; Mikhailova et al. 2011; Avdeyeva and Krivonosenko 2013; Belanova et al. 2016). Nevertheless, most part of the characteristics obtained were usually applicable only for current season and unsuitable for revealing time variations or trends. In this context, series of annual growth rings in the trunk could be much more informative and allow fulfilling retrospective and predicting patterns of trunk radial growth process. On one side, growth ring anatomical structure characterized by evolutionary stability, on the other, has a high degree of functional adaptation, especially reflected in water transport function (Gamaley 2011). It has been repeatedly established that tree rings record information on climate (Fritts 1976, Schweingruber 1996, Vaganov et al. 2006) and environment extreme impacts, such as lack of light, draught, severe frost, defoliation by insects, etc. (Schweingruber et al. 2006, He et al. 2007, Gillner et al. 2013, Selikhovkin 2013). The studies of industrial pollution effect on radial growth and wood anatomical structure of trees have a significant place among others. Most of the studies were conducted in native forests and parks developed near big industrial centers (Pasternak et al. 1985, Alexeyev 1990, Arsenyeva and Chavchavadze 2001, Rossinina et al. 2008, Skripal'shchikova et al. 2009b, Kirryanov et al. 2014, Tyukavina and Lezhneva 2014). Only few studies were concentrated in certain pollutant: nuclear radiation (Musaev 1996),

traffic impact (Artemiev and Arsent'yeva 2014), heavy metal ions absorbed by roots from the soil (Fedorkov 2006). From this review, it follows that woody species used in city greenings were poorly represented in the studies, predominately by *Caragana* sp., *Quercus* sp., *Populus balsamifera*.

From the review above, it is evident, that the issue remains open in connection with variety of ecological conditions between industrial cities and between districts within the city as well as diversity of the species studied. The purpose of our study was to analyze dynamics of diameter growth of trunks as one of the characteristics of vital state of seven woody species in various ecological zones of a Siberian industrial city.

Materials and Methods

Study area

The research object was the trunk diameter growth dynamics of seven woody species (*Picea pungens* Engelm. (Colorado spruce), *Betula pendula* Roth. (Common birch), *Ulmus pumila* L. (Siberian elm), *Populus balsamifera* L. (Balsam poplar), *Sorbus aucuparia* L. (European mountain ash), *Padus maackii* Rupr. (Maack cherry), *Malus baccata* (L.) Borkh. (Dwarf apple)), most often used in greening of Siberian cities (Vstovskaya and Koropachinskiy 2003). One of the largest Siberian industrial cities, Krasnoyarsk was under study as an example of highly polluted urban area.

Krasnoyarsk is situated at the junction of three geomorphological regions: Yenisei River valley, the plateaus adjoining the valley, and the foothills of Sayan Mountains. Largely, Krasnoyarsk is locat-

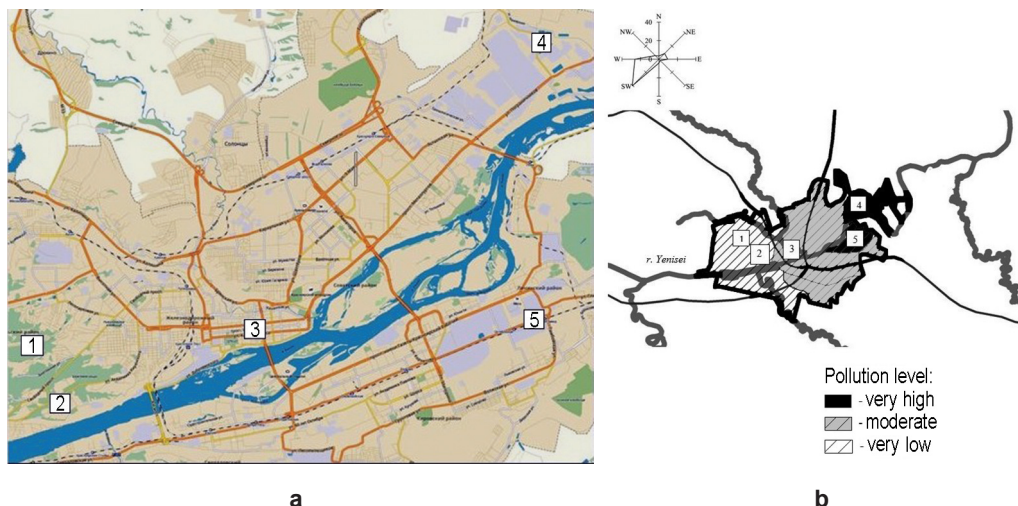


Fig. 1. Sampling plots locations on the territory of Krasnoyarsk: a – Yandex map of Krasnoyarsk with sample plots (1–5); b – ecological zones on the territory of Krasnoyarsk characterized by very low (white), moderate (grey), and very high (black) level of air pollution.

Note: 1 and 2 – very slightly polluted plots, 3 – moderately polluted plot, 4 and 5 – very heavily polluted plots.

ed in Yenisei valley (Fig. 1a). There is a flood plain in the valley and nine terraces discontinuous with the town. The left bank terraces border on the plateaus. On the right bank, Sayan foothills fringe the valley. The left bank of the river is dominated by typical forest-steppe, whereas mountain taiga forest occupies the right bank. The climate is sharply continental, with mean annual, January, and July air temperatures being 0.6 °C, -16.7 °C, and +18.6 °C, respectively. Average precipitation is 372 mm a year, annual relative humidity averages 69 % (Shver and Gerasimova 1982). The soils in the study area had been strongly influenced by the processes of urbanization and long-term aerosol impact by industry, so that, they could not be genetically classified, and as such are related to 'Technogenic Surface Formations' (TSF) (Shishov et al. 2004).

Sampling design

In general, the air in Krasnoyarsk is heavily polluted. Air pollutants distribute within its territory depending on district-specific topography, wind regime, and land-use change. Its local concentration varies frequently from rather slight to very high. Unfortunately, the current Municipal estimates in the frame of the city districts concerning concentration of certain components in air pollution have not been available for us. Nevertheless, taking into account the published data (Skrpal'shchikova et al. 2009a, Khlebopros et al. 2012) and basic facts, we could approximately border three contrasting ecological zones (Fig. 1b, white, grey and black coloured) characterized by very low, moderate and very high level of air pollution. Within these zones we chose five greenery ob-

jects and used them as 'temporal sampling plots'. Two sample plots, AP and HP, were located in the heavily polluted zone (Fig. 1b, black coloured), near Aluminum and other nonferrous metallurgy enterprises (AP plot) and Heat Power Plants (HP plot) accompanied with chemical enterprises, windward. Another one, DT plot, was positioned in the moderately polluted zone (Fig. 1b, grey coloured, crosshatched), in lowland, heavily populated Downtown. The remainders, AK and VL plots, were located in the favourable, very slightly polluted ecological zone (Fig. 1b, white coloured, crosshatched), at the leeward western outskirts of the town, far from industrial spots, in the city districts 'Akademgorodok' and 'Vetluzhanka'.

On AP plot, the composition of air pollution is typical for Aluminum and other nonferrous metallurgy industry and associated with fluoric, calcium, magnesium, and sulphuric compounds, as well as benzo[a]pyrene, CO, and dust particles. Pollution on HP plot is typical for Heat Power Plants working on brown coals. Emission contains acrylonitrile, aldehydes, butadiene, hydrogen sulphide, formaldehyde, CO, NO, NO₂, SO₂, and ash, abundantly supplied with CaCO₃. On DT plot vehicle-caused pollution including CO, NO, NO₂, SO₂, benzo[a]pyrene, and formaldehyde emissions prevailed (Khlebopros et al. 2012). AK and VL plots are very slightly polluted by light local traffic.

The individuals belonging to all these species grow in all studied sample plots; only the trees of *U. pumila* were absent on AK plot. In our study, each species on each sample plot was represented by ten experimental trees. All these ten trees had approximately the same age and well-developed crown that has no signs of pruning. The trees were planted 3–5 m from each other (according to the greenery

planting rules in Russia), in rows on AP, HP and DT plots, and in small groups on VL and AK plots. To minimize vehicle-caused pollution effect and concentrate on industrial emission influence, the experimental trees on AP and HP plots were selected approximately 20 m away from the roads. Wood cores taken at 1.3 m from experimental trees by Pressler borer were used in analysis. In total, 370 woody samples (cores) were extracted in 2012–2013 vegetation seasons.

Data analysis

Tree-ring widths (TRW) were measured with an accuracy of 0.01 mm according to standard technics in dendrochronology by means of the semi-automatic device LINTAB (Frank Rinn SA, Heidelberg, Germany). Ring widths were recorded using the original computer program 'Time Series and Presentation Program TSAP V3.5' (Rinn 1998).

Ageing effect in tree radial growth process could emerge from the dependence 'tree-ring width vs tree age' (Schweingruber 1996), characterized by high year-to-year variability especially caused by seasonal variation of weather conditions (climate factors) (Fritts 1976, Schweingruber 1996). In this paper, we favoured analyzing the dependence 'trunk diameter at breast height (DBH) vs tree age', because in this dependence seasonal variations are smoothing (i.e.) (Simanko 2014, Mashukov et al. 2018). By the latter, we neglected climate impact.

Using measured data on TRW, annual diameter growth values for each experimental tree were reconstructed, from the year of planting in greenery through the year we took a core, by summing ring widths multiplied by 2 sequentially, year by year, along one radius of the

trunk (along the core). By averaging, we obtained mean annual trunk diameter of each tree and then, mean annual data of trunk diameter (accompanied with standard deviation) for each species on each experimental plot. The dependences of mean trunk DBH vs an age for 7 species studied growing on 5 sample plots are shown in figures 2 A–G. We split each curve into one to three linear sections. By each linear portion, we obtained the value of mean diameter growth rate in corresponding period of ageing (in X-axis) and then, we analyzed dynamics of trunk DBH growth of the species growing on each sample plot.

Results

Picea pungens (Fig. 2A)

Comparatively high diameter growth intensity was on the ecologically safe VL and AK plots. It took the value 7.5 ± 0.5 mm·year⁻¹ (curve 1) and 8.3 ± 0.7 mm·year⁻¹ (curve 2) in average (the difference between them are not significant at F-test, $P \geq 0.95$). These characteristics stayed approximately invariable for 19 years, from the start of tree growth to the age of taking cores.

On DT plot (curve 3), affected by heavy recreation impact and traffic pollutants, diameter growth rate averaged 4.0 ± 0.6 mm·year⁻¹ for the first four years after planting and then it increased to 7.0 ± 0.6 mm·year⁻¹.

On very heavily polluted AP plot, diameter growth rate averaged 3.4 ± 1.0 mm·year⁻¹ from the year of planting to the year of taking cores (curve 4). Growth process suppressed obviously by constant negative impact of atmospheric emissions represented chemical compounds of nonferrous metallurgy.

On very heavily polluted HP plot (curve 5), the trees grew slowly during the first seven post-planting years with DBH growth rate being 3.1 ± 1.0 mm·year⁻¹, then it follows a phase of rather intensive growth (9.4 ± 1.0 mm·year⁻¹).

Betula pendula (Fig. 2B)

On the quite clear VL and AK plots (curves 1 and 2), the birch trees showed relatively high average DBH growth rate in comparison to the others. From planting to 14 years in age these values were 9.4 ± 1.0 mm·year⁻¹ on AK plot and 8.0 ± 1.0 mm·year⁻¹ on VL plot. Then, these values continuously dropped down: on AK plot to 5.9 ± 1.0 mm·year⁻¹ and on VL plot to 7.4 (to 37 years) and then, to 3.6 mm·year⁻¹ from 37 to 42 years in age.

On the moderate- and high-polluted DT and AP plots (curves 3 and 4) the individuals grew in diameter by approximately the same average rate of 6.5 ± 0.4 and 6.5 ± 1.1 mm·year⁻¹ up to 18 years of age. Then, the rates dropped down to 3.0 ± 0.3 mm·year⁻¹ on AP plot and 4.3 ± 0.1 mm·year⁻¹ on DT plot.

On the very dirty HP plot the DBH growth rate averaged 5.6 ± 1.1 mm·year⁻¹ for the first eight years after planting (curve 5), then it dropped down to 3.0 ± 1.0 mm·year⁻¹.

Ulmus pumila (Fig. 2C)

The experimental trees on VL plot (curve 1) grew in diameter with even average rate of 8.3 ± 1.1 mm·year⁻¹ from planting through the age 18 (the age when we took the cores).

On the very high-polluted AP plot (curve 4) the saplings grew quite rapidly for 4–5 years after planting with mean growth rate of 11.0 ± 0.5 mm·year⁻¹; then,

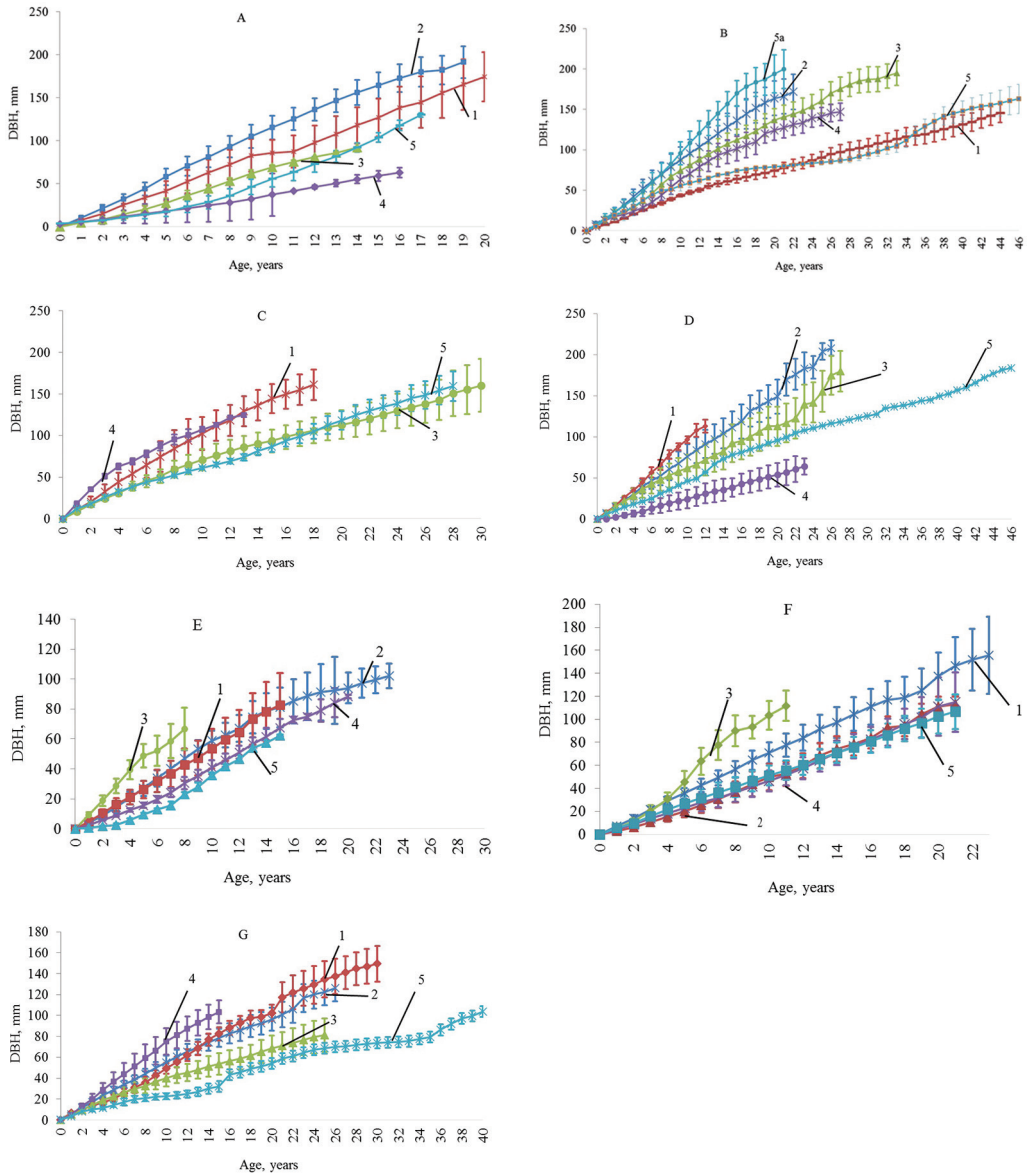


Fig. 2. Mean DBH diameter vs an age for *P. pungens* (A), *B. pendula* (B), *U. pumila* (C), *P. balsamifera* (D), *S. aucuparia* (E), *P. maackii* (F), and *M. baccata* (G).

Note: plots: 1 – VL, 2 – AK, 3 – DT, 4 – AP, 5 – HP.

from the age of 6 to 13 (being the coring age), averaged diameter growth rate halved to $6.2 \pm 0.6 \text{ mm} \cdot \text{year}^{-1}$.

On moderate polluted DT plot (curve 3)

the individuals exhibited DBH growth rate equaled by $6.3 \pm 1.1 \text{ mm} \cdot \text{year}^{-1}$ during the first 7–9 years. With time, from the age of 10 to 30 (being the coring age), this value

dropped to 4.8 ± 1.0 mm·year⁻¹. Approximately the same dynamics of DBH growth was established on very-high-polluted HP plot (curve 5): from the age of 10 to the coring age, this value was equaled to 5.2 ± 1.2 mm·year⁻¹.

***Populus balsamifera* (Fig. 2D)**

Averaged diameter growth rate on all sample plots did not significantly varied ($P \geq 0.95$) from planting to taking cores. Poplar trees grew in diameter rather intensively on quite clear VL and AK plots (10.1 ± 0.5 and 7.7 ± 1.1 mm·year⁻¹ respectively, curves 1 and 2), but slower on very-high-polluted AP and HP plots (3.9 ± 0.8 and 3.4 ± 0.1 mm·year⁻¹, curves 4 and 5). On moderate-polluted DT plot (curve 3), this value was 5.3 ± 1.0 mm·year⁻¹.

***Sorbus aucuparia* (Fig. 2E)**

On moderate polluted DT plot (curve 3), DBH growth rate was highest, 9.0 ± 1.1 mm·year⁻¹ in average, after planting up to the age of 4. At the age of 5 to 8 (being the age of taking cores), this parameter decreased to 7.0 ± 1.1 mm·year⁻¹.

On low-polluted VL and AK plots (curves 1 and 2), the averaged diameter growth rates were 4.9 ± 1.5 and 5.4 ± 0.8 mm·year⁻¹, which did not vary to the age of 15 (being the age of taking cores on VL plot). On AK plot, from 15 to 23 years of age, this value dropped to 2.3 ± 1.6 mm·year⁻¹.

On high-polluted AP and HP plots (curves 4 and 5), averaged diameter growth rate was very low during six post-planting years – 2.9 ± 0.3 and 2.0 ± 0.2 mm·year⁻¹ respectively. Then, until the year of taking cores, these values increased gradually on both sites to reach 4.6 ± 0.4 and 5.4 ± 0.2 mm·year⁻¹ respectively.

***Padus maackii* (Fig. 2F)**

On clear VL and AK plots, as well as on very dirty AP and HP plots (curves 1, 2, 4 and 5, respectively) DBH growth rates did not vary significantly from the year of planting to the year of taking cores. The average value was about 5.1 ± 0.6 mm·year⁻¹ on AK, AP and HP plots (curves 2, 4 and 5), but on VL plot (curve 1) it was higher, 6.5 ± 0.6 mm·year⁻¹.

On DT plot (curve 3), diameter growth rate of saplings was quite high, averaged by 6.1 mm·year⁻¹ to the age of 4. Between 5 and 9 years in age, this parameter increased markedly to 11.0 ± 0.8 mm·year⁻¹. From 8 to 11 years of age (being the age of taking cores), the growth rate dropped again to 5.5 ± 0.8 mm·year⁻¹. Commonly, dynamics of DBH growth for *P. maackii* and *S. aucuparia* growing on DT plot are similar to each other (figs 2E and 2F, curve 3).

***Malus baccata* (Fig. 2G)**

On clear VL and AK plots (curves 1 and 2) growth rates did not vary significantly, exhibited averaged meanings 5.7 ± 0.3 and 4.8 ± 0.6 mm·year⁻¹ until 17 years of age, since then these parameters decreased to become almost equal ($P \geq 0.95$) (4.0 ± 1.2 and 4.0 ± 0.4 mm·year⁻¹ to the age of taking cores).

Until the age of 10, the trees growing on heavy polluted AP plot (curve 4), had the highest average growth rate equaled by 6.6 ± 1.1 mm·year⁻¹. Over the past years to the year of taking cores, it dropped to 4.4 ± 0.3 mm·year⁻¹. Meanwhile, on heavy polluted HP plot (curve 5), the trees exhibited the lowest average diameter growth rate – 2.5 ± 0.3 mm·year⁻¹ in average from the year of planting to the year of taking cores.

On DT plot (curve 3), DBH growth rate, equaled by $2.7 \pm 0.7 \text{ mm} \cdot \text{year}^{-1}$ in average, has remained stable in time.

Discussion

Our study aimed at practical demands, implied in developing and implementation successful management programs for urban greening taking into account specific tolerance to particular air pollutants. Because of that, we made some preliminary simplifications before interpretation of the results.

Highlighting the importance of air pollution impact on DBH growth dynamics, we made the effort to eliminate some other factors could hardly be considered. As it follows from Fig. 2, for several years after planting some saplings grew slowly, but the others grew fast (as an example, *S. aucuparia* in Fig. 2E, curve 5 and *U. pumila* in Fig. 2C, curve 4). Such opposite particularities are possibly caused by low or high quality of planting material, bad or good looking after planting or different specific adaptive strategy to new conditions just after planting, etc. Then, after this initial period, diameter growth rate of the trees became more or less stable for some time (second period of growth) and then, it could gradually diminish (third period) caused by lots of reasons (ageing effect, insect attacks, pruning and other harmful impacts). For further analysis we took into account the stable period of growth, avoiding the other two. We believed by this approach pollution impacts got highlighted. Then, we changed over from the numerical values of obtained DBH growth rate, statistically distinguished at F-test ($P \geq 0.95$), to three qualitative characteristics which indicated comparatively high, moderate and slow DBH growth intensity of the certain spe-

cies growing on various sample plots. We represented comparatively high, moderate and slow DBH growth intensity for every species studied by green, yellow and red. This simplification may be of advantage in greenery management practices.

From Table 1, it follows that the dependence 'the heavier the industrial pollution – the lower DBH growth rate' does not universally true. Out of the seven species studied only *P. balsamifera* obeyed the dependence mentioned. It characterized by low DBH growth intensity near highly polluted Aluminum Plant (AP plot) and Heat Power Plants accompanied with chemical enterprises (HP plot), medium growth intensity on moderately polluted plots and high intensity on clear VL and AK plots. We also fixed crown density decline and chemical burns on lives accompanied slow diameter growth of poplar trees on AP and HP plots. Based on those features, *P. balsamifera* should be used as indicator in assessment of industrial air pollution extent.

Our attention focused on *P. pungens* on heavily polluted HP and *M. baccata* on heavily polluted AP plot, characterized by comparatively high DBH growth rates (Table 1). It served to suggest that technogenic substances could influence positively in some cases.

To take well-known illustration, air polluted ash, resulting from brown coal burning in heat power plants, contains CaCO_3 which, landing on soil, continuously deoxidizes it. The latter takes place on HP plot. The positive effect of deoxidizing was especially obvious in *P. pungens*; this effect was slightly lowered by pathogen damages in *S. aucuparia* and *P. maackii* (we found them when expertise their crowns). The other four species studied demonstrated negative reaction on technogenic substances polluted HP plot.

Table 1. Qualitative representation of mean DBH growth rates of the species.

Species	Sample plots				
	VL	AK	DT	AP	HP
<i>P. pungens</i>	7.0-8.0	7.5-9.0	6.4-7.6	1.9-4.9	8.4-9.4
<i>B. pendula</i>	6.4-8.4	7.0-9.0	6.1-6.9	5.4-7.6	2.0-4.0
<i>U. pumila</i>	7.2-9.4	-	3.8-5.8	5.6-6.8	4.0-6.4
<i>P. balsamifera</i>	10.6-11.6	6.6-8.8	4.3-6.3	3.1-4.7	3.3-3.5
<i>S. aucuparia</i>	3.4-6.4	4.6-6.2	5.9-8.1	4.2-5.0	5.2-5.6
<i>P. maackii</i>	5.9-7.1	4.5-5.7	10.2-11.8	4.5-5.7	4.5-5.7
<i>M. baccata</i>	5.4-6.0	4.2-5.4	2.0-3.4	5.5-7.7	2.2-2.8

Note: comparatively low, moderate and high growth rates marked by red, yellow and green are significantly different according to F-test at $P \geq 0.95$.

As to our assessment (Table 1), on AP plot, situated near nonferrous metallurgy enterprises, the trees of *B. pendula*, *U. pumila*, *P. maackii* and especially *M. baccata* grew in diameter quite well in spite of toxic air pollution impact. We believe that 'positive' effect of the latter concerned suppression of vital activity of harmful insect species. Indeed, the effect of their suppression by toxic pollution from Aluminum and pulp and paper enterprises was reveled in earlier entomologic studies (Selikhovkin 2013). When expertise crowns of the species growing on AP plot, we did not fix any insects, only its slight markings on *P. balsamifera* leaves (at the same time, in quite clear sites poplar leaves were hitting markedly). This 'indirect' positive effect slightly lowered in *B. pendula*, *U. pumil* and *P. maackii* trees by appearance of chemical burns we fixed in their crowns (Klad'ko and Skripal'shchikova 2019), caused by toxic pollutants. In *P. pungens*, *P. balsamifera* and *S. aucuparia* comparatively slow DBH growth accompanied of crown density decline and hard chemical burns on needles and leaves (Klad'ko and Skripal'shchikova 2019).

The Downtown gardenings (DT plot, Table 1) are characterized by heavy recreation and moderate vehicle-caused im-

pacts which affected quite adversely on diameter growth rate of *U. pumila* and *M. baccata* trees; we also fixed their crown density decline, harmful insects and chemical burns on the surface of needles and leaves. Meanwhile, *S. aucuparia* and *P. maackii* trees exhibited comparatively high DBH growth rates accompanied of healthy crowns.

Conclusion

The current state of greenings and parks in the large industrial city of Krasnoyarsk requires urgent measures to improve their quality (Lisotova et al. 2018). Unfortunately they have been hardly updated; the woody plants have been regularly partly eliminated without equivalent planting. In greening, specific resistance to toxic pollution impacts has not been taken into account. Information resided in reconstructed dynamics of tree diameter growth in some cases could substitute regular visual monitoring, as it reflects resulting impact of many factors on urban tree health. In this paper, we tried to highlight technogenic impact as the major one analyzing specific adaptation of woody trees in greening to air industrial pollution of

various composition. In the next studies, we are going to revise climate influence on urban greening.

In accordance with specific response of woody species studied to pollution impacts in Krasnoyarsk we could conclude the following.

In the greenings being under heavy recreation and vehicle-caused pollutions we could not recommend planting *Ulmus pumila* and *Malus baccata*; *Sorbus aucuparia* and *Padus maackii* have high advantages over them and other species studied, nevertheless, *Picea pungens*, *Betula pendula* and *Populus balsamifera* could be successfully used also.

In greenings heavily polluted by non-ferrous metallurgy enterprises we could not recommend planting *Picea pungens*, *Sorbus aucuparia* and *Populus balsamifera*. Greening should be composed with tolerant *Betula pendula*, *Ulmus pumila*, and *Padus maackii* but *Malus baccata* should be prevailed.

In greenings heavily polluted by heat power plants and chemical (pulp and paper) enterprises should be composed with tolerant *Picea pungens*, *Sorbus aucuparia*, *Padus maackii*.

These recommendations could serve for better efficiency of greening in polluted districts of Krasnoyarsk and other industrial Siberian cities.

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NEW CRITERIA FOR AWARDING MEDALS TO GOLDEN JACKAL TROPHIES

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Abstract

Hunting exhibitions are valuable sources of morphometric data. Although considering only two craniometric measurements, i.e. maximum length and zygomatic breadth, a huge data base has been created. Trophies from almost all predator species are presented at hunting exhibitions and measured, thus making it possible to collect much more craniometric data in addition to the standard trophy evaluation. However, the CIC (Conseil International de la Chasse) have firmly established and appropriate criteria for awarding medals for only a very few carnivore species. Golden jackal (*Canis aureus* Linnaeus, 1758) is hunted as a game species in many European countries, following its ongoing expansion, but still very few trophies are presented and measured at hunting exhibitions. Often different criteria have been applied for awarding medals to jackal trophies decided on an *ad hoc* basis by the evaluation committees. Recently, new criteria for awarding jackal trophies were officially adopted by CIC in the latest edition of the Handbook for the Evaluation and Measurement of Hunting Trophies. However, not so many trophies of jackal skulls were measured since then and it seems that these criteria are determined arbitrarily and are not based on research or large amounts of data. Bulgarian territory is considered the core area of Golden jackal distribution in Europe with the highest population density, but morphometric studies, including skulls from Bulgaria, are very scarce and local so far. In the present research an extensive morphometric data of jackal skulls from Bulgaria and Romania was analysed to suggest and justify new criteria for awarding medals to jackal trophies. Statistical distribution of trophy scores was approximated by normal distribution with mean and variance calculated from the large Bulgarian sample. According to the results, gold medals must be awarded to a trophy scoring 27.00 CIC points and above, silver – from 26.50 to 26.99 and bronze – from 26.00 to 26.49.

Key words: *Canis aureus*, CIC scores, cranial variability, hunting exhibitions, skull morphology, trophy.

Introduction

Golden jackal (*Canis aureus* Linnaeus, 1758) is one of the most widely distributed canid species and is found in many areas of Europe and Asia (Jhala and Moehlman 2004, Arnold et al. 2012, Hoffmann et al. 2018, Moehlman and Hayssen 2018,

Spasov and Acosta-Pankov 2019). Since the 1980s, jackals have increased in their distribution and abundance in what is arguably the most dramatic recent expansion among native predators on the continent (Jhala and Moehlman 2004, Šálek et al. 2014, Koepfli et al. 2015, Trouwborst et al. 2015). The jackal expansion in the last

two decades has been rapid and is still ongoing. Jackals have spread into Switzerland, Lichtenstein, Germany, Denmark, Poland, France, Netherlands, Belarus, Ukraine, Baltic states and, in 2019, also to Finland (Pyšková et al. 2016, Volokh and Roženko 2016, Krofel et al. 2017, Potočník et al. 2019). The ongoing expansion of the species in Europe has caused concerns regarding the possible negative effects that its presence could exert, due to excessive predation of other wildlife species or livestock, and the transmission of pathogens (Rutkowski et al. 2015, Čirović et al. 2016). In addition, there are several uncertainties regarding jackal management and policies, often in association with the unknown origins of jackal populations (Trouwborst et al. 2015). Nowadays Golden jackal is hunted as a game species in Austria, Bulgaria, Bosnia and Herzegovina, Montenegro, Estonia, Latvia, Lithuania, Hungary, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, Serbia, Turkey and Ukraine (Potočník et al. 2019), but still very few trophies are presented and measured at hunting exhibitions. Jackal expansion in the last decades has triggered research interest in Europe. However, very few studies have focused on cranial variability of Golden jackal in Europe (Kryštufek and Tvrtković 1990, Stoyanov 2012, Volokh and Roženko 2016, Markov et al. 2017, Rezić et al. 2017, Krendl et al. 2018, Stoyanov 2019, Stoyanov 2020), despite its wide distribution in recent decades.

Natural history collections are valuable source of morphometric data. However, for many game species in Bulgaria like Grey wolf (*Canis lupus* Linnaeus, 1758), Golden jackal and Red fox (*Vulpes vulpes* (Linnaeus, 1758)), a big part of skulls is stored in hunters' private trophy collections, and such data remains hidden and

inaccessible to researchers. Hunting exhibitions provide good opportunities for scientists to collect such data, but hunters should be motivated to present their trophies. The idea to evaluate hunting trophies of carnivore species came for the first time in Florence in 1964, where skulls of Brown bear (*Ursus arctos* Linnaeus, 1758) were measured, and data collection started (Ninov 2015). In all the exhibitions conducted so far, the skulls of 19 species and 5 subspecies of carnivores were evaluated (Hromas 1998). Although considering only two craniometric measurements, i.e. maximum length and zygomatic breadth, a huge data base was created exceeding in the number of measured skulls all the world's natural history collections. Initially, only the skulls of Brown bear, Grey wolf and European wildcat (*Felis silvestris* Schreber, 1777) were evaluated. Nowadays, hunting trophies from almost all predator species are presented at hunting exhibitions and measured, thus making it possible to collect much more craniometric data in addition to the standard trophy evaluation. Moreover, estimating the age of animals by upper incise teeth wear (Lombaard 1971) or by counting the annual cementum layers in canines (Klevezal and Kleinenberg 1967) provides valuable data on population demography. Although the skulls of all carnivore game species are presented and evaluated at hunting exhibitions, not for all of them CIC (Conseil International de la Chasse) have firmly established and appropriate criteria for awarding medals, as they had been developed and accepted for Brown bear, Grey wolf and European wildcat. In the most popular 'Blue book' of CIC, where criteria for awarding medals were published (Whitehead et al. 1986), such criteria are missing for the Golden jackal and many other carnivore species.

A Jackal skull from Africa was first presented, but not evaluated, at an exhibition in 1954 in Düsseldorf. For the first time Golden jackal trophies were evaluated and awarded medals by certain criteria at the 1996 hunting exhibition in Novi Sad (Ninov 2015). Most often during the hunting exhibitions different criteria have been applied for awarding medals decided on an *ad hoc* basis by the evaluation committees. Such criteria are usually determined arbitrarily and are not based on research or a large database. Angelescu (2004), in his monograph on Golden jackal in Romania, proposed criteria for awarding jackal trophies, which were officially adopted by CIC in the latest edition of Handbook for the Evaluation and Measurement of Hunting Trophies (Crombrughe et al. 2014) that replaced the old 'Blue book'. In Plovdiv (2013) only 25 Golden jackal skulls were measured and received 10 gold, 3 silver and 5 bronze medals, according to these criteria. However, not so many trophies of Golden jackal skulls were measured since then and it seems that these criteria are determined arbitrarily and are not based on large database either. Still more research is needed.

Bulgarian territory is considered the core area of golden jackal distribution in Europe with the highest population density (Stoyanov 2013, Spassov and Acosta-Pankov 2019), but morphometric studies, including skulls from Bulgaria, are very scarce and local so far (e.g. Markov et al. 2017, Krendl et al. 2018). In the most comprehensive recent morphometric research in Bulgaria an extensive morphometric data of jackal skulls was analysed (Stoyanov 2019) and this database was used in the present study to suggest and justify new criteria for awarding medals to Golden jackal trophies.

Material and Methods

A total of 210 skulls of Golden jackal, 137 from Bulgaria and 73 from Romania were analysed. The Bulgarian sample comprised of 73 specimens, collected between 1998 and 2007 from 20 different sites all over the country, but most of them coming from three main regions with the jackal's highest population density: Yambol, Veliko Tarnovo and Burgas. It also included 36 skulls, collected by Stoyan Vassilev in the end of 1980s, 12 specimens from the scientific collection of the National Museum of Natural History dating back to the last century, and 18 skulls, collected between 2005 and 2012, measured at a national trophy exhibition in 2013. Most of skulls are with known sex, but 11 skulls with unknown sex were also included. The age of jackals was determined by assessment of upper incise teeth wear (Lombaard 1971) and for some individuals also by counting the annual cementum layers in canines (Klevezel and Kleinenberg 1967). Both methods are reliable enough for the purposes of the study and provide accurate results, with precision up to one year for the first one (Harris et al. 1992, Raichev 2002). The skulls were assigned to three age groups: juveniles, subadults and adults. Juveniles were defined as individuals with fully developed second dentition, but less than 11 months of age, subadults as individuals older than 10 months, when they reach sexual maturity, but less than two years of age, and adults as two years and older. Skulls of juveniles were excluded from further analyses. For comparison 73 skulls from Romania (Angelescu 2004) were included. On each skull two measurements were taken by using digital sliding calliper, maximum length and zygomatic breadth (Fig. 1), corresponding to

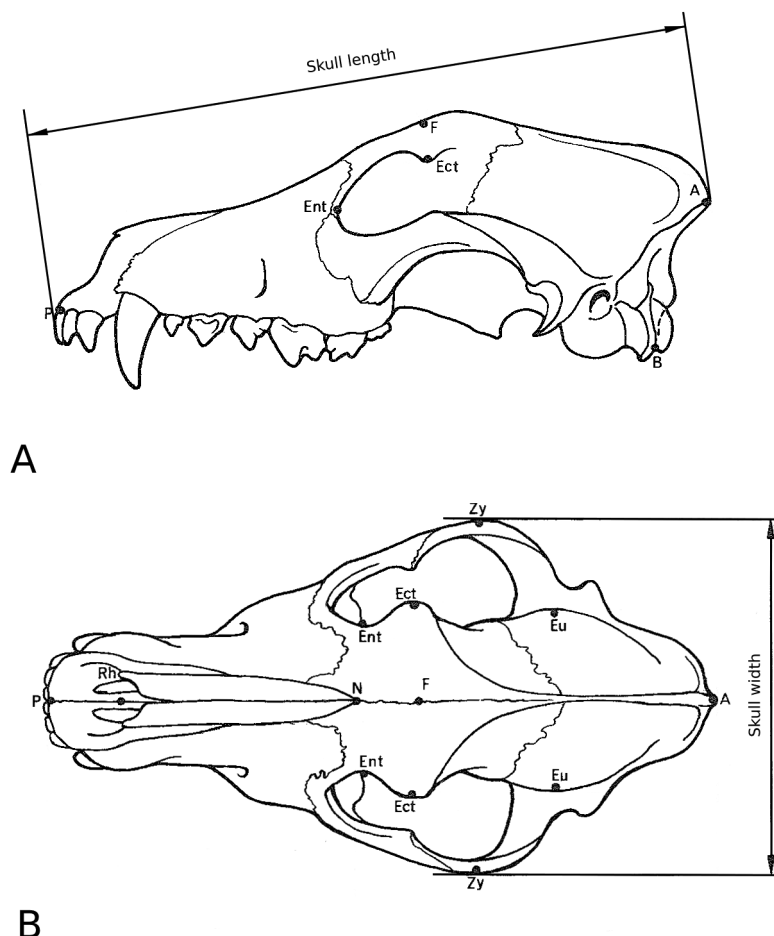


Fig. 1. Measurement parameters for trophy evaluation of carnivore skull (Hromas 1998, Crombrughe et al. 2014, Ninov 2015).

Note: A. *Canis* cranium, left side view; B. *Canis* cranium, dorsal view.

skull length and skull width, accordingly, following the rules for evaluation of carnivore trophies (Hromas 1998, Crombrughe et al. 2014, Ninov 2015). According to these rules, skull length is measured between the foremost part of the teeth and Akrokranium, and skull width is the maximum breadth at the zygomatic arches (Zygion-Zygion). For a detailed description of craniometric measurements of *Canis* skull see von den Driesch (1976). Both

measurements were taken with precision up to 0.1 mm. The CIC score of the trophy in points is the sum of both measurements in centimetres and is calculated with precision up to 0.01 points.

Statistical methods

All measurements and calculated trophy scores were tested for normality by QQ

plot and Shapiro-Wilk test. Distribution of trophy score for all measured skulls was approximated by normal distribution with mean and variance calculated from our sample. All statistical and graphical analyses were performed with R, version 3.6.1 (R Core Team 2019). For some graphics, software package 'lattice' (Sarkar 2008) was employed.

Ethics Statement

The skull samples used in this study were obtained from individuals that died in vehicle collisions, due to natural causes or

as a result of legal hunting. Specimens from Natural history museum and private collections were measured as well. No animal was killed for the purpose of this study.

Results and Discussion

Comparison between Bulgarian and Romanian jackal trophies showed that the two samples had similar distribution (Fig. 2). However, the age of the animals was not known for the Romanian sample, and the presence of several Romanian trophies with a score below 23 points could

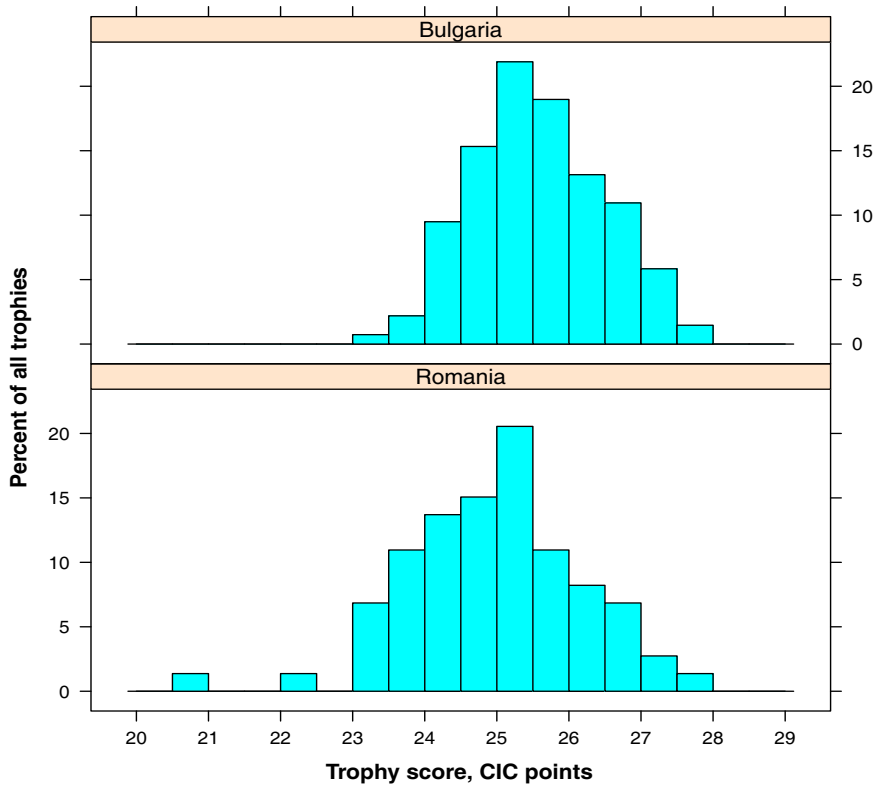


Fig. 2. Distribution of jackal trophies according to their CIC score.

be explained by the age-related differences in size of skulls. Recent morphometric research in Bulgaria (Stoyanov 2019) showed that the differences in shape and size of jackal skulls, as far as they exist, are age-related, but only juveniles, i.e. younger than 11 months, could be easily distinguished. According to the same study, subadult and adult jackals largely overlap in skull size and shape, and sexual dimorphism in jackal skulls is weakly pronounced, with older males having slightly larger skull than females. Hence Romanian sample was excluded from

further analyses. Although subadult and adult jackals differ in zygomatic breadth, they were included in one sample, considering the CIC score of the trophy. Males and females were not divided either, because of slightly pronounced differences in size, but with a large overlap between sexes (Stoyanov 2019).

Shapiro-Wilk test and QQ plot showed that the CIC trophy score did not deviate significantly from normal distribution (Fig. 3). Hence, we can approximate it by normal distribution with mean and variance calculated from our sample.

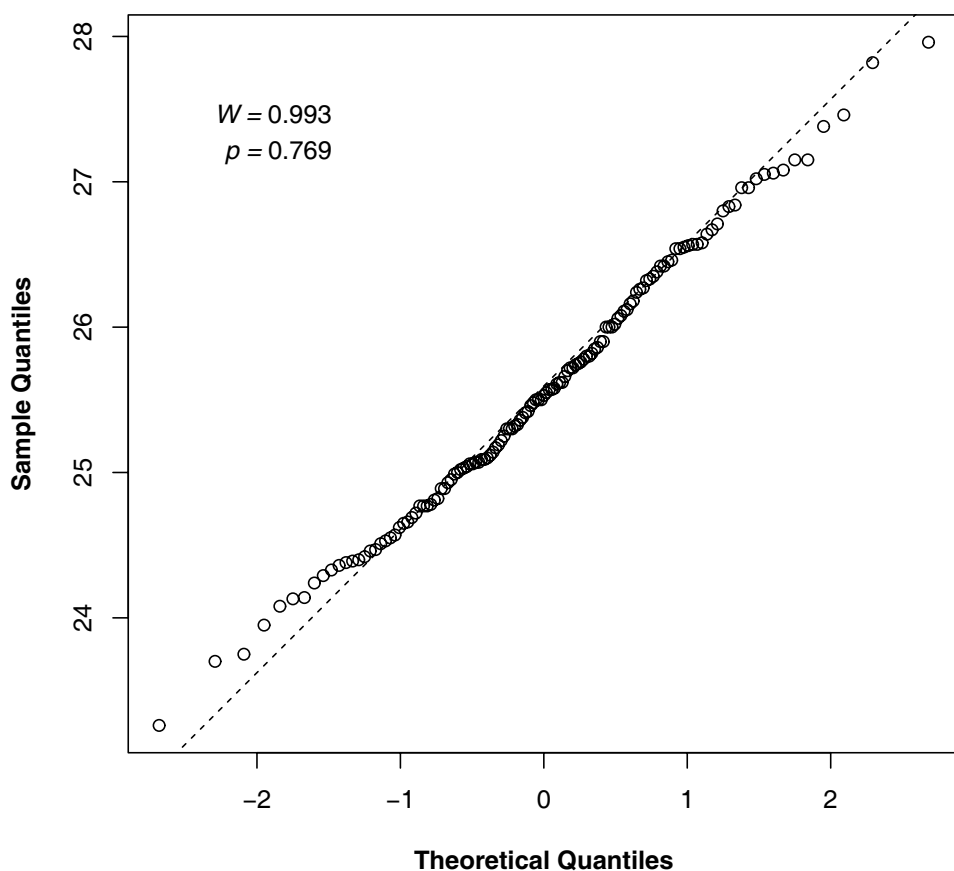


Fig. 3. Tests for normal distribution of CIC trophy score by QQ plot and Shapiro-Wilk test.

Note: W – test statistic, p – level of statistical significance.

The ranking of trophies and the awarding of medals can be compared with the evaluation in each field of activity, e.g. in academic grading, sport competitions etc. It is logical that the strongest 10 % of all trophies are considered the best. On the other hand, the lower limits of the criteria for awarding medals to trophies are usually related to integers or half of integers. During the first hunting exhibition where Golden jackal trophies were evaluated in Novi Sad (1996) and in Plovdiv (2013) with the largest number of evaluated jackal trophies so far, various criteria had been applied for awarding medals decided on an *ad hoc* basis by the evaluation committees (Table 1). According to the criteria used at the Novi Sad exhibition (1996), 6.7 % of jackals from our Bulga-

rian sample would receive a gold medal, 24.6 % – silver and 41.8 % – bronze, or a total of 73.1% of trophies would be awarded medals. According to the criteria proposed by Angelescu (2004), adopted by CIC, and applied at the trophy exhibition in Plovdiv (2013), 31.3 % of trophies would receive a gold medal, 19.4 % – silver and 22.4 % – bronze. Similar distribution of medals was shown for 19 trophies of male jackals from Ukraine, evaluated according to the present CIC criteria, 6 gold, 3 silver and 3 bronze medals, or 63 % of trophies would be awarded medals (Volokh 2018). The percentage distribution of trophy scores within fixed intervals allows us to determine which criteria are most appropriate for jackal trophies (Table 2).

Table 1. Criteria for awarding medals to Golden jackal trophy applied so far.

Hunting exhibition	Medal		
	Bronze	Silver	Gold
Novi Sad, 1996	25.00–25.99	26.00–26.99	27.00+
Plovdiv, 2013	25.00–25.49	25.50–25.99	26.00+

Note: The values in table cells show trophy scores for the respective medal.

Table 2. Empirical and theoretical distribution of Golden jackal trophy scores.

Sample	Trophy score, CIC points				
	25.00–25.49	25.50–25.99	26.00–26.49	26.50–26.99	27.00+
Bulgaria	22.4 %	19.4 %	13.4 %	11.2 %	6.7 %
Romania	20.5 %	11.0 %	8.2 %	6.8 %	4.1 %
Theoretical distribution*	20.6 %	21.5 %	16.5 %	9.4 %	5.5 %

Note: The values in table cells show the percent of all skulls falling within respective interval.

*Normal distribution with mean and standard deviation based on our Bulgarian sample.

According to our results, new criteria for awarding medals should be adopted by CIC. We suggest that gold medal must be awarded to a trophy rated 27.00 CIC points and above, silver – from 26.50 to 26.99 and bronze – from 26.00 to 26.49 (Fig. 4).

If accepted by the CIC, 6.7 % of the analysed skulls in our sample would re-

ceive a gold medal, 11.2 % – silver and 13.4 % – bronze (Table 2), or just over 30 % of all trophies would be awarded a medal. The exact limits for the intervals depend on how many trophies should be awarded medals. If the experts of CIC and evaluation committees decide that more than 70 % of all trophies should be awarded, then the criteria applied in Novi Sad

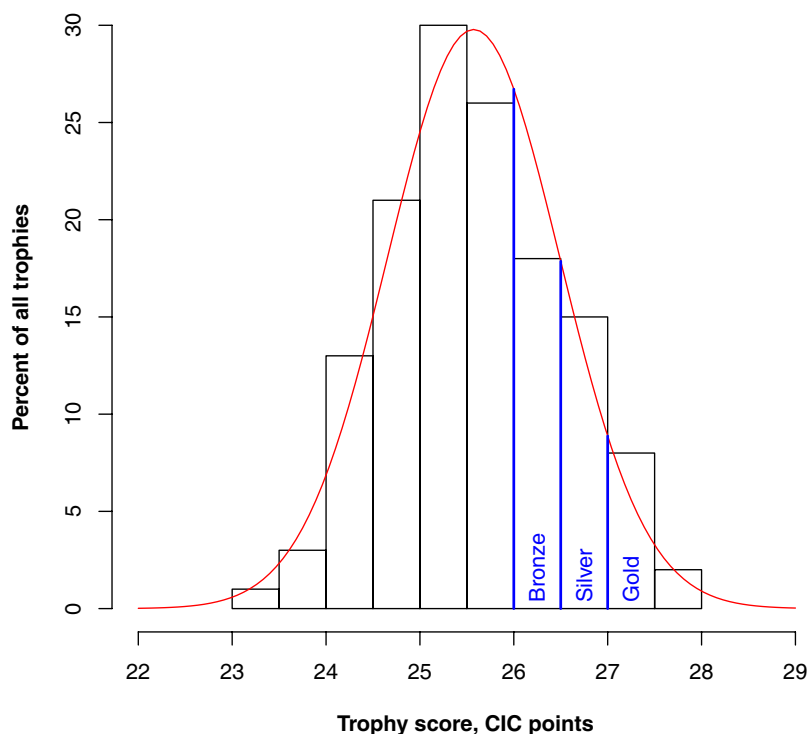


Fig. 4. Suggested new criteria for awarding medals to Golden jackal trophies.

Note: Bars represent the percent of trophies falling within each interval, according to their score in CIC points. The red curve represents theoretical normal distribution with mean and standard deviation calculated about trophy scores from Bulgarian sample.

(1996) could be adopted. According to the criteria used in recent exhibitions, more trophies are awarded a gold medal, than silver and bronze, which is not acceptable. If no more than 35 % of all trophies should be awarded medals, then the suggested criteria in the present study are the most appropriate.

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MILLIMETER LEVEL ACCURACY POINT POSITIONING IN WOODLAND AREA BY USING HYBRID METHOD

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Abstract

The hybrid techniques (rapid static/total station) can be very helpful technology for centimetre and millimetre level positioning in the woodland. Point Positioning with CORS GNSS (Continuously Operating Reference Stations Global Navigation Satellite System) in the woodland is a significant challenge in terms of time saving to obtain high accurate coordinates of the points. The time for integer carrier-phase ambiguity solution takes approximately one-hour or more time for point positioning under the woodland with GNSS surveys. In this study, hybrid techniques for estimating point coordinates under woodland has been performed, which gives the positioning results with millimetre and centimetre level accuracy and nearly 30 minutes are required to provide the new point location in the woodland. The proposed method may also have practical usage for forest-woodland areas applications with desired accuracy at mm level, which is reached in a short observation time. A fieldwork has been performed to obtain coordinates of the point (K) in woodland with CORS GNSS system and supplementary measurements by establishing two control points (T_1 , T_2) observed by rapid static method located at the border of the woodland. On the other hand, the coordinates of point (K) have been also gained by using a static method (3 hours observation). The coordinate differences (static-hybrid) show that a satisfactory solution for woodland is reached at mm level in a short observation time.

Key words: forest, Global Navigation Satellite System, surveying, Virtual Reference Station.

Introduction

Forest canopy is one of the most significant restricting components in utilizing the *Global Navigation Satellite System* (GNSS) for positioning and mapping. However, forestry and natural resources applications are also among the largest users of GNSS technology. The use of GNSS in forestry has become increasingly established particularly in the field of logistics, inventories for surveying. However, the uninitiated forest user takes it for granted that GNSS will always work to the

same level of accuracy in any location, while the more critical foresters assume on the other hand, that GNSS cannot possibly function properly anywhere under the canopy of forest trees and reject it for this reason. The impacts of forest can essentially debase the precision and, accuracy of GNSS positions. The GNSS signals are influenced by the canopy and this obviously influences the nature of the processed position. Forest canopy effects on the GNSS signal include obstruction, attenuation and reflection. The signal attenuation can make it very difficult for

a GNSS receiver to track the signals. At some points, the receiver will not be able to track the signal at all and the effect will be the same as if the signal has been obstructed. Even if the signal can be tracked, some receivers will have difficulty for accurately measuring pseudo ranges. There are a lot of factors caused by forest conditions which can influence positioning accuracy. Forests are a barrier for signal propagation so the final radio wave is weak and the reflection causes an elevated signal-to-noise ratio, which is caused by the so called multipath effect. The base idea of multipath is strictly connected to signal reflections from objects located near the receiver, which ultimately causes an error in distance measurements. There are many software and hardware solutions to weaken this effect, however it still does not solve the strong forest influence. Additionally, the multipath effect is multiplied by high moisture and the presence of leaves. The forested environment create many obstructions that produce cycle slips in the satellite signals for each observation for the stations. High density sites, tree species, satellite constellation and observation times, are important factors for accurate positioning. When compared to open sky conditions, leaves decrease a number of visible satellites, and hence geometry (PDOP value) is deteriorating. PDOP predicts the accuracy of positions relative to satellite geometry. A low PDOP indicates a higher probability of position accuracy. A high PDOP indicates a lower probability of accuracy. In dense forest where PDOP is relatively low (around 2) the accuracy is really low. It is generally caused by multipath effect signal loses-not PDOP value. The short observation times (RTK and CORS) may not have provided enough time in the forested environment to determine a fixed ambiguity resolution.

There are numerous studies concentrating on positioning under forest canopies utilizing different GNSS devices and processing techniques, and the results show that a dense forest canopy can lessen the accuracy of the GNSS instruments. In these situations, the surveys were gained during static sessions of varying length, and the positioning accuracy fluctuated from a few centimetres to several meters, depending on the instrumentation, length of data observation period, and processing (Kaartinen et al. 2015, El-Rabbany 2006, Hoffmann-Wellenhof et al. 2008, Wright et al. 2017, Brach and Zasada 2014).

Fast static, also known as rapid static has similar concept with traditional static surveys. The difference is the time durations of the GNSS observations. Rapid static observations range from 8–30 minutes. The observation times will be based on the site conditions and satellite signals. Rapid static surveying is ideal for many engineering surveys and is halfway between static and kinematic procedures. This method is accurate and economic even there are many points to be surveyed. It is ideally suited for short baselines where systematic errors such as atmospheric, orbital, etc. may be regarded as equal at all points and so differenced out. It can be used on large lines but may require longer observation periods due to the erratic behaviour of the ionosphere. If the observations are carried out at night when the ionosphere has more stable times that may be reduced. This procedure is similar to static surveying, except that one receiver always remains on a control station while the other(s) are moved progressively from one unknown point to the next. An observation session is conducted for each point, but the sessions are shorter than for the static method. The rapid static procedure is suitable for observation baselines up to

20 km in length and at good observation conditions. Rapid static positioning can also yield accuracies approximately $\pm$ (3 to 5 mm +1 ppm). GNSS receivers reduce the time required at each station in a rapid static survey due to the increased number of visible satellites and improved satellite geometry. If during the observations the surveyor notices high RMS or other problems, then the surveyor should make and record additional measurements. These additional measurements allow bad measurements to be discarded during the network analysis. Additional measurements at a different time with a different satellite constellation may be necessary (El-Rabbany 2006, Hoffmann-Wellenhof et al. 2008, Pirti et al. 2010, Ghilani and Wolf 2012, Bakula 2013, Pirti et al. 2016).

Total Station is the term applied to modern surveying instruments that incorporate an Electronic Distance Measurement (EDM), a digital theodolite and a microprocessor. This combination of components provides the capability of electronically making simultaneous slope distance and horizontal and vertical angle measurements. Total stations measure very rapidly and display the data automatically in digital format. The microprocessors within the total station display the horizontal and vertical components of sloping lines in real time. Total stations can also be connected to data collectors that enable the automatic recording of field measurements for further processing and plotting capabilities. Robotic total stations (Reflectorless) allow the operator to control the instrument from a distance via remote control and surveys the data by reflectorless mode. This eliminates the need for an assistant staff member as the operator holds the reflector and controls the total station from the observed point (Ghilani and Wolf 2012).

This study investigates the hybrid (rapid static/total station) method achievable accuracy in forest area. The aim of this study is to examine the applicability of hybrid system (GNSS (especially for rapid static method) and total station) for computing the position of a point (K) placed under the forested area, according to short observation duration (approximately 30 minutes) and the required horizontal accuracies (± 1 cm and below). Two observation stages were performed at the same time: 1) GNSS observations rapid static (about 20 min), and 2) total station surveys (Topcon OS Total Station). This study also intends to supply an economical and practical measurement method to gain accurate point positioning under the forest environments for forestry applications. In this study, it is emphasized how long the solution time of the integer ambiguity and its validity can be camouflaged among the difficulties encountered in determining the location in forest and wooded regions. In this, the hybrid method (Fast Static + Robotic Total Station) which I suggested as an alternative technique is explained. In previous studies, both static and kinematic methods have been tried to determine the position with GPS, GPS + GLONASS and the obtained position accuracy has been in the range of $\pm$ (2–15) cm. In addition, in order to achieve this location accuracy (fixing Integer ambiguity), it has to be waited between 1–3 hours in the forest and wooded regions. With this proposed hybrid method, an accuracy of between centimeters and millimeters can be easily reached in the range of about 20 to 30 minutes. This hybrid method provides a great advantage in both economy and time saving in terms of engineering applications; it is presented as an alternative technique to the world of science (Parkinson and Spilker 1996, El-Rabbany 2006,

Hoffmann-Wellenhof et al. 2008, Pirti et al. 2010, Ghilani and Wolf 2012, Brach and Zasada 2014, Pirti et al. 2016).

Materials and Methods

Four temporary test points (T_1 , T_2 , T_3 , and T_4) were established to calculate the coordinates of the point (K) under the woodland, located at the Yildiz Technical University, Campus of Davutpaşa, Istanbul, Turkey. The specification of the project area of interest is that it is located at the border of the forested environment and open sky. To eliminate the negative effects (signal attenuation, diffraction, multipath and signal losses), rapid static

GNSS surveys (Topcon Hiper SR receivers) have been performed at the open area side of the border aiming at providing observations accurately to enhance the communications of the GNSS receiver with satellites from two points. Besides, terrestrial measurements have been performed simultaneously by using the other two points (T_3 and T_4). The point (K), which coordinates are being computed was located in the woodland, and terrestrial measurements and static GNSS surveys were also performed (3 hours). The project area selected in the woodland is illustrated in Figure 1 (Pirti et al. 2016).

In this project, static and rapid-static GNSS observations were processed with post-processing computation based on



Fig. 1. Network of reference stations with study area.

İSKİ-CORS network, which covers the project area. İSKİ-CORS Network, which coverage area is Istanbul, was established by Istanbul Water and Sewerage Administration (İSKİ) and involves 10 permanent stations. The İSKİ-CORS Network is an active GNSS Network and transmits the correction data to all users completely real-time via the data links and communication systems. The system consists of a number of automated GNSS tracking stations, which continuously record carrier phase and pseudo range measurements for all GNSS satellites in view. Figure 1 shows the coverage area of İSKİ-CORS network, which contains the boundary of the province of Istanbul. İSKİ-CORS network can also supply VRS, FKP and MAC corrections (Pirti et al. 2016).

Four points in all were located around

the woodland, namely T_1 , T_2 , T_3 and T_4 (Fig. 2 and Fig. 3a). Simultaneous surveys were performed from the field site to shorten the measurement time, and then, within about 30 minutes the GNSS (rapid-static/20 minutes) and total station measurements (10 min) finished. To calculate the coordinates of K , placed under the woodland, coordinates of T_1 and T_2 were determined by rapid-static GNSS surveys. The measurements on the two points (T_1 and T_2) were performed in the rapid-static mode with at least 20 min of observation time (total 6 hours). The minimum elevation cut-off angle and record interval were 10° and 30 seconds, respectively. All of the GNSS data processing and network adjustments were conducted using Topcon MAGNET Tools Software. In the adjustment procedure,



Fig. 2. Points in the project area: a) Point T_1 , T_2 , T_3 and T_4 ; b) Point K in the study area; c) Sky visibility from point K .

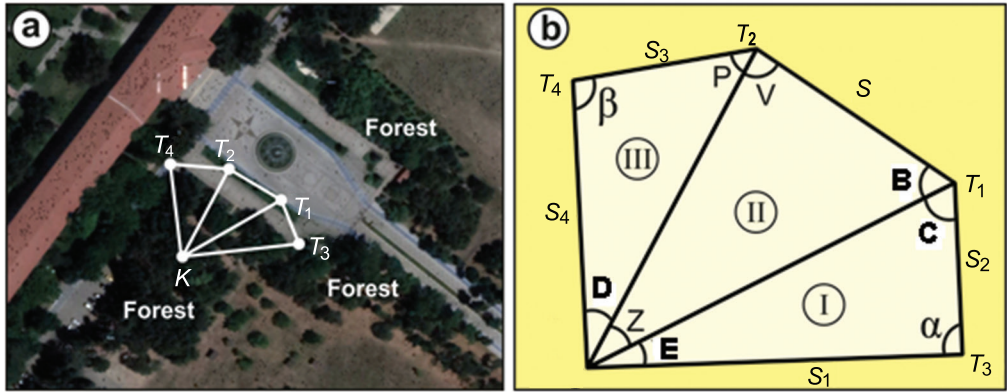


Fig. 3. Four points located near the woodland (a) and calculation design (b).

the ITRF 2008 coordinates of the points KCEK and PALA; İSKI-CORS reference stations, (approximately 10 km far away from the project area) were taken fixed (Table 1). To check the coordinates of K, static GNSS observation was performed during 3-hour observation time. A three hour-static GNSS survey at point K

(under the forested area, see Fig. 3) was computed by using PALA and KCEK) with commercial post-processing GNSS software, Topcon MAGNET Tools, see Table 1. Coordinates of T_3 and T_4 were computed using terrestrial surveys from two triangles (Triangle I and III, see Fig. 3b).

Table 1. Coordinates and their standard deviations of the three points (3 hours static GNSS surveys).

Point No	X, m	Std., mm	Y, m	Std., mm	h, m	Std.,mm
PALA	4,550,678.133	Fixed	412,882.267	Fixed	170.543	Fixed
KCEK	4,541,595.806	Fixed	397,337.575	Fixed	122.893	Fixed
T_1	4,543,944.263	4	406,700.460	3	113.434	8
T_2	4,543,955.951	4	406,685.336	3	113.892	8
T_3	4,543,928.027	4	406,702.052	3	113.752	8
T_4	4,543,949.683	4	406,663.259	3	113.548	8
K	4,543,920.870	5	406,663.963	4	112.860	10

Note: h is ellipsoidal height.

Figure 3b also shows the survey sketch. Even though one triangle is enough to compute the point coordinates, namely K, placed under the woodland, the model is built for solving the problem using three triangles, not only to control the measurements surveyed at field site but also to control the coordinates of the points, namely T_3 , T_4 and K which angles

(directions) or distances are measured. The above-mentioned angular variables seen in Figure 4b were computed for each triangle using equations (1) and (2). The equations were generated according to Triangle I (Pirti et al. 2016).

$$\alpha = \arccos\left(\frac{S_1^2 + S_2^2 - S_3^2}{2 \cdot S_1 \cdot S_2}\right), \quad (1)$$

$$t = \arctan\left(\frac{dy}{dx}\right), \quad (2)$$

where: α is one of the interior angles of Triangle-I and β is one of the interior angles of Triangle-III were measured. S_1 , S_2 and S_3 , S_4 indicate measured horizontal distance of the Triangle-I and II, respectively. t is the azimuth angle. dy and dx are departure and latitude values, which are y

and x components of a line in a rectangular grid system, respectively.

Equation (1) is the cosine rule for finding angles and Equation (2) is the formula of finding the azimuth, which is defined as a horizontal angle measured clockwise from the north. Table 2 illustrates the coordinate's computation procedure of point K . The formulation has been given for Triangle I and III (Pirti et al. 2016).

Table 2. Formulas for computing K coordinates.

Parameters	T_3	K from Triangle I
Azimuth	$t_{T_3T_2} = t_{T_1T_2} - X$	$t_{T_3K} = t_{T_1T_2} - \alpha$
Coordinates	$Y_{T_3} = Y_{T_1} + S_{T_1T_3} \cdot \sin t_{T_1T_3}$	$Y_K = Y_{T_3} + S_{KT_3} \cdot \sin t_{T_3K}$
	$X_{T_3} = X_{T_1} + S_{T_1T_3} \cdot \cos t_{T_1T_3}$	$X_K = X_{T_3} + S_{KT_3} \cdot \cos t_{T_3K}$
	T_4	K from Triangle III
Azimuth	$t_{T_4T_2} = t_{T_2T_1} + V + P$	$t_{T_4K} = t_{T_2T_1} + \beta$
Coordinates	$Y_{T_4} = Y_{T_2} + S_{T_2T_4} \cdot \sin t_{T_2T_4}$	$Y_K = Y_{T_4} + S_{KT_4} \cdot \sin t_{T_4K}$
	$X_{T_4} = X_{T_2} + S_{T_2T_4} \cdot \cos t_{T_2T_4}$	$X_K = X_{T_4} + S_{KT_4} \cdot \cos t_{T_4K}$

Table 2 shows X and Y horizontal coordinates, S horizontal distance, V interior horizontal angle in triangle II, α interior horizontal angle in Triangle I, P interior horizontal angle and β interior horizontal angle in Triangle III. Equation (1) and Equation (2) were used to calculate the interior angles of generated triangles and the azimuth of related line ($T_1 T_2$). All the others were computed in the same way.

Results

To supply the available condition in this computation strategy, visibility between points $T_3 - T_1$, $T_3 - K$ and $T_4 - T_2$, $T_4 - K$ should be provided.

The terrestrial surveys performed with robotic total station presented in Table 3 were performed to obtain the horizontal directions, vertical directions and horizon-

Table 3. Total station surveys to compute the coordinates of point K .

Station No	Target No	Horizontal angle, grad	Vertical angle, grad	Horizontal length, m	Explanation
T_3	K	0.0000	100.5408	38.751	$t_K = 1.485$ m
$i = 1.551$ m	T_1	105.6120	98.8956	16.314	$t_{T_1} = 1.508$ m
T_4	T_2	0.0000	100.6872	22.950	$t_{T_2} = 1.560$ m
$i = 1.460$ m	K	116.0430	103.0050	28.827	$t_K = 1.485$ m

Note: i – instrument heights, t – target heights.

tal lengths. And then the three triangles were checked by using the sum of the an-

Table 4. Angle computations to check the triangles (Fig. 4).

Triangle		
I	II	III
$\alpha=105.6124$ grad	$Z=28.8784$ grad	$D=36.3917$ grad
$E=24.4637$ grad	$V=92.9377$ grad	$P=47.5651$ grad
$C=69.9239$ grad	$B=78.1839$ grad	$\beta=116.0432$ grad
$\alpha+E+C = 200$ grad	$Z+V+B = 200$ grad	$D+P+\beta = 200$ grad

GNSS rapid-static surveys were conducted at T_1 and T_2 simultaneously. Points T_1 and T_2 were surveyed by rapid-static method by using İSKİ-CORS network (Fig. 2), and then the coordinates of these

points were determined. The Position dilution of precision (PDOP) values for T_1 and T_2 were between 1.8 and 3.8, see figures 4 and 5. The elevation mask is 10 degree, and record interval is 30 seconds.

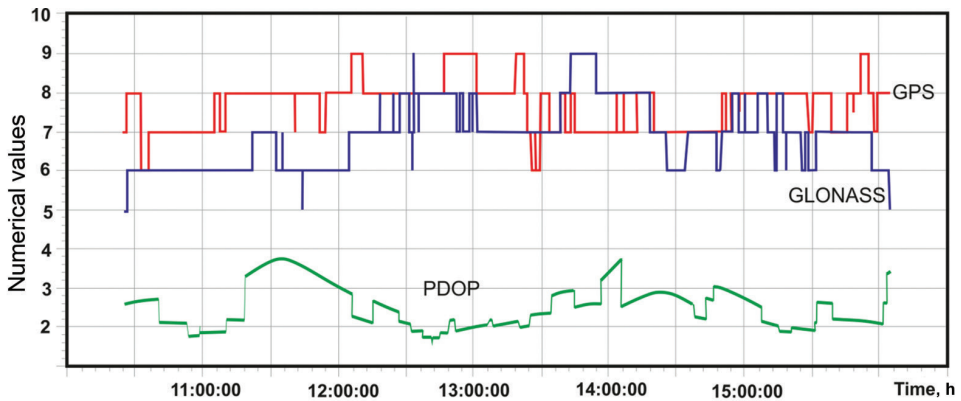


Fig. 4. PDOP and number of satellites for point T_1 .

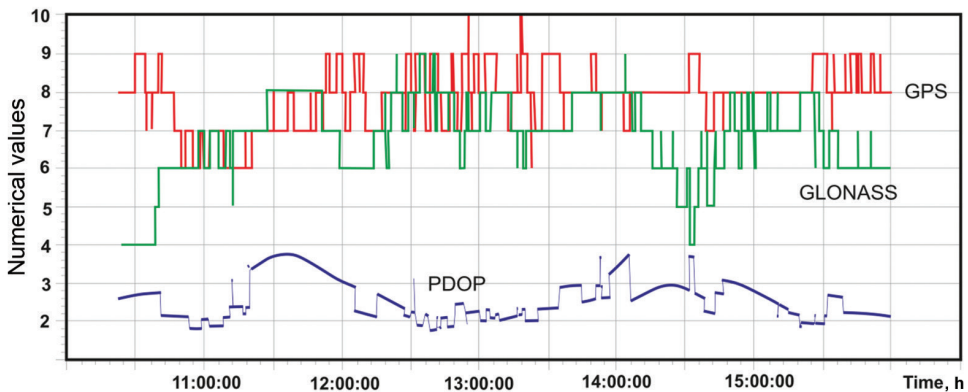


Fig. 5. PDOP and number of satellites for point T_2 .

The visible satellite numbers for T_1 and T_2 were between 13 with 9 GPS+4 GLONASS and 16 with 10 GPS+6 GLONASS; between 13 with 5 GPS+8 GLONASS and 17 with 9 GPS+8 GLONASS respectively (figs 5 and 6). There are accuracy improvements associated with enhancing GNSS; by far the greatest benefit is improved visibility of satellites. The provided coordinates depending on these survey

situations were computed as shown in figures 6 and 7.

Figures 6 and 7 show the comparison of static with rapid static results for point T_1 and T_2 . The standard deviation values of the differences (T_1 and T_2 horizontal coordinates) were also less than 5 mm in general for X and Y coordinates. The mean values of the differences were also less than 6 mm for X and Y coordinates.

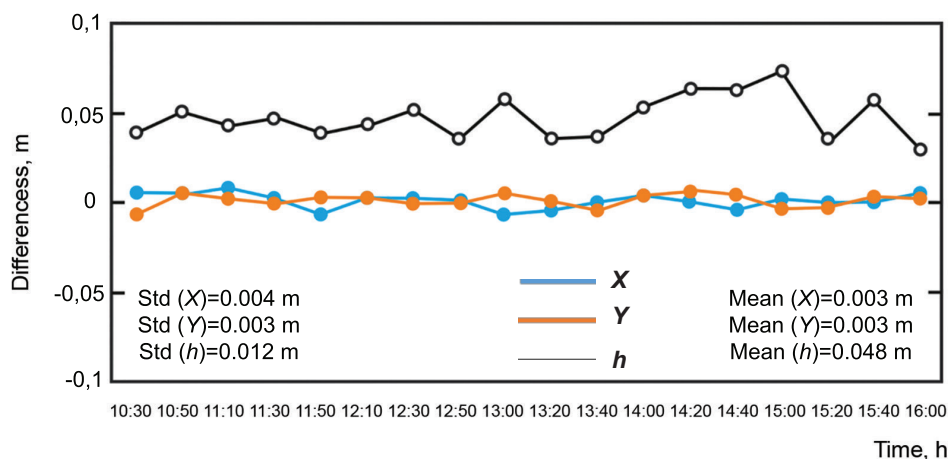


Fig. 6. Compare static results with rapid static results (20 minutes) for point T_1 .

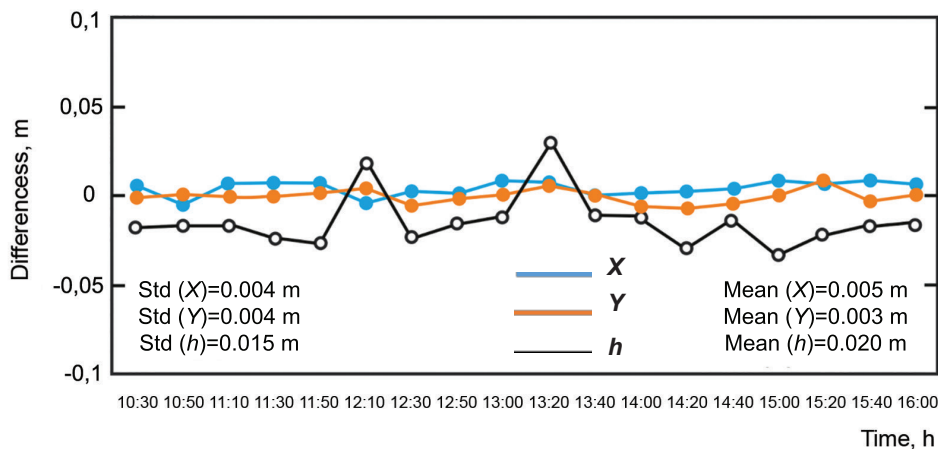


Fig. 7. Compare static results with rapid static results (20 minutes) for point T_2 .

The height component was however less consistent with changes ranging between about 10 mm up to 75 mm.

Table 5 shows the computation of the coordinate results for point *K* using hy-

brid method (rapid static and total station techniques). Triangle I, triangle II, triangle III were used for these computations. T_1 , T_2 , T_3 and T_4 could be used to help solve these problems.

Table 5. Computation results of coordinates.

Parameters	T_1	K from Triangle II
Azimuth	$t_{T_1T_2}=341^{\circ}.8858437$	$t_{T_1K}=263^{\circ}.7019437$
	$S_{T_1T_2}=19.114$ m	$S_{T_1K}=43.350$ m
Coordinates	$Y_{T_1}=406700.460$	$Y_K=406663.968$
	$X_{T_1}=4543944.263$	$X_K=4543920.864$
	T_2	K from Triangle II
Azimuth	$t_{T_2T_1}=141^{\circ}.8858437$	$t_{T_2K}=234^{\circ}.8236437$
	$S_{T_2T_1}=19.114$ m	$S_{T_2K}=41.079$ m
Coordinates	$Y_{T_2}=406685.336$	$Y_K=406663.968$
	$X_{T_2}=4543955.951$	$X_K=4543920.864$
	T_3	K from Triangle I
Azimuth	$t_{T_1T_3}=193^{\circ}.7780437$	$t_{T_3K}=288^{\circ}.1656437$
	$S_{T_1T_3}=16.314$ m	$S_{T_3K}=38.751$ m
Coordinates	$Y_{T_3}=406702.0519$	$Y_K=406663.968$
	$X_{T_3}=4543928.027$	$X_K=4543920.865$
	T_4	K from Triangle III
Azimuth	$t_{T_2T_4}=282^{\circ}.3887294$	$t_{T_4K}=198^{\circ}.4319294$
	$S_{T_2T_4}=22.950$ m	$S_{T_4K}=28.827$ m
Coordinates	$Y_{T_4}=406663.2586$	$Y_K=406663.969$
	$X_{T_4}=4543949.683$	$X_K=4543920.865$

When the accuracies were compared with static GNSS surveys in both coordinate components, computation showed differences in Y and X coordinates up to 0.273 and 0.170 m, respectively. They indicated that there were significant differences in the horizontal and vertical coordinates at difficult points. The results derived from this study show that with an integrated (hybrid) survey methodology within quite short duration of the survey

(about 30 min), measurements within ± 1 cm can be guaranteed, see tables 6 and 7. Figures 8, 9 and 10 show the comparison of static with hybrid (rapid static/total station) results. The standard deviation values of the differences (K horizontal coordinates) were also less than 5 mm in general for X and Y coordinate components. The mean values of the differences were also less than 6 mm for X and Y coordinates.

Table 6. The obtained point K coordinate results by using three different methods.

Surveys	K		
	Y, m	X, m	h, m
Post Processing Static GNSS (PPSGNSS)	406663.963	4543920.870	112.86
Hybrid method (Total Station+Rapid Static)	406663.968	4543920.865	112.877
CORS VRS	406663.695	4543920.700	112.809

Table 7. Comparison of the obtained coordinate results for point K.

Methods	ΔY , m	ΔX , m	Δh , m
PPSGNSS-Hybrid Method	0.005	0.005	0.017
PPSGNSS-CORS VRS	0.268	0.170	0.051
Hybrid Method-CORS VRS	0.273	0.165	0.068

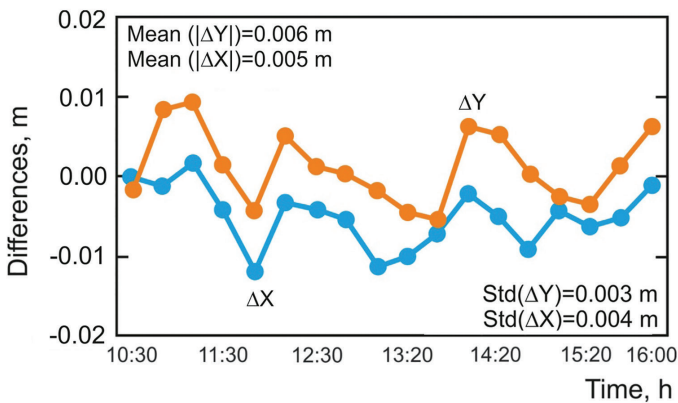


Fig. 8. Comparison of static with hybrid method results (X and Y coordinate differences of point K) by using point T_1 .

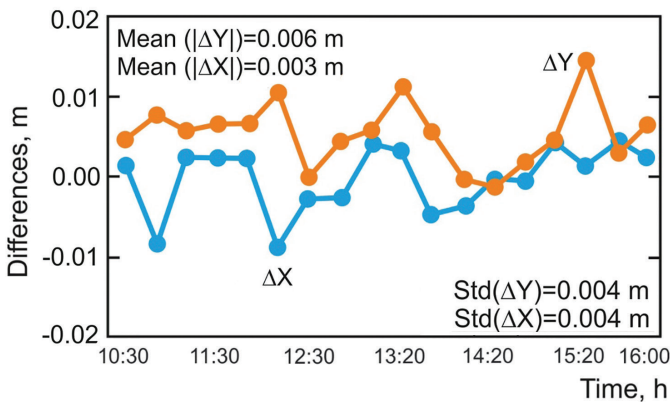


Fig. 9. Comparison of static with hybrid method results (X and Y coordinate differences of point K) by using point T_2 .

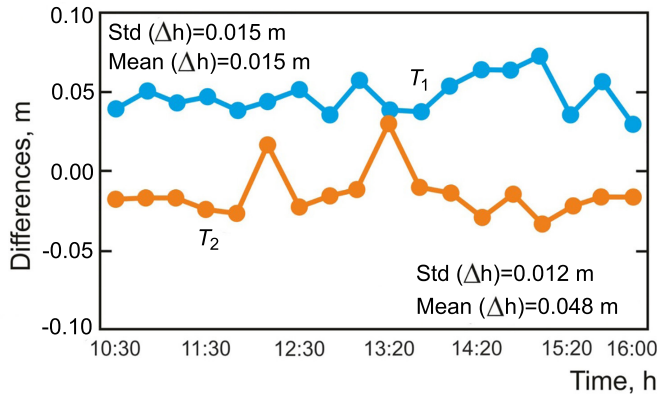


Fig. 10. Comparison of static with hybrid method results (h coordinate differences of point K) by using points T_1 and T_2 .

The hybrid method derived horizontal coordinates were very consistent, with changes ranging between a few millimetres up to 14 mm (figs 8 and 9). The height component was however less consistent with changes ranging between 40 mm up to 75 mm (Fig. 10).

Conclusion

The points, which are located under trees, are blocked from good satellite observations. The GNSS points, which are located in more open areas, where good measurements to unobstructed satellites can be made. This method is also effective when satellite signals are poor or unavailable because of canyons, steep north slopes, tunnels, dense tree canopy or stems, and similar situations. This paper shows that rapid-static survey can be used for woodland or forest surveys (obtaining accuracy mm level), although a common obstacle, sky blockage, hinders its full effectiveness. However, this problem can be overcome if supplemented by conventional survey

techniques. In this study, the CORS-RTK (VRS/FKP) required approximately 60 minutes to survey a point (K). The hybrid (integrated) methodology provides accurate coordinate solutions by resection computation method to obtain the coordinates of point (K). The hybrid method of surveying a point took approximately 30 minutes in the field. For a point (K under the woodland) the horizontal plane coordinates differed up to ± 1 cm. Therefore, it appears that in difficult environments (woodland), measurements with ± 1 cm and below can be guaranteed in all situations by using this hybrid method. In the future the best way to improve my research would be measure more points in real forest and check the accuracy of GNSS positioning using CORS VRS.

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CLASSIFICATION OF THE FOREST VEGETATION OF ETROPOLSKA STARA PLANINA MT. IN BULGARIA

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Abstract

A new classification approach of the forest vegetation in Etropolska Stara Planina Mt. is applied in the paper. The dominant and most widespread forest stands in the region have been investigated. They are represented mostly by *Fagus sylvatica*, *Carpinus betulus*, *Quercus petraea*, *Betula pendula*, *Alnus glutinosa*, etc. In total, 71 relevés collected according to the Braun-Blanquet's methodology have been analyzed. As a result, five associations and three forest communities without phytosociological rank were identified. They were classified into four alliances and two classes: *Carpino-Fagetea sylvaticae* with *Luzulo-Fagion sylvaticae*, *Fagion sylvaticae* and *Carpinion betuli*, and *Alno glutinosae-Populetea albae* represented by the alliance *Alnion incanae*. The vegetation of the studied area demonstrates high similarity with the mesophilous to mesohygrophilous deciduous forests typical to Southeastern and Central Europe.

Key words: *Alno glutinosae-Populetea albae*, *Carpino-Fagetea*, Central Balkan Range, forest stands, syntaxonomy.

Introduction

According to the geobotanical zoning of Bulgaria (Bondev 2002), the main forest stands in Etropolska Stara Planina are dominated by *Fagus sylvatica*, *Fagus moesiaca* (considered as morphotype within *F. sylvatica*, Tutin and Akeroyd 1993, Denk 1999, etc.), *Quercus petraea* (treated as *Quercus dalechampii* in the Bulgarian phytocenological sources), *Carpinus betulus*, and more limited of *Betula pendula*.

The forest vegetation of the region has not been sufficiently well investigated so far. Only few papers (Dodev 2016, Lyubenova and Dimova 2000, Iliev 1988)

were found. Their purpose is not in the field of forest syntaxonomy or classification. Therefore, they affect the current research rather indirectly. Comparatively detailed information about the main forest phytocoenoses spread in the region is presented by Bondev (1991) in the vegetation map (1:600 000) of Bulgaria, but they were classified according to the Dominant approach (Velchev et al. 1969). The studied area was also object of some broader researches of vegetation types in Bulgaria. An ecological-phytocoenological characterization of beech forests in the upper forest belt of the Central Balkan Range has been done by Marinov et al. (1987). This study includes information

about their status, species composition, ecological peculiarities and distribution. Focused on the beech forests is also the work of Marinov et al. (1961) in the field of forest ecology and forestry practices. Species composition and distribution of the oak forests in the country have been published by Radkov and Minkov (1963). The work of Bondev et al. (2000) contains data about the vegetation and soil diversity of the Balkan Range. There are also some palynological and paleobotanical studies (Filipovich et al. 1997, 1998, Atanassova 2007) containing valuable information about the origin and historical background of the forest vegetation in Stara Planina Mt.

Research according to the Braun-Blanquet's methodology is almost missing in the region. Only the beech forests occupying considerable areas in the Balkan Range, respectively the studied region, were object of special research interest (Tzonev et al. 2006, Tzonev 2011). A specific type of forest vegetation distributed in Etropoleška Stara Planina is the birch forests. Their syntaxonomy has not been studied in Bulgaria, excluding only one research, which deals with the birch forests distributed in some areas along the timberline in the Central Balkan Range (Nikolov and Dimitrov 2015). These forests are better investigated in some other European countries (Theodoropoulos et al. 2003, Exner and Willner 2004, Šilc et al. 2008). The region has a well-developed river network, which also favours development of alluvial forests dominated by *Alnus glutinosa* and some *Salix* spp., as well. Syntaxonomically, they are not yet investigated in the region and either on a national level. Only the floodplain (longoz) vegetation, which includes similar phytocoenoses, has been studied according to the Braun-Blanquet's methodology in

Bulgaria until now (Soó 1957, Pavlov and Dimitrov 2002). These forests and their syntaxonomy have been studied in other European countries and on European level (Douda 2008, Sburlino et al. 2011, Douda et al. 2015).

The main aim of the current research is a syntaxonomic investigation of forest vegetation in Etropoleška Stara Planina according to the phytosociological methodology of Braun-Blanquet (1964).

Material and Methods

Study area

The current study area is located in Western Bulgaria. It falls within the boundaries of the Central Balkan Range from the Arabakonak Pass to the western border of the Central Balkan National Park. It encompasses an area of 476 km² including the whole Etropoleška Stara Planina and the most western part of Zlatishko-Tetevenska Stara Planina (Fig. 1). The region is typically mountainous with a narrow and monolithic main ridge, which is characteristic to the central parts of the Balkan Range. It has a distinct asymmetric profile with short and steep southern slopes and comparatively longer northern slopes, also with steeper parts and rocky rims (Penchev et al. 1989). The main geological units are Paleozoic crystalline metamorphic and magmatic rocks and also Mesozoic and Neozoic sediment rocks. The majority of bedrock types are acidic and with siliceous content (Aleksiev 2002). The highest peaks are Svishti Plaz (1888 m a.s.l.), Mara Gidiya (1790 m a.s.l.) and Etropoleška Baba (1787 m a.s.l.). The soil cover is formed mainly by *Dystric* and *Eutric Cambisols* and *Gray Luvisols* (Ninov 2002). The river network is formed by

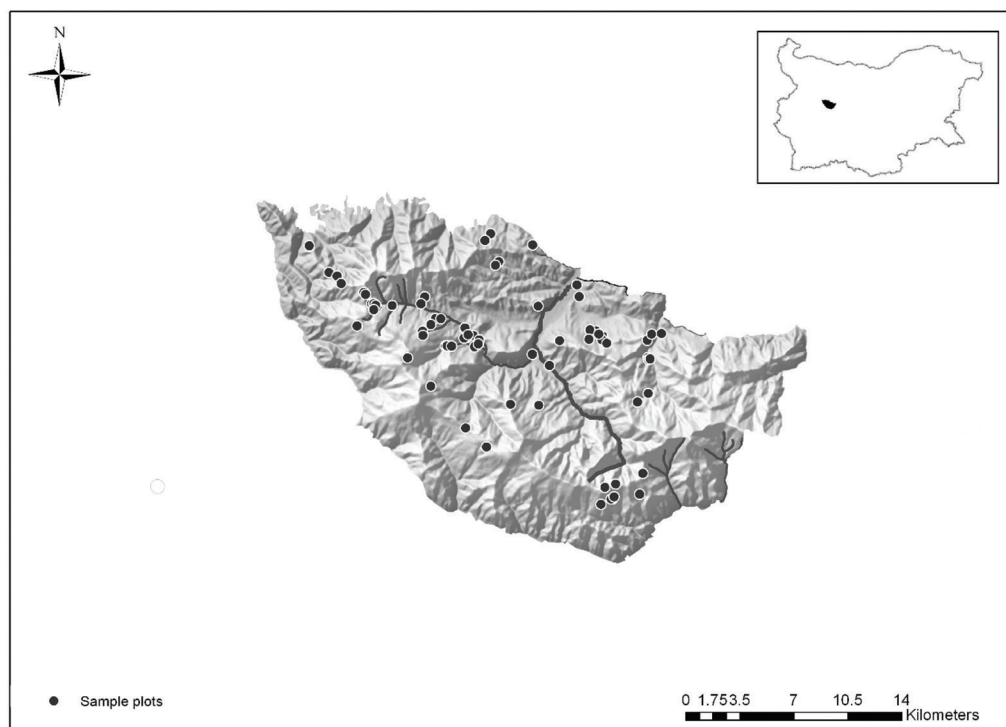


Fig. 1. Study area map with the locations of sample plots (relevés).

the Malak Iskar River and its tributaries, which cross the whole territory and form so-called Etropole Valley Extension (Stefanov 2002). The climate falls mainly in two climatic regions - the temperate-continental (in lower parts) and the mountainous (in higher parts) (Velev 2002). According to the closest climatic station situated on Murgash Peak (1687 m), the average annual temperature is 3.4 °C with highest average temperatures in August (12.4 °C) and lowest in January (-6.1 °C) (Kyuchukova et al. 1983). The average annual sum of rainfall is 882 mm (max. 130 mm in June and min. 44 mm in February). The highest snow cover is registered in January-March (Koleva and Peneva 1990). Despite the comparatively small area, there is great diversity of forest phytocoenoses in the region (see Bondev 1991). Forest

vegetation occupies most of area with significant dominance of *Fagus sylvatica*. The value of the region is emphasized by many protected areas established especially to preserve some old growth forests, as well as landscapes of scenic beauty, waterfalls and rich biodiversity. Such areas are 'Batchishte', 'Belikata', 'Pantata', 'Manastir Sv. Troitsa' and the natural landmarks 'Grohotaka', 'Elaka', 'Varovitec', 'Kozi dol', 'Rudinata'. Especially 'Belikata' is a unique area to Bulgaria because it has been designated (Order № 754/13.08.1981) to protect rare for the country natural forests of *Betula pendula*. Small parts of the mountain are also included in Natura 2000 sites: BG0001043 Etropole-Bailovo (SCI) 'BG0001493 Tsentralen Balkan Buffer' (SCI) and 'BG0002128 Tsentralen Balkan Buffer' (SPA).

Methods

Vegetation sampling was done in 2017–2018 according to the Braun-Blanquet's methodology (Braun-Blanquet 1964, Mueller-Dombois and Ellenberg 1974). In total, 71 relevés were collected. Their plot sizes vary between 80 and 400 m². Minimal distance between plots was 200 m. Cover-abundance values were estimated according to the 9-degree scale and its transformation (Westhoff and van der Maarel 1978, van der Maarel 1979). The cluster analysis was performed using the SYN-TAX computer software (Podani 2001). The average-linkage method UPGMA was used as sorting strategy. The floristic similarity between relevés in the dissimilarity matrix was calculated by using the Horn's index (Horn 1966). Diagnostic species of each cluster were determined using JUICE 7.0 (Tichý 2002). The fidelity of each species to each cluster was calculated using the phi coefficient of association based on presence/absence (Sokal and Rohlf 1995, Chytrý et al. 2002). The size of target groups was fixed to 10 % of the total data set (Tichý and Chytrý 2006). The threshold phi (fidelity) value for the diagnostic species was set to 0.30 (multiplied by 100 in JUICE 7.0 software) and Fisher's exact test was calculated to give a zero value to those species whose fidelity was not statistically significant ($p < 0.01$). Cover values of the woody species from different layers prior to analysis were merged.

Each group was described on the basis of its diagnostic, constant and dominant species. One of the relevés presented in the cluster dendrogram was not taken into account in the following analysis because of its complexity (Group 5, relevé No 6). The similarity between the two relevés included in group 5 was

less than 35 %, which is due only to the presence of the beech. Because group 5 is represented by only one relevé, the referred diagnostic species are based on literature data (Tzonev et al. 2006). Species with low frequency percentage (equal or less than 14) without any diagnostic or characteristic value were removed from the synoptic table (Table 1). Species were considered as constant if their frequency exceeded 50 % for the group. Dominant species were defined as those reaching coverage higher than 50 %. The diagnostic species of each group are presented with their fidelity measures in brackets. The constant and dominant species are indicated by their percentage frequencies (constancy). The syntaxonomic nomenclature follows the checklist of Mucina et al. (2016). The names of the plant taxa are given according to Delipavlov and Cheshmedjiev (2003).

Results and Discussion

The dendrogram of the cluster analysis was used to distinguish eight groups of relevés (Fig. 2), which are presented in the synoptic table (Table 1). They were identified as five associations and three further plant communities without syntaxonomic rank and belong to four alliances and orders and two classes.

Based on the analysis, the following syntaxonomic synopsis was proposed for the forest vegetation in Etropole Stara Planina:

Class *Carpino-Fagetea sylvaticae* Jakucs ex Passarge 1968

Order *Luzulo-Fagetalia sylvaticae*
Scamoni et Passarge 1959

Alliance *Luzulo-Fagion sylvaticae*
Lohmeyer et Tx. in Tx. 1954

1. Association *Luzulo luzuloid-*

Table 1. Synoptic table with percentage frequency (constancy values in percentages) and standardized fidelity index (Φ - phi coefficient values presented in superscript) of forest communities in Etropoleška Stara Planina.

Alliances	A			B			C			D		
Group No	1	2	3	4	5	6	7	8				
No of relevés	31	9	7	9	1	3	3	7				
Constancy (%), fidelity (Φ)	% Φ	% Φ	% Φ	% Φ	% Φ	% Φ	% Φ	% Φ				
Association <i>Luzulo luzuloidis-Fagetum sylvaticae</i>												
<i>Luzula luzuloides</i> (Lam.) Dandy & Willmott	94 50	.	57 ---	33 ---	.	.	33 ---	.				
Association <i>Galio odorati-Fagetum sylvaticae</i>												
<i>Galium odoratum</i> (L.) Scop.	45 ---	100 39	43 ---	33 ---	50 ---	.	33 ---	.				
Community of <i>Carpinus betulus</i> and <i>Fagus sylvatica</i>												
<i>Carpinus betulus</i> L.	23 ---	56 ---	100 43	22 ---	.	100 ---	100 ---	.				
<i>Campanula sparsa</i> Friv.	10 ---	11 ---	57 38	22 ---	.	.	.	.			14 ---	
Association <i>Fago sylvaticae-Betuletum pendulae</i>												
<i>Betula pendula</i> Roth	.	.	14 ---	78 79	.	.	.	.			.	
<i>Pteridium aquilinum</i> (L.) Kuhn	.	.	.	33 56	.	.	.	.			.	
Association <i>Umbilico erecti-Fagetum sylvaticae</i> subass. <i>typicum</i>												
<i>Phyllitis scolopendrium</i> (L.) Newm.	.	.	.	.	100 ---	.	.	.			.	
<i>Lunaria rediviva</i> L.	.	.	.	.	100 ---	.	.	.			.	
Association <i>Aremonio agrimonoidis-Fagetum sylvaticae</i> subass. <i>allietosum ursini</i>												
<i>Allium ursinum</i> L.	.	.	.	.	.	67 80	.	.			.	
Mixed communities of <i>Carpinus betulus</i>												
<i>Quercus cerris</i> L.	3 ---	.	14 ---	11 ---	.	.	100 78	.			.	
Community of <i>Alnus glutinosa</i>												
<i>Rubus caesius</i> L.	.	.	.	.	.	.	.	.			100 100	
<i>Alnus glutinosa</i> (L.) Gaertner	.	.	.	.	.	.	.	.			86 92	
<i>Corylus avellana</i> L.	3 ---	11 ---	.	.	100 ---	.	33 ---	.			86 68	
<i>Salix fragilis</i> L.	.	.	.	.	.	.	.	.			57 74	
<i>Sambucus ebulus</i> L.	.	.	.	.	.	.	.	.			43 64	

Diagnostic for more than one group*Helieborus odoratus* Waldst. & Kit.**Alliance Luzulo-Fagion sylvaticae (A)***Prenanthes purpurea* L.*Oxalis acetosella* L.*Geranium macrorrhizum* L.*Vaccinium myrtillus* L.*Picea abies* (L.) Karst.*Abies alba* Mill.**Alliance Fagion sylvaticae (B)***Geranium robertianum* L.*Carex sylvatica* Huds.*Athyrium filix-femina* (L.) Roth*Veronica montana* L.*Dentaria bulbifera* L.**Alliance Carpinion betuli(C)***Lathyrus vernus* (L.) Bernh.*Pulmonaria officinalis* L.*Quercus petraea* subsp. *petraea* (Matt.) Liebl.**Class Carpino-Fagetea sylvaticae***Fagus sylvatica* L.*Viola reichenbachiana* Jord. ex Boreau*Mycelis muralis* (L.) Dumort.*Euphorbia amygdaloides* L.*Glechoma hirsuta* Waldst. & Kit.*Potentilla micrantha* Ramond ex DC.*Rubus hirtus* Waldst. & Kit*Melica uniflora* Retz.*Hepatica nobilis* Mill.

6 ---	67 37	. ---	22 ---	. ---	100 55	67 ---	14 ---
16 ---	. ---	. ---	11 ---	. ---	. ---	. ---	. ---
13 ---	. ---	14 ---	11 ---	100 ---	. ---	. ---	. ---
3 ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
3 ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
6 ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
6 ---	. ---	. ---	. ---	. ---	. ---	33 ---	. ---
23 ---	33 ---	29 ---	56 ---	100 ---	. ---	. ---	. ---
13 ---	22 ---	43 ---	22 ---	. ---	. ---	. ---	. ---
3 ---	11 ---	29 ---	. ---	. ---	. ---	. ---	. ---
. ---	. ---	14 ---	. ---	. ---	. ---	. ---	. ---
. ---	. ---	14 ---	. ---	. ---	. ---	. ---	. ---
. ---	11 ---	. ---	11 ---	. ---	33 ---	33 ---	14 ---
. ---	33 ---	. ---	11 ---	. ---	33 ---	33 ---	14 ---
. ---	22 ---	29 ---	. ---	. ---	. ---	33 ---	. ---
100 17	100 ---	100 ---	100 ---	100 ---	100 ---	33 ---	. ---
52 ---	67 ---	43 ---	89 ---	100 ---	100 ---	33 ---	. ---
55 ---	78 ---	57 ---	33 ---	100 ---	33 ---	100 ---	. ---
23 ---	56 ---	14 ---	78 32	. ---	33 ---	100 ---	. ---
26 ---	44 ---	14 ---	33 ---	100 ---	33 ---	. ---	. ---
16 ---	44 ---	14 ---	44 ---	. ---	33 ---	. ---	. ---
68 ---	56 ---	86 ---	78 ---	. ---	. ---	67 ---	14 ---
6 ---	56 ---	. ---	67 39	. ---	33 ---	33 ---	. ---
6 ---	11 ---	. ---	22 ---	. ---	67 ---	33 ---	. ---

<i>Festuca drymeja</i> Mert & Koch.	26 ---	. ---	. ---	. ---	56 ---	. ---	. ---	67 ---	. ---
<i>Ulmus glabra</i> Hudson	3 ---	44 42	. ---	. ---	11 ---	. ---	. ---	33 ---	. ---
<i>Poa nemoralis</i> L.	48 ---	33 ---	43 ---	. ---	56 ---	. ---	. ---	. ---	. ---
<i>Sanicula europaea</i> L.	10 ---	33 ---	14 ---	. ---	11 ---	. ---	. ---	. ---	. ---
<i>Mercurialis perennis</i> L.	13 ---	33 ---	. ---	. ---	22 ---	. ---	33 ---	. ---	. ---
<i>Dryopteris filix-mas</i> (L.) Schott	52 23	67 ---	29 ---	. ---	. ---	. ---	. ---	. ---	. ---
<i>Aremonia agrimonoides</i> (L.) DC.	16 ---	11 ---	. ---	. ---	56 39	. ---	. ---	. ---	. ---
<i>Cruciata glabra</i> (L.) Ehrend.	29 ---	11 ---	. ---	. ---	44 ---	. ---	. ---	. ---	. ---
<i>Hordelymus europaeus</i> (L.) C. O. Harz	3 ---	11 ---	. ---	. ---	. ---	. ---	33 ---	. ---	. ---
<i>Stachys sylvatica</i> L.	10 ---	22 ---	. ---	. ---	11 ---	. ---	. ---	. ---	. ---
<i>Ajuga reptans</i> L.	6 ---	. ---	43 ---	. ---	22 ---	. ---	. ---	. ---	. ---
<i>Aegopodium podagraria</i> L.	3 ---	22 ---	. ---	. ---	. ---	100 ---	. ---	. ---	. ---
<i>Hedera helix</i> L.	10 ---	. ---	. ---	. ---	. ---	. ---	33 ---	. ---	. ---
<i>Anemone nemorosa</i> L.	3 ---	. ---	. ---	. ---	. ---	. ---	33 ---	. ---	. ---
<i>Hieracium gentile</i> Jordan ex Boreau	3 ---	. ---	29 ---	. ---	. ---	. ---	. ---	. ---	. ---
<i>Sorbus aucuparia</i> L.	13 ---	. ---	. ---	. ---	11 ---	. ---	. ---	. ---	. ---
<i>Festuca gigantea</i> (L.) Vill.	3 ---	11 ---	. ---	. ---	. ---	. ---	. ---	33 ---	. ---
<i>Tilia cordata</i> Miller	. ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
<i>Asarum europaeum</i> L.	. ---	. ---	14 ---	. ---	. ---	. ---	. ---	. ---	. ---
<i>Sambucus nigra</i> L.	. ---	11 ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
<i>Milium effusum</i> L.	10 ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
<i>Senecio nemorensis</i> L.	3 ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
<i>Paris quadrifolia</i> L.	3 ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---
Alliance <i>Alnion incanae</i> and Class <i>Alno glutinosae-Populetea albae</i>									
<i>Geum urbanum</i> L.	10 ---	11 ---	. ---	. ---	11 ---	. ---	33 ---	67 ---	57 ---
<i>Brachypodium sylvaticum</i> (Hudson) Beauv.	. ---	. ---	. ---	. ---	11 ---	. ---	33 ---	. ---	43 46
<i>Fraxinus excelsior</i> L.	. ---	. ---	. ---	. ---	. ---	. ---	. ---	. ---	29 51
<i>Circea lutetiana</i> L.	13 ---	. ---	14 ---	. ---	. ---	100 ---	. ---	. ---	29 ---
<i>Carex remota</i> L.	3 ---	. ---	14 ---	. ---	11 ---	. ---	. ---	. ---	29 ---

<i>Urtica dioica</i> L.	.	---	.	---	14	---	.	---	.	---	29	---
<i>Impatiens noli-tangere</i> L.	.	3	---	.	.	---	.	---	.	---	14	---
<i>Myosoton aquaticum</i> (L.) Moench	.	---	.	---	.	---	.	---	.	---	14	---
<i>Rumex sanguineus</i> L.	.	---	.	---	.	---	.	---	.	---	14	---
<i>Chrysosplenium alternifolium</i> L.	.	---	.	---	.	---	.	---	.	---	14	---
Other species												
<i>Crataegus monogyna</i> Jacq.	13	---	44	---	14	---	22	---	.	---	67	---
<i>Rosa canina</i> L.	13	---	33	---	.	---	11	---	.	---	100	56
<i>Acer campestre</i> L.	.	---	22	---	14	---	22	---	.	---	33	---
<i>Brachythecium velutina</i> (Hedw.) Schimp	52	41	22	---	.	---	33	56	100	---	.	---
<i>Physospermum cornubiense</i> (L.) DC.	.	---	11	---	14	---	11	---	.	---	33	---
<i>Calamintha grandiflora</i> (L.) Moench	16	---	22	---	14	---	11	---	33	---	.	---
<i>Deschampsia flexuosa</i> (L.) Trin.	16	---	22	---	14	---	.	---	.	---	.	---
<i>Prunella vulgaris</i> L.	6	---	.	---	29	---	.	---	.	---	33	---
<i>Lysimachia punctata</i> L.	.	---	.	---	14	---	11	---	.	---	67	66
<i>Dactylis glomerata</i> L.	.	---	11	---	.	---	.	---	.	---	33	---
<i>Lysimachia nummularia</i> L.	3	---	.	---	29	---	.	---	.	---	71	68
<i>Juglans regia</i> L.	3	---	22	---	.	---	.	---	.	---	57	53
<i>Torilis japonica</i> (Houtt.) DC.	.	---	11	---	.	---	.	---	33	---	29	---
<i>Brachypodium pinnatum</i> (L.) Beauv.	6	---	.	---	29	---	.	---	.	---	29	---
<i>Galium rotundifolium</i> L.	13	---	.	---	.	---	22	---	.	---	43	---
<i>Viola hirta</i> L.	.	---	.	---	.	---	22	---	.	---	29	---
<i>Fraxinus ornus</i> L.	3	---	.	---	.	---	.	---	100	93	.	---
<i>Galium aparine</i> L.	13	---	.	---	.	---	.	---	.	---	.	---
<i>Lapsana communis</i> L.	.	---	.	---	14	---	.	---	.	---	43	---
<i>Fragaria vesca</i> L.	.	---	.	---	.	---	.	---	.	---	14	---
<i>Galeopsis speciosa</i> Miller	.	---	.	---	.	---	11	---	.	---	33	---
<i>Galeopsis tetrahit</i> L.	23	---	11	---	.	---	.	---	.	---	43	54
<i>Acer pseudoplatanus</i> L.	13	---	33	---	.	---	.	---	.	---	.	---

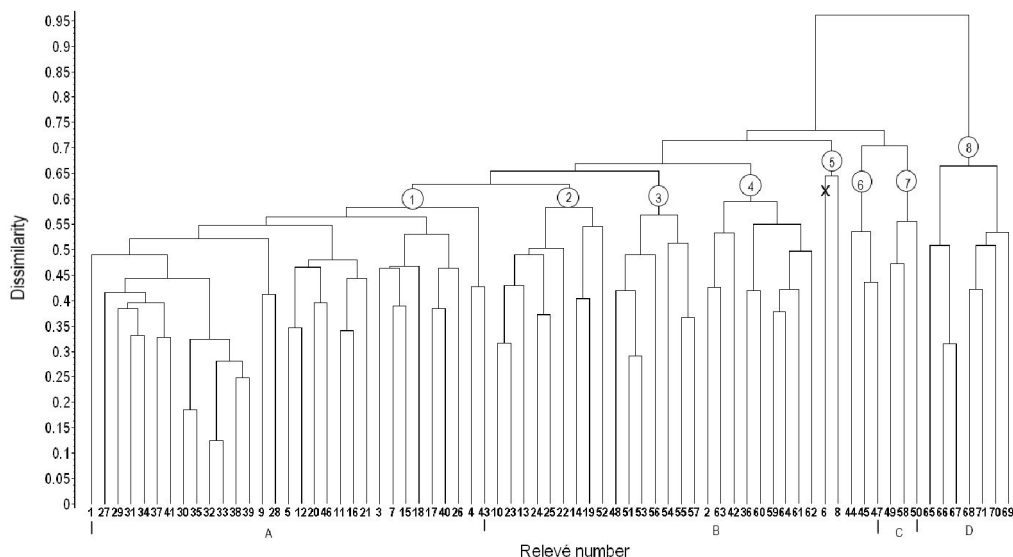


Fig. 2. Cluster dendrogram of the analysis of forest stands in Etropoleška Stara Planina.

Note: A – *Luzulo - Fagion sylvaticae*, B – *Fagion sylvaticae*, C – *Carpinion betuli*, D – *Alnion incanae*; X – indicates a relevé number which is not taken into account in the following analysis.

is-Fagetum sylvaticae Meusel 1937

Order *Fagetalia sylvaticae* Pawłowski 1928

Alliance *Fagion sylvaticae* Luquet 1926

2. Association *Galio odorati-Fagetum sylvaticae* Sougnez et Thill 1959

3. Association *Fago sylvaticae-Betuletum pendulae* Theodoropoulos et al. 2003

4. Community of *Carpinus betulus* and *Fagus sylvatica*

5. Association *Umbilico erecti-Fagetum sylvaticae* Tzonev et al. 2006 subass. *typicum*

6. Association *Aremonio agrimonoidis-Fagetum sylvaticae* Boscaiu in Resmerita 1972 subass. *allietosum ursini* Tzonev et al. 2006

Order *Carpinetalia betuli* P. Fukarek 1968

Alliance *Carpinion betuli* Issler 1931

7. Mixed communities of *Carpinus betulus*

Class *Alno glutinosae-Populetea albae* P. Fukarek et Fabijanić 1968

Order *Alno-Fraxinetalia excelsioris* Passarge 1968

Alliance *Alnion incanae* Pawłowski et al. 1928

8. Community of *Alnus glutinosa*

Group 1: Association *Luzulo luzuloidis-Fagetum sylvaticae*

Number of relevés: 31.

Diagnostic species: *Luzula luzuloides* (50).

Constant species: *Fagus sylvatica* (100), *Luzula luzuloides* (94), *Rubus hirtus* (68), *Mycelis muralis* (55), *Dryopteris filix-mas* (52), *Viola reichenbachiana* (52), *Poa nemoralis* (48).

Dominant species: *Fagus sylvatica* (100), *Luzula luzuloides* (94), *Festuca drymeja* (26).

These forest stands occur mostly in the high-altitudinal beech forest belt at 720–1550 m a.s.l. They are distributed mainly on steep slopes up to 40° with dif-

ferent exposition, but often east or with eastern component. The soil is mainly relatively poor and acidic, often eroded (*Dystric Cambisols*). The bedrock is predominantly silicate. Structurally, these phytocoenoses are organized in three layers. In some places the cover of the herb layer reaches 100 % while the shrub layer is often of low cover or missing. The tree layer is usually comprised only of *Fagus sylvatica*.

This is the most widespread association of acidophilous beech forests in the whole country. It was found in Stara Planina, Sredna Gora Mts., Ossogovska Mts., Western Rhodopi Mts., Vrachanska Planina, Vassilyovska Mts., Belassitsa Mts. (Tzonev et al. 2006). It was also described in some local studies from the Central Balkan Range (Pavlov et al. 2006, Pachedjieva 2012), as well as Western Bulgaria (Dimitrov and Petrova 2014). Divchovoto village and Boatin Reserve are the closest localities where this association was recorded (Tzonev et al. 2006). The poor species richness of these forests stands and the ecology put them very close to the Central European acidophilous beech forests (Leuschner and Ellenberg 2017).

Group 2: Association *Galio odorati-Fagetum sylvaticae*

Number of relevés: 9.

Diagnostic species: *Galium odoratum* (39), *Helleborus odoratus* (37).

Constant species: *Galium odoratum* (100), *Fagus sylvatica* (100), *Mycelis muralis* (78), *Dryopteris filix-mas* (67), *Helleborus odoratus* (67), *Viola reichenbachiana* (67), *Melica uniflora* (56), *Euphorbia amygdaloides* (56), *Carpinus betulus* (56), *Rubus hirtus* (56).

Dominant species: *Fagus sylvatica* (100), *Mercurialis perennis* (33), *Carpinus betulus* (56).

These neutrophilous, species-poor

forests occupy mostly lower parts of the beech forest belt between 620 and 1035 m a.s.l. on slopes with different exposition. In comparison with the previous forest type, these stands are developed on terrains with slight inclination predominantly between 10 – 25° and lower altitude. The soils are mainly rich in nutrients, neutral and slightly acidic. This is the most widespread beech forest association in Bulgaria (Tzonev et al. 2006). According to this study, the association was found in most of the Bulgarian mountains: Stara Planina, Sredna Gora Mts., Ossogovska Mts., Belassitsa Mts., Rhodopi Mts., Rila Mts., Pirin Mts., Rui Mts., Vlahina Mts., Konyavska Mts., Vassilyovska Mts. and Mikrenski Hills. It has also been recorded from Bulgarka Natural Park where its communities form specific aspects with the relict species *Prunus laurocerasus* and *Taxus baccata* (Pavlov et al. 2006), as well as in some local studies in Kamenishtica reserve (Pachedjieva 2012) and Ponor SPA (Dimitrov and Petrova 2014).

Group 3: Community of *Carpinus betulus* and *Fagus sylvatica*

Number of relevés: 7.

Diagnostic species: *Carpinus betulus* (42), *Campanula sparsa* (38).

Constant species: *Carpinus betulus* (100), *Fagus sylvatica* (100), *Rubus hirtus* (86), *Luzula luzuloides* (57), *Campanula sparsa* (57), *Mycelis muralis* (57).

Dominant species: *Carpinus betulus* (100), *Carex sylvatica* (86).

These forest stands are developed in the lower mountain region up to 1000 m a.s.l. on slopes mostly with north or north-west exposition. The group includes mixed forests of *Carpinus betulus* and *Fagus sylvatica*. There are relatively well-represented shrub and herb layers with many species typical for the beech forests (*Luzula luzuloides*, *Mycelis muralis*, *Rubus*

hirtus etc.). A high frequency of species typical for the alliances *Fagion sylvaticae* (*Mycelis muralis*, *Galium odoratum* etc.) and *Carpinion betuli* (*Carpinus betulus*, *Quercus petraea*, etc.) demonstrates their transitional character between the neutrophilous beech and oak-hornbeam forests. The species composition indicates a great similarity with the *Carpino-Fagetum* Pauca 1941 described earlier in Romania (Ardelean 2006, Morar 2013). Both plant communities include many species typical for the class *Carpino-Fagetea sylvaticae* and especially high participation as co-dominants of *Fagus sylvatica* and *Carpinus betulus*. But nevertheless we conclude that the forests described in Etropole Stara Planina do not belong to the *Carpino-Fagetum* because it is related to the Carpathian alliance *Lathyro hallesteinii-Carpinion* (Ardelean 2006, Morar 2013), a geographical vicariant of the *Carpinion betuli* characterized by some typical Carpathian species such as *Dentaria glandulosa*, *Helleborus purpurascens*, *Lathyrus hallersteinii*, etc. Central-southern Balkan oak-hornbeam forests have been assigned to the *Aceri tatarici-Carpinenion* Košir et al. 2012, a suballiance of the *Erythronio-Carpinion*, but there are some disagreements about this alliance. For example, oak-hornbeam forests in Slovenia and Croatia are related to the *Erythronio-Carpinion* (Vukelić 2012, Košir et al. 2012), but it is not accepted by some other authors because of its insufficient characterization by diagnostic species (Willner and Grabherr 2007, Borhidi et al. 2012, Stupar and Čarni 2017). It is also recognized as synvicariant of *Carpinion betuli*. More studies are necessary to solve the problem with the syntaxonomical position of Bulgarian and even Balkan oak-hornbeam forest stands.

Group 4: *Fago sylvaticae-Betuletum*

pendulae

Number of relevés: 9.

Diagnostic species: *Betula pendula* (79), *Pteridium aquilinum* (58).

Constant species: *Fagus sylvatica* (100), *Viola reichenbachiana* (89), *Betula pendula* (78), *Euphorbia amygdaloides* (78), *Rubus hirtus* (78), *Melica uniflora* (67), *Aremonia agrimonoides* (56), *Festuca drymeja* (56), *Poa nemoralis* (56), *Geranium robertianum* (56).

Dominant species: *Fagus sylvatica* (100), *Betula pendula* (78).

The forests of *Betula pendula* in Etropole Stara Planina are distributed between 810 and 1330 m a.s.l. on slopes with different inclination and exposition. The soil cover is formed mainly by relatively rich *Cambisols* on silicate rocks. These forest stands are characterized by a high participation of *Fagus sylvatica*, which forms the lower forest sublayer in some places. This is an indicator for the stage of their successional development. It will probably finish with their transformation into *Fagus sylvatica* forests. Presumably these forests (described mostly in 'Belikata' Protected Area) were better developed during the Holocene, but after the last glacial period. The same processes were reported also for these types of forests from Vitosha Mts. (Bondev 2002). *Betula pendula* forests are fragmentarily distributed in all Bulgarian mountains because this species is a pioneer element, which naturally occurs in groups or single trees in mesophilous coniferous or beech forests (Bondev 1991). They are usually developed in places where the natural forest vegetation has been destroyed by some anthropogenic activities or natural disasters. Sometimes they could occupy also abandoned pastures and meadows (Dimitrov 2015b). The birch forests in Etropole Stara Planina are among the

largest in the country (Dimitrov 2015b).

The syntaxonomy of *Betula pendula* communities has not been fully studied in Bulgaria until now. Only one paper according to the Braun-Blanquet's methodology (Nikolov and Dimitrov 2015) and two local papers following the Dominant approach have been done (Penev 1960, Gorunova and Kochev 1991). Forest stands described earlier in Central Stara Planina by Nikolov and Dimitrov (2015) grow in higher altitudinal range (1400–1600 m), around the timberline, where spruce forests are also distributed. Birch phytocoenoses from Etropolevska Planina demonstrate huge similarity to the association *Fago sylvaticae*–*Betuletum pendulae* from Northern Greece (Theodoropoulos et al. 2003), which has similar floristic composition and structure, especially in the high participation of *Fagus sylvatica*. The high presence of *Pteridium aquilinum* as diagnostic species probably is an indicator that these communities have derived from a previous successional stage, the *Pteridio-Betuletum*. The latter association was described in Slovenia and Croatia (Trinajstić 2004, Šilc et al. 2008) as final stage of *Betula pendula* forests before its transition into the potential forest vegetation, which probably is the *Galio odorati-Fagetum sylvaticae* for the studied region.

Group 5: Association *Umblico erecti-Fagetum sylvaticae* subass. *typicum*

Number of relevés: 1.

Diagnostic species: *Phyllitis scolopendrium*, *Lunaria rediviva*.

Constant species: *Fraxinus ornus* (100), *Fagus sylvatica* (100), *Phyllitis scolopendrium* (100), *Lunaria rediviva* (100) etc.

Dominant species: *Fagus sylvatica* (100).

This phytocoenosis has been de-

scribed close to the Varovitec Waterfall on 674 m a.s.l. It is developed on shady limestone rocks and *Eutric Cambisols* under the conditions of high air and soil humidity. It is similar to the wettest beech forests in Bulgaria, which are typical to the northern slopes of the Central Balkan Range, Sredna Gora Mts., Lozenska Mt. and Vassilyovska Mt. (Tzonev et al. 2006). Their species composition is comprised by many mesohygrophytes like *Carex remota*, *Chrysosplenium alternifolium* and *Circaea lutetiana*, etc. (Tzonev et al. 2006, Dimitrov 2015a). The herb layer of this stand is dominated by *Aegopodium podagraria* and *Phyllitis scolopendrium*. Other typical species with lower participation are *Lunaria rediviva*, *Circaea lutetiana*, *Asplenium trichomanes*, etc. The referred association is a geographic synvicariant to the Central European *Tilio-Acerion* alliance, or some specific Central European beech forests, which occur in wet and shady valleys.

Group 6: Association *Aremonio agrimonoidis-Fagetum sylvaticae* subass. *alietosum ursini*

Number of relevés: 3.

Diagnostic species: *Allium ursinum* (80), *Helleborus odoratus* (55).

Constant species: *Carpinus betulus* (100), *Helleborus odoratus* (100), *Viola reichenbachiana* (100), *Fagus sylvatica* (100), *Allium ursinum* (67), *Hepatica nobilis* (67).

Dominant species: *Fagus sylvatica* (100), *Allium ursinum* (67).

Forest stands of this association occupy slightly steep terrains with north or north-western aspect between 690 and 960 m a.s.l. They are developed on rich *Cambisols* with well-developed herb layer, which is comprised mainly by *Allium ursinum*, *Viola reichenbachiana*, *Hepatica nobilis*, etc. It has been pointed out for Vrachanska Planina Mt., Sredna gora Mt. and

Stara Planina Mt., where it occurs mostly on nutrient-rich and humid soils (Tzonev et al. 2006). We suppose that some future research could establish its wider distribution in Etropole Stara Planina, where *Allium ursinum* could form the spring herb layer in many neutrophilous beech forests.

Group 7: Mixed communities of *Carpinus betulus*.

Number of relevés: 3.

Diagnostic species: *Quercus cerris* (78).

Constant species: *Carpinus betulus* (100), *Rosa canina* (100), *Quercus cerris* (100), *Mycelis muralis* (100), *Lysimachia punctata* (67), *Viola hirta* (67), *Crataegus monogyna* (67), *Helleborus odoratus* (67), *Rubus hirtus* (67), *Festuca drymeja* (67), *Geum urbanum* (67), *Euphorbia amygdaloides* (33).

Dominant species: *Carpinus betulus* (100), *Festuca drymeja* (67), *Quercus petraea* (33).

These forest stands are distributed on terrains with different inclination and exposition on 690–780 m a.s.l. The presence of species like *Geum urbanum*, *Prunella vulgaris*, *Dactylis glomerata*, etc., show anthropogenic impact, which is probably a result of their closeness to the Etropole town. These phytocoenoses have transitional features between thermophilous beech forests and typical hornbeam-oak forests. Future research could clarify their syntaxonomic position not only in the studied area but also in other regions.

Group 8: *Alnus glutinosa* community.

Number of relevés: 7.

Diagnostic species: *Rubus caesius* (100), *Alnus glutinosa* (92), *Salix fragilis* (74), *Corylus avellana* (68), *Sambucus ebulus* (64).

Constant species: *Rubus caesius* (100), *Crataegus monogyna* (86), *Corylus avellana* (86), *Alnus glutinosa* (86), *Dac-*

tylis glomerata (71), *Agrimonia eupatoria* (71), *Salix fragilis* (57), *Rosa canina* (57), *Potentilla reptans* (57), *Plantago lanceolata* (57), *Lysimachia nummularia* (57), *Geum urbanum* (57), *Dipsacus fullonum* (57), *Erigeron annuus* (57).

Dominant species: *Alnus glutinosa* (86).

The riverine forest stands (galleries), dominated by *Alnus glutinosa*, are distributed as narrow strips along the river banks, mostly on *Fluvisols*. They are strongly influenced by an anthropogenic impact because they are located mostly near Etropole town. The studied phytocoenoses are located on 490–710 m a.s.l. The species richness, especially of the herb layer, is comparatively high and includes typical hygrophytes (*Alnus glutinosa*, *Persicaria hydropiper*) and mesohygrophytes (*Lysimachia nummularia*), as well as many nitrophilous ruderals (*Geum urbanum*, *Urtica dioica*).

These forests are not among the well-investigated vegetation types in Bulgaria. However, only two studies according to the Braun-Blanquet's approach (Soó 1957, Pavlov and Dimitrov 2002) have been done until now. They both describe typical floodplain ('longoz') vegetation distributed along some larger rivers at the Black Sea Coast or South-eastern Bulgaria. The typical longoz communities are rich of lianas, herbaceous climbers and many woody species, which give them physiognomy similar to the tropical forests (Pavlov and Dimitrov 2002). In comparison, the communities of *Alnus glutinosa* in Etropole Stara Planina are poorer in species composition, and their flooding is relatively limited in duration and dimension.

The phytocoenoses with dominance of alders are widely distributed in Europe. They are united mainly in the alliance *Al-*

nion incanae, which include azonal forest vegetation growing in localities with high groundwater table (Oberdorfer 1953; Bodeux 1955; Dierßen 1996; Neuhäuslová 2000, 2003). The most recent and comprehensive work concerning this type of vegetation is the paper of Douda et al. (2015), where the authors summarized a huge database of relevés collected across whole Europe and as a result presented detailed formalized classification of European floodplain forests and alder carrs. The phytocoenoses of alders are discussed also in studies on national level in several European countries, such as Romania (Coldea et al. 2015), Czech Republic (Douda 2008, Chytrý 2013), Italy (Sburlino et al. 2011), etc., where detailed syntaxonomy and classification of these forests is presented. At this stage we cannot relate the black alder phytocoenoses described in Etropolea Stara Planina *Alnus glutinosa* communities to any of the associations described so far because of the lack of diagnostic species for these associations and the small number of relevés. Future research of this type of vegetation in Etropolea Stara Planina will clarify their syntaxonomy and floristic classification.

Conclusion

The results of the present study refer to the forest vegetation of Etropolea Stara Planina. The dominating forest types belong to widespread Middle European neutrophilous and acidophilous beech forests and mixed *Carpinus betulus* and *Quercus petraea* forests. It is also evidenced by the existing data that the class *Carpino-Fagetea sylvaticae* is represented by *Luzulo-Fagion sylvaticae*, *Fagion sylvaticae* and *Carpinion betuli*. Specific

and still poorly known are the riverine galleries of *Alnus glutinosa*, which belong to the *Alno glutinosae-Populetea albae* and the *Alnion incanae*. They are typical for the South-eastern and Central European deciduous mesophilous to hygrophilous alluvial forests. However, more research is necessary to establish their syntaxonomical relationships and positions.

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ALLOMETRIC MODEL OF WOOD BIOMASS AND CARBON FOR GLIRICIDIA (*GLIRICIDIA* *SEPIUM* (JACQ.) KUNTH EX WALP.) AT BIOENERGY PLANTATION IN INDONESIA

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Abstract

The paradigm of multipurpose forest management in gliricidia plantation can be developed to produce woody biomass and carbon stock. Production estimation of gliricidia plants in producing woody biomass and carbon stocks needs to be estimated through allometric models. The research objective is determining the best allometric equations of wood biomass and carbon stocks with predictors of stem diameter. The materials used in the study were the gliricidia stand with age 1–5 years at Forest Management Unit Semarang. The method used in measuring and estimating forest carbon stocks refers to Indonesian National Standard (SNI) No 7724: 2011 and the SNI No 7725: 2011. The results showed that the biomass of gliricidia plants was distributed in stems (10.75 %), branches (86.30 %), and leaves (2.93 %). Furthermore, the average carbon content in stems was 57.40 %, in branches – 56.30 %, and in leaves – 52.90 % of the dry weight. R^2_{adj} of allometric models were 0.780 (linear); 0.730 (exponential); 0.532 (logarithmic); 0.799 (polynomial); and 0.959 (power). While the RMSE values were 38.89 %, 1.20 %, 56.66 %, 37.16 %, and 0.48 %, respectively. The allometric model validation showed that power model is the best allometric model for wood biomass and total carbon content. Thus, it can be considered to estimate wood biomass and total carbon with predictors of stem diameter. Further research by adding other predictors is needed to make the result of allometric models more accurate.

Key words: coppice system, multipurpose forest, multi-stem, short rotation coppice.

Introduction

An option for obtaining renewable energy, which could substitute fossil fuels in the future, is the utilization of biomass for bioenergy. Indonesia, as a tropical country, has great potential in producing biomass from the agriculture and forestry sectors by utilizing the biomass and biomass waste into bioenergy (Febijanto 2007) and utilize marginal land for bioenergy plantation

(Narendra et al. 2019). In the new policy scenario of the government of the Republic of Indonesia, between 2011 and 2035 renewable energy will increase by 75 % and the main source will come from bioenergy (Dewan Energi Nasional 2014) and by 2050 the utilization of bioenergy can reach at least 31 % (Government of Indonesia Decree No 79 2014).

The forestry sector can play an important role in support of renewable energy

policies, particularly bioenergy, by the use of biomass with multipurpose forest management. Forest can be utilized considering various objectives such as wood and non-wood (Miina et al. 2010, Tahvanainen et al. 2018), wood and wildlife conservation (Toyoshima et al. 2013), as well as wood with environmental services to absorb forest carbon (Tiryana 2016, Nölte et al. 2018). Carbon sequestration is a potential indicator in measuring environmental services for regulating global climate change (Groot et al. 2010).

Some countries with boreal and temperate forests have been developing short rotation coppice (SRC) plantation in marginal land using multipurpose forest management approaches to mitigate climate change. For instance, Canada developed willow and poplar cultivation for bioenergy source, land rehabilitation, and carbon sequestration (Amichev et al. 2010, Lupi et al. 2015, Jego et al. 2017). European countries also have been developing SRC plantation, for instance Poland (Stolarski et al. 2018), Bulgaria (Marinov et al. 2013), Belgium (Laureysens et al. 2005), Italy (Bacenetti et al. 2016), Germany (Faasch and Patenaude 2012) for mitigating climate change. Development of SRC plantation provides multiple effects such as bio-economy and environmental services.

Since 2012, Indonesia Forest Enterprise (Perhutani) started using *Gliricidia* (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) species for SRC plantation in Forest Management Unit (FMU) Semarang. The management purposes of *gliricidia* plantations are to produce wood biomass for bioenergy and to provide environmental services such as carbon storage. Generally, the potential of carbon sequestration has not yet been integrated into forest management plans, even though the function of

forests as carbon sinks has an important role (Baskent et al. 2008). For instance, Tiryana (2016) has examined the multipurpose forest management for teak plantation in Perhutani that considers aspects of teak production and carbon sequestration. Furthermore, Tiryana (2016) states that modeling between carbon sequestration and logging schedule can help forest managers to obtain optimal volumes and maintain the age structure of teak stands at the end of the cycle, so this modeling needs to be applied to other plantations.

Unfortunately, achieving multipurpose forest management on *gliricidia* plantation faces difficulty due to a lack of information on *gliricidia*'s allometric model. The development of allometric models is an important phase in estimating the volume and biomass from forests (Rutishauser et al. 2013) and developing short-rotation plantation (Amichev et al. 2010, Jego et al. 2017). The allometric models for estimating volume/biomass and forest carbon stocks in Indonesia have been carried out by terrestrial measurements (Akbar 2012) and using satellite imagery (Wahyuni and Suryawan 2012, Wahyuni 2014, Yuwono et al. 2015). The biomass allometric model is built based on easily measured data (diameter, height, age) and could be used for both practical and scientific purposes (Saint-Andre et al. 2005, Istrefi et al. 2018).

Mostly, allometric models in Indonesia that consider diameter as a predictor are used to estimate the tree volume dimension of a single stem (Siswanto and Imanuddin 2008, Hardjana et al. 2012, Qirom et al. 2012, Qirom and Supriyadi 2012, Kuswandi 2016, Samsedin et al. 2016, Qirom 2018). Whereas, *gliricidia* tree is multi-stem and the biomass is the main feature for bioenergy production. Thus, this study aims to determine the

in 2013, 2014, 2015, 2016, and 2017.

Data collection

Primary data for the preparation of biomass allometric models and carbon stocks in gliricidia plantations refer to Indonesia National Standard (SNI) No 7724 concerning measurement and calculation of carbon stocks – field measurements for estimating forest carbon stocks and SNI No 7725 concerning the preparation of allometric equations for estimating forest carbon stocks based on field measurements (Badan Standarisasi Nasional

The study was conducted at the Forest Management Unit Semarang for five months (April – September 2019) and distributed for all ages (Fig. 1). *Gliricidia* plants used in the research were planted



2011a, 2011b). Usually, the diameter was measured at breast high (DBH), but for multi-stem tree's diameter measurement is considered at 0.3 m above the ground (Brown 1997, Amichev et al. 2010, Jego et al. 2017). Furthermore, in this research, the stem diameters were measured on 0.3 m.

The sample included 66 gliricidia trees, of which 33 trees were used to develop wood biomass and carbon stock allometric models and 33 trees for validity test. Furthermore, wood biomass allometric models developed from fresh-cut and dry weight were used for the carbon stock allometric model. Drying of samples was carried out in the laboratory in the Department of Forest Product Technology Universitas Gadjah Mada (UGM), whereas carbon organic content testing was carried out in the Laboratory of soil science, Faculty of Agriculture UGM.

Data analysis

Primary data from laboratory tests were analyzed using the regression approach to estimate the gliricidia's woody biomass and carbon content. Firstly, data were checked for normal distribution and then tested for some regression model (linear, exponential, logarithmic, polynomial, and power) using equations (1–5).

$$\text{Linear: } B = \beta_0 + \beta_1 D, \quad (1)$$

$$\text{Exponential: } B = \beta_0 e^{\beta_1 D}, \quad (2)$$

$$\text{Logarithmic: } B = \beta_0 + \beta_1 \ln(D), \quad (3)$$

$$\text{Polynomial: } B = \beta_0 + \beta_1 D + \beta_2 D^2, \quad (4)$$

$$\text{Power: } B = \beta_0 D^{\beta_1}, \quad (5)$$

where: B is biomass of fresh-cut weight or carbon content (kg), D is stem base diameter (cm), β_0 is intercept/constant,

and β_1 and β_2 are gradient.

Criteria for evaluating biomass allometric models were the root mean square error (RMSE) and coefficient of determination (R^2) (Krisnawati et al. 2012, Almulqu et al. 2019): bias, aggregate deviation (AD), and relative deviation (RD) (Qirom et al. 2012, Qirom 2018).

The reliability test of the allometric model uses the parameters of aggregate deviation (AD), relative deviation (RD), and bias. A good allometric model has an AD value of $<1\%$, $RD < 10\%$, and minimal bias (Sumadi and Siahaan 2010, Kuswandi 2016, Qirom 2018). The selection of the best model based on the ranking has been made on the research of allometric models on the Red balau tree (*Shorea balangeran* (Korth.) Burck) in Central Kalimantan (Qirom 2018), commercial species in Papua (Kuswandi 2016), and Blackboard tree (*Alstonia scholaris*) in South Sumatra (Sumadi et al. 2010). The ranking is done with a score of 1–5 so that the best model is the allometric model with the lowest total score.

Results and Discussion

The overview of gliricidia plantation at FMU Semarang

The gliricidia plantation was established in FMU Semarang in collaboration with the Korean Green Promotion Agency (KGPA). A few years later, KGPA changed into Korean Forestry Promotion Institute (KOFPI). Initially, gliricidia plantation was established on marginal land in the FMU Semarang's forest area that covered 477.60 ha. Every year, KOFPI establishes gliricidia plantations in some areas and by 2017 the total area planted at FMU Semarang reached almost 2000 ha.

Research data obtained from the inventory of *gliricidia* stands at all stand ages (1, 2, 3, 4, and 5 years) at FMU Semarang were stem diameter and weight of biomass produced from stems, branches, and leaves, and the number of plants per sample plot. *Gliricidia* stands of different age possessed specific characteristics on the number of areas, stand density, and productivity (Fig. 2).

Figure 2 shows that the *gliricidia* plantations in FMU Semarang are dominated by young stands (around 50 %). The stand density on the research site at different ages is more than 2000 trees/ha.

Allometry model for wood biomass and carbon stock of *gliricidia*

Based on the results of the inventory of *Gliricidia* plantation performed in 2018, the diameter distribution was classified into 11 diameter classes with an interval of 2 cm. For each diameter class, harvested trees were measured in detail on the stem, branches, and leaves (Table 1).

Gliricidia plantation is categorized as a short rotation coppice system in which the stem can produce several branches and they can be harvested in less than five years. The average length of the main stem was 103.5 cm with the number of

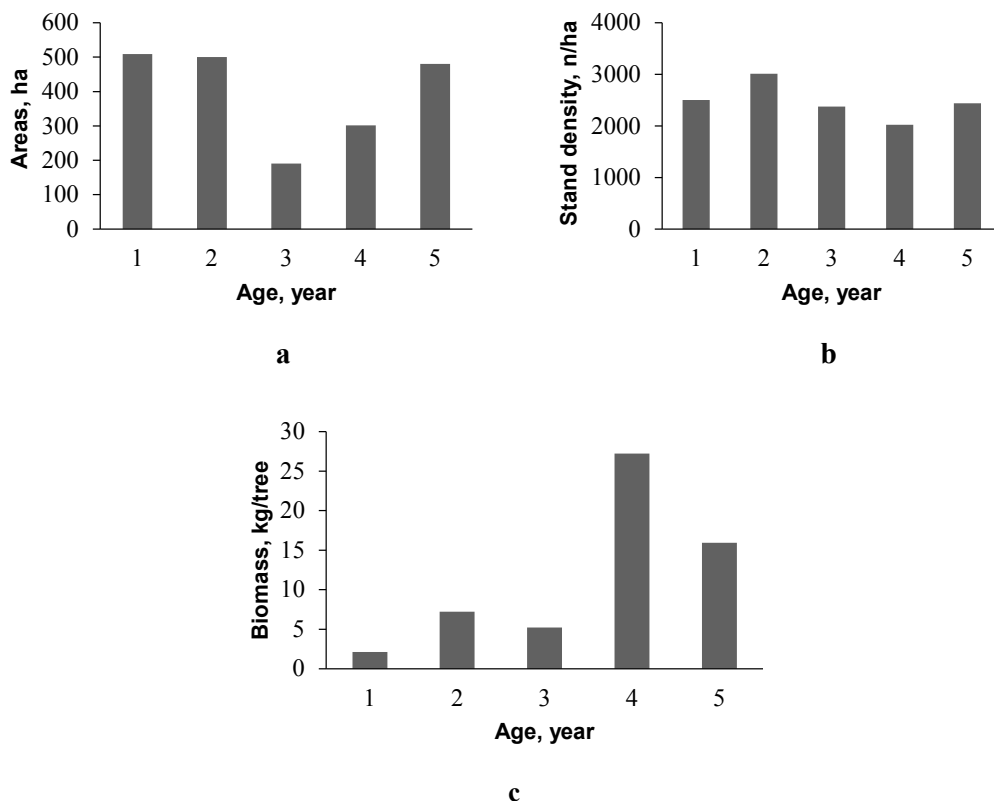


Fig. 2. Stand distribution of *gliricidia* plantation at FMU Semarang by (a) number of area, (b) stand density, and (c) tree biomass.

Table 1. Characteristics of samples.

Variables	Minimum	Maximum	Average	Standard deviation
Stem diameter, cm	0.640	21.940	11.126	6.450
Branch diameter, cm	0.380	14.30	6.409	2.909
Fresh-cut weight of stem, kg/tree	0.007	42.350	8.560	9.187
Fresh-cut weight of branch, kg/tree	0.001	175.000	24.726	30.305
Fresh-cut weight of leave, kg/tree	0.002	8.917	2.330	2.674

branches varying between 2 and 6. In addition, the average length of branches reached 626.9 cm and the total biomass of branches per tree became larger than the biomass of stem. Although the

average stem diameter was greater than the average branch diameter (Table 1), the biomass of the branch section was more dominant than the stem section (Fig. 3).

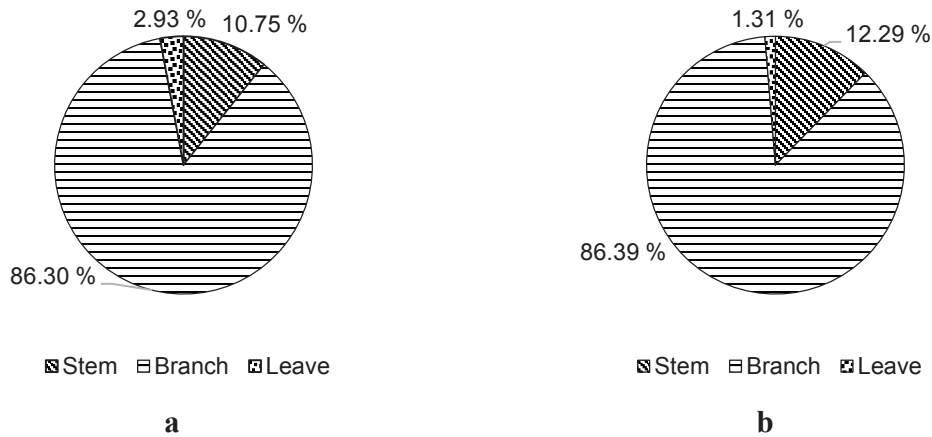


Fig. 3. The distribution of fresh-cut biomass (a) and total carbon (b) in gliricidia plant.

The composition of fresh-cut weight and the total carbon content of stem, branches, and leaves showed similar trends. Changing the percentage of total fresh-cut weight to total carbon was affected by the drying process and organic carbon content in each part of the plant. The water content of the stems, branches, and leaves were 88.95 %, 103.72 %, and 338.53 %, respectively.

There was a positive relationship between stem diameter and biomass (total fresh-cut weight and total carbon). The biomass production and total carbon increased with increasing of the stem di-

ameter (Fig. 4). Such positive relationship between diameter and volume was also found in *Shorea balangeran* (Qirom 2018), *Dyera polyphylla* (Qirom and Supriyadi 2012), and *Ficus variegata* (Qirom and Supriyadi 2013).

Normality test showed that the values of diameter at stem base and the total, and fresh-cut weight of gliricidia are normally distributed. Arrangement of allometric models for estimating wood biomass (fresh-cut weight) with predictors of stem diameter using linear and non-linear regression equations are shown in Table 2.

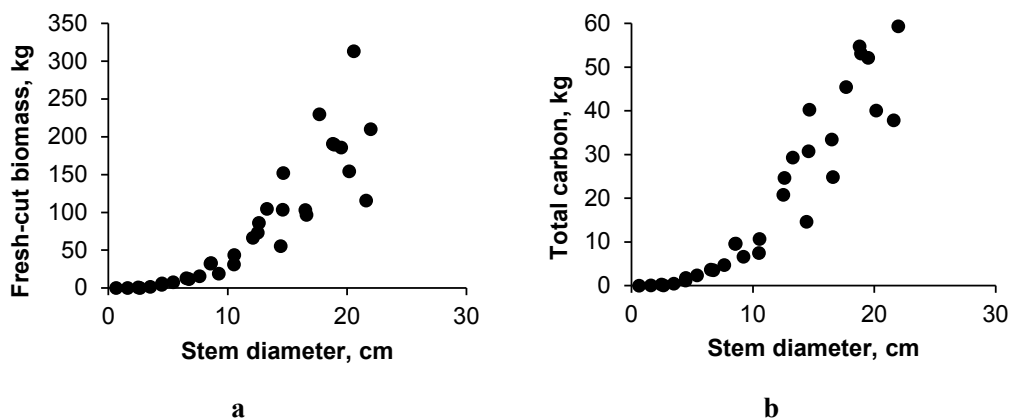


Fig. 4. Distribution pattern between stem diameters and fresh-cut biomass (a), total carbon (b).

Table 2. Correlation between stem diameters and fresh-cut weight of gliricidia tree.

No	Model	Equation	R^2_{adj}	RMSE, %
1	Linear	$B = -47.441 + 11.390D$	0.780	38.889
2	Exponential	$B = 0.793e^{0.308D}$	0.730	1.203
3	Logarithmic	$B = -79.797 + 73.564\ln(D)$	0.532	56.655
4	Polynomial	$B = -13.181 + 2.799D + 0.362D^2$	0.799	37.163
5	Power	$B = 0.068D^{2.722}$	0.959	0.479

Note: RMSE is root mean square error.

Carbon content in plants was obtained by using the guideline in the SNI 7724:2011. Based on the results of testing in the laboratory, the average carbon content in stems was 57.40 %, in branches – 56.30 %, and in leaves – 52.90 % of the dry weight of *gliricidia* plants. Therefore, the total carbon allometric equation will be different from the wood biomass allometric model (Table 3).

Prospective allometric models can be selected based on the value of R^2_{adj} and RMSE. The greater value of the corrected determination coefficient (R^2_{adj}) indicates stronger relationship. The smaller RMSE value is considered to choose the allometric model. For the allometric wood biomass ($B = 0.068D^{2.722}$) and total carbon

stock models ($B = 0.019D^{2.719}$), the power model produces R^2_{adj} above 0.9 and the RMSE value below 1 %. Allometric model for willow (a multi-stem species) in Canada shows the similar pattern, and power model can explain the relationship between stem diameter at 30 cm height (D_{30}) and dry mass (DM) (Amichev et al. 2010, Jegu et al. 2017).

In Indonesia, allometric models were developed to predict stem volume by a diameter at breast height (DBH), or tree height predictors were added (Sumadi et al. 2010; Sumadi and Siahaan 2010; Qirom et al. 2012; Qirom and Supriyadi 2012, 2013; Kuswandi 2016; Qirom 2018). The power model in estimating the volume of the *Shorea balangeran* has an

Table 3. Correlation between stem diameters and total carbon of gliricidia tree.

No	Model	Equation	R^2_{adj}	RMSE
1	Linear	$B = -13.391 + 3.167D$	0.767	11.192
2	Exponential	$B = 0.224e^{0.307D}$	0.726	1.210
3	Logarithmic	$B = -22.129 + 20.337\ln(D)$	0.517	16.126
4	Polynomial	$B = -2.135 + 0.403D + 0.119D^2$	0.796	10.480
5	Power	$B = 0.019D^{2.7192}$	0.958	0.472

R^2_{adj} of 0.837 (Qirom 2018). Application of power model to estimate volume of *Alstonia scholaris* plants produced R^2 of 0.964 (Sumadi et al. 2010). The power model also fits to estimate biomass of *Ziziphus mauritiana*, with R^2 0.920 (Kurniawan and Pujiono 2019). The allometric model reliability test was carried out on 33 sample

trees to find out the actual value of wood biomass and total carbon with the estimated value based on allometric equations. The difference between the actual value and the estimated value can be seen in the results of the aggregate deviation (AD), relative deviation (RD), or bias (Table 4 and Table 5).

Table 4. Reliability test of an allometric model for stem diameters and fresh-cut weight.

No	Model	Equation	AD , %	RD , %	Bias, %
1	Linear	$B = -47.441 + 11.390D$	45.727	3.907	5.313
2	Exponential	$B = 0.793e^{0.308D}$	-81.637	1.288	-37.765
3	Logarithmic	$B = -79.797 + 73.564\ln(D)$	75.144	8.775	362.126
4	polynomial	$B = -13.181 + 2.977D + 0.362D^2$	40.241	2.258	57.824
5	Power	$B = 0.068D^{2.722}$	1.172	0.786	-2.214

Note: AD is aggregate deviation, RD is relative deviation.

Table 5. Reliability test of an allometric model for stem diameters and total carbon.

No	Model	Equation	AD , %	RD , %	Bias, %
1	Linear	$B = -13.391 + 3.167D$	-47.304	4.196	21.210
2	Exponential	$B = 0.224e^{0.307D}$	69.354	1.182	-32.630
3	Logarithmic	$B = -22.129 + 20.337\ln(D)$	-76.385	9.391	408.438
4	polynomial	$B = -2.135 + 0.403D + 0.119D^2$	-40.689	2.170	73.463
5	Power	$B = 0.019D^{2.7192}$	-7.000	0.858	6.633

The reliability test of the wood biomass allometric model and carbon stock shows that the power model predicts carbon stocks that meet the AD (-7.00 %) and RD (0.858 %) requirements. However, the power model for estimating woody biomass does not meet AD requirements below 1 % and RD below 10 %. The same

result was also found in the development of the *Shorea balangeran* tree volume estimator model with a single predictor of the trunk diameter, where the AD and RD values did not meet the requirements of a reliable model (Qirom 2018). Furthermore, ranking can be applied to determine the best allometric model (Table 6).

Table 6. The allometric model ranking.

No	Equation	Score					
		AD, %	RD, %	Bias, %	R ² _{adj}	RMSE	Total
1	$B = -47.441 + 11.390D$	4	4	3	3	4	18
	$B = -13.391 + 3.167D$	2	4	3	3	4	16
2	$B = 0.793e^{0.308D}$	1	2	1	4	2	10
	$B = 0.224e^{0.307D}$	5	2	1	4	2	14
3	$B = -79.797 + 73.564\ln(D)$	5	5	5	5	5	25
	$B = -22.129 + 20.337\ln(D)$	1	5	5	5	5	21
4	$B = -13.181 + 2.977D + 0.362D^2$	3	3	4	2	3	15
	$B = -2.135 + 0.403D + 0.119D^2$	3	3	4	2	3	15
5	$B = 0.068D^{2.722}$	2	1	2	1	1	7
	$B = 0.019D^{2.7192}$	4	1	2	1	1	9

Note: the formulas for fresh-cut weight are in bold, while the formulas for total carbon are not bolded.

Of all models tested in this study (Table 6), power model ranks first as the best one for estimating wood biomass and total carbon of *gliricidia* plants. The least appropriate model is the Logarithmic one, as illustrated by the resulting AD, RD, bias, R²_{adj}, and RMSE values, which do not meet the allometric model reliability requirements.

Conclusion

We have tested some allometric model to predict the biomass and carbon of *gliricidia* plants. The best allometric model for *gliricidia* plants in FMU Semarang, which has 1–5 years with a diameter range of 0.1–22.5 cm is the power model. The power model fits in the first rotation of *gliricidia* stand management and specific site.

Recommendation

Further research to obtain a better allometric model can be done by adding predic-

tors of plant height, branch diameter, or the number of branches per tree.

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ENVIRONMENTAL INDICATORS OF THE BALANCE OF THE TERRITORIES OF SMALL TOWNS IN KYIV REGION

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Abstract

Based on the data of the StateGeoCadastre of Ukraine and the General development plans of towns, a comparative analysis of the structure of the land fund of small towns of Kyiv region has been carried out with the following ecological indicators: ratio of different types of land use, level of greening, population/green plantings ratio. Data analysis of the level of greening of towns and the availability of green public landscapes for general population has been conducted and it revealed that the current state of land use of small towns, as well as other urbanized territories, does not meet the requirements of environment management. Results of the analysis suggest that small towns are characterized by an excessive proportion of property development areas and suboptimal areas of natural territories, as well as insufficient greenery plantings, which require further balancing. In most of the studied small towns ecological situation can be considered satisfactory. Due to the extraordinary diversity of ecological and geographical conditions, individual approach to the development and improvement of greenery systems of small towns has been deemed feasible.

Key words: built-up land, green space provision, greening level, urban landscape.

Introduction

Historical human development of the territories, growth of the built-up area caused the violation of natural systems in such limits, which made the world community to develop a concept of sustainable development of the territories for the possibility of preserving it for descendants (Gerasimchuk 2009). Land use in the world will undergo dramatic changes and will be accompanied by conflicts of land demand, which will require a coherent integrated policy on the ground to promote responsible land use and limit the negative ef-

fects of land use. Towns need scientifically-based solutions to urban development, such as the creation of green spaces (Eionet 2017). A European Environment Agency report published today says that the continent's land use increasingly sees striking changes and conflicts over land demand, which will require reconciling place-based management and macro policies to foster responsible land use.

Landscape-ecological optimization of the territory assumes to reach optimal relations between economic and natural lands (Pozniak and Tsaryk 2013). According to the UN recommendations, forests in

the land should occupy 50 %, agricultural land – 45 %, built-up land – 5 %. More than 42 % of the territory of Europe are covered with forests, which makes the continent one of the world's regions richest in forests (Cvejić et al. 2015). The optimal correlation between land use types in Ukraine includes forests 25–30 %, arable land 30–35 %, hayfields and pastures 20 %, about 6 % of built-up land, over 10 % of protected areas. Currently, anthropogenic landscapes in the territory of Ukraine occupy 58 %, anthropogenic-natural – 35 %, natural – only 7 % (Shashula 2009), and anthropogenic load on the environment exceeds several times the corresponding indicators of developed countries of the world.

Urban ecosystems can play a positive role in providing sustainable development despite the fact that towns worsen the natural environment (McHale et al. 2015). The review and improvement of the methodology of urban planning in the conditions of decentralization of investment activity, changes in land use, the character of the urban development process, and the strengthening of the role of the ecological component in urban development in Ukraine are relevant (Yegorov 2010). The unprecedented rate of residential development makes the study of green plantations against the background of a rapidly changing urban environment extremely relevant. The results of research on a single town cannot currently be interpreted to characterize another one (Narbut and Mirzekhanova 2016). The conceptual framework for comparative research in different towns must be developed (McPhearson et al. 2016).

Green spaces, known as green infrastructure or urban vegetation, are vital to urban dwellers, as they play an important role in eliminating the effects of urban

thermal sources, climate change, and the provision of ecosystem and aesthetic services (Ramos-Gonzalez 2014). Optimization of the ecological situation of urban areas presupposes, first of all, an analysis of their condition, including planting of greenery. Environmental indicators of sustainable development of territories characterize the quality of life of people, the state of the environment, and the impact of human activities on natural ecosystems. As indicators of sustainable urban development, it was proposed to consider quantitative indices of the existing areas of protected and nature-recreational territories and forest lands, the level of greening of cities and the provision of population with landscape and recreational areas (Valeto and Ulasik 2013). According to Vagin et al. (2015), one of the disadvantages of the existing basic system of indicators of sustainable development is that it does not take into account the percentage of greenery in urban areas, the proportion of urban and natural areas and other important aspects of the ecological state of the town. It is believed that the best correlation in urban practice is between 60 % and 40 % of natural areas, which are stabilizing the potential of the urban landscape (Barmin and Nikulina 2011). According to Gerasimchuk (2009), a favourable ratio of built-up area and greenery, which, according to urban planning requirements, should be 50:50, is currently not met even in most regional centres of Ukraine, where the share of the territory under buildings varies from 36.1 % (Chernivtsi) to 95.6 % (Vinnytsya), and agricultural land development exceeds the ecologically acceptable level in most regions. The trend towards the development of free areas by reducing the green area of towns leads to the loss of land, ecologically important urban reserves and environmental priority in the

process of urban development.

According to the norms, the level of greening of settlements in Belarus should be at least 40 %, and within the limits of development – not less than 25 % (Valeto and Ulasik 2013). According to the data of the Department of Ecology and Natural Resources of the Kyiv Regional State Administration (Regional report ... 2014), green areas in Ukrainian towns occupy 38.4 % of urban areas (at least 40 % of the norm), with general use only 13.4 %. In the city of Berlin, the cover of green space is 46 % of the city (Cvejić et al. 2015), the city of San Juan (Puerto Rico), Boston and Miami (United States) – over 42 %. One resident of San Juan has 122.2 m² of green space (Ramos-Gonzalez 2014), while a resident of Ukraine has 16.3 m² of greenery (Regional report ... 2014). At the same time, EU standards require 26 m² of green space per inhabitant, and according to the requirements of the World Health Organization – 50 m²/capita (Chiriak et al. 2009). Naturally, the minimum standards depend on the geographical location of the cities. According to Khalil (2014) and Thaiutsa et al. (2008), the standards of living in green spaces for USA and UN include 18 and 30 m²/capita, respectively. WHO recommends at least 9 m²/capita to provide environmental stability and other benefits.

This research is carried out in the framework of the development of conceptual foundations of the system of green plantations in small towns of Kyiv region in the context of ecologically balanced development. Small towns are the most widespread category of Ukrainian cities, and their number is over 75 % of the total. About 20 % of the urban population of the country lives there. Small towns are an intermediate link between big cities and rural settlements and the most degrad-

ed link in the urban process. At the same time, a small city can be considered a psychologically comfortable stereotype of an urbanized environment (Petryshyn 2008). Compared to large cities, small towns are characterized by a simplified system of landscaping, often lacking or neglecting out-of-town landscaping, lower normative indicators. Currently, the study of the environmental situation of the urban environment concerned, as a rule, large cities. This precisely led to the consideration of the situation in small towns and, first of all, in the Kyiv agglomeration, where small towns can serve as a recreation area for the capital's inhabitants. Intensive urbanization (especially in the metropolitan region) and the strategic course on sustainable eco-balanced development make research on the current state of small towns extremely relevant.

Kyiv region is one of the leading regions of Ukraine, the area of which (excluding Kyiv) is 4.7 % of the territory of Ukraine, and the population is 4.1 % of the total population of the country, 61.8 % of which is urban. Kiev region is one of the most developed industrial and agrarian regions of Ukraine. For the period from 2008 to 2014, the area of agricultural land in the region decreased by 7600 ha (up to 63.6 % of the total), forests – by 300 ha (up to 23.0 %), areas with surface water – by 300 ha (up to 6.2 %). Instead, built-up land increased by 12,600 ha (up to 4.8 %). The reduction of land potential of the region adversely affects the quality and quantity of other natural resources, including water, forest, and vegetation (Shevchenko 2015).

The purpose of the study is to determine the eco-balance of small towns in the Kyiv region based on an analysis of the structure of their land fund and such indicators as the ratio of land use types,

the level of landscaping and the number of green spaces per capita, and to compare the value of these indicators with European cities.

Material and Methods

There are 20 small towns in the Kyiv region. The main comparative studies were carried out for the territories of small towns: Boiarka, Bucha, Vyshhorod, Vyshneve, Fastiv, for which there are more detailed data on the distribution of urban territories by types of land use. The towns

of Vasylikiv, Kaharlyk, Ukrainka were connected to separate analyzes (if available data). The comparisons of greening indicators were carried out for 9 small cities of the region, which provided with actual master plans developed after 2000, including Yagotyn.

Studied towns of Kyiv region belong to small towns (with a population of 10–50 thousand inhabitants) located in the zone of influence of Kyiv at a distance of 2 km (Vyshneve) to 38 km (Vasylikiv and Ukrainka) and only Kaharlyk is at a distance of 77 km (Fig. 1). The choice of towns was justified by the availability of

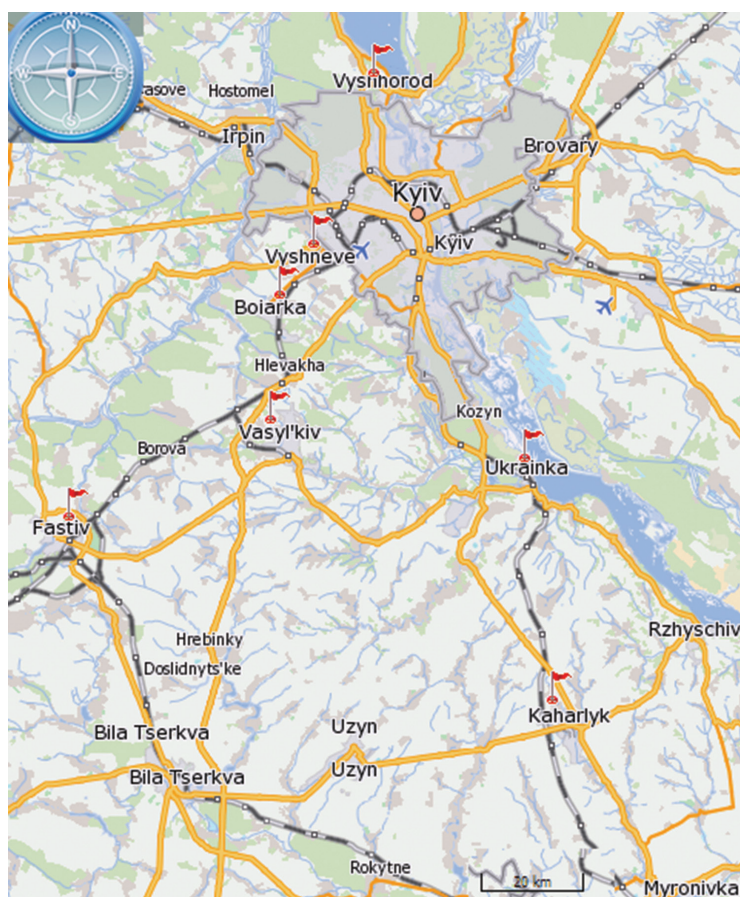


Fig. 1. Scheme of the location of pilot small towns relative to Kyiv.

publicly available fund material for analytical research.

The towns are located on the Kyiv Plateau, in the mixed forest zone, in the Kyiv Polissya (Boiarka, Bucha, Vyshhorod) and in the Forest-Steppe zone, the Kyiv highland area (Vyshneve, Kaharlyk, Vasylykiv, Ukrainka and Fastiv). Pine forests (Polissya) or agrocoenoses on oak forests site(s) (Forest-Steppe) dominate around the city. The ecological situation, where for estimating the living conditions of the population were taken into account the natural conditions of the territory, the pollution of the natural environment, anthropogenic loading on the territory is assessed as moderately favourable for Bucha, Vasylykiv and Fastiv and satisfactory

for Boiarka, Vyshhorod, Vyshneve, Kaharlyk and Ukrainka (Shevchenko 2015).

The analysis of the structural distribution of the land funds of towns was carried out on the basis of the data of their Master plans, which often did not coincide, and plans of perspective development were not developed for all towns. Before 2011 inventory of green spaces has not been carried out in small towns, just like the census because of expense of local budgets. Therefore, for objective reasons, for some towns there is no data for comparisons.

The data obtained from studied small towns was compared with data about a number of major European cities (Table 1).

Table 1. Per capita values for European cities (Cvejić et al. 2015).

Indicator	Berlin	Malmö	Ljubljana	Edinburgh	Bari	Łódź
Green space, m ² /capita	16.35	32.86	8.85	31.39	5.81	12.50
Green+forest, m ² /capita	60.84	36.28	422.30	59.97	6.04	60.03
Water area, m ² /capita	14.50	5.87	9.72	5.38	0.15	0.82

According to the obtained data about the ecological indicators of small towns of Kyiv region, a comparison of the actual and normative relations of agricultural, natural and built-up areas of cities was made (Zibtseva 2015) and the level of greening of towns with provision by green public space, all green space and green infrastructure was analyzed.

Results and Discussion

The main indicators of the territory of small towns are shown in Figure 2. There is proportion of residential space (multi-apartment buildings and manor houses), urban forests, and greenery (all categories of greenery are included in this category: general use, gardens, meadows, cem-

eteries, gardens, other open spaces). The share of green public spaces (parks, parks, gardens, boulevards) is set separately – the only indicator of urban planning, which is accurately calibrated in terms of green spaces, as well as the percentage of water surface.

The relative size of living space in all five studied small towns varies from 9.1 % (Fastiv) to 41.9 % (Boiarka) and averages 26.6 %, while in the indicated European cities ranges from 11.3 % (Ljubljana) to 32.3 % (Berlin) and averages 20.8 %. That is, residential development in small towns also fluctuates widely and occupies an average 6.1 % higher share in urban areas. The relative area of development in Boyarka is twice the average in European countries. As a rule, this is due to the predominance of the private building

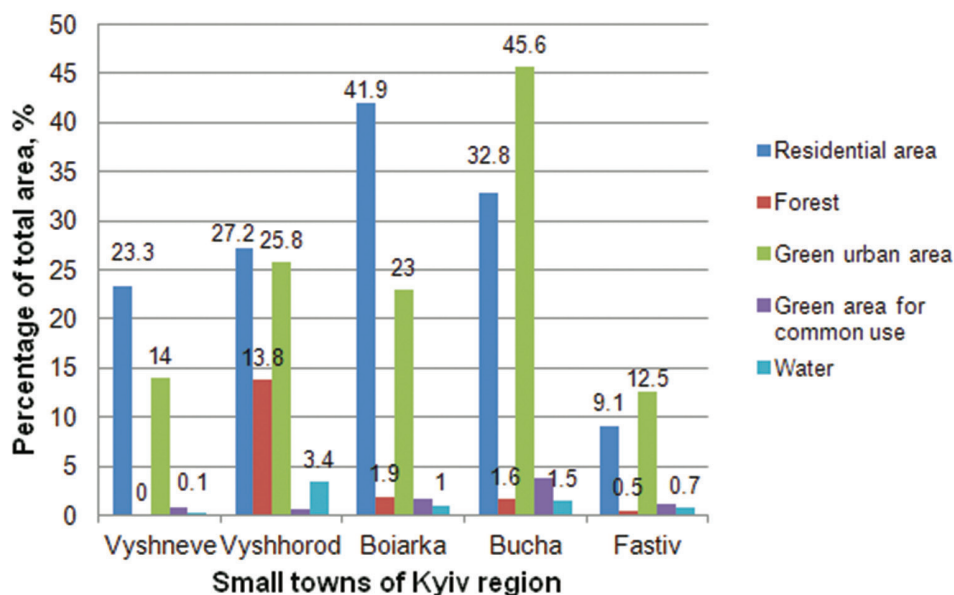


Fig. 2. Ecological indicators of small towns.

in the small town area.

Specific forest area in small towns ranges from 0 (Vyshneve) to 1.9 % (Boiarka) and only in Vyshhorod it is 13.8 %, the average value for the towns is 3.6 %. A similar situation is observed in European cities, where the forest area ranges from 0.06 % (Bari) to 17.5 % (Berlin) and only in Ljubljana is 42.1 % and the average value is 12.8 %, which is 3.6 times higher than the average value for the studied Ukrainian small towns. Unfortunately, at present, forests in small Ukrainian towns are not considered as a recreational or eco-stabilizing facility, but only as a reserve for expansion.

The relative area under green space in small towns ranges from 12.5 % (Fastiv) to 45.6 % (Bucha) with an average of 24.2 %, whereas in European cities – from 0.5 % (Ljubljana) to 6.8 % (Edinburgh) with an average of 4.2 %. The area of green public spaces (the indicator not applicable for European cities) in small towns varies

from 0.68 % (Vyshhorod) to 3.8 % (Bucha) and an average of 1.6 %. The value of this indicator is 2.7 times lower than the previous one for European cities.

Green public use according to the norms for small towns of Ukraine should make up 22–25 % of the total area of green plantations on the territory of development. In fact, in the pilot towns, their percentage in the total area of the green plantations of the towns range from 2.2 % (Vyshhorod) to 8.7 % (Fastiv), this is 2.5–11 times lower than the normative indicator.

Water surfaces in small towns occupy from 0.1 % (Vyshneve) to 1.5 % (Bucha) and only in Vyshgorod (at the expense of the Dnieper and hydraulic structures) reach 3.4 %. In European cities, there is a similar situation: the surface area of water surfaces ranges from 0.1 % (Bari) to 1.2 % (Malmö) and only in Berlin is 5.7 %.

The structure of land resources of small towns in the order of growth of built-

up areas is illustrated by Figure 3. If on the whole in the Kyiv region the area of development is 4.5 %, then on the territory of small towns it varies from 10.3 % (Kaharlyk) to 84.6 % (Vyshneve). The optimal value (not exceeding 50 % of the town's territory) is constructed in only half of the research towns – Kaharlyk, Fastiv and Bucha.

The area of agricultural land varies from 5.5 % (Vyshneve) to 81.2 % (Kaharlyk) with an average of 29.6 %. The share of agricultural land in Fastiv is 59 %, which is equivalent to the average value in the Kyiv region (Fig. 3). In small towns, a fairly tight inverse correlation between the built-up area and the agricultural area can be traced: $r=-0.841 \pm 0.131$, $t=6.42$ ($P=0.99$).

There is no prospect of increasing agricultural land in small towns, and the priority for compacted multi-storey construc-

tion is still here. As a whole, agricultural lands in the region are twice more than it is recommended, and natural territories are twice less. There are very few natural areas in small towns. In the most secured in this regard, Kaharlyk town is 12.5 times less than the recommended value. At the same time, the number of built-up land is not critical and has a reserve for growth (4.5 % against 6.0 %).

The area of natural territories, to which all of the inbuilt territories with natural cover are attributed to us, are: landscaped territories, perennial plantations, water surfaces and other lands, are ranging from 8.5 and 9.9 % in small towns (respectively, Kaharlyk and Vyshneve) to 32.4 and 34.1 % (Vyshhorod and Bucha).

In general, the most optimistic aspect of the land is the Bucha area, where the maximum area of natural territories is pre-

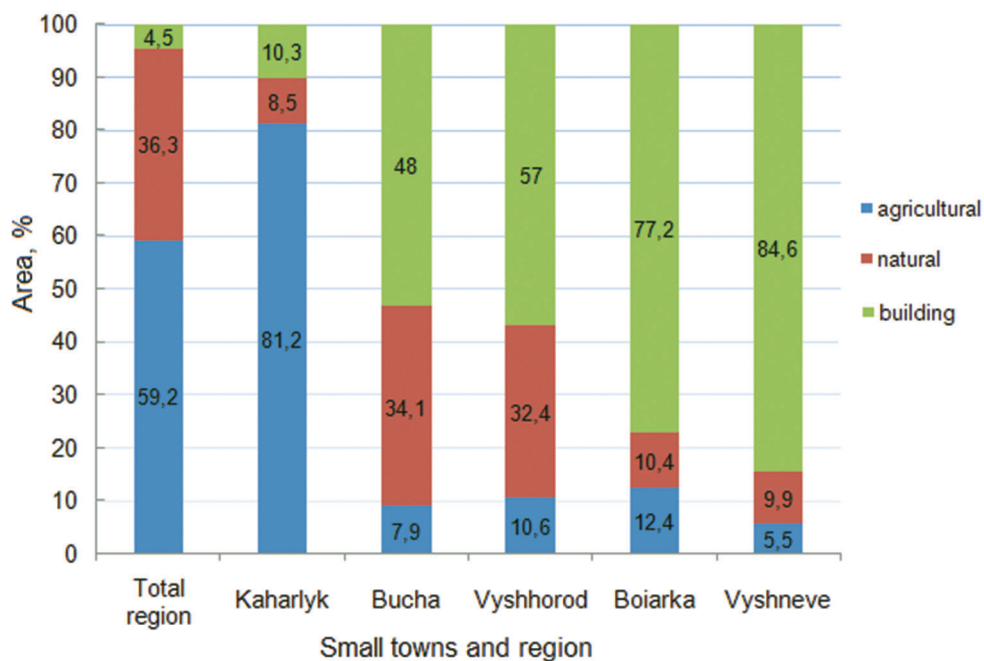


Fig. 3. Distribution of small towns by category of land use.

served and the area of development does not exceed the normative value. Second place in the balance of land belongs to Vyshgorod, where, despite the excess of built-up land (by 7 %), almost a third is natural territory. In the town of Vyshneve, the share of built-up areas is 8.2 times higher than in Kaharlyk. Natural areas are almost absent. According to the indicators, the situation is worse there. The ecological framework of the town is not formed.

The study of small towns in Belarus (Ministry ... 2010) revealed a large share of arable land, a significant proportion of meadow (47.4 %) and low-stem forest (5.3 %). The share of natural areas in the structure of the land fund of small towns of Belarus is 19 % (9 % are meadows, 4 % are bushy-vegetation, 3 % are water bodies, 2 % are marshes and 1 % is forests). Moreover, forest lands are only in 20 small towns of 74. Instead, there is no mire in only 13 towns, meadows – in 6. A characteristic feature of most small towns of Belarus (as well as small towns of Kyiv region) is the presence of water in the city and in suburban areas water objects. Forest areas are often found near small towns, but the introduction of them at the border of towns does not always correspond to the economic interests of the town economy, and the request for recreational use of forests in small towns is lower than in large, although in small towns there is a higher interest in the use of non-wood forest resources.

According to the recommendations of Luse (1978), developed in the Soviet times for small towns in Latvia, the greening rate for small towns should regulate the maximum permissible level of landscaping and be about 4 m² per capita. In our opinion, the introduction of such regulation for small Ukrainian cities would be extremely inappropriate and would lead

to an even more intensive reduction (development) of urban green spaces. According to the data of Srodnykh (2005), the number of common use plantings in most towns varies from 1.0 to 3.3 m²/capita, whereas according to norms should be 8 m²/capita. The provision of green public landscapes in studied small towns ranges from 1.2 m²/capita in Vyshneve to 17 m²/capita in Bucha (Fig. 4). Only two towns – Bucha and Ukrainka – have complied with this standard.

The disappointment dynamics of the provision of green public landscapes (parks, squares). Thus, at the time of the development of the past Master plan of Vyshhorod, the provision of green public landscapes was 6.7 m²/capita, while the Master plan provided for its increase to 13.0 m²/capita. Instead, the park in the centre of the town was built up with multi-storey buildings, and now the territory of common-use plantations has decreased by 2.7 times: from 13.7 to 5.1 ha, and their population's supply – by 3.4 times: from 6.7 to 2 m²/capita. The newly created park is a garden. A similar situation is observed in Vyshneve. In Bucha, however, 47.7 % of the greened areas constitute green public utilities, and 52.3 % are urban forests.

Per capita green space index in European cities (Table 1) ranges from 5.8 (Bari) and 8.8 (Ljubljana) to 32.9 (Malmo) and 31.4 (Edinburgh), although in the total for Eastern Europe was 13.7 m²/capita. Comparing with these figures, the value of provision of green public landscapes, only among the Ukrainian small towns in Bucha, this indicator corresponds to the average for Eastern Europe. Counting all the green spaces, which included garden communities, recreation centres, cemeteries, meadows and other territories, in addition to the green spaces of gener-

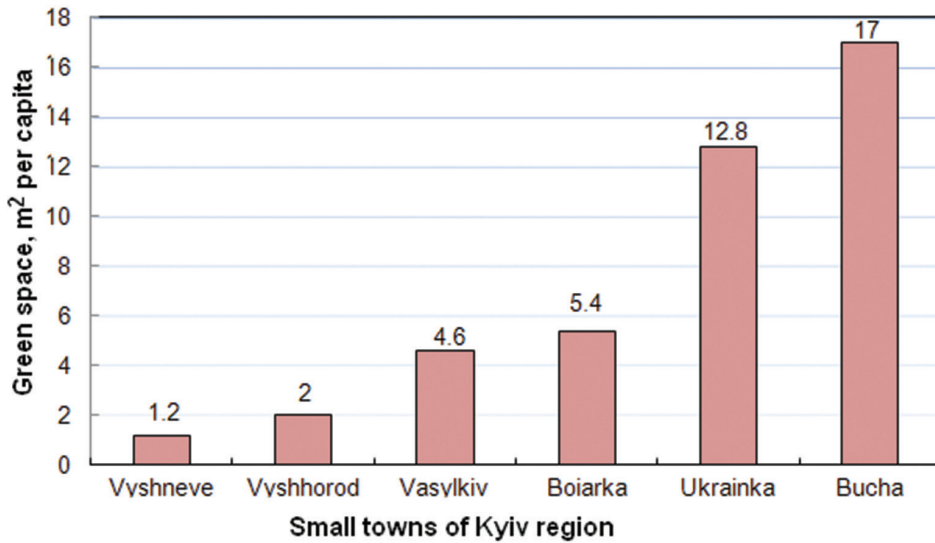


Fig. 4. Provision of small towns with green spaces of public use.

al use, allowed obtaining the results of the provision of greenery in cities within 25.7 m²/capita (Vyshneve) to 294.9 m²/capita (Bucha) that is comparable to European cities (Table 2).

The inclusion in the calculation of ur-

ban forests did not improve the figure for Vyshneve, where there are no forests. Table 3 shows the public availability of green public spaces, all green spaces and green infrastructure calculated according to the actual master plans of small cities.

Table 2. Per capita values for Kyiv's small towns.

Indicator	Vyshneve	Vyshhorod	Kaharlyk	Boiarka	Bucha
Per capita green space, m ²	25.7	40.3	73	73.8	294.9
Per capita green+forest, m ²	25.7	83.7	398.3	79.9	310.2
Per capita water area, m ²	0.1	10.6	76.4	3.1	14.4

Table 3. The provision of the population of small towns of Kyiv region with green space.

Town	Provision, m ² per capita		
	Green spaces of public use	Green areas	Green infrastructure
Vyshneve	1.2	25	25
Vyshhorod	1.8	128	167
Vasylkiv	4.6	177	328
Boiarka	5.4	118	145
Fastiv	17.8	166	436
Bucha	25.9	192	326
Yagotyn	30.7	365	1968
Pereyaslav	42.5	313	530
Kaharlyk	73	283	1188

The relatively high rates for Kaharlyk are explained by the small population (13.8 thousand) and the large area of the town, over 80 % of which is occupied by agricultural land, and for Yagotyn by the large area of reservoirs. In general, the data obtained indicate that the results of the approach to landscaping indicators used in Ukraine differ significantly from those used in developed European countries: the availability of green space (green plantations) differs significantly from the area of all green space and the area of green infrastructure. According to the traditional calculation for the post-Soviet space, the area of green space exceeds 300 m² per capita for only two towns, and for green infrastructure – for six towns.

The indicator of green space for public use meets the established standard (8–11 m² per capita) only for Kaharlyk, Pereyaslav, Yagotyn, Bucha, Fastiv (in order of decreasing its nominal value). Taking into account all green infrastructure (i.e. not all built-up areas covered by vegetation or water), it is 25 m² per capita only for Vyshneve, and for the rest towns it ranges from 167 to 196 m² per capita.

Figure 5 shows the dendrogram for 9 observations of small towns of Kyiv region by the similarity of the main indicators of landscaping of their territories.

The first cluster included towns with maximum green space and relatively low landscaping; to the second cluster – towns with higher levels of landscaping

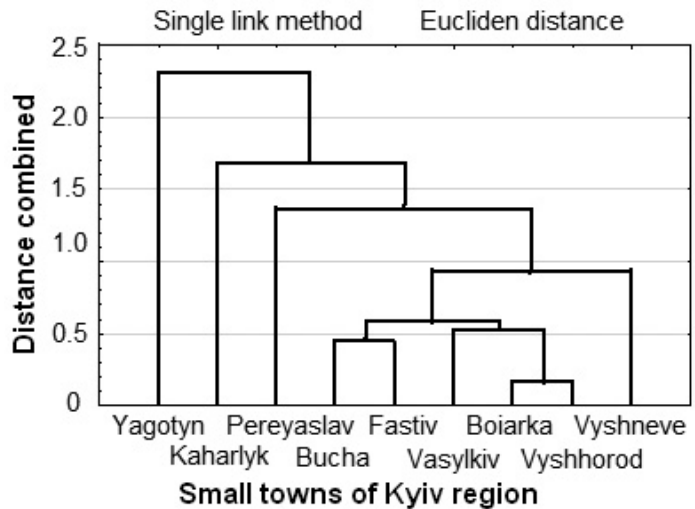


Fig. 5. Dendrogram of similarity of small towns of Kyiv region in terms of landscaping.

Note: Cluster 1: Yagotyn, Pereyaslav, Kaharlyk; cluster 2: Vyshhorod, Vasylykiv, Boiarka, Fastiv, Bucha; cluster 3: Vyshneve.

but low availability of green spaces for public use. The third cluster included the town with the worst greening values. The data obtained indicate a polarized situation in small towns of the region. Similar results were found for the balance of China's urban infrastructures, with only 40 % of cities achieving acceptable performance (Wang et al. 2019).

Conclusions

Results of the conducted analysis confirm the data available in literary sources on the current state of use of land resources of small towns, as well as other urban areas, therefore highlighting the fact that the norm and requirements of sustainable environment management are not adhered. Investigated small towns are characterized by excessive areas of property development and extremely low levels of natural areas, and often insufficient

areas of green space, especially those intended for public use (i.e., parklands, unrestricted recreational use), which requires further balancing. Such situation is typical for cities, where recreation areas are scarce due to the excessive property development. In small cities, there is a fairly dense inverse correlation between the built-up area and the agricultural area, which primarily results in the expansion of the building.

Compared to European cities, the relative size of living space in the structure of small towns is on average 6.1 % higher and the area of urban forests on average 3.6 times smaller. The relative area of green space in small towns is much higher than in European cities.

The analysis of small towns by arrangement of green spaces indicators as eco-performance of territories showed that, with the exception of Vyshneve, the ecological situation in the pilot small towns of the Kyiv region can be considered satisfactory.

Only 21 % of experimental small towns have relatively high landscaping rates. Provision of green space for residents of Ukrainian small towns is comparable to similar indicators of European cities.

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STRUCTURE AND STOCKING CONTROL OF UNEVEN-AGED CONIFEROUS STANDS IN BULGARIA

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Abstract

This paper presents results of a study on the stand structure and some stocking control approaches of uneven-aged coniferous stands. The even-aged forest management prevails in silvicultural practices in Bulgarian forestry. Uneven-aged silviculture started in the early 1930s when the Biolley control method has been applied in the forest management plan of 'Chamkoria' forest. There is relatively little knowledge of uneven-aged forest management compared to a large amount of forest research related to even-aged one. The stand structure of uneven-aged stands is described by diameter distribution and normal, exponential and Weibull distributions have been tested for fit. The optimal distribution of trees by diameter classes (14–18 cm, 22–38 cm, above 42 cm) is calculated for stands with exponential and Weibull distribution.

Key words: exponential distribution, Gini index, normal distribution, Norway spruce, Silver fir, Weibull distribution.

Introduction

The uneven-aged forest management in Bulgaria started in 1924 (Rafailov 2003) when in the then definitive forest management plan of the 'Chamkoria' municipal forest the separation of 2 management units was envisaged, for one of which (200 ha) a selection system with a 40-year rotation period was planned to be introduced. In the definitive forest management plan (DFMP) of the same forest from 1936, the uneven-aged management was planned to be carried out on an area of 1325.41 ha, using the control method, and another 218.93 ha had to be selected for selection segments, the amount of use of which to be tailored to 'recreational needs at any given time' (cit. DFMP).

Due to the lack of regional data on the structure of the stands and the optimal growing stock, data from Switzerland were adopted. The following diameter classes were proposed: small – 14–24 cm, medium – 26–40 cm and large – over 40 cm, with a stock ratio of 20:30:50 % respectively.

The application of the control method has been interrupted in 1952, and this required the development of new methods for the management of these forests. Nedyalkov (1963, 1965a,b) grouped the stands at three levels of productivity at equal ratio of tree number and stocks by diameter classes (40:50:10 % and 15:50:35 %).

In clarifying the questions regarding the distribution of the trees by diameter

classes, different approaches have been developed over the years.

Among the most widespread distribution models are the negative exponential distribution (Meyer 1953, Leak 1965, Alexander and Edminster 1977, Murphy and Farrar 1981, Cancino and von Gadow 2002, Gül et al. 2005, Westphal et al. 2006), Weibull distribution (Stiff 1979, Martin 1982, Khatouri and Denis 1990, Gove and Fairweather 1992, Zhang and Liu 2006) and the Beta distribution (Zöhrer 1969, 1970; Loetsch et al. 1973; Larsary et al. 2016).

The negative exponential diameter distribution has an advantage due to its comparative simplicity and its widespread practical application in the management of the uneven-aged forests, whereas the Weibull distribution is characterized by its versatility and ability to describe a variety of different biological models.

Various methods for describing the diameter distribution are also known in the literature provided that the basal area is adopted in advance (Leak 1964, Moser 1976, Cancino and von Gadow 2002). The approach of Cancino and von Gadow (2002) is appropriate for determining the annual allowable cut for the uneven-aged forest when a pre-determined balanced exponential distribution is established.

The ideal diameter distribution could be described (Meyer 1953) using the smallest diameter ($d_{\min}$), the target diameter (d_t), the coefficient q , the target basal area (B) and the number of trees with the target diameter (N_t).

According to Kerr (2014), the publication of de Liocourt of 1898 has been misunderstood and incorrectly quoted. The most common error is that in this case the Silver fir stands that are managed under the selection system have a diameter distribution with a constant value of

q , and according to Kerr (2014), none of the distributions have a constant value of q . Picard and Gasparotto (2016), revising the original publication of de Liocourt of 1898, conclude that nothing is said about a geometric sequence for reducing the number of trees from small to large diameter classes, and in fact the publication concerns only a polynomial of 4th degree. Thus, the well-known common ratio of the geometric sequence has been described in 1900 by de Liocourt (1900) (according to Picard and Gasparotto 2016) and the average ratio was 1.4.

One of the main considerations for the management of multi-aged forest stands is to achieve sustainability in terms of productivity and forest structure. The objective is to maintain a sustainable horizontal and vertical structure in each subsequent rotation period (cutting cycle) while maintaining the constant target stock.

One of the most popular methods for the management of uneven-aged stands is the BDq method (O'Hara 2002, Rafailov 2003, Trasobares and Pukkala 2004). It is believed (Kerr 2014), that it has been first applied in the northern hardwood forests of the eastern side of North America by Meyer and Stevenson (1943) (cit. by Kerr 2014). The B defines a basal area, the D is the target diameter at breast height and q is the common ratio of geometric series of the number of trees by diameter classes.

The change in the value of ' B ' allows foresters to increase or decrease the growing stock of the stands. At the same value of q , the increase in B will result in an increase in the number of trees by diameter classes and hence an increase in the stock. The target diameter can also be changed and will accordingly affect the value of the basal area.

The value of the coefficient q does

not have a biological meaning, and it is not sufficient for determining the density of individual forest stands and what type of cuttings to plan. Managing of uneven-aged forests is a complex task, which, except the balanced structure of diameter and different treatment for individual tree species in the stand composition, includes also the issue what diameter classes will be harvested.

Maintaining the diameter distributions by changing the q values will result in a different number of trees in small and large diameter classes, and hence in the density and area available for the individual trees. Ideally, only the trees that exceed the ideal distribution should be cut. In practice, the shortage of trees at certain diameter classes will lead to deviations in the use of adjacent classes.

The disadvantage of this method is that it cannot be used for cases when uneven-sized forest stands are concerned which however are not uneven balanced. With the adoption of the negative exponential distribution, trees can be cut without considering the rate of growth and the individual characteristics of the stands.

Stand density index (SDI) has been developed by Reineke (1933) as a measure of relative density for even-aged stands. There is a linear relationship between the logarithm of the number of trees (N) and the logarithm of quadratic mean diameter for even-aged stands at maximum stand density.

For uneven-aged stands SDI has been proposed by Long and Daniel (1990) using individual tree diameters – equation (1) or diameter classes – equation (2) and the number of trees represented by the tree or class.

$$SDI = \sum \left(\frac{D_i}{10} \right)^{1.6}, \quad (1)$$

where D_i is the breast height diameter in

inches of the i -th tree in the stand.

$$SDI = \sum (TPA_j \left(\frac{D_j}{10} \right)^{1.6}), \quad (2)$$

where: D_j is the middle of the j -th diameter class (in inches), and TPA_j is the number of trees per acre in the j -th diameter class.

When SDI is calculated by any of the above formulas, according to Ducey and Larson (2003) it is not identical with the one proposed by Reineke and should be marked with SDI^* . Long and Daniel (1990) consider it is not necessary the distributions that are considered to be balanced to have even distribution of their basal area or SDI by diameter classes. This contradicts the assumption that the balanced uneven-aged structure has an equal growing space by diameter classes. An alternative is allowed, with the presence of fewer trees with small diameters, a larger number of thicker trees, and a smaller total number of trees.

An alternative method for stocking control of an uneven-aged stand has been proposed by O'Hara (1988), recommending the use of the leaf area index (LAI), which is a ratio of the total leaf area per unit of a land surface. The author suggests that with such an approach, the forester can be advised about the possible density of the understory at a given diameter distribution of the upper layer.

This is a non-standard approach that goes beyond maintaining certain diameter distributions but focuses on maintaining structures that are directly related to productivity and growth and considers the differential growth rates of the particular cohort as well as the maximum LAI. In loblolly-shortleaf pine stands management in the USA volume control guiding diameter limit method has been used (Baker et al. 1996, Guldin 2002). First the maximum stand productivity must be determined, then the volume growth rate calculated

and the cutting cycle length determined. Determining the allowable cut is done by multiplying the annual growth rate by the cutting cycle length.

The 'unit area control' method (Hallin 1959) has been developed as a means for controlling heterogeneous forest stands by separating them into small areas, thus transforming an uneven-aged structure throughout a form of group selection.

The optimization of the forest management can be done through a set of models and appropriate software for predicting the dynamics of the stands under different management parameters (Haight et al. 1992, Palahí and Pukkala 2003, Trasobares and Pukkala 2004).

Krastanov (1975) has suggested a method for calculation the value of annual allowable cut that has been subsequently implemented in Bulgaria and is still used today, which is related to the analysis of the value of the growing stock and its comparison first to the optimal growing stock, then to the volume distribution of territory by age classes and last – to the number of trees. Then the number of trees is compared to the optimal structure within the diameter classes. The intervals in the diameter classes are 14–18 cm, 22–38 cm and over 42 cm.

Annual cut (E) is given by equation (3).

$$E = V_a - V_{opt} + Z_v \quad (3)$$

where: V_a is actual growing stock, $\text{m}^3 \cdot \text{ha}^{-1}$; V_{opt} – optimal growing stock, $\text{m}^3 \cdot \text{ha}^{-1}$; Z_v – current annual increment for the future 10-years, $\text{m}^3 \cdot \text{ha}^{-1}$.

For the optimal stock structure by diameter classes and productivity groups, the following ratios are assumed for the volume (5:35:60, 8:37:55, 10:40:50 %) and for the number of trees (35:45:20, 40:42:18, 45:40:15 %). Optimal growing stocks are 400, 300, 250 $\text{m}^3 \cdot \text{ha}^{-1}$, and target diameters – 74, 70, 66 cm.

The goals of this study were to quantify existing structure in uneven-aged mixed and pure conifer stands with a focus on diameter distribution, to assess the capacity of two indices (Gini index and coefficient of variation) and to propose optimal percentage structure of the number of trees in three diameter classes (I: 14–18 cm; II: 22–38 cm; and III: over 42 cm).

Materials and Methods

The data for this study was collected in Rila and Rhodopes Mountains of the Republic of Bulgaria at the territories of experimental forestry enterprise 'Yundola' and State forestry enterprise 'Beglika' (Fig. 1).

The average temperatures for the Rila Mountains are 4.8–7.4 °C, the average number of days with $t > 10$ °C is 110–150, the amount of precipitation is 850–960 mm per year. For the region of the western part of the Rhodopes the average temperatures are 4.8–6.4 °C, the average number of days with $t > 10$ °C is 100–140, the amount of precipitation is 800–950 mm per year.

The forest stands in which the sample plots were located are predominantly mixed fir-spruce-beech-pine and pure spruce stands and are situated in the range 1400–1750 m a.s.l. They are classified as EUNIS (Davies et al. 2004) habitat types: G3.4C Southeastern European *Pinus sylvestris* forests, G3.1E *Abies* and *Picea* woodland, G3.16 Moesian *Abies alba* forests, G4.6 Mixed *Abies-Picea-Fagus* woodland.

All stands are managed. On the territory of Yundola single-tree selection system and selection thinning has been carried out. In the early stages of transformation on the territory of Beglika, a group-selec-

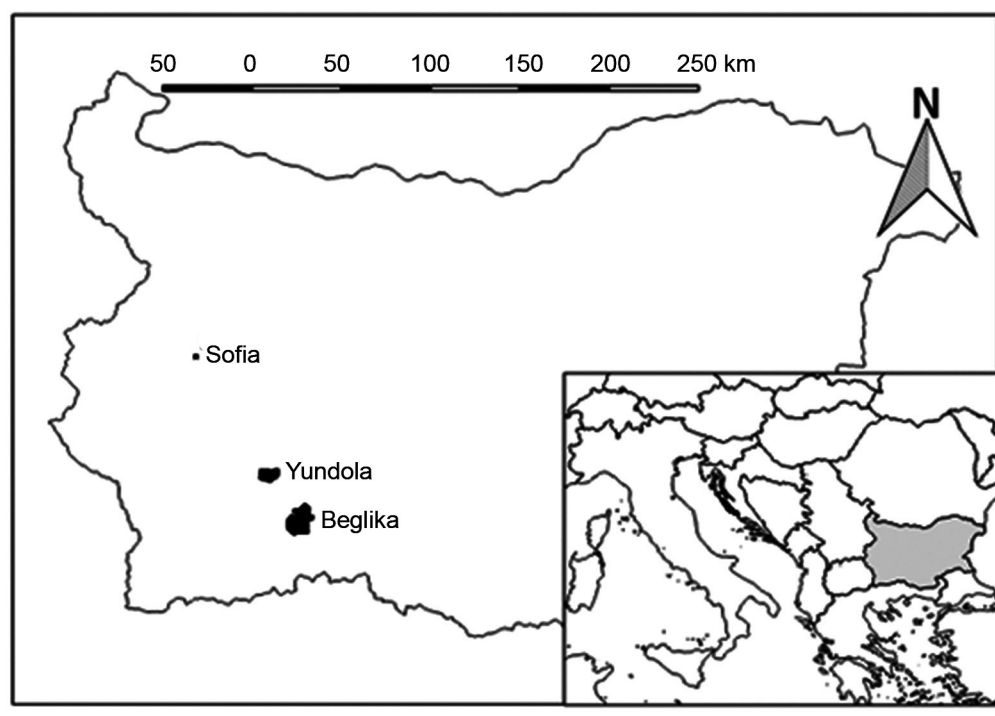


Fig. 1. Study area of experimental forestry enterprise 'Yundola' and state forestry enterprise 'Beglika'.

tion system has been carried out for heterogenization of the vertical stand structure.

Data were collected from 2 permanent and 24 temporary sample plots. The permanent sample plots have been set up in 1949. They are rectangular with an area of 0.2 ha and the aim was an observation of structure and productivity of stands for conversion into two-aged Scots pine-Norway spruce stands. The temporary sample plots were circular with radii of 20 or 25 m, requiring a minimum of 50 trees. All trees with a diameter at breast height over 6 cm were inventoried by diameter classes of 4 cm.

The characteristics of sample plots are given in Table 1.

To estimate the heterogeneity of all stands using the 'gini' function from 'reld-

ist' package (Handcock 2016), the Gini index (the ratio of the area separated by the Lorenz curve and the diagonal and area which is below the diagonal – Fig. 2) was calculated by equation (4).

$$G = \frac{\sum_{j=1}^n (2j - n - 1) g_j}{\sum g_j (n - 1)}, \quad (4)$$

where: g_j is the basal area of the tree with rank j ; j is tree rank according to a diameter at breast height in ascending order 1, ..., n ; n is total number of trees.

The index quantifies the deviation of the index from the perfect equality line with a minimum of zero and a theoretical maximum value of 1. With the increase of stands heterogeneity, the Gini index has higher values.

Table 1. Characteristics of sample plots.

Sam- ple plot	Stand composition, %	Upper diameter class, cm	Average diameter, cm	Dominant height, m
Yu1	PA – 65, AA – 31.4, FS – 3.6	98	33.8	38.5
Yu2	PA – 59.6, PS – 20.8, AA – 16.3, FS – 3.3	82	33.9	39.5
Yu3	PA – 61.9, PS – 19.5, AA – 15.6, FS – 3.0	74	35.9	36.3
Yu4	PA – 46.6, PS – 35.7, AA – 17.0, FS – 0.6	86	33.4	37.1
Yu5	PA – 47.3, PS – 36.0, AA – 15.4, FS – 1.4	86	32.4	37.2
Yu6	AA – 53.8, PA – 33.4, PS – 8.4, FS – 4.5	82	31.2	35.4
Yu7	PS – 46.3, PA – 32.4, AA – 20.9, FS – 0.4	86	32.7	35.2
Yu8	PS – 58.3, PA – 25.3, AA – 15.5, FS – 0.4, PT – 0.3	82	32.6	34.1
Yu9	AA – 67.8, PA – 17.6, FS – 12.7, SA – 0.7, PS – 0.6, SC – 0.6	102	35.7	32.8
Yu10	AA – 67.9, FS – 17.3, PA – 14.6, PS – 0.2	94	40.2	32.2
Yu11	AA – 63.2, PA – 21.0, FS – 15.7, PS – 0.1	110	34.7	36.3
Yu12	AA – 72, PA – 17.9, FS – 9.5, SA – 0.6	82	32.3	31.9
Yu13	AA – 76.9, PA – 12.8, FS – 9.9, PS – 0.3	74	33.1	34.3
Yu14	AA – 58.8, PA – 32.3, FS – 8.8, PS – 0.2	90	31.9	33.3
Yu15	AA – 49.0, PA – 31.2, FS – 18.7, PS – 1.2	102	34.8	37.6
Yu16	PS – 72.4, PA – 27.6	46	24.6	30.8
Yu17	PS – 52.5, PA – 47.5	46	25.8	31.6
Yu18	PA – 100	34	14.6	14.5
Yu19	PS – 75.2, PA – 24.8	42	23.7	32.8
Yu20	PS – 52.6, PA – 47.4	46	25.0	34.3
Yu21	PA – 100	34	15.3	15.3
Be1	PA – 82.6, PS – 17.4	86	37.6	35.3
Be2	PA – 82.1, PS – 17.7, AA – 0.2	82	34.8	34.1
Be3	PA – 90.1, PS – 9.9	82	33.8	35.8
Be4	PA – 95.2, PS – 4.8, AA	90	35.9	32.2
Be5	PA – 99.5, PS – 0.3, AA – 0.2	70	32.8	34.0

Note: AA – Silver fir (*Abies alba* Mill.), PA – Norway spruce (*Picea abies* (L.) H. Karst.), PS – Scots pine (*Pinus sylvestris* L.), FS – European beech (*Fagus sylvatica* L.), PT – European aspen (*Populus tremula* L.), SA – Rowan (*Sorbus aucuparia* L.), SC – Goat willow (*Salix caprea* L.).

The normal, the Weibull and the negative exponential distributions are used for fitting the empirical data. The probability density functions (PDFs) of the normal, the Weibull, and the negative exponential distribution were calculated by equations (5), (6), and (7) respectively.

$$f_{(norm)}(x | \mu, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad (5)$$

where: μ and σ are the mean and the standard deviation;

$$f_{(Weibull)}(x | \alpha, \beta) = \frac{\alpha}{\beta} \left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^\alpha}, \quad (6)$$

where: α and β are the shape and the scale parameter;

$$f_{(exp)}(x | \alpha, \gamma) = \alpha \exp(\alpha, x), \quad (7)$$

where: scale parameter $\alpha > 0$.

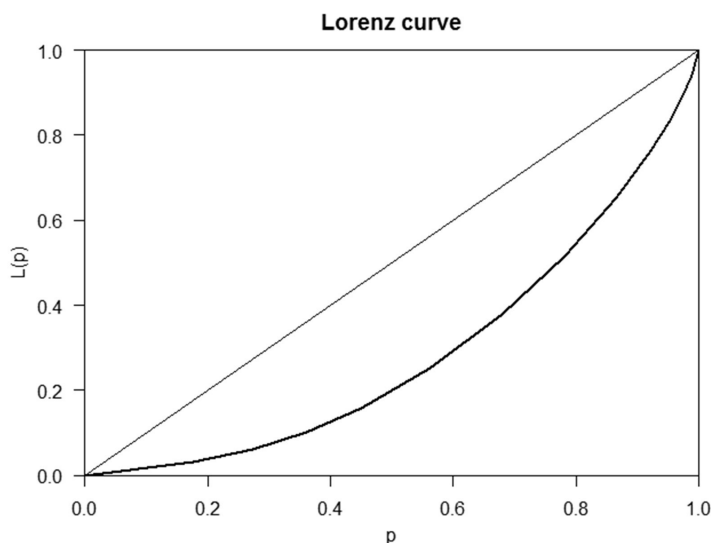


Fig. 2. Lorenz curve for sample plot U7.

The coefficient of variation (CV%) was calculated using equation (8).

$$CV\% = \frac{s}{\bar{x}} 100, \quad (8)$$

where: s is the standard deviation of diameters for grouped values; $\bar{x}$ – an average of diameters.

The Shapiro-Wilk test was used for determining of sample plots with the normal distribution. The Hartigan Modality Test (Maechler 2016) was applied to identify all sample plots with most likely bimodal or multimodal distributions. The most likely theoretical distribution for sample plots that reject the null hypothesis (H_0 : data come from a population with normal distribution) was determined using the Anderson-Darling test and the `fitdistr` function of the MASS package (Venables and Ripley 2002). When there was more than one adequate model, the choice was based on the lower Akaike information criterion (AIC).

To analyze the differences of the Gini coefficients and the variation coefficients

by type of distribution, the single-factor ANOVA was used, followed by a post-hoc Tukey multiple range test. To determine the confidence interval of the Gini indices and the variation coefficient, a bootstrap procedure based on the Monte-Carlo method (Canty and Ripley 2017) was applied.

Parameter q that characterizes the diminution ratio of the number of trees between successive diameter classes was calculated according to Meyer (1952) and Gul et al.

(2005) using equation (9):

$$q = e^{-\alpha w}, \quad (9)$$

where: α is the rate of negative exponential function; w – width of the diameter class.

Results

After applying the Shapiro-Wilks test whether the samples come from a normal distribution, it was found that 8 of the 26 sample plots could not reject the null hypothesis (Yu16-Yu21, Be2, Be4), which indicates that the distributions are normal. In the remaining 18 stands, most adequate distribution was determined using the Anderson-Darling test goodness-of-fit to a specified continuous univariate probability distribution.

For sample plots, Yu2, Yu4-Yu9, Yu11, Yu12, Yu14, Yu15 the Weibull distribution model was the most adequate and for sample plots Yu1, Yu3, Yu10, Yu13, Be1,

Be3, Be5 the most adequate model was the exponential distribution.

According to the Hartigan test, no bi-modal or multimodal distribution is presented in the investigated sample plots.

For the comparing the results to these of other studies, the coefficients of the Gini index and the variation coefficient were calculated for diameters of breast height over 12 cm.

The Gini coefficients varied from 0.243 to 0.609 with an average value of 0.442, with the coefficient of variation $\min = 22.9\%$, $\max = 65.9\%$, average value of 44.22 %.

The one-way ANOVA shows a statistically significant difference between the Gini coefficient, the variation coefficient (C.V.) and the factor 'type of distribution' (Table 2).

Table 2. Anova table for the Gini coefficient and the variation coefficient.

Source	Degrees of freedom	Sum of squares	Mean squares	F value	Pr (>F)
Gini – type of distribution	2	0.1147	0.0574	16.50	<0.001
Gini-residuals	23	0.0800	0.0035		
C.V. – type of distribution	2	1492.79	746.40	15.43	<0.001
C.V. – residuals	23	1112.82	48.36		

The Tukey's range test was performed to identify differences between means of each type of distribution for the Gini coefficient and the variation coefficient. There were no significant differences between mean values for Weibull-exponential distribution,

while the means of the normal-exponential and the Weibull-normal distributions were significantly different (Fig. 3).

To evaluate forest stands heterogeneity in terms of the diameter distribution by classes according to the values of the

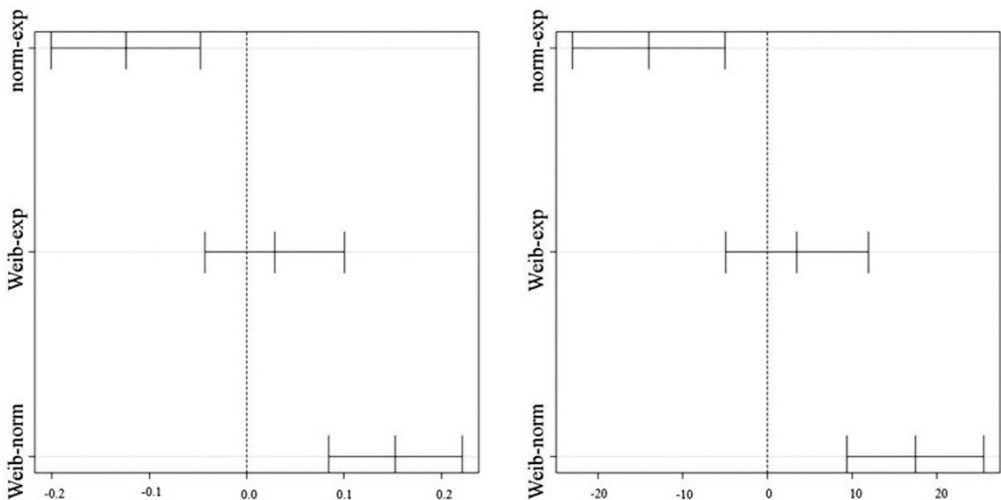


Fig. 3. Plot of the Tukey's HSD estimated differences and confidence intervals for the Gini index (left) and for the variation coefficient (right).

Gini index and the coefficient of variation, their confidence intervals are determined

by applying the bootstrap procedure. The results are presented in Table 3.

Table 3. 95% confidence intervals of variation of the Gini index and the variation coefficient.

Type distribution	Gini coefficient			Variation coefficient		
	Kendall's tau	lower	upper	Kendall's tau	lower	upper
Normal	0.344	0.297	0.391	33.05	28.27	37.96
Weibull	0.497	0.463	0.531	50.54	46.18	54.68
Exponential	0.468	0.443	0.4939	47.04	44.27	49.75

The confidence intervals of the exponential-normal distribution and the Weibull-normal did not overlap until the Weibull-exponential distribution did. In other words, according to the Gini coefficient and the variation coefficient, only the exponential from the normal distribution and the Weibull from the normal distribution could be distinguished with statistical confidence.

Linear regression analysis and Pearson correlation coefficient were performed to determine the correlation between the Gini index and the variation coefficient (VC%) of diameter numbers by equation (10).

$$VC\% = 115.159 \cdot \text{Gini index} - 6.711 \quad (10)$$

The coefficients of VC% (10) were statistically significant, R -squared = 0.9907.

The obtained equation allows predicting the values of the variation coefficient and hence the affiliation of a stand to the respective distribution type only by the value of the Gini coefficient, which could be calculated easily after the inventorying the trees.

The q -coefficient values for the exponential and the Weibull distribution ranged from 1.164 to 2.059 with a mean of 1.444 (p -value < 0.001). The Kruskal-Wallis test showed a statistically significant difference between the values of q -coefficient

and the factor 'type' of distribution (Kruskal-Wallis chi-squared = 7.138, p -value = 0.0075). The 95% intervals for the q -coefficient for the exponential and the Weibull distribution were obtained after the bootstrap procedure. The intervals were 1.195–1.290 (Kendall's tau – 1.242) for the exponential and 1.405–1.739 (Kendall's tau – 1.572) for the Weibull distribution, respectively.

There was no statistically significant difference between the percentage of trees for the different diameter classes and the type of distribution. The average values for Class I (14–18 cm) were 34.5 %, for Class II (22–38 cm) – 39.0 % and for Class III (>42 cm) – 26.5 %.

Discussion

From the study of 14 Alpine Norway spruce stands in the Rhodopes, Aleksandrov (2015) has found that 5 of the stands fits the exponential, 4 – the uniform, 3 – the normal distribution and 1 stand is bimodal. Aleksandrov and Molle (2014) reported no statistically significant relationship between the Gini index values and the three groups of distributions, and only the STVI index (Staudhammer and LeMay 2001) demonstrated such a relationship. There was a clear distinction between the

exponential and the bimodal distributions on the one hand and the uniform distributions, on the other. There was no significant difference between STVI values and the bimodal distribution, and the exponential distribution.

Although there are numerous indices in the literature to describe the heterogeneity of the stand structure, the Gini index has become the best predictor (Lexerød and Eid 2006).

In a study of the diameter structure for even-aged and uneven-aged stands of Norway spruce and Scots pine, Lexerød and Eid (2006) set a Gini coefficient in the range from 0.21 to 0.51 (mean value – 0.38). They reported that the values from 0.16 to 0.30 corresponded to normal distribution, while the range from 0.44 to 0.57 corresponded to J-shaped distribution.

In a study of management systems (clear cut management system and selection forestry) for Austria, Sterba and Ledermann (2006) found range of the Gini coefficient from 0.3 to 0.5, and for most of the studied period the values were above 0.4. For mixed Norway spruce, Silver fir and European beech stands in Switzerland O'Hara et al. (2007) reported values for even-aged stands between 0.2 and 0.6 (except values above 0.3) and uneven-age stands between 0.4 and 0.7.

For uneven-aged Norway spruce, Silver fir and European beech stands in Romania, Duduman (2011) established the following ranges for the Gini index (G_i): even-sized structure: $G_i \leq 0.35$; two-sized: $0.35 < G_i \leq 0.43$; uneven-sized irregular: $0.43 < G_i \leq 0.51$ and uneven-sized balanced: $G_i > 0.51$. Studying the stand dynamics of Silver fir and European beech stands in Slovenia Klopčič and Bončina (2011) set values of G_i 0.35 to 0.52, while the values for mixed uneven-aged forests of two study areas of *Juglans mandshurica*

Maxim., *Fraxinus mandshurica* Rupr. and *Phellodendron amurense* Rupr., *Quercus liaotungensis* Koidz., *Carya cathayensis* Sarg. and *Pinus armandii* Franch. of Northern China ranged from 0.58 to 0.64 (Hui and Pommerening 2014).

Studying the results of a 40-year transformation period to an uneven-sized structure of *Picea abies*, *Abies alba*, *Fagus sylvatica*, *Larix decidua*, *Pinus sylvestris* in the Czech Republic Kadavý et al. (2017) obtained a Gini index variation values from 0.32 to 0.59.

Duduman (2011) and Kadavý et al. (2017) established a linear relationship between the Gini index and the coefficient of variation of the diameters, with the resulting patterns of this regression being relatively close. The linear model derived from our data is very close to the Duduman model (2011) and differs from that of Kadavý et al. (2017).

Applying Gini index interval values from the present study with those reported of Duduman (2011) for all sample plots, 4 of the stands reach the even-sized structure, 6 stands reach the two-sized structure, 12 stands reach the uneven-sized irregular structure and 4 stands reach the uneven-sized balanced structure. The Gini index increases with age for uneven-aged stands, while in the even-aged stands cases it decreases. This, according to O'Hara et al. (2007) is due to the greater variety in the classes of diameter, and the increase in some even-aged stands is related to the development of the second cohort of trees.

Despite the advantages of the Gini Index, it cannot be used as a universal tool for assessing the structural diversity of the stands. It should be noted that stands with a different structure in diameter may have the same Gini indices (Weiner and Solbrig 1984), and the time between two

successive inventories should be considered (Kadavý et al. 2017). Also, the Gini index cannot distinguish the differences between a managed forest and an unmanaged one (Rouvinen and Kuuluvainen 2005).

The values of the variation coefficient of diameters here obtained are similar to these in similar stands in Romania (Giurgiu 1969, 1979; Leahu 1994), and for uneven-aged stands – 50–80 %.

The optimal structure of stands is an important feature of the selection forests. This structure, which provides long-term maximum current annual increment, can be considered as optimal. The optimal growing stock of a forest under certain habitat conditions, forest type and management is a variable that depends on the state of the stands of this type of forest. In each stand condition, it has certain values that must be the goal of the management for the future cutting cycle. Due to the small number of stands with an uneven-aged balanced stand structure, according to Duduman (2011) the range of the Gini coefficient, no optimum stock values are given, but only a distribution of the percentage of trees by diameter classes.

The values of the percentage distribution of the number of trees by diameter classes are very similar to these of Krastanov (1975) for the first group of productivity and for the habitat Mixed fir-spruce-beech woodland.

Conclusions

The distribution of studied coniferous stands could be fitted with the normal, the exponential and the Weibull function. The Gini index is a good descriptor of the type of diameter distribution and it is highly correlated with the variation coefficient. The

exponential from the normal distributions on one hand and the Weibull from the normal distribution on the other hand could be distinguished using the Gini index and the variation coefficient. The Gini index values obtained from this study are similar to these reported for the Central European forests.

Because of the lack of statistically significant difference between the percentage of trees for the different diameter classes from our data and these from Krastanov (1975) we could use them for stocking control and calculating the annual allowable cut for similar type of stands in other regions of Bulgaria.

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PHYTOINDICATIVE ASSESSMENT AND ANALYSIS VEGETATION IN DISTURBED AREAS AFTER ILLEGAL AMBER MINING IN THE WESTERN POLISSYA OF UKRAINE

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Abstract

The article presents results of studies on the vegetation of forest territories in the western part of Ukrainian Polissya, touched upon because of illegal amber mining. It has been established that the total species composition consists of 111 species, 80 genera and 30 families of vascular plants. Leading positions in the number of species occupy the families Poaceae and Asteraceae. According to the ratio of diagnostic species among the vegetation classes, representatives of the two classes *Molinio-Arrhenatheretea* and *Quercetea roburi-petraeae* occupy the leading positions in the phytosociological structure, and in general, the distribution of species of the Braun-Blanquet's classes of the flora studied is consistent with the type of vegetation, which prevailed in the territories prior the violations. According to the Calinski-Harabasz criterion, clustering the relevés dataset into two groups (A and B) is most acceptable. The naturalness of species composition of cluster A is higher and is credibly different from cluster B. Phytoindication scores of most factors except humidity (*Hd*) are significantly different between clusters A and B. Additionally, the largest difference being observed in the nitrogen values, with the sites of the cluster A corresponding to soils with the lower nitrogen availability. The studied vegetation retaining sand is comprising some natural features of the surrounding type of vegetation of Ukrainian Polissya. Moreover, the relative remoteness from populated and industrial places, together with the conservation of the surrounding forests creates a potential for a substantial recolonization of the land by forest plant species. Despite this, it is advisable to conduct land restoration activities and monitor succession changes over longer period.

Key words: constant species, differentiating species, land restoration, partial flora, phytoindication.

Introduction

The anthropogenic transformation of the natural environment, including its main consequence – the changes of vegetation – is rampant in the modern world (McGrath et al. 2015, Alkama and Cescatti 2016, Zanon et al. 2018). Historically, the territory of Ukrainian Polissya has been under a significant anthropogenic impact caused by agricultural practices (Bozhok 1976, Alekseyevsky and Bakhmachuk 1992, Khomyak et al. 2018) and radionuclide contamination (Yablokov et al. 2010, Beresford et al. 2016). In recent years, another environmental problem has been aggravated in Ukrainian Polissya – the illegal amber mining, which has long-term, serious environmental, social and economic consequences (Kazymyr and Bedernichek 2017, Kovalevsky et al. 2017, 2019, Kovalevskiy and Kovalevskiy 2019).

Amber is a mineral of organic origin, a petrified resin of ancient gymnosperms (including representatives of the Cupressaceae, Taxodiaceae and some others), and is now highly valued in various fields of industries, particularly in jewellery, chemical, and pharmaceutical industry (Melnichuk and Krynytska 2018).

Adverse effects of illegal amber mining are related to the disturbance or destruction of natural biotopes on large areas and the lack of land reclamation after mining activities. The types of anthropogenic impact associated with amber mining can be divided into two subtypes – direct (pitting, water washing) and indirect (cutting, changing the water-mineral regime of soils, biological invasions). All these factors slow down the processes of natural restoration of vegetation cover significantly, sometimes making them impossible (Gordeychuk 2013, Kazymyr and Bedernichek 2017,

Kovalevsky et al. 2017).

In the recent years, there has been a growing scientific interest in identifying new territories disturbed by illegal amber mining (Filipovich 2015, Filipovich and Shevchuk 2016, Masley et al. 2016, Shevchuk 2017, Yanchuk et al. 2017, Kravsovskiy et al. 2018), the effects of mining on the environment, and its impact on the restoration of forest and wetland landscapes of Polissya, including the territories of Rivne (Gordeychuk 2013, Lehkyi and Kovalevskii 2018), Zhytomyr (Kovalevsky et al. 2017, 2019), and Volyn (Kazymyr and Bedernichek 2017) regions of Ukraine.

At the same time, our knowledge on changes in environmental regimes and transformation of habitats due to illegal amber mining activities still remains insufficient and challenges the need for additional researches. Our study has been devoted to measure the mentioned points quantitatively using a method of phytointication, which gives us a basis for understanding of underlying processes in vegetation and is certainly a necessary condition for the rational use and conservation of the disturbed area.

The purpose of our research was to study the structure of vegetation resulting from amber mining activities, and environmental analysis of habitats. The changes of this level of the ecosystem components directly affect the potential restoration of primary vegetation after reduction of anthropogenic impact. The anthropogenic impact not only affects vegetation, but also potentiates a change in the environmental conditions. Therefore, the application of phytointication is still relevant from the point of view of predicting the future trend in the restoration of vegetation and assessing the potential recoverability of climax vegetation.

Region of Research

Figure 1 reveals the location of 6 amber mining sites where the vegetation studies and ecological assessment of habitats were conducted. The localities are in

the central and western part of Ukrainian Polissya in the Northwestern Part of Ukraine.

General characteristics of the territories studied, as well as the scale and methods of amber mining are shown in Table 1.

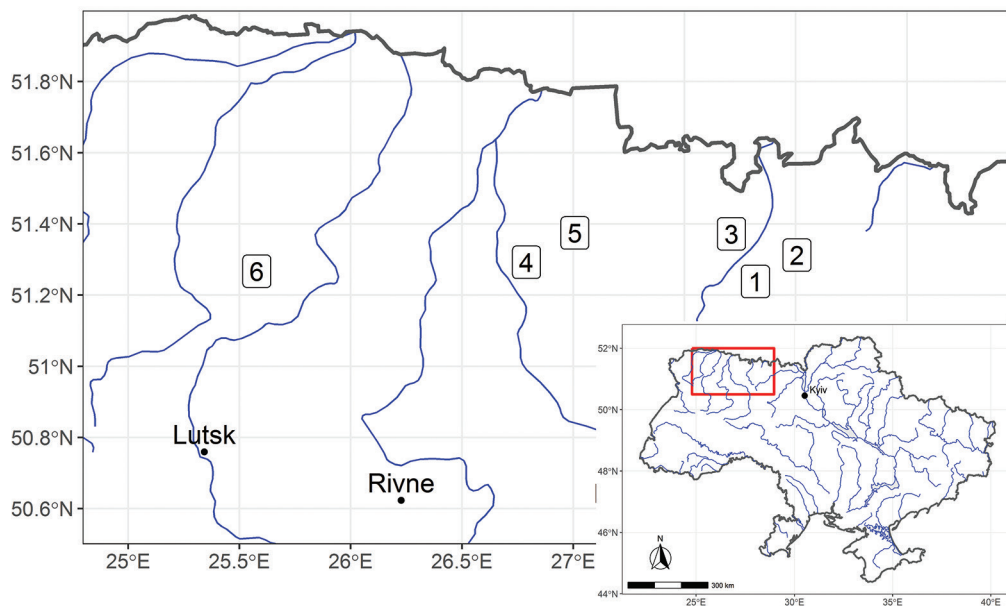


Fig. 1. Location of amber mining sites on the map of Ukraine studied in this research.

Table 1. Localities of the Western part of Ukrainian Polissya damaged by illegal amber mining.

No	Name of forestry (forest square/ allotment)	Type of EUNIS habitats prior disturbance*	Estimated area of disturbance, ha	Year of starting of field work	Preferred mining method**
Olevsk district, Zhytomyr region					
1	Poiaskivske (21/5,7,18)	G3.4	27,2	2014	1
2	Poiaskivske (20/17,20,32)	G3.4	6,5	2014–2016	1
3	Yuriivske (65/14)	G3.4	0,6	2015	2
Klesiv district, Rivne region					
4	Klesivske (40/8)	G3.E	2,8	2014	1
5	Liubonske (7/14)	G3.4	2,1	2014	2
Manevychy district, Volyn region					
6	Vovchetske(42/28)	G3.E	5,9	2014	2

Note: * – following Onyshchenko (2017); ** 1 – underground water washing (hydromechanical method), 2 – manual digging of amber (after Volnenko et al. 2017).

Depending on the method of amber production, the nature of transformation of edaphotopes at the sites studied differs (Malanchuk et al. 2016, Volnenko et al. 2017). The main soil-forming layers are the re-deposited fluvio-glacial deposits (moraines), on which podzolic and sod-podzolic weak- and medium-podzolic soils of light (sandy), rarely sandy loam, mechanical composition were formed. Most often, after the hydro-fluid, a secondary wetland is formed, with the upper horizons of the soil profile being washed away, overlapping with a slurry solution. In the case of amber mining, the site has an uneven micro-relief, covered with pits; the upper horizons of the soil profile are mixed with clay layers and siltstones, fluvio-glacial deposits, moraine.

The vegetation is dominated by fresh pineta (pure Scots pine forests) and subors (Scots pine forests with an additional tree stratum), as well as dry (lichen) pinetum sand oligotrophic and mesotrophic marshes. The main forest-forming species is *Pinus sylvestris* L. with an admixture of *Betula pendula* Roth. Such species as *Betula pubescens* Ehrh., *Quercus robur* L., *Populus tremula* L., and *Alnus glutinosa* (L.) Gaertn, tend to occur in relief depressions.

Materials and Methods

In amber mining sites, vegetation studies were carried out using phytosociological methods (Mueller-Dombois and Ellenberg 2002).

Vegetation was studied on 100 m² sample plots. The cover abundance score of all vascular plants was recorded using a 6-point Braun-Blanquet's scale (Braun-Blanquet 1964). The adopted taxonomic concept of species corresponds to

the checklist of species of Ukraine (Mosyakin and Fedoronchuk 1999). Classification of species relative to Braun-Blanquet's classes follows the EuroVegChecklist (Mucina et al. 2016).

Further analysis of phytosociological data was carried out in two main directions – with the combined species composition, i.e. partial flora (here in after referred to as 'flora'), and considering the individual relevés and their clusters, similar in terms of habitat and type of vegetation.

Additional list of species of relevés was analyzed in order to establish the structure of the partial flora. Species composition of relevés was mainly used for phytoindicational assessment of habitats (Ellenberg et al. 1991, Didukh 2011).

The floristic composition was analyzed using the ratio of the species groups under various classification systems of species – taxonomical, biomorphological, phytosociological etc. It led to a derivation of different structures, including taxonomic groups of a higher rank (systematic structure of partial flora); considering plant life forms (Raunkiaer 1937); by the proportions of diagnostic species of different classes of vegetation (Braun-Blanquet 1964).

The calculations of the ratios of species (spectra) were performed by two quantitative approaches: an unweighted and a weighted one. In the unweighted case, the calculation is based only on frequencies of species without taking into account their different coenotical role (cover and abundances). In a weighted approach of calculations by formula (1), the ratios were accounted using the phytocoenotic activity index of species (*PAI* for short), which is an arithmetic mean of the relative occurrences of species and its average abundance in relevés where species are present.

$$PAI = \frac{\frac{\sum freq}{N} + \frac{\sum \log_2(abund)}{N_p}}{2}, \quad (1)$$

where: *PAI* – the index of phytocoenotic activity, *freq* – frequency of species, *N* – total number of relevés, *abund* – abundance of species, expressed in percentages, *N_p* – number of relevés in which species occurs.

The index of *PAI* takes into account two main indicators that characterize the behaviour of the species–frequency and abundance. The latter characterizes the environment-forming ability of species and depends on population and coenotic characteristics. Most important of them are the degree of matching the amplitude (optimum) of species and habitat conditions, the reproductive efficiency of species, type of its renewal, the biotic interfering potential, the adaptive strategy. Thus, the *PAI* is a combined (integrating) indicator of species success in real conditions.

Assessment of habitats was carried out using a well-proved phytoindication approach (Ramensky et al. 1956, Ellenberg et al. 1991, Didukh 2011). The choice of this method was motivated, firstly, by the need for a quick screening assessment of habitats of a significant area, as well as the need to generalize and scope the ‘long-term’ changes in vegetation. Phytoindication does not replace, but supplements the direct instrumental methods, and provides an integral measurement tool since vegetation reflects environmental conditions as a years-averaged generalized trend (Goncharenko 2017).

Ecological scales of 9 factors were used for phytoindicational calculations: *Hd* (soil moisture), *Rc* (soil acidity), *Tr* (total salt regime of soils), *Nt* (content of nitrogen compounds), *Lc* (general light re-

gime), *Tm* (climate), *Kn* (continentality), *fH* (variability of moisture), *Ca* (calcium content) (Didukh 2011). In addition, to quantify the anthropogenic transformation, we used the scales related to anthropogenic impact measuring: *Hm* (hemeroby) (Frank and Klotz 1990) and *Nv* (naturalness index) (Borhidi 1995). For comparability of scores on various factors, the values in phytoindicational scales were standardized to a single 100-point scale before calculations.

The results of phytoindication were used for the numerical classification of habitats. To achieve this, the hierarchical cluster analysis was carried out with the distance matrix based on the Euclidean distance using standardized data and the Ward’s agglomeration method, which is often used due to the formation of compact clusters and the insusceptibility of a chaining phenomenon (Granato and Ares 2013). The use of phytoindication scores for cluster analysis was motivated by the main task of classifying the habitats, not the vegetation itself. The optimal number of clusters was determined by the maximization of the Calinski-Harabasz criterion (Halkidi et al. 2001).

To understand the interrelations between environmental parameters the phytoindication results matrix was subjected to principal component analysis. Although environmental factors in phytoindication are postulated as orthogonal (independent) from each other, correlations between them are usually found (Didukh and Plyuta 1994). It is explained by two reasons – an integrating nature of the reaction of plants to environment and the mutual conjugation from hidden factors, for example anthropogenic pressure.

The degree of anthropogenic transformation of vegetation was assessed based on several criteria: share of therophytes,

ratio of diagnostic species of synanthropic classes, as well as number of adventive species. Measuring anthropogenic transformation of vegetation using phytoindication techniques have been discussed in detail (Goncharenko 2017). To determine environmental factors by which differences in the stated group of relevés were the most significant, we applied the Student's t-test of comparing means.

All calculations were processed in R software (CRAN 2019). The following libraries were used: tmap (Tennekes 2018) – for mapping, fpc (Hennig 2019) – for cluster validation, vegan (Oksanen et al. 2018) – for pre-transforming data, dendextend (Galili 2015) – when working with dendrograms, as well as popular universal libraries (reshape2 (Wickham 2007),

ggplot2 (Wickham 2016) and packages built into the R (hclust – hierarchical cluster analysis, prcomp – principal component analysis).

Results and Discussions

Taxonomic structure of the partial flora

The total species composition of relevés consists of 111 species belonging to 80 genera and 30 families, so the ratio between them equals 1/1.39/2.67. Figure 2 presents the taxonomical relations taking into account the first most numerous 10 families. Two histogram columns are given for each family – the first column based

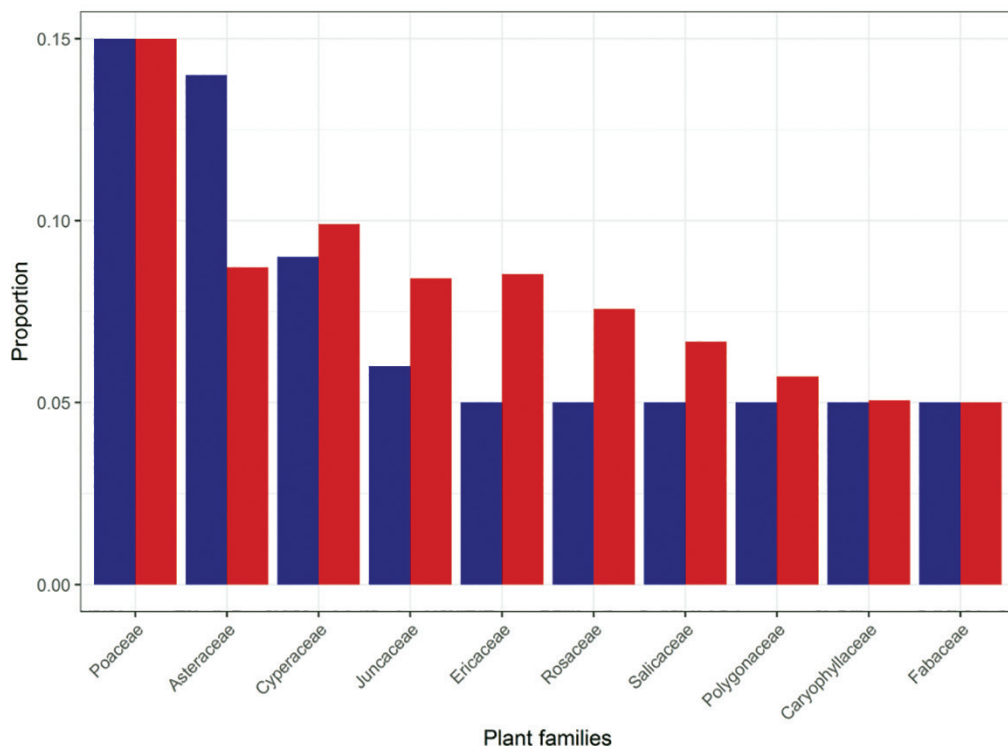


Fig. 2. Taxonomic ratios of species of 10 leading families in the joint species composition of relevés.

only on the number of species, the second one takes into account the *PAI* index (see Materials and methods).

As can be seen, the leading positions belong to the families of Poaceae and Asteraceae. When comparing the obtained ratios with those typical for the flora of Ukraine, the fact draws attention that Poaceae comes first; while in the flora of Ukraine (Zaveruha 1985, Mosyakin and Fedoronchuk 1999), as in most floras of temperate regions, Asteraceae is usually leading. This is connected with the restoration of the vegetation, which starts with a stage of intense sodding in the given climatic conditions with grasses playing a major role. High positions of the families Cyperaceae and Juncaceae (3rd and 4th, respectively) and Salicaceae (7th) are characteristic for northern floras with most of their species being meso-hydrophytes. On the contrary, the lowering of Fabaceae to the 10th place also characterizes the studied flora as being of northern type because Fabaceae is more typical for southern floras, for example, flora of Pivnichne Prychornomoria (Moysiienko 2013).

If we take into account the *PAI* index of species, the differences in taxonomic ratios are considered to be significant for some families. For example, although Asteraceae is represented by numerous species, their phytocoenotic role is not quite high. Conversely, both indicators equal to 0.15 and are maximal for Poaceae. In six families (Cyperaceae – Polygonaceae, see Fig. 2), the opposite trend is observed. Distribution when *PAI* index is considered gives higher scores than when based only on the species diversity. The phytocenotic activity of members of Cyperaceae and Juncaceae species is also high due to favourable hydrophilic and acidophilic condition prevail. It was also found that the distribution of frequency classes

of species is skewed. For example, only 4.5 % of species occur in more than half of relevés (Table 2), among them, the tree species (*Pinus sylvestris*, *Betula pendula*) and perennial herbaceous species (*Chamerion angustifolium* (L.) Holub, *Juncus effusus* L., *Molinia caerulea* (L.) Moench).

Table 2. Distribution of frequency classes of species in the plant communities studied.

Frequency of occurrence	Number of species	Percentage, %
High (≥50 %)	5	4.5
Medium (25–49 %)	13	11.7
Low (10–24 %)	45	40.5
Very low (<10 %)	48	43.2
Total:	111	100.0

Species that are widespread (recorded in 25–49 % of relevés) belong to different plant life forms, including trees – *Populus tremula*, shrubs – *Frangula alnus* Mill., *Rubus caesius* L., *Sorbus aucuparia* L., bushes – *Vaccinium myrtillus* L., perennial herbs – *Calamagrostis arundinacea* (L.) Roth, *Carex echinata* Murr., *C. leporina* L., *C. nigra* (L.) Reichard, *Phragmites australis* (Cav.) Trin. ex Steud., *Pteridium aquilinum* (L.) Kuhn, *Rumex acetosella* L., *Veronica officinalis* L.

Biomorphological structure of the partial flora

Figure 3 shows the relationships between the quantities of species of different Raunkiaer's life forms. Two indicators are presented (in columns): the first one is calculated only by number of species of each life form class, and the second one reflects the phytocoenotical role of species of various life forms.

As can be seen, the prevailing life form according to both criteria is that of hemic-

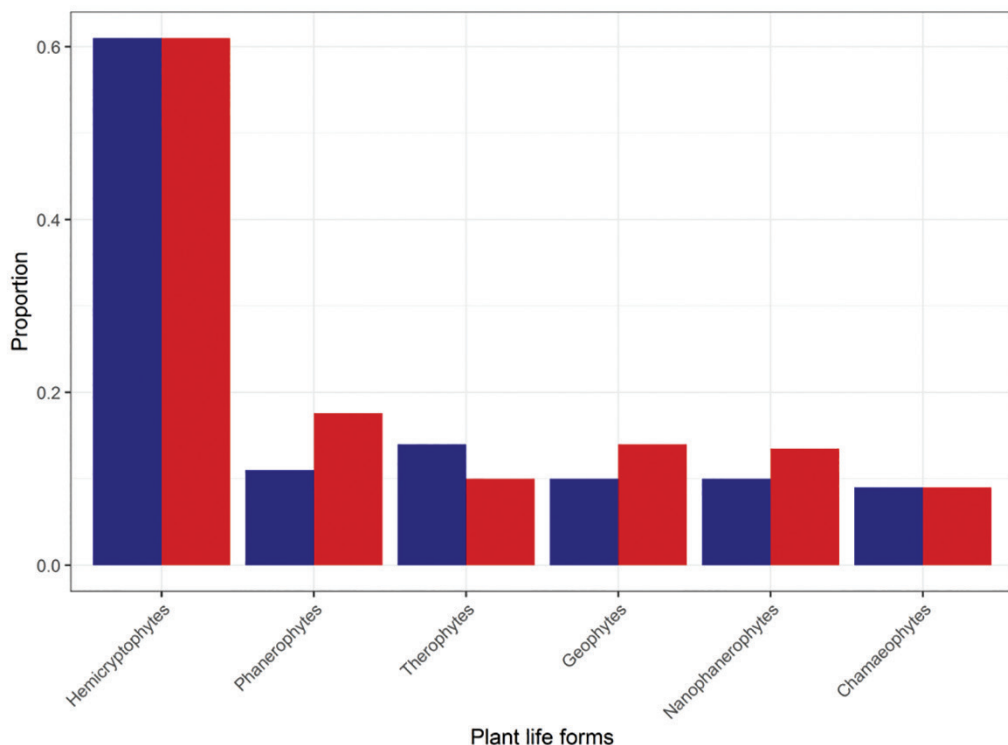


Fig. 3. The ratio of species of different life forms (according to the Raunkiaer's classification) of the partial flora investigated.

ryptophytes. This can be explained by the fact that this life form combines species with a relatively high degree of tolerance to anthropogenic impact of medium intensity. Most hemicryptophytes are stable unless the soil profile is completely destroyed, and they are more plastic than phanerophytes under such conditions. The phanerophytes keep second position. With the *PAI* index taken into account, their role is higher, which is explained by the intensive environment-forming ability of species of this life form.

Therophytes occupy the 3rd place (Fig. 3) and this is of diagnostic importance in relation to anthropogenic transformation of the studied communities. They express explerent reproductive strategy (Whittaker 1980, Zlobin 2009), having low competi-

tive ability in undisturbed conditions, but quickly capture the vacated territories. This is an obvious consequence and an indicator of the degree of anthropogenic transformation of the studied plant communities. The ranks in the spectrum of other life forms (geophytes, nanophanerophytes, and chamaephytes) correspond to their role in forest vegetation. In general, the biomorphological structure is of 'forest' type, but enriched with hemicryptophytes, which is the result of meadow-type succession, and with therophytes due to anthropogenic disturbances.

Phytosociological structure

Figure 4 presents the ratios of diagnostic species of different vegetation classes.

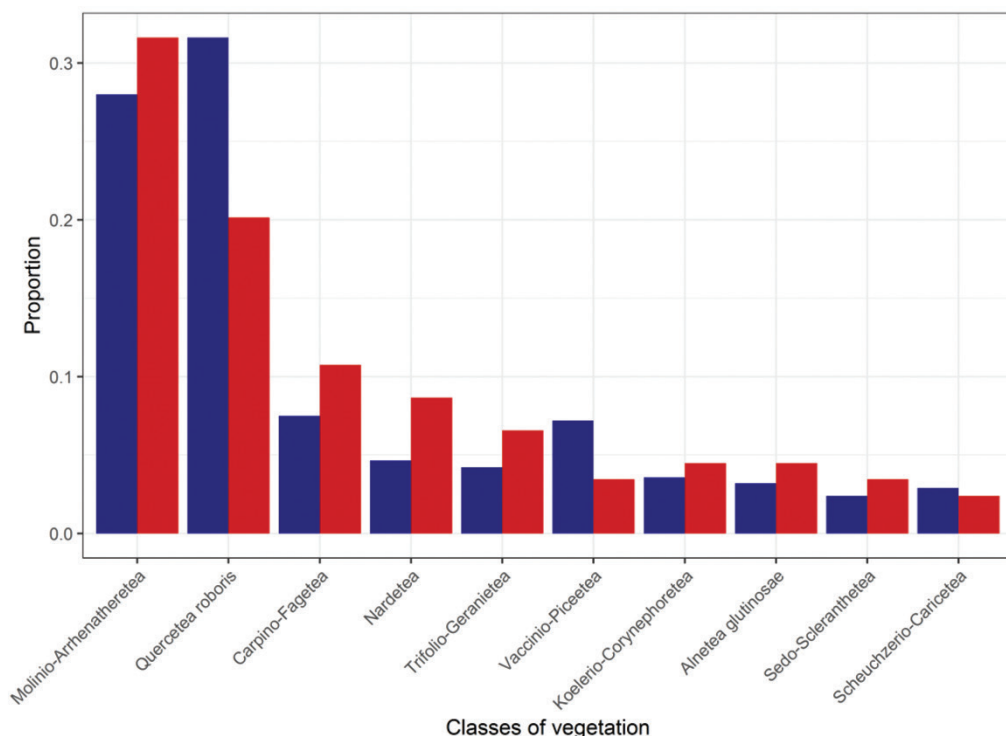


Fig. 4. Distribution of species belonging to different classes of vegetation.

Since most species are not confined to the only class of vegetation, they were accounted for each class for which they are considered to be diagnostic.

As can be seen, two classes *Molinio-Arrhenatheretea* and *Quercetea roboris-petraeae* occupy leading positions in the phytosociological spectrum. *Quercetea roboris-petraeae* dominates in the number of species, but *Molinio-Arrhenatheretea* is in first place taken into account the PAI index of species. At the current stage of restoration, meadow species predominate in abundance over the forest species. *Molinio-Arrhenatheretea* species are light-demanding and benefit also due to their plasticity and speed of growth. The occurrence of *Quercetea roboris-petraeae*, *Carpino-Fagetea* and *Vaccinio-Piceetea* species is related to the pattern of sur-

rounding vegetation. A significant number of species of acidophilic classes, including *Quercetea roboris-petraeae*, *Nardetea*, *Scheuchzerio-Caricetea*, are explained by acidic and nutrient-poor soils. The positions of *Koelerio-Corynephoretea* and *Sedo-Scleranthetea* classes are associated with a light soil textures, which is favorable for the growth of psammophytes and form the core of these classes. In general, the distribution of species of different classes of vegetation is in good agreement with the type of primary vegetation which grew prior the start of disturbances.

Numerical classification of habitats

Figure 5 shows a dendrogram demonstrating the degree of similarity of habitats according to their assessment from the phy-

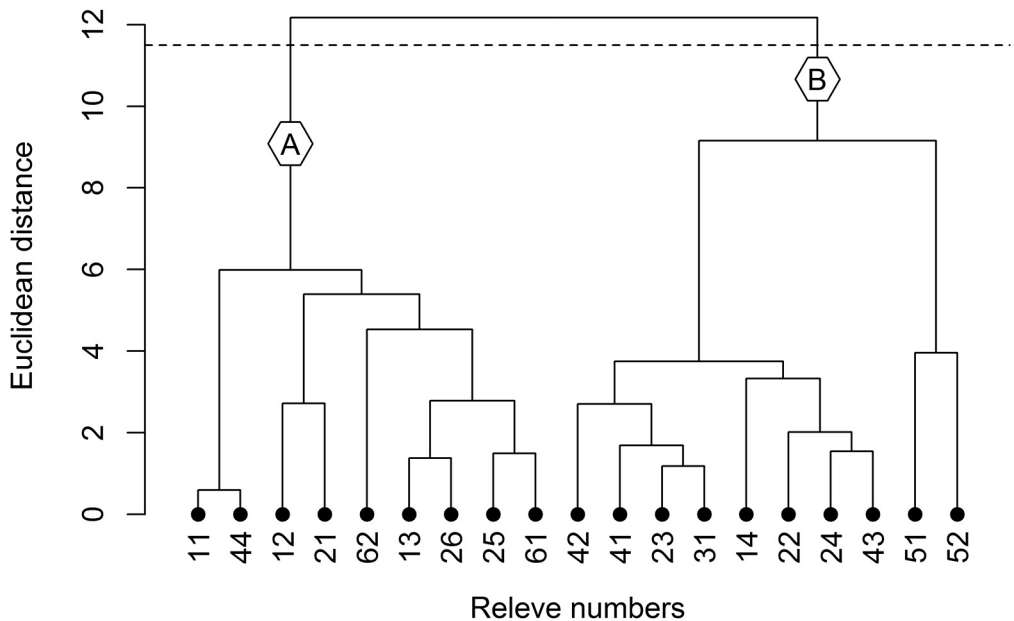


Fig. 5. Cluster analysis of habitats according to phytoindication scores of relevés.

Note: The first digit in relevé numbers indicate the geographic location of relevés and corresponds to the locality id (see map on Fig. 1).

toindication. Partitioning into two groups (clusters A and B) is considered optimal according to the Calinski-Harabasz criterion (see Materials and methods).

Table 3 presents the diagnostic (constant and differentiating) species of the vegetation studied. Species with a rela-

tive frequency in each of the clusters of at least 50 % were considered constant. Such species are common to both types of habitats. The list of differentiating species includes species with an affinity calculated by the Ochiai's coefficient of higher than 50 %.

Table 3. Constant and differentiating species of the two main types of habitats (see Fig. 5).

Cluster A	ClusterB
<i>Betula pendula</i> , <i>Chamerion angustifolium</i> , <i>Juncus effusus</i> , <i>Molinia caerulea</i> , <i>Pinus sylvestris</i>	
<i>Calamagrostis arundinacea</i> , <i>Calluna vulgaris</i> , <i>Frangula alnus</i> , <i>Pteridium aquilinum</i> , <i>Vaccinium myrtillus</i> , <i>Vaccinium vitis-idaea</i> , <i>Veronica officinalis</i>	<i>Calamagrostis epigeios</i> , <i>Carex echinata</i> , <i>Carex leporina</i> , <i>Corynephorus canescens</i> , <i>Oenothera biennis</i> , <i>Phragmites australis</i> , <i>Rubus caesius</i>

For example, cluster A comprises the sites which are related to pine and mixed forests on fresh podzolic soils, mainly with the dominance of *Vaccinium myr-*

tillus. Cluster B combines psammophytic communities with the dominance of *Corynephorus canescens*. Other species, for example, *Chamerion angustifolium*,

Oenothera biennis are considered to be secondary and a consequence of fellings. Such species as *Juncus effusus*, *Calamagrostis epigeios*, *Phragmites australis* are components of surrounding natural vegetation but their abundances increased significantly after anthropogenic impact. The forest species, which are associated with the primary vegetation, prevail in the group of diagnostic species. Conversely, meadow, meadow-bog, and psammophytic species have appeared or changed their phytocoenotical role as a result of anthropogenic impact.

PCA structure of correlations of ecological factors

Figure 6 summarizes results of the principal component analysis based on the correlation matrix of phytoindication scores of relevés. Environmental factors are shown by arrows with the angles between them and the lengths indicating the contribution of individual factors to the first and second components (axes). Only the first two main components are shown because considering the remaining components is not relevant since the first two main axes

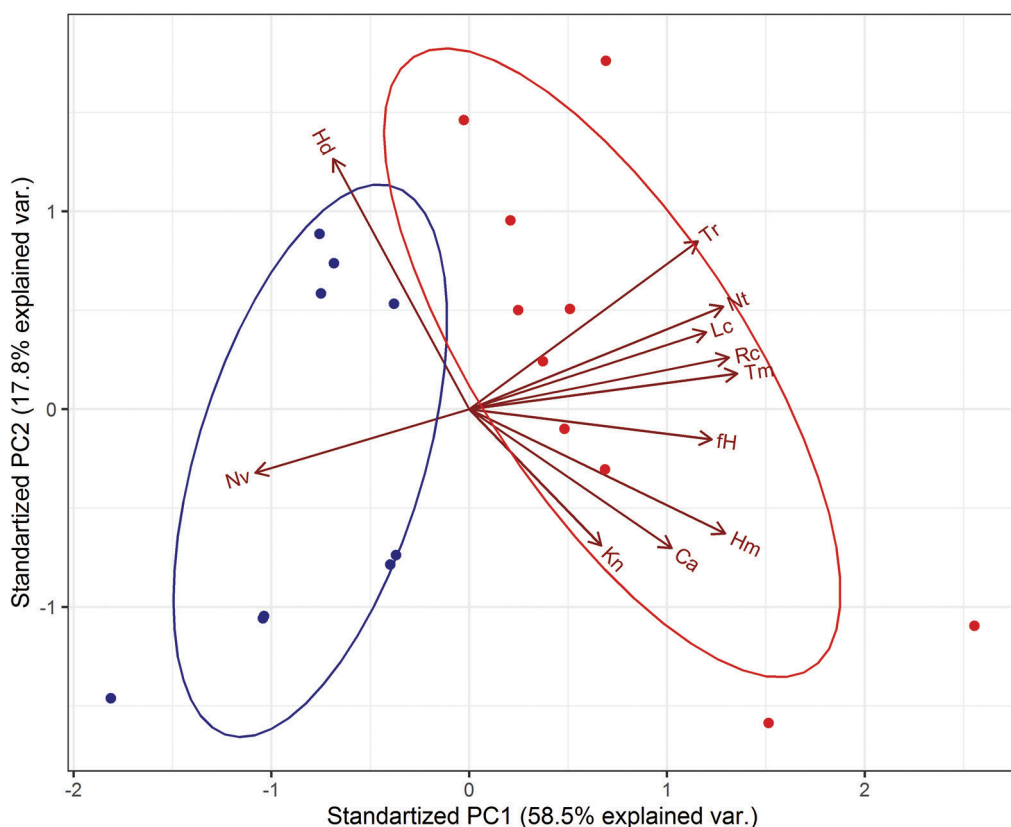


Fig. 6. Principal component analysis (PCA) of environmental factors based on the results of the phytoindicational assessment.

Note: Ellipses indicate two clusters of habitats: cluster A (left) and cluster B (right).

explain about $\frac{3}{4}$ (58.5 % + 17.8 %) of the total variation.

The first axis reflects more than half (58.5 %) of the total variation, and the second one contributes more than 3 times smaller (17.8 %). This indicates the significant multicollinearity, which is confirmed by the co-directionality of some vectors (*Tr*–*Kn*). It can be explained by two reasons. Firstly, the phytoindication data are derived from the one source – the phytocoenotical dataset. Secondly, large number of inter-correlations among the environmental factors that have been discovered is associated with the existence of a strong (limiting) factor to which vegetation mainly responds.

The factors related mainly to the first component belong to two major groups – edaphic (*Tr*, *Nt*, *Rc*) and anthropogenic (*Hm*, *Nv*). As for the second component, a connection with the humidity (*Hd*) is mainly manifested. The direction of vectors suggests that the habitats in cluster A should be interpreted as oligotrophic and acidophytic. Cluster B combines habitats of acidic and poor soils too, which is typical for Polissya as a whole, but inferior to cluster A in these indicators. The difference in the group means is significant, which will be shown further in the text.

Significant contribution to the PCA model of the anthropogenic factors (*Hm*, *Nv*) is confirmed by a large amount of variation explained by the first axis. In addition to a direct effect on vegetation, the anthropogenic factors also modulate other factors, for example, edaphic ones. Anthropogenic impact, direct (as a result of mining activity) or indirect (through the disturbance of vegetation), potentiates changes in the water and mineral regimes of soils, the intensity of the podzolic process, the rate of decomposition (mineralization) of the litter.

In general, the revealed strong correlations characterize the studied habitats as a marginal (evasive) type. Taking into account the worse ability of vegetation to recover in rather discouraging conditions, a prediction for possibility of demutational succession of studied plant communities is unfavorable.

Phytoindication comparing of two types of habitats of amber mining sites

Figure 7 shows the distributions of main phytoindication variables, including edaphic (*Hd*, *Tr*, *Rc*, *Nt*), light value (*Lc*), and naturalness index (*Nv*), between two types of habitats (see Fig. 5, clusters A and B). When choosing factors for the analysis, we focused on the selection of factors of different nature, describing soil, light and anthropogenic conditions.

As can be seen, the differences for most factors, except humidity (*Hd*), are significant at $p < 0.05$. The largest difference is observed for the nitrogen (*Nt*) ($p = 2.1 \times 10^{-5}$), with the cluster A corresponding to soils poor in nitrogen compounds. At the same time, the habitats are acidophytic and oligotrophic, with significant differences in these indicators from the cluster B. Cluster A relates to the primarily forested sites which results in lower *Lc* values and the preservation of many forest species as *Pteridium aquilinum*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Veronica officinalis* (see Table 3). And the naturalness index (*Nv*) of relevés of cluster A is higher and significantly different from the cluster B. The cluster B is quite heterogeneous phytocoenotically. It combines secondary vegetation types, which were formed after at least two different types of primary natural vegetation types. They are the psamphytic and xe-

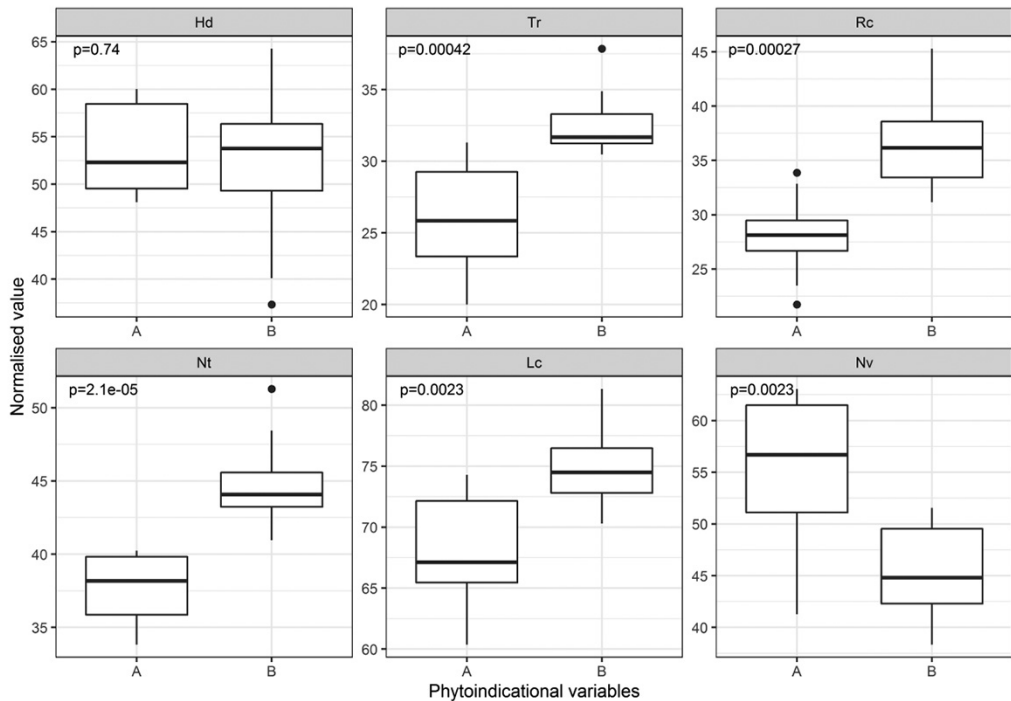


Fig. 7. Distribution of phytoindicational scores in two groups of habitats (clusters A and B, see Fig. 5).

Note: The t-test significance level is denoted by the p -value (abbreviated p).

rophytic communities with the dominance of *Corynephorus canescens* and the pine and pine-birch forests with *Molinia caerulea* dominating in the herbaceous layer as well.

Anthropogenic transformation of vegetation

Amber mining activity started in 2014 in all studied localities, i.e. there is reason to measure and observe the anthropogenic changes in vegetation over a 5-year period. Some of the manifestations of anthropogenic impact, such as an increase in the proportion of therophyte sand others, were also mentioned. The relation of the anthropogenic-mediated factors (*Hm*, *Nv*) to the first PCA axis testifies their signifi-

cant influence on the studied vegetation. The taxonomic structure of the flora as a whole is one of the most conservative indicators, so we did not find any anthropogenic-associated changes in it. Phytosociological structure is also similar to surrounding natural vegetation. However, estimates of anthropogenic transformation will not be optimistic if we take into account the share of synanthropic species with 30 species out of 111 being synanthropic. Therefore, the background synanthropization is 27 % which is quite high. The share of adventitious species equals 10 %, which is also a high level of anthropogenic transformation. Among adventitious species, there is a significant number of kenophytes (*Robinia pseudo-acacia*, *Bidens frondosa*, *Phalacrolo-*

annuum, *Oenothera biennis*, *Kochia scoparia*, *Conyza canadensis*) (Protopopova 1991, Mosyakin and Yavorska 2002), and their presence can be explained only by anthropogenic influence. Archaeophytes (*Xanthium strumarium*, *Scleranthus annuus*, *Lactuca serriola*, *Fallopia convolvulus*, *Ballota nigra*) are also found, but in pine forests, they are alien and also secondary.

We also stated a relative enrichment of the species compositions of relevés with nitrophilous species. In particular, such species as *Fallopia convolvulus*, *Ballota nigra*, etc., are characteristic of richer soils and their occurrence on poor sandy soils in the study area can be explained by the relative enrichment of soils with this important nutrient not caused by the external flow, but due to the accelerated mineralization in case of disturbance of the forest ecosystems. This promotes the growth of nitrophilous species in such poor-sandy conditions (Goncharenko 2017).

In the vegetation we studied, the enhanced growth of *Juncus effusus* is obviously associated with its nitrogen fixing ability (Stewart 1977, Halda-Alija 2003). This species has a dense root system, favorable for the settlement of nitrogen-fixing bacteria. This specific feature in combination with humid conditions in the studied sites is one of the main reasons for the formation of communities where *Juncus effusus* is dominating in amber mining sites. Such species as *Carex echinata* and *C. leporina*, having similar ecological requirements are usually co-growing with *Juncus effusus*.

In case of grazing conditions or the formation of tall-meadow communities, the undergrowth of trees will have competitive relations with herbaceous species. They last with higher level of plasticity and

speed of growth are likely to have advantages in comparison with trees. Therefore, the current intensive growth of meadow and meadow-bog species in amber-mining abandoned territories will most likely negatively affect the ability of tree species to recover naturally.

Conclusions

In the present study, we examined the structure of vegetation and habitats after amber mining works.

The phytointercational description of habitats was given and two principal groups of them that are now prevalent in the abandoned areas were established.

Multiparametric analysis of anthropogenic changes in vegetation showed that different features of the habitat are transformed at different speeds and are at different stages of restoration processes currently. For example, the taxonomic structure of the studied flora has preserved its natural features and is typical for most northern floras. Biomorphological structure is also preserved and has natural features, but we noted an increase in the share of therophytes, which is a definite sign of anthropogenic changes. The phytosociological structure is also ambivalent in terms of anthropogenic changes. On the one hand, synanthropic classes of vegetation were not found among the top 10 classes of the phytosociological spectrum. On the other hand, the total number of synanthropic species (not taking into account vegetation classes) was 27% and the share of adventitious species was 10%, both of which are quite high in terms of anthropogenic transformation. The correlative structure of the phytointercational scores matrix, as well as the subdivision of habitats into two types, is more relevant

to natural features, as the two clusters of habitat types and their differentiating species are in a stronger agreement with the natural vegetation types that existed prior to illegal amber mining activity.

In general, given that, the ability of vegetation to recover under conditions far from optimal decreases (especially when moving to the north), this worsens the prognosis of the potential recoverability of the vegetation examined in this study and arising in the place and as a result of amber mining. However, among the factors favoring the natural course of restoration, one can name the remoteness from large settlements and the relatively high preservation of the surrounding forests, which creates the potential for the secondary resettlement of forest species from adjacent territories. In any case, remediation measures and monitoring of succession changes in the longer term are appropriate.

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STAND STRUCTURE OF PRIVATE SMALLHOLDER FOREST AS A REFLECTION OF LIVELIHOOD STRATEGIES: A CASE STUDY OF SEMOYO VILLAGE, GUNUNGKIDUL REGENCY, INDONESIA

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Abstract

The private smallholder forest significantly contributes to the wood industry as well as to the livelihood and needs of the society. Farmers grow mixtures of crops and species leading to a multi-layer vegetation covers, and forest stand. However, the structure and composition of the forest exposes a unique mosaic on the landscape. Therefore, the purpose of this study is to determine the association between forest stand structure and composition with varying farmer's livelihood strategies such as fully-managed forest farmer, partly-managed forest farmer, and non-managed forest farmer. Data were obtained from Semoyo Village, Patuk District, Gunungkidul Regency from 72 plots representing two types of planting pattern, namely: trees along the border and mixed patterns. The negative exponential model was used to describe the forest structure model. The results showed that fully-managed forest farmers tend to have few trees with the smallest diameter at breast height, plant more multi-purposes trees species. All stand structures in the three types of farmers' can be described by a negative exponential model, but each type possessing a different rate of diminishing in the number of trees. All of these showed that differences in stand structure are a reflection of differences in livelihood strategies.

Key words: diameter distribution, farmers occupation, negative exponential, planting pattern.

Introduction

Private smallholder forest (PF) can provide contribution to reducing the deficit of wood demand is being faced by the forestry world. In Indonesia, the supply of raw materials from community forests increased from 4.8 million m³ in 2015 to 6.2 million m³ in 2018 (Nurmansyah

2019). As well as in Java island PF has grown rapidly over the years and has become the main source of raw materials for wood industries. The wide geographical distribution of PF has been influenced by government-initiated programs such as re-greening, land rehabilitation (watershed), and conservation. These programs generated self-sustained forests that have

hugely benefited the communities. Therefore the development of PFs which also means developing the lives of PF farmers is important to study.

On the PF land, the farmers combine timber trees with agricultural crops (agroforestry) and applying the pattern of mixing various types of plants in a field (Amin and Mas'ud 2017). Trees are grown along the boundaries of fields and terraces in dryland systems or on hillsides (Sabastian et al. 2014). According to previous studies, diversification of crops even on small pieces of land affected both economic and ecological benefits (Regmi 2003, Zuazo and Pleguezuelo 2009, Atangana et al. 2014, Oktalina et al. 2016, Achmad and Diniyati 2018). Although communities practiced agroforestry in small pieces of lands, it still created opportunities for increasing crop production, as well as higher biodiversity (Grimble et al. 1994, Tilman et al. 2006, Clough et al. 2011).

Stand structures and compositions are influenced by farmer's orientation in forest establishment/management. According to Sanudin and Fauziyah (2015), the structures and compositions of monoculture forests optimize product uniformity which was a characteristic of commercial-oriented farmers, while subsistence farmers tend to cultivate mixed crops. Triwiyanto et al. (2015) stated that agroforestry practiced on dry land at Bulu, Kulon Progo showed mixed patterns and proximity models of uneven-aged forest stands.

Agroforestry systems include not only a form of forest dominated by 'cultivated trees', but also an anthropogenic vegetation formation derived from previous agricultural farming practices (Rahman et al. 2016). The old tradition of private ownership with smallholder social structure was the main reason for the variability in stand structure and species assemblage (Wulf

and Klok 2014). The numerous benefits of PF have been triggered by structures and composition which were affected by the livelihood strategy (Peyre et al. 2006, Wulandari et al. 2014).

Farmers' livelihood strategies are reflected in their main types of occupation. Farmers' livelihoods can be grouped into full-time farmers, part-time farmers, and not working in agriculture (non-farmers) (Guillermie et al. 2011, Liu et al. 2018, Dhehibi et al. 2020). Previous research on community forest structure was found associated with altitude (Talaohu 2012), land area (Triwiyanto et al. 2015), whereas concerning farmer livelihood strategy was not found. The purpose of this study is to determine the association between the PF stand structure with farmers' livelihood strategies.

Materials and Methods

Study area

This study was conducted at Semoyo Village, Patuk District, Gunungkidul Regency, Special Region of Yogyakarta Province, Indonesia. The village is geographically located at 7°51'0.61" – 7°53'25.45" S and 110°28'3.17" – 110°29'30.66" E (Fig. 1). It was selected because from a Government document (2018), it was obtained that 90.77 % of the family heads are farmers who lean on land to fulfill their family needs.

Sampling methods, tools and measurement methods

The research data were obtained from 'Serikat Petani Pembaharu' (SPP) farmers' group including 262 members. This

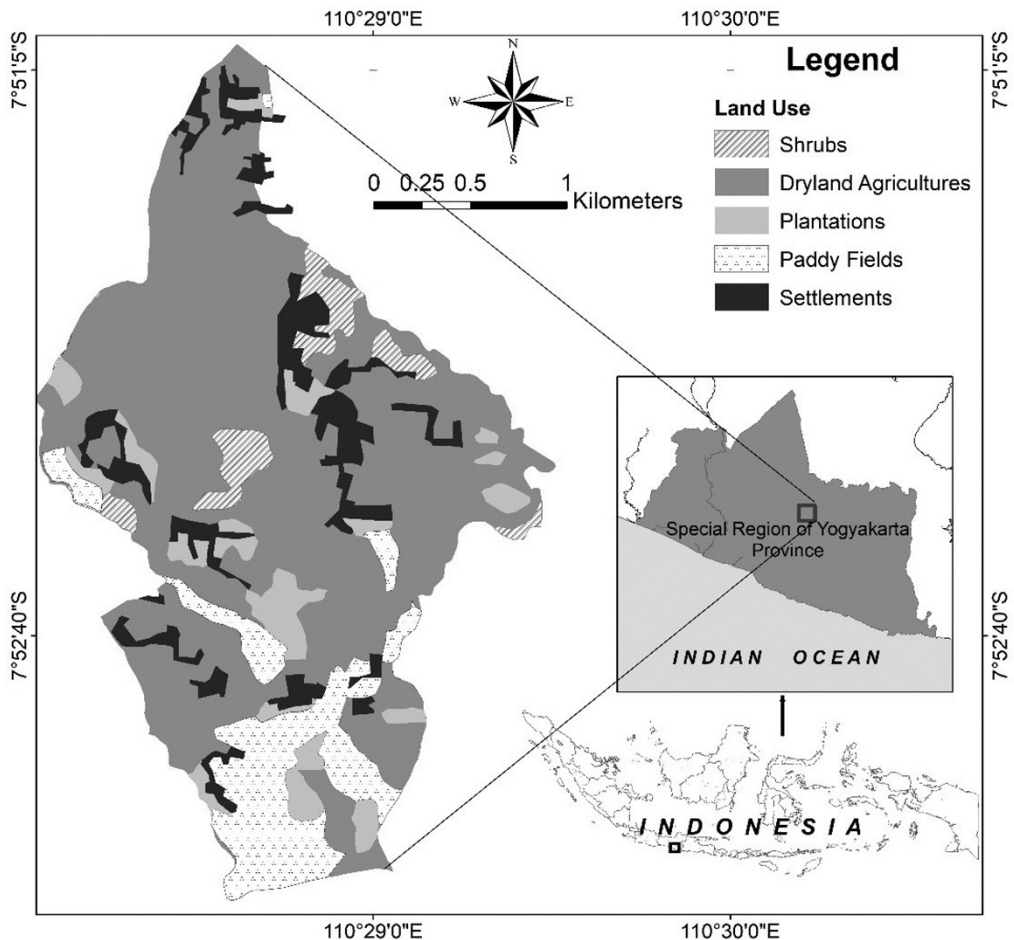


Fig. 1. Location of Semoyo Village.

study was conducted from February to December 2018. A total sample of 72 farm-lands was selected based on the 27.5 % sampling intensity and an error limit tolerance of less than 10 % as stated by Israel (1992). Samples were selected by using purposive sampling method based on the type of occupation, namely 38 fully-managed forest farmers, 29 partly-managed forest farmers, and 5 non-managed forest farmers.

Observations were carried out to obtain distinct categories of forest stands

and community livelihoods. Furthermore, parcels of lands were classified based on planting patterns, i.e. trees along the border (TAB), and mixed planting. There were observed 23 (33 %) samples of TAB patterns and 49 (67 %) samples of mixed patterns. Diameter at breast height (DBH) of five species of timber forest product (TFP) trees commonly found at the research sites was measured using a diameter tape. The commonly cultivated species for timber are Java teak (*Tectona grandis* L.f.), Big-leaf mahogany (*Swietenia mac-*

rophylla King), Indian rosewood (*Dalbergia latifolia* Roxb.), Batay (*Paraserianthes falcataria* (L.) Nielsen), and Australian wattle (*Acacia auriculiformis* A. Cunn. ex Benth). The measurement of TFP with a diameter of 5 cm and above, the various types and number of multi-purposes trees species (MPTS) trees were all recorded without diameter measurements. The area of land was also measured with a GPS Garmin ETREX 30x. Additionally, respondents were interviewed to ascertain the socio-economic conditions and land management practices executed in the community.

Data analysis

Data were analyzed to obtain PF stand structure in the form of tree diameter distribution which was a reflection of farmers' livelihood strategies in practicing the two types of planting patterns. Ziegenspeck (2004) divided the lifestyle of farmers into full-time, spare-time, and non-farmers. This research separates farmers into three type's occupation as reflected their livelihood strategies, namely:

1) Fully-managed forest farmers. They are farmers who do not have other occupations and depend on land-based activities to meet their needs.

2) Partly-managed forest farmers. They have other occupations such as construction or factory workers. However, income generated from land-based activities does not meet their cost of living so they spend their spare time working in other places. Therefore they depend on other sources for income.

3) Non-managed forest farmers. These are farmers with permanent occupations such as government employees, teachers. They tend to fulfill their needs without depending on land-based activities. How-

ever, they have very little leisure time to manage their forest.

The stand structure represented by the diameter distribution in the two planting patterns practiced by different types of farmers was analyzed. Triwiyanto et al. (2015) found that the diameter distribution model in PF can be described in a negative exponential model. All analyses were carried out by developing a tree diameter distribution model using the negative exponential equation (1) as stated by Meyer (1952).

$$N_i = K \cdot e^{-\alpha \cdot DBH_i}, \quad (1)$$

where: N_i and DBH_i are number of stems and midpoint of the i -th diameter class, respectively; α and K are the parameters of the distribution; $e = 2.7183$. The parameter α determines the rate at which trees diminish in successive diameter classes, while K indicates the relative density of the stand.

Results

Generally, most farmers in Semoyo Village own 2 parcels of land, dominated by landholding area less than 0.5 ha on fully-managed forest farmer and partly-managed forest farmer (Table 1).

The farmers practiced agroforestry by managing drylands to plant crops, fruit-trees, timber-trees, and MPTS. However, it was discovered that PF is the major source of livelihood. Variation in species composition showed that the combination dominated by timber forest product (TFP), non-timber forest product (NTFP), fruits product (FrP), and food crops (FC) (Table 2). There were 5 kinds of TFP species, 12 NTFP, 11 FrP, 3 FC, and 2 HnS (herbs and spices) (Table 3).

Table 1. Land characteristic.

Land Characteristic	Interval	Percentage, %		
		Fully-managed forest farmer	Partly-managed forest farmer	Non-managed forest farmer
Landholding area, ha	<0.5	52.6	58.6	40.0
	0.5-1	26.3	27.6	0.0
	>1	21.1	13.8	60.0
Number of land parcels	1	10.5	13.8	0.0
	2	36.9	34.5	60.0
	3	52.6	51.7	40.0

Table 2. Variation of species composition.

No	Species composition	Number of species	Number of respondents
1	TFP+NTFP + FC	2 to 4 TFP + 1 to 2 NTFP + 1 FC	2
2	TFP+ NTFP+FrP + FC	2 to 5 TFP + 1 to 5 NTFP+ 1 to 6 FrP + 1 to 2 FC	44
3	TFP+NTFP+FrP+F- C+HnS	2 to 5 TFP + 0 to 4 NTFP+ 2 to 7 FrP + 1 to 2 FC + 1-2 HnS	21
4	TFP+NTFP+FrP+F- C+HnS+Veg	2 to 5 TFP + 1 to 2 NTFP+ 2 to 5 FrP + 1 FC + 1 HnS + 1 Veg	2
5	TFP+NTFP+FrP+F- C+HnS+Veg+F	2 to 4 TFP + 1 to 2 NTFP+ 2 to 5 FrP + 1 to 2 FC + 1 HnS + 1 to 3 Veg+ F	3

Note: TFP – timber forest product; NTFP – non timber forest product; FrP – fruits product; FC – food crops; HnS – herbs and spices; Veg : vegetable; F – forage.

Table 3. Types of plants.

No	Group	Local name	English name	Latin name
1	TFP	Mahoni	Big-leaf mahogany	Swietenia macrophylla King
		Jati	Java teak	<i>Tectona grandis</i> L.f.
		Sonokeling	Indian rosewood	<i>Dalbergia latifolia</i> Roxb.
		Akasia	Australian wattle	<i>Acacia auriculiformis</i> A. Cunn. ex Benth.
		Sengon	Batay	<i>Paraserianthes falcata</i> (L.) Nielsen
2	NTFP	Kopi	Coffe tree	<i>Coffea robusta</i> Lindl. Ex De Willd
		Cengkeh	Clove	<i>Syzygium aromaticum</i> (L.) Meer. & Perry
		Cacao	Cacao tree	<i>Theobroma cacao</i> L.
		Petai	Bitter bean	<i>Parkia speciosa</i> Hassk.
		Jengkol	Dog-fruit	<i>Archidendron pauciflorum</i> Benth.
		Kemiri	Candlenut	<i>Aleurites moluccana</i> (L.) Willd.
		Asam	Tamarin	<i>Tamarindus indica</i> L.
		Randu	Ceiba	<i>Ceiba pentandra</i> Gaertn.
		Ketapang	Umbrella tree	<i>Terminalia catappa</i> L.
		Melinjo	Gnetum	<i>Gnetum gnemon</i> L.
		Gliriside	Gliricidia	<i>Gliricidia sepium</i> (Jacq.) Walp.
		Bambu	Bamboo	<i>Gigantocloa apus</i> Kurz.

No	Group	Local name	English name	Latin name
3	FrP	Kelapa	Coconut	<i>Cocos nucifera</i> L.
		Nangka	Jackfruit	<i>Artocarpus heterophyllus</i> Lamk.
		Sirsak	Soursop	<i>Annona muricata</i> L.
		Jambu mete	Chasew	<i>Anacardium occidentale</i> L.
		Mangga	Mango	<i>Mangifera indica</i> L.
		Rambutan	Rambutan	<i>Nephelium lappaceum</i> L.
		Durian	Durian	<i>Durio zibethinus</i> Murr.
		Alpukat	Avocado	<i>Persea americana</i> Mill.
		Pisang	Bananas	<i>Musa paradisiaca</i> L.
		Nanas	Pineapple	<i>Ananas comosus</i> (L.) Merr.
		Pepaya	Papaya	<i>Carica papaya</i> L.
4	FC/ additional staple food	Singkong	Casava	<i>Manihot esculenta</i> Crantz.
		Jagung	Corn	<i>Zea mays</i> L.
		Ketela ram- bat	Sweet potatoes	<i>Ipomea batata</i> L.
5	HnS	Laos	Galangal	<i>Alpinia galanga</i> (L.) Willd.
		Sereh	Lemongrass	<i>Cymbopogon citratus</i> L.
6	Vegeta- bles	Cabai	Chili	<i>Capsicum frutescens</i> L.
		Terung	Eggplant	<i>Solanum melongena</i> L.

Table 4 showed that the fully-managed forest farmers planted more MPTS in the TAB pattern and the smallest percentage

of mixed patterns. Mahogany and teak were the dominant species of TFP.

Table 4. Share of TFP and MPTS.

No	Species	TAB				Mixed					
		Fully-man- aged forest farmer		Partly-man- aged forest farmer		Fully-man- aged forest farmer		Part- ly-man- aged for- est farmer		Non- managed for- est farmer	
		%	N, ha ⁻¹	%	N, ha ⁻¹	%	N, ha ⁻¹	%	N, ha ⁻¹	%	N, ha ⁻¹
1	<i>Tectona grandis</i>	21.6	133	29.5	145	21.4	214	20.3	175	20.3	276
2	<i>Swietenia mac- rophylla</i>	37.5	231	29.0	142	44.0	441	43.3	373	61.1	829
3	<i>Dalbergia lati- folia</i>	21.3	132	28.3	139	15.5	155	17.5	151	7.4	100
4	<i>Paraserianthes falcataria</i>	2.6	16	4.3	21	7.2	72	6.1	53	0.9	12
5	<i>Acacia auriculi- formis</i>	0.7	4	1.0	5	2.1	21	1.5	13	0.2	3
6	MPTS	16.4	101	7.9	39	9.9	99	11.3	98	10.1	137

Note: N – number of trees.

All the negative exponential equations obtained a high squared R ($R^2 > 0.7$) value, therefore it was stated that the models were suitable for describing data. The reverse J-shaped curves drawn based on these equations are shown in figures 2 and 3. Fully-managed forest farmers have the highest rate of diminish in the num-

ber of trees owned and this is shown in the α values in Table 5 and figures 2 and 3. Furthermore, for diameters more than 10 cm, non-managed forest farmers have highest number of trees and biggest diameter compared to other types of farmers as shown in Table 6.

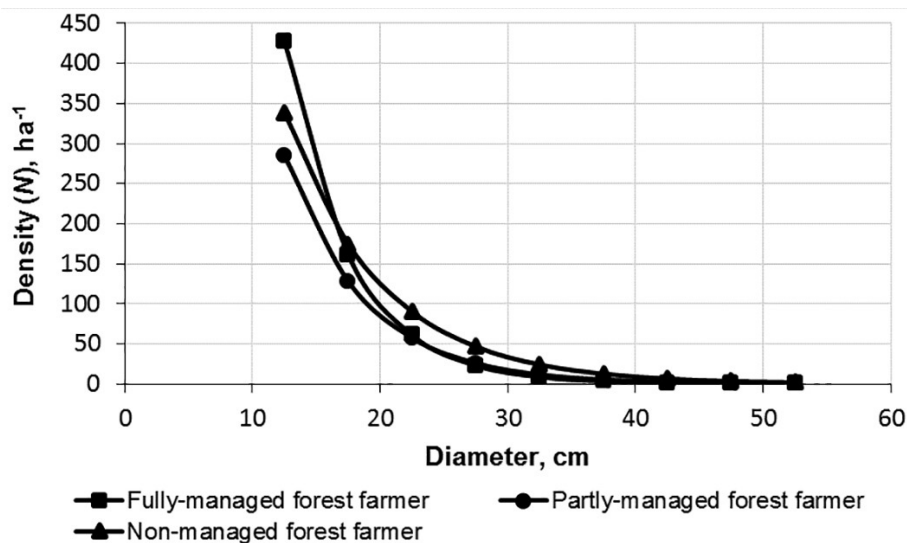


Fig. 2. Tree diameter distribution in mixed pattern.

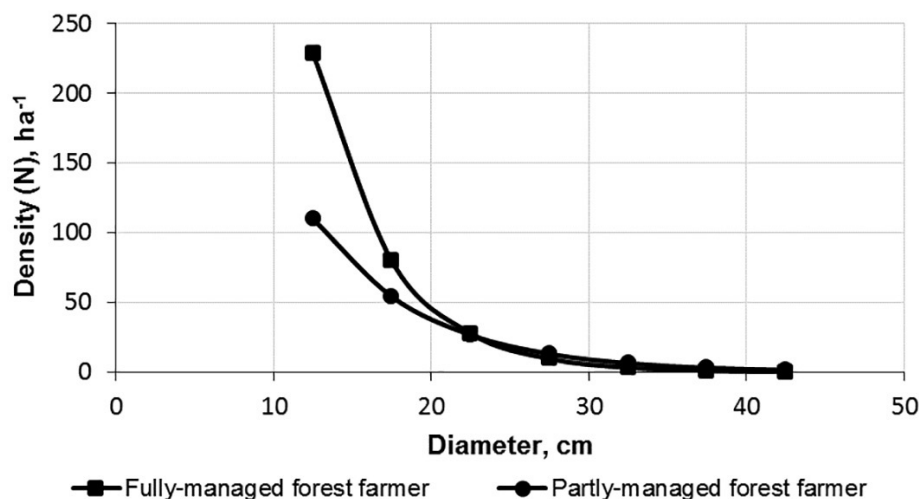


Fig. 3. Tree diameter distribution in TAB pattern.

Table 5. Negative exponential model for stand diameter distribution.

Agroforestry pattern	Types of farmers	Equation	Square <i>R</i>
TAB	Fully-managed forest farmer	$N_i=3,150,380*2.7128^{-0.210DBHi}$	0.99
	Partly-managed forest farmer	$N_i=641,080*2.7128^{-0.141 DBHi}$	0.78
Mixed	Fully-managed forest farmer	$N_i=4890,987*2.7128^{-0.195 DBHi}$	0.86
	Partly-managed forest farmer	$N_i=2108,219*2.7128^{-0.160 DBHi}$	0.99
	Non-managed forest farmer	$N_i=1766.657*2.7128^{-0.132 DBHi}$	0.93

Note: *N* – number of trees; *DBH* – diameter at breast height.

Table 6. Stand characteristic.

Main occupation	TAB				Mixed			
	<i>N</i> , ha ⁻¹		DBH, cm		<i>N</i> , ha ⁻¹		DBH, cm	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Fully-managed forest farmer	357	141.9	15.4	2.1	509	347.0	16.8	1.8
Partly-managed forest farmer	262	54.6	15.9	2.7	452	203.4	17.3	2.8
Non-managed forest farmer	-	-	-	-	812	464.5	17.6	1.1

Note: *N* – number of trees; Sd – standard deviation.

This model shows that non-managed forest farmers have the highest number of trees (184 ha⁻¹) with a mean diameter of 27.5 cm. However, partly-managed forest farmers have a higher number of trees and mean diameter in the two planting patterns as shown in Table 7, com-

pared to fully-managed forest farmers. The number of trees with diameters more than 20 cm in TAB pattern owned by fully-managed forest farmers is 43 trees·ha⁻¹ less than partly-managed forest farmers 52 trees·ha⁻¹.

Table 7. Number of trees more than 20 cm in diameter (based on model).

Types of farmer	TAB		Mixed	
	<i>N</i> , ha ⁻¹	Mean of DBH, cm	<i>N</i> , ha ⁻¹	Mean of DBH, cm
Fully-managed forest farmer	43	25.1	97	25.5
Partly-managed forest farmer	52	26.6	104	26.4
Non-managed forest farmer	-	-	184	27.5

Note: *N* – number of trees.

Discussion

Composition of trees

Trees along border and mixed planting patterns were generally practiced with two to five species of TFP trees which were either combined with MPTS (trees that produce various products namely leaves, fruits, vegetables, firewood, timber, etc.). Meanwhile, Triwiyanto et al. (2015) stated that there were three models of cultivated land in Bulu namely mixed, MPTS dominant plants, and forest dominant models.

Farmers decided to cultivate food crops in most areas of land, while the trees were only planted at the boundary of the land to reduce the impact of tree shade factors. According to Iskandar et al. (2017), the plants were categorized into 6 main functions, namely additional staple food/carbohydrate source, fruit, vegetable, spice, industry/commercial, and wood. However, in Semoyo Village, a vegetable was not common and was found only in some farms. Several types of NTFP and FrP were similar to the ones discovered in other regions of Java (Pratama et al. 2015).

Farmers in Semoyo depend on food crops such as cassava, corn, and sweet potatoes to fulfill their daily needs. The typical agroforestry pattern used to achieve this is the TAB. Farmers practice TAB pattern on land that has a relatively flat topography or good biophysical conditions, with the food crops cultivated in the middle of the farm and surrounded by trees. Farmers are faced two options either to fulfill their basic needs by cultivating crops or planting trees as stated by Soerianegara and Mansuri (1994).

These composition differences are likely due to differences in management, as written by McClellan et al. (2018). Farmers are knowledgeable of the value of on-

farm tree diversity for the sustenance of their livelihood. This is in accordance with Regmi (2003), Oktalina (2016). Banana and coconut are types of FrP that are always planted by fully-managed forest and partly-managed forest farmers because they produce fruits throughout the season, thereby generating income throughout the season. The composition of these plants allows farmers to have continuous income even during different harvest periods of various plants, as stated by Herwanti et al. (2019). This was the economic gains a farmer received from the practice of agroforestry (El-Tantawi et al. 2017).

Generally, most farmers in Semoyo Village own 2 parcels of land and these help in the selection of land allocation for planting patterns. Additionally, both fully-managed forest and partly-managed forest farmers own a variety of species while non-farmers cultivated less number of species. It was observed that fully-managed forest farmers prefer to plant food crops than trees. However, trees that produce fruits, TFP, and NTFP are planted at the boundary of the land and prevent soil erosion. Fully-managed forest farmers are characterized by optimal use of land because the farmers tend to cultivate crops and trees even though the land that is owned is narrow.

The farmers practiced agroforestry patterns after considering the biophysical conditions of the land (topography, soil fertility), landholding area, and availability of manpower because they aid the farming processes and socio-economic needs as found in Fujiwara et al. (2017) and Suhartati et al. (2018). Relatively fertile land with flat topography and availability of manpower, the farmers manage food crops using the TAB pattern, and in the absence of manpower, the mixed pattern becomes an option. Partly-managed forest farmers

adopted mixed patterns because there was not enough time to cultivate the land. The wives of the farmers usually work on the farms, this is in line with the statement by Achmad and Diniyati (2018). Additionally, intensive tree planting is associated with increased off-farm incomes (Sabastian et al. 2014).

The farmers in Semoyo were interested in planting trees on their farms because of its land suitable, economic values, and the availability of good seedlings. Teak is suitable for environments that have existed since time immemorial and are costly while mahogany easily grows in the study area. Rosewood grows slowly, however, it has also been cultivated for a long time and is even costlier than teak. Australian wattle was introduced for land rehabilitation, while Batay was chosen because of its high demand by light wood industries. Teak, mahogany, and rosewood have a good seedling that regenerates naturally. Huxley (1999) stated that the choice of species is influenced by both the farmer's objectives and constraints. Meanwhile, the farmer's choice of tree species differs according socio-economic and environment factors (Goibov et al. 2012), social capital and networks, labour availability (Teklewold *et al.* 2013), inherited across generation (Salampessy et al. 2017) and land suitability, increment, availability of manpower, cost, and easy maintenance (Wijayanto 2011).

Fully-managed forest farmers have a higher percentage of MPTS in TAB patterns than partly-managed forest farmers. They tend to manage land and completely depend on land-based activities so they need to produce varieties of crops for sale. Furthermore, the planting of MPTS plays an important role in their basic income and they tend to cultivate more FrP and NTFP trees as medium-term

commodities to satisfy their basic needs unlike partly-managed forest farmers and non-managed forest farmers. While non-managed forest farmers have the highest percentage of mahogany in the mixed pattern (61.1 %) as a result of the fact that they naturally regenerate faster than teak. Non-managed forest farmers do not cultivate and manage their lands, let the trees grow without maintenance.

Modeling in stand structure

Stand structures of forests were described by age, diameter distribution, and canopy classes. It was also observed by its density level which indicates its condition. Farmers usually do not remember the ages of certain trees, because they were not planted simultaneously on one land, making it difficult to detect. These types of PF were uneven-age stand. In an uneven-aged stand, the frequency distribution of the trees is based on its diameter and these lead to a reverse J-shaped curve (Daniel et al. 1979). Reverse J-shaped curve in the negative exponential model was also found in PF (Triwiyanto et al. 2015). The diameter distribution of trees resembles a reverse J-shaped curve and this indicates an uneven-aged structure, therefore tree density decreases with an increasing diameter (Daniel et al. 1979, Tavankar 2015).

In this research, stand structures were showed by the diameter distributions of five TFP trees, well modeled by the negative exponential. The number of trees in various diameter classes per hectare is one of the parameters that indicates stand performance. The performance showed that farmers have trees for the next harvesting. Referring to uneven-aged forests, this condition is said in a balanced condition (Pamoengkas and Zamzam 2017,

Pamoengkas et al. 2018).

Farmers in the various occupational categories have different rates of diminishing in the number of trees at the two planting patterns. Fully-managed forest farmers have the highest rate of diminishing than other farmers in both planting patterns. Furthermore, the average non-managed forest farmer's diameter of trees was higher than the other main occupations. Fully-managed forest farmers sell and cut trees more often than partly-managed forest farmers and non-managed forest farmers. When social needs (ceremonial expenses, marriage ceremonies) have the highest frequency, therefore a large number of cash resources was needed. The increase in social needed, generally fulfilled by selling many cattle (hen or cock), and when this is not sufficient, the farmers sell trees to obtain cash, in line with Dhubháin et al. (2010). The diameter distributions of trees tend to differ due to planting pattern and types of farmer.

Stand structure and livelihood strategies

The PF stand structure is the result of planting, maintaining, and cutting. Tree planting activities are part of livelihood strategies to meet their needs. It was observed that PF cannot be separated from livelihoods. PFs were built because farmers need wood and a variety of products which serve as a livelihood strategy. Ellis (2000) states that farmers' livelihood strategies aim to maximize the benefits derived from land, trees, labour, cash, and other constraints, and at the same time, reduce critical risk factors. Meanwhile, Reed et al. (2017) state that integrating trees on agricultural land provides additional sources of income and greater resilience strategies to adapt to market or climate shocks.

The number of trees in each diameter class is an indicator of stand growth. Stand growth is a result of ingrowth, mortality, cutting (Davis and Johnson (1987) and upgrowth (Lei et al. 2006). Upgrowth is triggered and controlled by the maintenance of trees. In the case of PF in Semoyo Village, upgrowth was not triggered because there was no specific treatment for trees like fertilizers (on average is once per year), this was confirmed by Hani et al. (2016), or weeding. However, ingrowth was triggered by planting or enrichment of the farms where all the farmers get approximately 95 % of a seedling from their lands (natural seedling). In the two planting patterns, farmers do not have to cultivate crops regularly or even space it. The number of trees planted was not remembered. Furthermore, the mortality rate was one variable that was difficult to analyze because it was rare. Therefore, the most predictable variable that tends to influence the structure of PF forests is cutting.

Cutting was conducted by combining the cutting needs and selective cutting systems. The cutting needs system was practiced whenever farmers needed cash while the selective cutting system was particularly practised for house renovation and it was carried out by choosing trees that have large diameters and are quite old. However, both types of cutting systems are implemented by all of the respondents. This indicates that the PF is savings for immediate or emergency needs as stated in a research conducted by Pratama et al. (2015).

The cutting intensity was discovered to be consistent with the need for cash. The number and volume were adjusted according to the need. Furthermore, tree cutting is also carried out by fully-managed forest farmers that solely depend on land-based activities for income whenever

cash was needed to purchase agriculture production facilities, especially fertilizers for paddy fields. According to Soraya (2017), cutting intensity tends to influence the structure of PF because the average diameter of the remaining trees is generally smaller since the fact that those with larger diameters are hugely accepted in the market. Most trees sold usually have a diameter more than 20 cm.

Partly-managed forest farmers have more trees (more than 20 cm in diameter) compared with fully-managed forest farmers because they satisfy some of their needs by working as labourers. Anonymous (2007) stated that reduction of rural poverty among small farm households includes increasing opportunities for off-farm work alongside ongoing efforts to improve agricultural productivity while Regmi (2003) discovered that changes in livelihood priorities and opportunities encouraged households to plant more trees on farms. Generally, fully-managed forest farmers tend to have the least number of trees and DBH unlike the partly-managed forest farmers and non-managed forest farmers.

The availability of farming manpower resources is a limiting factor in determining forest structure, especially for partly-managed forest farmers. Family members of farmers that engage in off-farm income-generating activities tend to limit the available manpower for agricultural purposes and this makes the planting of trees to be easier for them because it requires comparatively less manpower input. Furthermore, the rapid growth of off-farm employment in Semoyo Village creates a great challenge for the younger generations that seem not to be interested in working as farmers. This was in line with Vanwey and Vithayathil (2013) and Zhu et al. (2019).

Conclusion

Our findings indicate that there were differences in the stand structure and composition of the three types of farmers. The stand structure characterized by differences in the percentage of MPTS, number of trees (N , ha^{-1}), the average diameter and rate of diminishing in number of trees shows that stand structure is a reflection of different livelihood strategies in the fully-managed forest, partly-managed forest, and non-managed forest farmers.

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DIFFERENCES IN RESPONSE OF RADIAL GROWTH OF PEDUNCULATE OAK (*QUERCUS ROBUR* L.) TO CLIMATE CHANGE IN SHELTERBELT AND FOREST STAND IN THE FOREST-STEPPE ZONE OF UKRAINE

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Abstract

This paper presents an analysis of climatic factors affecting radial increment in pedunculate oak (*Quercus robur* L.) in shelterbelt and forest stand in conditions of the Left Bank Forest Steppe of Ukraine. Standard dendrochronological methods and methods of variational statistics have been used. Tree sensitivity over time was assessed in terms of Pearson's correlation strength. Two periods (1965–1990 and 1991–2016) were compared to detect features of the response of latewood, earlywood, and total rings to climate change in the shelterbelt and forest stand. The following tendency was revealed: increase in the mean annual temperature by 1.1°C (15 %), increase in the temperature in April–August by 1.1 °C (6 %), increase in March temperature by 1.4 °C (1470%), increase in winter temperature by 1.0 °C (25 %) in 1965–1990 by comparison with 1991–2016. Mean annual precipitation increased by 20 mm (4 %), precipitation in April–August increased by 10 mm (4 %) and winter precipitation decreased by 32 mm (10 %). For the shelterbelt, the significant negative correlations between the annual and latewood index series and temperatures for April, June, the average temperatures for April–August and average annual temperatures were detected for 1965–1990. Also, a significant negative correlation between the annual index series and temperature for April was revealed. Precipitation for June significantly restricted the annual increment. At the same time for forest stand only significant negative correlations between the annual and latewood index series and precipitation for April were found. In 1991–2017 significant negative correlations between latewood and September temperatures for the shelterbelt were found. Despite greater sensitivity of the oak radial growth to changes in environmental conditions and its lower stability in the shelterbelt compared to the forest stand, the radial growth of trees surviving after a severe drought in 1975 stabilized in 2010–2017.

Key words: climate change, shelterbelt, radial increment, pedunculate oak, weather parameters

Introduction

Degradation of agro-landscapes is one of the main factors in reducing the productivity of land resources. It is caused by the long-term use of insufficiently ecological systems of agriculture, violation of optimal structural and functional organization of the territory, as well as the balance of its main stabilizing components. All this leads to a decrease in anti-erosion resistance of agricultural landscapes, deterioration of their ecological condition. Shelterbelts are an integral part of fields. Their main function is to protect the soil from water and wind erosion, increase crop yields. Where forest shelterbelts are cut down, wind erosion prevails: winds blow away dried fertile soil layer, causing dust storms. And only the rock remains in the place of weathered chernozem (Koptev 1981, Stadnik 2004, Gladun et al. 2014). It has been calculated that the ecological and economic efficiency of forested landscapes is 20–30 % higher than in open areas (Yukhnovsky 2003).

There are many publications covering problems of protective forestry and agro-forestry. It is emphasized that the solution to these problems is possible when monitoring and restoring the existing forest stands and shelterbelts (Maluha 1998, Furdychko and Stadnik 2009, Stadnik 2012, Gladun et al. 2014, Kalbarczyk et al. 2016, Maillet et al. 2017, Howat and Laroque 2019).

Shelterbelts are an important component of ecological networks. Without them it is impossible to improve the conditions for the formation and restoration of the environment, enhancement of the natural resource potential of the territory, conservation of landscape and species biodiversity, habitats, genetic resources, ways of animal migration, etc. (Yukhnovsky 2003,

Maksymenko and Klieshc 2018, Maksymenko et al. 2018).

A number of works have emphasized on the impact of shelterbelts on agro-landscapes' optimization (Koptev 1981, Yukhnovsky 2003, Gladun et al. 2014), but few of them have been devoted to the health condition of shelterbelts (Vysotska et al. 2018). At present, the state of the protected forest stands in Ukraine, their functioning and protective efficiency are not yet at the proper level.

In Ukraine, the protection of fields with shelterbelts has been a priority (Koptev 1981, Gladun et al. 2014), but the condition of these forest belts under climate warming has not been sufficiently studied. Trees in the protective forest belts are deteriorating. This is associated with a decrease in the stand resilience in the face of climate change. Consequently, monitoring of the health condition of forest shelterbelts is extremely urgent.

Radial increment is an integral parameter that is a bioindicator reflecting the tree's response to environmental changes. The loss of forest resilience in the event of an unstable ecological situation can be reflected in the radial growth variability of the trees and its constant suppression. The assumption that global climate change is the most common cause of massive forest decline is nowadays almost an alternative hypothesis. However, it is extremely relevant to identify specific mechanisms of mass forest decline (Ray et al. 2010, Ramsfield et al. 2016, Seidl et al 2017, Jactel et. al 2019,). Dendrochronological methods allow us to carry out research both in spatial and temporal aspects (Bitvinskis 1974).

Dendrochronological studies of pedunculate oak in the Left-bank forest-steppe forest stands have been carried out (Koval et al. 2017), but the variability of radi-

al growth in shelterbelts of the region is a 'white spot' in the studies. Studying the dynamics of oak radial growth in shelterbelts of the Left-bank Forest Steppe will allow a better understanding of the health condition of this species in the region.

The purpose of the research was to identify the features of the response of radial increment of *Quercus robur* L. to climate changes in the shelterbelt and forest stand in the Left Bank Forest Steppe of Ukraine.

Materials and Methods

The study of radial growth of trees was carried out in 2017, in 70-year-old pedunculate oak stands in shelterbelt and forest stand growing on the territory of the Research and Production Center (Research Center) 'Research Field' of V.V. Dokuchaev Kharkiv National Agrarian University in the forest-steppe zone (Fig. 1). The distance between the shelterbelt and forest stand is 2 km. Cores were taken in shelterbelt (latitude: 49°54'15" N, longitude: 36°26'54" E) and forest stand (latitude: 49°54'42" N, longitude: 36°27'22" E).

The shelterbelt and forest stand consists of *Quercus robur* L. with admixtures of *Acer platanoides* and *Fraxinus excelsior* L. The shelterbelt has 5 rows of trees. The average tree diameter (DBH) is 29.2 cm in the shelterbelt, and 24.0 cm in the forest stand.

Climatic parameters (monthly air temperature and precipitation) were taken from Kharkiv weather station (latitude: 49°58'50" N, longitude: 36°15'09" E, altitude: 113 m a.s.l.). The climate is temperate continental. According to Kharkiv weather station, the warmest (21.0 °C) and wettest (61 mm) months are July, and the coldest is January (-5.5 °C); March (34.2 mm) is characterized by the lowest rainfall. The average temperature for the year is 8.2 °C, and precipitation sum is 552 mm. Mean annual temperature and annual precipitation, as well as same monthly parameters, were calculated for 1960–2017. Soils are chernozem, typical heavy loam.

Standard dendrochronological methods have been used (Bitvinskas 1974, Cook and Kairiukstis 1990). The cores have been taken from 20–25 trees at a height of 1.3 m from the surface using a



Fig. 1. Geographical location of experimental plots.

Pressler borer. Then all cores were air-dried.

The widths of early, late and annual increments were measured with a digital equipment HENSON up to 0.01 mm. All cores were dated using visual and graphical techniques to reveal the exact date of formation for each tree ring (Cook and Kairiukstis 1990). The proportion of latewood was calculated for 1960–2017 for cores from shelterbelt and forest stand. Tree-ring chronologies were indexed by the 3-year moving average (Bitvinskas 1974).

The development of oak in the shelterbelt and in the forest stand was investigated analyzing curves of the oak radial growth. We applied the methods of descriptive statistics and correlation analysis to study tree ring chronologies for earlywood, latewood and annual ring for 1960–2017 and correlation analysis to evaluate the relationships between ring index chronologies of oak trees and climatic parameters for 1965–1990 and 1991–2016 using software Excel 2010. Tree sensitivity over time was assessed using Pearson's

correlation.

Results and Discussion

Analysis of the dynamics of the early, late and annual increment of oak trees for both experimental plots has shown their highest growth in 1960–1968. In 1969–1975 there was a decrease in growth. In 1976–1984 an increment of all wood layers increased again. In the following period 1985–2017, a gradual decrease of the radial increment was observed in the shelterbelt, while the stabilization of radial increment was observed in the forest stand (figs 2 and 3).

No significant difference was found between the width of early, late and annual wood in the shelterbelt and forest stand over the period 1960–2017. It has been found that annual oak rings were wider in the shelterbelt due to better lighting and larger nutrition area for the trees. The difference between the mean values of annual wood was 9 %, of latewood – 15 %, while no significant difference was found for earlywood (Table 1).

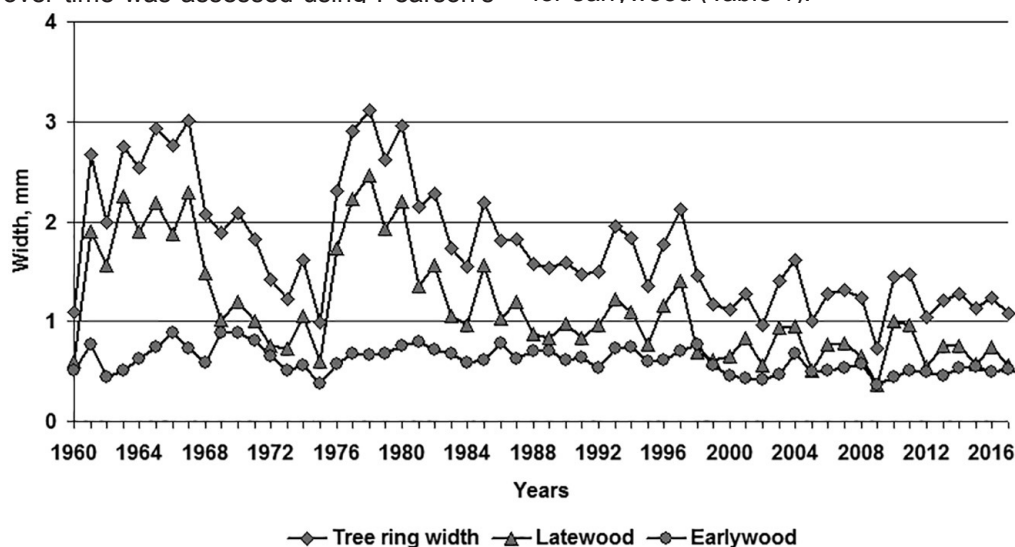


Fig. 2. Dynamics of annual, latewood and earlywood of oak trees in shelterbelt.

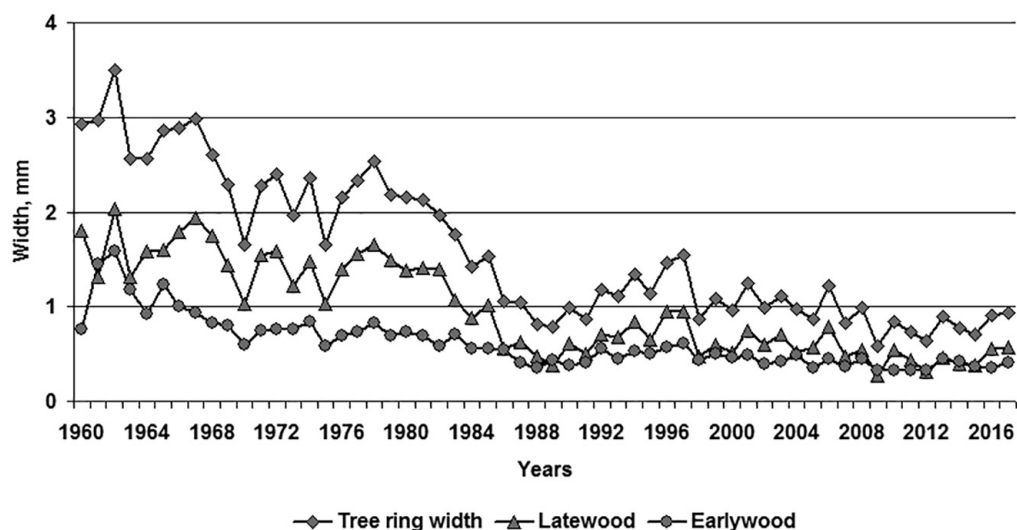


Fig. 3. Dynamics of annual, latewood and earlywood of oak trees in forest stand.

Table 1. Statistics of earlywood, latewood, and annual radial increment in forest stand and shelterbelt for 1960–2017.

Variant	Radial increment, mm ±SE	Variation coefficient, %	Significance of difference between radial increment in shelterbelt and forest stand	
			<i>t</i> _{fact}	<i>t</i> _{0.05}
Annual wood				
Shelterbelt	1.75 ±0.08	35	1.24	1.96
Forest stand	1.59 ±0.10	49		
Latewood				
Shelterbelt	1.14 ±0.07	48	1.78	1.96
Forest stand	0.97 ±0.07	51		
Earlywood				
Shelterbelt	0.61 ±0.02	21	0.06	1.96
Forest stand	0.61 ±0.02	44		

Latewood was the most sensitive to environmental changes for both stands (see Table 1). Annual wood took the second place, and the earlywood took the third place, as evidenced by variation coefficients. The variability of types of wood is significant because it exceeds 20 % (Dospekhov 1985). This can be explained by the fact that the formation of earlywood is affected by weather conditions not only of the current year but also the previous

years, while formation of latewood is influenced mainly by the conditions of the current year (Table 1).

The similarity of dynamics of increment of earlywood, latewood and annual wood for both stands was proved by the correlation analysis (Table 2). Close correlations between all types of increments have been calculated for forest stand, unlike the shelterbelt, where high correlations are observed only for latewood and

annual wood. Average correlation is found for earlywood and latewood, annual wood and earlywood. This is evidenced by a large number of factors influencing the radial growth in the shelterbelt and difference in conditions for the growth of trees for both stands.

Table 2. Correlation coefficients between different types of wood for shelterbelt and forest stand, growing on the territory of the 'Research field', V. V. Dokuchayiv Kharkiv Agrarian University for the period of 1960–2017.

Type of wood	Correlation coefficient	t_{fact}	$t_{\text{theoretical}}$
Shelterbelt			
Annual and late	0.98 ± 0.02	39.68	$3.39_{0.001}$
Annual and early	0.61 ± 0.10	5.81	$3.39_{0.001}$
Late and early	0.46 ± 0.12	3.89	$3.39_{0.001}$

Forest stand			
Annual and late	0.98 ± 0.03	34.14	$3.39_{0.001}$
Annual and early	0.92 ± 0.05	17.01	$3.39_{0.001}$
Late and early	0.83 ± 0.08	10.76	$3.39_{0.001}$

The formation of earlywood layers is influenced by weather conditions of previous years, unlike latewood, which is formed mainly under the influence of weather conditions of the current year.

Oak latewood more fully reflects the stress conditions for tree growth than earlywood because it is more sensitive to changing environmental conditions (Amineva et al. 2014). In our research under stressful conditions in shelterbelts, where there is a higher wind speed and temperature contrasts, the correlation between earlywood and latewood is average, that is, weaker than between other types of wood mentioned in the above studies.

As noted by Bitvinskas (1974), the ratio of earlywood and latewood in the annual ring is influenced by the age of the tree, its height, type of growth and location of the tree in the stand. The long-term variability of earlywood and latewood is, in most cases, influenced by a nearly identical set of meteorological conditions, determining the variability of the tree ring width as a whole. In some years, there are quite significant deviations from the 'normal' ratios of earlywood and latewood in the annual ring of the tree (i.e. the advantage of earlywood or latewood). These deviations are probably most often caused by the effects of short-term extreme changes in environmental conditions.

There were 63 % of latewood in the annual tree increment in the shelterbelt, and 60 % in the forest stand, i.e. the difference was insignificant. The percentage of latewood ranged from 44 % to 82 %. It has been confirmed that the percentage of latewood in oak decreases with age (Fig. 4).

There are three periods of oak radial increment for shelterbelt and forest stands:

- The first period (1960–1970) was characterized by synchronous growth and excess of the average width of annual rings in the forest stand by 14 %, i.e. the difference between the absolute values of radial growth was insignificant.

- The second period (1971–1975) was characterized by a sharp decrease in the oak radial increment in the shelterbelt, when it was reduced by 37 %, and this difference was significant. This was due to the arid year 1971, when a deviation from the precipitation rate was 24 %. As a result, oak growth in the shelterbelt has sharply worsened. The drought triggered a decrease in radial growth in the shelterbelt with less favorable conditions

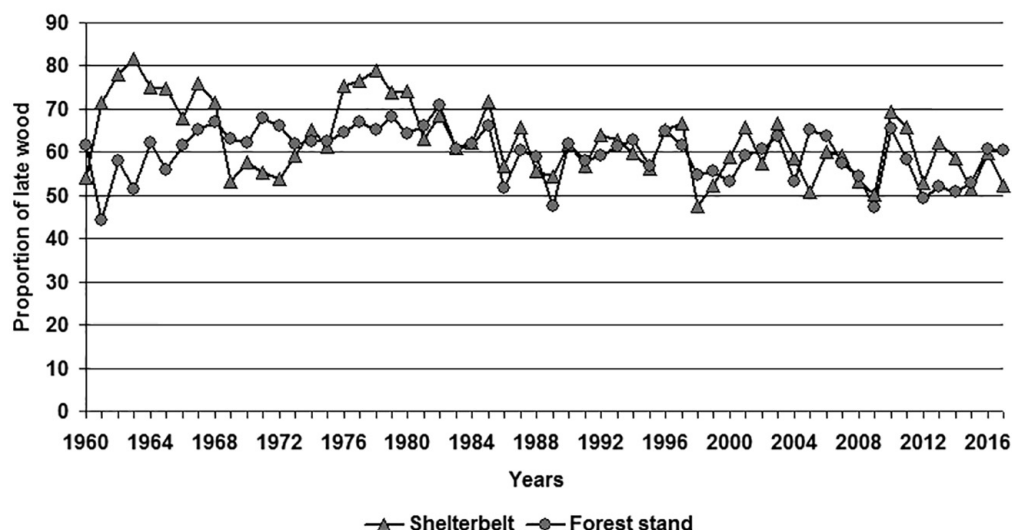


Fig. 4. Proportion of latewood in the width tree ring of oak trees in the shelterbelt and forest stand.

than in forest stand because the growth conditions for the trees in the shelterbelt were more extreme than in the forest due to higher moisture deficiency.

- The third period (1976–2017) was characterized by a 25 % increase in radial increment for the shelterbelt by comparison with the corresponding values in the forest due to severe drought in 1975 (30 % less precipitation than normal) (Fig. 4), which caused the mortality of weakened trees in the shelterbelt. Due to this the area of nutrition supply and lighting increased, causing a sharp radial growth in the shelterbelt.

Therefore, despite the fact that oak radial increment is more sensitive to changes in environmental conditions and less stable in the shelterbelt compared to the corresponding values on the control, radial growth of trees that survived the severe droughts of 1975 and 2002 stabilized in 2010–2017 (figs 5 and 6).

Years of minimum increment for both plots are 1964, 1970, 1975, 1984, 1989,

1995, 2002, 2005, 2009, 2013 and 2015. Years of maximum increment are 1967, 1974, 1978, 1985, 1997, 2006, 2010 and 2016. Growth depressions are caused by low precipitation and high temperatures. Wide annual rings formed due to favorable heat and moisture ratio (figs 4 and 5).

Radial growth indices for earlywood, latewood, and annual wood were evaluated to find the relationship between climatic factors and radial growth.

The following tendency was revealed: increase in the mean annual temperature by 1.1 °C (15 %), increase in the temperature in April–August by 1.1 °C (6 %), increase in March temperature by 1.4 °C (1470 %), increase in winter temperature by 1.1 °C (25 %) in 1965–1990 in comparison 1991–2016. Mean annual precipitation increased by 20 mm (4 %), precipitation in April–August increased by 10 mm (4 %) and winter precipitation decreased by 32 mm (10 %) in 1965–1990 in comparison to 1991–2016.

For the shelterbelt, the significant neg-

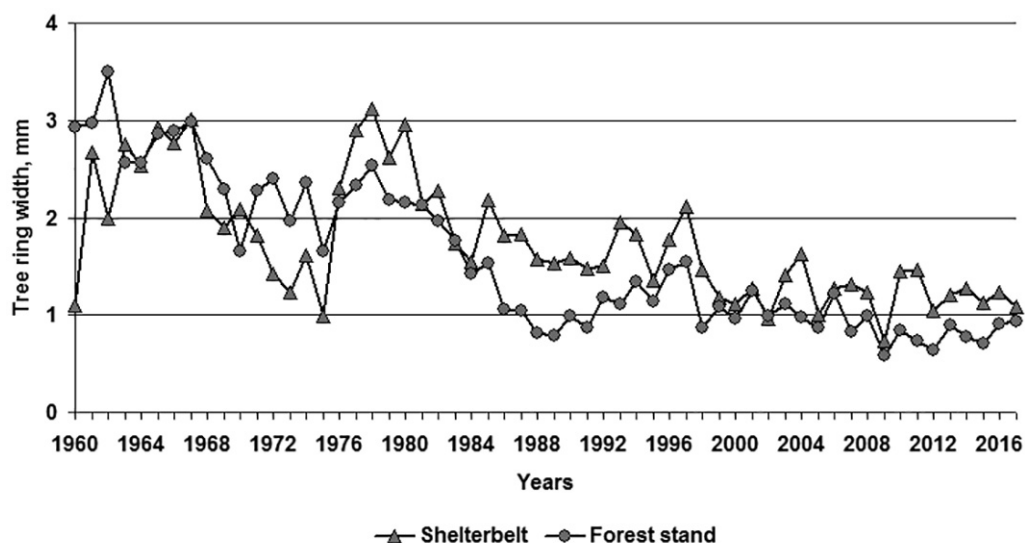


Fig. 5. Dynamics of radial growth of oak trees in shelterbelt and in forest stand.

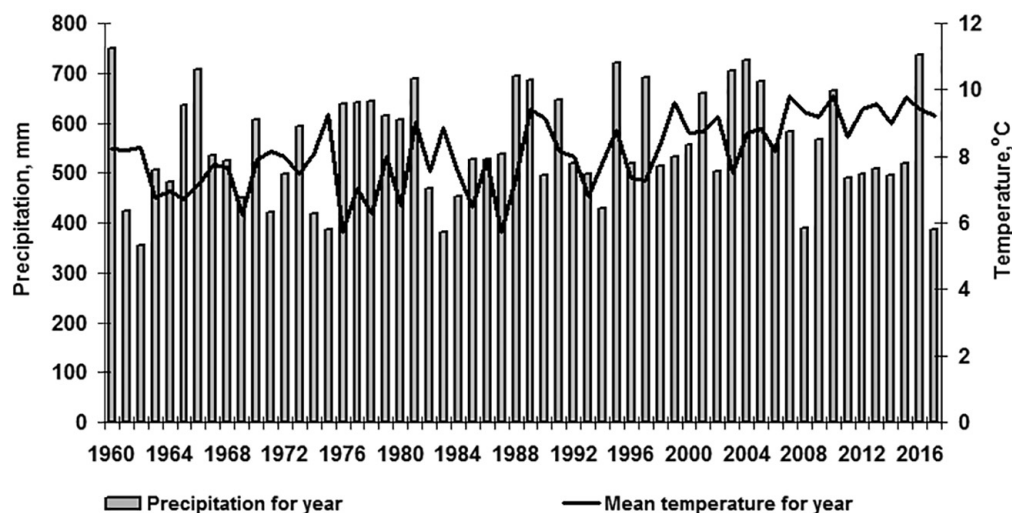


Fig. 6. Dynamics of annual precipitation and mean temperatures according to Kharkiv Weather Station.

ative correlations between annual and latewood index series and temperatures for April, June, the average temperature for April–August and average annual temperatures were detected for 1965–1990. Also, a significant negative correlation between annual index series and temper-

ature for April was revealed. Precipitation for June significantly restricted the annual increment. At the same time for forest stand only significant negative correlations between the annual and latewood index series and precipitation for April were found (Table 3).

Table 3. Correlation analysis between the indices of radial growth and climatic parameters for two periods: 1965–1990 and 1991–2016.

Parameter	1965–1990			1991–2016		
	Annual wood	Latewood	Earlywood	Annual wood	Latewood	Earlywood
Shelterbelt						
Average temperature in April, °C	-0.43 _{0.05}	-0.43 _{0.05}	-0.15	-0.11	-0.15	0.10
Average temperature in May, °C	-0.49 _{0.05}	-0.40	-0.41	-0.09	-0.03	-0.23
Average temperature in June, °C	-0.67 _{0.001}	-0.66 _{0.001}	-0.23	-0.20	-0.18	-0.17
Average temperature in September, °C	-0.20	-0.18	-0.14	-0.35	-0.43 _{0.05}	0.04
Average temperature in April–August, °C	-0.58 _{0.01}	-0.59 _{0.01}	-0.11	-0.07	-0.05	-0.10
Average annual temperatures, °C	-0.44 _{0.05}	-0.44 _{0.05}	-0.10	-0.23	-0.23	-0.09
Total precipitation in June, mm	0.53 _{0.01}	0.50	0.27	0.18	0.18	0.10
Forest stand						
Average temperature in April, °C	-0.46 _{0.05}	-0.42 _{0.05}	-0.30	0.01	0.02	-0.06

In 1991–2016 significant negative correlations were found between latewood and September temperatures for the shelterbelt (Table 3). Despite greater sensitivity of oak radial growth to changes in environmental conditions and its lower stability in shelterbelt compared to forest stand, the radial growth of trees surviving after a severe drought in 1975 stabilized in 2010–2016.

The shelterbelt was much more sensitive to weather stress factors as com-

pared to the forest stand because it has a greater number of significant correlations between the radial increment and climatic parameters. For the first period, a negative correlation was found between the tree ring indices of annual and latewood from one site and April, May, June, the average temperature for April–June and annual temperature from another site except for latewood and May temperature. June precipitation restricts the annual ring growth (Table 3). That is, annual and late-

wood were the most sensitive to changes in environmental conditions. In the forest stand the formation of annual rings and latewood was restricted by April temperatures for the first period.

In the second period, significant negative correlations were found only between latewood and September temperatures for the shelterbelt.

Previous studies of radial growth of pedunculate oak in the green zone of Kharkiv (Koval and Kostyashkin 2015) have revealed that the number of significant correlations decreased in 1988–2011 compared with 1967–1987. In the first period (1967–1987) radial growth was restricted mainly by the temperatures of the growing season and early spring, and in the second period – only by early spring. In our case, in the second period, there is also a decrease in significant correlations between radial growth and climate parameters.

Thus, it turned out that oak was more sensitive, and therefore, less resistant to weather stress in the shelterbelt. In the second period, the number of significant correlations between radial growth and climatic factors declined significantly.

Presently oak trees in shelterbelt and forest stand are adapted to climate change in the Left Bank Forest Steppe of Ukraine. This information can help guide the management of shelterbelt systems in this area.

Conclusions

It has been revealed that radial growth in the shelterbelt is more sensitive to changes in environmental conditions than in forest stand, as evidenced by poorer correlations between tree-ring chronologies

of annual increment, earlywood, and latewood compared to the corresponding values for the forest stand.

The drought in 1975 (by 30 % less precipitation than normal) caused drying up of some trees in the shelterbelt and forest stand, which led to increase in the radial growth of the remained alive trees due to increased nutrition areas and improved light conditions.

During 1965–1990 the negative correlations were found between the tree ring indices of annual and latewood from one site and April, May, June, the average temperature for April–June and annual temperature from another site except for relationships for latewood and May temperature. June precipitation restricted annual rings. In the forest stand the formations of annual rings and latewood were restricted by April temperatures for the first period. In 1991–2016 significant negative correlations were found only between latewood and September temperatures for the shelterbelt. Despite greater sensitivity of oak radial growth to changes in environmental conditions and its lower stability in the shelterbelt, compared to the forest stand, the radial growth of trees surviving after severe droughts in 1975 stabilized in 2010–2017.

Presently oak trees in shelterbelt and forest stand have adapted to climate change in the Left Bank Forest Steppe of Ukraine.

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INVESTIGATION OF MECHANICAL PROPERTIES AND ROOT ARCHITECTURE OF PLANTS AND SOIL PHYSICAL PROPERTIES FOR SOIL SHEAR STRENGTH

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Abstract

The use of vegetation as slope cover becomes an alternative solution for slope stabilization instead of using shotcrete cover. Use of vegetation is a way to reduce the impact of engineering works and increase the landscape quality. Although the use of vegetation to reduce slope failure is common around the world during the last decades, but in Malaysia there is still lack of such studies. Therefore, to answer the question whether the existence of tropical trees increase the soil shear strength against slope failure and measuring the amount of increase, the soil engineering properties of two tropical species were studied. Eight trees of similar age of *Acacia mangium* and *Macaranga tanarius*, were selected along the East-West highway, Malaysia. The direct shear tests were used to analyze the effect of tree roots on soil mechanical properties. Soil and root properties such as moisture and bulk density with and without root and root architecture of two species were analyzed. The results showed that the existence of roots increases soil shear strength and this is higher in soil sample with *M. tanarius* roots which increases it with about 11 % to 44 % while *A. mangium* trees increase soil shear strength with about 7 % to 27 %. The soil particle size in *M. tanarius* samples shows higher coarse grain size, therefore, the higher soil shear strength could be explained. The results showed that there is a negative correlation between soil moisture and soil shear strength and a positive correlation between soil bulk density and soil shear strength. The root architecture of *M. tanarius* with VH-type also imply the higher soil shear strength compare with *A. mangium*. In conclusion, *M. tanarius* root and soil properties implied higher soil shear strength of soil samples compared to *A. mangium*.

Key words: engineering properties, root architecture, soil and root properties, soil bulk density, soil cohesion, soil shear strength.

Introduction

Soil stabilization using roots in woody shrubs and trees, and root reinforcement of sloping ground is one of the least recognized measures. A summary of engineering influences of vegetation used

to stabilise sloping ground (Norris and Greenwood 2006) include additional effective cohesion due to the vegetation; tensile reinforcement force by the existence of roots; soil strength changes due to moisture removal by the vegetation; pore water pressure changes due to the

existence of roots.

Utilization of bio-engineering on slopes and road cuttings depicts the use of vegetation for protection of river banks and slopes. Bio-engineering combines understanding of engineering principles with knowledge of vegetation and its interaction with soil. Understanding plant root functions and soil-root interaction is the first step to improve bioengineering techniques and use of living plants instead of industry materials to stabilize slope and therefore to construct sustainable future.

The presence of vegetation can significantly affect water level in the soil and also the pore pressure of water (Greenwood et al. 2004). Vegetation has two main effects on the slope stability. By its hydrological effect, vegetation can increase the capacity of water infiltration and reduce water content in the soil and also with evapotranspiration increase the effective soil cohesion and the effective soil cohesion enhances by increasing in reinforcement effect (Das et al. 2017b). By mechanical effect the presence of vegetation roots crosses the potential failure slip surface, provides a tensile force which is an additional restrain on the potential slip (Burylo et al. 2011). Use of vegetation for slope stabilization has lower initial construction cost and needs just regular observation and maintenance. Hence, bio-engineering offers an alternative solution instead of using a conventional massive structure for slope stability and shallow landslide (Leung et al. 2015).

Krzeminska et al. (2019) monitored the hydrological and mechanical effects of selected Norwegian species (trees, shrubs and grass) on stream bank stability in Norway. Soil shear strength and porosity, soil moisture, groundwater level and stream water level were monitored in this study. They conducted that there is no significant

difference between grass and shrub plots but they found lower soil moisture and porosity, and higher soil shear strength within the tree plots.

Cebada (2017) calculated the mechanical effects of 17 different species in Nepal on slope stability. Out of the 17 plant species in the study, two were grasses, two bamboos, five shrubs and eight trees. The results showed that use of grasses, like *Thysanolaena maxima* (Roxb.) resulted in increased factor of safety (FOS). *Vitex negundo* L. showed the highest FOS among shrubs. *Salix tetrasperma* Roxb. provides better reinforcement due to its root cohesion. They concluded that a combination of species rather than monoculture provides good protection against slope failure.

Some authors such as O'Loughlin and Ziemer (1982), Sonnenberg et al. (2010) and Ali et al. (2012) agreed that mechanical functions of roots are more accepted than hydrological functions regarding slope stability. Even though, plant roots reduce the pore water pressure, but it is obviously accepted that mechanical functions effect directly on slope stability and decide whether or not the slope is stable or fail during shear stress. Simon and Collison (2002) showed that the hydrological effect of riparian vegetation increases slope stability by only 29 %, but in contrast the mechanical effect increases the stability about 53 %. Abernethy and Rutherford (2001) also mentioned that the mechanical benefit of vegetation can be more than the hydrological.

Ali (2010) mentioned that more information is still needed on Malaysian plant roots system regarding to slope stability. Information on the nature and on their performance of Malaysian species for bio-engineering purposes is poor. In case of below-ground performance, there are

few studies on root system architecture of exotic or native tree species. This is due to the fact that study on root system is time-consuming as they are below-ground, especially for large trees, and also root system is in direct collaboration with soil conditions therefore the comparisons would be difficult.

One of the limiting factors in the use of biotechnology of environmental engineering is lack of knowledge about the characteristic of root systems. Therefore, knowledge on their morphological and mechanical properties of different plant species is an effective parameter to select an appropriate slope stability species. The main objective of this study is to investigate the effect of vegetation roots of two broadleaf species on soil shear strength. In this study, we would like to answer the question whether the existence of *Acacia mangium* Willd. and *Macaranga tanarius* (L.) Müll. Arg. root system in soil increases the soil shear strength or not. And if yes, how much they can increase the soil shear strength.

Material and Methods

Study area

The study area is located along the East-West Highway of Malaysia. It is one of the major roads in the northern part of Peninsular Malaysia between N 05°27'32.0" E 101°07'42.3" and N 5°42'11.15" E 101°49'54.74". The length of the highway is 119 km which links two districts namely Gerik in Perak and Jeli in Kelantan. The climate of the study area is humid and annual mean precipitation is 1957.5 mm. The minimum altitude is 283 m above the sea level. The type of soil is clayey with a mixture of sand and gravel. The geolo-

gy of the area consists of granite, schist, phyllite, slate and limestone, meta-volcanic, mylonite, amphibole schist, thick bedded to massive quartzite with thin phyllites interbed (Lloyd et al. 2001) (Fig. 1).

In this study, investigated species are *Acacia mangium* (Malay name: Mangium) and *Macaranga tanarius* (Malay name: Mahang). The studied species were selected based on the following factors/criteria to select slope stability species (Stokes et al. 2008):

- Fast growing plant species (*M. tanarius* and *A. mangium*);
- Small species with a low canopy (*M. tanarius*);
- Self-renewal ability (*A. mangium*);
- Nitrogen fixing plants (*A. mangium*) improve soil materials with their nodulation functions; strong resistance; have a beneficial effect on soil resistance and infertility and soil and water conservation;
- No study about the effect of its root on soil cohesion and also it is the common species in Malaysia (*M. tanarius*) (Zakaria et al. 2008).

Methodology

Soil mechanical tests

Direct shear box test

The soil shear strength is its resistance to shearing stress. For engineering situations such as investigating slope stability or cuts, the shear strength data are needed. Soil derives its shear strength from two parameters, internal friction angle and cohesion.

One of the oldest and cheapest tests for soil is a direct shear test. The shear strength is done in the laboratory by a direct shear device. Fan and Su (2008) and Zhang et al. (2010) mentioned the

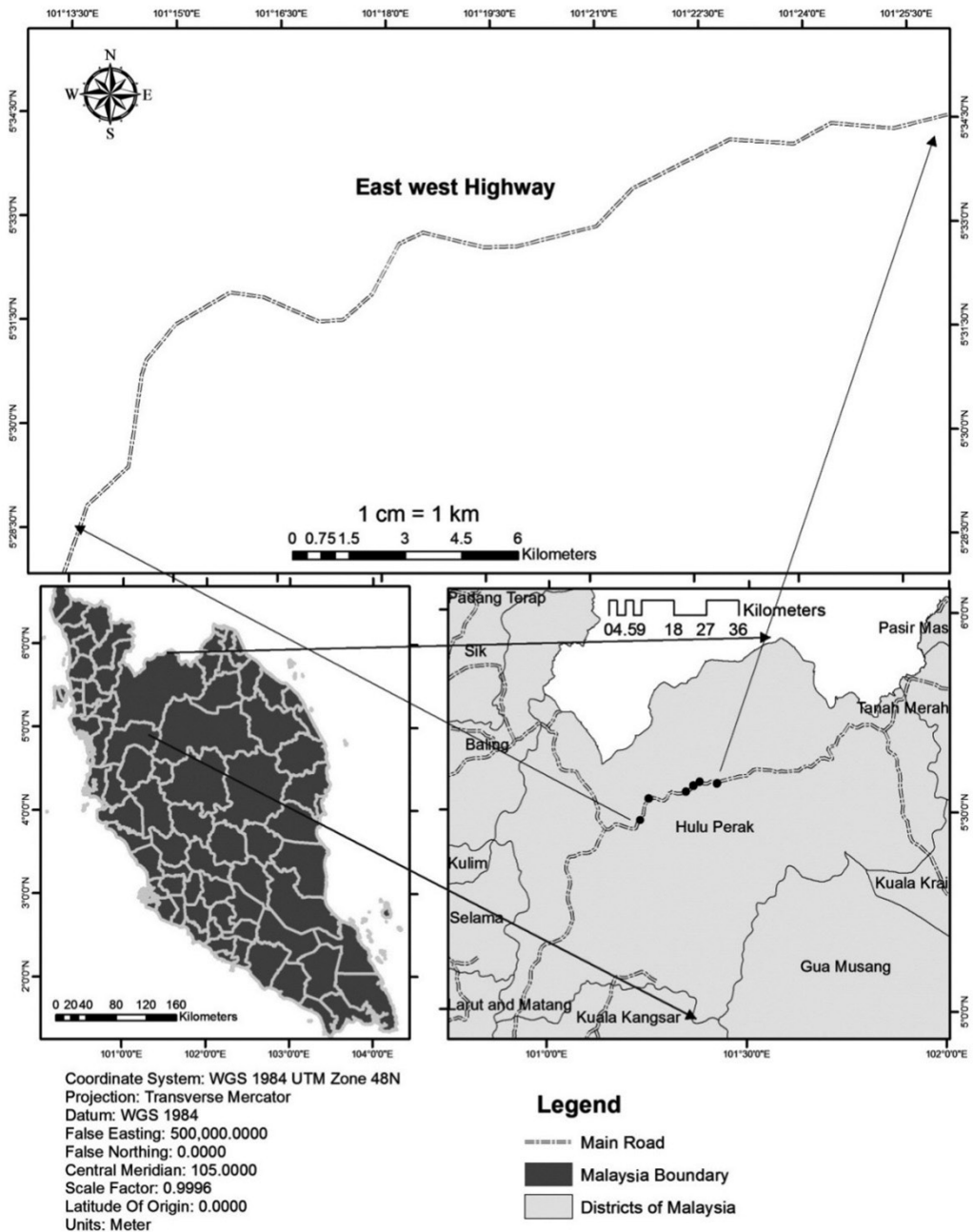


Fig. 1. Location of the study area.

low cost and direct visual process as the advantages of this test. The other advan-

tages mentioned by Ali and Osman (2008) are: samples at different depth can be in-

vestigated; uniform soil sample can be prepared and saturation of each sample can be obtained. The biggest disadvantage is that the shear plane is assumed.

Shear strength is measured by continuing the displacement of soil particles and the resistance of soil to this shifting. Two loads are applied in soil particles in the direct shear test. A normal stress (vertical) is applied and held stable, and then a shear stress is applied until rupture.

In direct shear test equipment, soil specimen is placed in a metal box which splits into two halves horizontally. Through a metal plate, vertical force (normal stress) is applied and continues. By moving one half of the box relative to the other one, shear force is applied to failure in the soil.

The procedure of soil direct shear test

Firstly, the area of the shear box was measured, then the top and bottom of shear box were fixed together and set in contact. Then shear box was placed in the machine and the normal force with three loads – 10 kg, 20 kg and 40 kg, were applied. After that the motor was started (0.25 mm/min). Data of horizontal displacement, vertical displacement and shear load were recorded by data logger. Reading was continued until the soil failed.

To determine soil mechanical properties, soil cohesion and internal friction angle, three undisturbed samples of rooted soil and non-rooted soil (for each soil sample with and without root) at 30 cm soil depth were taken by manually pushing the cylinder with a known volume (63.4 mm diameter × 20 mm height). Strain-controlled direct shear test machine was used (Direct/Residual Shear Apparatus, MCR 2110/1, Geotechnical laboratory, University Sains Malaysia). The undisturbed soil samples were placed in a shear test-

ing device under the three normal loads. A lateral displacement was applied at 0.25 mm/min until failure occurred and the peak shear force was noted (Fig. 2).



Fig. 2. The process of undisturbed soil sampling and analyzing with direct shear box machine.

Data processing

The collected 3 soil samples from each profile of trees at 30 cm soil depth, and the direct shear test under 10, 20 and 40 kg vertical pressure was carried out. A lateral displacement was applied at 0.25 mm/min until failure occurred and the peak shear force was noted. When 3 data of peak shear strength were measured, were plotted to find the relationship between vertical pressure and shear strength, therefore the intercept of the line is soil cohesion and the linear slope is $\tan \phi$.

The soil engineering properties (soil cohesion and internal friction angle) were measured based on Coulomb equation (1).

$$\tau = \sigma \cdot \tan \phi + C, \quad (1)$$

where: τ is soil shear strength, KPa; ϕ is the internal friction angle, degree; C is the

cohesion, KPa.

The normal stress (σ) in KPa, is given by equation (2).

$$\sigma = [(9.81 \cdot m) \cdot 1000^{-1}] \cdot A^{-1}, \quad (2)$$

where: m is the mass of frame loadings and loads weights (kg) (in this study the frame weight is 4.476 kg); $1 \text{ kg}_{\text{force}} = 9.81 \text{ N}$; A is the soil area (the area of shear box = 0.003157 mm^2).

Soil physical tests

Soil moisture content, specific gravity and particle size of samples with and without roots were determined in this study. For analyzing the moisture percentage of a soil sample, it is necessary to weight the container with and without soil and then dry it in oven at 105°C for 24 h. Soil specific gravity is necessary for some tests such as: porosity, soil particle size and soil saturation. The pycnometer method was used to calculate the soil specific gravity. Particle size distribution is a necessary test that presents the relative portions of soil particle size. Then it is possible to determine that soil consists mainly of gravel, sand, silt or clay particles. There are two methods to analyze soil particle size namely, mechanical analysis and hydrometer methods.

Root architecture

Since the end of 1990s, coarse root architecture was measured by new devices and techniques such as volume location and semi-automatic 3D digitizing. Root architecture can be achieved by classifying individual roots in several types (Danjon and Reubens 2008). Based on general form and branching pattern, Yen (1987) classifies root architecture in five types, such as H-type, VH-type, M-type, V-type and R-type (cited in Reubens et al. 2007). Fan and Chen (2010) state that the VH- and H-types are introduced to be used in slope stability application, whereas the M-type and H-type are introduced for use in soil reinforcement and restoration as well as erosion control.

Leung et al. (2015) mentioned that soil reinforcement which caused by vegetation roots depends on root architecture.

Results

Soil physical results

Table 1 shows the result of soil physical tests, soil moisture content, specific gravity bulk density and soil type of rooted and non-rooted soil sample.

Table 1. The average meaning of parameters.

Soil physical tests Sample	Soil moisture, %	Specific gravity, g/cm^3	Initial bulk density, mg/m^3	Soil type
<i>A. mangium</i>	25.41625	2.32	0.796375	sandy-silt
<i>M. tanarius</i>	27.155	2.20625	0.80125	silty-sand
No root	21.945	2.29375	0.8275	silty-sand

Soil mechanical results

The relationship between shear stress and normal stress of undisturbed soil samples with and without root is shown

in Figure 3.

Table 2 shows the cohesion and internal friction angle of soil samples with *A. mangium* and *M. tanarius* roots as well as soil without root.

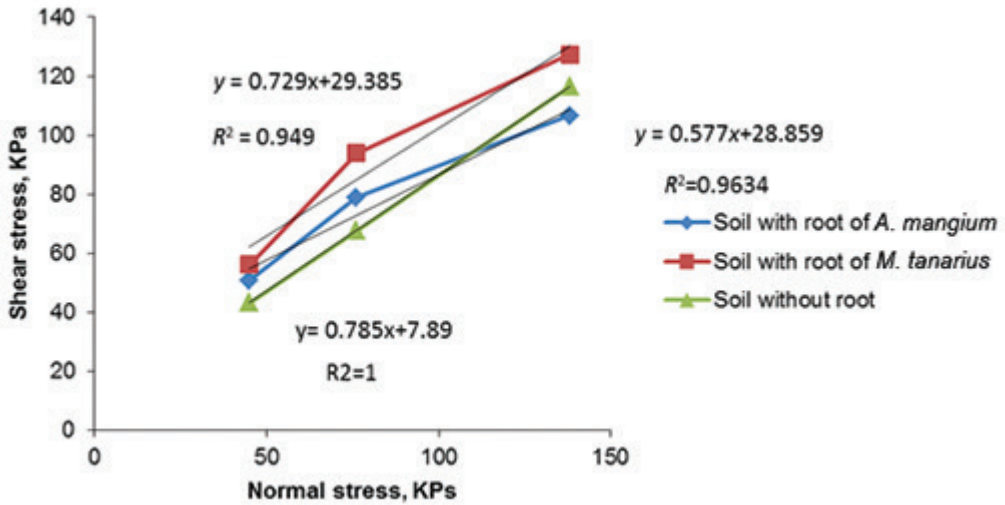


Fig. 3. The relationship between shear stress and normal stress.

Table 2. The mechanical properties.

Sample	Soil cohesion (C), KPa	Internal friction angle, °
<i>A. mangium</i>	28.859	30
<i>M. tanarius</i>	29.385	36.12
Non-rooted soil	7.8935	38.15

Soil shear strength increased due to the existence of roots

Soil shear strength is the maximum shear stress that soil can carry without rupture. The shear strength of soil (τ , KPa) is directly related to the normal stress (σ , KPa) acting in shear zone, assuming that other factors are certain. The Mohr-Coulomb law shows the relationship between soil shear strength and normal stress – based on equation (1).

The composite cohesion comes from not only soil particles but also the interaction between soil and roots. Therefore, the cohesion can be defined as integrated cohesion by equation (3).

$$C = C_s + C_r, \quad (3)$$

where: C_s is the soil cohesion and C_r is root cohesion.

Table 3 shows the integrated cohesion C , root cohesion C_r and internal friction angle of soil with *A. mangium* and *M. tanarius* root and soil without root to calculate soil shear strength.

Table 3. Indexes of shear strength.

Index of shear strength/sample	Soil and root cohesion (C), KPa	Root cohesion (C_r), KPa	ϕ , °
Plain soil	7.9	-	38.15
<i>A. mangium</i>	28.9	21	30
<i>M. tanarius</i>	29.4	21.5	36.12

Indexes of shear strength in Table 3 can be used to calculate shear strength of rooted and non-rooted soil samples with Mohr-Coulomb equation – refer to equation (2).

According to Coulomb model the shear strength is proportional to the normal stress; therefore, shear strength will be valid for any normal stress. Table 4 shows

the amount of soil shear strength (τ , KPa) with normal stress (σ) of 44.98 KPa.

Table 4. Shear strength calculated ($\sigma = 44.98$ KPa).

Samples	ϕ , °	C, KPa	τ , KPa
Plain soil	38.15	7.9	43.23
<i>A. mangium</i>	30	28.9	54.86
<i>M. tanarius</i>	36.12	29.4	62.22

One-way analysis of variance was used to determine the significant difference between shear strength of plain soil and soil with *A. mangium* and *M. tanarius* roots. The results showed that there is a significant difference between shear strength of plain soil and soil with roots (under 10 kg normal load) ($F_{2,21} = 5.140$, $p < 0.05$).

Post hoc comparisons using Tukey HSD test showed that the mean val-

ue of soil shear strength of *M. tanarius* ($M = 62.22$ KPa) is significantly different than soil shear strength of plain soil ($M = 43.23$ KPa; $p < 0.05$). However, the mean value of soil shear strength of *A. mangium* ($M = 54.86$ KPa) did not significantly differ from plain soil ($p = 0.152$) as well as mean value of soil shear strength of *M. tanarius* ($p = 0.444$).

According to Figure 4, under vertical pressure of 10 kg, the shear strength of soil samples with *M. tanarius* roots is significantly higher than that without roots. It shows that shear strength of soil with *M. tanarius* roots is higher than *A. mangium* root samples; even a significant difference is not identified.

Table 5 shows the amount of shear strength of rooted and non-rooted soil samples with normal stress of 76.05 KPa.

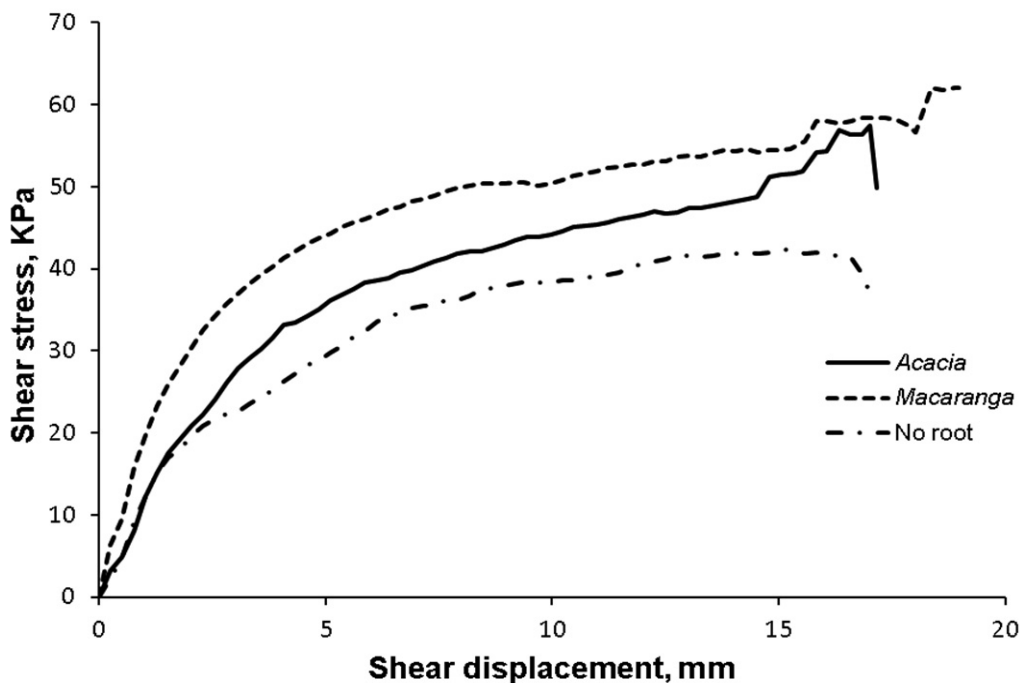


Fig. 4. Relationship between shear stress and shear displacement of rooted and non-rooted soil samples (applying normal stress of 44.98 KPa).

Table 5. Shear strength calculated
($\sigma = 76.05$ KPa).

Samples	ϕ , °	C, KPa	τ , KPa
Plain soil	38.15	7.9	67.63
<i>A. mangium</i>	30	28.9	72.80
<i>M. tanarius</i>	36.12	29.4	84.89

One-way analysis of variance was used to determine the significant difference between shear strength of plain soil and soil with roots. The results showed that there is no significant difference between shear strength of plain soil and soil with *A. mangium* and *M. tanarius* roots (under 20 kg normal load) ($F_{2,21} = 2.983$; $p = 0.072$). With normal stress of 76.05 KPa, the relationship between shear stress and shear displacement of rooted and non-rooted soil samples is shown in Figure 5.

Table 6 shows the amount of shear strength of rooted and non-rooted

soil samples with normal stress of 138.19 KPa.

Table 6. Shear strength calculated
(Normal stress = 138.19 KPa).

Samples	ϕ , °	C, KPa	τ , KPa
Plain soil	38.15	7.9	116.45
<i>A. mangium</i>	30	28.9	108.68
<i>M. tanarius</i>	36.12	29.4	130.24

One-way analysis of variance was used to determine the significant difference between shear strength of plain soil and soil with *A. mangium* and *M. tanarius* roots. The results showed that there is no significant difference between soil shear strength of samples (under 40 kg normal load) ($F_{2,21} = 2.028$; $p = 0.157$). The relationship between shear stress and shear displacement of rooted and non-rooted soil samples under normal stress of 138.19 KPa is shown in Figure 6.

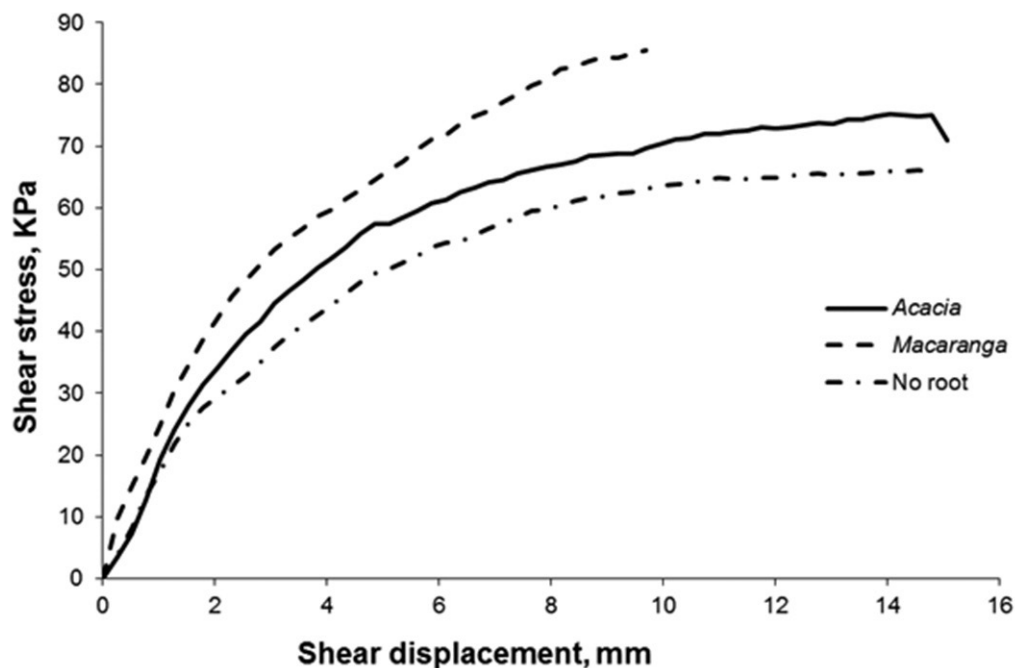


Fig. 5. Relationship between shear stress and shear displacement of rooted and non-rooted soil samples (applying normal stress of 76.05 KPa).

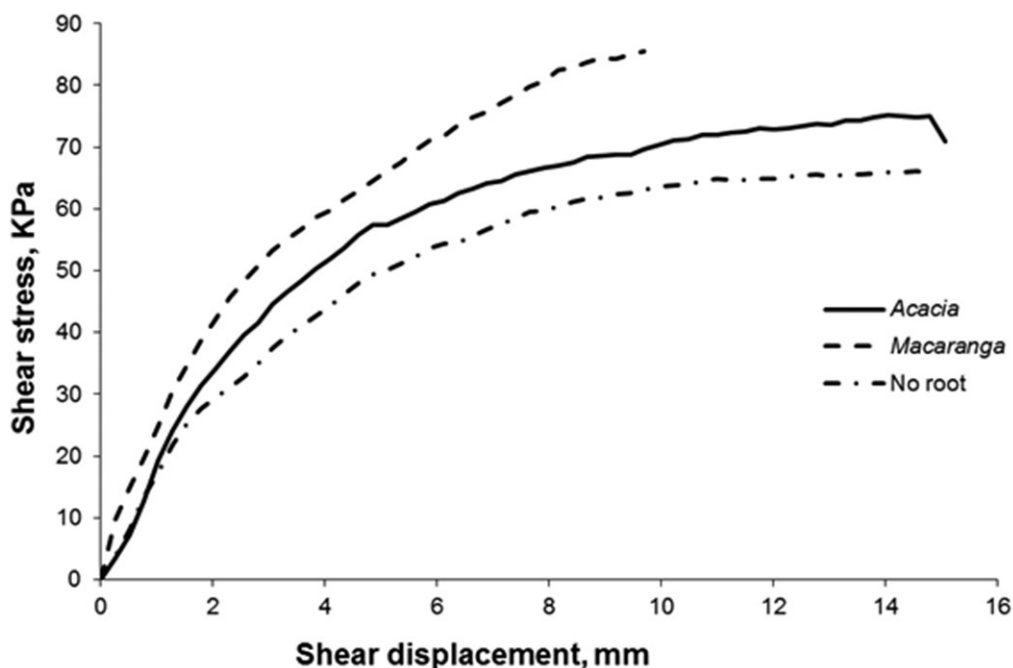


Fig. 6. Relationship between shear stress and shear displacement of rooted and non-rooted soil samples (applying normal stress of 138.19 KPa).

Soil shear strength and soil physical properties

The relationship between soil moisture content and soil shear strength in soil samples with roots and samples without roots shows that there is a negative correlation between soil shear strength and soil moisture. The relationship of soil shear strength and soil moisture for soil sample with *M. tanarius* roots is $y = -0.49 \cdot x + 75.75$ and for soil sample with *A. mangium* roots is $y = -0.48 \cdot x + 67.11$ and for soil sample without roots is $y = -0.33 \cdot x + 50.47$.

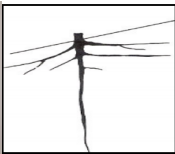
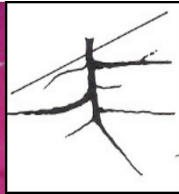
The relationship between soil bulk density and soil shear strength in soil

samples with *A. mangium* and *M. tanarius* roots and samples without roots shows that there is a positive correlation between soil shear strength and soil bulk density. The relationship of soil shear strength and soil bulk density for soil sample with *M. tanarius* roots is $y = 98.2 \cdot x - 16.5$ and for soil sample with *A. mangium* roots is $y = 57.2 \cdot x + 9.1$ and for soil sample without roots is $y = 58.5 \cdot x - 5.2$.

Root architecture

Table 7 shows the root growth pattern in two studied species based on Yen (1987) which is VH-type (*M. tanarius*) and H-type (*A. mangium*).

Table 7. Root growth pattern of two species.

Species	Root pattern growth		Root growth type
<i>M. tanarius</i>			VH-type (this research)
<i>A. mangium</i>			H-type (Ali 2010)

Discussion

Soil mechanical properties of rooted and non-rooted soil

Many authors around the world have used the laboratory and *in situ* shear tests on root permeated soil blocks to analyze the mechanical properties of soil with and without roots (Operstein and Frydman 2000; Docker and Hubble 2008; Askarinejad and Springman 2014; Fan and Tsai 2016; Das et al. 2017a, 2017b; Lateh and Avani 2018; Raj et al. 2018; Maffra et al. 2019).

Two parameters of soil mechanical properties, soil cohesion and internal friction angle influence on soil shear strength which studied by many researchers to find out which one increase soil shear strength. For instance, the soil shear strength of rooted and non-rooted soil samples of *Robinia pseudoacacia* L. with a triaxial compression test was studied by Zhang et al. (2010). They found that roots have more impacts on the soil cohesion than the soil friction angle. They argue that due to the presence of root, one index of soil shear strength (soil cohesion) increases and the other factor (friction angle) may in-

crease or decrease. Abdullah et al. (2011) state that the friction angle of soil has no significant effect on soil shear strength of three studied species compared to bare soil. The study shows that the cohesion of soil with roots is significantly higher than those without roots and this amount is significantly higher for *Leucaena leucocephala* (Lam.) de Wit. It could be due to the differences in root growth pattern which follows tap root system with long vertical root in *L. leucocephala*. Ali and Osman (2008) claim that the soil shear strength increases by increasing soil cohesion due to the presence of the plant roots in the soil and the effect of soil internal friction angle is negligible. They analyzed increased soil shear strength of four different species namely: *Vetiveria zizanoides* (L.) Roberty, *Leucaena leucocephala*, *Bixaorellana* L. and *Bauhinia purpurea* (L.) Benth. Their results show that shear strength (soil cohesion) increases in *L. leucocephala* more than that of the other species. O'Loughlin and Ziemer (1982) also mention that the existence of Beech roots in soil increase the soil cohesion from 3.3 to 6.6 KPa compared to non-rooted soil samples and the effect of roots on internal friction angle is negligible.

On the other hand, some other authors such as Frei (2009), Graf et al. (2009), Jiao et al. (2010), Davoudi (2011) and Askarinejad and Springman (2014), mentioned that an increase in the internal friction angle of soil caused increase in the soil shear strength. Frei (2009) and Graf et al. (2009) stated that an increase in the soil shear strength of moraine with alder trees (*Alnus incana* (L.) Moench) is due to an increase of the internal friction angle of soil from 34.3° to 39.4° without any change in soil cohesion. Jiao et al. (2010) showed that the internal friction angle of soil sample with more roots is larger than that of soil samples without roots. This is due to the roots which increase the friction of the soil and therefore increases soil friction angle. The study found that the existence of the roots destroys the connections of clay particles and therefore diminishes the soil cohesion. He claims that in the direct shear test, the internal friction angle of soil contributes mainly to the root anchorage force. Therefore, roots can increase the friction angle and produce resistance to shear stress.

Askarinejad and Springman (2014) showed that the existence of *Avena sativa* L. roots in soil increase the soil internal friction angle compared to non-vegetated soil and in overall increase the soil shear strength. Davoudi (2011) also showed that the existence of Willow root in the soil increase internal friction angle of soil, and in overall increase soil shear strength.

Slope stability improvement is provided by increasing the apparent root cohesion and rooting depth (Chok et al. 2004). Many studies have shown that the increase in soil shear strength is usually attributed to an increase in the apparent soil cohesion (Operstein and Frydman 2000, Ali and Osman 2008). In agreement with other authors, Pollen-Bankhead et al.

(2009) also found that the effect of tree roots (Tamarisk and Russian-olive) on soil shear strength increases the soil cohesion without any changes in soil internal friction angle.

Other authors such as Tang et al. (2007) and Chen and Loehr (2008) found an increase in both soil cohesion and internal friction angle of clayey soil reinforced with polypropylene and sandy soil respectively. Tengbeh (1989) also claim that grass roots increase the soil shear strength parameters (both soil cohesion and internal friction angle) of sandy clay loam soils, but for clay soil, it only increases soil cohesion. Maffra et al. (2019) also evaluate the roots influence on the shear strength of a clay soil and a sandy soil. They found that in the sandy soil, roots influenced the shear strength by increasing the cohesion value with 234 %, while in the clay soil with 32 % and the internal friction angle with 14.4 %.

The result of this study is in agreement with those who claim that the shear strength of soil increases due to the increase in soil cohesion. Therefore, this research is in agreement with Operstein and Frydman (2000), Ali and Osman (2008), Pollen-Bankhead et al. (2009), Lin et al. (2010), Davoudi (2011), Abdullah et al. (2011). According to the results, the soil cohesion of samples with roots for both species is higher than that without roots. The results show that the amount of soil cohesion of *M. tanarius* is more than *A. mangium*.

In conclusion, Veylon et al. (2015) suggested that the impact of root on soil shear resistance whether by increasing soil cohesion or internal friction angle depends especially on species. On the other hand, Chok et al. (2004) mentioned that slope stability improvement is provided by increasing the apparent root cohesion

(additional soil cohesion due to root). To understand the root function on soil shear strength, root system knowledge is required because this complex biological structure is unknown to the engineers. It is necessary to upgrade the engineering knowledge of vegetation such as additional soil cohesion due to the existence of root, vegetation interacts with soil, water, and climate, which many engineers are not familiar with the use of vegetation as an engineering material.

Soil shear strength

It is observed that the shear strength of soil permeated roots is higher than that without roots (figs 5, 6 and 7) (except for *A. mangium* soil samples with normal stress of 138.19 KPa; Fig. 6). Therefore, the study question has been answered and revealed that the existence of roots in soil will increase the shear strength of soil. The shear strength of soil increases about 44 % due to the existence of *M. tanarius* tree roots and this amount for *A. mangium* tree roots is about 27 % under normal stress of 44.98 KPa compared to non-reinforced soil with roots (Table 4). Therefore, *M. tanarius* roots increase shear strength of soil much more than that of *A. mangium* roots. Cazzuffi et al. (2006) also used big shear box machine to compare the effect of grass roots on soil shear strength compared with non-rooted soil samples. They found that Vetiver and Elygrass roots shows higher soil shear strength compared the other species. These differences could be explained by differences in root systems and environmental situation.

By increasing the normal stress to 76.05 KPa, the soil shear strength of rooted soil with *M. tanarius* increases to about 25.52 % and for *A. mangium* roots about 7.64 % compared to non-reinforced soil

with roots (Table 5). With normal stress of 138.19 KPa, the results show that the soil shear strength with *M. tanarius* roots increased about 11.84 % and for *A. mangium*, the soil shear strength decreases to about -6.67 % (Table 6, Fig. 6).

The shear stress-displacement curve for studied species and plain soil under 10 kg normal load is shown in Figure 8. The maximum shear stress-displacement point is significantly higher in soil permeated roots of *M. tanarius* than that those without root ($p < 0.05$, ANOVA). It is observed that *M. tanarius* has higher displacement before it achieves the maximum shear strength, it means high resistance towards the force applied before it losses the strength. This result is in agreement with Fan and Tsai (2016) who showed that the shear stress-displacement peak of soil samples without root occur before the peak shear strength of soil with *L. leucocephala* roots.

Docker and Hubbel (2008) showed the relation between shear stress versus shear displacement of four tree species (*Acacia floribunda* (Vent.) Willd, *Casuarina glauca* Sieber, *Eucalyptus elata* Dehnh. and *Eucalyptus amplifolia* Naudin) in Australia as well as soil without roots. They show that when soil samples without roots reach its peak strength, resistance of soil samples with roots is still increasing. They state that all species demonstrate higher soil shear strength compare to non-rooted soil, but *A. floribunda* shows a greater amount compared to other species.

Fan and Su (2008) mentioned root efficiency (RE) (the role of roots in shear strength of root permeated soil) in their research which comes from the increase in soil shear strength divided by shear strength of root-free soil. Referring to this study, the root efficiency of *A. mangium* (with higher normal stress) is below than

zero, therefore it shows that the efficiency of *A. mangium* roots to increase shear strength of soil with higher normal stress is not applicable.

Soil mechanical properties and root architecture

The result of internal friction angle showed difference between two studied species (internal friction angle of soil with *A. mangium* roots is 30° , and with *M. tanarius* roots is 36.12°). Therefore it showed that *M. tanarius* roots can increase the shear resistance more than *A. mangium* as they increase the internal friction angle more. Zhang et al. (2010) state that roots can meaningfully produce resistance to the shear stress with increase the internal friction angle.

The differences in internal friction angle of two species refer to the differences in root pattern. As the root system of *A. mangium* is H-type (Ali 2010) in which most of the roots grow horizontally, but *M. tanarius* roots growth type is VH-type (this research) whereby roots grow horizontally and vertically, therefore, the friction between root and soil increased. Saifuddin and Osman (2014) describe the VH-type root system as: strong tap root which lateral roots extended in a low orientation with horizontal plane. Zhang et al. (2010) stated that roots in horizontal or vertical forms reinforce soil in one direction, but roots in cross form reinforce soil in two directions. Therefore, trees with cross form roots are expected to reinforce soil and slope stabilization more than other root pattern forms. Abdullah et al. (2011) also mentioned that the root growth pattern in *L. leucocephala* which follows tap root system with long vertical root caused higher soil shear strength compared to other species. Riestenberg (1994) also

compared the root architecture of two species namely: maple sugar and white ash, and mentioned that sugar maple with lateral roots which do not develop a tap root cannot stabilize deep seated landslides, while white ash with developed roots in first centimeters depth and a tap root which penetrate in depth can stabilize deep seated landslides. Several species according to their enhancement in slope stability were ranked by Cebada (2017) and they concluded that *Vitex negundo* (shrub) and *Acacia catechu* (L.) Willd. (tree) has represented the highest rank among other species due to the fact that their root system develops a tap root with extensive lateral roots which can increase soil cohesion.

According to Tengbeh (1989), cohesion increases by increasing root amount in the soil, therefore, the differences in soil cohesion may be due to the differences in root profile. On the other hand, soil cohesion increases linearly with an increase in root cross-sectional area at the shear plane.

Soil shear strength and physical properties of soil

The results show that with increasing soil moisture, the value of soil shear strength decreases. This result is in agreement with Zhang et al. (2010), Veylon et al. (2015) and Dhawale and Harle (2017) which show that water content in soil decrease the soil shear strength.

The results of soil bulk density show that by increasing it the amount of soil shear strength increases. Rahardjo et al. (2014) mention that the soil with higher coarse grain particles shows higher shear strength due to an increase in contact pressure between particles. As the soil particle size in *M. tanarius* soil samples

shows higher coarse grain size, therefore, the higher soil shear strength could be explained.

Conclusions

The results show that the soil engineering properties (cohesion and internal friction angle) for both species in this research increase compared to non-rooted soil sample. This increase is more in soil with *M. tanarius* roots than *A. mangium* roots. Soil shear strength improves by the presence of roots in the study area and this amount is higher in *M. tanarius* than *A. mangium*. The result of this study is useful to protect the areas prone to slope failure with the increase of soil shear strength using the studied two categories of plants. The roots of these two plants show considerable mechanical properties that can contribute in protecting slope soil erosion.

In this research, for *A. mangium* at higher normal stress, maximum shear strength is less than that of soil samples without root. This result may be attributed to the position of soil cores collected in relation to slope angle and root architecture as well as soil moisture. Root system architecture can be driven by slope angle and knowing the upslope and downslope region of the sampled core may influence the maximum shear stress. If upslope cores are placed in the shear assembly with shear force acting in a relative upslope direction, roots are likely to be in compression and therefore exhibit lower values of shear stress. Ideally, cores should be sheared in a downslope direction to ensure that: a) soil will be sheared in the direction of most likely failure; b) roots will take up stress more quickly and, therefore, more likely to show root derived reinforcement at relative low lev-

els of displacement (strain). It is therefore important to consider sample orientation when analyzing the effect of soil sampling position on maximum soil shear strength. Therefore, it is suggested as a further research topic.

The soil moisture of samples without root has higher amount compare to soil samples with root and it is shown that with higher normal stress in soil sample with *A. mangium* roots, the amount of maximum shear strength is less than soil sample without roots. It may be due to less soil moisture in soil sample without roots which can resist more when the normal stress increased. However, there is not a proper study to represent the relationship between maximum shear strength and soil moisture according to different normal stress, therefore further studies in this matter is needed.

Due to the lack of knowledge and information regarding the root systems of common tropical species and their effect on soil shear strength, this subject is an important research area for further studies to applicate soil bioengineering techniques instead of civil engineering works in slope stability projects.

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MULTIFACTORIAL METHODOLOGY FOR NATURAL HAZARDS RISK ASSESSMENT

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Abstract

During the last years new methodologies are developed for the natural hazards risk assessment. The presented work deals with the methodology firstly developed by several bodies at global and regional level (United Nations programs – ISDR, UNDP; Inter-American Development Bank and Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (GTZ); ESPON 3.1.3 Hazards Project; Joint Research Centre (JRC), EC. Our goal is to further improve these methodologies including some new elements such as: building risk profiles, introduction of the qualitative and quantitative risk levels, combination of several hazards and the influencing factors, and application of the developed methodology to some selected objects in Bulgaria (forest fires around Etropole town surroundings). Presented methodology shows reasonable results and could be explored and exploited by the local authorities, civil defense and risk managers.

Key words: factor analysis, forest fires application, risk assessment.

Introduction

Recent disasters dramatically affected millions of people, with hundreds of thousands of lives and USD 1.5 trillion lost between 2005 and 2014. Global economic loss from disasters varies on average from USD 250 to 300 billion each year. Changing climate, rapid urbanization, ongoing violence and conflicts in many parts of the world, changing demographics, technological innovations, increasing inequality and many other known and emerging changes with their inherent uncertainties have created an unprecedented context for disaster impact. The risk assessment (analysis) of natural hazards is a disaster preparedness activity including pre-disas-

ter risk reduction phase of the risk management process. Risk analysis is a base for decision making and the main tool for the risk management and scenarios development about the risk reduction. UN terms and definition are accepted and approved among risk management specialists. According that, risk assessment includes three main activities: vulnerability, hazard and coping capacity assessment.

The initial definition is given by Blaikie et al. (1994): Risk = Hazard potential × Vulnerability or Risk = Hazard × Vulnerability/Coping capacity (UNISDR 2002). It must be mentioned that these are not algebraic equations and only show the interactions between risk, hazard and vulnerability.

The aim of this study is to present the complex methodology for risk assessment generated by different natural hazards, to improve the approach introducing correct weighting coefficients, to include risk perception as an important factor for the risk assessment.

A holistic risk assessment that considers all relevant hazards and vulnerabilities, both direct and indirect impacts, and a diagnosis of the sources of risk will support the design of policies and investments that are efficient and effective in reducing risk (UNDRR 2019).

Methodology for risk and multi-risk assessment

There are many models and methods for disaster and damage assessment caused by particular natural hazards. The methods used own specific features and the differences in models often lead to some disadvantages like: different results, different scenarios with various initial and final data, incompatibility, inappropriateness, etc. That is why during the last years the efforts are directed to holistic approach including all factors and parameters concerning risk assessment and analysis.

Basic methods and methodologies about the risk and multi-risk assessment are developed by: United Nations programs (UN) – ISDR, UNDP; Inter-American Development Bank and Deutsche Gesellschaft für Technische Zusammenarbeit (IADB 2003, IADB 2005); ESPON 3.1.3 Hazards Project (2004); Joint Research Centre (JRC), EC.

We accepted the following parameters modifying them from the original methodology. For the risk assessment – all components (hazards, exposure, vulnerability and coping capacity) are expressed by

the equations (1–4).

$$H = w(H_1) \cdot H_1 + w(H_2) \cdot H_2 + w(H_3) \cdot H_3 + \dots + w(H_n) \cdot H_n, \quad (1)$$

$$E = w(E_1) \cdot E_1 + w(E_2) \cdot E_2 + w(E_3) \cdot E_3 + \dots + w(E_n) \cdot E_n, \quad (2)$$

$$V = w(V_1) \cdot V_1 + w(V_2) \cdot V_2 + w(V_3) \cdot V_3 + \dots + w(V_n) \cdot V_n, \quad (3)$$

$$C = w(C_1) \cdot C_1 + w(C_2) \cdot C_2 + w(C_3) \cdot C_3 + \dots + w(C_n) \cdot C_n, \quad (4)$$

where: H , E , V and C are the values of the Hazard, Exposure, Vulnerability, and Capacity and Measures, respectively; H_1 , H_2 , H_n , E_1 , E_2 , E_n , V_1 , V_2 , V_n , C_1 , C_2 , C_n refer to the scaled values of the indicators; and w_i are the weights. A total sum of the weighting coefficients must be equal to 100. Our approach to introduce normalized weights is accepted to be able to create compatible values of all 4 components.

The risk profile for the given selected area is expressed by formula (5).

$$R = w \cdot H + w \cdot E + w \cdot V + w \cdot C, \quad (5)$$

where: R is the overall risk index, H , E , V and C are the values of the hazard, exposure, vulnerability and coping capacity, respectively, and w is the weighting coefficient.

Multifactorial methodology

The developed and adapted methodology for risk and multi-risk assessment includes:

• Risk perception as a part of the risk assessment

Considering the models and research, risk perception can be accepted as a root foundation related to the risk management. Therefore, the inclusion in the risk assessment is imperative. The psychological judgement 'It won't happen to me'

is associated with the personality. But the analogous psychological factors are the base of human behavior and decisions. Risk perception as a key factor may be becomes the main reason for maximize vulnerability or respectively its reduction.

The study of risk perception arose out of the observation that experts and people often disagreed about the risky various technologies and natural hazards. Three major families of theory have been developed: psychology approaches (heuristics and cognitive), anthropology/sociology approaches (cultural theory) and interdisciplinary approaches (social amplification of risk framework). The earliest psychometric research was done by psychologists Daniel Kahneman and Amos Tversky (Kahneman et al. 1982, Kahneman and et al. 2000).

Research within the psychometric paradigm turned to focus on the roles of affect, emotion, believes, etc, in influencing risk perception. Melissa Finucane and Paul Slovic have been the key researchers here.

On the basis of the knowledge of non-physical dimensions and contextual risk properties we can understand the hu-

man behavior against natural events and threats. What a society defines or professes to perceive as risk is thus not necessarily in any direct relation to the magnitude of risk as defined by the two components of probability of occurrence and extent of damage. It is very important for several reasons that a proactive and rationally structured risk policy addresses the issue of risk perception – the behavior of people is guided by their perceptions and not by scientific risk models (Pidgeon et al. 1992, Renn 1998, Fischhoff et al. 2000, Slovic 2000).

The algorithm presented as chain of elements (Fig. 1) follows the methodology logic: the hazard is characterized by place and time of occurrence. It could be different natural phenomena (in our case) or anthropogenic influence (excluded in this study). The unsafe conditions affect both (person and/or society) disturbing their zone of comfort. The risk perception is related to the conditions before and after the disaster.

Following this logic we build up a risk profile, using the theory expressed in topic Methodology.

Thereby, the risk profile for the given

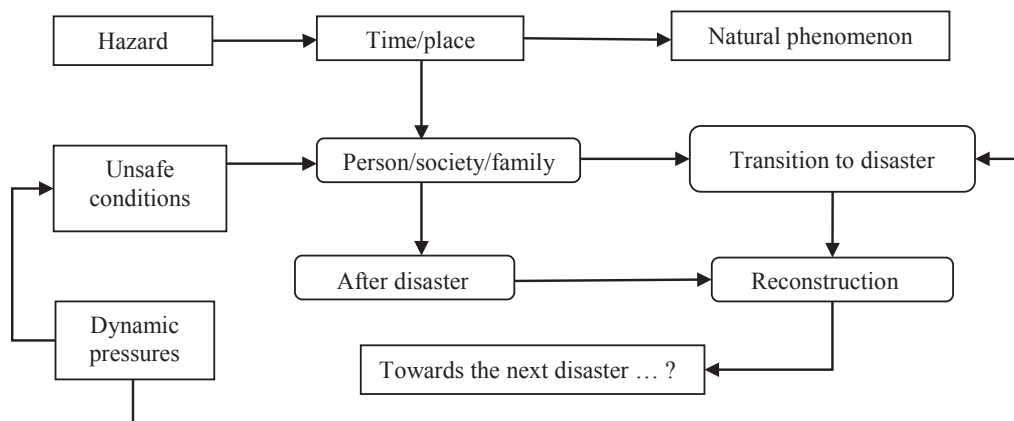


Fig. 1. From hazard to disaster (Blaikie et al. 1994).

selected area is expressed by formula (6).

$$R=w \cdot H+w \cdot E+w \cdot V+w \cdot RP-w \cdot C, \quad (6)$$

where: H , E , V , C and PR are the values of the Hazard, Exposure, Vulnerability, Coping Capacity and Risk Perception, respectively; $H_1, H_2 \dots, E_1, E_2 \dots, V_1, V_2 \dots, C_1, C_2 \dots$ refer to the scaled values of the indicators; and w are the weights.

As was mentioned before all four factors are well defined and used in many studies. Our goal is to include the risk perception and exposure as another main factor, not less important than others (Fig. 2). It is important to point out that the risk perception and its factors are included as novelty part of the standard methodology. It reflects the individual perception of a single person as well as the society. Both react in a different way. The person received increased physiological pressure and has to accommodate. Same is society, but the collective reaction reflects other peculiarities, which could be investigated in a future extended study.

The main feature of the methodology is the acceptance that the coefficient w is not equal to the five factors; it is assumed that various factors have varying weights and contribute in changing magnitude for the assessment of the risk levels. The values of weighting coefficients are defined similar as it is presumed that all risk factors contribute equally to the increasing or reducing of given risk. For the time being there are no scientific studies or technical methods which are able to defined whether the factor 'hazard' is more important than the factor 'vulnerability' or 'copping capacity'. The risk factors are closely related to environment and the areas to be considered and thus their impact can range from minimum to maximum.

• **Global Change Syndromes, specific to particular natural hazards for selected areas**

All syndromes must meet the following criteria, however (WGBU 1998):

- Each syndrome relates directly or

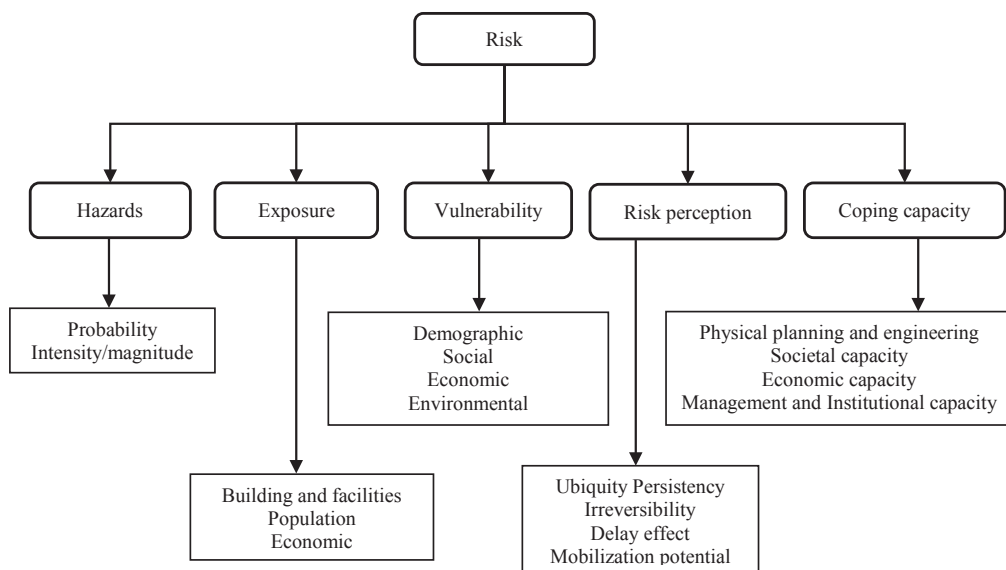


Fig. 2. The factors, included in the newly developed and adapted multifactorial methodology for risk and complex risk assessment (Frantsova 2017).

indirectly to the environment; exclusive reference to core problems within the anthroposphere is not permitted;

- The syndrome should occur as a visible or virulent cross-cutting problem in many regions of the world;

- The syndrome should describe non-sustainable development and/or significant environmental degradation.

A cardinal feature of global change is that humankind itself is now an active factor within the Earth System, playing a significant role at the planetary scale. Human interventions, as manifested in the depletion of raw materials, shifts in material and energy fluxes, changes to large-scale natural structures and critical stresses on environmental assets, are altering the very character of the Earth System to an increasing degree. The complexity of the processes involved or driven by these changes poses a major challenge for the scientific community and generates a number of new research issues.

Global change research must therefore deal with the diagnosis, prediction and assessment of global trends, the prevention of negative trends, 'repairing' existing damage (rehabilitation and reconstruction) and adaptation to the unavoidable. The hazards have clear nonlinear effects to the society and individuals (Ranguelov 2011). Therefore, the primary interactions between these trends must be identified, described and explained.

Such research should be guided by the principle of sustainable development. The crucial element of this concept, now generally acknowledged, is the interdependence of environment and development. This reflects a growing insight that human beings and their environment are closely integrated within a system of mutual interaction. Research on global change is therefore confronted with two

fundamental problems. Firstly, the investigation of the Earth System requires an integrative approach because the interactions between its components operate across the boundaries of single disciplines, sectors or environmental media. The second fundamental problem is the enormous complexity of the dynamic interrelationships involved, which makes a distinct description, any overall analysis and modeling much more difficult. The only approach capable of responding adequately to these problems is one that is networked and interdisciplinary.

The syndrome concept provides a new basis for global change research, the knowledge base of which continues to be split up according to the environmental media or core problems. This sectoral or disciplinary approach is certainly justified: without searching for a deeper understanding of the individual problem areas and their functional mechanisms, it is impossible to understand the specific aspects of environmental stress.

Results and Discussion

Multifactorial methodology is validated via a former disastrous event. Forest fire in the area of Etropole, November 2010, in Stara Planina Mountain has been selected for the performance of the described methodology. According to data of the Ministry of Interior, on November 10, 37 fires were burning on the territory of the country. The most severe forest fires are located in Stara Planina, Lovech region.

One of the heaviest fires in Stara Planina Mountain, emerged on November 6, 2010 in difficult accessible, highly intersected area, near the villages of Yamna, Patno Bardo, Duckot, Zarbavica (Fig. 3). The situation is further complicated due to

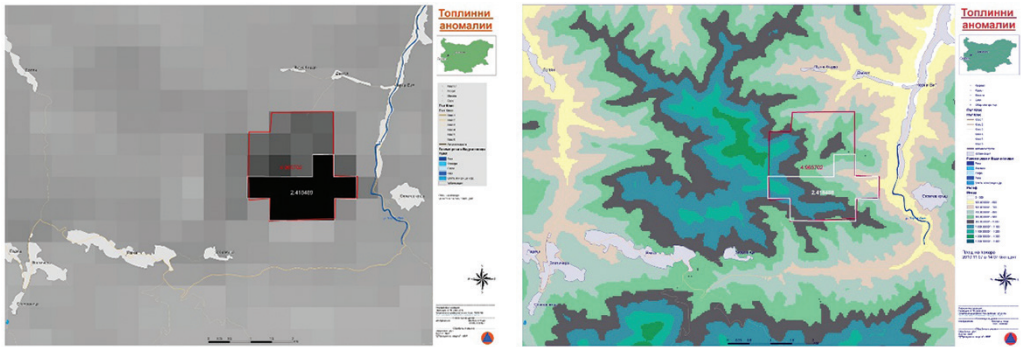


Fig. 3. Forest fire area – Etropole, November 6, 2010, Stara Planina Mountain (2418 km²).

Note: The maps are prepared in the former DG Civil Protection, Mol.

high air temperature, strong winds in the area of fire and the very low soil humidity. The fire was suppressed on November 10 using aviation equipment.

Meteorological parameters are based on the data from United States Air Force Weather Agency (AFWA) and World Meteorological Organization (WMO), published in the official site of the United States Department of Agriculture (USDA 2019). (Some of them are presented in the figures 4, 5, 6 and 7).

WMO and AFWA data show a lack of rainfall, very low soil humidity and high level of drought. The state of the environment can be described with high volume of the fuel materials (predominantly grass, shrub and wood) with high density due to the autumn fall.

Based on the analysis of the available

data (not specified here), we can conclude that under existing conditions, the fire hazard is significantly high for the given area.

Risk assessment is based on: 4 indicators for hazard; 7 indicators for exposure; 19 indicators for vulnerability; 19 indicators for coping capacity and risk perception conception. Such clarifications could be found in Rangelov (2013). The values are divided into five risk classes and described the risk levels – the data falls in the interval between 0 and 56.25 (Table 1).

The quantification of the risk levels in five categories is a product of the numbers obtained by the application of the described methodology. They are equally digitized by a factor of 11.25. This value is due to the perception of the influence equality of the obtained risk levels.

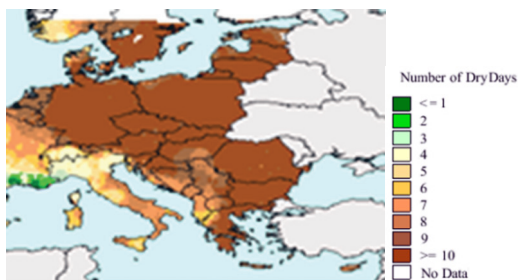


Fig. 4. Number of dry days from 01.10 to 11.10.2010. (Data from USDA 2019)

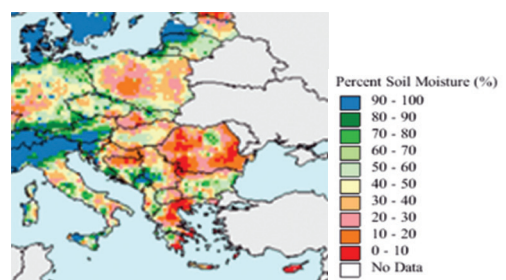


Fig. 5. Soil moisture from 01.10 to 11.10.2010 (%). (Data from USDA 2019)

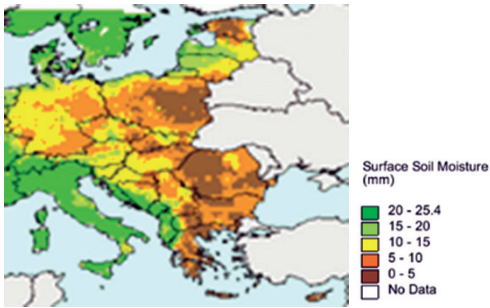


Fig. 6. Soil moisture from 01.10 to 11.10.2010 (mm). (Data from USDA 2019)

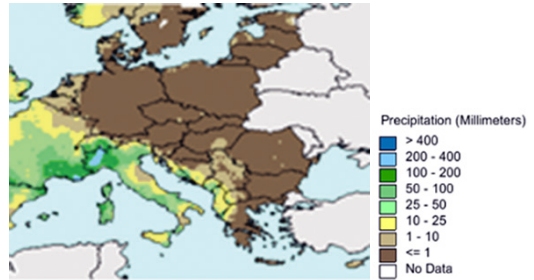


Fig. 7. Precipitation from 01.10 to 11.10.2010. (Data from USDA 2019)

Table 1. The quantification of the risk levels.

Risk levels	Very low	Low	Medium	High	Very high
Value	0–11.25	11.25–22.50	22.50–33.75	33.75–45	45–56.25

Calculated results with value 19.5 (34.67 %) show low risk profile for the given selected area which is consistent with the real situation.

Conclusions

The main conclusions are related to the adaptation and use of the developed holistic methodology about risk assessment.

The adaptation is focused to the clarification and selection of the risk factors, weighting coefficients assessment and sensitive analysis.

For the first time the risk perception is included as important factor, extending the developed methodologies, used up to now. Its quantification influence is not easy to be presented as numbers. We consider this challenge to be solved in a future study.

The application of the developed methodology to the forest fire in the area of Etropole, October 2010 in Stara Planina Mountain shows reasonable results and considerations.

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FOREST DORMOUSE (*DRYOMYS NITEDULA*, RODENTIA, GLIRIDAE) – A HIGHLY CONTAGIOUS RODENT IN RELATION TO ZOONOTIC DISEASES

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Abstract

Republic of Mordovia in Russia is a historical focus for hemorrhagic fever with renal syndrome and tularemia. This study aimed at assessing the current status of these foci by studying their rodent reservoirs. Among the small rodents in Mordovia, the red bank vole, the common vole and the house mouse play an important role as carriers of zoonotic diseases. However, it is necessary to take into account the role of such a small species as forest dormouse (*Dryomys nitedula*), which has a high percentage of infection. Of all examined dormice, 66.7 % were found to have antigens of hemorrhagic fever with renal syndrome viral pathogen, and 33.3 % - to have antigens of tularemia pathogen. Only one specimen (16.7 %) was found to have no antigens of zoonotic diseases. Our study concluded that the forest dormouse in the Republic of Mordovia was incriminated as a pathogen reservoir causing infectious diseases in human.

Key words: hemorrhagic fever, Mordovia, rodents, tularemia.

Introduction

Hemorrhagic fever with renal syndrome (HFRS) is the most common natural rodent borne disease of viral etiology in the Republic of Mordovia. The intensive rate of morbidity per 100,000 population of the Mordovia Republic during the period from 2001 to 2006, varied from 10.5 to 18.0, and the average long-term rate for this period was 14.4 ± 1.1 , which exceeded the same value in the Russian Federation by 2.8 times. Broad-leaved forests and agricultural lands are predominant in all areas of HFRS infection (Churbanova 2008). A similar situation is shown for another re-

gion of Middle Volga (Ulyanovsk region) (Nafeev et al. 2009). Small mammals are the most incriminated reservoirs for viral pathogen agents causing human HFRS in the natural environments (Tsvirko and Kozlov 2012).

In addition to HFRS, small rodents in this region are reservoirs in the circulation and the transmission of widespread human infectious diseases like tularemia and leptospirosis. In the natural foci of HFRS, epizootics occur periodically. Thus, small rodents perform one of the main roles in the spread of the zoonotic diseases.

The red bank vole (*Myodes glareolus*) has been considered the main reservoir

among rodents in the zoonotic circulation in Mordovia and throughout Volga region (Trankvilevsky et al. 2015, Andreychev et al. 2019). The yellow-necked mouse (*Apodemus flavicollis*), the striped field mouse (*Apodemus agrarius*), and the red bank vole (*M. glareolus*) play an important role in zoonotic circulation of HFRS in the Balkan Peninsula (Stanko et al. 2004, Rogozi et al. 2013, Papa et al. 2016).

Ergeshbayev (2018), in the Kyrgyz Republic mentioned the high degree of ectoparasite infestation of forest dormouse *Dryomys nitedula* (Pallas, 1778) (18 species), as well as its contact with numerous representatives of the rodent order. The researcher noted that it carried only one species-specific parasite and 17 species peculiar to marmots, voles, mice, gray hamster, Turkestan rat and other rodents. Among them, five flea's species *Callopsylla caspia*, *Amphipsylla phaiomydis*, *A. anceps*, *A. asiatica* and *Leptopsylla nemorosa* were identified. Cultures of the plague pathogen from these flea's species were isolated for this territory. This causes an important epizootological significance of this rodent species. The importance of forest dormice as carrier of parasites was also reported in Russia. In Central Russia, ectoparasites were found in 90–95 % of forest dormice, and endoparasites were found in 50–70 % of small animals (Rosolimo et al. 2001).

Some small mammals are breeding in the grounds among other species. In particular, such reports about the yellow-necked mouse are known. Dobrava-Belgrade virus strain (DOBV), causing in humans HFRS has been reported to be originated by *A. flavicollis*, *A. sylvaticus* and *M. musculus* (Weidmann et al. 2005). A previous study in Greece showed that approximately 10 % of *A. flavicollis* carried DOBV (Papa et al. 2000).

The report on the presence of tularemia in forest dormouse in Mordovia is of interest, since previously in the domestic and international literature it was not detected in this species, for example in Bulgaria (Pavlov et al. 1978). The results of standard tube agglutination test in Western Iran showed seropositive cases among 4.8 % of the rodents, including *D. nitedula* (Mostafavi et al. 2017). Positive results on tularemia in the Republic of Moldova were recorded in the following species: *M. glareolus*, *Apodemus uralensis*, *A. sylvaticus*, *A. flavicollis*, *M. musculus*, *M. spicilegus*, and *Crocidura suaveolens* (Chicu et al. 2010).

The forest dormice has not been reported infected with tularemia and HFRS, for example in Turkey (Laakkonen et al. 2006), and Ukraine (Demchyshyna et al. 2020).

The dynamics of identifying the causative agent of tularemia in Mordovia should be noted in 2015, 2017 and 2018, which are characterized by peak values (Andreychev, Boyarova and Kuznetsov 2016). Mostly, the tularemia microbe antigen was most often detected in areas along the middle rivers (Sura, Alatyr), rather than in areas that do not have such water arteries. In pellets of prey birds, the causative agent of tularemia was detected in the districts more often than in the biomaterial from rodents. This circumstance can be explained from the position that the remains of the hunted preys can contain several prey species at once. This is evidenced by the results of studies of osteological material (Andreychev et al. 2014, Andreychev, Lapshin and Kuznetsov 2016, Andreychev and Lapshin 2017). Therefore, the probability of detecting tularemia microbe antigen here is higher (Andreychev et al. 2019).

The purpose of this article is to study

the role of the forest dormouse as carrier or reservoir of rodent-borne diseases. In addition to the red bank vole, there is a high probability in the circulation of zoonotic diseases in the forest dormouse.

Material and Methods

Small mammals capturing and testing for different possible pathogen agents, are the material for this study in the territory of the Republic of Mordovia (53°38'–55°11'N and 42°11'–46°45' E) (Fig. 1) for epizootological research purposes. Coniferous forest, broad-leaved forests, shrub steppe and meadow steppe compose the rodents' habitat structure in the territory of Mordovia. The main forests are composed by pine *Pinus sylvestris* (L.), spruce *Picea abies* (L.) Karst., European larch *Larix decidua* (Mill.), oak *Quercus robur* (L.), common ash *Fraxinus excelsior* (L.), Norway maple *Acer platanoides* (L.), European white elm *Ulmus laevis* (Pall.), silver birch *Betula pendula* (Roth.), white birch *Betula pubescens* (Ehrh.), common alder *Alnus glutinosa* (L.), small-leaved lime *Tilia cordata* (Mill.), black poplar *Populus nigra* (L.).

The research was conducted in June and July 2018 and 2019. The live traps were set in the typical habitats of the forest dormouse for several days and then transferred to the next site. We used four trap lines. The number of traps in each line was 25. Snap traps were set for no more than 1 or 2 days. Salami and apple were used as baits. Traps were set mainly in mixed and broad-leaved forests. The latter biotope is a favourite habitat (Grigoryeva et al. 2015, Andreychev and Kiyaykina 2020). The material of the forest dormouse (dead animals) was obtained in small quantities, since this rare species in

the region. This is due to the peculiarities of its distribution. Forest dormouse occurs from Western Europe across Asia Minor, Caucasus, reaching to Central Russia and Central Asia. In this extensive area, the species is rare in many parts of its native range, especially in Western Europe and Russia (Batsaikhan et al. 2008, Markov et al. 2017).

All animal carcasses were used as a result of basic research on population genetics (Grigoryeva et al. 2015) and homing (Andreychev and Kiyaykina 2020). During the research period of 2009–2019, a total of 1995 individuals of the following rodent species were trapped: red bank vole (*M. glareolus*) – 30.9 %, common vole (*M. arvalis*) – 23.8 %, Ural field mouse (*A. uralensis*) – 18.7 %, yellow-necked mouse (*A. flavicollis*) – 11.5 %, striped field mouse (*A. agrarius*) – 10.4 %, house mouse (*M. musculus*) – 4.4 %, and forest dormouse (*D. nitedula*) – 0.3 %. The captured rodents were transported to the laboratory of the Center for Hygiene and Epidemiology in the Republic of Mordovia. Enzyme-linked immune sorbent assay (ELISA), using the 'Huntagnost' test system for the presence of the pathogen, was the main method used to detect the HFRS antibodies in homogenized rodent's lungs. Studies on tularemia were performed using serological and bacteriological methods. For leptospirosis and yersiniosis, studies were conducted by serological method (Methodical Instructions 2012).

Results and Discussion

Of the six examined dormice, four individuals (66.7 %) were found to have antigens of the pathogen causing HFRS, and two individuals (33.3 %) were found to have antigens of tularemia pathogen. Only one

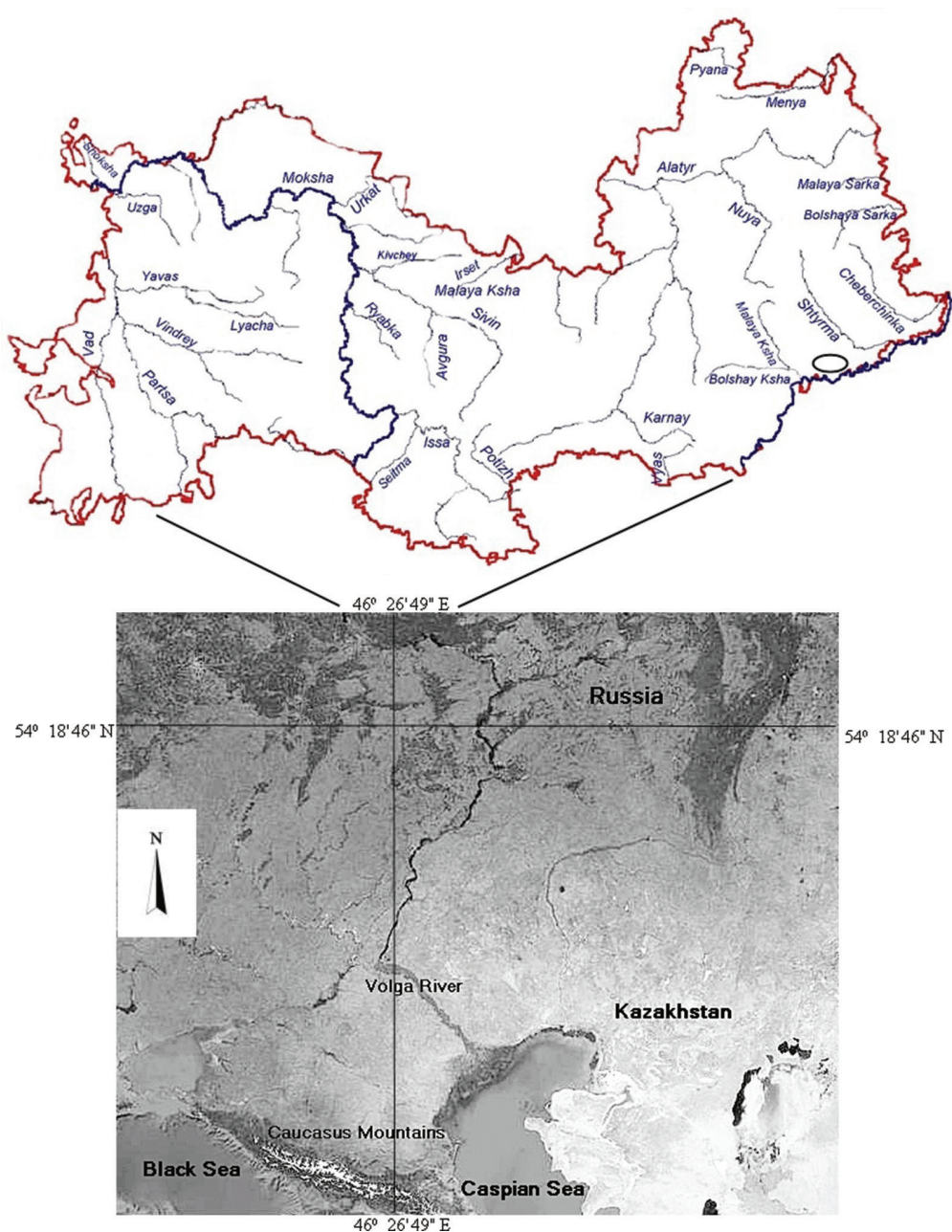


Fig. 1. Map of the Republic of Mordovia – oval – where animals were trapped.

individual of the forest dormouse was found to have no antigens of zoonotic diseases.

Comparing the results obtained in Mordovia by the spectrum of mouse rodent species infected with tularemia (Fig. 2)

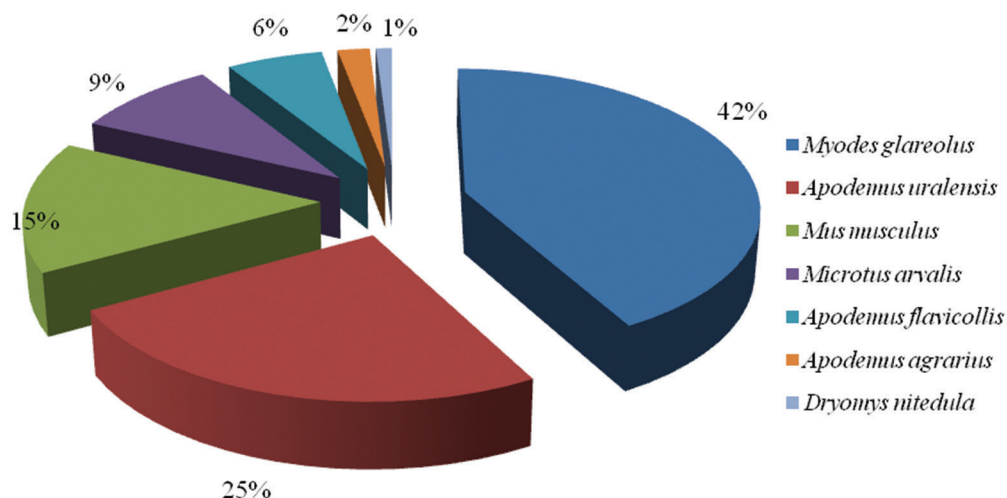


Fig. 2. Rodents' population structure involved as the reservoirs of tularemia and its circulation in 2019.

with the data obtained for the entire Volga Federal district (Trankvilevsky et al. 2015), a similar picture should be noted in the primary role of the carrier of this disease, the red bank vole (*M. glareolus*) (in Mordovia – 42 %, in Volga Federal district – 56.2 %) and Ural field mouse (*A. uralensis*) (in Mordovia – 25 %, in Volga Federal district – 21.9 %).

M. musculus, the house mouse, was the third rodent species found positive for the presence of tularemia bacteria (15 %); meanwhile, the field mouse, *A. agrarius*, was found positive for the same bacteria (15.6 %) in Volga Federal district area.

Analyzing the results of infection of rodents with hantavirus for 1997–2001 by Chumakov (2003) and 2007 by Churbanova (2008), as well as the results obtained by our study a change in the role of the main carrier of this disease could be stated. Thus, in 1997–2001, a high proportion of infected individuals were observed among the yellow-necked mouse, field mouse, red bank vole and the common vole captured, meanwhile in 2007,

the common vole was found positive as well (21.4 %). Our study showed that the house mouse (41 %) was of primary importance, while the red bank vole (23 %) and the common vole (23 %) were highly infected (Fig. 3). Perhaps the reason for this is that a large number of animals were captured near settlements. Our study showed as well, that the field mouse was not infected with the pathogen causing HFRS among common small mammals in the region, although this species may be active in the epizootic process in Russia (Trankvilevsky et al. 2011).

The highest rate of infection with the leptospirosis pathogen was observed in the common vole. The field mouse was the second most infected (34 %). To a lesser extent, infection was detected in the house mouse. In other captured rodents' species, the pathogen was not detected.

Thus, among small mammals in Mordovia, the red bank vole, the common vole and the house mouse have an important role as carriers of zoonotic diseases. This

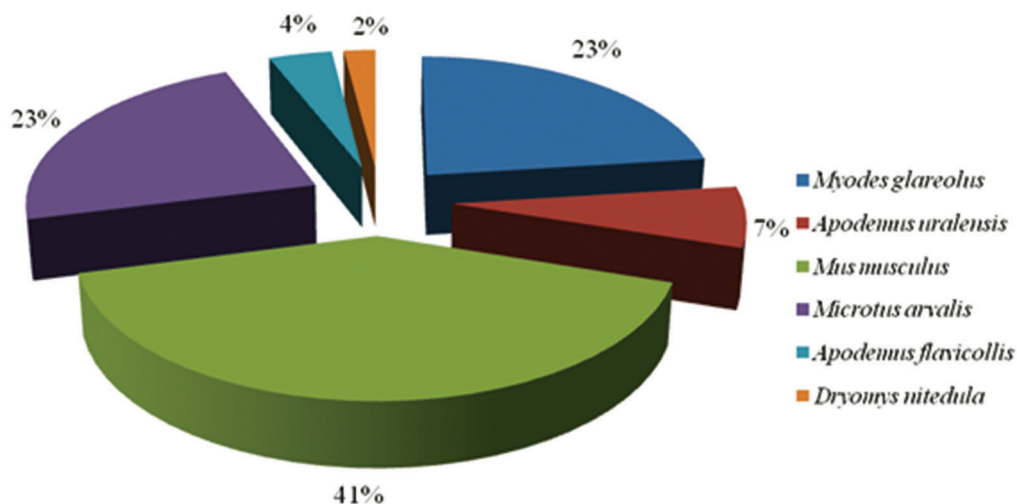


Fig. 3. Rodents' population structure involved as reservoirs of HFRS and its circulation in 2019.

circumstance is due to the high number of these species representing the rodent fauna of each region. However, it is necessary to take into account the role of such species like the forest dormouse, which has a high percentage of the tularemia and hantavirus pathogen. High diversity of small mammals' species in Mordovia with positive infection results is ensuring the persistence and circulation of the tularemia agents in the natural foci, which maintain a high risk of human disease cases.

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