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REVISING FIRE HAZARD RATING METHODS FOR FOREST STANDS IN UKRAINE ON THE EXAMPLE OF OVRUCH SPECIALIZED FOREST ENTERPRISE

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Abstract

Forest fires play an important role in the deterioration of forests. In 2020, in Zhytomyr region, 28,300 ha of forests were damaged by fire, including about 15,000 ha in Ovruch Specialized Forest Enterprise. Forest fire occurrence depends on forest site conditions, age and type of stands (coniferous or deciduous), and humidity index. However, the significance of neighbouring subcompartments for fire spread has been proved. The number and area of such subcompartments increase after bark beetles' outbreaks or windstorms. The aim of this research was to evaluate the change in the class of fire hazard in Ovruch Specialized Forest Enterprise forests by baseline approach and considering the type of neighbouring subcompartments using GIS technologies. Considering the categories of lands of neighbouring subcompartments shows that for 2010–2018 the class of fire hazard decreased, i.e. the hazard has increased. The area of 1st class stands in 2018 is 3577.5 ha more in the approach of considering the neighbouring subcompartments compared to the baseline approach. Fire hazard in 2018 increased due to a 3063.6 ha increase in the area of subcompartments, which bordered with clear-cuts and unclosed plantations. The effectiveness of predicting the fire occurrence was confirmed by analysing data on the fire spread in 2020. Therefore, this approach is advisable to be widely implemented by the State Agency of Forest Resources of Ukraine to determine the list of forest compartments with a high risk of fire, to evaluate their area, to calculate the location of IP cameras, as well as for navigation and calculation of the optimal path for fire suppression.

Key words: clear-cut, GIS, land category, subcompartments.

Introduction

Lately, thousands of hectares of forests in different parts of the world have been damaged by fire (Alonso-Betanzos et al. 2003, Halofsky et al. 2020, Phelps and Woolford 2021, Woolford et al. 2021). In Polissya, due to climate change and frequent droughts, the frequency and intensity of fires have also increased. For

example, in 2010, Zhytomyr region (Forest natural zone) had 1.17 Mha of forest over 39 % of its land area. In 2020, it lost 28,300 ha of forest (Forest Monitoring … 2021). In particular, in Ovruch Specialized Forest Enterprise, fires damaged about 15,000 ha of forested area.

One of the reasons for the increase in the frequency and area of fires is global climate change, an increase in the periods with low precipitations and high temperatures (Goldammer et al. 2013). Another reason is the increase of forest decline by various causes, including outbreaks of bark beetles (Andreieva and Goychuk 2018; Meshkova 2019, 2021). Such areas accumulate a lot of combustible materials. For example, the direct cause of 2020 fire in Zhytomyr region was the burning of stubble in the fields, and the widespread fire was facilitated by the increase in treeless areas in the middle of forests, formed as a result of sanitary felling in the foci of bark beetles. These foci developed in the region in the last decade after the years of drought (Andreieva and Goychuk 2018, Andreieva et al. 2018).

The high costs and complications of fire-fighting necessitate improving the system for fire risk prediction. In different countries, many models have been developed that predict the risk of a fire spread (Kitzberger et al. 2012, Sakellariou et al. 2017, Naderpour et al. 2021). At the same time, data from satellite imagery, information about weather, placement of combustible materials, terrain, composition of a forest stand, etc. are used (Viedma et al. 2009, Maillard et al. 2020). Despite this, fires continue to cover large areas (Forest Monitoring … 2021).

In Ukraine predicting forest fire includes its monitoring based on the data of forest inventory when all forest subcompartments are classified into five hazard classes with the highest being the 1st class (Rules … 2005). A scale for assessing the natural fire hazard of forest lands takes into account three main features: type of stands (coniferous or deciduous), humidity index, and age of stands. Therefore, the database of forest subcompartments includes special field which characterizes the class of fire hazard assessed considering these features.

However, the class of fire hazard of certain subcompartments depends also on their location relative to neighbouring subcompartments (Polupan et al. 2010). Hence, on the border with fresh clear-cut, suddenly lightened trees are weakened (Parkins et al. 2018, Meshkova 2019, Maillard et al. 2020), attacked by pests (Meshkova and Borysenko 2017, 2018), dry out, and are easily affected by fire (Viedma et al. 2009).

Therefore, the level of fire hazard may decrease with forest age (Kitzberger et al. 2012) and with the replacement of coniferous forests to deciduous ones (Polupan et al. 2010). However, more often it can increase due to the change of land categories of neighbouring subcompartments, particularly if the forest is replaced by clear-cuts, burnt areas, unclosed plantations, buildings, roads, etc. (Meshkova and Borysenko 2017, 2018).

Data on increased fire hazard in areas neighbouring to certain categories of land (Borysenko 2017), and the use of GIS (Polupan et al. 2010) makes it possible to improve the system for forecasting forest fire occurrence, particularly to determine the list of forest compartments with a high fire hazard, to evaluate their area, to build appropriate thematic maps, to plan necessary measures and to develop the algorithms for optimal mobilization traffic funds in case of forest fires. It assists in planning fire prevention and suppression.

Materials and Methods

Ovruch Specialized Forest Enterprise is located in the North-East part of Zhytomyr region (51°19′28″ N and 28°48′29″ E) (Fig. 1). It belongs to the zone of Central Polissya with mixed coniferous and deciduous forests. The climate is temperate continental and is characterized by relatively mild winters, warm summers, and significant rainfall (Anonymous 2021).

Database of Production Association 'Ukrderzhlisproekt' (by 2010 and 2018) was analysed. Each section in the database is characterised by a fire hazard class, which was assessed according to the 'Rules of fire safety in the forests of Ukraine' (Rules ... 2005) taking into account the type of target forest management (coniferous or deciduous stands), the humidity index, or hygrotope (Migunova 1993), and the age of stands. There are 5 classes of a fire hazard (CFH): 1 – high, 2 – above average, 3 – average, 4 – below average, and 5 – low.

By the first (baseline) approach for each subcompartment with coniferous stands under the age of 40 CFH = 1. For coniferous stands older than 40 years and for deciduous stands, the humidity index was considered. Coniferous stands obtained CFH = 1 in very dry and dry conditions, CFH = 2 – in fresh conditions, CFH = 3 in moist and damp conditions, CFH = 4 in wet conditions. Deciduous stands obtained CFH = 2 in very dry and dry conditions, CFH = 3 in fresh conditions, CFH = 4 – in moist and damp conditions, CFH = 5 in wet conditions.

By the second approach during the evaluation of CFH for each subcompartment, an adjustment was made to the

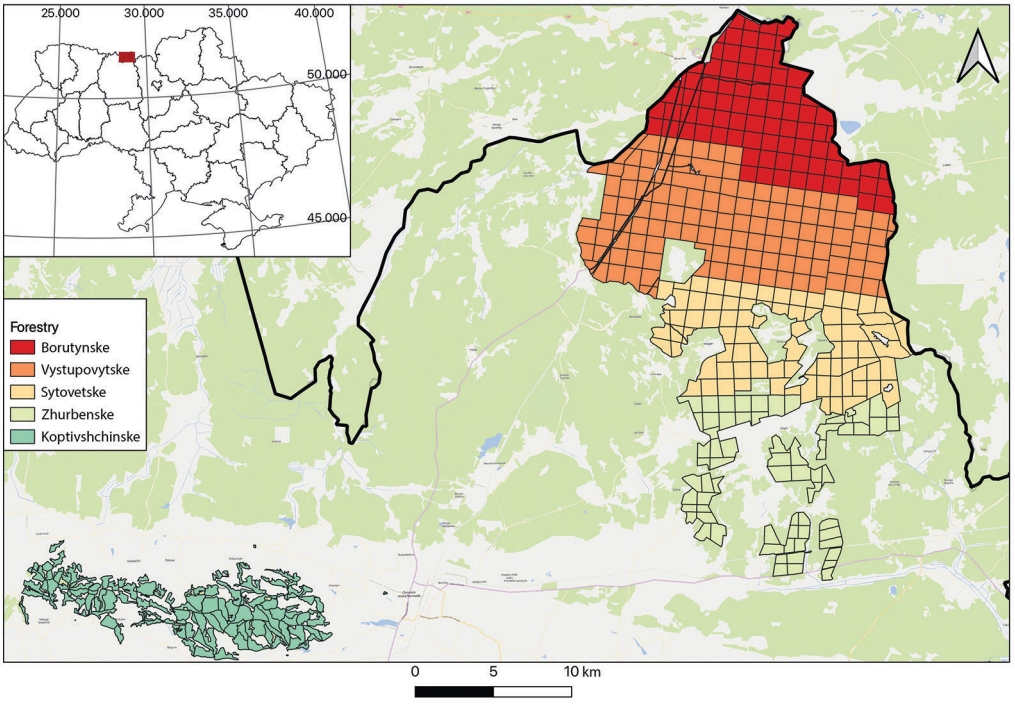

Fig. 1. Ovruch Specialized Forest Enterprise in the map of Ukraine.

impact on it of neighbouring subcompartments.

Using QGIS 2.18, the spatial query was formed with the fulfillment of the predicates of neighbourhood, affiliation, and adjoining.

With this said, if the forest plot is bordered with clear-cut of a coniferous stand, then 1 point was added to CFH. In the case of clear-cut of a deciduous stand, the predominant tree species in the neighbouring subcompartment were considered. In the case of predominance of conifers in the neighbouring subcompartment, CFH was taken as 1, and in the case of predominance of deciduous species CFH was taken as 4.

Thematic maps on fire hazard were built using QGIS 2.18 for the whole territory of Ovruch Specialized Forest Enterprise forest fund. Here we show only the maps for Vystupovytske forestry by the variants:

– as of 2010 without considering the land category of neighbouring plots;

– as of 2010 with considering the land category of neighbouring plots;

– as of 2018 without considering the land category of neighbouring plots;

– as of 2018 with considering the land category of neighbouring plots.

The reliability of the suggested approach for predicting the occurrence of a forest fire was assessed in two ways.

In the first method, Sorensen similarity index C_{sc} was used, taking into account the lists of subcompartments by formula (1) where the fire was predicted (*a*) and where it actually occurred (*b*) (Leontyev 2007).

$$C_{sc} = \frac{2c}{a+b}, \qquad (1)$$

where: *a* is the number of subcompartments in which the fire was predicted, *b* is the number of subcompartments in which the fire actually occurred, *c* is the number of subcompartments present in both lists.

Similar calculations were performed using the area of these subcompartments.

In the second method (Atramentova and Utevskaya 2008), tetrachoric correlation coefficient (*r*) and chi-square test (χ^2) were calculated, according to formulas (2) and (3)

$$r = \frac{ad - bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}, \qquad (2)$$

where: *a* is the number of subcompartments present in the predicted and actual list of fires, *b* is the number of subcompartments present in the actual and absent in the predicted list of fires, *c* is the number of subcompartments present in the predicted and absent from the actual list of fires, *d* is the number of subcompartments absent from both lists.

$$\chi^2 = n \cdot r^2, \qquad (3)$$

where: $n = (a + b + c + d)$.

The relationship was considered statistically significant if $\chi^2_{observed} > \chi^2_{0.05}$.

Similar calculations were performed using the area of these subcompartments.

In both methods, the predicted indicators were estimated for two options:

– without considering the category of lands of neighbouring subcompartments;

– considering the category of lands of neighbouring subcompartments.

Results and Discussion

Calculations in accordance with the ‘Rules of fire safety in the forests of Ukraine’ (Rules … 2005) show that Ovruch Specialized Forest Enterprise as of 2010 presents all classes of fire hazard. In general, the 2nd (28.9 %) and the 3rd (28.8 %) ones dominate, with a weighted average CFH = 2.75 (Table 1).

Table 1. Distribution of forest area of Ovruch Specialized Forest Enterprise by CFH as of 2010 without considering land categories of neighbouring plots.

Forestries	Area by fire hazard classes, ha/%					Total area, ha/%	Weighted average CFH, points
	1	2	3	4	5		
Sytovetske	1430.2 16.5	3126.2 36.0	2165.3 24.9	1486.8 17.1	482.5 5.6	8691.0 100	2.59
Borutynske	1243.0 13.8	2417.1 26.8	2272.7 25.2	2619.4 29.0	470.8 5.2	9023.0 100	2.85
Vystupovytske	2431.4 17.9	2743.5 20.2	3930.7 29.0	3412.8 25.2	1031.6 7.6	13,550.0 100	2.84
Zhurbenske	782.3 15.3	2081.3 40.6	1226.2 23.9	766.4 15.0	268.8 5.2	5125.0 100	2.54
Koptivshchinske	234.9 5.0	1501.9 32.3	2212.4 47.5	518.9 11.1	187.9 4.0	4656.0 100	2.77
Total	6121.8 14.9	11,870.0 28.9	11,807.3 28.8	8804.3 21.5	2441.6 5.9	41,045.0 100	2.75

The lowest value (i.e. the greatest fire hazard) was found for Zhurbenske and Sitovetske (2.54 and 2.59), and the greatest for Vystupovichske and Borutinske forestries (2.84 and 2.85 respectively). At the same time, 2nd class predominates (36 %) in Sytovetske forestry, which is largely due to the terrain features and distribution of stands by type of forest site conditions.

The evaluation of the distribution of forest land area by CFH in all forestries shows that the weighted average in 2010 is less considering the categories of lands of neighbouring subcompartments than without such consideration (tables 1 and 2). The difference of CFH is 0.17 points for the whole Enterprise. The area of the stands of the 1st class of fire hazard is more by 2080.8 ha, including in Sitovtske and Zhurbenske – by 992.1 and 484.5 ha, or 11.9 and 10.2 %, respectively.

The highest fire hazard there is in Zhurbenske (2.32) and Sytovetske (2.33) forestries, where the stands of 1st–3rd classes predominate (Table 2).

Table 2. Distribution of forest area of Ovruch Specialized Forest Enterprise by CFH as of 2010 considering land categories of neighbouring plots.

Forestries	Area by fire hazard classes, ha/%					Total area, ha/%	Weighted average CFH, points
	1	2	3	4	5		
Sytovetske	2422.3 28.4	2649.5 31.1	1997.9 23.5	1136.9 13.3	313.1 3.7	8519.7 100	2.33
Borutynske	1448.0 16.4	2366.4 26.9	2248.2 25.5	2475.6 28.1	269.9 3.1	8808.1 100	2.74
Vystupovytske	2764.5 20.8	2911.5 21.9	3919.6 29.5	3058.8 23.1	613.5 4.6	13,267.9 100.0	2.69
Zhurbenske	1266.8 25.5	1780.0 35.8	1150.8 23.1	598.7 12.0	175.5 3.5	4971.8 100	2.32
Koptivshchinske	301.0 6.5	1535.0 33.0	2146.8 46.2	508.8 10.9	155.4 3.3	4647.0 100	2.72
Total	8202.6 20.4	11,242.4 28.0	11,463.3 28.5	7778.8 19.3	1527.4 3.8	40,214.5 100	2.58

When calculating data for 2018 without considering the categories of lands of neighbouring subcompartments it can be seen that in general the fire hazard slightly changed (the class of fire hazard increased from 2.75 to 2.77) (Table 3).

When calculating data for 2018 without considering the categories of lands of neighbouring subcompartments, it is clear that the fire hazard has slightly decreased (CFH increased from 2.75 to 2.77) (Table 3). At the same time, the area of the stands of the 1st class in the whole Ovruch Specialized Enterprise increased by 456.3 ha. In Sitovetske and Borutynske forestries, CFH increased (by 0.08 and 0.12 respectively) and in the rest of forestries it decreased (tables 1 and 3).

Analysis of the distribution of forest land area of Ovruch Specialized Forest Enterprise by CFH, considering the categories of lands of neighbouring subcompartments (Table 4) shows that for 2010–2018 CFH decreased in all forestries by 0.01–0.04, i.e. the hazard has increased, for the whole enterprise by 0.04. The area of stands with 1st class increased by 1577.3 ha in the whole Enterprise, most of all in Zhurbenske forestry (by 635 ha). The area of stands of 5th class decreased by 157.3 ha for the whole Enterprise, most of all in Zhurbenske forestry (by 123.4 ha) (tables 2 and 4).

Comparison of data in tables 3 and 4 shows that considering the neighbouring subcompartments, the CFH is less by 0.15, most of all in Zhurbenske (by 0.28), Sitovetske (by 0.23), and Borutynske forestry (by 0.20). This class slightly increased only in Koptivshchinske forestry (by 0.06).

The area of stands of the 1st class increased by 3577.5 ha, including in Sitovetske forestry by 1028.2 ha, and in Zhurbenske forestry by 979.4 ha.

Spatial analysis shows that the fire hazard in 2018 has increased due to an increase in the area of subcompartments, which bordered with clear-cuts and unclosed plantations. This area amounted to 7309.3 ha in 2010 and 10,372.9 ha in 2018, i.e. increased by 3063.6 ha. At the same time, some subcompartments (especially of a large length) bordered with several (from 1 to 9) subcompartments with the named categories of lands (Fig. 2).

Table 3. Distribution of forest area of Ovruch Specialized Forest Enterprise by CFH as of 2018 without considering land categories of neighbouring plots.

Forestries	Area by fire hazard classes, ha/%					Total area, ha/%	Weighted average CFH, points
	1	2	3	4	5		
Sytovetske	1632.8 18.7	2212.5 25.4	2615.6 30.0	1861.7 21.4	395.6 4.5	8718.2 100	2.68
Borutynske	929.1 10.4	2159.5 24.1	2342.8 26.1	3275.9 36.5	256.7 2.9	8964.0 100	2.97
Vystupovytske	2374.3 17.5	2797.2 20.7	3819.6 28.2	3758.3 27.8	782.1 5.8	13,531.5 100.0	2.84
Zhurbenske	1073.1 20.8	1875.3 36.4	1151.9 22.3	883.2 17.1	171.4 3.3	5154.9 100	2.46
Koptivshchinske	568.8 12.6	1073.7 23.8	2203.7 48.8	510.0 11.3	161.5 3.6	4517.7 100	2.69
Total	6578.1 16.1	10,118.2 24.7	12,133.6 29.7	10,289.1 25.2	1767.3 4.3	40,886.3 100	2.77

Table 4. Distribution of forest area of Ovruch Forest Enterprise by CFH as of 2018 considering land categories of neighbouring plots.

Forestries	Area by fire hazard classes, ha/%					Total area, ha/%	Weighted average CFH, points
	1	2	3	4	5		
Sytovetske	2601.7 28.4	2105.9 31.1	2304.7 23.5	1380.7 13.3	214.3 3.7	8607.3 100.0	2.36
Borutynske	1648.5 16.4	2119.1 26.9	2082.6 25.5	2904.0 28.1	77.5 3.1	8831.7 100.0	2.73
Vystupovytske	3059.1 20.8	3003.5 21.9	3370.4 29.5	3505.4 23.1	422.8 4.6	13,361.2 100.0	2.64
Zhurbenske	1901.8 25.5	1478.6 35.8	994.1 23.1	636.2 12.0	84.5 3.5	5095.2 100.0	2.12
Koptivshchinske	568.8 6.5	1074.9 33.0	2203.5 46.2	512.4 10.9	116.8 3.3	4476.4 100.0	2.67
Total	9779.9 20.4	9782.0 28.0	10,955.3 28.5	8938.7 19.3	915.9 3.8	40,371.8 100.0	2.54

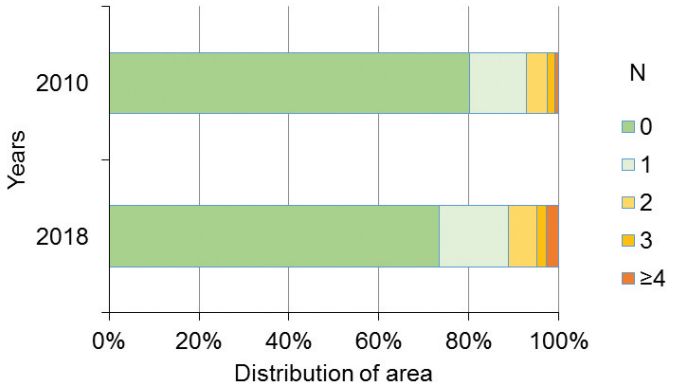

Fig. 2. Distribution by area of forest stands bordering on plots, the neighbouring of which increases the fire hazard.

Note: N is number of subcompartments which increase the fire hazard.

Thematic maps on fire hazard for Vystupovytske forestry (Fig. 3) show the predominance of shades of red (CFH in 2018 compared to 2010) and on the right side of the figure (analysis considering neighbouring subcompartments) compared to the left side of the figure (analysis without taking into account neighbouring areas).

So for the period 2010–2018, the average weighted CFH without considering the land categories of neighbouring subcompartments almost did not change. The area of stands of almost all CFH decreased, except for the 2nd, which increased by 54 ha (tables 1 and 3). Taking into account the neighbouring subcompartments in 2010, the weighted average CFH decreased over the analysed period.

The area of stands with the highest risk of fire hazard in 2018 was 3059.1 ha, i.e. was 294.6 ha more than excluding neighbours (tables 2 and 4), and compared to 2018, excluding neighbours (Table 3), it was 684.8 ha higher.

The total area of 1st and 2nd classes in Vystupovytske forestry, excluding neighbouring subcompartments, has changed little over the period 2010–2018 since neither the stand composition nor the hygrotope changed during this time (tables 1 and 3). At the same time, the difference between these values when analysed with regard to neighbouring subcompartments

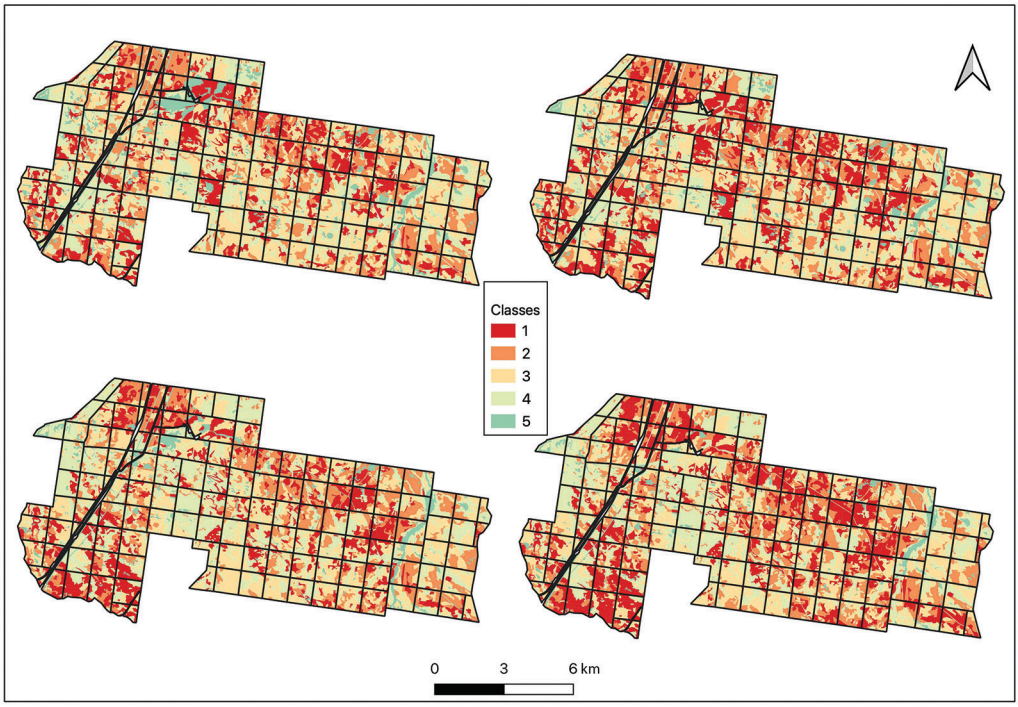

Fig. 3. Distribution of forest subcompartments of Vystupovytske forestry by CFH.
Note: upper row – as of 2010, lower row – as of 2018; on the left – CFH defined without considering the land categories of neighbouring subcompartments; on the right – CFH defined with considering the land categories of neighbouring subcompartments.

is 386.6 ha (tables 2 and 4).

The calculation of Sorensen similarity index shows a high coincidence of the predicted list of subcompartments with a fire threat and the actual list of such subcompartments (Table 5).

Also, high values of Sorensen similarity index were obtained when using the area of respective subcompartments in the calculation. Sorensen similarity index, when taking into account the land categories in neighbouring subcompartments, has a greater value (0.85 and 0.86) than without taking them into account (0.76 and 0.75), which confirms the advantages of the suggested approach (Table 5).

The calculation according to the second approach made it possible to obtain significant values of the correlation index *r* and chi-square test taking into account both the number of subcompartments and their area (Table 6).

The correlation index *r* when taking into account the land categories in neighbouring subcompartments, has a greater value (0.765 and 0.776) than without taking them into account (0.631 and 0.601). Chi-square test when taking into account the categories of land in neighbouring subcompartments has also greater value than without taking them into account.

Given methodological approach has been earlier tested on the materials of the forest fund of Kreminske Forest and Hunt-

Table 5. Data for calculation Sorensen similarity index C_{sc} for fire prediction approaches.

Parameters	Without considering the land category of neighbouring subcompartments		Considering the land category of neighbouring subcompartments	
	Number of subcompartments	Area, ha	Number of subcompartments	Area, ha
Predicted	6132	16,696.3	6986	19,561.9
Fact	5208	14,720.4	5208	14,720.4
Common	4313	11,811.1	5164	14,670.8
C_{sc}	0.76	0.75	0.85	0.86

Table 6. Calculated data for the correlation index *r* and chi-square test for fire prediction approaches.

Set of subcompartments	Without considering the land category of neighbouring subcompartments		Considering the land category of neighbouring subcompartments	
	Number of subcompartments	Area, ha	Number of subcompartments	Area, ha
Present in the predicted and actual list of fires	4313	11,811.1	5164	14,670.8
Present in the predicted and absent from the actual list of fires	1819	4885.2	1822	4891.1
Present in the actual and absent in the predicted list of fires	895	2909.3	44	49.6
Absent from both lists	8587	21,280.7	7586	20,760.3
r	0.631	0.601	0.765	0.776
χ^2	6212.3	14,779.6	8553.2	24,324.8

Note: at df > 100 and $p < 0.05$, $r = 0.06$ and $\chi^2 = 124.3$.

ing Enterprise of Luhansk region (Steppe natural zone). The predicted location of subcompartments with a high fire hazard coincided with the actual situation (Borysenko 2017).

Having data for each subcompartment, in this study we were able to assess the reliability of forecasting the list of forest compartments with a high fire hazard and their area using the new approach and compare it with the results of the classical one. The calculation of Sorensen similarity index, correlation index, and chi-square test shows a high coincidence of the predicted list of subcompartments with a fire threat and the actual list of such subcompartments. Suggested approach does not consider fire ignition causes and types, however, it gives the possibility to recognise more exactly compared to baseline approach the list, location, and area of subcompartments vulnerable to fire damage considering the categories of lands of neighbouring subcompartments. The obtained data can be used to calculate the location of IP cameras, as well as for navigation and calculation of the optimal path for fire suppression.

Conclusions

Taking into account the risk of an increase in a fire hazard in the forest subcompartments bordering with clear-cuts and some other categories of land, where the forest was replaced by treeless areas, an algorithm was applied to determine the amendment to fire hazard classes using a forest inventory database and cartographic materials. The suggested approach makes it possible to identify additional subcompartments of the stands with an increased risk of fire.

The analysis showed that in all forestries of Ovruch Specialized Forest Enterprise for 2010–2018 the class of fire hazard decreased, i.e. the hazard has enhanced. The area of stands of the 1st class in 2018 is 3577.5 ha more in the approach of considering the neighbouring subcompartments, particularly, 3063.6 ha due to an increase in the area of subcompartments, which bordered with clear-cuts and unclosed plantations. The effectiveness of predicting the list of subcompartments vulnerable to fire damage considering the categories of lands of neighbouring subcompartments was confirmed by analysing data on the fire spread in 2020. Therefore, this approach is advisable to be widely implemented by the State Agency of Forest Resources of Ukraine to determine the list of forest compartments with a high risk of fires, to evaluate their area, and to improve fire prevention and suppression.

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AGE-SIZE STRUCTURE AND GROWTH RATE OF *SQUALIUS ORPHEUS* (KOTTELAT & ECONOMIDIS, 2006) FROM THE RIVERS TOPOLNITSA AND LUDA YANA

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Abstract

This article presents the results of a study of the growth rates of Orpheus Dace from the rivers Topolnitsa and Luda Yana, tributaries of the Maritsa River's middle zone. The study assesses species' length and weight growth pattern. Samples were collected mainly in the autumns of 2006, 2007, 2010. A total of 552 fish were caught by electrofishing, 297 of which were caught in the Topolnitsa River and other 255 in the Luda Yana River. The oldest fish, caught in the Topolnitsa River, were four-year-old, while those from the Luda Yana River were three-year-old. More than 70 % of the specimens, caught in the Luda Yana River, were one-year-old. Average length of three-year-old Orpheus dace from the Topolnitsa River was 125 mm and average weight was 30 g. Average length of three-year-old fish from the Luda Yana River was 168 mm and average weight was 56 g.

Key words: length growth, weight growth, Orpheus dace, size-age composition.

Introduction

Orpheus dace (*Squalius orpheus* Kottelat & Economidis 2006) is a common species in the middle and lower parts of many rivers of the Aegean watershed and it is considered endemic to the Balkan Peninsula. The species distribution expands in Bulgaria, Greece and Turkey (Kottelat and Freyhof 2007, Economidis et al. 2009, Barbieri et al. 2015, Rozdina and Raikova 2020). It is a rheophilic species, but it also inhabits some dams (Michailova 1964, Marinov 1989, Economidis et al. 2009). Orpheus dace inhabits rivers with gravel and sandy bottoms and prefers areas with moderate water flow. The fish is omnivorous and remains active almost all year round (Michailova 1964). In Bulgaria's Struma River basin, the breeding season lasts from the beginning of April to the beginning of August. Data about the sexual maturation and fertility of Orpheus dace from the Struma River has already been published (Michailova 1964). The species' linear growth is relatively slow. In Bulgarian rivers, one-year-old fish reach about 60 mm standard length. Length of four-year-old fish usually exceeds 200 mm (Dikov and Zhivkov 1985, Marinov 1989,

Dikov et al. 1994, Stefanova et al. 2008, Kolev and Raikova 2015). Rate of mass growth is also slow and five-year-old fish weigh more than 100 g (Kolev and Raikova 2015).

There is no published data about the length and weight relationship of Orpheus dace from the rivers Topolnitsa and Stryama, so this paper studies the growth parameters of Orpheus dace in these two rivers, filling the knowledge gap that exist for this species.

Study area

The research project studies two tributaries of the Maritsa River. The first of them – the Topolnitsa River originates in Sashtinska Sredna Gora; its springs are located below the peak Bich (1447 m a.s.l.). In its upper course, the river flows to the northwest and is called Shirineyska. The river passes through the town of Koprivshtitsa and afterwards there are three dams along the river's watercourse: Dushantsi, Zhekov vir and Topolnitsa. Near the village of Muhovo, the river flows to the south and enters the Upper Thracian valley. The Topolnitsa River flows into the Maritsa River, not far from the town of Pazardzhik (Fig. 1). This water course has a total length of 154.8 km, and a catchment area of 1788.8 km^2 (Hristova 2012).

The other river, Luda Yana, also originates below the peak Beach in Sashtinska Sredna Gora, but flows southwest and crosses the town of Panagyurishte, where

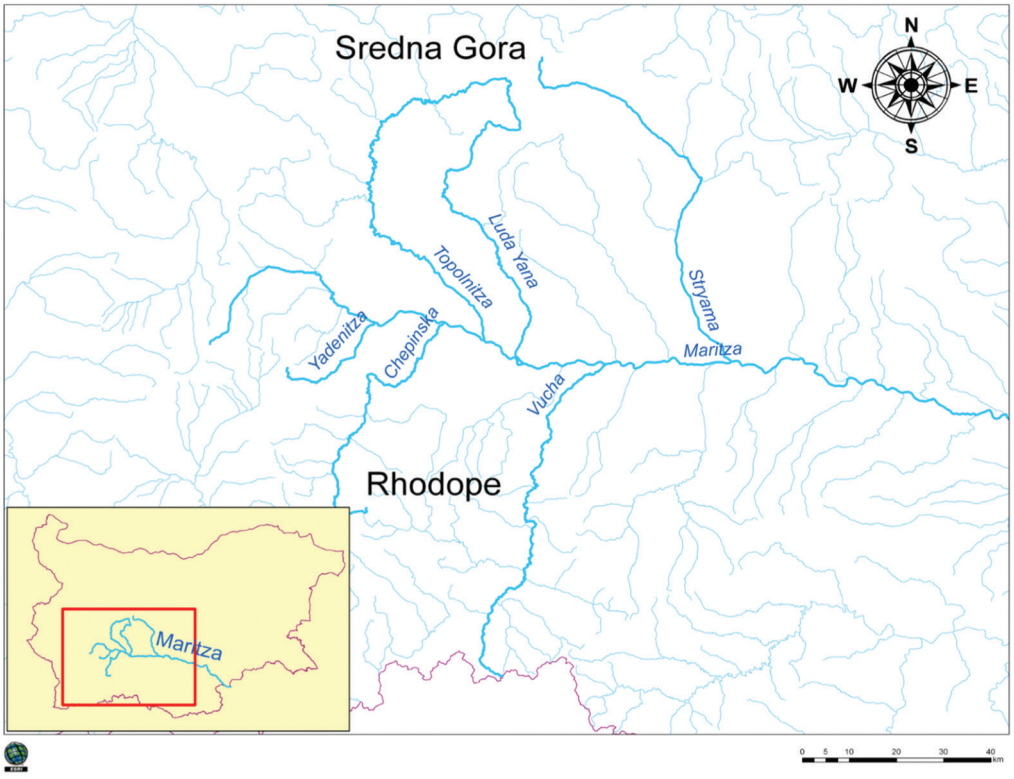

Fig. 1. Location of the riversTopolnitsa and Luda Yana River, Arc Map 10.0 (ArcGIS 2013).

it is called Panagyurska. Below the town, the river merges with its largest tributary Strelchenska and not far from the village of Rosen, enters the Upper Thracian valley. Near the village of Sinitovo its water course flows into the Maritsa River. The length of the river is 74 km and its catchment area is 685.3 km^2 (Hristova 2012).

In both studied rivers, water temperature reaches 25 °C in summer. The Luda Yana River is characterized by lower average water flow and small average altitude of its water bed, compared with the Topolnitsa River. The Topolnitsa River has the largest average annual water quantities compared to all other tributaries from the middle zone of the Maritsa River.

Materials

Specimens were collected mostly in the autumn, during the 2006–2011 period. A total of 522 Orpheus dace specimens were caught in the rivers Topolnitsa and Luda Yana by electrofishing. A SAMUS 725G converter was used. Usually during the sampling, the appliance is set to the following parameters: frequency of 50 Hz and output power between 150 and 200 W. The catch was performed according to the EN 14011:2004 instruction (Water quality – Sampling of fish with electricity). Five sampling areas, located at different parts of the studied rivers, were used (Table 1).

Table 1. Sampling areas along the rivers Topolnitsa and Luda Yana.

No	Location	Geographic coordinates		Altitude, m	Date of sampling
		N	E		
	Topolnitsa River				
1	In the vicinity of the village of Lesichevo	42°21’34.87’’	24°05’44.22’’	288	04.11.2006
2	In the vicinity of the village of Muhovo	42°24’39.77’’	23°59’55.44’’	346	05.11.2006
3	West of the town of Pazardzhik	42°12’25.24’’	24°17’44.77’’	214	29.10.2006 05.11.2006
	Luda Yana River				
4	East of the town of Pazardzhik	42°11’39.43’’	24°23’55.35’’	209	10.11.2006 13.10.2007
5	In the vicinity of the village of Chernogorovo	42°16’24.63’’	24°23’25.95’’	235	10.11.2006 14.06.2010

Standard length (*L*) was measured with a 1 mm precision, while weight (*W*) was measured with a 1 g precision.

Methods

More than ten fish-scales were collected from each Orpheus dace specimen. They were taken from underneath the dorsal fin; an equal number of scales was taken from the left and right side of the dorsal fin. The scales were then examined under a microscope Olympus CX 31, at 40× magnification. Each scale was placed between two microscope slides. Fish age was determined by counting the annual rings of a scale. For this purpose, the diagonal caudal radius of a scale was used.

A fish’s linear growth was determined via a back-calculation of length (*L)* from the diagonal caudal radius of a scale (*S*) (Zhivkov 1993). This relation is well described by a linear equation (1):

$$L = a+b \cdot S, \quad (1)$$

where: L – length of fish, mm; S – diagonal caudal radius of a fish scale (eyepiece micrometer scales divisions); a, b – equation coefficients.

Net weight (W) values were estimated by equation (2), used by many authors (Zhivkov and Raikova-Petrova 1996, Kukushkin 1997, Belomacheva et al. 2005) and recommended by Zhivkov (1993, 1999):

$$W = a \cdot L^b, \text{ g} \quad (2)$$

where: L – length of fish, mm; a, b – equation coefficients.

A comparison of the length growth of different Orpheus dace's populations is made by ranking them according to their average length at the same age (Zhivkov 1972).

To compare the weight growth (W) of fish from different populations, a method proposed by Zhivkov (1993, 1999) is used. A relationship is expressed by the following equation (3):

$$\log W = \log a + b \cdot \log L \quad (3)$$

where: L – length of fish, mm; W – total weight of fish g; a, b – equation coefficients.

In order to obtain comparable values of W in equation (3), pre-selected rounded values of L (50, 100, 150, 200, 250, 300, 350, and 400 mm) are successively substituted in place of L ($L=50$, $L=100$, $L=150$, …). Using equation (3) with the listed values of L (mm), allows obtaining the corresponding values of mass W – $W_{L=50}$, $W_{L=100}$, $W_{L=150}$, $W_{L=200}$, $W_{L=250}$, $W_{L=300}$, $W_{L=350}$, $W_{L=400}$. The so-obtained mass values ($W_{L=50}$, $W_{L=100}$, $W_{L=150}$, $W_{L=200}$, $W_{L=250}$, $W_{L=300}$, $W_{L=350}$, $W_{L=400}$) for each of the studied populations are then compared (Zhivkov 1993, 1999; Zhivkov and Raikova-Petrova 1996, 2001).

Results

Age-size composition

The Orpheus dace samples from the rivers Topolnitsa and Luda Yana consists mainly of young fish. The oldest specimen is a four-year-old fish, with total length 205 mm and weight 129 g. A sample from the Topolnitsa River includes at most two- and tree-year-old fish. One- and four-year-old specimens are relatively few. It was found that most fish are 100–150 mm long. The largest specimen obtained from this river is a four-year-old fish, which is 225 mm long and weighs 171 g (figs 2 and 3). One-year-old Orpheus dace predominates in the Luda Yana River, constituting more than 77 % of the sample. These fish are shorter than 70 mm (figs 4 and 5).

Growth rate

A relationship between the average values of L (standard length) and S (fish-scale radius) was described by the equations for each river, as follow:

$L = 15.475+2.1985 \cdot S$; $r = 0.9931$, $n = 297$, the Topolnitsa River;

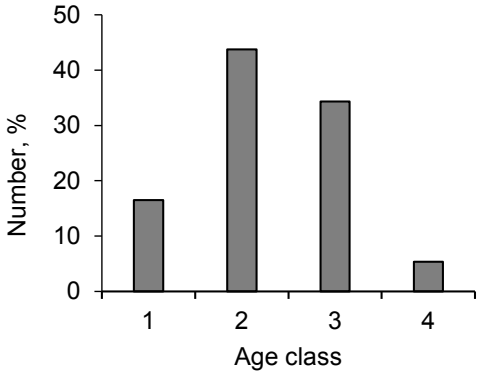

Fig. 2. Age structure of Orpheus dace, the Topolnitsa River.

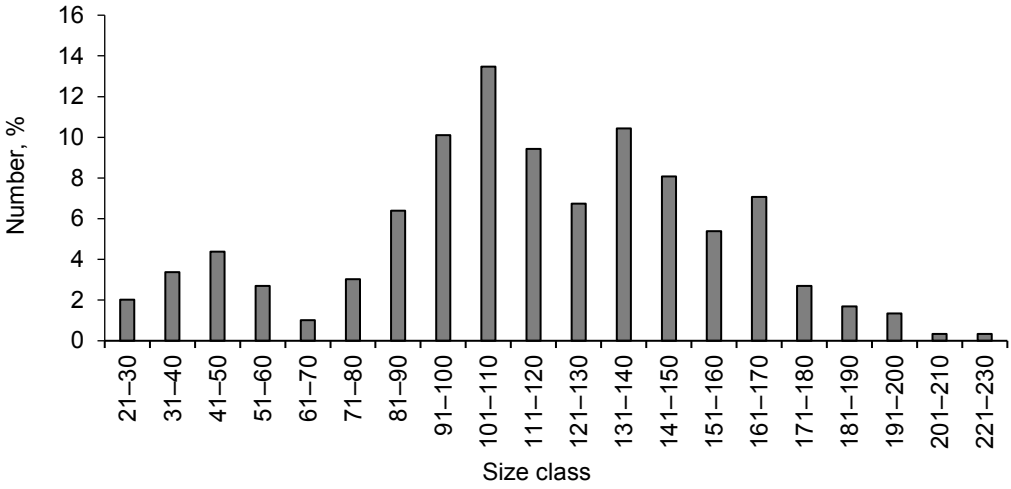

Fig. 3. Size classes of Orpheus dace, the Topolnitsa River.

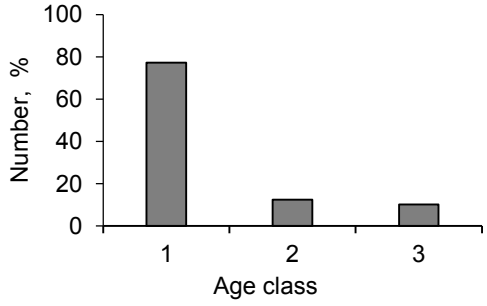

Fig. 4. Age structure of Orpheus dace, the Luda Yana River.

$L = 16.536+2.1041 \cdot S$; $r = 0.9944$, $n = 255$, the Luda Yana River.

Although during the first year of Orpheus dace's life, length growth is similar for both rivers, in general, fish reaches greater length in the Luda Yana River. Annual length growth is greater for fish from the Luda Yana River. Thus, three-year-old fish from the Luda Yana River reach greater length than four-year-old fish from the Topolnitsa River. In both rivers, in 2006, fish grew slightly faster (tables 2 and 3).

Generally, the length of one-year-old fish varies between 35 and 70 mm, of two-year-old fish – between 70 and 130 mm, of three-year-old fish between 140 and 170 mm.

A relationship between fish weight W (eviscerated weight) and L (standard length) is very well expressed by a power function with a high degree of reliability. The equations for each river are shown as follows:

$W = 0.000009 \cdot L^{3.1061}$; $r = 0.9998$, $n = 297$, Topolnitsa River;

$W = 0.00001 \cdot L^{3.0305}$; $r = 0.9940$, $n = 255$, Luda Yana River.

A comparison of an increase of mass between the two rivers shows that two- and three-year-old fish in the Luda Yana River grow faster than that in the Topolnitsa River. Annual growth in mass is greater in the Luda Yana River. Two- and three-year-old fish from the Luda Yana River weight twice as fast as those from the Topolnitsa River. Three-year-old fish from the Luda Yana River reach greater mass than four-year-old fish from the Topolnitsa River (tables 2 and 3).

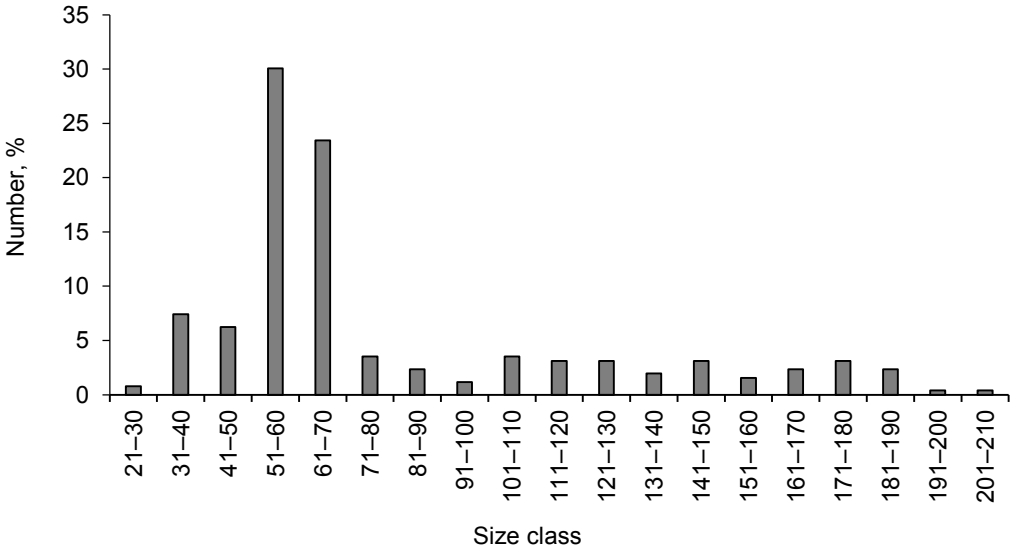

Fig. 5. Size classes of Orpheus dace, the Luda Yana River.

Table 2. Back-calculated body length of Orpheus dace from the Topolnitsa River.

Year	Age group	Back-calculated length (*L*, mm) at the end of each year of fish's lifespan.				Number
		L_1	L_2	L_3	L_4	
2006	I	46				40
2005	II	57	98			98
2004	III	65	90	131		65
2003	IV	64	78	119	148	94
Total						297
Average body length, mm		58	89	125	148	
Length increments, mm		58	31	36	23	

Table 3. Back-calculated body length of Orpheus dace from the Luda Yana River.

Year	Age group	Back-calculated length (*L*, mm) at the end of each year of fish's lifespan.			Number
		L_1	L_2	L_3	
2007	I	67			33
2006	II	37	67		180
2005	II	56	129		12
2004	III	66	112	168	30
Total					255
Average body length, mm		57	103	168	
Length increments, mm		57	46	65	

Discussion

The paper presents a systematic sample of the Orpheus dace populations from the rivers Topolnitsa and Luda Yana. Despite a significant number of caught specimens, the sample cannot cover the entire age diversity of the populations. However, the study shows a clear tendency for young fish to predominate, especially in the Luda Yana River. The populations in both studied rivers are very young. This is an indicator of significant fishing or predators' pressure and the elimination of older fish of mostly larger sizes (Pravdin 1966).

In the Topolnitsa River, length-growth is fast in the first year, after which it slows down. Two- and three-year-old fish from the Luda Yana River have greater length-growth (tables 2 and 3). Orpheus dace is characterized by gradual mass accumulation with age. The rate of weight growth increases with age in both rivers, but the increase is faster for the Luda Yana River population (tables 4 and 5). Faster growth and a presence of mostly one-year-old specimens indicate that the Luda Yana River population is reduced in numbers (Pravdin 1966). The population seeks to restore its numbers by accelerating growth and shortening the time to maturity (Nikolsky 1965).

A comparison of length-growth of Orpheus dace from different water bodies, using the Zhivkov's method (1972), shows that fish grows faster in dams than in rives (Table 6).

Table 4. Back-calculated body weight of Orpheus dace from the Topolnitsa River.

Year	Age group	Back-calculated weight (*W*, g) at the end of fisher's lifespan.				Number
		W_1	W_2	W_3	W_4	
2006	I	1.3				40
2005	II	2.6	12.6			98
2004	III	3.8	10.4	34		65
2003	IV	3.7	6.9	24.9	49.6	94
Total						297
Average body weight, g		2.9	9.9	29.5	49.6	
Weight increment, g		2.9	7.0	19.6	20.1	

Table 5. Back-calculated body weight of Orpheus dace from the Luda Yana River.

Year	Age group	Back-calculated weight (*W*, g) at the end of fisher's lifespan.			Number
		W_1	W_2	W_3	
2007	I	3.4			33
2006	II	0.6	3.5		180
2005	II	2	24.7		12
2004	III	3.2	16.3	55.5	30
Total					255
Average body weight, g		2.3	14.8	55.5	
Weight increment, g		2.3	12.5	40.7	

Table 6. A comparison of the average length of same-aged Orpheus dace from different water bodies of its habitat.

Sources	River or Dam	Body length (L, mm) of Orpheus dace at the end of each year of its lifespan.										
		L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}
Present data (2015)	Topolnitsa River	58	89	125	148	-	-	-	-	-	-	-
Dikov et al. (1994)	Arda River	58	104	137	159							
Kolev and Raikova (2015)	Stryama River	58	83	121	162	192						
Marinov (1989)	Chepinska River	61	115	152								
Dikov et al. (1994)	Mesta River	64	114	159	195	214						
Dikov et al. (1994)	Struma River	54	119	164	211	223	241	243				
Stefanova et al. (2008)	Maritsa River	60	95	130	240							
Present data (2015)	Luda Yana River	57	103	168	-	-	-	-	-	-	-	-
Zhivkov (1981)	Batak Dam	96	163	215	247	272	294	318	352	379	397	406
Boyadgiev (1966)	Pyasachnik Dam	89	155	218	298	316						
Marinov and Boyadjiev (1967)	Koprinka Dam	73	193	261	-	-	-	-	-	-	-	-

Table 7. Condition factor of Orpheus dace in different water bodies.

Sources	River or Dam	Population equation	Weight calculated at one the same length				
			W_{50}	W_{100}	W_{150}	W_{200}	W_{250}
Present data (2021)	Luda Yana	$W = 0.00001 \cdot L^{3.0305}$	1.4	12	39	94	185
Dikov et al. (1994)	Arda	$W = 0.00005 \cdot L^{2.7522}$	2.3	16	49	108	199
Present data (2021)	Topolnitsa	$W = 0.000009 \cdot L^{3.1061}$	1.7	18	52	126	253
Kolev and Raikova (2015)	Stryama	$W = 0.000009 \cdot L^{3.1154}$	1.8	15	54	133	266
Dikov et al. (1994)	Struma	$W = 0.00003 \cdot L^{2.9007}$	2.5	19	62	141	271
Zhivkov (1981)	Batak	$W = 0.000007 \cdot L^{3.1662}$	1.7	15	54	135	274
Dikov et al. (1994)	Mesta	$W = 0.00006 \cdot L^{2.7793}$	3.2	22	67	149	277
Stefanova et al. (2008)	Maritsa	$W = 0.0148 \cdot L^{3.0595}$	2.0	17	59	142	280
Michailova (1964)	Struma	$W = 0.00001 \cdot L^{3.1175}$	2.0	17	61	149	299
Dikov and Zhivkov (1985)	Dzerman	$W = 0.0116 \cdot L^{3.05}$	2.2	19	65	154	305

Length-growth of Orpheus dace differs in different water bodies. However, for different age groups length-growth varies within certain limits regardless of the water body, inhabited by the fish. Differences in length-growth between individual populations are affected by abundance of food, length of the growing season, altitude and length of winter, water quantity. In all three dams: Batak, Pyasacnik and Koprinka, length-growth is faster than that in rivers. This finding can be explained by the impact of a larger press of predators on fish populations (Zhivkov 1981, Kolev 2013) and the desire of fish to escape the press of predators. Greater length-growth is also due to a richer nutrient base in the dams. Fish from the Luda Yana River grows in length the fastest, in comparison with fish from all studied tributaries of the Maritsa River; its length-growth is close to that of Orpheus dace from the Maritsa River.

Orpheus dace accumulates mass relatively slow. One-year-old fish weigh only a few grams.

A comparison of the weight of Orpheus dace from different watercourses shows that weight growth is faster in the Batak Dam. In general, Orpheus dace increases in mass faster, when it is inhabiting main watercourses – the rivers Struma, Mesta and Maritsa, in comparison with their tributaries. In the rivers Topolnitsa and Luda Yana, Orpheus dace grows in weight more slowly than in other water bodies (Table 7).

Conclusions

Populations of Orpheus dace from the rivers Topolnitsa and Luda Yana are characterized by a small number of age groups. A fish population from the Luda Yana River consists mostly by juveniles. Compared to other Bulgarian rivers, Orpheus dace grows in length more rapidly in the Luda Yana River, but the accumulation of biomass in this river is the smallest of all studied Bulgarian water bodies. In both water courses: the rivers Topolnitsa and Luda Yana, accumulation of mass is relatively slow. Three-year-old specimens in these rivers reach an average weight of 30–50 g.

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FIRST RESULTS FROM RADIOTELEMTRY TRACKING OF WILD GREY PARTRIDGES IN SOUTH BULGARIA

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Abstract

The Grey partridge (*Perdix perdix* L.) is a common gamebird in Bulgaria but some important parameters of its population are still poorly studied. In this paper we present results from the first radio telemetry study of wild Grey partridges in the country. A total of six partridge males were captured in two study sites in Upper Thracian Plain. Monitored birds stayed near the capture point with a mean dispersion distance of 486.9 m ±309.5 SD (min-max 54.28–1307.24 m). Sufficient data to define home range size was possible for only one adult individual and 100 % Minimum convex polygon (MCP) equaled 17 ha. Within its home range, this male partridge showed a preference for an unusual part of its home range, an area for the storage of straw bales used by a bioenergy production facility. This observation confirms the species ability to adapt to changing types of land use in agricultural ecosystems.

Key words: dispersion, habitat use, MCP, radio telemetry.

Introduction

The Grey partridge (*Perdix perdix* L.) is a common species with a decreasing population trend across most of its range (Keller et al. 2020) caused by drastic changes in habitats due to agriculture intensification over recent decades (Kuijper et al. 2009). In Bulgaria, the Grey partridge is under a regime of conservation and regulated hunting (Hunting and Game Preservation Act, Annex 1). The better understanding of some population and ecological parameters like home range, dispersion, survival, habitat preferences, etc. are important to successful management. Furthermore, recent papers report dynamics of these parameters over time as a result of adaptation of the Grey partridge to the changes in its habitats (Ronnenberg et al. 2016, Harmange et al. 2019). At the same time, data on such parameters of the species' population on the Balkan Peninsula are scarce.

This study presents results from the first Bulgarian radiotelemetry survey of partridges from wild populations in the species' typical habitats in the Upper Thracian Plain.

Materials and Methods

The study was carried out at two separate sites: Stroevo (42°14‘ N, 24°41’ E) in 2016 and Saraya (42°14‘ N, 24°19‘ E) in 2019. Both sites are located in the Upper Thracian Plain (Middle South Bulgaria) and comprise predominantly arable land sustaining breeding densities in the surveyed years of respectively 20.5 pairs/km^2 and 12.8 pairs/km^2, which could be accepted as high compared to that reported in numerous European countries (Bro et al. 2005). Predator control in these areas was not carried out as part of the study. Red foxes (*Vulpes vulpes*) and Golden jackal (*Canis aureus*) were rarely hunted by the local hunters.

The birds are captured on March 15th and March 19th 2016 in Stroevo and on March 15th 2019 in Saraya using MIST NET 716/7 (ECOTONE) and each bird was tagged with 10g radio transmitter RI-2B (Holohil Ltd.) with mortality mode and necklace type of attachment. The tracking of the tagged birds was conducted by using a Field Marshall 4000 receiver with Yagi antenna (Marshall Radio Telemetry) and range of up to 3 miles. The location of each bird was determined via triangulation and switching between *Far* and *Medium* range settings of the receiver allowed us to obtain precise location whit minimum or no disturbance of the birds. The tagged birds were located every 3–7 days, between mid-March and late-June. The gender of captured Grey partridges was determined according to Schroeder and Robb (2005). A total of four adult male Grey partridges were tracked in Stroevo in 2016 and two males (one adult and one juvenile) in Saraya in 2019.

The dispersion of the birds was measured with Google Earth Pro (Google LLC) as a straight line between the capture point and each location during the tracking. The difference between dispersion of the birds in the two areas was analyzed with Kruskal-Wallis nonparametric test carried out in free software product PAST (Hammer et al. 2001).

Tagged individuals’ home ranges were defined by minimum convex polygon (MCP) (Mohr 1947) using CALHOME software (Kie et al. 1996) and birds’ habitat preferences were estimated by applying Jacob’s Index (Jacobs 1974) for the predefined seven habitat types within the 100 % MCP and six within the 95 % and 90 % MCP. Within the 100 % MCP, the cereals had the greatest coverage (65.4 %), followed by the sunflower (10.8 %) and the straw bales storage area (11.8 %). The alfalfa, the abandoned irrigation channel and the earth roads occupied 5.14 %, 4.55 % and 1.48 % of the area, respectively. A small proportion (0.8 %) of the 100% MCP was occupied by a small, relatively dense patch of black locust (*Robinia pseudoacacia* L.) with approximate vegetation height of 5 m.

Results and Discussion

Two of the tagged birds in Stroevo died within 10 days after releasing due to predation and the fate of a third individual remained unknown because of losing the signal from the transmitter. Other three individuals (one from Stroevo and two from Saraya) survived to the end of the study, hence the estimated survival is at least 50 %.

The male partridge in Stroevo was monitored for nearly 3 months until the transmitter fell off due to failure of the harness. We were able to observe the two birds in Saraya for about a month but both individuals were legally shot on December

8th 2020, 21 months after tagging. Hence the adult male was at least two and a half years old at the time it was shot. Although on March 23rd 2019 it was observed with sings of injury (missing rectrices and contour feathers, damaged remiges) and poorly flying the individual managed to survive longer than the mean longevity reported in other parts of its range (Weigand 1980).

The mean dispersion distance of all tagged individuals was 486.9 m ±309.5 SD (min-max 54.28–1307.24 m). The estimated mean dispersion distance of the monitored partridges in Stroevo was 288.23 m ±126.7 SD (min-max 54.28–530.43 m) and was significantly lower than that observed in Saraya 884.24 m ±282.9 SD (min-max 604.11–1307.24 m) (Kruskal-Wallis chi square = 10.5, $p < 0.01$). The observed mean dispersing distance was lower than reported in similar studies in other parts of the Grey partridge's range (Putaala and Hissa 1998).

Estimating the MCP was possible for only one of the tagged birds, which was located 10 times between March 19th and June 30th. The 100 % MCP of this individual captured in Stroevo was 17 ha and the area of 95 % and 90 % MCP was 9.4 ha and 5.8 ha respectively. Observed home range size in the present study was much lower than previously reported for reared Grey partridges in CW Bulgaria (Angelov et al. 2019) which is expected given the poor habitat quality in that particular site and the origin of the released birds. So far there are no data on Grey partridge's home range size in Bulgaria, but results in the present study are similar to those observed in high density wild populations in Central Europe (Šálek et al. 2002, Warren et al. 2017). The results of the Jacob's index for estimating habitat preferences of the monitored bird are based on 10 locations recorded between mid-March and the end of June (Table 1). This male partridge showed a preference for the abandoned irrigation channel, a small patch of black locust and to an unusual part of the study site occupied by a storage area for straw bales used in a bioenergy production facility (Fig. 1). The individual was located in that area on four consecutive observations between April 26th and May 23rd 2016.

The longest monitored male partridge at Stroevo inhabited an area less than 10ha (MCP 95%) from March 19th until the end of June 2016. Reported Grey partridge's home range during breeding season varies considerably across different studies from several (Šálek et al. 2002) to hundreds of hectares (Novoa et al. 2006) according to the habitat quality. Our results are similar to those reported for France and Czech Republic (Birkan and Serre 1988, Šálek et al. 2002).

The bird showed a preference for an abandoned irrigation channel and a straw bale storage area instead of the other parts of the habitat such as alfalfa, cereal and sunflower fields as well as earth roads within the bird's home range. The irrigation channel can be considered as a permanent shrub-dominated cover strip, which partridges can benefit from as reported in other studies (e.g. Panek and Kamieniarz 2000). The sunflower crops had a negative Jacob's index. During the monitored period, the sunflower was short and sparse, and did not provide shelter or feeding places. This is the probable cause for the negative Jacob's index in the study period. The next habitat with a negative index was cereal crops. During the study period these crops had a greater height and coverage. Such vegetation has been reported to increase vigilance consequently reducing fitness of the birds

Table 1. Jacob's index values for every habitat type determined in each MCP* area.

MCP, %	Sunflower	Cereals	Alfalfa	Abandoned irrigation channel	Earth Roads	Black locust patch	Straw bales storage
100	-0.04	-0.53	-1.00	**0.38**	-1,00	**0.92**	**0.54**
95	-0.03	-0.53	N/A	**0.81**	-1.00	**0.88**	**0.34**
90	-0.16	-0.54	N/A	**0.76**	-1.00	**0.82**	**0.70**

Note: *MCP is Minimum convex polygon; values in bold show preference to a particular type of habitat.

Fig. 1. Tagged individual observed in the straw bale storage area in Stroevo.

(Watson et al. 2007).

The preference of Grey partridges for the storage areas for straw bales has not been reported in Bulgaria yet. The factors driving this behavior should be subject to further studies but one can hypothesize that stacked in such a manner (Fig. 1) the straw bales: 1) provide suitable shelter against predators and the elements, 2) probably create a favorable environment for invertebrates of great importance to the chicks and 3) the decaying of some bales generates heat which the birds may benefit from. Across its range, the Grey partridge is known to use farmstead areas with stored bales near them. Although the straw bale storage area somewhat resembles a traditional farmstead it is placed over large area far from urban territories and the birds within the study area managed to occupy the newly opened niche in less than three years after its appearance. Such behavior of the Grey partridge is expected during late autumn and winter but the present study show evidence for usage of the straw bale storage area by

the partridges during breeding season. This observation is important not as representative for Grey partridge population in the Thracian Plain, but as indication of the ecological plasticity of the species and the ability to adapt different types of land use in agricultural ecosystems.

Conclusion

Although our sample size was very small, the present study gives the first data about some ecological parameters of the Grey partridge for the South of Bulgaria. The estimated dispersion and home range size of the few monitored birds may indicate good habitat quality within the Upper Thracian Plain. The usage of unusual habitats by one of the tagged birds confirms the habitat adaptability of the grey partridge, which is well known for the species within its farmed environment but also indicated that such facilities may be of importance to the Grey partridge not only in autumn and winter but during the breeding seasons as well.

Authors' statement

The present study was conducted in accordance with the national legislation.

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DISTRIBUTION AND CYCLING OF NUTRIENTS IN A MOUNTAIN FIR ECOSYSTEM IN CENTRAL GREECE

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Abstract

The distribution and cycling of nutrients were examined in a mature Bulgarian fir forest (*Abies borisii-regis* Mattf.) in the area of Karpenisi, Central Greece. More specifically, the current and second year concentrations of Ca, Mg, K, N, P, S, Fe, Mn, Cu and Zn in bulk deposition, throughfall and litterfall in the fir needles and fluxes were determined. In addition, their total amounts were measured in the standing and ground vegetation as well as in soil up to 80 cm. It was found that the throughfall deposition was a significant source of S and K. The foliar, woody and rest fractions of litterfall were 71, 19 and 10 % of the total litterfall, respectively. Among all the ecosystem components, the highest nutrient quantities were found in the mineral soil, forest floor, trunk wood, trunk bark and canopies of the fir trees. The trunk bark proved an appreciable pool for P and S. In order to calculate the mean residence time of nutrients in the forest floor, througlfall and litterfall fluxes were taken as input. It was found that the mean residence times of nutrients in forest floor followed the order Fe>Mn>Zn>Mg>Cu>P>N>Ca>K>S. According to nutrient concentrations ranges in conifer needles and soils, the fir forest is in a very good condition with regard to nutrient status. Consequently, all the environmental parameters measured in the forest can serve as a comparison reference level for other (mature) mountainous *Abies* forests in Europe.

Key words: forest floor, litterfall, macronutrients, micronutrients, precipitation, throughfall deposition.

Introduction

Fir (*Abies* species) forests, especially silver fir (*Abies alba* Mill.), Greek fir (*Abies cephalonica* Loudon) and Bulgarian fir (*Abies borisii-regis* Mattf.), are sensitive to environmental changes (Potocic et al. 2005). Fir is predominantly a mountain species. In warm climate areas, it moves to higher altitudes. In a mountainous area

in the Czech Republic Mikulenka et al. (2020) found that low temperature and frost were limiting factors of radial growth for silver fir. Macias et al. (2006) studied its growth the Main Range in the Pyrenees and southern peripheral ranges. They found that the radial growth of the fir trees was constrained by water stress during the summer before the next growth period. In the early 1970s, fir was the first species to show symptoms of a strange forest disease in Northern Europe (Krause et al. 1986). That disease was related to Mg deficiency and increased Al concentration in soil solution. Species of the fungus *Armillaria* were commonly observed on dead silver fir trees (Oliva and Colinas 2007) in Spain, whereas *Heterobasidion annosum* was found to cause increased mortality in fir forests of the area of Tuscany in Italy (Certini et al. 2000). In Greece, there was extensive necrosis of fir trees (Greek and Bulgarian firs) in the late 80's. That was due to drought, which brought about an outbreak of the secondary bark-boring beetles (Markalas 1992). Certini et al. (2000) argued that the importance of soil was somewhat neglected with regard to fir decline because the pathogen attacks were more severe in sites where soil was shallow or infertile. For these reasons, there is some research on fir nutrition although not as much as on other conifers. Novotný et al. (2010) presented data with the nutrient concentrations in the needles of silver fir grown in the Bohemian Forest in the Czech Republic and Szymoura (2009) dealt with the nutrient concentrations in fir needles as a function of age. Comandini et al. (1998) did research with fir mycorrhiza and Berg et al. (2003) with the decomposition of fir needles in the forest floor. Up to date, no complete nutrient cycle has been studied in any of the three species of fir mentioned above. In general, for the proper management of a forest ecosystem, the study of the nutrient cycle is necessary (Kimmins 1996). The Bulgarian fir is a species native to the mountains of the Balkan Peninsula in Bulgaria, Northern Greece, North Macedonia, Albania and Serbia. It occurs at altitudes of 800–1800 m, on mountains with an annual rainfall of over 1000 mm. Some botanists consider it as a natural hybrid between silver and Greek fir. The aims of this work were to assess the nutrient status of a Bulgarian fir stand in foliage, and calculate the nutrient fluxes in precipitation and litterfall together with the nutrient stocks in the various components of the ecosystem. When comparing the results of this work with those of other ones involving firs, the authors treated the three *Abies* species as one.

Materials and Methods

Site description

The experimental plot to which the present work refers is located on the ridges of the Timfristos Mountain in Central Greece at an altitude of 1170 m, with an area of 0.27 ha and is included in a catchment area of 147 ha. The coordinates are 21°51′57" longitude and 38°52′28" latitude. The site belongs to the Intensive Monitoring Survey of ICP Forests network (UN-ICP-Forests 2020).

The average annual rainfall on the surface is 1670 mm (1997–2018). The vegetation cover consists of an even aged Bulgarian fir (*Abies borisii-regis* Mattf.) stand in good health having an average age of 100 years approximately. The ground vegetation consists mainly of ferns (*Pteridium aquilinum* L.), shrubs (*Rubus hirtus* W. & K.), herbs (*Sanicula europaea* L., *Geranium lucidum* L., *Geranium rotundifolium* L.,

Luzula forsteri Sm.) and plants from the family Gramineae such as *Melica uniflora* R. and *Brachypodium sylvaticum* H. The tree density of fir species is 299 trees·ha^{-1}, the average tree height 24.3 m and the average diameter 42.5 cm (data assessed in 2009).

The soil of the stand is clay loam; it is deep and classified as a Cambisol (WRB 2006). The average pH (determined in water in a water-soil ratio 1:5 by volume) of FH horizon was found 6.48 and that of the mineral layers ranged from 6.07 in the soil surface to 5.32 down to 80 cm depth.

Collection of precipitation

In the year 1997, deposition collectors were placed inside the plot for the assessment and chemical analysis of the bulk and throughfall deposition. More specifically, the throughfall deposition was estimated with 20 collectors placed randomly within the stand and bulk deposition with three collectors placed in a clearing about 100 m from the plot. The collectors consisted of a plastic tube with a height of 1.05 and a diameter of 0.2 m, respectively. A plastic funnel with a diameter of 0.18 m was attached to the mouth.

Every week, on the same day, samples of rainwater were collected which, after measuring the volume of water, were transported approximately once a month in sealed containers to the laboratory for chemical analysis. The data covers the period 1997–2018.

Collection of current and second year needles

Needle samples of current and second year were collected every two years in winter (dormant period) from the upper part of the crown from five dominant trees and formed a pooled sample. The collection always took place from the same trees. The two fractions of needles were dried at 80 °C for 48 h and then ground in a special mill for analysis. The data covers the period 1995–2019.

Collection of litterfall

Litterfall was collected with 10 plastic cylinders systematically placed in a straight line at a distance of 5 m from each other with a surface area of 0.242 m^2 each. A composite sample of the 10 traps in total was transferred to the laboratory at each sampling. The litterfall was separated into its fractions, i.e. foliar, woody (twigs, bark parts) and rest (fruits, lichens, mosses, insect frass) and weighed. Subsamples were ground in a ball mill for total analysis. The litterfall data covers the period 2009–2019.

Collection of soil samples and ground vegetation

Soil collection and ground vegetation was carried out by systematic sampling in 2007. For each layer of L, FH, 0–10 cm, 10–20 cm, 20–40 cm and 40–80 cm depths three replicates in space were formed. Details of the soils sampling can be found in Michopoulos et al. (2020a).

L and FH layers were weighed. The bulk density of mineral soils in all layers was measured by a cylinder 129 cm^3. The samples of FH and mineral layers passed through a 2 mm sieve.

Subsamples of L, FH and mineral soils were pulverized in a ball mill for total elemental analysis.

The ground vegetation was collected systematically with a framework having an area of 0.544 m^2. In total 10 collections took place.

Chemical analysis

The concentrations of Ca, Mg, K in deposition were measured with an atomic absorption spectrophotometer (Perkin Elmer 3110), whereas those of P, Mn, Fe, Zn and Cu with an ICP-MS instrument (Thermo iCAP Qc). The concentrations of NH_4^+-N, NO_3^--N and SO_4^{2-}-S were determined with ion chromatography. All analyses were done according to EMEP (1996).

Foliage, ground vegetation, wood and bark were digested in a mixture of HNO_3-$HClO_4$. Ca, Mg, K, Mn Fe, Zn and Cu were measured with atomic absorption spectroscopy. N was measured with the Kjeldahl method (Velp-UDK 126A) and P with the Mo blue method and a U/V spectrophotometer (Varian Carry). S was determined with a CNS analyzer (CNS analyzer, Vario MAX).

Exchangeable Ca^{2+}, Mg^{2+} and K^+ in FH and mineral soil layers were extracted with a 0.1 M unbuffered $BaCl_2$ solution and their concentrations were determined with FAAS spectroscopy. Available P in soils was extracted with a $NaHCO_3$ solution (Olsen and Sommers 1982) and its concentration was measured with the methods mentioned above. Available trace elements (Fe, Zn, Mn and Cu) in soil were extracted with DTPA (Lindsay and Norvell 1978) and their concentrations were determined with FAAA spectroscopy. Total P and S in soil samples were measured by means of the Energy Dispersive X-Ray Fluorescence (ED-XRF) method (XEROS model of the TURBOQUANT Company). The concentrations of total N and organic C in soils with the CNS analyzer mentioned above. For total metal analysis, soil samples were digested in a microwave oven with HF and *aqua regia* at a temperature range of 160–170 °C for 20 min. Concentrations of metals in the digests were determined with the ICP-MS instrument mentioned above.

Data handling and statistics

For tables 1, 2, 3 and 5 the means and coefficient of variations (percentages of the standard deviations over the averages) of the macronutrients and micronutrients in the various components of the fir forest were calculated.

Comparison of nutrient concentrations in tree needles

The nutrient concentrations in current year and second year needles were compared with a paired t-test. Before the tests were applied, the data were transformed to logarithms to be closer to normal distribution.

Fluxes in deposition and litterfall

Nutrient fluxes in the hydrological cycle for the period 1997–2018 were calculated by taking into account water volumes and nutrient concentrations. The fluxes of P and micronutrients were assessed only for the year 2013, as they were not monitored on a routine basis. This is the reason that there are no coefficients of variations for these elements.

Annual fluxes of masses and nutrients were calculated for the three fractions of litterfall, foliar, woody and rest litterfall, by multiplying nutrient concentrations times the masses of litterfall in each fraction.

Calculation of nutrient stocks in canopies, trunk wood, and bark samples

A tree with the average height and diameter was cut down and trunk and bark samples were collected to estimate density

and carry out chemical analysis. The densities of wood and bark were calculated and the volume of all trees in the plot were calculated with equations (specialised for fir trees) based on the height and diameter of the trees (Apatsidis and Sifakis 1999). The equations (1–3) used were:

$$G = \frac{\pi \cdot d^2}{4} \cdot 10{,}000^{-1} \quad (1)$$

$$V_{nb} = 6.366 \cdot d^{1.76} \cdot h^{1.061} \cdot 10^{-5} \quad (2)$$

$$V_{wb} = 0.024 + 1.101 \cdot G, \quad (3)$$

where: G is basal area of the circle area of a tree trunk at DBH (m^2), V_{nb} is trunk volume with no bark (m^3), V_{wb} is trunk volume with bark (m^3), d is the tree diameter (cm), h is the tree height (m).

The mass of trees per ha was then calculated taking into account (apart from the volume) the densities of the wood and bark. For each tree, the crown mass per ha was calculated by specific equations for fir by inserting tree heights and diameters (Kittredge 1944). The equation (4) used was:

$$\lg(gf) = 2.1 \cdot \lg(d_{in}) - 0.5, \quad (4)$$

where: gf is the mass of green foliage (kg) per tree and d_{in} is the tree diameter in inches.

Finally the total crown dry mass per ha was calculated (in $kg \cdot ha^{-1}$).

Tree branches were counted and needle samples were collected from 10 branches around the perimeter of the crown so that the chemical composition of the needles would be representative. Multiplying the canopy mass by the concentration of each element yielded the total amount of each element in the canopy of the trees per ha.

Stocks of nutrients in soils

The calculation of nutrient stocks in L and FH horizons was based on masses and concentrations. The means and coefficients of variations were calculated for the three-pooled samples (three replicates). Total nutrient stocks in the mineral soil were found by adding the stocks derived from each separate layer. In each separate layer, nutrient stocks were calculated by multiplying layer masses by nutrient concentrations. The layer masses were found by multiplying layer volumes by the soil bulk densities. Coefficients of variation of total nutrients stocks were calculated by taking into account the variability of each separate layer (Miller and Miller 1988).

Nutrient residence time in forest floor

The residence time of nutrients in forest floor is calculated as the ratio of the amount of stocks of nutrients in the forest floor over the sum of the data in the fluxes of litterfall and throughfall deposition (Gosz et al. 1976). The presupposition for this equation is the equilibrium between the input and the output of nutrients. This is something that cannot always be attained. Nevertheless, by applying the equation we can have a strong indication of the residence times.

Results and Discussion

Nutrient concentrations in needles

The statistical comparison in Table 1 deals with different nutrient concentrations in needles of different ages. Ca, Fe and Mn had higher concentrations in the second year needles, whereas Mg and K had higher concentrations in the current year needles. In general, there is a decline in the mineral content of leaves with age caused by relative increase in the proportion of

structural material (cell walls and lignin) and of storage compounds (e.g. starch) in the dry matter (Marschner 1989). This is a dilution effect. It does not stand for Ca, which is itself a cell structural component. In addition, it does not seem to apply for N, S and P concentrations of which do not differ significantly in the needles of different age. This means that there is ample uptake of these elements, which is called luxurious consumption (Marschner 1989).

Increase of Mn and Fe concentrations in older needles in various conifer species had also been found in an old work by Turner et al. (1977). The dilution effect should be complimented by another theory, which is the mobility of ions. Nutrient mobility, or immobility, helps us to diagnose deficiency symptoms. If the deficiency symptom appears first in the old growth, we know that the deficient nutrient is mobile. In general, when certain nutrients are deficient in the plant tissue, older leaves are able to translocate them to younger leaves (Mauseth 1998). Nutrients with this ability are mobile nutrients, and include N, P, K S and Mg. In contrast, immobile nutrients such as Ca, Fe and Mn do not have that ability because once they reach plant cells they are no longer able to enter the phloem. The fir in our work does not present symptoms of nutrient deficiency. So the dilution effect, the luxu-

Table 1. Nutrient concentrations in current and second year needles in present work and other data.

Needle age	Ca	Mg	K	N	P	S	Mn	Fe	Cu	Zn
	g·kg^{-1}						mg·kg^{-1}			
Bulgarian fir (present work)										
Current year	9.56 a (24)	1.40 a (18)	7.76 a (17)	13.6 a (11)	1.33 a (21)	1.22 a (12)	298 a (34)	94.6 a (36)	4.29 a (35)	31.8 a (41)
Second year	13.8 b (18)	1.35 b (16)	7.21 b (19)	13.6 a (12)	1.26 a (15)	1.24 a (10)	434 b (29)	115 b (37)	4.17 a (45)	29.1 a (39)
Silver fir in Spain[1]										
Current year	12.0	1.41	8.12	12.0	1.38	1.4	629	101	No data	46
Silver fir in the Czech Republic[2]										
Current year	5.43	1.97	6.20	13.9	2.8	1.35	625	54.0	No data	41.0
Greek fir in Greece[3]										
Current year	8.31	1.38	7.71	11.6	0.968	No data	126	48.5	3.33	31.8
Critical concentrations in needles in conifers										
Current year	1.7	0.6	3.0	12.0	1.40	No data	25.0	50.0	3.0	14.0

Note: coefficients of variations are in parentheses. In Bulgarian fir data in the first two rows, letters (a and b) in the same column differ for at least 0.05 probability level. Sources for the other data: [1]EC-UN/ECE-FBVA (1997), [2]Novotný et al. (2010), and [3]Michopoulos (2013).

rious consumption (in fertile soils) and the mobility concepts apply together in order to interpret results.

In terms of absolute concentrations, it can be concluded that there is no deficiency in any nutrient. Table 1 contains the average nutrient concentrations of silver fir in Spain (EC-UN/ECE-FBVA 1997) and the Bohemian Forest in the Czech Republic (Novotný et al. 2010), as well as Greek fir in Greece (Michopoulos 2013). The last row gives information on the critical nutrient concentrations for conifers derived from literature (Morrison 1974, Wyttenbach et al. 1985, Wyttenbach and Tobler 2000, Maňkovská et al. 2004, Szymura 2009). For most elements, the concentrations in Bulgarian fir needles are more similar to those in Spain. The concentrations of P in the Bohemian Forest were found rather high as the authors acknowledged.

Elemental fluxes in bulk deposition and throughfall

With the exception of both forms of inorganic N there was enrichment (ratio of throughfall/bulk deposition fluxes>1) in the throughfall fluxes for all nutrients (Table 2). It is obvious that fir needles absorbed N for their nutritional needs. This is not always the case in forests. There was N absorption in Norway spruce and mixed stands of conifers in Italy (Balestrini et al. 1998) but not in Norway spruce in Austria (Berger et al. 2008). In our work the sum of the average values of inorganic N in precipitation were 8.85 and 6.62 $kg \cdot ha^{-1} \cdot yr^{-1}$ in bulk and throughfall deposition, respectively. These values are considered rather low considering that in many forest sites in Europe the throughfall deposition fluxes of N range between 15–20 $kg \cdot ha^{-1} \cdot yr^{-1}$ (Michel et al. 2020). According to Dise and Wright (1995), the inorganic N fluxes in throughfall must be greater than 10 $kg \cdot ha^{-1} \cdot yr^{-1}$ to start causing a nutrient cycle problem.

Despite the low values of inorganic N, the fluxes of -S in the fir stand are rather high (Table 2) taking into account that the value of 8 $kg \cdot ha^{-1} \cdot yr^{-1}$ is a threshold sign for human activities for most European forests (Michel et al. 2020). The throughfall fluxes are considered more important that the bulk ones because the enrichment in them is mainly due to dry deposition which in turn is due to anthropogenic sources (Johnson 1984). In the 1980s far higher fluxes of SO_4^{2-}-S ranging from 15 to 54 $kg \cdot ha^{-1} \cdot yr^{-1}$ had been observed in

Table 2. Average values of nutrient fluxes and height in bulk and throughfall deposition in the period 1997–2018.

Ca	Mg	K	SO_4^{2-}-S	NH_4^+-N	NO_3^--N	P	Mn	Fe	Cu	Zn	Height,
$kg \cdot ha^{-1} \cdot yr^{-1}$											mm
Bulk deposition											
21.4	2.36	7.36	14.0	4.61	4.23	1.24	0.137	0.189	0.316	0.019	1670
(41)	(35)	(55)	(20)	(44)	(32)						(17)
Throughfall deposition											
28.6	5.40	46.6	18.8	3.39	3.23	0.992	0.188	0.424	0.0264	0.0598	1372
(24)	(18)	(31)	(26)	(47)	(34)						(18)

Note: coefficients of variations are in parentheses. Fluxes of P and micronutrients were calculated only for the year 2014.

Austrian forests (Berger et al. 2008). The excess SO_4^{2-}-S fluxes in the fir area could be ascribed to fossil fuel consumption for heating purposes of the local population. Temperatures are very low in winter.

The bulk deposition of P in the fir stand was in the range of 0.05–1.7 kg·ha^{-1}·yr^{-1} that characterizes its inputs from the atmosphere (Newman 1995). There was absorption of P from needles as the throughfall fluxes were lower than those in the bulk deposition (Table 2). Belyazid and Belyazid (2012) argued that absorption or leaching depends on the growing period, microbial activity in the canopy and species.

The fluxes of Ca and Mg in throughfall deposition are considered high according to Michel et al. (2020) which set the thresholds 10 and 3 kg·ha^{-1}·yr^{-1} for Ca and Mg, respectively. The enrichment of deposition with the last two elements can be due to Sahara dust often settled on Greek lands. Among all metals, the highest enrichment was observed for K. This is something common for forests as throughfall is the main path towards forest floor for this element, exceeding even litterfall (Parker 1983).

With regard to micronutrients, there was enrichment in the three of them with the exception of Cu (Table 2). According to McColl (1981), the enrichment of Fe and Zn is only due to dry deposition, whereas for Mn exudation from leaves and bark can be a significant factor. In a mixed forest of Norway spruce and beech with 709 mm of annual rain height Fišák et al. (2006) found enrichment in throughfall only for Mn (0.460 kg·ha^{-1}·yr^{-1}), whereas Zn and Fe had a flux of 0.053 and 0.154 kg·ha^{-1}·yr^{-1} respectively.

Litterfall

Littefall is the main path through which the forest soil is enriched with nutrients. Monitoring it over time is essential to assess the health of forest ecosystems as abrupt changes in litterfall fluxes are equivalent to changes in the abiotic and biotic environment (Pedersen and Hansen 1999). Fluctuations in the masses of litterfall productions are strongly related to weather conditions (Finer 1996). The variability of 19 % for the foliar fraction mass (Table 3)

Table 3. Average fluxes of nutrients in the three fractions of litterfall in the period 2009–2019.

Ca	Mg	K	N	P	S	Mn	Fe	Cu	Zn	Mass,
kg·ha^{-1}·yr^{-1}										t·ha^{-1}·yr^{-1}
Foliar litterfall										
67.8	5.75	12.4	48.3	3.27	4.92	1.78	2.32	0.040	0.15	3.88
(22)*	(21)	(34)	(29)	(46)	(31)	(27)	(51)	(92)	(44)	(19)
Woody litterfall										
16.6	1.03	1.58	10.8	0.700	1.29	0.215	0.869	0.008	0.041	1.02
(73)	(75)	(73)	(89)	(93)	(80)	(84)	(102)	(98)	(118)	(65)
Rest litterfall										
5.38	0.784	2.45	7.52	0.610	0.746	0.168	0.473	0.005	0.021	0.578
(82)	(71)	(105)	(83)	(86)	(78)	(83)	(79)	(87)	(90)	(73)

Note: coefficients of variations are in parentheses.

is low if we take into account the 40 % coefficient of variation found in the foliar litterfall mass of Scots pine monitored over 24 years (Kouki and Hokkanen 1992).

When studying litterfall, researchers must pay attention to the climatic variables and single events, which could affect fluxes for example storms (Portillo-Estrada et al. 2013). Johnson and Turner (2019) stressed the importance of including catastrophic events such as wildfire, insect attacks, hurricanes, etc. in nutrient cycling studies. In our plot, no extreme event was observed in the 11 years of monitoring. There were some winters with heavy snow but they did not affect the overall variability of foliar biomass. The other two fractions did not have low variability and this fact is worth studying. Probably the slightest change of environmental parameters can affect their production. Cole and Rapp (1981) recorded elemental fluxes of litterfall for many forest stands. All quantities of N, Ca, Mg, K and P in the Bulgarian fir stand are considered large in relation to most of the forest species recorded by the above researchers apart from those in the litterfall of *Picea abies* (L.) Karst. stands grown on deep soils in Sweden and Germany. Mass percentages of the three litterfall fractions calculated from Table 3 were 70.7 % foliar, 18.7 % woody and 10.6 % rest litterfall. For the elements Ca, S and Fe the woody fraction proved appreciable. The rest litterfall fraction was lower in quantities than the other two. However, it should not be underestimated because some parts of it are more decomposable than the previous two fractions.

Biomass allocation and nutrient stocks in tree parts

From Table 4 it appears that the largest amounts of elements are accumulated in the trunk wood and trunk bark. The biomass allocation followed the sequence: trunk wood>trunk bark>branches>canopy>twigs. For some important macronutrients (N, P, S) and micronutrients (Mn, Zn) the bark is more important source than the trunk wood despite the larger mass of the latter due to the higher elemental concentrations in comparison with the trunk wood. Adhikari et al. (1995b) found higher stocks in all elements in the trunk wood of silver fir in a high altitude forest of Central Himalaya. That forest had a higher tree number per ha (355) in comparison to 299 in our work and higher vegetation biomass (454 $t \cdot ha^{-1}$) (Adhikari et al. 1995a) in comparison to 356 $t \cdot ha^{-1}$ in the fir stand in our work (Table 4).

The highest number of trees the more the nutrient stocks in trunk wood in even aged stands because there is no much variation in tree diameters and heights. The elements contained in the trunk and bark are relatively inactive. They re-enter the cycle of elements with the fall and decay of the trees. However, if the trees are cut down and removed, these elements are lost from the ecosystem forever. In addition, if the canopy of the trees is also removed, nutrient deficiency problems may appear in the forest. In a mixed oak site, Johnson et al. (2016) found that whole tree harvesting affected the concentrations of exchangeable Ca and Mg in soils after some years. The last component in biomass and nutrient stocks is the ground (understory) vegetation. The stocks of nutrients (Table 4) in comparison with the other components is low but its role is important in retaining nutrients within the ecosystem. This occurs during the decomposition of organic matter. The elements are released in inorganic form and the ground vegetation with its rich root system absorbs them and thus pre-

Table 4. Stocks of nutrients and biomass dry weights in the tree components and ground vegetation.

Component	Ca	Mg	K	N	P	S	Mn	Fe	Cu	Zn	Biomass, t·ha^{-1}
	kg·ha^{-1}										
Canopy	324	26.8	122	294	25.7	25.3	8.83	3.28	0.091	0.030	20.2
Twigs	104	8.83	72.6	79.9	1.08	7.07	7.18	4.69	0.070	0.444	11.7
Branches	136	8.67	43.3	32.6	4.64	4.58	5.62	2.11	0.104	0.347	34.7
Trunk wood	350	40.0	175	360	4.00	4.74	5.74	20.0	0.581	1.21	250
Trunk bark	292	18.8	36.8	599	36.1	13.6	19.2	3.72	0.274	1.56	39.1
Ground vegetation	4.33	1.34	8.64	9.34	1.037	1.012	0.083	0.206	0.003	0.020	0.418

vents them from leaching. Xie et al. (2019) found that the understory plants affected the relationship between litter and soil in Chinese fir plantations.

Concentrations and stocks of nutrients in soil

The nutrient concentrations in Table 5 are usually those to assess the fertility of soils. There are thresholds values for this purpose. It must be taken into account that these values were derived for agricultural soils and the extrapolation to forest soils should be held with caution. According to BAI (1984) all concentrations for exchangeable cations (Ca, Mg, K), organic C and Kjeldahl N are well above the deficiency limits with the exception of available P in the mineral soil layers. An adequate concentration for Olsen P is considered 11–25 mg·kg^{-1}.

The pH range in the soil of the fir stand (6.48 to 5.32) is ideal for P availability. However, even in the first mineral layer (0–10 cm) the P concentration is low. The latter does not depend on forest types because low concentrations of P in mineral layers in comparison were found in other forest soils as well (Michopoulos et al. 2020b). It seems that the humus layer plays an important role in supplying P for the uptake. The humus contribution is complimented with the re-translocation capacity trees have to transfer nutrients to new tissues before abscission.

The C/N ratio calculated from Table 5, ranges from 18.9 in the FH layer to 11.2 in the 40–80 cm mineral one. The fact that we have *Abies* sp. and no other conifer in the stand is the explanation of the relatively low C/N ratio. Cools et al. (2014) found a strong dependence of it and tree species in the European forests. Among all coniferous stands, only 34 % had C/N ratio lower than 25. However, one should not overestimate its role with regard to organic matter decomposition. Michopoulos et al. (2020a) found that a maquis stand in Greece with a higher ratio of C/N in L soil layer than L layer of the fir plot in the present study had a faster decomposition rate due to higher ambient temperatures. So abiotic environmental factors can have a predominant role.

There are not many works concerning the stocks of nutrients in forest soils. Eriksson and Rosen (1994) found lower stocks of macronutrients in the forest floor in a 35–40-years-old forest stand of silver fir in Sweden. For example, the N stock was 844 kg·ha^{-1} in the forest floor and 5000 kg·ha^{-1} in the mineral soil down to 95 cm depth. In our work, we

Table 5. Concentrations and stocks of nutrients in the organic soil horizons and mineral soil as well as residence times (years) of nutrients in the forest floor.

Exchangeable cations, total C and N as well as available P and micronutrients in five soil layers										
Layer	Ca	Mg	K	N	P	C	Mn	Fe	Cu	Zn
	$cmoles_c \cdot kg^{-1}$			$g \cdot kg^{-1}$	$mg \cdot kg^{-1}$	$g \cdot kg^{-1}$	$mg \cdot kg^{-1}$			
FH	52.6	4.00	1.09	12.2	30.5	230	370	133	1.45	18.5
	(9.4)	(7.2)	(23)	(13)	(6.0)	(14)	(5.7)	(12)	(4.9)	(15)
0–10 cm	15.6	1.63	0.599	3.31	5.26	51.2	151	54.4	0.358	1.38
	(16)	(9.2)	(20)	(16)	(28)	(20)	(15)	(25)	(20)	(54)
10–20 cm	8.97	1.32	0.593	2.45	2.68	33.6	116	45.3	0.383	0.483
	(18)	(1.8)	(23)	(9.4)	(14)	(10)	(14)	(5.0)	(32)	(18)
20–40 cm	5.65	1.18	0.55	2.12	2.90	27.5	92.5	41.5	0.575	0.275
	(9.3)	(11)	(16)	(4.4)	(36)	(3.5)	(28)	(4.2)	(15)	(16)
40–80 cm	2.28	1.13	0.29	1.35	6.3	15.3	65.0	32.9	0.438	0.175
	(25)	(17)	(28)	(15)	(37)	(19)	(37)	(0.54)	(12)	(0.0)
Stocks of nutrients in the forest floor and mineral soil										
Layer	Ca	Mg	K	N	P	S	Mn	Fe	Cu	Zn
				$t \cdot ha^{-1}$					$kg \cdot ha^{-1}$	
L+FH	1.34	0.419	0.568	1.091	0.110	0.0973	0.144	2.036	1.87	9.13
	(4.6)	(10)	(9.9)	(11)	(5.2)	(7.9)	(4.6)	(15)	(7.2)	(5.6)
0–80 cm	15.5	42.3	57.2	9.77	3.748	1.309	4.278	239	131	519
	(5.1)	(1.8)	(1.9)	(5.4)	(1.8)	(3.2)	(18)	(2.8)	(5.1)	(4.0)
Residence times of nutrients in the forest floor in years										
Layer	Ca	Mg	K	N	P	S	Mn	Fe	Cu	Zn
L+FH	11.4	32.3	9.02	14.9	19.7	3.78	61.2	498	24.7	33.6

Note: coefficients of variations are in parentheses.

found 1091 $kg \cdot ha^{-1}$ in the forest floor and 9770 $kg \cdot ha^{-1}$ N in the mineral soil (80 cm depth) (Table 5). This difference stresses the importance of the maturity of stands with regard to the total nutrients pool. To the best of our knowledge, there is no information in literature for micronutrients stocks in forest soils. The high amounts of Fe and Mn were expected, as mineral oxides are abundant in soils. The other two micronutrients Cu and Zn were in small amounts. The mineral soil contains the largest amounts of nutrients (Table 5) but the forest floor is the most active layer of soil in terms of microbial activity. It has to be mentioned that of the large amounts of elements in the mineral soil layers only a small percentage is available for plants. This is not necessarily bad for the ecosystem because the essentials elements are not in the risk of leaching. However, climate change can increase temperatures and thus accelerate organic matter decomposition and organic N mineralization.

That will be a constant point of alert in the future.

Residence time of nutrients in the forest floor

The calculation of this parameter is of great importance because, as mentioned above, the forest floor is the most active biological pool of forest soils. Table 5 shows the length of time of the various elements in the forest floor. It can be seen that S and K have the shortest residence time and Fe has the longest one. The high amounts of both S and K in throughfall deposition contributed to their short residence time. Iron forms strong bond with the soil organic matter and for this reason its residence time is high. Cole and Rapp (1981) quoted the mean residence time of five macronutrients in the forest floor of 13 temperate coniferous sites in the world. The N (17.9 years) and P (15.3 years) were similar to those found in our work (Table 5). There was an appreciable difference for the residence times of Ca, Mg and K, which was higher in the fir plot. This must be related with the nature of the parent material among the various forest sites. There has not been any information on S and micronutrients.

Conclusions

The Bulgarian fir under consideration is in good nutritional condition judging from foliar and soil analysis. In contrast to other nutrients, P concentrations were low in the mineral soil but this does not seem to be a problem because its availability in the humus layer and the re-translocation capacity that trees have fully cover P needs. Sulphate S fluxes in throughfall are high and thus they shorten the residence time of this element in the forest floor. The highest stocks of nutrients were in the mineral soil, forest floor, trunk wood and trunk bark as well as foliage canopy. Trunk bark was a large pool for N, P and S. This finding is important to consider (especially for P) when a logging plan is applied. It is recommended that the logging remnants should stay in the forest to enrich the forest floor. The high amounts of N in the mineral soil can be a point of alert for climate change as mineralization of organic N can be increased due to a rise in ambient temperature. The shortening of the residence time of this element in the forest floor can be an indication of that change. The fir plot in our work can serve as a reference level for comparison under the presupposition that we have mature and mountainous *Abies* species.

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ALLOZYME VARIATION IN *QUERCUS FRAINETTO* TEN. POPULATIONS IN BULGARIA

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Abstract

The paper presents a survey on the genetic variation of *Quercus frainetto* Ten., an economically important tree species. Allozyme markers were applied to detect intra- and inter-population variation. The level of genetic diversity within populations was relatively high, like in other oak species with similar life history characteristics – mean expected and observed heterozygosities were 0.231, and 0.196, respectively. The major part of genetic diversity was attributed to within-population component of variation. Genetic differentiation measured by F-statistics was 0.027. No significant isolation by distance and small-scale geographic subdivision was detected, which indicates substantial gene flow among populations.

Key words: conservation, differentiation, genetic diversity, Hungarian oak.

Introduction

The Hungarian oak (*Quercus frainetto* Ten.) is widely distributed on the Balkan Peninsula. It is drought tolerant species, occupies mostly dryer and moderately rich habitats and has an exceptional good quality timber (Kalinkov 1960, 1961; Kalinkov and Shipchanov 1976; Yurukov and Panayotov 2015; Bordács et al. 2019). Therefore, the species is considered important from both economic and ecological points of view. It grows in pure and mixed stands, most often with *Quercus cerris* L. and significant part of *Q. frainetto* stands are of coppice origin.

Genetics of European oaks was studied extensively in western, and in part of Central Europe (Aas 1993, Kleinschmit et al. 1995, Stejnhoff 1997, but see Kremer and Hipp 2020, for a review). The methods of documenting the genetic diversity of oaks consist mostly of isozyme and DNA gene markers, but the quantitative adaptive traits are considered very important, too (Kremer and LeCorre 2012). Genetic diversity of *Q. robur* L. and *Q. petraea* (Matt.) Liebl. is relatively well documented (Zanetto et al. 1994, Zanetto and Kremer 1995, Kremer and Zanetto 1997, Bacilieri et al. 1996, Finkeldey 2001, Gömöry et al. 2001). However, while the biology and sylviculture of *Q. frainetto* have been extensively studied during the past decades (Marinov et al. 1995) its genetic diversity remained less studied, mostly because its

natural area of distribution is in southeastern Europe, and particularly, on the Balkan Peninsula (Bordács et al. 2019). Recent studies have shown that it attracts the attention of geneticists in its area of natural distribution and its genetic variation was studied in different aspects – hybridization, distribution of genetic diversity, differentiation, adaptation and growth performance of different provenances (Belletti et al. 2005; Curtu et al. 2007, 2011; Fortini et al. 2015, Apostol et al. 2020).

In Bulgaria, most studies are related to describing its phenotypic variation, which is extremely high, especially in leaf traits (Stefanoff 1943, Kalinkov 1960, Garilov and Stoykov 1978). According to the taxonomic scheme of Schwarz (1937–1939, 1964), applied to the Flora of Bulgaria (vol. 3; Ganchev and Bondev 1966) *Quercus frainetto* belongs to the section *Dascia* Kotschy, together with three other species of the Bulgarian flora – *Q. brachyphylla* Kotschy, *Q. virgiliana* Ten. and *Q. pubescens* Willd. (Ganchev and Bondev 1966). *Q. frainetto* is characterized by the presence of stipitate-fasciculate trichomes fused at the base, as well as by the presence of large amount of secretory trichomes. An important differentiating trait is the ratio between covering and secretory trichomes, which is 1:21 for *Q. frainetto*, thus differentiating it from the other species of the section (Uzunova and Palamarev 1992, Uzunova et al. 1997).

The knowledge of the genetic diversity and differentiation of *Q. frainetto* is important due to several reasons: First, it could be very useful for developing strategies for gene conservation; second, it could serve as a basis for sustainable management of its genetic resources; and third, it would be very useful for practical breeding programs.

Therefore, our objective was to study the distribution of genetic diversity within and among the populations of *Q. frainetto* in Bulgaria using allozymes as genetic markers.

Materials and Methods

Populations and sampling

Fifteen Bulgarian populations were selected for this study. The populations cover the whole natural range of the species in Bulgaria (Fig. 1, Table 2). Fifty to sixty individuals were sampled in each population. Branches with dormant winter buds were sampled and stored at 0–2 ºC until analyses.

Enzyme extraction, electrophoresis and enzyme staining

Bud tissues (2–3 buds per tree, scales removed) were homogenized in 100 µl Tris-HCl buffer pH 7.5, containing 15 mg Dithiothreitol, 5 mg Na_2EDTA, 100 mg PVP and 300 mg sucrose per 20 ml buffer. Also, ten milligrams of PVPP-40 were added as stabilizing agent. The enzymes were absorbed by wicks 3×8 mm Whatman 3MM chromatographic paper and the wicks were inserted into the gel. Standard starch-gel electrophoresis was used in two buffer systems: Lithium-borate – Tris-citrate discontinuous buffer system pH 8.1 (Ashton and Braden 1961) and Tris-citrate continuous buffer system pH 7.0 (Shaw and Prasad 1970). The enzyme systems studied and the loci scored are listed in Table 1. Staining procedures followed Shaw and Prasad (1970) and Cheliak and Pitel (1984) with slight modifications.

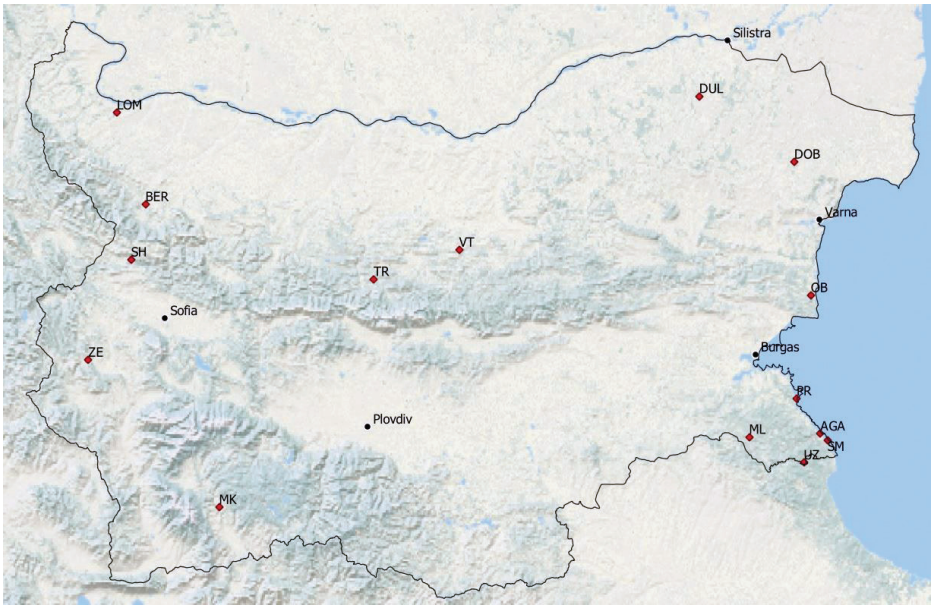

Fig. 1. Location of the populations studied.

Note: see Table 2 for the abbreviations.

Table 1. Enzyme systems studied and the loci scored.

Enzyme system (abbreviation and EC code)	**No of loci scored**	**Buffer system**
Glutamate-oxaloacetate transaminase (GOT, 2.6.1.1)	2	A
Isocitrate dehydrogenase (IDH, 1.1.1.42)	1	TC
Leucine aminopeptidase (LAP, 3.4.11.1)	1	A
Malate dehydrogenase (MDH, 1.1.1.37)	4	TC
Menadione reductase (MNR, 1.6.99.2)	1	A
Phosphoglucomutase (PGM, 5.4.2.2)	1	TC
Phosphpoglucose isomerase (PGI, 5.3.1.9)	2	A
6-phosphogluconate dehydrogenase (6PG, 1.1.1.44)	2	TC
Shikimate dehydrogenase (SkDH, 1.1.1.25)	2	TC

Legend: A – Lithium borate (pH 8.1) + Tris Citrate (pH 8.1) discontinuous buffer system according to Ashton and Braden (1961); TC – Tris Citrate (pH 7.0) continuous buffer system according to Shaw and Prasad (1970).

Data analysis

The allelic frequencies were calculated based on diploid genotypes. They are available from the authors upon request. The expected and observed heterozygosities, mean number of alleles per locus and effective allele numbers were calculated by means of software Genepop v. 3.1c (Raymond and Rousset 1995) and Popgene v. 1.31. (Yeh and Boyle 1997).

Deviations from Hardy-Weinberg expectations due to heterozygote deficiency or excess, and to linkage disequilibrium,

were tested by Genepop (Raymond and Rousset 1995).

Genetic diversity among populations was evaluated by Nei's genetic distance (Nei 1978) and the differentiation measure was Wright's F-statistics (Wright 1965), calculated by the method of Weir and Cockerham (1984) using F-STAT software (Goudet 1995). Genetic distances (Nei 1978) were obtained by using the software Popgene, and cluster analysis was applied by means of the software DendroUPGMA (http://genomes.urv.cat/UPGMA, Garcia-Vallve et al. 1999).

Results

All loci showed minor polymorphism (*sensu* Lewontin 1985), which means that the frequency of the most common allele was always higher than 0.5.

Statistically significant linkage disequilibrium was detected in 12 of 344 possible two locus combinations in all populations (2.6 %) and concerned the populations Obzor (3), Ahtopol (2), Sinemorets (3) and Dulovo, Troyan, Momina kula and Veliko Tarnovo (1 each). The loci involved in the linkage disequilibrium were: PGI-2 (9 combinations), GOT-2 (5), LAP1 (3), PGM (3), MNR (2), and SKD2 (2). At overall level, when the data of all populations were pooled, significant linkage disequilibrium was detected in only one of 28 (3.6 %) two-locus combinations (PGI-2-LAP1). As a whole, the amount of linkage disequilibrium was negligible and therefore, we retained all loci for further analyses.

Nine significant cases of deviation from Hardy-Weinberg equilibrium were detected (one in each of nine populations), and all deviations were due to heterozygote deficiency. The most polymorphic loci were PGI-2 and MNR – each with 5 alleles, while 2 to 3 alleles were detected in the other loci.

Mean allele number per locus (Table 2) varied from 1.9 (Lom) to 3 (Sinemorec). Effective allele number varied from 1.15 (Veliko Tarnovo) to 1.35 (Berkovitza). Percent of polymorphic loci ranged from 25 to 75. Expected heterozygosity was relatively high, ranging from 0.147 (Veliko Tarnovo), to 0.253 (Berkovitza). Observed heterozygosities had values close to the expected ones, which resulted in low values of the inbreeding coefficient (-0.043 to 0.190).

Shannon index of diversity was the highest in locus Pgi-2, and also in the loci Got-2, Mnr and Lap1 (Table 3). The average value of all population was 0.36.

Nei (1978) genetic distances are presented in Table 4. The distance values are low indicating little genetic differences among the populations. The cluster dendrogram based on genetic distances (Fig. 2) revealed some grouping without clear trend – Obzor is the most distant population, while in the pairs and groups formed by the other populations, the closely situated Sinemoretz and Uzunbodzhak form a mini-cluster, like Shuma and Zemen. The other populations are placed without correlation among the genetic differences and geographic distance.

F-statistics showed that the overall differentiation is low – only about 3 % of the total variation was due to genetic differences among populations; the remaining variation could be attributed to intra-population genetic diversity (Table 5). Number of migrants was 27 using the private allele method), and 9, calculated by using F_{ST} method, The isolation-by-distance test calculated by plotting pairwise differentiation $F_{ST} \cdot (1-F_{ST})^{-1}$ against the log-transformed distance in km was not significant ($p = 0.089$).

Table 2. Information about the populations studied, and results of polymorphism and diversity.

Population (abbreviation)	Geographic coordinates	Altitude, m	S_m	A_m	A_e	P	H_o (s.e.)	H_e (s.e.)	F
Akhtopol (AGA)	42° 06' N 27°55' E	20	41.6	2.5	1.266	75	0.210 (0.038)	0.233 (0.043)	0.102
Berkovitza (BER)	43°17 'N 23°11' E	250	49.4	2.0	1.346	50	0.257 (0.062)	0.253 (0.059)	- 0.015
Dobrich (DOB)	43°30' N 27°44' E	200	46.6	2.25	1.304	62.5	0.233 (0.060)	0.237 (0.055)	0.016
Dulovo (DUL)	43°50' N 27° 04' E	200	49.9	2.5	1.244	37.5	0.196 (0.050)	0.208 (0.056)	0.057
Lom (LOM)	43°45' N 22°59' E	50	21.9	1.9	1.198	50	0.165 (0.066)	0.167 (0.062)	0.012
Mladezhka River (ML)	42° 05' N 27°25' E	250	55.8	2.63	1.256	75	0.204 (0.059)	0.213 (0.057)	0.043
Momina kula (MK)	41°43' N 23°42' E	650	53.4	2.25	1.176	37.5	0.150 (0.064)	0.147 (0.062)	0.020
Obzor (OB)	42°49' N 27°51' E	200	55.3	2.38	1.276	62.5	0.216 (0.047)	0.207 (0.051)	0.043
Perla (PR)	42°17' N 27°45' E	20	47.2	2.5	1.222	50	0.182 (0.035)	0.224 (0.045)	0.190
Shuma (SH)	43°00' N 23° 05' E	800	47.5	2.5	1.183	62.5	0.155 (0.061)	0.159 (0.051)	0.025
Sinemorec (SM)	42° 04' N 27°58' E	30	59.1	3	1.319	62.5	0.242 (0.046)	0.264 (0.053)	0.085
Troyan (TR)	42°54' N 24°47' E	500	55.7	2.25	1.248	50	0.199 (0.054)	0.210 (0.059)	0.053
Uzunbodzhak (UZ)	41°57' N 27°48' E	180	48.6	2.62	1.235	75	0.190 (0.055)	0.210 (0.057)	0.037
Veliko Tarnovo (VT)	43° 03' N 25°23' E	400	48.1	2.13	1.147	25	0.128 (0.062)	0.147 (0.067)	0.129
Zemen (ZE)	42°29' N 22°47' E	600	43.7	2.37	1.282	62.5	0.220 (0.059)	0.225 (0.059)	0.023
Mean			48.3	2.38	1.247	55.8	0.196 (0.059)	0.231 (0.056)	0.046

Note: A locus is considered polymorphic if the frequency of the most common allele does not exceed 0.95. Legend: S_m – mean sample size; A_m – mean number of alleles per locus; A_e – effective allele number (Crow and Kimura 1970); P – percent of polymorphic loci (0.05 criterion); H_o – observed heterozygosity; H_e – expected heterozygosity under Hardy-Weinberg equilibrium; s.e. – standard errors; F – inbreeding coefficient ($F = 1-H_o \cdot H_e^{-1}$).

Discussion

The polymorphism and diversity established in the studied populations showed that *Q. frainetto* exhibits levels of genetic diversity well within the range of these reported for other oak species (Hamrick et al. 1992). The levels of genetic diversity

Table 3. Shannon information diversity index (*I*).

Locus	Sample size	*I*
PGI-2	1520	0.8222
LAP-1	1538	0.3987
GOT-2	1134	0.5710
MNR	1508	0.3462
6PGD	1534	0.2626
PGM	1548	0.0990
SKD-1	1372	0.1751
SKD-2	1434	0.2152
Mean	1448	0.3612 ±0.24 (SD)

were more or less typical for species with similar life-history characteristics like *Q. frainetto*. Shannon's index of diversity confirmed the trend detected by the heterozygosity levels in separate loci. Analogously to heterozygosity, this index has the highest values when the alleles are evenly represented. Originally developed for information theory (Crow 2001), it has been successfully applied in ecology, but seems of little use in population genetics. Similar levels of genetic diversity were recorded in other studies. Curtu et al. (2011) found a bit higher differentiation (F_{ST} = 0.067); however, *Q. pubescens* populations were included in their dataset. Most studies report relatively high genetic diversity within populations and lower differentiation among populations, which was detected in the present study. There was no spatial trend in the distribution of genetic diversity. The cluster dendrogram revealed some grouping of closely situat-

Table 4. Genetic distances among populations (Nei 1978).

Populations*	SH	OB	UZ	PER	AGA	MLAD	SIN	DUL	ZEM	TROY	DOB	BER	MOM	VT
OB	0.0079													
UZ	0.0034	0.0124												
PER	0.0077	0.0155	0.0058											
AGA	0.0064	0.0136	0.0033	0.0009										
MLAD	0.0095	0.0168	0.0026	0.0069	0.0047									
SIN	0.0041	0.0051	0.0039	0.0070	0.0062	0.0076								
DUL	0.0059	0.0137	0.0116	0.0160	0.0112	0.0209	0.0152							
ZEM	0.0004	0.0092	0.0029	0.0069	0.0066	0.0066	0.0045	0.0093						
TROY	0.0026	0.0108	0.0069	0.0192	0.0144	0.0161	0.0084	0.0072	0.0050					
DOB	0.0028	0.0105	0.0027	0.0018	0.0006	0.0063	0.0046	0.0084	0.0020	0.0097				
BER	0.0076	0.0146	0.0065	0.0089	0.0074	0.0023	0.0071	0.0174	0.0053	0.0133	0.0071			
MOM	0.0015	0.0077	0.0042	0.0040	0.0032	0.0066	0.0040	0.0084	0.0017	0.0082	0.0012	0.0043		
VT	0.0016	0.0090	0.0053	0.0071	0.0060	0.0075	0.0034	0.0107	0.0021	0.0069	0.0032	0.0035	0.0001	
LOM	0.0027	0.0133	0.0072	0.0034	0.0041	0.0085	0.0079	0.0074	0.0020	0.0108	0.0017	0.0040	0.0010	0.0021

Note: * For full names of populations, see Table 2.

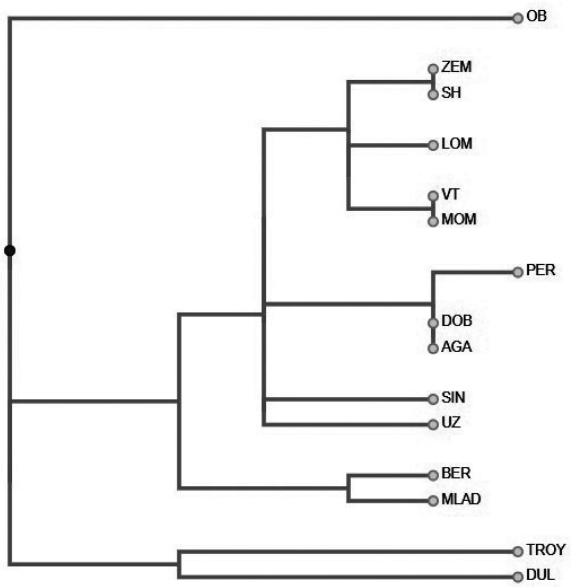

Fig. 2. Cluster dendrogram expressing the affinity among the populations based on the genetic distances.

Table 5. F-statistics and genetic differentiation.

Locus	F_{IS}	F_{IT}	F_{ST}
PGI-2	-0.0353	-0.0189	0.0159
LAP-1	0.1230	0.1475	0.0279
GOT-2	-0.0223	0.0137	0.0352
MNR	0.1924	0.2395	0.0583
6PGD	0.1224	0.1216	-0.0009
PGM	0.0566	0.0624	0.0061
SKD1	0.1924	0.2098	0.0216
SKD2	-0.0058	0.0513	0.0568
All	0.0421	0.0682	0.0272
95% CI*	-0.11-0.138	0.013-0.164	0.017-0.042

Note: *CI is confidence interval.

ed populations, for example Zemen and Shuma, Perla and Ahtopol, Sinemoretz and Uzunbodzhak, but some geographically distant populations were grouped together, too, like Berkovitza and Mladezhka River. These results can be explained by the neutral character of the allozyme markers, but also, with the extensive gene flow among the populations. The number of migrants was high, calculated both by private allele method and F_{ST} method. Whitlock and McCauley (1999) questioned the utility of F_{ST} method for reliable estimate of migrants and stated that one migrant per generation can reduce the population differences, which could arise from the genetic drift.

Low differentiation makes difficult the task of selecting populations of *Q. frainetto* for gene conservation. However, in similar cases it is always recommendable to select genetic entries representing all regions of the species distribution and the whole range of environmental conditions. The low among population diversity points out the necessity of application of more polymorphic and informative genetic markers (Bordács et al. 2002, Fineschi et al. 2002). Genetic integrity of the populations is not threated by hybridization with other oak species (Curtu et al. 2011) – in Bulgaria the issue has not been studied in detail, but if existing at all, it is of minor importance.

The populations studied had different size and included also some small and isolated stands. The results indicate that even small and isolated populations from the fragmented landscape still contain significant amount of genetic variation and, therefore, they must be considered in the sustainable management activities (Zhelev et al. 2002).

Conclusions

The study on the genetic diversity of *Q. frainetto* by using allozyme gene markers allows the following main conclusions:

- The levels of genetic diversity and differentiation of Bulgarian populations correspond to these reported for species with similar life history characteristics (e.g. Hamrick et al. 1992).

- No clear spatial trend was observed, which confirms the neutrality of allozyme markers and points out the significance of gene flow as a factor minimizing the genetic differences among populations.

- The major part of genetic diversity was attributed to within-population component of variation. No small-scale geographic subdivision was detected, which indicates the presence of substantial gene flow among populations.

- Selecting populations for gene conservation should be based on territorial principle with the aim to cover the diversity in the environmental conditions.

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GROWTH, QUALITY AND REGENERATION OF SESSILE OAK (*QUERCUS PETRAEA* (MATT.) LIEBL.) IN COPPICE WITH STANDARDS IN FRANCONIA, GERMANY

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Abstract

Coppice with standards (CWS) has recently regained importance in forestry. This is due to increased demand for firewood, the high ecological value of CWS, its potential to produce highly valuable timber from oak and Noble Hardwoods and its potential to adapt forests to climate change. In silvicultural investigations of CWS in Franconia/Bavaria which began in 2007, three treatments were carried out in oak-dominated (*Quercus petraea* (Matt.) Liebl.) forests on two different sites. Local coppicing systems varied as to the amount of basal area maintained, canopy cover and volume hectare. Investigations of the maidens showed that pruning to a height of 6 m in 2007 failed to improve stem quality. Due to epicormic shoots, the pruned maidens had significantly shorter branch-free bole lengths five years after pruning. The level of regeneration was high (up to 220.000 plants·ha^{-1}), with a large oak component (up to 95 %). Generative regeneration dominated, with coppice shoots comprising a small share of the total of young plants (<23 %). Although oak dominated in numbers, shade-tolerant species like beech (*Fagus sylvatica* L.) gained more height. Thus, oak is expected to play a minor role in the next stand generation and mixture regulation is needed if oak is favored. The mean height of regeneration decreased with increasing canopy cover. Furthermore, the larger the diameter of the coppiced oak stump, the more coppice shoots were produced. These results can be used to modernize and adapt management options for CWS in times of climate change, and also can give some hints for the heavy crown thinnings that have become common today in the management of broadleaf, and particularly, of oak stands with elite trees.

Key words: climate change, maidens, pruning, sprouting, timber quality.

Introduction

Coppicing – with or without standards – used to be a common silvicultural technique practiced throughout Europe (Ellenberg 1978, Hausrath 1982, Bärnthol 2003) and dates back to 13th – 14th century (Burschel and Huss 2003, Hausrath 1982). Decreasing demand for firewood virtually ended this silvicultural system in Germany up to 200 years ago, and most former coppices have been converted into high forests for the production of larger amounts of stem wood (Cotta 1828, Hartig 1861, Hausrath 1982, Vollmuth 2021). Hence, the importance and share of total forest area has decreased dramatically for this management system not only in Germany. Today, this silvicultural technique is very rare, and only of local importance in small areas of Germany – most notably in Bavaria and Rhineland-Palatine (BMVEL 2004, Albrecht and Müller 2008, Vollmuth 2021). In contrast, other European countries such as France, still have a lot of coppiced area (Fischer 2003, Ruch 2017). The substitution of coal and petroleum for firewood (Bärnthol 2003, Burschel and Huss 2003, Geb at al. 2004) and the often unsatisfying yield and quality of logs from coppices (Mayer 1977, Freist 1985, Hochbichler 2008, Beinhofer and Knoke 2009) are the main reasons this silvicultural technique has been abandoned across large areas. Currently, however, coppice with standards (CWS hereafter) is again becoming of interest to forest practitioners. CWS provides firewood, for which demand has again increased (Grütz 1986, Bally 1999, Hochbichler 2008, Short and Hawe 2012). Due to the high ecological habitat quality that is provided by CWS (Brand 1997; Bolz 1999; Coch and Müller-Bauerfeind 2002; Treiber 2002, 2003; Müller-Kroehling 2007; Albrecht and Müller 2008; Short and Hawe 2012, Vollmuth 2021) nature protection programs focus on this type of forest, and state subsidies are available to support reactivation of CWS (Freist and Klüssendorf 1991, Schulte et al. 2004, Mosandl et al. 2010). The chance to input new climate-adapted tree species by every coppicing-cycle – thus much more often than in a common forest rotation period – is a further advantage of CWS in times of climate change.

Coppice with standards

A CWS is a mixture of a coppice and a high forest on the same area (Hartig 1861), where a combination of vegetative and generative regeneration form a two layer forest (Krissl and Müller 1989). The vegetative component of regeneration takes place in the regularly coppiced understory that re-sprouts from stumps, and the generative regeneration component forms the overstory, mostly dominated by oak (Groß and Konold 2010) and admixed Noble Hardwoods. The best-formed trunks resulting from this generative regeneration are chosen before coppicing is carried out on the remaining stand and are maintained as so-called maidens. Timbal and Aussenac (1996) reported that *Quercus robur* L. is favored over *Q. petraea* (Matt.) Liebl. for CWS. However, Vlad (1940) pointed out that the choice of appropriate species in CWS is dependent on site conditions, with *Q. robur* being better suited to floodplain sites, and *Q. petraea* to dryer regions. Due to the existence of hybrids of the two species, the right provenance may be of more importance, however, than the species (Aas 1991, Steinhoff 1993, Neophytou et al. 2010). A CWS stand has no homogeneous age like a high forest because of its perpetuating nature, and thus is more similar to an uneven-aged forest

(Duchiron 2000, Schütz 2001, Kerr 2002). Each tree falls into an age class characterized by the number of coppice-cuttings it has undergone. Normally, six coppicing cycles are thought to be optimal, with a single rotation lasting about 30 years (Cotta 1828, Hartig 1861, Heyer 1893, Hamm 1896). Therefore, 6×30 years corresponds to a rotation time that is quite common for oak silviculture in Germany (Krahl-Urban 1959, Fleder 1981, Mosandl and Paulus 2002). The number of trees per ha in each age class is quite strictly regulated in theory – according to the old references, which date back prior to 1900 (Cotta 1828, Hartig 1861, Heyer 1893, Hamm 1896) – and approximates the distribution similar to an uneven aged forest (Mayer 1977, Schütz 2001; Hochbichler 2008). With reference to volume per ha or canopy cover percentage, CWS are typically classified as rich, normal or poor in yield (Hamm 1896, 1900; Vanselow 1941; Schaeffer and Schaeffer 1951; Köstler 1955; Mayer 1977; Grütz 1986, Hochbichler 2008). It is important to note that CWS is a form of land-use that influences and changes natural vegetation cover intensely (Pott 1981). Oaks and admixed species of Noble Hardwoods were fostered for centuries at the expense of naturally dominating beech due to their timber value and masting quality for livestock (Fischer 2003, Küster 2008). Hence, CWS is a very artificial vegetation cover while at the same time, it is considered very valuable for biodiversity, firewood production and maintenance of rare species.

Although a lot of traditional and descriptive information is available, however, current and data-based information and knowledge on CWS is limited (e.g. Utinek 2004, Hochbichler 2008, Pyttel 2012). Therefore, this study aimed to investigate whether the CWS stands studied were similar to theoretical considerations in terms of structure and species composition. So these parameters as well as the increment were assessed.

Furthermore, pruned oaks were investigated to find out whether the quality of timber could be improved by this treatment. Additionally, the regeneration was studied to clarify whether oak dominance can be maintained for the future by practicing current management techniques.

Material and Methods

Study area and experimental design

The investigation took place in one of the last remaining Bavarian CWS, situated in the Steigerwald area – a hilly region in the middle of Germany located between Nuremberg and Wuerzburg in Franconia. Two forests were chosen near the localities of Weigenheim (hereafter referred to as W, 49°34´29" N, 10°15´47" E) and Iphofen (hereafter referred to as I, 49°40´16" N, 10°19´19" E). The elevation of the forests ranges between 270 and 493 m in altitude. The climatic conditions can be described as viticultural; with an average temperature of about 8.5 °C, about 700 mm precipitation per year with a maximum in summer, and a growing period of 170 days. The woodland near W is located on a moderately dry site with a flat exposition and brown soil formed by clay and loam, which is quite poor in nutrients. The mixed hardwood forest on this site is dominated by sessile oak (*Quercus petraea*) and other associated species, such as pedunculate oak (*Quercus robur*), European beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus* L.), wild service tree (*Sorbus torminalis* (L.) Crantz), birch (*Betula* sp. L.), aspen (*Populus tremula*

L.), European wild pear (*Pyrus pyraster* (L.) Burgsd.) and small-leaved lime (*Tilia cordata* Mill.). The second forest focused on in this study is located on a south-facing slope near I. It is also dominated by sessile oak, in association with pedunculate oak, hornbeam, beech, lime and true service tree (*Sorbus domestica* L.). The soil on this site is also classified as a brown soil on quite dry sand beds, but the soil fertility is slightly higher than in the previously described site. The tree species that occurred in the regeneration of the forests on both sites were next to the mentioned ones out of the overstory European ash (*Fraxinus excelsior* L.), field maple (*Acer campestre* L.), sycamore maple (*Acer pseudoplatanus* L.), wild cherry (*Prunus avium* L.), mountain ash (*Sorbus aucuparia* L.), crab apple (*Malus sylvestris* (L.) Mill.), blackthorn (*Prunus spinosa* L.), hawthorn (*Crataegus laevigata* L.), goat willow (*Salix caprea* L.), hazel (*Corylus avellana* L.), elder (*Sambucus nigra* L.), privet (*Ligustrum vulgare* L.) and rose (*Rosa canina* L.).

The experiment was established in 2007. Three different treatments were carried out in the CWS:

a) Treatment 'control' (C): In these plots, no coppicing was to be carried out in the future and the stands were to be transformed passively into high forest since the 1960s.

b) Treatment 'traditional' (T): In these plots, coppicing is carried out by locally common practice.

c) Treatment 'modified' (M): These plots were coppiced in 2007 following the recommendations given by Cotta (1828), Hartig (1861), Heyer (1893) and Hamm (1896) to realize a true CWS structure. To improve timber quality, all oak maidens (trees up to 20 cm DBH in the second coppicing cycle) were pruned of all branches below a height of 6 m in 2007, and again of all braches below 5 m in 2013.

For easier data collection and analysis, a coding system has been used, where the letter codes for each of the two sites – W and I – are combined with the first letter of each of the treatments (e.g. IM means Iphofen treatment 'modified', WC means Weigenheim treatment 'control') – thus distinguishing among the 6 variants forming the experiment. There were two replications of each treatment per site. Therefore, on each site, 6 randomly arranged experimental stands were used (3 treatments × 2 replications) and thus, in total, 12 stands formed the experiment (6 stands per site × 2 sites). Each of the experimental stands had an area of 0.25 ha, for a total of 3 ha in the entire area investigated. In each plot, a 24 m × 24 m raster was applied to identify 49 inventory points at a distance of 3 m from one another. Each point served as the center of a 1 m^2 circle where the data was collected for regeneration assessment. In the managed stands in W, the last coppicing took place in 2006/07, while in the control stands on this site conversion to high forest (abandonment of the use of coppicing) had begun in the 1960s. In the managed stands in I, the last coppicing took place in 2003/04 while the transformation into high forest had also begun in the 1960s. Due to very intense coppice cutting in W, additional maidens had to be chosen outside of the plots in the WT stands in order to gather adequate sample size. Further information about the experimental design can be found in Summa and Mosandl (2009) and Mosandl et al. (2010).

Data collection

Data was collected in the summer of 2011 and the spring of 2013. In 2011, a com-

plete inventory of each stand (including but not limited to the area within the 1 m^2 circles described above) was carried out. For every tree in each stand with a DBH larger than 7 cm, the species and DBH were recorded. The height of each of these trees was measured using a Vertex IV by Haglöf®. Also in each stand, 8 crown radii – one in each of the main cardinal directions – were estimated for each of 15 oaks ranging in size across the spectrum of DBH, which were randomly chosen. Hence, 12 stands × 15 oaks = 180 oak crowns were measured by visual estimation (Preuhsler 1979). For every maiden present, the number of epicormic branches was recorded using a 3-point scale, where 1 = less than 5 branches, 2 = from 6 to 20 and 3 = more than 20. Next, an inventory of regeneration was carried out in the 1 m^2 circles, where each tree species found was recorded, and the number of individuals and their origin (seedling or coppice shoot) was noted. The height of the tallest individual of each tree species was also recorded. The diameter of any stumps of which more than 50 % was located inside the circles were assessed and recorded. Furthermore, the data reported by Summa and Mosandl (2009) and Mosandl et al. (2010) was used to determine the amount of development and change in the stands since the beginning of the experiment. In the spring of 2013, the maidens in the 'modified' treatment were re-pruned up to a height of 5m on both the W and I sites. Due to maidens which had been lost in WT in 2011 because of worn markings, new ones were chosen outside the experimental stands and newly measured in 2013. Bias of the results was not expected from this measure, because the entire forest was coppiced in the same way throughout the experiment. The newly chosen trees were included in the analysis of branch-free bole length in maidens, but not in any other analysis. Data analysis was done using the Statistic Package for Social Science 19 (IBM SPSS Statistics 2011) for all analysis consisting of linear regression models, independent one-way ANOVA and non-parametric tests when the assumption of normality or homogeneity of variance was not met. The normality of residuals was checked visually (Field 2009, Backhaus et al. 2011).

Calculation of further parameters

Using the raw data from 2011 and 2013, the following specific parameters were derived to be used in the analysis. Basal area (*BA*) was computed for each tree and then summed to the stand level ($BA = \frac{DBH^2}{4\pi}$). Afterwards, this *BA* value was extrapolated to ha-unit. For each stand, a height curve was estimated using a linear regression model (height [m] = b_0 + b_1 · ln DBH [cm]). All trees were included in this regression, regardless of species. To reach linearity, DBH was log-transformed (ln). To describe the stands, d_g and h_g were derived ($d_g = \sqrt{\frac{\sum n_i \cdot d_i^2}{N}}$). The stand height curves were used to estimate h_g by using d_g. The volume of the stands was determined using form-height-curves ($V = HF = \frac{DBH^2 \cdot \pi}{40000}$) reported by Kennel (1973). In doing so, the measured DBHs and the heights derived from the linear regression model were used. The coefficients for *HF* used were those reported by Kennel (1973). A linear regression model was calculated to link DBH and crown projection area (*CPA*). *CPA* for each

single tree was computed following the suggestions of Kramer and Dong (1985) ($CPA = \sum_{n=1}^{8} \frac{1}{8} \cdot \pi \cdot \text{crown radius}_n^2$). Afterwards, the single values of CPA were summed and then extrapolated to ha unit. Slenderness (*SL*) was also derived for each individual tree ($SL = \frac{h}{DBH}$) in order to check for a possible relationship between *SL* and the number of epicormic branches. For the parameters of the regression models see Appendix 1 to 4.

Results

Main stand

The number of trees that formed the main stand (those with a DBH > 7 cm) ranged between 80 and 419 ha^{-1} among the variants (Table 1). The number of trees per ha was largest in variants WC (419) and IT (258), followed by IC (210). This can be attributed to the number of stems maintained in a forest where the traditional coppice concept used in I is practiced. Similarly, the basal area showed differences between treatments (Fig. 1). Coppiced stands in W had a basal area of 6.7 to 7.2 m^2·ha^{-1}, while the real correspondent stand IM showed a basal area of 10.1 m^2·ha^{-1} in 2011. In the stand IT, *BA* of 18.1 m^2·ha^{-1} was detected. A similar amount – 19.3 m^2·ha^{-1} was found in both IC and WC h in 2011. Thus, the traditionally coppiced variant in I showed rather the same basal area as the control stands in I and also resulted in a larger total basal area than in W. The absolute increment in basal area from 2007 to 2011 was different between control and coppiced stands. In WC the *BA* increment was as high as 4 m^2·ha^{-1} as compared to 3 m^2·ha^{-1} in IC, whereas the *BA* in the coppiced stands increased in this time only between 0.5 m^2·ha^{-1} in WT and 2.5 m^2·ha^{-1} in IM. Table 2 lists the d_g and h_g of the experimental stands. It was observed that the d_g

Table 1. Number of trees per ha by species and variant in 2011.

Tree species	WC	WT	WM	IC	IT	IM
Oak (*Quercus* sp.)	321	60	102	140	190	140
European beech (*Fagus sylvatica*)	0	2	2	44	22	0
Birch (*Betula* sp.)	0	4	0	4	8	2
Aspen (*Populus tremula*)	4	2	0	0	0	0
Small-leaved lime (*Tilia cordata*)	23	0	0	12	28	28
Wild service tee (*Sorbus torminalis*)	21	8	0	8	8	6
True service tree (*Sorbus domestica*)	0	0	0	2	2	4
Ash (*Fraxinus excelsior*)	2	0	0	0	0	0
Field maple (*Acer campestre*)	2	2	2	0	0	4
Hornbeam (*Carpinus betulus*)	44	0	0	0	0	2
European wild pear (*Pyrus pyraster*)	2	2	2	0	0	0
Σ	419	80	108	210	258	186

Note: the abbreviations in the tables 1–7, figures 1, 2 and 6, and Appendixes 1 and 2 have the following meanings: WC – Weigenheim treatment 'control', WT – Weigenheim treatment 'traditional' WM – Weigenheim treatment 'modified', IC – Iphofen treatment 'control', IT – Iphofen treatment 'traditional', IM – Iphofen treatment 'modified'.

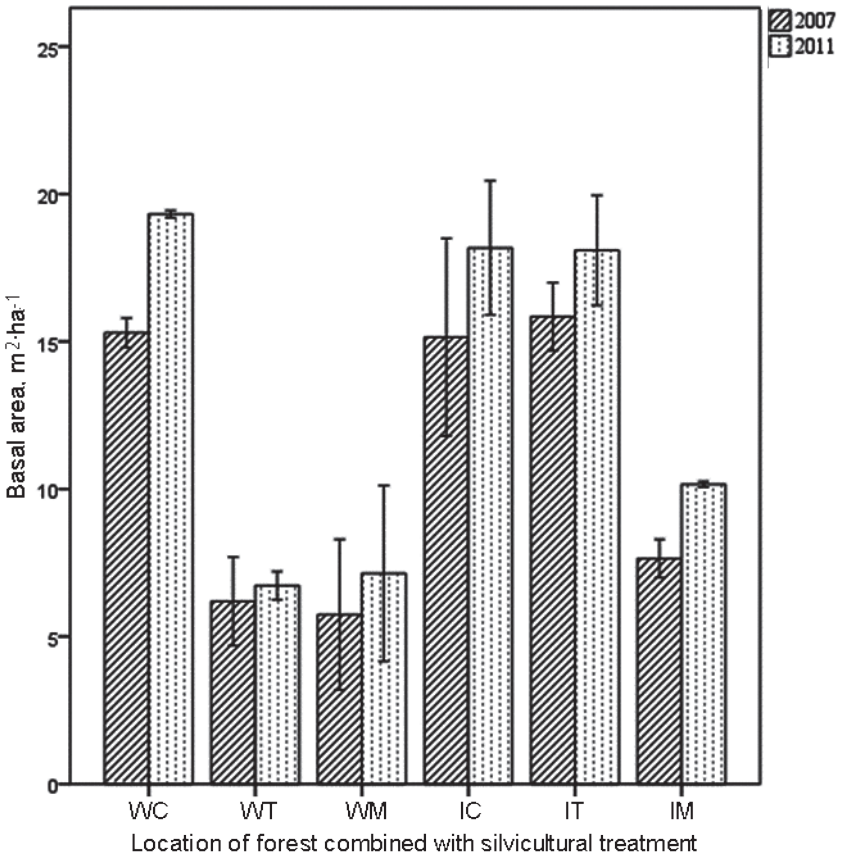

Fig. 1. Basal area of experimental CWS stands in 2007 and 2011.
Note: Error bars shown are standard errors.

Table 2. Basal center trunk diameter (d_g) and height (h_g) in stands and treatments in 2007 and 2011 and increment (Δ) relative to the year 2007.

Indicators and years		WC	WT	WM	IC	IT	IM
d_g, cm	2007	21.6	31.5	23,9	31.1	28.7	28.3
	2011	24.5	32.6	28.1	33.7	29.5	27.8
	Δ, %	13.4	3.5	17.5	8.3	2.8	-1.8
h_g, m	2007	16.6	16.5	15.2	19.1	18,3	18.6
	2011	17.9	17.3	15.8	20.2	18.5	17.9
	Δ, %	7.8	4.8	3.9	5.7	1.1	-3.8

values did not differ significantly between treatments (Kruskal-Wallis $H(2) = 1.4$; $p > 0.05$) just as h_g did (Kruskal-Wallis $H(2) = 2.1$; $p > 0.05$). Therefore, height-growth was not shown to be affected by the silvicultural management carried out. Height curves were determined for each treatment on every site. So, six height

curves were computed using linear regression models. The results of these regressions are reported in Appendix 1. Differences in the volumes detected in the stands were evident between I and W. In I, the volumes were generally higher than in W – both in control stands and in coppiced stands (Table 3). However, the increment

Table 3. Volume in stands and treatments in 2007 and 2011 and increment (Δ) relative to the year 2007.

Indicators and years		WC	WT	WM	IC	IT	IM
Volume, $m^3 \cdot ha^{-1}$	2007	133.7	58.3	49.5	170.9	164.7	80.1
	2011	185.1	66.6	66.5	214.9	197.2	106.9
	Δ, %	38.4	14.2	34.3	25.7	19.7	33.5
Ø increment, m^3 per year		10.3	1.7	3.4	8.8	6.5	5.4

in trees bigger than DBH 7 cm in WC was 10.3 m^3 per year, and therefore, even higher than that found in IC – 8.8 m^3 per year in the control stands. However, merely 16 % (1.7 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) of the increment compared to WC as a potential maximum was detected for the overstory in WT. In the IM stands the share was 61 % (5.4 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) of the potential showed by IC. Burschel and Huss (2003) and Hochbichler (2008) described that the increment of a CWS is not different to a high forest. Therefore, the missing proportion of the increment that was detected in the CWS plots (up to 84 %) is supposed to be accumulated in the regeneration fraction – anyway, it was not assessed in this study.

The canopy cover of the stands was derived using linear regression models. Six models were computed to link DBH to the corresponding crown projection area. They are reported in Appendix 2. Coppiced stands showed distinctly lower canopy cover percentages than those that had already been converted to high forests (Fig. 2). Again, IT with a canopy cover of about 70 % showed more similarity to a high forest than to a CWS. In W, the coppiced stands showed the lowest canopy cover percentage – about 30 %.

In general, the allometric relationship between the DBH and the crown projection area that is generally known in forest science was shown to fit also for CWS by the study at hand.

Maidens

The DBH of oak maidens in the different stands in 2011 and 2013 is listed in Table 4. In total, 244 maidens (all of them oaks) were measured. The DBH of the maidens ranged between a maximum of 24.8 cm and a minimum of 5.7 cm. The smallest tree was recorded in W although its DBH was less than 7 cm because it was the fastest growing individual in the surrounding area, and there was a lack of maidens in W. The mean DBH of all maidens was 17.3 cm. Figure 3 shows the DBH increment of the maidens since 2007. In WT only 2 trees formed the mean and therefore results should be interpreted with caution. Nevertheless, maidens generally showed the potential to form year-rings of more than 5 mm. No treatment showed less growth than 2.5 mm between measurements. In I the increment was generally lower than in W, with the exception of variant IM. Pruned trees showed no difference in DBH growth performance between 2007 to 2011 than unpruned ones in W (Kruskal-Wallis $H(2) = 2.5$; $p > 0.05$). However, in I there was a

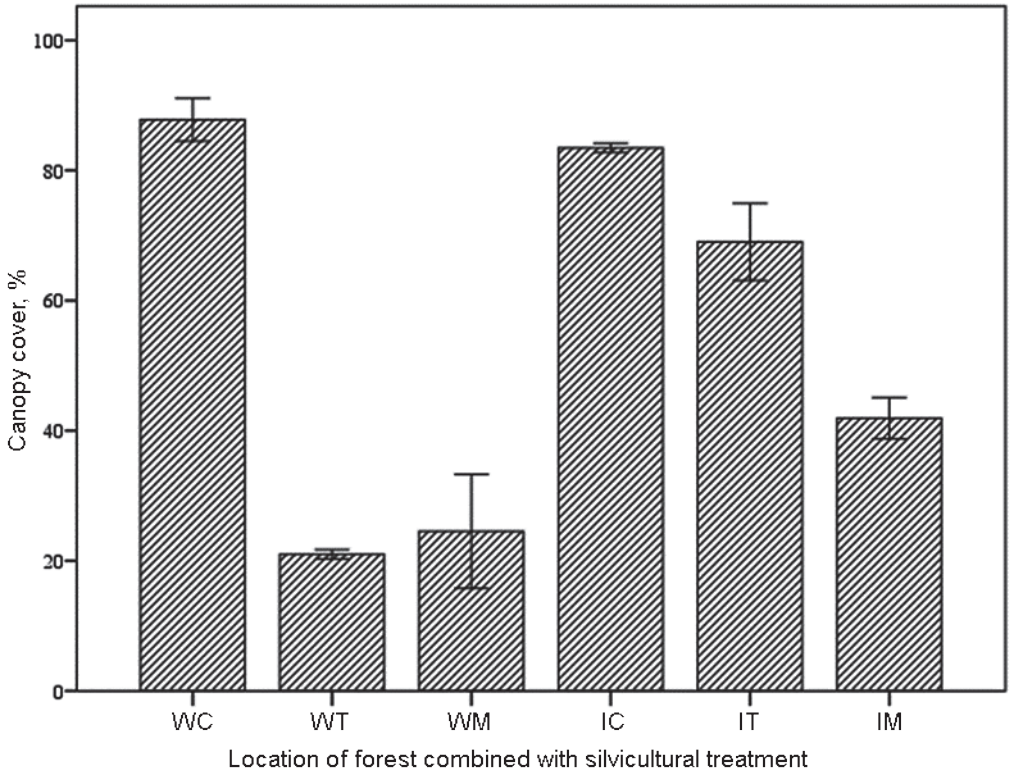

Fig. 2. Canopy cover of the experimental CWS stands in 2011.
Note: Error bars shown are standard errors.

Table 4. DBH of maidens in 2011 respectively 2013.

Stands in silvicultural technique	*N*	Ø DBH, cm	min DBH, cm	max DBH, cm	SD
WC	94	19.5	7.0	24.3	3.66
WT	20	16.6	5.7	24.0	4.21
WM	23	14.4	8.8	19.5	3.18
IC	24	15.3	8.0	23.5	4.82
IT	45	15.9	7.3	24.8	4.91
IM	38	15.7	7.3	24.8	5.36
Over all	244	17.3	5.7	24.8	4.80

Note: Abbreviations code *N* in quantity, Ø as average, and SD as standard deviation of data analyzed.

significant difference in DBH increment between treatments (Kruskal-Wallis $H(2) = 21.8$; $p < 0.000$), with the pruned trees which were promoted by the additional coppicing in 2007 showing better growth than the un-pruned ones. Table 5 lists the

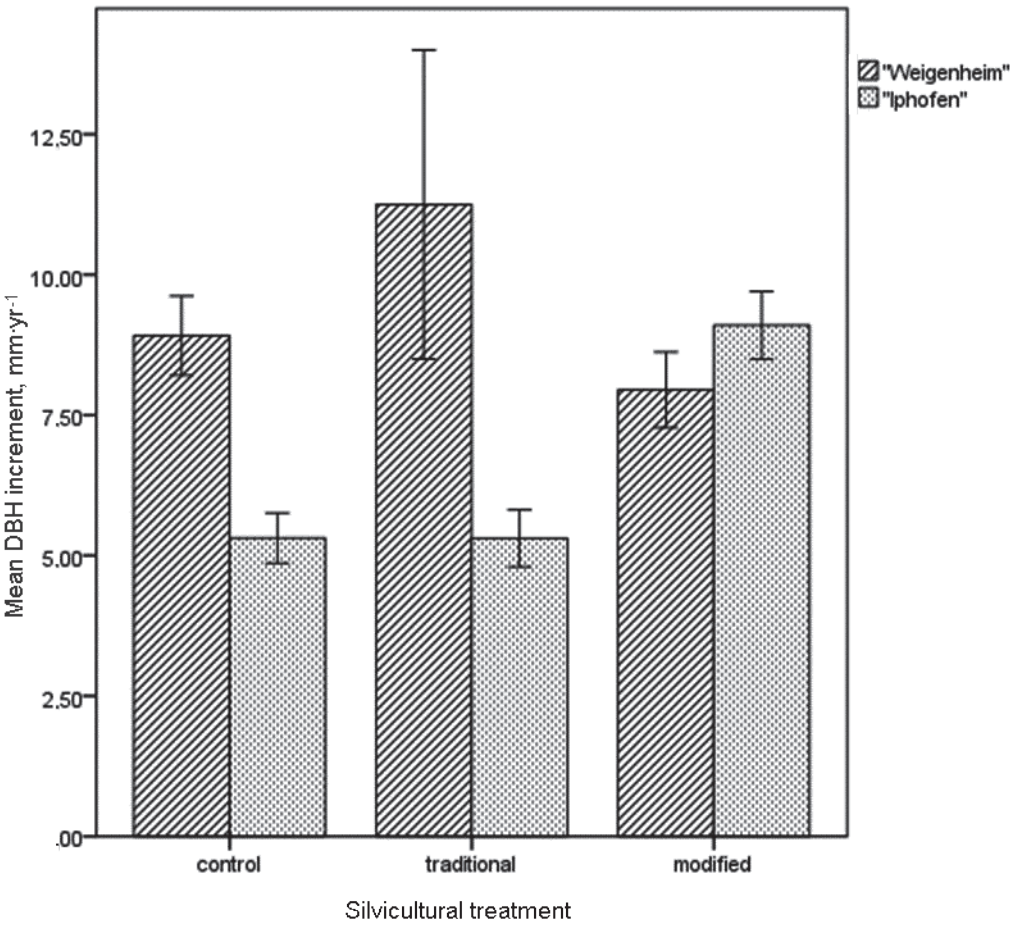

Fig. 3. Mean increment of maidens in DBH per annum and treatment on the two sites.
Note: Error bars shown are standard errors.

branch-free bole length of the trunks – one of the most important quality criteria in timber assessment. The data displayed was gathered during the inventories conducted in 2011 and 2013. The mean branch-free bole length over all maidens was 3.1 m. While some trees reached more than 12 m of branch-free bole length, others had epicormic branches beginning right at the butt end. The branch-free bole length was not always greatest in the control stands. Figure 4 shows the branch-free bole length of the maidens in the treatment 'modified' on the two sites before and after pruning in 2007 and 2013. Again, during the pruning in 2007, all branches were removed up to a height of 6 m: However, when the branch-free bole length was re-measured prior to pruning in 2013, it had decreased significantly in W (Mann-Whitney U = 72.5; p < 0.000; r = -0.57) as well as in I (Mann-Whitney U = 42; p < 0.000; r = -0.73). Therefore, the maidens were re-pruned in 2013. To reduce re-growth of epicormic branches pruning was done only up to 5 m. In total,

Table 5. Branch-free bole length of maidens in 2011 and before second pruning in 2013.

Stands in silvicultural technique	*N*	Ø, m	min, m	max, m	SD
WC	94	3.7	1.0	10.9	1.93
WT	20	1.7	0.9	7.4	1.34
WM	23	3.2	0.8	7.6	2.31
IC	24	1.9	0.5	4.4	.98
IT	45	3.1	0.5	12.0	2.53
IM	38	2.4	0.1	7.2	1.84
Over all	244	3.1	0.1	12.0	2.7

Note: Abbreviations code *N* in quantity, Ø as average, and SD as standard deviation of data analyzed.

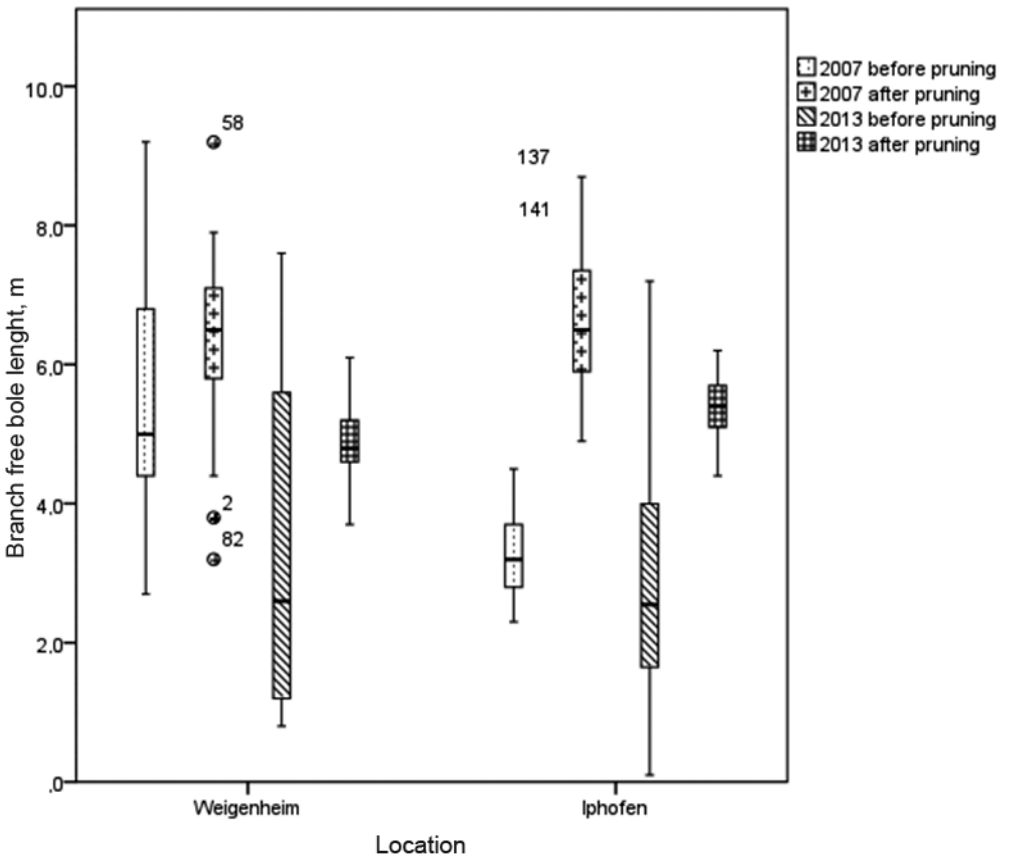

Fig. 4. Branch-free bole length of maidens before and after pruning in 2007 and 2013 in treatment 'modified'.

Note: Error bars shown are standard errors.

61 maidens were re-pruned in 2013, 1570 epicormic branches were cut for with an average per tree of 26.6 branches (as min 1 and as max 74) with a maximum basis diameter of 52 mm. Slenderness values are given in Table 6. Slenderness had no influence on the number of epicormic branches, as proven by an independent one-way ANOVA with F (2.250) = 0.23; $p > 0.05$.

Table 6. Slenderness *h*/*d* of maidens in 2011 and before second pruning in 2013.

Stands in silvicultural technique	*N*	Ø *h*/*d*	min *h*/*d*	max *h*/*d*	SD
WC	94	154	103	278	27.51
WT	20	218	162	284	36.55
WM	23	164	134	210	21.09
IC	24	153	111	251	29.64
IT	45	161	94	231	32.33
IM	38	177	114	351	48.20
Over all	244	164	94	351	36.97

Note: Abbreviations code *N* in quantity, Ø as average, and SD as standard deviation of data analyzed.

The need of pruning to receive branch-free bole lengths shows the need to manage maidens in CWS as natural processes do not lead to these desired stem qualities. Without silvicultural actions focusing on maidens the production of high-quality timber seems to be impossible or at least very uncertain.

Regeneration

Table 7 shows the number of all regeneration (DBH < 7 cm) next to separately shown oak regeneration in both 2007 and 2011. Regeneration was vigorous, with up to 220.000 plants per ha in WT in 2007. In total, 23 native tree and shrub species were detected among the new individuals identified in 2011. The number of young plants generally decreased after 2007 up to 35.6 %, except to the variant IC. Here, the regeneration was stable or even slightly higher between 2007 and 2011. Oak formed a large fraction of the number of new individuals ranging from 42 % in variant WM up to 95 % in variant IT. However, the number of new oak individuals decreased more than that of other species between 2007 and 2011. Furthermore, Figure 5 shows that the

Table 7. Number of regenerated plants per ha in stands and treatments in 2007 and 2011 and increment (Δ) relative to the year 2007.

Indicators and years		WC	WT	WM	IC	IT	IM
All plants, N·ha^{-1}	2007	127.143	220.205	123.673	112.040	163.469	90.204
	2011	81.837	158.163	122.551	116.836	133.572	75.408
	Δ, %	-35.6	-28.2	-0.9	4.3	-18.3	-16.4
Oak, N·ha^{-1}	2007	117.767	196.955	95.655	100.620	160.855	88.340
	2011	72.143	104.490	52.449	101.326	127.245	66.633
	Δ, %	-38.7	-46.9	-45.2	0.7	-20.9	-24.6

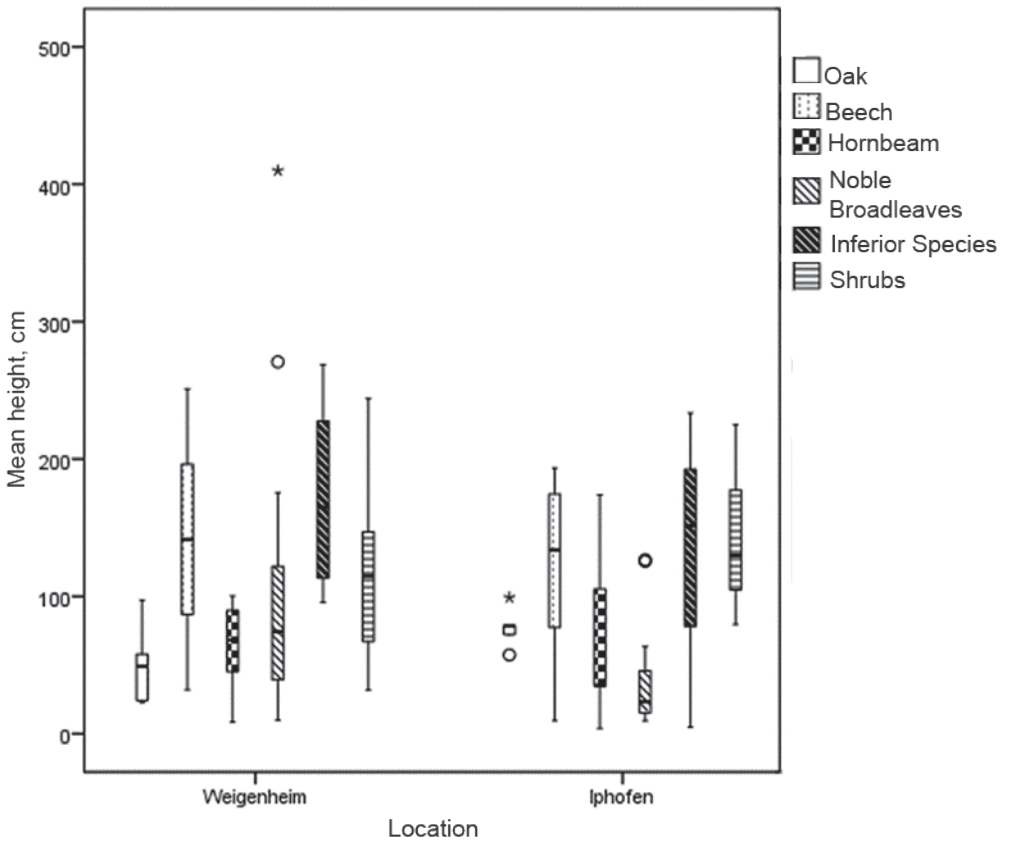

Fig. 5. Mean heights of different groups of regeneration in 2011.
Note: Error bars shown are standard errors.

mean height of the young oaks was less than that of the other species. Particularly individuals of shade-tolerant species such as beech and hornbeam gained more in height during this period, but also inferior species such as goat willow or aspen performed better than oak. Figure 6 shows the relationship between the mean height of all new individuals and the percent canopy cover. A linear regression model was computed to describe the relationship of decreasing mean with increasing canopy cover. The model is reported in Appendix 3. The largest amount of regeneration detected was of generative origin, with less than 23 % of the new stems found being coppice shoots. Hence, the vegetative regeneration was of minor importance to the total amount of regeneration. A positive relationship between stump diameter and the number of coppice shoots was detected in the experimental stands – the higher the mean diameter of the stump, the higher was the number of shoots. A linear regression model was computed using a ln transformation for the number of shoots. The model is reported in Appendix 4 and illustrated in Figure 7.

Thus, the cutting of older and bigger trees indicates a more intense sprouting

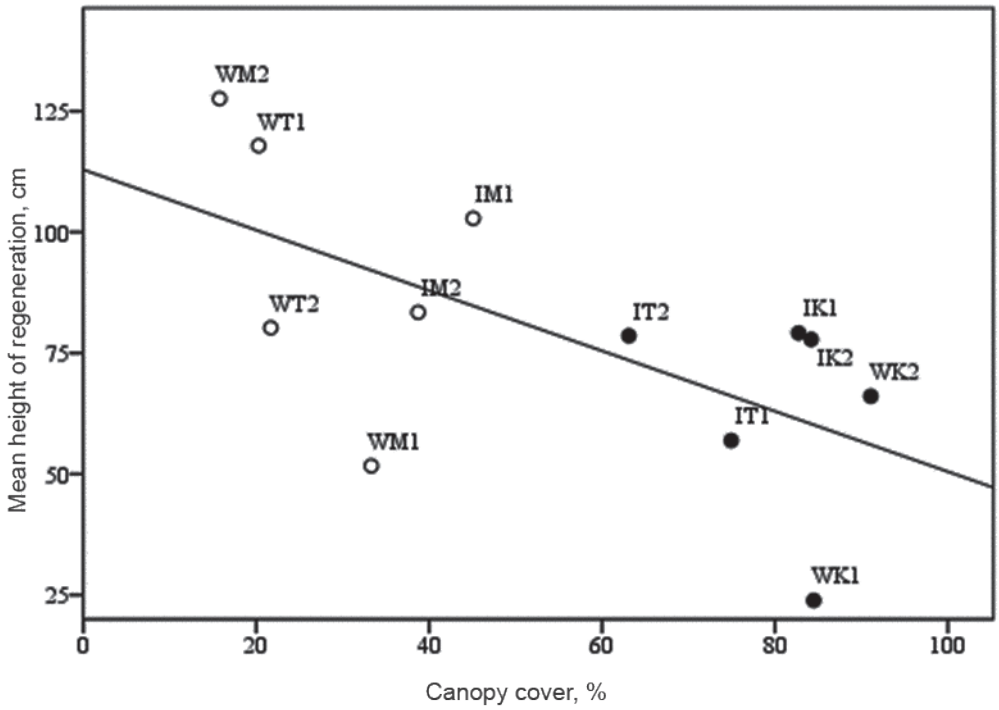

Fig. 6. Mean height of regeneration and canopy cover in 2011.

Note: Open circles represent CWS stands, filled circles symbolize high-forest-like stands with canopy cover higher than that of typical CWS.

effect than in younger trees. Combined with the finding that regeneration in CWS is depending on canopy cover hints are given to land managers how to control regeneration. The more generative regeneration is claimed, the more open the canopy layer and the less dimensioned harvested logs should be.

Discussion

Characteristics of the main stand in the CWS

CWS is a type of forest that incorporates a large number of both tree and shrub species (Grütz 1986, Decocq et al. 2004, Hochbichler 2008, Collet et al. 2008, Dodet et al. 2011). In this study, 23 species occurred in either the overstory or regeneration layer. Some of them (for example wild sevice tree and true service tree) are considered vulnerable in Germany (BLE 2013). This finding fits very well the nature of a classical CWS – where normally a lot of associated Noble Hardwoods occur more often than in high forest. On the W site, the CWS had a structure accordingly to theory (Cotta 1828; Hartig 1861; Heyer 1893; Hamm 1896, 1900) and also Czech, Austrian and German studies reported that such stands are still detectable today (Utinek 2004, Hochbichler 2008, Beinhofer et al. 2009). But in single stands in I the number of trees and the canopy cover was higher than is generally the case in a classical CWS. Refer-

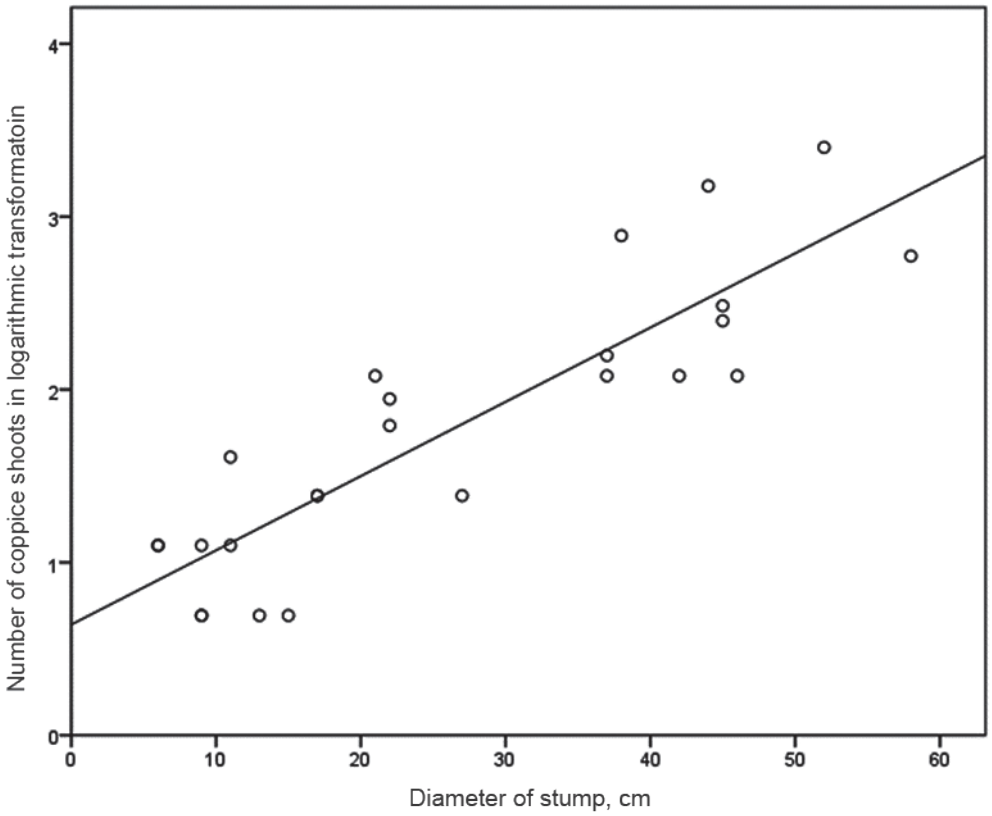

Fig. 7. Number of coppice shoots (transformed using ln-function) and stump diameter.

ring to the thresholds in literature (Hamm 1896, 1900; Vanselow 1941; Schaeffer and Schaeffer 1951; Köstler 1955; Mayer 1977; Grütz 1986) the coppiced stands in W can be defined as poor in terms of volume, whereas in I, the traditionally coppiced stands were normal or even rich in volume. A high volume can lead to a loss of CWS structure. This seems to be the general problem nowadays in CWS and not only in the stands in the current study (Hochbichler 2008, Beinhofer et al. 2009). Additionally, a large percentage of beech was found on the I site in the overstory – in the CWS up to 22 trees·ha^{-1}. Normally, beech is not considered to be a suitable or desired tree species in a classical CWS, and was therefore selected against through management techniques in the past (Fischer 2003, Küster 2008). The findings of different beech shares correspond to the management system that is carried out in the study area.

The control stands produced a volume increment of up to 10.3 m^3 per year. This is more than reported by Jüttner (1955) for first yield class for oak high forests. In coppiced stands, the increment of the main overstory stand was lower, of course, due to a smaller overstory component, although the total increment including all trees also being smaller than DBH 7 cm, is thought to be the same as in control plots (Burschel and Huss 2003, Hoch-

bichler 2008). The reduced increment for the overstory found in this study was similar to the findings of Crockford and Savill (1991), Hochbichler (2008) and Beinhofer et al. (2009).

The correlation between increment and basal area per hectare showed also that the coppiced stands on site I were more similar to a high forest than to a classical CWS (Borchert and Reitenspieß 2009, Beinhofer et al. 2009, this study). Due to the high number of beech trees in the control stands, the process of transformation into a high forest and one that could be referred to as a 'close to nature forest' in terms of species can be said to have begun.

Characteristics of the maidens in the CWS

The DBH increment of maidens in this study was observed to be up to 1 cm per year. This is a quite high value compared to that generally found for oaks in high forests that have been thinned heavily to promote DBH growth. The literature reports results for oaks in the pole stage ranging from 2 mm to 4.5 mm under heavy thinning regimes (Mosandl et al. 1991, Spiecker 1991, Hochbichler 1993, Kerr 1996, El Kateb et al. 2006, Nagel 2007, Dong et al. 2007, Abt 2018). Results from the CWS showed comparable increments in DBH on the upper threshold of high forest oaks, ranging 2.5 mm to 3.5 mm (Krissl and Müller 1989, Beinhofer et al. 2009). Hein (2009) as well as Wilhelm and Rieger (2013) however, stated that oaks are able to grow even faster than in the study at hand, and to achieve up to 8 mm year-rings. Next to the diameter and the volume, the branch-free bole length is the main criteria in assessing the quality of oak logs (Schulz 1961, Lüpke 1998). One of the research questions addressed by this study was whether it is possible to improve the timber quality of maidens in a CWS stand by pruning. Pruning of oaks is common practice in many European countries in both CWS (Hamm 1900, Vlad 1940, Köstler 1955, Vollmuth 2021) and in high forests (Zieren 1970, Holten 1986, Hochbichler et al. 1990, Hochbichler 1993, Jensen and Skovsgaard 2009, Kerr 1996, Lemaire 2010, Attocchi 2013, Wilhelm and Rieger 2013). However, in this study pruning failed to produce better timber quality, due to the intense occurrence of epicormic branches afterwards. Every single tree formed epicormic shoots after pruning in 2007, and the branch-free bole length was actually reduced notably by the time the trees were re-measured in 2013 compared to the status right after pruning. Attocchi (2013) reports similar results for pedunculate oak in high forests – pruning led to an increase in the total production of epicormic shoots. Hubert and Courrad (2002) reported critical values for slenderness that were thought to foster the growth of epicormics – for *Q. petraea*, these were thought to be higher than 50, and for *Q. robur* higher than 45. This relationship was not found in this study, with epicormic branch occurrence showing no relationship with slenderness value. Attocchi (2013) and Zieren (1970) observed increased production of epicormic shoots after pruning in pedunculate oak. In contrast, Hochbichler et al. (1990) recommended pruning of oak up to 6 m, and reported only minor problems in the occurrence of epicormics. Kerr and Harmer (2001) reported that a pruning regime for oaks had no statistically significant effect on the production of new epicormic shoots. The production of epicormic shoots is thought to occur for several reasons, and as yet has not been complete-

ly assessed. Genetic aspects (Harmer 1990, Spiecker 1991, Savill and Kanowski 1993, Jensen 2000, Colin et al. 2010), site index (Muchin 2005), social status (Fabricius 1932, Rohmeder 1935), inadequate light conditions (Fabricius 1932, Harmer 1990), high slenderness values (Hubert and Courrad 2002) stand density (Ward 1966, Dale and Sonderman 1984, Miller 1996, Fontaine et al. 2001, Colin et al. 2008, Morisset et al. 2012), species (Jensen 2000) or temperature on the bole (Wignal and Browning 1988) are all reasons that have been given for the occurrence of epicormic branches. It is probable that a combination of these factors with certain anatomical aspects (Fontaine et al. 1998, Morisset et al. 2012) control the occurrence of epicormics. Nevertheless, in 2013 re-pruning was carried out up to 5 m, both in order to reduce the number of epicormic shoots for better timber quality and to assess the impacts of such re-pruning. Losses in DBH increment were not detected for pruned trees compared to ones that were not pruned. Thus, the loss of epicormic branches did not seem to affect the metabolism of the pruned oaks. In summary it can be stated that high quality timber, at least in terms of dimension can be produced in a CWS in a short time if the high increment in DBH can be maintained. Today, the veneer industry accepts oak with up to 4 mm year-rings (Lüpke 1998). This is in contrast to former times when the limit was from 1 mm to 2 mm (Fleder 1981, Polge 1984, Lüpke 1998). The oaks in this study showed larger year-rings as those reported by Lüpke (1998), but in the end it can be expected that the dimension of the logs will be the most important factor influencing price (Schulz 1955, 1961; Göttlein 1994; Diwold 2008), and that the width of year rings might be less important, as long as it is consistent throughout the log. If in the future, epicormic branching can be prevented by re-pruning, then production of large-dimension branch-free timber in a short time frame seems to be a realistic and achievable target, as described by Beinhofer (2010).

Characteristics of the regeneration in the CWS

The amount of regeneration observed in this study was quite large. Johnson (1977) pointed on the high silvicultural importance of generative advance regeneration in CWS generally – thus in times of climate change a most important factor to maintain forests. Hamm (1900) reported 100,000 young plants per ha as a maximum to be expected for a CWS. Pyttel (2012) refer to 56,000 young plants per ha after coppicing in a coppice of oaks in Rhineland-Palatine, Dworschak (1996) reported 15.000 plants·ha^{-1} 7 years after cutting, whereas the most commonly occurring trees were of inferior species (*Sorbus aucuparia, Betula* sp.*, Populus* sp.) with low timber value. Tiefenbacher (1996) pointed out the importance of regeneration of Noble Hardwoods in CWS in times of oak decline. Such a decline has already been detected in recent times in the region where the experiment is located (Wolf and Petercord 2012). Brand (1997) reported that planted hornbeam was suppressed by Noble Hardwoods following coppicing in a CWS in Lower Saxony; he found about 20.000 young plants per ha after coppicing. In our study, more than 220.000 young plants per ha were found. Most of these young trees were of generative origin, and thus, the fraction of coppice shoots was never more than 23 %. Brand (1997) found a fraction of 40 % of coppice shoots in his investiga-

tion in Lower Saxony. Hochbichler (2008) reported a share of coppice shoots ranging from 8 % to more than 40 % in a CWS in Austria. Hence, the portion of coppice shoots in the study at hand (0.8–22.8 %) was quite low compared to that reported in the literature. For the further growth dynamic of the coppice shoots the distinction between adventitious and dormant (preventive) buds is of importance, but was not analyzed so far in the study at hand. A regression analysis showed that the number of coppice shoots was higher for oak stumps as the stump diameter increased (Albrecht and Abt 2014). This finding was opposite to findings from other studies on *Quercus alba* L. (Johnson 1977, Weigel and Peng 2002, Gould et al. 2007, Sands and Abrams 2009). Due to the fact that *Quercus alba*, *Q. petraea* and *Q. robur* are all closely related in the subgenus *Leucobalanus* (Nixon 1993, Schütt et al. 2002), a comparison in this subgenus seemed to be more valid than a comparison with other oak subgenera, sections and species, such as *Quercus rubra* L. Hartig (1861), Grütz (1986) and Müller (1986) all concluded that the older a European oak stump is, the lower the probability that it will re-sprout after coppicing. Indirectly, this could be linked to the diameter of the stump. In contrast, Pyttel (2012) reported for a CWS in Rhineland-Palatine that there was no correlation between the rate of sprouting of an oak stump and the corresponding DBH. The reasons for these divergent findings could be an objective of further investigations.

The fraction of oak was never less than 42 % and in some cases was up to 95 % of the regeneration. The combination of a high percentage of generative regeneration and a high share of oak can be seen as a very good start to the rejuvenation of the stands, as well as the maintenance of oak-dominated forests in the future. However, as oak was found here to have a mean height lower than the other species present, especially the shade-tolerant ones like beech and hornbeam, tending seems to be necessary in order to promote oak and avoid beech dominance in these stands in the future (Fleder 1981, 1988; Mosandl et al. 1991; Küster 2000; Collet et al. 2008). Pott (1981) and Fischer (2003) both pointed to the fact that a reduction in or abandonment of coppicing leads to the re-establishment of the naturally occurring beech-forest structures and a rising faction of beech in European forests. The height increment of regeneration was dependent on canopy cover of the stands, as proven by a regression analysis presented above. The greater the percentage of canopy cover was detected the lower the height increment of regeneration was observed. This phenomenon is well-known and caused by shading or less resource availability (Bolte and Roloff 1993; Ammer 1996, 2000, 2003; Gemmel et al. 1996; Collet et al. 1997, 2001; Finzi and Canham 2000; Löf 2000; Hees and Clerkx 2003), but was not reported for CWS before.

To conclude, it can be stated that if the fraction of oak should be maintained, in some cases the canopy should be opened more and in some cases tending will be unavoidable. This way mixed stands that consist of a lot of generatively regenerated individuals of a wide variety of species could be formed.

These mixed stands consisting of Noble Hardwoods and oak could clearly be an advantage in a future forest which is expected to be greatly affected by climate change.

Conclusions and Recommendations

CWS is a silvicultural system that has a high potential for fulfilling a broad spectrum of societal needs from forest in the future. In addition to meeting the public´s demands for both biodiversity protection and recreation, fuel wood as well highly valuable timber could be produced – and forests can be maintained despite challenges caused by climate change. In the end, one prerequisite for the production of high quality timber from CWS is the suppression of epicormic sprouts in maidens. It could be reasonable to change the classical coppicing system by maintaining secondary species (especially shrubs like blackthorn or hawthorn) in a small radius around maidens and other overstory trees to improve their quality by shading the trunks. Hence, the need for pruning could be reduced and the production of epicormic shoots could be hindered, or at least reduced following heavy crown thinnings. To do pruning merely is risky due to the tendency to result in an increase in epicormic shoots and cannot be recommended based on the results of this study. Heavy crown thinnings are common today in broadleaf forest management. This practice is thought to have been derived from and inspired by CWS practices (Wilhelm et al. 1999, Wilhelm and Rieger 2013), as these kinds of thinnings lead to structures in high forests that are very like those present in CWS. Therefore, the results found in this study can serve as a silvicultural feedback both, high forest and CWS.

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Appendix 1

Regression model for stand height curves:
Height [m] = b_0 + b_1 · ln DBH [cm]

Group	*N*	R^2	b_0	SD	b_1	SD	ß	*p*-value for b_1
WC	201	0.60	-3,84	1.20	6.80	0.39	0.77	<0.000
WT	39	0.82	-10.32	1.97	7.93	0,54	0.90	<0.000
WM	52	0.84	-4.73	1.18	6.24	0.37	0.92	<0.000
IC	105	0.81	-10.27	1.32	8.66	0.40	0.90	<0.000
IT	129	0.81	-8.23	1.03	7.89	0.33	0.90	<0.000
IM	92	0.79	-11.91	1.43	8.96	0.47	0.89	<0.000

Note: Abbreviations in all 4 appendixes: Group codes the experimental stands, *N* indicates the quantity, R^2 is the coefficient of determination in the regression model, SD is standard deviation, and ß is the coefficient of the regression model.

Appendix 2

Regression model for crown projection area of Oaks:
Crown projection area [m²] = b_0 + b_1 · DBH [cm]

Group	*N*	R^2	b_0	SD	b_1	SD	ß	*p*-value for b_1
WC	30	0.57	-10.58	7.05	1.40	0.22	0.75	<0.000
WT	29	0.61	-33.12	9.76	1.75	0.27	0.78	<0.000
WM	30	0.78	-8.26	3.50	1.17	0.11	0.88	<0.000
IC	30	0.56	-1.32	7.24	1.33	0.22	0.75	<0.000
IT	30	0.68	-6.36	4.55	1.27	0.16	0.82	<0.000
IM	29	0.55	-11.18	7.33	1.45	0.25	0.74	<0.000

Appendix 3

Regression model for canopy cover and height of regeneration:
Mean height of regeneration [cm] = b_0 + b_1 · canopy cover [%]

N	R^2	b_0	SD	b_1	SD	ß	*p*-value for b_1
12	0.39	112.92	15.03	-0.62	0.24	-0.62	<0.05

Appendix 4

Regression model for stump diameter and number of coppice shoots:
ln number of coppice shoots [ln N] = b_0 + b_1 · stump diameter [cm]

N	R^2	b_0	SD	b_1	SD	ß	*p*-value for b_1
25	0.77	0.64	0.15	0.04	0.00	0.87	<0.000

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INSECTICIDAL ASPECT TO *DIPRION PINI* L. (HYMENOPTERA; DIPRIONIDAE) AND *APIS MELLIFERA* L. (HYMENOPTERA; APIDAE)

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Abstract

The substance 1,3-Diazaspiro[4.4]nonane-2,4-dithione was tested in laboratory conditions for insecticidal activity against *Diprion pini* L. (Hymenoptera; Diprionidae) and *Apis mellifera* L. (Hymenoptera; Apidae). High mortality of 93.1 % was found against the larvae of *D. pini* with a concentration 0.01 %. The lifespan of the bees consumed food containing 0.01 % of the tested substance was up to 8 hour, with an average of 3.6 hour. The highest mortality was reported up to the 3rd hour, while the highest value was established at the 2nd hour. The bees fed on clean food lived up to 168 hour, an average of 120 hour. The highest mortality was reported at the 120th hour.

Key words: honey bee, insecticidal effect, sawfly, spirohydantoin.

Introduction

Pesticides are chemicals used against weeds, insects and pathogens. Over 75 % of them are applied in agriculture for plant protection. After more than six decades of use, their side effects onto ecosystems are visible (Sánchez-Bayo 2011). The use of pesticides is associated with a risk of environmental pollution and adverse effects on non-target organisms (Tilman et al. 2011). It is estimated that only 0.1 % of the pesticides used affect target organisms, while the remaining 99 % affect the environment (Pimentel 1995). In Persia, it was found that the extract from chrysanthemum flowers had insecticidal activities against crop pests (Gabriel and Mark 1996). During recent years, spirohydantoin compounds have found application as pesticides in agriculture (Marinov et al. 2012). Hydantoins are organic compounds with wide application, most significantly in the area of medicine (Sarges et al. 1988).

The purpose of this study is to establish the potential insecticidal effect of 1,3-Diazaspiro[4.4]nonane-2,4-dithione, a substance of the spirohydantoin group, on sawfly *Diprion pini* L. and *Apis mellifera* L. as a non-target organism.

Materials and Methods

An *in vitro* study was done in laboratory conditions in 2015 of the insecticidal activity of a substance from spirohydantoin group with respect to *D. pini*. The substance was tested in five concentrations

ranging from 0.001 % to 0.01 %, in order to determine the highest efficacy. Each concentration was tested on 10 larvae placed on filter paper in 100×20 mm Petri dishes. Each test variant was repeated three times. The larvae of each test variant were sprayed with the respective solution of the substance. Petri dishes were covered and left at room temperature of 20–21 °C. Mortality was taken at the 24th, 48th and 72nd hour after treatment. The efficacy of the substance was calculated using Abbott's formula (Abbott 1925):

$$E(\%) = \frac{(T - t) \cdot 100}{T},$$

where: T is mean number of alive larvae on control, t is mean number of alive larvae on each treatment.

The concentration with highest efficacy was tested against *A. mellifera*. In two groups of five wooden cages (10×10×10 cm) 20 newly hatched bees were placed and fed on 50 % sugar syrup. To both groups, in quantity of 20 mL sugar syrup 2 g of *Helianthus annuus* L. pollen with protein content of 14.83 % (Radev 2021) was added. The food was delivered to the cages through a 2 mL pipette. Tested substance was added to the food of the first group at a concentration of 0.01 %, while the bees from second group consumed just pure food. The syrup was renewed daily. The cages were covered and left at room temperature of 20–21 °C. During the first day, the bees were monitored an hour, later every 24 hour subsequently.

The results were statistically processed by Excel and Anova.

Results and Discussion

The laboratory results show an insecticidal effect on the larvae of *D. pini*. According to Abbott's formula (Abbott 1925) and the obtained data, the dose-response curve displays the insecticidal activity at the highest concentration. No insecticidal effect is found at concentration of 0.001 %, and at 0.003 % and 0.005 % the efficacy is low. Good toxicity is measured at concentration 0.008 %, while the highest efficacy of 93.1 % is measured at concentration 0.01 % of the tested agent ($F > F_{crit}$, Anova: Single factor) (Fig. 1).

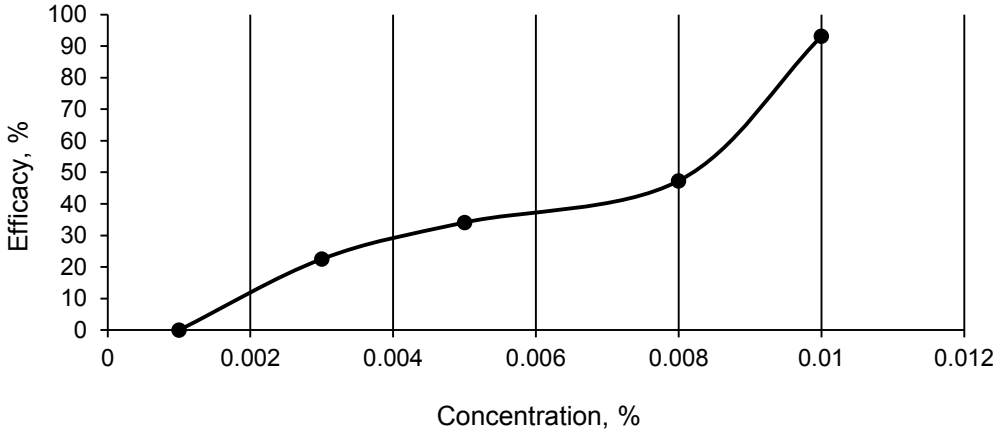

Fig. 1. Insecticidal efficacy of 1,3-Diazaspiro[4.4]nonane–2,4–dithione against larvae of *D. pini*.

Due to the limitation of conventional means for plant protection, it is necessary to investigate and create alternative means for control of plant pests. These means must be selective to the beneficial entomofauna and toxic to the highest degree to the harmful. In this connection, the tested substance is applied for testing at concentration 0.01 % with representatives of *A. mellifera* in order to determine the insecticidal effect.

The results show a lifespan of worker bees of up to 8 h, with an average of 3.6 h. The highest mortality was reported up to the 3rd hour, while the highest value was at the 2nd hour (means ±SD 7.8 ±1.9) Fig. 2). The bees fed on clean food lived up to 168 h, an average of 120 h. The highest mortality was measured at the 120th hour (means ±SD 6.2 ±1.6) (Fig. 3).

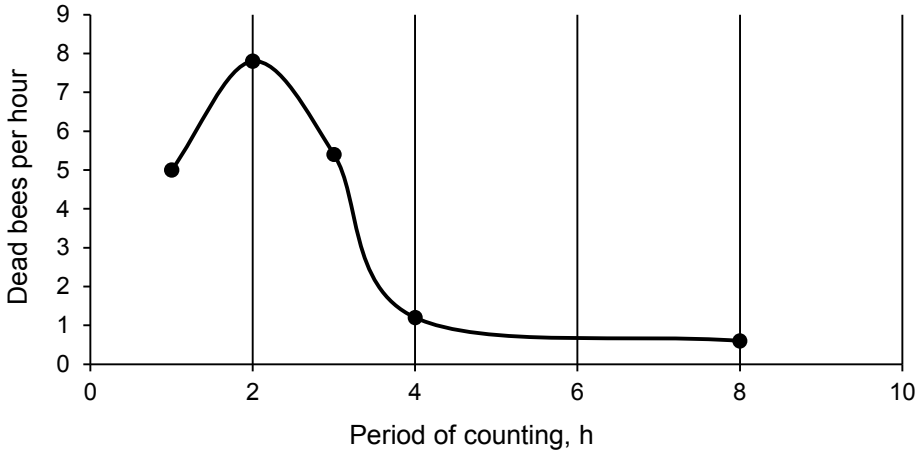

Fig. 2. Insecticidal impact of 0.01 % 1,3–Diazaspiro[4.4]nonane–2,4–dithione to *A. mellifera*.

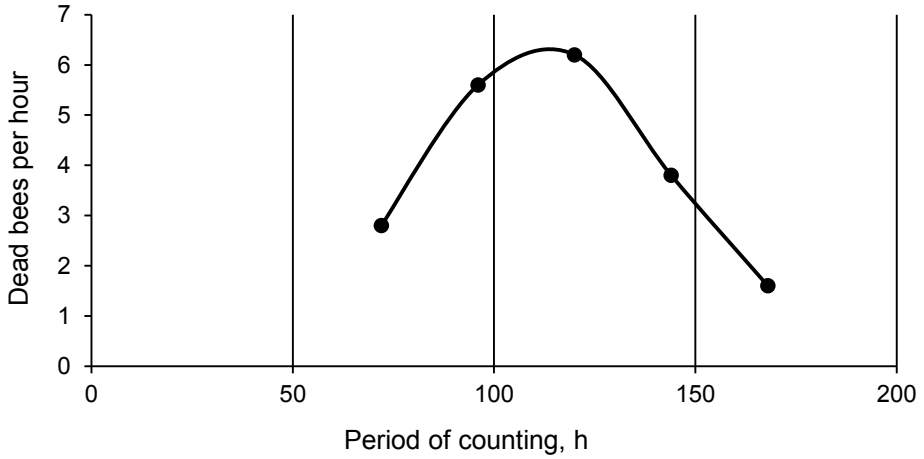

Fig. 3. Lifespan of *A. mellifera* fed on pure food.

These results show difference in the effect of the substance tested on the lifespan of worker bees ($F > F_{crit}$, Anova: Single factor). The data obtained confirm the findings established by Radev (2020). Numerous studies have found toxicity of many groups of pesticides to honey bees (Smarta and Stevensona 1982, Blacquière et al. 2012). Experimental outdoor work with bee colonies is mandatory and the results to be obtained may vary from the laboratory ones.

Conclusions

High mortality of 93.1 % was found against the larvae of *D. pini* with concentration 0.01 % of the tested agent as well as much lower lifespan of the bees which consumed it.

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STUDY ON TOXIC TOLERANCE OF BENEFICIAL ENTOMOFAUNA (*APIS MELLIFERA* L.) THROUGH USAGE OF POLLEN FROM A FORESTRY AREA

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Abstract

Toxic tolerance study of 1,3-Diazaspiro[4.4]nonane-2,4-dithione of *Apis mellifera* L. was performed in a laboratory using pollen with different protein content. There is higher toxic tolerance when bees consumed pollen with higher protein content. The lifespan of bees after application of the substance varies from 6 h for those which consumed pollen from *Chondrilla juncea* L. with 12.3 % protein content to 36 h for those which consumed pollen from *Cornus sanguinea* L. with 27.7 % protein content. When bees consumed pollen with a protein content of more than 21 %, lived longer. It seems that bees which consumed pollen with a protein content of 14.2 % had a lower toxic tolerance.

Keywords: honey bee, bee-pollen, lifespan.

Introduction

Modern agricultural practices have an impact on biodiversity, and must be assessed in order to protect wildlife and increase agriculture production (Norris 2008). Agroecosystems must play a main role in conserving biodiversity (Fischer et al. 2006). In the last 60 years, the use of pesticides increased in agriculture (Tilman et al. 2001). Use of pesticides leads to direct and indirect effects on the environment (Woodcock et al. 2016). The amount and balance of macro- and micronutrients and secondary metabolites in the diet of insects affects their condition (Simpson and Raubenheimer 2012). There is a connection between insect's sensitivity to toxins and the protein:carbohydrate ratio (Deans et al. 2017). Secondary metabolites may increase insect resistance to various pesticides (Johnson et al. 2012). This is extremely important for *Apis mellifera* L., the main pollinator on the Earth (Hung et al. 2018).

The aim of this study was to investigate toxic tolerance of beneficial entomofauna (*Apis mellifera* L.) depending on protein content of consumed pollen.

Materials and Methods

A laboratory experiment was performed in 2015. Pollen with established botanical origin and protein content were used: *Chondrilla juncea* L. pollen with protein content of 12.3 %, *Cichorium intybus* L. – 14.2 %, *Cornus mas* L. – 21.7 %, *Pyrus malus* Borkh. – 26.1 % and *Cornus sanguinea*

L. – 27.7 % collected from forestry area Borushtitsa (42°73′38" N and 25°57′29" E) (Radev 2021). As a toxic agent for bees 1,3-Diazaspiro[4.4]nonane-2,4-dithione was used in a concentration of 0.01 %.

Five experimental groups were used, every group consisted of three wooden cages 10×10×10 cm. Twenty newly hatched bees were placed in every cage and fed on 50 % sugar syrup for three days. On the fourth day tested substance was added to the food of all five groups in a concentration of 0.01 %. Every group also received 20 mL sugar syrup containing 2 g of pollen: 1st group received from *C. juncea*, 2nd group from *C. intybus,* 3rd group from *C. mas,* 4th group from *P. malus* and 5th group from *C. sanguinea*. The food was delivered to the cages through 2 mL pipette. The syrup was renewed daily. The cages were covered and left at room temperature of 20–21 °C. During the first 3 days, the bees were monitored once a day when changing the syrup, on the 4th day every hour and on the 5th day every 3 hours.

The results were statistically processed by Excel and Anova and method of low significant difference (LSD) at $p \leq 0.05$.

Results and Discussion

The results show higher toxic tolerance of *A. mellifera* to the applied substance when consumed pollen with higher protein content. The lifespan of bees fed on the substance varies from 6 h for those which consumed *C. juncea* pollen with 12.3 % protein content to 36 h for those which consumed *C. sanguinea* pollen with 27.7 % protein content (Table 1).

Table 1. Lifespan of bees fed on 1,3-Diazaspiro[4.4]nonane–2,4–dithione 0.01 % and pollen with different protein content, %.

Period of counting live bees	Group I, survived bees	Group II, survived bees	Group III, survived bees	Group IV, survived bees	Group V, survived bees
Till 1st h	73.0	76.5	100.0	100.0	100.0
Till 2nd h	41.5	56.5	100.0	100.0	100.0
Till 3rd h	21.5	36.5	100.0	100.0	100.0
Till 4th h	2.3	16.5	100.0	100.0	100.0
Till 5th h	11.5	11.5	100.0	100.0	100.0
Till 6th h	0.0	8.5	100.0	100.0	100.0
Till 8th h	NF	0.0	96.5	100.0	100.0
Till 10th h	NF	NF	76.5	81.5	96.5
Till 14th h	NF	NF	55.0	12.6	88.0
Till 18th h	NF	NF	21.5	63.0	71.5
Till 24th h	NF	NF	5.0	30.0	45.0
Till 27th h	NF	NF	0.0	23.0	23.0
Till 30th h	NF	NF	NF	8.0	15.0
Till 33th h	NF	NF	NF	0.0	11.5
Till 36th h	NF	NF	NF	NF	0.0
$LSD_{p \leq 0.05}$	0.65	0.65	0.69	0.69	0.69

Note: NF – not found.

As protein content in pollen increased lifespan of bees also increased. When bees consuming pollen with protein content more than 21 %, lived longer. It seems that bees which consumed pollen with protein content up to 14.2 % have low toxic tolerance. In groups I and II the highest mortality was reported by the 3rd h and in groups III, IV and V a gradual loss of bees was observed, starting after 6th h. There is no difference between groups I and II ($F \leq F_{crit,}$ Anova: Single factor), as well as between groups III, IV and V ($F \leq F_{crit,}$ Anova: Single factor). A difference was found when comparing groups I and II with groups III, IV and V ($F > F_{crit,}$ Anova: Single factor). According to the obtained results, it is necessary to conduct field experiments work with bee hives, as the results may be different from the laboratory.

In the present study, the effect of protein content in the pollen on pesticide toxicity was considered, taking into account its positive effect. Wahl and Ulm (1983) first mentioned that pollen increases the tolerance of honey bees to pesticides. Consumption of pollen reduces the susceptibility of bees to chlorpyrifos compared to bees fed without pollen (Schmehl et al. 2014). Carrying out research work in this direction is imperative, having in mind bee colonies losses worldwide. Barascou et al. (2021) found a reduction in pesticide toxicity in honey bees depending on different pollen. Honey bees have been exposed to a number of stressors in recent years, including pesticides (Goulson et al. 2015).

Conclusions

The protein-rich pollen feeding could somewhat increase the toxic tolerance in bees. As protein content in pollen increased lifespan of bees also increased.

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FEATURES OF FOREST COMMUNITIES AND SOILS FORMED ON AN ASH DUMP OF THE MIDDLE URALS

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Abstract

Forest communities formed on a part of ash dumps during their existence can be taken into account when assessing forest lands. The aim of this study is to identify the features of forest communities and soils formed on a fly ash dump located in southern taiga. The structure of forest communities and physico-chemical characteristics of soils formed during spontaneous overgrowth of an ash dump of Sredneuralskaya Thermal Power Plant (TPP) were studied. Mixed forest phytocoenoses with a predominance of *Populus tremula* L. and *Betula pendula* Roth aged 45–50 years age have formed on the non recultivated area of the ash dump. They are close in composition to the zonal secondary forests, have less species richness and similar reserves of living aboveground phytomass. The soils formed on the ash dump have horizons with low thickness, in which pH has shifted towards the neutral, and organic matter and basic nutrients have accumulated. Technosol humus horizons in terms of the main biogenic element content (C, N, Ca, Mg, K, P) are close to that of the background soil or even contain them in larger quantities. The formation of forest communities and soils on the ash dump is proceeding according to the zonal type. Studying forest phytocoenosis forming on the ashes with different properties and a varied combination of natural conditions will make it possible to establish patterns in the formation of forest communities on technogenic substrates and influence their speed.

Key words: *Betula pendula* Roth, fly ash, natural colonization, *Populus tremula* L., southern taiga, Technosols.

Introduction

Intensive industrial development has led to accumulation of various wastes, which, for example, ash from power plants, occupy large areas in many countries (Gajic et al 2019, Khokhlov and Melnikov 2019, Marinina et al. 2021). On some ash dumps several decades old (subjected to recultivation or left for natural colonisation), forest communities were formed, the state of which must be taken into account in the overall assessment of forest lands, including in accordance with the challenges of the time in terms of carbon sequestration.

Due to the fact that the features of plant communities formed on technogenic substrate are influenced by the physico-chem-

ical features of a particular object and the climate of ash dump location (Jusaitis and Pillman 1997, Makhnev et al. 2002, Pandey and Bajpai 2016), available data on them are diverse. Since the properties of ash depend on the characteristics of the burnt coal, technological factors, as well as the natural and climatic conditions of its storage (Pasynkova 1974, Maiti 2013, Shaheen et al. 2014), information on forest communities formed on the surface of ash dumps with different properties and varied combination of natural conditions is of high scientific and practical importance.

During the formation of forest communities on ash dumps, the properties of technogenic substrate are changed by the processes of soil formation. A number of publications are devoted to issues touching the characteristics of individual tree species and young soils of ash dumps where they grow (Kostic et al. 2012; Mitrovic et al. 2012; Uzarowicz et al. 2017, 2018a,b; Pietrzykowski et al. 2018). At the same time, only planted woody species and soils formed on the recultivated ash dump surface are studied, which certainly affects the speed and, possibly, the direction of community and soil formation, while forest communities and soils formed on a technogenic substrate without human assistance are rarely investigated (Nekrasova et al. 2020). Not enough attention is paid to comprehensive studies of forest phytocoenoses and soils formed under their influence on ash substrate, mutually dependent on each other. Forest communities of ash dumps in the southern taiga of the Middle Urals have been also actively studied in relation to the characteristics of individual plant species (Filimonova et al. 2017, Kalashnikova et al. 2021, Maleva et al. 2021), while the system 'forest community – young soil' in which a biological (small) cycle occurs remains poorly understood.

The purpose of this study is to identify the features of forest communities and soils formed during 50 years on non recultivated fly ash derived from Ekibastuz brown coal in southern taiga conditions.

Materials and Methods

The work was done on an ash dump after Ekibastuz brown coal burning by Srednеuralskaya Thermal Power Plant (SUTPP) in Sverdlovsk region in the Middle Urals (57°00' N and 60°28' E). The ash dump is located on the eastern shore of Lake Isetskoe. The relief of the area is hilly: the prevailing heights vary from 250 to 300 m a.s.l. The territory under study is located in the Middle Urals southern taiga, its climate is moderately cold (the average annual temperature is 2.2 °C, the sum of the temperatures more than 10 °C is equal to 1600 °C), and over-humidified (the annual precipitation is near 600 mm, the hydrothermal coefficient is about 1.5) (National atlas … 2008, CLIMATE-DATA.ORG 2021). Indigenous vegetation is represented by southern taiga pine forests, pine-spruce forests as well as by secondary birch and mixed birch-pine forests (Shakirov 2011).

The fly ash dump occupies 1.04 km^2. Part of it was left for natural revegetation after the end of dumping in 1968.

The objects of our investigation carried in 2019 were forest communities formed on non recultivated part of Srednеuralskaya TPP ash dump in the process of natural colonisation. Complex geobotanical and soil studies were carried out on three identified typical forest sites. Two undisturbed background forest sites were used as control.

The area of geobotanical description

was 250–300 m^2 in each site. Species composition, crown density, as well as height and trunk diameter (at 1.3 m) were taken into account during describing the tree layer. Beside, all individuals of each species were counted and young growth and self-sown ones were recorded. The projective cover, height and composition of shrub layer, herb-shrub layer, and moss-lichen cover were determined.

Fifty of Raunkier's plots (S = 0.25 m^2) were laid at each site to characterise the herb-shrub layer. Floristic lists with an assessment of each species abundance were made using Drude scale, the dominant species were identified based on the assessment of projective cover and phytomass stocks (Lavrenko et al. 1964).

Soil sections and their morphological descriptions were done in each site of ash dump and control areas. Sampling was done every 5–10 cm, taking into account the horizon boundaries. pH was determined in a supernatant of soil and water in a ratio of 1:2.5 (ANION 4100, Russia), particle size distribution – by the pipette method (Kachinsky 1958), total organic carbon (TOC) – by wet combustion in a mixture of potassium dichromate and sulphuric acid (Tjurin method), total N – by Kjeldahl method with termination on a spectrophotometer UNICO 2100 (United Product & Instruments, Dayton, NJ, USA). Available phosphorus (P_2O_5) was detected by ammonium molybdate method using UV spectrophotometer (UV-probe 1650), available potassium (K_2O) – in the same extract by flame photometer PFA-378 (Russia), and exchangeable Ca^{2+} and Mg^{2+} – complexometrically, using Trilon B (Arinushkina 1970, Vorob'eva 2006).

Statistical processing was carried out using Mann-Whitney criterion (Quinn and Keough 2002).

Results

Characteristics of ash dump forest communities

In the forest sites of SUTPP ash dump flora species richness is represented by 55 species of vascular plants. The forest stand is dominated by *Populus tremula* L. and *Betula pendula* Roth., less often are *B. pubescens* Ehrh. and *Pinus sylvestris* L. The young growth is represented by the same species as the previous layer, their height is up to 2 m high. The shrub layer is formed by 11 species of shrubs 1.5–2 m high. It is sparse, with average projective crown coverage of 30–35 %. *Chamaecytisus ruthenicus* (Fisch.ex Woloszcz.) Klaskova*, Sorbus aucuparia* L., *Viburnum opulus* L., *Padus avium* Mill. predominate, *Caragana arborescens* Lam.*, Rosa acicularis* Lindl. and *Frangula alnus* Mill. predominate.

The herb-shrub layer in all studied forest sites on ash is sparse, the following herbaceous plants predominate: *Equisetum pratense* L., *Vicia sylvatica* L., *Lathyrus pratensis* L., *Agrostis tenuis* Sibth., *Festuca rubra* L. and *Fragaria vesca* L. Moss-lichen cover is poorly expressed. *Amblystegium serpens* (Hedw.) Bruch et al., *Ceratodon purpureus* (Hedw.) Brid., *Leskea polycarpa* Hedw., *Myrinia pulvinata* (Wahlenb.) Schimp, *Sciuro-hypnum starkei* (Brid.), Ignatov et Huttunen and *Sanionia uncinata* (Hedw.) Loeskem are found mainly on woody remains and tree trunks with a small coverage. *Brachythecium salebrosum* (F. Weber et D. Mohr) Bruch et al., *Climacium dendroides* (Hedw.) F. Weber et D. Mohr, *Leptobryum pyriforme* (Hedw.) Wilson, *Pleurozium schreberi* (Brid.) Mitt., *Pohlia nutans* (Hedw.) Lindb., *Pylaisia*

polyantha (Hedw.) Bruch et al. are common on the substrate; *Bryum violaceum* Crundw. et Nyholm is rare. A brief description of the sites is given in Table 1.

Table 1. Characteristics of plant communities.

Characteristic	SUTPP ash dump			Control	
	Site 1	Site 2	Site 3	Site 1	Site 2
Forest stand					
Crown density	0.50	0.55–0.60	0.4–0.45	0.55-0.65	0.40-0.60
Average height of trees, m	17.5	18.0	18.5	19.0	23.0
Average diameter, cm	16.3	16.5	17.7	25.0	30.0
Age, years	45–50	45–50	45–50	80–100	100
Young growth and self-sown tree species					
Young growth height, m	1.5	1.2	1.8	0.1–3.8	0.1–6.2
Total number per hectare	8400	10000	1600	2100	1360
Shrub layer					
Projective cover, %	35	15	35–40	20	25-30
Average height, m	1.8	1.2	1.5	0.6–3.5	0.8–4.2
Ground layer					
Herb–shrub layer cover, %	80–90	80–85	75–80	80–85	80–95
Herb–shrub layer height, cm	22–40	15–35	35–40	45–55	50–70
Moss–lichen layer cover, %	5	5	10	305	35
Number of species per 0.25 m^2, (min–max)	8.9 (6–15)	9.5 (7–15)	8.8 (6–13)	9.6 (4–19)	14.1 (6–19)
Floristic abundance on the accounting area	42	36	31	51	66

Characteristics of ash and ash dump soils

Young soils have been formed on SUTPP ash dump for 50 years under the forest communities with the following horizons: O – litter with a thickness of about 0.5 cm; A – 2.5 cm thickness, grew, weakly textured, crumbling-pulverescent; AC – 7 cm thickness brownish-grew, weakly textured, lamellate-pulverescent; and C – from the depth of 10 cm opened to a depth of 40 cm, a loose structureless ash substrate serving as a soil-forming rock. They can be classified as Technosols (World Reference … 2014).

Alumosilicates predominate in the bulk composition of SUTPP ash on which Technosols were formed, while the rest of the oxides account for only 8–11 % (Table 2). As the results show, in the smallest amounts, not exceeding 1 %, the ash contains oxides of calcium, magnesium, potassium, sodium and phosphorus.

Analysis of the particle size distribution in Technosols mineral part (Fig. 1) showed dominating >0.01 mm (62–83 %) mainly due to the silt 0.01–0.05 mm in most samples, the sand particles with the diameter 0.25–1.00 mm had the smallest values not exceeding 4 %. Clay particles (important as main source of plant nutrition) were found in low amounts (4–6 %) in C horizons, their value increased up to 8–10 % in AC horizon. The accumulation maximum of particles <0.001 mm in the profile was in A horizon (14–20 %).

Table 2. Bulk composition of SUTPP ash in % to air-dry sample.

Variants	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5
1	44.3	47.1	4.3	0.9	0.6	0.5	0.4	1.6	0.4
2	52.0	39.7	4.4	0.8	0.6	0.5	0.4	1.3	0.3
3	48.0	44.0	4.4	0.5	0.3	0.7	0.2	1.4	0.5
4	56.0	36.5	4.2	0.6	0.3	0.6	0.2	1.3	0.4
5	44.8	44.0	7.2	0.6	0.4	0.6	0.2	1.5	0.6
6	50.3	41.6	4.4	0.5	0.4	0.8	0.2	1.5	0.4
x	49.2	42.2	4.8	0.7	0.4	0.6	0.3	1.4	0.4
SD	4.5	3.7	1.2	0.2	0.1	0.1	0.1	0.1	0.1

Legend: x – average; SD – standard deviation.

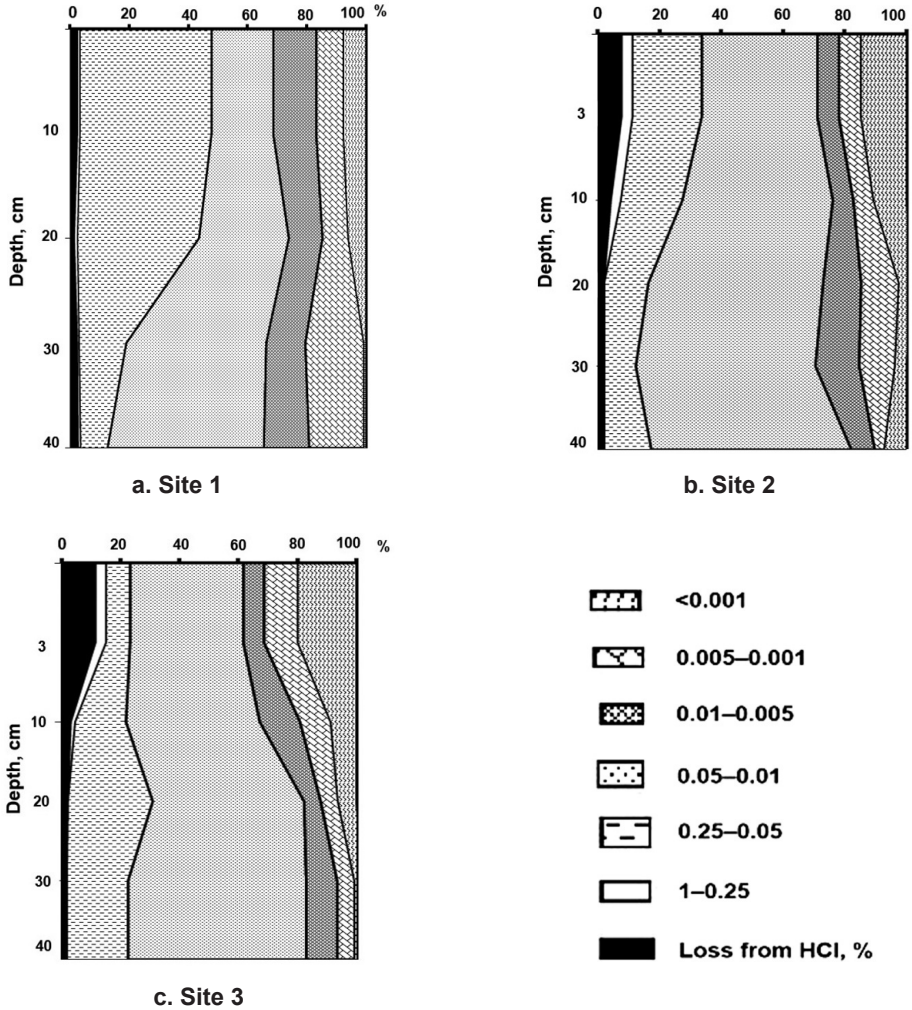

Fig. 1. Texture of Technosols.

The texture of the horizons of Technosols and ash substrate is mainly silt loam and silt in a few cases.

The ash substrate serving as a soil-forming rock (horizons C1, C2 and C3) (Table 3) had acidic reaction with pH values from 4.6 to 5.3, contained relatively high amounts of TOC – 2.0–3.9 % (that may be caused by unburned coal particles), traces amounts of total N (not exceeding 0.04 %), low amounts of absorbed calcium and magnesium cations (0.5–1.3 and 0.3–1.2 mmol·100g^{-1} respectively) as well as of mobile forms of potassium and phosphorus (0–3.9 and 1–5 mg·100g^{-1} respectively).

Table 3. Chemical properties of Technosols.

Horizon	Depth, cm	pH $_{H_2O}$	TOC	N	Ca^{2+}	Mg^{2+}	K_2O	P_2O_5
			%		mmol·100g^{-1}		mg·100g^{-1}	
Site 1								
O	0–0.5	6.40	28.55	1.13	25.0	20.0	33.1	9.9
A	0.5–3	6.70	9.57	0.47	17.5	6.3	18.0	4.6
AC	3–10	5.49	3.36	0.08	1.5	0.8	7.4	3.5
C1	10–20	5.29	2.14	0.03	0.8	0.7	3.9	1.0
C2	20–30	4.78	2.71	Traces	0.8	0.7	0.4	4.8
C3	30–40	5.05	2.31	Traces	1.3	1.2	0	4.1
Site 2								
O	0–0.5	6.56	34.61	1.10	40.0	25.0	33.3	11.7
A	0.5–3	6.70	6.50	0.30	14.3	4.8	18.0	6.1
AC	3–10	5.96	3.62	0.09	7.0	1.3	16.6	1.6
C1	10–20	5.37	2.03	0.03	1.2	0.3	2.4	3.2
C2	20–30	5.35	2.72	Traces	0.5	0.8	0.3	3.1
C3	30–40	5.54	3.93	Traces	0.8	1.0	0	4.8
Site 3								
O	0–0.5	6.55	34.33	1.18	50.0	15.0	31.7	9.5
A	0.5–3	5.93	19.44	0.71	24.5	14.0	34.2	10.5
AC	3–10	5.06	3.20	0.07	1.8	1.3	7.4	1.9
C1	10–20	5.40	2.70	0.04	0.7	1.0	1.6	3.3
C2	20–30	5.46	2.19	0.02	0.7	1.0	0.9	2.0
C3	30–40	5.58	3.72	0.04	0.7	1.0	2.2	3.4

In the formed horizons of Technosols, in comparison with the corresponding horizons C1 (Table 3, Fig. 2), there was an increase of the studied elements from AC towards O horizon (the differences are significant). The maximum accumulation of TOC (29–35 %), total N (1.1–1.2 %), absorbed Ca^{2+} (25–50 mmol·100g^{-1}) and Mg^{2+} (15–25 mmol·100g^{-1}), mobile forms of K (32–33 mg·100g^{-1}) and P (10–12 mg·100g^{-1}) was in the litter. In the same direction, there was an increase in pH values in profile in most cases, which may be a consequence of alkaline element accumulation by plants and correspondently by upper soil horizons.

Thus, young soils of ash disposal site during 50 years had accumulated significant amounts of biogenic elements in comparison with the ash substrate.

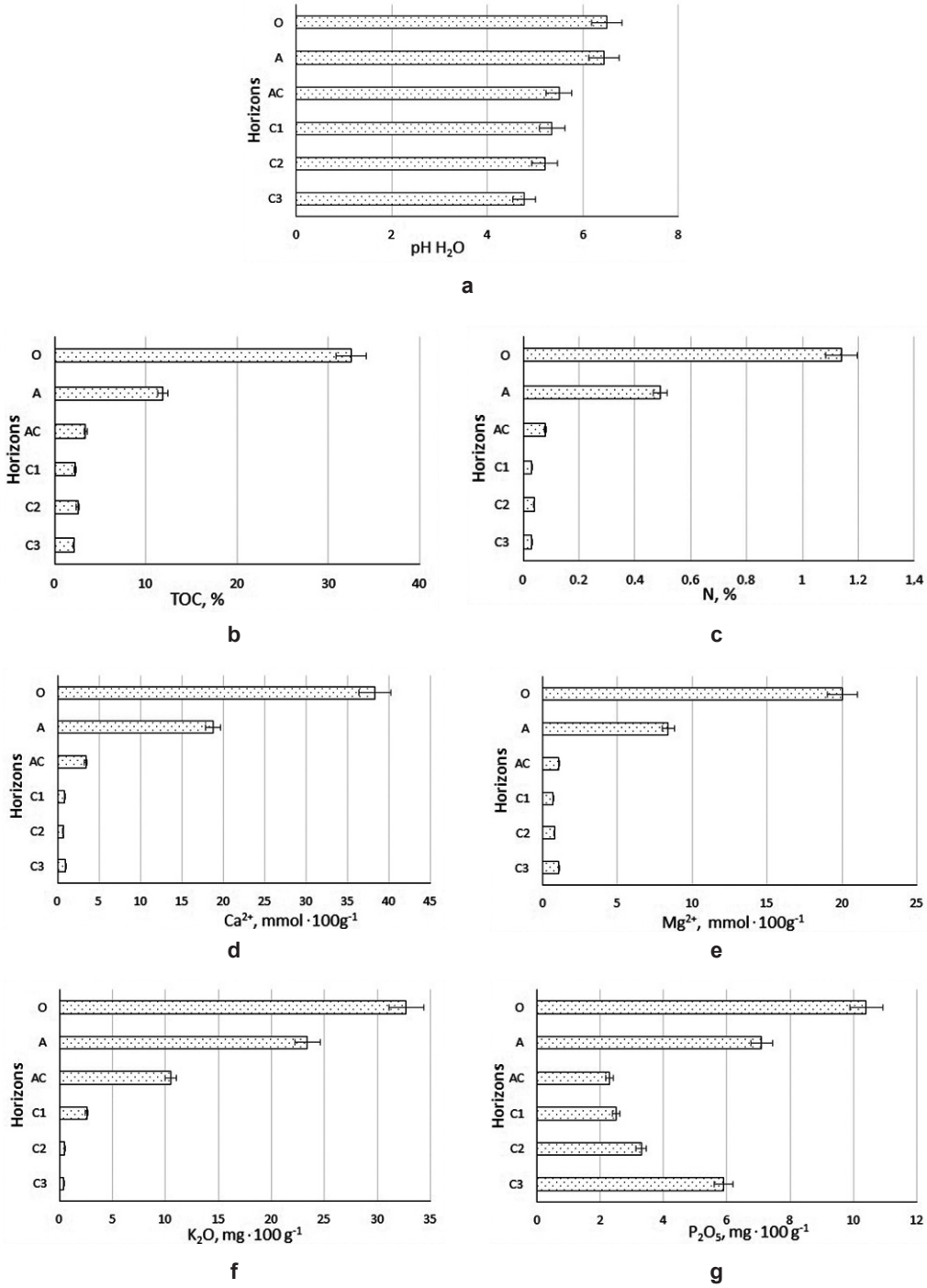

Fig. 2. Average Technosol characteristics and standard deviation.

Discussion

Features of ash dump forest communities in comparison with background ones

The forest communities formed on SUTPP ash dump have a similar species composition of the main forest-forming species, slightly differing in the share participation of individual species. All three sites are close floristically (Fig. 3). The forest communities of the ash dump differ little in crown density from the control forest, but are somewhat inferior in terms of the morphometric parameters of the stand (height and average diameter of trees). The shrub layer is poorly expressed in forest communities both on ash and in the control sites.

The cover of grass-shrub layer on ash dump sites is also close to the control sites, although the horizontal structure of communities on ash differs in the uneven nature of the distribution of individuals of some species (*Pyrola rotundifolia* L.*, Pyrola minor* L.*, Orthilia secunda* (L.) House*, Trifolium medium* L.). The phytomass reserve of living ground cover of herb-shrub layer of the forest communities of ash dump and background ones does not differ significantly (Table 4). If the maximum reserve on ash is 23.3 ±1.8 g per 0.25 m^{-2}, then in the control it is higher and equal to 27.4 ±1.4 $g \cdot m^{-2}$, though the differences are not significant.

As a result of geobotanical studies on SUTPP ash dump, it was found that in the process of spontaneous vegetation mixed forest phytocoenoses formed on

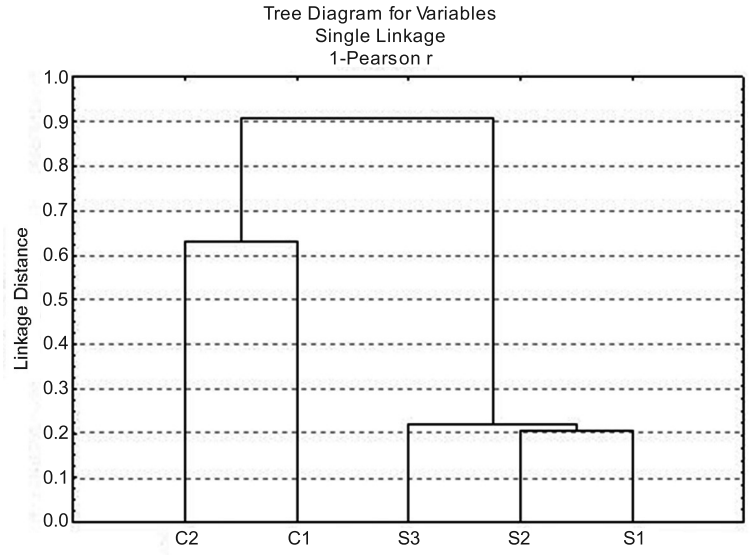

Fig. 3. Comparison of the species composition of SUTPP ash dump forest phytocoenoses with that of background.
Note: S1–S3 – ash dump sites; C1 and C2 – control sites.

Table 4. Stock of living aboveground phytomass of herb-shrub layer of forest phytocoenoses.

Indicators	SUTPP ash dump			Control	
	Site 1	Site 2	Site 3	Site 1	Site 2
Mass, g per 0.25 m^2	23.3 ±1.8	20.3 ±2.2	21.6 ±2.0	27.4 ±1.4	25.5 ±1.9
The limits of mass variation, g per 0.25 m^2	16.1–33.6	10.2–33.5	12.4–35.2	21.7–33.5	17.9–36.1

non recultivated fly ash for 40–50 years, which is similar in composition to zonal secondary forests with a predominance of broad-leaved tree species. In the ash communities in comparison with the background sites, there is lower species richness, while indicators of the stock of living aboveground phytomass are similar, which indicates a relatively high degree of lower layer formation. It was shown previously that the dominant species of trees (*Betula pendula* and *Populus tremula*) on SUTPP ash dump as well as that of control sites (*Betula pubescens* and *Betula pendula*) successfully formed mycorrhiza (Betekhtina et al. 2021).

Features of ash dump soils in comparison with background ones

Morphologically similar young soils have been formed in the upper thickness of SUTPP ash dump over 50 years with clear differentiation into litter, humus, AC and C horizons, though all horizons are of very low thickness.

An increase in the content of particles with diameter <0.001 mm in Technosols of all sites compared to the ash (Fig. 1) from which they are formed may be result of the destruction of larger size particles.

It should be noted that, as a rule, the substrate of ash dumps initially has an alkaline reaction (Pasinkova 1974, Uzarowicz et al. 2017, 2018a; Gajic et al. 2019), acidic pH values, as in SUTPP ash dump, are extremely rare. Alkalinisation in the topsoil of Technosols is probably associated with the consumption of calcium and potassium compounds by plant roots with further enrichment of the upper soil layers, which may contribute to an increase in pH values.

The storage of almost all considered elements have occurred in Technosols in comparison to the ash (Table 3 and Fig. 2). Organic carbon and nitrogen (the content of the last one was in trace amounts in ash substrate) were accumulated in Technosols during the forest community formation, while calcium and magnesium exchange cations together with potassium and phosphorus mobile forms were redistributed with the depth from the reserves in the ash.

The results obtained by us coincide with those for Technosols formed on ash after burning brown coal under cultivated woody plants in other natural and climatic conditions with respect to a decrease in pH and an increase in the content of C and N due to accumulation of organic matter (Uzarowicz et al. 2017, 2018a; Pietrzykowski et al. 2018).

Studied background soils were classified as soddy-podzolic soils (Egorov et al. 1977) or Retisols (World Reference … 2014) and characterised by the following genetic horizons O – A – E – B – BC – C.

The comparison of the limits of chemical characteristic variation of the corresponding upper horizons of Technosols and background soils (Table 5) showed the higher values of pH and the lower – of total nitrogen and exchangeable magnesium content in the litter of young soils (the differences are significant for pH and Mg^{2+}). The humus horizons of Technosols are close to control soils in the content of N, Ca^{2+} and Mg^{2+}. At the same time, they differ in the higher values of total organic carbon (most likely due to the presence of unburned particles in the ash) (Pasynkova 1974), mobile forms of potassium as well as phosphorus (the differences are significant for K_2O and P_2O_5).

Table 5. Limits of chemical characteristic variation in the upper horizons of Technosols and background soils.

Horizon	pH_{H_2O}	TOC	N	Ca^{2+}	Mg^{2+}	K_2O	P_2O_5
		%		mmol·100g^{-1}		mg·100g^{-1}	
Technosols							
O	6.40–6.56	28.55–34.61	1.10–1.18	25–50	15–25	32–33	10–12
A	5.93–6.70	6.50–19.44	0.30–0.71	14–25	5–14	18–34	5–11
Background soils							
O	5.73–6.02	22.10–33.00	1.18–1.36	23–33	30–45	29–57	4–12
A	5.15–6.51	5.83–9.35	0.42–0.89	10–23	8–14	6–13	0,2–0,9

Judging by the progressive development of forest communities on fly ash and thin topsoil litter (0.5 cm), it can be assumed that the biological cycle in the system 'forest community – young soil' proceeds with high intensity on SUTPP ash dump.

Conclusion

In the process of natural revegetation of SUTPP ash dump in the Middle Urals mixed forest phytocoenoses with a predominance of broad-leaved tree species was formed over 50 years, which are similar in composition to zonal secondary forests of southern taiga with a relatively high degree of lower layer formation.

The revealed features of the composition and structure of the ash dump communities make it possible to evaluate them as a stage of progressive succession with improvement of conditions due to biotic transformation of the habitat (derivatives of the zonal type forests).

Poorly differentiated soils have been formed on SUTPP fly ash dump in the southern taiga for half a century. Technosols in comparison with the parent ash content more clay particles, have more alkaline reaction of the medium and accumulated the essential nutrients (C, N, Ca, Mg, K, P). Their humus horizons contain the main biogenic elements in equal or larger quantities to that of background soils. The soil formation is proceeding according to the zonal type in the whole.

The accumulation of data characterising forest communities and soils formed on ash dumps with a specific chemical composition of ash located in various natural and climatic conditions will eventually allow us to predict the rate of formation of forest ecosystems on a technogenic substrate and to influence this process.

Acknowledgments

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DEMOGRAPHIC STRUCTURE AND MORPHOLOGICAL FEATURES OF *MALAXIS MONOPHYLLOS* (ORCHIDACEAE) POPULATIONS COLONIZING TECHNOGENIC SUBSTRATES

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Abstract

The study of the distribution, morphological and population characteristics of orchids and their responses to the technogenic and natural factors have a great importance for the development of measures for the protection of rare and endangered plant species. The preservation of rare species of the Orchidaceae family is of particular importance in the Urals, Russia, given the high level of industrialization in this area. One of these species is *Malaxis monophyllos* (L.) Sw., which is protected in many countries, including Russia. The aim of this research was to study the demographic structure and morphological features of *M. monophyllos* populations in the anthropogenically disturbed habitats, as well as in the natural forest community of the Middle Urals, Russia. It was shown that *M. monophyllos* settles in a sparse herbaceous layer of forest phytocoenoses dominated by early succession species, such as *Pinus sylvestris* L., *Populus tremula* L. and *Betula pendula* Roth. In anthropogenic habitats, *M. monophyllos* is able to form local populations with higher abundance and density than in the natural forest community with predominance of individuals in the generative state. It was revealed that *M. monophyllos* colonizing technogenic substrates corresponded to orchids from the natural forest community with respect to the most biometric parameters. At the same time, they were characterized by reduced fruit formation per plant (2.6 time on average), as well as the percentage of fruit set (2.7 times on average) compared with the plants from natural community, possibly due to unfavourable conditions of technogenic habitats, including putative *M. monophyllos* pollinators. Suitable humidity conditions and low competition in the man-made habitats favour the growth of *M. monophyllos*. However, the population persistence time in disturbed habitats will depend on the further succession processes and anthropogenic activities.

Key words: biometric parameters, industrial dumps, orchid, rare species, stages of development.

Introduction

The problem of species diversity preservation is of great importance. Industrial, economic and recreational human activity leads to significant changes in the vegetation cover of the Earth (Bolshakov and Chibrik 2007). The consequence of this process is the reduction in the natural ranges of rare species, which entails the decrease in their population numbers up to complete elimination. At the same time,

the changes human activity caused in the environment can lead to the creation of new secondary habitats that may be suitable for some rare plants (Nowak and Nowak 2006, Lundholm and Richardson 2010).

First of all, groups that need protection are plant species with a sporadic distribution, represented by small populations, confined to certain specific ecological niches with a long renewal cycle and low competitiveness in phytocoenosis (Vakhrameeva et al. 2014). Many of these traits are inherent in representatives of the Orchidaceae family (Mamaev et al. 2004). The orchid diversity of Russia includes 135 species and 13 subspecies belonging to 38 genera (Efimov 2020). Among these, about 40 orchids are found in the Middle Urals, which is one of the most industrial regions of Russia (Mamaev et al. 2004, Vakhrameeva et al. 2014). Changing natural habitats leads to the extinction of many orchid species. However, more information has been reported about the growth of certain orchid species on the anthropogenically disturbed territories. The colonization of such habitats (including lands disturbed by industry) with orchids has been lately noted by many researchers (Jakubska et al. 2006, Esfeld et al. 2008, Schefferson et al. 2008, Scheffknecht et al. 2010, Strel'nikova and Manakov 2010). The appearance of several orchid species on industrial dumps was also noted in the Middle Urals, Russia (Filimonova et al. 2018, 2020, 2022; Maleva et al. 2021). One such species is *Malaxis monophyllos* (L.) Sw., a rare orchid listed in the Red Books of 35 regions of Russia (Blinova 2013, Vakhrameeva et al. 2014) and protected in many European countries (Bilz et al. 2011) and Mongolia (Baasanmunkh et al. 2021).

Malaxis monophyllos is a boreal-mountain Eurasian species with a holarctic range, hemicryptophyte and polycarpic. The storage organs are represented by a terrestrial tuber of shoot origin (photosynthesizing pseudobulba) of an oval shape dressed with a sheath of a green leaf and lower scale-like and vaginal leaves (Vakhrameeva et al. 2014). *M. monophyllos* is a competitively weak species. It prefers to grow in a more or less sparse grass stand (total projective cover is not more than 60 %), avoiding the close proximity to large aboveground plant parts. It most often grows singly or in small groups of no more than 100 individuals (Vakhrameeva et al. 2014). This orchid plant occurs in a moderately shaded habitat in forest clearings and forest edges. It is a moesophyte, more often found in the moderate habitats avoiding dry ones (Vakhrameeva et al. 2008).

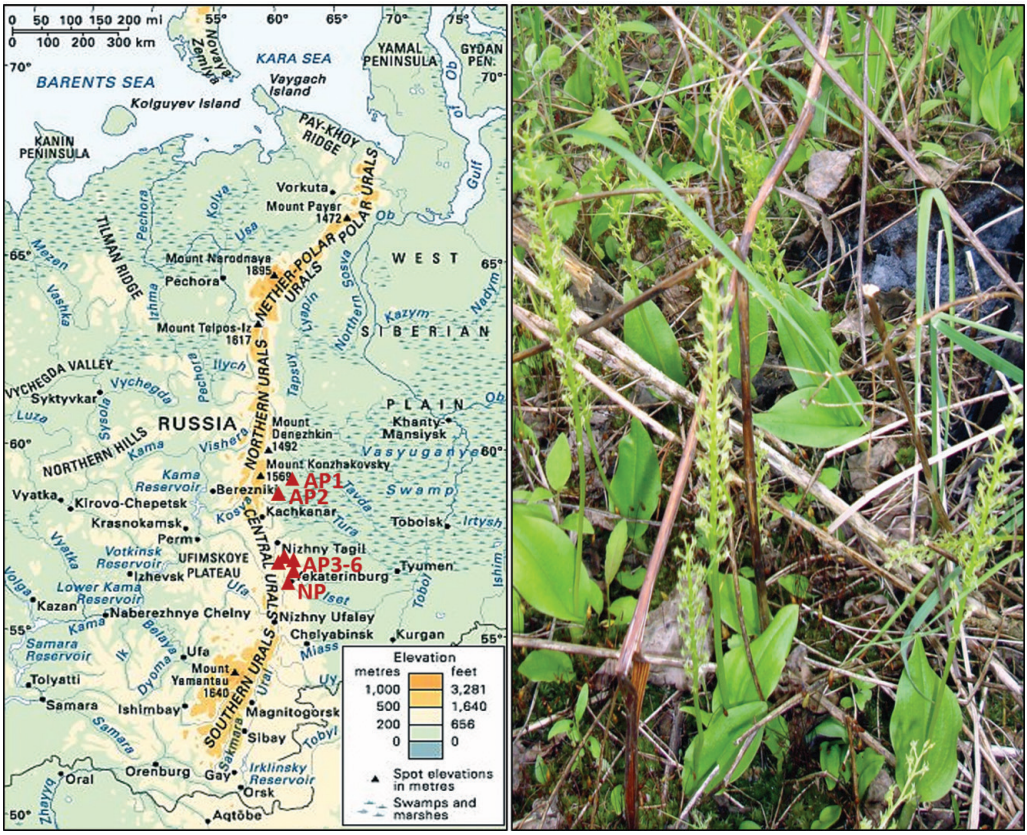
The aim of this work is to study the demographic structure and morphological features of *M. monophyllos* populations growing on industrially disturbed territories and in their natural habitat in the Middle Urals, Russia. The knowledge of the properties of secondary orchid populations is of great importance, especially in the context of the continued decline in their numbers in natural phytocoenoses.

Material and Methods

The field studies were carried out on the territory of the Middle Urals, Russia. The study area is located in the temperate continental boreal climatic zone, characterized by long cold winters (the average January temperature is -16.0 °C) and short, relatively warm summers (the average July temperature is +17.2 °C). The relief of the region is low-mountainous. Most of it is covered by coniferous

forests on mountainous podzolic soils (taiga zone). In the intermountain basins, there are boggy light forests, boggy and damp meadows, as well as various types of bogs. Plains are covered by forests, swamps and meadows (Shakirov 2011).

The study of *M. monophyllos* population demographic structure and some morphometric indicators of generative individuals was carried out in mid-July between 2016 and 2018. Populations of *M. monophyllos* were studied in 6 anthropogenic habitats (Fig. 1, Table 1): at the southern dump of the South Veselovsky brown coal mine (AP1), at the fly ash dump of the Nizhneturinskaya thermal power station, NTTPS (AP2), at the dam of the Shuralino-Yagodnoye placer gold deposit (AP3), at the fly ash dump of the Verkhnetagil'skaya thermal power station, VTTPS (AP4), at the Galkinsky dump of marbleized limestone (AP5) and at the dump of the Shabrovsky talc-magnesite deposit (AP6). The age of plant communities was determined according to the mine surveying data, which corresponded to the end of dumping and the cessation of anthropogenic activities. It varied from



a b

Fig. 1. Location of studied *Malaxis monophyllos* populations (a), example of a local orchid population (b).

Note: AP – population in anthropogenic habitat, NP – population in natural forest community.

Table 1. General characteristics of the studied sites.

Code	Sites	Coordinates	Type of substrate
AP1	South Veselovsky overburden dump (brown coal deposit)	59°41’20” N 59°55’28” E	Sandstones mixed with carbonaceous mudstones
AP2	Fly ash dump of Nizhneturinskaya thermal power station (non-reclaimed)	58°41’1” N 60°0’10” E	Fly ash
AP3	Hydro dump of clay rocks of the Shuralino-Yagodnoye alluvial gold deposit	57°24’34” N 60°10’28” E	Sediated clays, loams, sandy clays
AP4	Fly ash dump of the Verkhnetagil’skaya thermal power station (reclaimed)	57°20’21” N 59°56’30” E	Fly ash with clay soil application
AP5	Galkinsky dump of marbleized limestone	56°56′15″ N 59°49′06″ E	Limestones, sandy-argillaceous deposits
AP6	Dump of the Shabrovsky talc-magnesite deposit	56°37′45″ N 60°35′59″ E	Serpentines, talc-carbonate rocks
NP	Southwest forest park, Yekaterinburg	56º46’25” N 60º32’32” E	Sod-podzolic soil

Note: AP – population in anthropogenic habitat, NP – population in natural forest community.

20 to 55 years in the studied anthropogenic habitats. A more detailed description of technogenically disturbed territories was given earlier (Chibrik et al. 2011, Lukina et al. 2015).

As a reference control, we used the population of *M. monophyllos* from the natural forest community (NP) on the territory of the Southwest forest park, Yekaterinburg (Fig. 1, Table 1).

The populations of *M. monophyllos* differed according to the plant communities in which they were established. To survey the vegetation, a detailed route method was used. In places where orchids grew, geobotanical descriptions of sites (with minimum area of 100 m^2) were made. Such features as tree crown density, plant height, dominant species of the tree layer, species composition and richness of undergrowth and herb-shrub layers, the herb and shrub total projective cover (TPC) and the moss and lichen TPC of the sites surface were assessed.

To investigate the spatial and demographic structures of *M. monophyllos* populations in the studied plant communities, 50 counting plots (0.25 m^2) were randomly laid. The density of *M. monophyllos* populations was calculated as a number of individuals per 0.25 m^2.

The demographic structure of the populations was determined according to Vakhrameeva et al. (1993, 2014). *M. monophyllos* plants were divided into the following life history stages: juvenile (*j*), which have one green leaf up to 0.2–1.7 (maximum 2.0) cm long, 0.2–0.7 cm wide with 2–10 veins; immature (*im*) with a leaf up to 1.8–3.0 (maximum 3.2) cm long, 0.8–2 cm wide, with 10–14 veins; virginal (*v*) with a leaf up to 3.5–5.5 (maximum 7.0) cm long, 1.7–2 (maximum 2.5) cm wide with 16–22 veins; generative (*g*) with a leaf up to 5–8 (maximum 9.0) cm long, 2.2–4.5 (maximum 5.0) cm wide with 22–30 veins, the inflorescence is a loose narrow raceme of 30–60 (maximum 115) flowers (Vakhrameeva et al. 2014). The shoot height, the inflorescences length, the number of flowers and fruits per inflorescence were measured on generative individuals. Besides, the level of fruiting (calculated as a ratio of the number of

fruits to the number of flowers) was assessed.

All calculations were done using Microsoft Excel 16.0 and STATISITICA 10.0 software. After checking the normality by Shapiro–Wilk test and the homogeneity of variance by Levene's test, the differences between the studied orchid populations were tested using the non-parametric Kruskal–Wallis H test; the correlation coefficients (r) were calculated with non-parametric Spearman Rank Order Correlations ($p < 0.05$). On Figure 2, the small solid square indicates the mean values (n = 5–40), the boxes present mean ± standard error (SE), the whiskers are the mean ± standard deviation (SD). Different letters indicate significant differences between the studied populations at $p < 0.05$.

Results and Discussion

The AP1 population of *M. monophyllos* of about 12 individuals was found in the forest phytocoenosis, which was formed at the southern dump of the Veselovsky brown coal mine (Table 1). The plant community was 55-year-old. The height of the tree canopy averaged 16 m. The tree crown density was 0.6–0.7 (Table 2). The dominant species were *Pinus sylvestris* L., *Betula pendula* Roth, *Populus tremula* L., *Picea obovata* Ledeb., while *Pinus sibirica* Du Tour and *Larix sibirica* Ledeb. were found in the undergrowth. Single individuals of *Juniperus communis* L., *Sorbus aucuparia* L., *Lonicera altaica* Pall., *Salix caprea* L. grew in the shrub layer. The herb-shrub layer was dominated by *Vaccinium vitis-idaea* L., *Pyrola chlorantha* Sw., *Orthilia secunda* (L.) House, *Equisetum sylvaticum* L., *Lathyrus vernus* (L.) Bernh. and others. The TPC of this layer varied from 10 to 50 % (Table 2). The single individuals of *M. monophyllos* grew in a well-developed moss-lichen layer, the TPC of which varied from 20 to 80 %. The density of *M. monophyllos* in this anthropogenic habitat was low and varied from 1 to 2 individuals per 0.25 m^2 (1.2 on average, Table 3).

The AP2 population of *M. monophyllos* of 400 individuals was found in the non-reclaimed area of fly ash dump of NTTPS in a plant community, transforming from a shrub stage to the formation of a mixed forest phytocoenosis. The plant community was about 20-year-old. The tree layer was dominated by *B. pendula* and *P. sylvestris*. The height of individual trees reached 3.5 m, the tree crown density was absent (Table 2). The undergrowth included *P. tremula*, *Betula pubescens*

Table 2. Geobotanical characteristics of the studied sites.

Code	Tree crown density	Undergrowth cover, %	Herb-shrub cover, %	Moss-lichen cover, %	Litter thickness, cm	Species diversity, number of species per 0.25 m^2
AP1	0.6–0.7	0–10	10–50	20–80	2.0–3.0	5.3
AP2	0	35–40	10–50	0–85	0.0–1.0	4.0
AP3	0.5–0.6	30–65	10–35	0–5	2.0–5.0	6.4
AP4	0.7–0.8	16–20	25–60	5–10	2.0–3.0	3.7
AP5	0	35–45	25–45	0	1.5–2.5	11.1
AP6	0.5–0.6	0	5–50	0–7	2.0–4.0	2.5
NP	0.6–0.7	10–40	45–90	10–15	3.0–7.0	11.2

Note: AP – population in anthropogenic habitat, NP – population in natural forest community.

Table 3. Area, density and demographic structure of *M. monophyllos* populations.

Code	Population area, m²	Density of population, number of individuals per 0.25 m²	Percentage distribution of individuals at different age stage, %			
			j	*im*	*v*	*g*
AP1	300	1.2	8.3	25.0	25.0	41.7
AP2	200	8.2	6.0	9.0	25.0	60.0
AP3	300	2.4	6.7	20.0	13.3	60.0
AP4	200	1.8	7.0	20.0	17.0	56.0
AP5	100	3.0	14.3	38.1	14.3	33.3
AP6	200	3.9	14.8	22.2	33.4	29.6
NP	200	4.8	16.0	16.0	40.0	28.0

Note: AP – population in anthropogenic habitat, NP – population in natural forest community.

Ehrh., *Abies sibirica* Ledeb., *P. obovata*, *P. sibirica* and *L. sibirica*. The projective cover of this layer varied from 35 to 40 %. The shrub layer was represented by *Salix triandra* L., *S. phylicifolia* L. and single individuals of *S. aucuparia*, *Alnus incana* (L.) Moench, *Rosa glabrifolia* C.A. Mey. ex Rupr. and *Rubus idaeus* L. The herb-shrub layer occupied open areas among woody plants, the TPC varied from 10 to 50 %.

Such species as *Calamagrostis epigejos* (L.) Roth, *Chamaenerion angustifolium* (L.) Scop., *Deschampsia cespitosa* (L.) P. Beauv. were characterized by the most uniform distribution and high abundance, while *Trifolium pratense* L. and *Equisetum arvense* L. were found in groups.

The widespread coverage of the fly ash surface with a moss-lichen cover was noted, the TPC of which in some places reached up to 100 %. The most widespread were mosses of the genera *Pohlia*, *Bryum* and such species as *Marchantia polymorpha* L. and lichens of the genera *Peltigera* and *Cladonia*.

The density of *M. monophyllos* in AP2 was high and varied from 1 to 63 individuals per 0.25 m² (8.2 on average, Table 3). The population with the same high number and density of individuals was noted at the sludge storage of the Baikal Cellulose Plant (Vakhrameeva et al. 2014).

The AP3 population of *M. monophyllos* of 38 individuals was found at the dam of the Shuralino-Yagodnoye hydro dump of the placer gold deposit. The age of the forest phytocoenosis was 30. The tree crown density was 0.5–0.6 (Table 2). The tree layer was represented by *B. pendula*, *P. tremula*, *P. sylvestris*, *P. obovata*, *B. pubescens*, *A. incana*. The shrub layer was dominated by *Salix caprea* L., *S. cinerea* L., *S. myrsinifolia* Salisb., the TPC varied from 30 to 65 %. The average TPC of the herbs layer was 30 %, and dominated by *Lathyrus pratensis* L., *Tussilago farfara* L., *C. epigejos*, *E. arvense, O. secunda*, *Pyrola rotundifolia* L., *Fragaria vesca* L., *Vicia sepium* L. Orchids in the AP3 population grew in small groups. The density of *M. monophyllos* population varied from 1 to 14 individuals per 0.25 m² (2.4 on average, Table 3).

The AP4 population of *M. monophyllos* of 42 individuals was found in the forest phytocoenosis, which was formed in the reclaimed part of the fly ash dump of VTTPS. The territory was recultivated by applying strips of clay soil to the fly ash surface (Chibrik et al. 2016). The age of the plant community at the time of the sur-

vey was about 45. The tree canopy was two-tiered. The upper layer was characterized by a high proportion *of B. pendula*, *P. tremula*, *P. sylvestris*, *B. pubescens*. The tree crown density was 0.7–0.8. *P. obovata, P. sibirica* and single individuals of *A. sibirica* and *L. sibirica* were found in the undergrowth. The shrub layer contained *S. caprea*, *S. cinerea*, *S. aucuparia* and *Prunus padus* L. In the herb-shrub layer (TPC was 25–60 %) *F. vesca*, *Trifolium repens* L., *L. pratensis*, *Poa pratensis* L. prevailed. The density of *M. monophyllos* population in this community varied from 1 to 4 individuals per 0.25 m^2 (1.8 on average, Table 3).

The AP5 population of *M. monophyllos* of 15 individuals was found on the side of the road near the Galkinsky dump of marbleized limestone (Table 1). A group of *M. monophyllos* grew among the shrubs of *S. myrsinifolia*. In the herb-shrub layer (TPC was 35–45 %), the following species prevailed: *Carum carvi* L., *Taraxacum officinale* (L.) Webb ex F.H. Wigg., *Leucanthemum vulgare* Lam., *Poa trivialis* L. The density of *M. monophyllos* AP5 population varied from 1 to 6 individuals per 0.25 m^2 (3.0 on average, Table 3).

The AP6 population of *M. monophyllos* of 39 individuals was found on the dump slope of the Shabrovsky talc-magnesite deposit. Forest community was formed with the dominance of *P. sylvestris* and *B. pendula*. The plant community was 55-year-old. The stand height reached 20 m, the tree crown density was 0.5–0.6. *P. tremula*, *S. caprea*, *S. myrsinifolia* and other species of the genus *Salix* were single occurrences in the undergrowth. The TPC of herb-shrub layer varied in different areas from 5 to 50 %, averaging 20 %. *O. secunda*, *Chimaphila umbellata* (L.) W.P.C. Barton, *Moneses uniflora* (L.) A. Gray and *Pimpinella saxifraga* L. were abundant in the herb-shrub layer. The density of *M. monophyllos* population varied from 1 to 14 individuals per 0.25 m^2 (3.9 on average, Table 3).

The NP population of *M. monophyllos* from the natural forest community was about 38 individuals. The tree layer was dominated by *P. sylvestris*, while *B. pendula* and *P. tremula* were co-dominants. The average age of the trees was about 110 years. The tree crown density was 0.6–0.7. The lower canopy consisted of *S. caprea, S. aucuparia*, *R. idaeus*, *Rosa acicularis* Lindl., *Chamaecytisus ruthenicus* (Fisch. ex Wołoszcz.) Klásk. The TPC of the herb-shrub layer varied from 45 to 90 %. *Vaccinium myrtillus* L., *V. vitis-idaea*, *Aegopodium podagraria* L., *Calamagrostis arundinacea* (L.) Roth, *P. pratensis*, *T. repens*, *T. pratense*, *Galium boreale* L., *Veronica chamaedrys* L., *Adenophora lilifolia* (L.) A. DC., *D. cespitosa*, *Elytrigia repens* (L.) Desv. ex Nevski were found in the herb-shrub layer. In the areas where *M. monophyllos* grew, the herbaceous layer was sparser. The density of NP population varied from 1 to 9 individuals per 0.25 m^2 (4.8 on average, Table 3).

It is known that in Russia *M. monophyllos* grows in moderately humid areas in the slight shading: in forest clearings and forest edges, sometimes in marsh phytocoenoses (Vakhrameeva et al. 2014). In open habitats, the species settles less frequently. Strict phytocoenotic confinement in *M. monophyllos* is not observed.

Our studies have shown that *M. monophyllos* is able to settle in forest communities that are formed on industrial dumps in the Middle Urals. The dumps are composed of different substrates and are characterized mainly by moderate moisture conditions.

It has been shown that *M. monophyllos* grows in groups in the sites studied,

which is typical for this species and probably contributes to its successful pollination (Aguilar et al. 2006, Jermakowicz et al. 2015).

The number of *M. monophyllos* in most of the populations studied was small and averaged 31 individuals. The exception was the anthropogenic population AP2 of 400 individuals, found in the undergrowth of woody plants at the fly ash dump surrounded by impenetrable swamps and forests in the north of the Sverdlovsk region. Small populations by numbering up to 50 individuals are characteristic of *M. monophyllos* throughout its range, and only sometimes, especially in disturbed habitats, the species can form rather large populations of up to 800 individuals (Blinova 2013, Vakhrameeva et al. 2014, Jermakowicz et al. 2015).

The life cycle of *M. monophyllos* takes approximately 20 years (Vakhrameeva et al. 2014), including the underground phase between germination and the appearance of the first aerial leaf lasts about 5 years. The first flowering occurs on average 10–11 years after germination and can be repeated up to 4 seasons. After the flowering period, the plant dies off without turning into a senile state. One of the factors that determines the resistance of orchids is the completeness of the ontogenetic spectrum of populations (Valuiskikh and Teteryuk 2013, 2014; Jermakowicz et al. 2015). The analysis of the demographic structure of *M. monophyllos* populations revealed that all populations studied contained all age groups (Table 3). In the age classes of most populations, individuals of the generative (*g*) state accounted for a large proportion (44.0 % on average), which indicates their reproductive potential. It is known that flowering adults are one of the determining factors in the development of the population, since they can produce fruits and seeds that are important for seedlings replenishment. The larger the proportion of generative individuals, the larger probability for the development of population and the increase of the population size (Nurfadilah 2017). In most *M. monophyllos* anthropogenic populations, the proportion of generative individuals was higher by 1.7 times on average than in the natural habitat. At the same time the orchid population from natural forest community was characterized by a higher proportion of juvenile (*j*) individuals (1.9 times on average), which indicates its higher reproductive success. The closest to NP were the age spectra of AP5 and AP6 populations growing in phytocoenoses on stony substrates.

The analysis of the morphometric parameters of *M. monophyllos* generative individuals showed their significant variability (Fig. 2). On fly ash dumps, the plants reached maximum heights of 30.5 cm (AP2) and 30.8 cm (AP4), while in the natural phytocoenosis (NP) the maximum height was 29.5 cm (Fig. 2a). At the same time, on industrial dumps (AP5 and AP6) with more unfavourable conditions, this parameter was significantly ($p < 0.05$) lower than the control (1.5 times on average). In general, the results of morphological measurements are consistent with the literature data (Vakhrameeva et al. 1993, 2008; Blinova 2013).

The length of the inflorescences directly correlated with the length of the shoots ($r = 0.85$, $p < 0.05$) (Fig. 2b). The number of flowers in more humid technogenic substrates (fly ash) reached maximum 98 (AP2) and 84 (AP4) flowers per individual, averaging 46 and 50 flowers per individual, respectively (Fig. 2c). On drier stony substrates, much fewer flowers were formed: in AP5 and AP6, the maximum number of flowers was 44 and 49, respec-

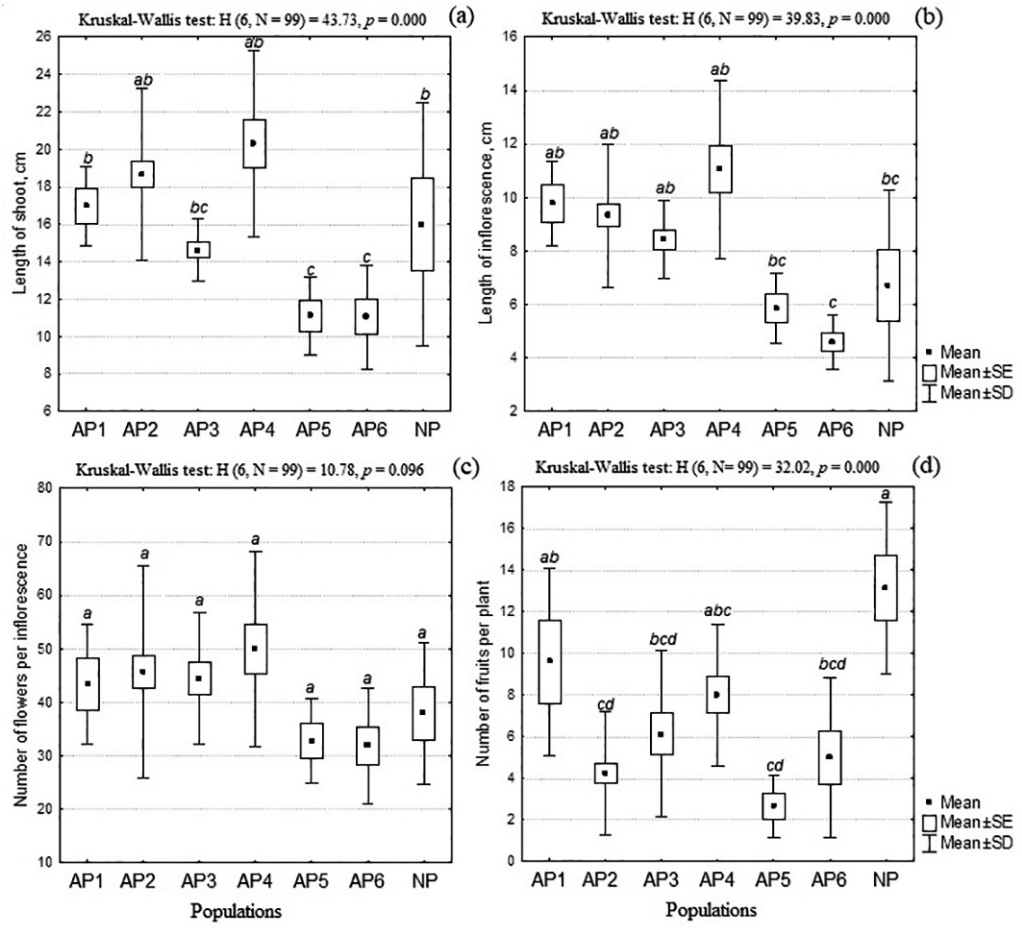


Fig. 2. Morphometric parameters of *M. monophyllos* in the studied populations: (a) the length of shoot; (b) the length of inflorescence; (c) the number of flowers per inflorescence; (d) the number of fruits per plant.

Note: The small solid square indicates the mean values (n = 5–40), the boxes are the mean ± standard error (SE), the whiskers are the mean ± standard deviation (SD). Different letters indicate the significant differences between the studied populations. AP – population in anthropogenic habitat, NP – population in natural forest community.

tively, averaging 33 and 32 flowers per individual. In the natural phytocoenosis, there were 38 flowers per individual on average and reached maximum 60. However, there were no significant differences in this parameter among the populations studied. Correlation analysis revealed a positive relationship between the number of flowers and the length of the inflorescence (r = 0.67, p < 0.05) and shoot (r = 0.60, p < 0.05).

The studies have shown that the number of fruits in orchids from the natural forest community was higher on average by 2.6 times than in individuals colonizing technogenic substrates (Fig. 2d). Similar

results were obtained in a comparative study of *M. monophyllos* populations in natural and anthropogenic habitats (Jermakowicz et al. 2015, Jermakowicz and Brzosko 2016), as well as in the study of other species of the Orchidaceae family (Pellegrino and Bellusci 2014).

One possible explanation for this could be the differences in pollinator efficiency in a variety of habitats. *M. monophyllos* is a cross-pollinated plant pollinated by various small insects, including mosquitoes. Therefore, fruit set and seed production may depend on pollinators availability (Vakhrameeva et al. 2008, Claessens and Kleynen 2011). In the studied technogenically disturbed territories, zoocoenoses may differ from those in the natural habitats (Jermakowicz et al. 2015).

There is evidence that the percentage of fruit set in *M. monophyllos* is low and varies from 5 to 33 % (Vakhrameeva et al. 2014). It largely depends on weather and climatic conditions and varies greatly in the same phytocoenosis from year to year. Our studies of *M. monophyllos* populations have confirmed these results. In anthropogenic populations, the percentage of fruit setting (AP1–AP6: 22.1, 9.3, 13.8, 16.0, 8.1, and 15.7 %, respectively) was significantly lower ($p < 0.05$) than in natural population (NP: 34.7 %).

It is known that *M. monophyllos* has a two-leaved form. It was noted earlier that the same individual can form one or two leaves in different years (Vakhrameeva et al. 2014). Our studies have shown that two-leaved individuals were quite often found on anthropogenically disturbed substrates (AP1–AP6: 20.0, 63.4, 84.2, 55.6, 28.6 and 40.0 %, respectively). In addition, one 3-leaved individual was encountered in AP4. In their natural habitat (NP), the percentage of occurrence of two-leaved individuals was very low (14.3 %).

Conclusions

The studies have shown that *Malaxis monophyllos,* a rare species of the Orchidaceae family, settles in the disturbed areas of the Middle Urals (Russia) in a sparse herbaceous layer of forest phytocoenoses, dominated by early succession species, such as *Pinus sylvestris*, *Populus tremula* and *Betula pendula*. In anthropogenic habitats, *M. monophyllos* is able to form local populations with higher abundance and density than in the natural forest community with a predominance of generative individuals by an average of 1.7 times. This indicates its rather high viability and adaptability to disturbed habitats.

It was revealed that *M. monophyllos* plants colonizing technogenic substrates, according to most biometric parameters, corresponded to orchids from the natural forest community. At the same time, they were characterized by the reduced fruit formation per plant (2.6 time on average), as well as the percentage of fruit set (2.7 times on average) compared with the plants from natural community. A possible reason for this could be the unfavourable conditions of technogenic habitats, including those for the putative *M. monophyllos* pollinators. Suitable humidity conditions and low competition in man-made habitats favour the growth of *M. monophyllos*. However, population persistence time in disturbed habitats will depend on further succession processes and anthropogenic activities.

The study of the distribution, morphological and population characteristics of orchids and their responses to the technogenic and natural factors have great importance for the development of measures to protect rare and endangered plant species. New colonies of *M. monophyllos*

on industrial dumps could provide the conservation of this rare species in the region.

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FOREST PHYTOCOENOSES FORMATION ON SERPENTINE DUMPS OF ASBESTOS DEPOSIT, MIDDLE URALS, RUSSIA

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Abstract

The mineral deposits' development is accompanied by significant disturbances of soil and vegetation in large areas. The study of initial stages of disturbed lands natural overgrowing makes it possible to assess patterns of vegetation formation. Forest phytocoenoses formation on serpentine substrates in the Middle Urals, Russia (taiga zone, subzone of southern taiga) was studied in this work. The research was carried out at four dumps of Anatol'sko-Shilovsky asbestos deposit. It was found that forest communities with the dominance of *Pinus sylvestris* L. are formed on dump sites with the predominance of overburden rocks. The herb-shrub layer of these phytocoenoses was dominated by *Calamagrostis arundinacea* (L.) Roth. The slopes of dumps and areas with compacted soil are overgrown with sparse undersized forest vegetation dominated by *P. sylvestris* and *Betula pendula* Roth. In herb-shrub layer of these areas, the most common were relict species *Dendranthema zawadskii* (Herbich) Tzvel. and rare for the Urals species, *Epipactis atrorubens* (Hoffm.) Besser (orchid) and *Thymus talijevii* Klok. & Des.-Shost. The geobotanical and soil investigations have shown that all studied parameters (such as humidity, pH value, Mg:Ca ratio) influenced the formation of forest phytocoenoses. In general, the formation of forest vegetation on serpentine dumps is a very long process and it depends on specific climatic and soil conditions.

Key words: asbestos mining, forest communities, orchids, *Pinus sylvestris,* relict and endemic species, ultrabasic rocks.

Introduction

Keeping and restoration of biological diversity and rational usage of natural resources are fundamental to sustainable development of regions. Primarily it is due to the global anthropogenic transformation of natural ecosystems, accompanied by the radical biocoenotic rearrangements, the change in succession processes, and a number of other negative consequences (Bolshakov and Chibrik 2007).

The Middle Urals (Russia) is the industrial developed territory, where intensive mining and processing of minerals is carried out, and as a result, there are significant areas of lands disturbed by industry (Chibrik et al. 2018, Filimonova et al. 2020). Deposits of chromium, platinum, sulphide copper-nickel and silicate nickel,

iron ores and ores of rare metals, mica, asbestos, diamonds, gemstones and other minerals, confined to the outcrops of ultrabasic rocks, are widespread (Rakov and Chibrik 2009). During production of mining products, a significant amount of unused mineral mass is removed to the surface and stored in dumps. Waste rock dumps are often 3–5 times larger in area than opencast mine workings themselves (Mormil et al. 2002).

The extraction of minerals leads to catastrophic changes in ecosystems and is accompanied by the destruction of lithological base, soil and vegetation cover. The dumps formed as a result of the transfer of rocks produce various ecological conditions that have a great influence on the species composition, abundance, and distribution of plants (Chibrik and Yelkin 1991, Manakov et al. 2011).

The weathering of ultrabasic rocks is very slow. The resulting serpentine soils are stony and contain a minimum amount of silty and clay particles, characterised by high contents of iron, magnesium, nickel, chromium and cobalt, which are toxic to most plants and bacterial communities and low ones in calcium, potassium, sodium and aluminium (Alexander et al. 2007, Brković et al. 2015, Kierczak et al. 2016). The serpentines contain little nitrogen, phosphorus and differ significantly from other soil types in chemical composition; the pH values vary from acidic to alkaline (Brady et al. 2005, Kazakou et al. 2008, Galey et al. 2017). The restoration of vegetation in such areas is extremely slow. Flora formed in serpentine areas is usually characterised by low species diversity and a sparse vegetation cover contributing to erosion and increase in soil temperature (Kruckeberg 2002). The combination of physical, chemical and biotic components that affecting the growth and development of plants on serpentine soils is called ‘serpentine syndrome’ (Jenny 1980).

All these environmental factors together with a small amount of moisture and a low level of nutrients create extremely unfavourable conditions for plant growth. In this regard very peculiar plant communities are formed on serpentines (Kruckeberg 2002, Branco and Ree 2010, Cano et al. 2014). The volume of this specificity depends on climate, age of the forest community, and chemical composition of rocks (Brooks 1987, Krämer 2010). Serpentine communities are known to botanists for accumulations of rare and narrowly endemic species, distribution of which is largely or entirely limited by serpentine areas (Alexander et al. 2007).

The aim of this work was to study forest phytocoenoses formation on serpentine substrates in the Middle Urals (taiga zone, subzone of the southern taiga). Study of flora and vegetation formation, as well as the growth and development of plants on serpentine rocks is very important to understand the ecology and evolution of plant adaptation to unfavourable conditions.

Material and Methods

Studies were carried out in 2018–2020 on the dumps of Anatol’sko-Shilovsky asbestos deposit located within Tagilo-Nevyansk hyperbasite area on the eastern slope of the Middle Urals, 132 km north of Yekaterinburg, 2.5 km from Novoasbest village, Sverdlovsk Region, Russia (Fig. 1).

The relief of province is ridge-valley, dissected, altitude ranges from 298 to 325 m a.s.l. The climate of region is sharply continental. The average annual air temperature is +1.0 °C, the average

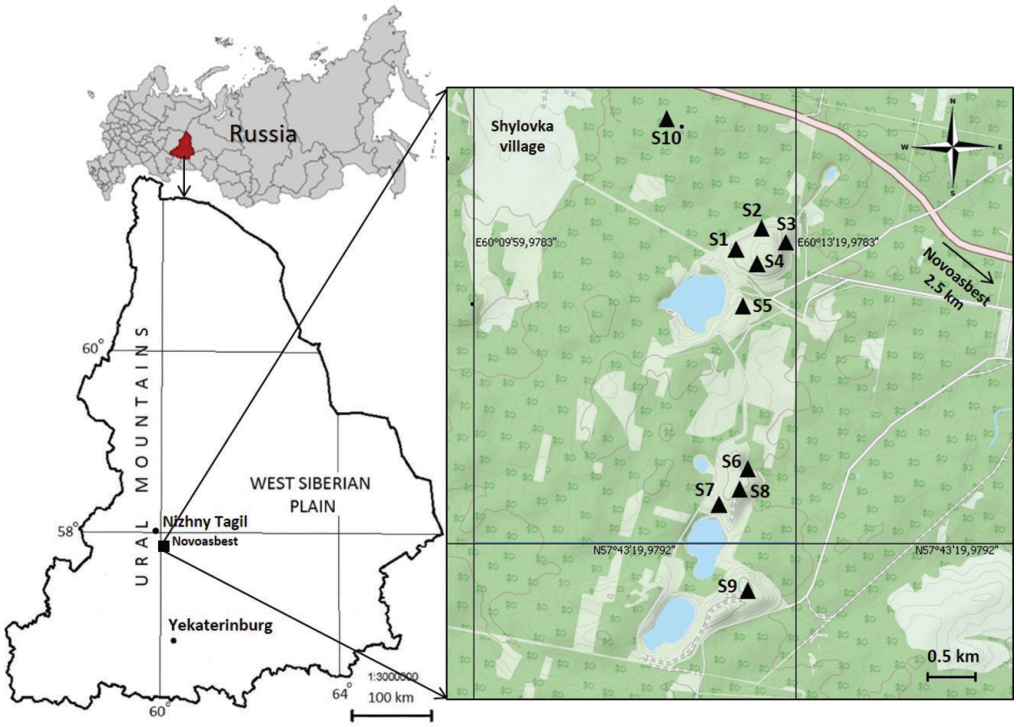

Fig. 1. Schematic map of Sverdlovsk Region with the study sites (S1–S10).

July temperature is +17.2 °C, the average January temperature is -16.0 °C (according to weather station in Nizhny Tagil) (Shakirov 2011). Minimum temperature was recorded in December (-39 °C), maximum in July (+35 °C). The average annual rainfall is 628 mm. The snow cover lasts from the second half of November to the beginning of April; its average thickness is 0.7 m. The depth of soil freezing is 0.8–1.7 m. The prevailing direction of winds in summer is west and south-west, in winter – west and north-west (Shakirov 2011).

At the Anatol'sko-Shilovsky deposit, a fibrous variety of serpentines (rezhikite-asbestos) belonging to the group of amphibole asbestos was mined as a mineral. The average asbestos content in rocks was about 4–5 % (Yanin 2013).

The development of fields was carried out by open pit mining from 1952 to 1992. As a result, the enterprise formed large 2–5-tier dumps of overburden, dumped by vehicles: Shilovsky (S1–S4), Anatol'sky (S6–S8), and Yuzhny (S9) with a total mass of 228.9 million tons. In addition, the dump-open pit complex includes a waste dump of crushing factory (S5). The dumps are mainly composed by rocks and only about 10 % of volume is loose material (harzburgites, serpentines and clay). As a control (S10), the pine forest community growing on the slope of Golaya Mount located between Shilovka and Novoasbest villages (about 2.0–2.5 km from Anatol'sko-Shilovsky asbestos deposit) was studied (Fig. 1, Table 1).

Table 1. General characteristics of studied sites.

Study area	Coordinates	Dump area, ha	Dump height, m	Sites	Code
Shilovsky dump	57°44′57″ N 60°12′35″ E	40	up to 50	Cultivated forest community	S1
				Forest community on the flat top	S2
				Emerging forest on the flat top	S3
				Emerging forest on the lower tier	S4
Stone cutter dump	57°44′34″ N 60°12′32″ E	7	5–8	Area with sparse undersized vegetation	S5
Anatol'sky dump	57°43′34″ N 60°12′30″ E	35	30–40	Forest community (30–40 years old)	S6
				Forest community (20–30 years old)	S7
				Emerging forest at the edge and along the road	S8
Yuzhny dump	57°43′04″ N 60°12′45″ E	35	up to 40	Sparse forest undersized vegetation	S9
Control site	57°46′05″ N 60°12′27″ E	-	-	Natural forest community on the slope of Golaya Mount	S10

The quarry-dump complex is surrounded by pine herbaceous and pine herbaceous bilberry forests dominated by *Pinus sylvestris* L. with the admixture of *Larix sibirica* Ledeb. and *Betula pendula* Roth. *Juniperus communis* L. and *Tilia cordata* Mill. were found undergrowth. The soils in this territory are sod-medium-podzolic, thin, heavily crushed, formed on ultrabasic rocks.

The study of phytocoenosis formed on the dumps was carried out according to generally accepted geobotanical methods: floristic richness as number of species in a community, abundance of each species according to Drude (Nekrasova et al. 2020), and similarity of floristic composition were determined. The qualitative similarity was assessed using Sørensen–Chekanovsky coefficient, calculated on the basis of pairwise comparison of the floristic lists in the studied sites by the presence of common species (Smith and Smith 2012). To quantify the species biodiversity, Shannon–Wiener diversity index was calculated and on its basis, Pielou evenness index, an indicator of community equitability, was estimated as it was described earlier (Filimonova et al. 2020). At each site at least 3 plots (S = 100 m^2) and at each plots at least 15 of Raunkier sites (S = 0.25 m^2) were laid; tree crown density, total projective cover (TPC) of vegetation by tiers were determined, and recalculation and measurement of tree species were carried out.

Soil samples for research were taken at each site from depth of 20 cm. The main physicochemical characteristics (presented in Table 3) were determined by the conventional methods of Russian pedology (Arinushkina 1970, Vorobyova 2006). The particle size distribution was determined by the pipette method; the total organic carbon (TOC) was measured by Tyurin's method; soil pH was analysed potentiometrically in the water solution (1:2.5 *w/v*). Exchangeable Ca^{2+} and Mg^{2+} were detected by the titration method (Nekrasova et al. 2020). The hygroscopic

moisture content of soil was determined by air drying method (Maiti 2013).

For comparative studies, *P. sylvestris* trees of the same age (20–25-year-old) were selected both in the natural forest community (control) and on the dumps of the Anatol'sko-Shilovsky asbestos deposit.

The statistical interpretation of the results was made by using the standard software package StatSoft STATISTICA 12.0 and Microsoft Excel 2013. The cluster analysis was performed using the following parameters: distance measure – Euclidean distance; the union rule is a single link. The initial data were the estimates of the abundance of species according to Drude, translated into expert estimates of the abundance (Chibrik and Yelkin 1991). Data shown in Table 3 are the means ± standard errors (n = 3). The correlation analysis was performed using Pearson's r-test at $p < 0.05$ (n = 10).

Results and Discussion

The study of the Anatol'sko-Shilovsky serpentine dumps showed the uneven formation of vegetation. This is probably due to variegated ecological conditions of technogenic habitats such as the composition and properties of rocks, the degree of rockiness and the compaction of surface, the exposure and steepness of slopes, the forms of meso- and micro-relief (Rakov and Chibrik 2009, Filimonova et al. 2020).

Site 1 was located on the southeastern side of Shilovsky dump loose overburden. In 1974 seedlings of *P. sylvestris* and *L. sibirica* were planted in this site. By 2018, a forest community with tree crown density of 0.7 was formed at the planting site. The average height of *P. sylvestris* was 9.3 ±1.0 m; the trunk diameter at 1.3 m was 7.5 ±0.6 cm; the average height of *L. sibirica* was 15.8 ±2.6 m; the trunk diameter at 1.3 m was 13.8 ±1.7 cm. In herb-shrub layer cover, TPC with vegetation varied from 0 to 20 % (Table 2). Species composition was dominated by *Calamagrostis arundinacea* (L.) Roth, *C. epigeios* (L.) Roth, with a high abundance of *Festuca pratensis* Huds., *Seseli libanotis* (L.) W.D.J. Koch, *Hieracium umbellatum* L., *Solidago virgaurea* L., *Poa pratensis* L., *Orthilia secunda* (L.) House, *Fragaria vesca* L., *Achillea millefolium* L.

Site 2 was located on the flat top of Shilovsky dump in the area of loose soil dumping. The forest phytocoenosis with the dominance of *P. sylvestris* was formed there; the age of trees was between 20 and 30 years. Their height reached 7–8 m, the diameter of trunks was 12–16 cm. Tree crown density was 0.6–0.7 (Table 2). Forest species found singularly were *Populus laurifolia* Ledeb., *P. suaveolens* Fisch., *Salix caprea* L. The herb-shrub layer was sparse, and TPC varied from 10 to 40 %. Shrubs included *Vaccinium vitis-idaea* L. and *V. myrtillus* L. Herbaceous species were presented by *C. epigeios*, *C. arundinacea*, *F. vesca*, *Rubus saxatilis* L., *Dendranthema zawadskii* (Herbich) Tzvel.

Site 3 was located on the top of Shilovsky dump covered with stony compacted soil. This site was overgrown with undergrowth *P. sylvestris*, *B. pendula*, *Populus tremula* L., *P. balsamifera* L., *P. laurifolia*, *P. suaveolens*, *Salix bebbiana* Sarg., *S. caprea*, *S. myrsinifolia* Salisb., *S. pentandra* L., *S. phylicifolia* L., *S. rosmarinifolia* L. and *S. viminalis* L. The height of the trees and shrubs did not exceed 2.0 m. Herbaceous vegetation was fragmentary and sparse, and TPC varied from 0 to 10 %. The most common herbaceous species were *D. zawadskii*, *Epipactis atro-*

Table 2. Geobotanical characteristics and biodiversity of phytocoenoses in studied sites.

	Phytocoenotic characteristics				Biodiversity of studied populations			
Code	Community age, years	Tree crown density	Herb-shrub layer cover, %	Moss-lichen layer cover, %	Species richness, total number of vascular plants	Species diversity, number of species per 0.25 m^2/min–max	Shan-non-Wiener index	Pielou evenness index
S1	43–45	0.7	0–20	15–35	39	4.1/1–6	2.17	0.90
S2	25–30	0.6–0.7	10–40	1–5	46	5.2/3–8	2.56	0.92
S3	25–27	-	0–10	-	48	3.8/0–8	2.58	0.85
S4	25–27	-	0–15	1–2	39	2.4/0–7	2.48	0.80
S5	20–25	-	0–5	1–5	11	2.1/1–3	1.98	0.86
S6	30–35	0.5–0.6	0–20	60–80	32	6.9/5–9	2.80	0.94
S7	25–30	0.5–0.6	40–50	35–45	51	4.6/1–8	2.96	0.88
S8	25–27	-	15–30	1–5	38	5.9/1–10	2.68	0.89
S9	25–27	-	0–3	-	22	1.9/0–5	1.60	0.69
S10	60–80	0.5–0.6	40–80	20–65	76	8.6/4–14	3.21	0.84

rubens (Hoffm.) Besser, *C. epigeios*, *Rumex thyrsiflorus* Fingerh.; other species were rare.

Site 4 was an open area located on berm of the first tier (on the south side of Shilovsky dump). On the flat surface, rolled by road transport, there was a sparse undergrowth of *B. pendula*, *P. sylvestris*, *P. tremula*, as well as species of *Populus* and *Salix* genera. There was no dense forest stand. In herb-shrub layer (TPC 0–15 %), *D. zawadskii*, *E. atrorubens*, *Thymus talijevii* Klok. & Des.-Shost., *S. virgaurea*, *C. epigeios* prevailed; *O. secunda*, *Antennaria dioica* (L.) Gaertn., *F. vesca* were rare (Table 2).

Site 5 was located on a crushing factory waste heap. The dump is being overgrown with the forest species undergrowth: *P. sylvestris* and *B. pendula* were 0.3–0.7 m high; *P. tremula* was found occasionally. Some individuals of *P. sylvestris* were 20–25 years old. Herb-shrub cover was very sparse (TPC was 0–5 %) and was represented by single individuals of *Dianthus versicolor* Fisch. ex Link, *R. thyrsiflorus*, *D. zawadskii*, *E. atrorubens*, *Festuca rubra* L.

Site 6 was a forest phytocoenosis formed on the second tier of Anatol'sky dump on the eastern side. The tree layer was dominated by *P. sylvestris*, the age of trees was from 10 to 35 years, tree crown density was 0.5–0.6. The average density of *P. sylvestris* was 10 individuals per 100 m^2, height varied from 4 to 9 m. *Sorbus aucuparia* L. and *Chamaecytisus ruthenicus* (Fisch. ex Wołoszcz.) Klásková were found in undergrowth. *C. arundinacea* dominated in herb-shrub layer (TPC was 0–20 %);

S. libanotis, *Th. talijevii*, *Sanguisorba officinalis* L. were found in groups, shrubs included *V. myrtillus* and *V. vitis-idaea*.

Site 7 was located on the southwestern side of Anatol'sky dump. The forest phytocoenosis with the dominance of *P. sylvestris* was formed there; the age of trees was between 25 and 30 years, tree crown density was 0.5–0.6 (the height was from 6 to 8 m). *Trifolium lupinaster* L. predominated in herb-shrub layer (TPC was 10–30 %); there were only single individuals of *C. arundinacea*, *C. epigeios*, *S. virgaurea*, *H. umbellatum*, *D. zawadskii*.

Site 8 was located on a tier 2 berm of Anatol'sky dump. Here at the edge of forest phytocoenosis in an open area with a compacted substrate undergrowth included *P. sylvestris* and *B. pendula* and species of *Populus* genus (*P. balsamifera*, *P. laurifolia*, *P. suaveolens*, *P. tremula*), and *Salix* genus (*S. bebbiana*, *Salix cinerea* L., *S. phylicifolia*). *D. zawadskii*, *Th. talijevii* dominated in sparse herbaceous layer (TPC 15–25 %). High abundance had *Festuca rubra*, *F. pratensis*, *E. atrorubens*, *H. umbellatum*, *T. lupinaster*, *A. millefolium*, *F. vesca*, *Lathyrus pratensis* L.

Site 9 was located on the upper tier of Yuzhny dump. Plateau-like top and slopes of dump were overgrown, mainly with low-growing forest vegetation; there was no closeness of tree layer. Dominant tree species were *P. sylvestris*, *Betula pubescens* Ehrh., *B. pendula;* undergrowth and seedlings were presented by *P. balsamifera*, *P. laurifolia*, *P. suaveolens*, *P. tremula*, *S. phylicifolia*, *S. myrsinifolia*, *S. caprea*, *S. pentandra*. TPC of herb-shrub layer was 1–3 %. Herbaceous species: *E. atrorubens*, *C. epigeios*, *F. rubra*, *Poa trivialis* L., and *Puccinellia hauptiana* (V.I. Krecz.) Kitag. were rare.

Control forest area (site 10) was dominated by *P. sylvestris*. The average age of trees was between 60 and 80 years, height of stand averaged 20 m, the diameter of trees at 1.3 m varied from 15 to 35 cm, tree crown density was 0.5–0.6 (Table 2). Besides, *L. sibirica*, *B. pendula*, *Picea obovata* Ledeb. were rarely found in stand; single individuals of *J. communis*, *Rosa acicularis* Lindl., *S. aucuparia*, *Ch. ruthenicus* grew in undergrowth. In it *P. sylvestris* and rare groups of *B. pendula* grew in height from 0.4 to 2.5 m. In herb-shrub layer (TPC 40–80 %), shrubs were represented by such species as *V. myrtillus* and *V. vitis-idaea*, *Linnaea borealis* L., *O. secunda*, *Pyrola media* Sw. and others; the herbaceous species were dominated by *C. arundinacea*, *Brachypodium pinnatum* (L.) Beauv., *Geranium sylvaticum* L., *R. saxatilis*, *F. vesca*, *Potentilla erecta* (L.) Raeusch. Orchids, such as *E. atrorubens*, *Platanthera bifolia* (L.) Rich., and *Goodyera repens* (L.) R.Br., were rarely found in herb-shrub layer on mountain side. *D. zawadskii* and *Th. talijevii* grew on rocky areas with a thin grassy cover.

The indicators of the species richness of studied plant communities are presented in Table 2. Plant communities formed on serpentine dumps (S1–S9) were characterised by lower values of **α**-diversity indicators (species richness and diversity, Shannon-Wiener index) and a sparser vegetation cover compared to control forest phytocoenosis (S10). With the increase in the age of plant communities, the increase in **α**-diversity was observed. Pielou evenness index varied from 0.69 to 0.94 on studied sites, which indicates an uneven distribution of plants. The plant communities formed on dumps and in control forest phytocoenosis had a low Chekanovsky-Sørensen similarity coefficient (0.38).

Previously, agrochemical analysis showed that the substrate of Anatol'sko

-Shilovsky deposit was characterised by a low content of alkaline hydrolysable nitrogen, an average content of available phosphorus and potassium, and at the same time, increased concentrations of total and available nickel, chromium, cobalt and iron compared to another type of substrate formed on granites (Filimonova et al. 2020).

The analysis of the substrates of studied sites revealed their substantial variations (Table 3). The pH of substrate varied from slightly acidic (6.44–6.79) under forest phytocoenoses to alkaline (7.75–8.11) in open stony areas dominated by sparse undersized forest vegetation. In areas with a higher content of clay particles moisture content was significantly (2.1–3.5 times) higher than in areas with a predominance of sand fraction. The studies have shown that the forest phytocoenoses on dumps were formed in the areas with admixture of loose overburden. Clay had a higher water-holding capacity than sand and gravel. Ca^{2+} content in dump samples varied from 3.6 to 5.4 mmol per 100 g of substrate. Soil from forest phytocoenoses contained more TOC and Mg^{2+}, in comparison with stony areas under sparse undersized vegetation. The ratio of Mg:Ca varied from one to six (2.9 on average) in all studied sites.

Table 3. Physicochemical characteristics of soil in studied sites.

Code	pH_{H_2O}	Ca^{2+}, mmol/100 g of substrate	Mg^{2+}, mmol/100 g of substrate	Total organic carbon, %	Hygroscopic moisture, %	Particle diameter, %	
						1.0–0.01 mm	<0.01 mm
S1	6.44 ±0.01	4.72 ±0.22	17.30 ±1.12	4.15 ±0.17	4.69 ±0.05	45.3	54.7
S2	7.06 ±0.02	4.51 ±0.30	13.34 ±0.92	2.81 ±0.09	3.23 ±0.06	51.2	48.8
S3	8.11 ±0.06	5.14 ±0.42	6.51 ±0.35	0.46 ±0.02	2.68 ±0.02	48.6	21.4
S4	6.67 ±0.02	3.60 ±0.12	15.50 ±1.14	0.52 ±0.03	1.01 ±0.02	41.2	58.8
S5	7.75 ±0.02	4.49 ±0.25	9.54 ±0.66	0.70 ±0.04	1.99 ±0.03	77.5	22.5
S6	6.74 ±0.03	3.44 ±0.14	20.62 ±1.50	2.03 ±0.10	5.71 ±0.10	32.8	67.2
S7	6.79 ±0.02	4.10 ±0.20	12.30 ±0.82	4.16 ±0.16	3.22 ±0.06	45.5	54.5
S8	6.83 ±0.04	4.60 ±0.23	14.22 ±0.91	2.62 ±0.08	4.39 ±0.05	42.5	57.5
S9	8.06 ±0.10	5.39 ±0.26	5.50 ±0.15	0.49 ±0.02	1.56 ±0.02	81.1	18.9
S10	6.55 ±0.03	7.24 ±0.36	9.04 ±0.50	8.16 ±0.22	3.45 ±0.03	57.7	42.3

Note: data presented as the means ± standard errors (n = 3).

The dendrogram of the species composition similarity of plant communities formed on dumps of Anatol'sko-Shilovsky asbestos deposit taking into account species abundance (Euclidean distances) divided the studied sites into two groups (Fig. 2). The first group included forest phytocoenoses with the high density of forest species with a pronounced herb-shrub layer. The second group included plant communities with sparse undersized tree undergrowth with a weakly expressed herb-shrub layer.

According to the results of the cluster analysis of plant communities on the dumps of Anatol'sko-Shilovsky asbestos deposit it was revealed that granulometric composition and compaction of substrate were determining factors in serpentine rocks vegetation formation. Factor I combined areas which substrates contained the admixture of loose overburden (Ta-

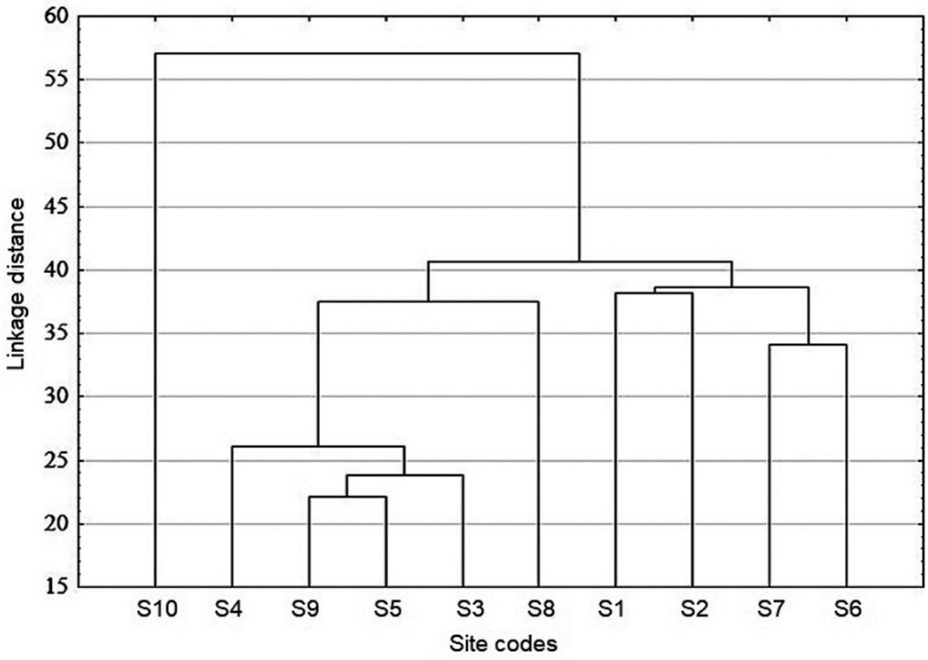

Fig. 2. Dendrogram of species composition similarity of studied plant communities, taking into account species abundance (Euclidean distances).

ble 4). In these areas the formation of vegetation proceeded according to the forest type. According to factor II the open areas of wide berms and upper tiers with strong surface rockiness and compaction of substrates with automotive technology were grouped.

On dump sites with the admixture of loose overburden (factor I) forest phytocoenoses were formed with the predominance of *P. sylvestris*. In herb-shrub layer of forest and meadow-forest phytocoenoses such species as *C. arundinacea*, *C. epigeios*, *S. libanotis*, *R. saxatilis*, *V. vitis-idaea*, *T. lupinaster* had the highest factor loads (Table 5). In open habitats (factor II), species of the herb-shrub layer with a high abundance and occurrence had the highest factor loads. These species include a relict in the Urals *D.*

Table 4. Factor loads of studied plant communities, taking into account species abundance.

Sites	Factor loadings	
	Factor I	Factor II
S1	**0.82**	0.3
S2	**0.84**	0.24
S3	0.09	**0.81**
S4	0	**0.87**
S5	0.29	**0.75**
S6	**0.91**	0.17
S7	**0.87**	0.27
S8	0.2	**0.63**
S9	0,49	**0,55**
S10	**0.88**	-0.05
Dispersion	**0.41**	**0.29**

Note: Loadings given in bold show the highest correlations between original values and principal components scores.

Table 5. Factor loads of dominant species in studied plant communities.

Species name	Factor loadings	
	Factor I	Factor II
Pinus sylvestris L.	**9.87**	**2.71**
Betula pendula Roth	-0.54	**4.46**
Dendranthema zawadskii (Herbich) Tzvel.	-0.21	**4.33**
Epipactis atrorubens (Hoffm.) Besser	-0.71	**4.15**
Calamagrostis arundinacea (L.) Roth	**2.74**	-1.15
Thymus talijevii Klok. & Des.-Shost.	-0.49	**2.90**
Calamagrostis epigeios (L.) Roth	**1.89**	**1.2**
Seseli libanotis (L.) W.D.J.Koch	**1.67**	-0.99
Fragaria vesca L.	**1.24**	-0.61
Populus tremula L.	-0.63	**2.22**
Salix phylicifolia L.	-0.54	**1.43**
Dianthus versicolor Fisch. ex Link	-0.59	**1.58**
Rumex thyrsiflorus Fingerh.	-0.13	**1.47**

Note: Loadings given in bold show the highest correlations between original values and principal components scores.

zawadskii (Asteraceae Dumort), which in its natural habitats prefers highly illuminated and well-warmed coastal outcrops of limestone and calcareous shale, open rubble talus, as well as two rare plants included in the Red Book of Sverdlovsk region, such as *E. atrorubens* (Orchidaceae Juss.), which occurs naturally on dry stony slopes and rocky outcrops of limestone and gypsum in dry light pine and birch forests (Vakhrameeva et al. 2008), and *Th. talijevii* (Lamiaceae Lindl.), growing on scree and calcareous outcrops. Additionally, herbaceous species that prefer limestone outcrops under natural conditions (*D. versicolor*, *R. thyrsiflorus*) and some deciduous species forming tree undergrowth (*B. pendula*, *P. tremula*, *S. phylicifolia*) also had high factor loads.

Common to all sites was dominance of *P. sylvestris* (57–99 %), the most common forest-forming species in the Urals (Fig. 3). It is a species with a pioneering ecological strategy capable of quickly colonising disturbed areas characterised by strong rockiness, low fertility, and an unfavourable water regime (Smirnova et al. 2004, Treshchevskaya et al. 2017). Other woody plant species accounted for 1 to 43 %.

Morphological features of *P. sylvestris* are highly variable within range. From southern taiga and forest-steppe towards north to forest-tundra and south to steppe island forests, as well as from plain to mountains, there is a gradual decrease in absolute dimensions of trunk, crown, shoots, needles (Mamaev 1983, Galdina and Khazova 2019).

The analysis of the morphological parameters of *P. sylvestris,* carried out earlier, showed that under conditions of dumps in areas with a compacted stony substrate, the indicators of tree height, the average growth of trunk and the length of needles decreased, that indicates about xerophytic conditions (Lukina et al. 2021). A similar reaction of plants growing on serpentine substrate was described by some authors (Alexander et al. 2007, Giuliani et al. 2008).

Pearson correlation coefficients revealed a high dependence of morphological parameters of *P. sylvestris* on properties of the substrate. So height and growth of trunk depended on content of hygroscopic moisture (r_p = 0.88, n = 10), associated with clay fraction content. In addition, these morphological parameters of *P. sylvestris* showed a high degree of dependence on acidity level of substrate (r_p = -0.89, r_p = -0.85, n = 10). In areas

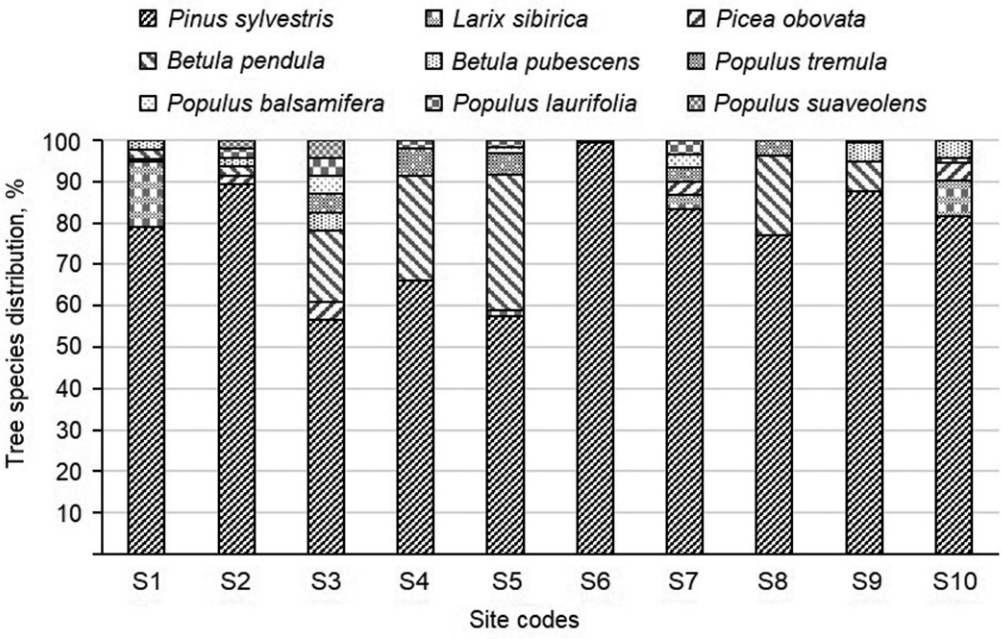

Fig. 3. Percentage distribution of tree species in studied plant communities.

with high pH values a decrease in the growth of *P. sylvestris* was observed. This is probably because of mycorrhizal fungi entering into symbiosis with *P. sylvestris* are acidophiles (Smith and Read 2008).

Our research also revealed a high degree of dependence of trunk height and growth of *P. sylvestris* on Mg content (r_p = 0.93, r_p = 0.89, n = 10). Many authors have previously noted the influence of a number of environmental factors, such as water deficiency, Mg:Ca ratio, high content of Ni and other metals, on the formation of vegetation on serpentine soils (Proctor 1999, Hughes et al. 2001, Brady et al. 2005).

Conclusions

The geobotanical survey of 20–40-year-old serpentine dumps of Anatol'sko-Shilovsky asbestos deposit showed that the intensity of their overgrowth depended on rock composition. Forest phytocoenoses dominated by *Pinus sylvestris* (79–99 %) were formed on the dump sites, composed of highly stony rocks with the admixture of loose rocks of light particle size distribution. Slopes and dump sites composed of rocks with a slight admixture of loose rocks were overgrown with sparse undersized woody vegetation with a predominance of *P. sylvestris* (57–66 %) and with a high proportion of deciduous species such as *Betula pendula*, *B. pubescens*, *Larix sibirica*, *Picea obovata*, *Populus tremula*, *P. balsamifera*, *P. laurifolia, P. suaveolenes* (34–43 %). The herbaceous vegetation on dumps was sparse; the total projective vegetation cover varied from 5 to 50 %, averaging 20 %. In the open areas of dumps under conditions of low competition, the relict species *Dendranthema zawadskii* and rare for the Urals species, *Epipactis atrorubens* (orchid)

and *Thymus talijevii*, were found.

The formation of plant communities was influenced by such properties of the substrate as moisture content, pH value, Mg:Ca ratio. In particular, the high positive correlation between such morphological characteristics of *P. sylvestris* as height and growth of trunk with hygroscopic moisture and Mg content (r_p = 0.88–0.92), and a negative correlation with the pH level (r_p = 0.85–0.89) were revealed.

The process of vegetation formation on serpentine dumps is very long, depending on specific edaphic conditions. Further investigation of the self-overgrowing processes will make it possible to determine the rate of colonisation by plants on substrate of different geological ages brought to the surface, which will make it possible to develop effective methods for the biological reclamation of disturbed territories.

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REGENERATION OF PINE STANDS AFTER SHELTERWOOD CUTTING IN FOREST ZONE OF UKRAINE

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Abstract

Features of regeneration of Scots pine (*Pinus sylvestris* L.) after shelterwood cutting in mature pine stands of Eastern Polissya of Ukraine (Chernihiv region) were studied. After the first stage of cutting, the density of stocking of pine stands of certain forest types was reduced to 0.2–0.6, and the natural regeneration of pine was supported by various methods of soil mineralization and seed sowing. Self-sown seedlings and young growth of tree species were recorded on accounting sites in strips on 2–5 % of the plot area. The most successful natural regeneration of Scots pine was found at fresh and humid oak-pine relatively poor forest types, with the density of stocking 0.4. The density of 3–4-year pine young growth was 9–34 thousand plants per ha, which corresponded to a successful regeneration rate. In the final stage of shelterwood cutting, more than 70 % of Scots pine and other species seedlings were preserved, which is sufficient for the formation of valuable stands of natural origin. Shelterwood cutting is an important system of measures for close-to-nature forestry.

Key words: regeneration success rate, Scots pine, self-sown seedling, young growth.

Introduction

Shelterwood cutting is carried out in mature stands to preserve the young growth of the main species and ensure the regeneration of valuable accompanying tree species. The gradual and selective cutting in forest stands is consistent with the European forest management strategy, which aims to preserve continuous forest cover (Mason et al. 2021).

In Ukraine, shelterwood cutting in pine stands was used for first time at the beginning of the twentieth century (Alekseev 1927, Pogrebniak 1968, Zhezhkun 2021). The vast majority of it in previous years was carried out in pine stands for the natural regeneration of Scots pine (*Pinus sylvestris* L.) (Megalinskiy and Nakonechniy 1965, Romashov 1971, Zhukovskyi et al. 2021). After shelterwood cutting, a satisfactory natural regeneration of English oak (*Quercus robur* L.) (Tikhonov 2018) and small-leaved linden (*Tilia cordata* Mill.) occurs (Zakamskii 2019).

Shelterwood cutting should not be carried out in the case of low wind resistance of stands (Brown et al. 2015), weak seed

yield in low-yielding years.

Clear-cuttings, compared with other logging systems, have higher efficiency: a high income from the sale of wood from 1 ha of the forest stand, in the case of rapid reproduction of the natural forest stand due to natural regeneration and high growth rates of self-sown seedling on the cutting area and remove of derived stands and exotic crops, the regeneration of which is not desirable (Brown et al. 2015).

The use of shelterwood cutting has environmental advantages over clear-cuttings, namely: regeneration of native indigenous stands of natural origin, absence of need to create forest plantations, reduction of the regeneration period, preservation of soil fertility, protecting and environmental functions of forests. According to its economic feasibility, an increase in the yield of wood per unit area, an increase in forest productivity, but, at the same time, an increase in the cost of 1 m^3 harvested wood (by 15–20 %) compared to clear-cutting, damage to trees left until the next cutting stage, grass cover growth. A considerable amount of young growth is damaged and destroyed during subsequent shelterwood cutting techniques. Therefore, it is not widely used, and the main method of final felling is clear-cuttings with the subsequent creation of forest crops at the clear-cuts (Gordienko et al. 2002). However, artificial stands and monocultures have low biotic resistance, which leads in modern conditions on the background of global climate change to a decrease and cessation of growth processes, weakening and mortality of pine stands (Gilliam 2016, Meshkova and Borysenko 2018, Hlasny et al. 2019, Reyna et al. 2019, Klein 2020, Zhezhkun and Porochniach 2020). In many sites, shelterwood cutting was not completed, as they were not sufficiently reforested with Scots pine and other valuable tree species.

So, various authors have obtained controversial results of the success of the natural regeneration of Scots pine and the feasibility of using shelterwood cutting for final felling. Therefore, it requires clarification and coverage of this problem in our article.

The aim of the research is to study the features of regeneration of Scots pine stands after shelterwood cutting.

Material and Methods

The research was carried out in Eastern Polissya of Ukraine, located on the left bank of the Dnieper River within the northern part of Chernihiv, Kyiv and Sumy regions. The climate of the region is temperate-continental. The average annual temperature is 6.6 °C, the average annual precipitation is 501–600 mm. The forest cover of the region is 25.6 %. As of 01.01.2011, the forest fund occupies 697,000 ha (6.7 % of the forest area of Ukraine). Stands with predominance of Scots pine cover 66.4 % of the forested land, English oak stands – 11.3 %, silver birch (*Betula pendula* Roth.) – 10.4 %. Pine stands are mostly of artificial origin (81.9 %), dominated by V–VIII age classes (50–80 years). The share of pines over 81 years is 19.7 % (Zhezhkun 2021).

Regeneration of tree species was studied in pine stands in which shelterwood cutting was planned. Pine stands were mainly of artificial origin, monocultures, or with an admixture of other species, with a density of stocking of 0.6–0.9. Permanent sample plots (PSP) were laid following the requirements (MAPU 2006). Estimation of evaluation indicators was carried out using regulatory reference materials (Kashpor and Strochynskyi 2013). Alek-

seyev-Pogrebnyak typology was used to classify forest types (Ostapenko and Tkach 2002). The research was carried out in two forest types: fresh relatively poor oak-pine type (B_2-dC) and wet relatively poor oak-pine type (B_3-dC).

Shelterwood cutting was carried out in two stages. At the first stage, dead-standing, trees with dead tops and other defects of all species, silver birch (*Betula pendula*), aspen (*Populus tremula* L.), goat willow (*Salix caprea* L.) trees were assigned to the felling, which regeneration was not desirable. Among trees of Scots pine, those with a crown length less than 1/3 of the height, as well as wide-crowned trees with a slope of trunks and other defects were assigned to cutting. In the final stage, all trees were cut. The technology of cutting operations provided for preliminary cutting of young growth, removal of dangerous trees. Felling of trees, pruning of branches in lines with a width of 50 m was carried out with chainsaws; skidding of tree trunks or their parts along technological corridors with a width of 5 m to the upper log yard was carried out by using wheeled tractors with a skidding device. Felling debris were placed in small piles and burned after a fire-prone period.

During the skidding of wood, the litter was removed and the soil was mineralised (up to 30 % of the site area). Measures to support natural regeneration also included: loosening the soil with disk cultivators, laying plow furrows, sowing pine seeds.

After the final stages of shelterwood cutting, the following categories of damage to the pine young growth were identified: top and branch breakage; stem slope of more than 20 °; bark peeling; crown damage.

Assessment of pine seeds under the canopy of thinned pine forests was carried out by the method of seed meters (Molotkov et al. 1993). In years with low seed yields, pine seeds were sown (1 kg·ha^{-1}) on cutting areas.

Assessment of self-sown seedling (1–2 years old) and young growth (older than 3 years) was carried out at sample sites according to the method of Pasternak (1990), in strips 20 m long and 2.5–4.0 m wide. The total area taken for assessment was 2–5 % of the cutting area. During assessment of young growth and self-sown seedling, its species composition, origin, age, viability, density, total assessed area and share of the site area were estimated. Surveys were performed separately for the mineralised and non-mineralised parts of cutting sites.

Regarding the criteria for assessing the progress of natural renewal, the success of renewal was determined according to the method of Pasternak, 1990 with our additions taking into account the number of viable undergrowth of Scotch pine, depending on age (Zhezhkun 2014, 2021). That is, at each site of uniformly gradual felling, the amount of pine undergrowth was taken into account and its progress was determined on an evaluation scale.

The data were verified, and a regression analysis of the amount of pine undergrowth was carried out depending on the density of pine forests in wet relatively poor oak-pine type (B_3-dC) using the standard Microsoft Excel software package.

Results

In the mature pine stands of State forestry enterprises of Chernihiv region of Ukraine, shelterwood cutting was carried out in 2013–2014 on an area of over 400 ha (Zhezhkun 2021). After the first cutting stage, the number of trees in pine stands

was 130–336 plants·ha^{-1}, basal area 9.9–30.3 m^2·ha^{-1}, the density of stocking – 0.2–0.6 (Table 1). For the first stage, from 91 (PSP 2-Brs) to 262 m^3·ha^{-1} of wood (PSP 1-Tpch) were removed. The intensity of felling varied from 24 % (PSP 4-Rdk) to 67 % (PSP 8-Krh) of growing stock. Experimental variants of shelterwood cutting exceeded the current standards (SFCU 2010). After the first stage in 2013, pine stands with a density of stocking 0.5 prevailed, and in 2014 – 0.4.

After the first stage of shelterwood cutting, up to 2–5 Scots pine trees per ha remained damaged (peeling of bark, or bark and wood), which made 1.3–2.4 % of the total number of remaining trees. About 3 thousands plants·ha^{-1} (91–95 %) of 3–5-year Scots pine regeneration were assessed at some sites.

After measures to support natural regeneration in the autumn of the cutting year or in the spring of the next year, the share of soil mineralisation was 50–60 % of the of the sample plot.

The number of young growth and self-sown seedling of Scots pine for 3–4 years after the first stage under the pine canopy was noticeably different (Table 2).

Discussion

In 2014, the seed production of Scots pine was low to medium (the number of seeds in seed collectors was 86–130 thousands seeds·ha^{-1}). With a sufficient number of pine seeds that fall on the mineralised soil after the first stage of shelterwood cutting, the emergence, survival, and growth of self-sown seedlings depended on the hereditary properties of plants, climatic, edaphic conditions under the canopy of sparse pine stands of certain forest types.

During January–March 2014, the pre-

Table 1. Forestry and evaluation indicators after the first stage of shelterwood cutting.

PSP	Species composition*	Age, years	Average height, m	Average DBH, cm	Density of stocking		Number trees·ha^{-1}	Growing stock, m^3·ha^{-1}	Forest type**
					Absolute, m^2·ha^{-1}	Relative			
8-Krh	10Pinsyl + Betpen	87	21.9	27.9	9.94	0.22	162	96	B_3-dC
1-Bat	10Pinsyl + Betpen, Querob	82	29.0	35.9	16.41	0.35	228	207	B_3-dC
1-Brs	10Pinsyl	82	25.5	30.0	18.71	0.39	263	215	B_2-dC
2-Brs	10Pinsyl + Querob	82	26.4	33.7	23.26	0.49	274	228	B_2-dC
1-Tpch	10Pinsyl	84	29.9	40.3	16.60	0.33	130	218	B_3-dC
2-Tpch	10Pinsyl + Poptre	84	30.2	42.9	23.00	0.45	155	290	B_3-dC
3-Tpch	10Pinsyl + Querob	84	29.3	37.2	25.56	0.52	236	330	B_3-dC
1-Blsh	10Pinsyl + Querob	88	28.8	35.0	23.65	0.47	263	287	B_3-dC
2-Blsh	10Pinsyl + Querob	88	29.5	36.6	15.70	0.31	172	209	B_3-dC
4-Rdk	10Pinsyl	86	26.2	34.3	30.29	0.63	336	351	B_2-dC

Notes: * Pinsyl – *Pinus sylvestris*, Poptre – *Populus tremula*, Querob – *Quercus robur*, Betpen – *Betula pendula*; ** B_2-dC – fresh oak-pine relatively poor forest type; B_3-dC – humid oak-pine relatively poor forest type.

Table 2. The abundance of young growth and self-sown seedling for 3–4 years after the first stage of shelterwood cutting.

PSPs	Number of natural Scots pine regeneration, thousand plants ha^{-1} by age groups				Regeneration success rate
	Self-sown seedling 1 year	Self-sown seedling 2 years	Young growth 3–10 years old	Total	
8-Krh	1.20	2.50	21.66	25.36	Good
1-Bat	1.34	2.42	8.98	12.74	Good
1-Brs	8.80	7.76	0.92	17.48	Satisfactory
2-Brs	2.30	6.40	0.50	9.20	Satisfactory
1-Tpch	-	5.33	10.17	16.5	Good
2-Tpch	0.83	3.96	26.87	31.66	Good
3-Tpch	2.08	6.12	6.50	14.70	Satisfactory
1-Blsh	0.78	2.94	26.60	30.32	Good
2-Blsh	1.16	1.66	30.60	33.42	Good
4-Rdk	2.40	1.20	1.80	5.40	Insufficient

cipitation was almost half of the long-term average for this period. Precipitation in April (31.1 mm) and May (47.9 mm) almost reached the annual average levels. According to surveys in the third decade of May 2014, Scots pine seedlings were found at all sites of shelterwood cutting, mainly in furrows, on the soil mineralised by disk cultivators and during skidding, and much less – at the plots with the intact forest litter.

In the absence of precipitation in June and exposure to high air temperatures (up to +32 °C) in some plots of shelterwood cutting, especially in fresh pine and oak-pine relatively poor forest type, pine self-sown seedling dieback was observed due to lack of moisture and damage caused by larvae of cockchafers. The increase in the temperature in July was regulated by an increase in precipitation (116.3 mm), which contributed to an improvement in the growth conditions of self-sown pine seedlings. In the future, the overlap of a period of high air temperatures in August and a decrease in precipitation (in August – 10.2 mm, in September – 33.8 mm, in October – 6.2 mm) determined critical conditions for the survival and growth of pine self-sown seedlings.

The next year after the first stage of shelterwood cutting in 2013, successful natural regeneration of pine took place at the sites with a total area of 44.6 ha (20.8 %). The most successful was found in the pine forests of the humid oak-pine relatively poor forest type with thinned to 0.4 of the density of stocking and furrowing: as of 09.10.2014, the density of 1-year self-sown seedling of pine was 24.3–58.3 thousand plants·ha^{-1}. It should be noted that there was no significant difference in the number of 1-year self-sown seedling of pine trees between the options with and without additional sowing in 2014.

Within 3–4 years after the first stage of shelterwood cutting in 2013, most of the Scots pine young growth was preserved and the density of regeneration was replenished by self-seeding. In the pine forests of the humid oak-pine relatively poor forest type, successful regeneration was found at the plots with a total area of 69.4 ha (66.2 %), which is twice as much as in the first year after cutting. In pine stands with a density of stocking

of 0.4, good and satisfactory pine regeneration was determined at 7 sample plots (77.8 %), with an area of 33.8 ha (88.3 %). At two plots (4.5 ha), poor and insufficient Scots pine regeneration in this forest type is explained by the suppression of regeneration by *Calamagrostis epigeios* (L.) Roth and damage by larvae of cockchafers (*Melolontha melolontha* L.). In Scots pine stand, with a density of stocking 0.31, 3 years after the 1st stage of shelterwood cutting 30.6 thousand plants·ha^{-1} (20 %) of 3-year-old pine young growth were preserved and natural regeneration in an amount 1.7 thousand plants·ha^{-1} 2-year-old and 1.2 thousand plants·ha^{-1} 1-year-old self-sown seedlings were revealed (Table 2). Therefore, it is advisable to reduce the density of stocking of pine forests to 0.3–0.4, which is consistent with the data (Karaziya 1982), provided that the wind resistance of thinned pine stands is preserved (Brown et al. 2015).

The process of accompanying pine regeneration in pine forests at fresh oak-pine relatively poor forest type is low due to insufficient soil moisture during seed germination and self-sown seedling growth, damage by cockchafer larvae, and competition with the grass cover. After the first stage of shelterwood cutting in 2013 with a decrease in density of stocking of 0.5 or more and soil mineralisation for 3–4 years, the natural regeneration success rate of pine was estimated as 'insufficient'. The number of 3–4 years old pine young growth is 2.0–6.3 thousand plants·ha^{-1}, 1–2-year-old self-seedings – 0.1–9.8 thousand plants·ha^{-1}. In pine forests with a density of stocking of 0.4, the regeneration success rate is satisfactory (PSP 1-Baht, PSP 1-Brs). Dryness of the soil and air were the highest in areas bordering cutting area, opened forest plantations, young forest stands which were one of the obstacles for the successful regeneration of pine, which is consistent with the data (Alekseev 1927).

In pine forests of fresh poor forest type, thinned out to a density of stocking of 0.5 without the support of regeneration at the first year of cutting and subsequent 3–4 years, the success rate of natural pine regeneration was unsatisfactory. The placement of pine young growth is uneven (the occurrence is 46–60 %).

Insufficient pine regeneration was determined under the canopy in most pine stands thinned to a density of stocking of 0.5 or more (PSP 4-Krh), as well as a result of grass cover growth in areas without natural regeneration support. In pine stands, with a second layer formed by *Robinia pseudoacacia* L., dense undergrowth of *Corylus avellana* L., abundant grass cover formed by *Calamagrostis epigeios*, pine regeneration is unsatisfactory. Therefore, in general, in pine stands thinned at the first stage of experimental shelterwood cutting in 2013, successful natural regeneration within 3–4 years occurred on 19 plots (32.2 %), with a total area of 76.3 ha (35.5 %).

In winter, the snow cover protects self-sown seedling from low temperatures, but in some years pine trees were affected by snow/needle blight (caused by the pathogen *Phacidium infestans* Karst.). During December 2014 – January 2015, the amount of precipitation was less than normal (snow cover melted in the second half of January), in February there was no precipitation at all, in March (20.2 mm) and April (20.4 mm) precipitation was low. A decrease in precipitation and an increase in air temperature in April – May contributed to the opening of pine cones. In 2015, with a high yield, from 540 to 1046 thousand plants·ha^{-1} of pine seeds fell under the canopy of pine forests thinned out by

the first stage of shelterwood cutting.

Under a favourable hydrological regime in May 2015 (precipitation – 145.7 mm or more than 3 times more than in previous years), seeds sprouted and the first pine shoots appeared on May 21. In June–July, precipitation (187.7 m) exceeded the long–term average by 75–100 mm. These conditions probably ensured the safety of self-sown seedling of pine trees during August (there was no rain) and in September, when only 20.2 mm of precipitation fell, and the sum of active temperatures for this month exceeded the long-term average. The dry period continued in October 2015 (14.9 mm of precipitation). In general, during 2015, the sum of active temperatures (2973 °C) was 1.3 % less, and the amount of precipitation (522.9 mm) was 39.5 % higher compared to the previous year. Therefore, better pine seed yield and favourable weather conditions in 2015 should have contributed to successful natural regeneration.

In pine stands of fresh oak-pine relatively poor forest type after the first stage of shelterwood cutting (2014) with a decrease in density of stocking to 0.30–0.32 and furrowing in March, as of 29.10.2015, from 19.1 to 24.0 thousand plants·ha^{-1} of 1-year-old self-sown seedlings of pine trees were registered. For 3 years, 8.1–17.6 thousand plants·ha^{-1} (42.4–73.3 %) of pine growth were preserved and its number was replenished by 3.5–7.0 thousand plants·ha^{-1} of 1–2-year-old self-sown seedling, which is sufficient under such conditions to complete shelterwood cutting.

In the pine forests of fresh oak-pine relatively poor forest type after the first stage (2014) of the shelterwood cutting with a decrease in density of stocking to 0.4 and satisfactory pine regeneration in the first year, the next two years the number of viable young growth, up to 0.5 m high (8.5–17.9 thousand plant·ha^{-1}) exceeds the standard (8 thousand plants·ha^{-1}), it has a uniform placement, which allows you to assign the final stage. After thinning the pine forests to a density of stocking of 0.5, for 3 to 4 years, the success rate of natural pine regeneration was satisfactory only in one third of the plots. Therefore, in the pine forests of fresh oak-pine relatively poor forest type, at the first stage of shelterwood cutting, it is more expedient to reduce the density of stocking to 0.4 and implement measures to support natural regeneration.

In pine stands at humid oak-pine relatively poor forest type, after the first stage of shelterwood cutting (2014), with a decrease in density of stocking to 0.3–0.4, preservation of young growth and soil mineralisation, a satisfactory regeneration of pine occurs. This is confirmed by the results of studies on shelterwood cutting sites in 2013. The density of 3–4-year-old pine young growth in pine forests with a density of stocking of 0.4 was 8.8–34.7 thousand plants·ha^{-1}, and with a density of stocking 0.3–9.1–11.3 thousand plants·ha^{-1} (Fig. 1). However, without measures to support regeneration, the amount of young growth and self-sown seedling of pine trees did not reach the standard and was 1.8–4 times less than in areas with soil mineralization. Therefore, even in the seed year after the first stage, it is desirable to carry out soil mineralisation.

In pine stands at humid oak-pine relatively poor forest type after the 1st stage of shelterwood cutting (2014) with a decrease in density of stocking to 0.5 and soil mineralisation, during the first year, a satisfactory accompanying regeneration of Scots pine occurred only in one PSP, and for the next 2–3 years – in

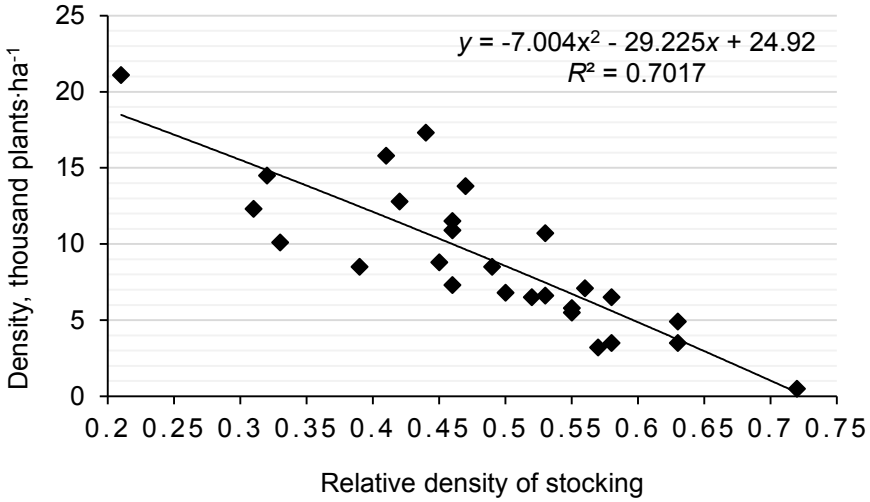

Fig. 1. Dependence of the density of young growth on the relative density of pine stands.

most areas, which is consistent with the results obtained in the cutting areas of 2013. The density of 3–4 – year young growth of Scots pine is 7.7–28.5 thousand plants·ha^{-1}, self-sown seedling – 2.2–20.2 thousand plants·ha^{-1}, young growth of English oak of seed origin – 0.3–3.3 thousand plants·ha^{-1}, of English oak of coppice origin – 0.6–1.1 thousand plants·ha^{-1}. The final stage can be assigned after 4 to 5 years from the start of cutting.

Satisfactory natural regeneration was determined in sites with preserved pine young growth (2.7–3.2 thousand plants·ha^{-1}) after thinning of pine stands of fresh and humid oak-pine relatively poor forest type with the first stage of shelterwood cutting to a density of stocking of 0.4–0.5 and replenishment with accompanying regeneration.

In pine stands, with the presence of the second layer of *Robinia pseudoacacia*, dense Hazel undergrowth, abundant grass cover from *Calamagrostis epigeios* after the first stage, the accompanying regeneration of pine similar to the previous year was unsatisfactory so, in general, in pine stands thinned out by the first stage of shelterwood cutting in 2014 for 3–4 years, good and satisfactory natural regeneration occurred on 20 plots (42.6 %), with a total area of 65.1 ha (35.5 %).

Thus, in mature pine stands, after the first stage carried out in 2013–2014, the process of natural regeneration of valuable species occurred noticeably differently. The most successful regeneration took place in the pine forests of fresh and humid oak-pine relatively poor forest type with sufficient seed production, after thinning to a density of stocking of 0.4 and measures to support natural regeneration.

In sites where a satisfactory natural regeneration of pine and other valuable species for 4–5 years occurred, the final stage of shelterwood cutting was carried out. The yield of industrial wood was 85–89 % of merchantable wood. During the final stage of cutting, from 9.1 to 26.8 thousand plants·ha^{-1} (71.3–96.2 %) of pine young growth were preserved (Table 3). The most common damage to the young

Table 3. Preservation of pine young growth after the final stage of shelterwood cutting.

PSPs	Number of pine young growth							
	After cutting	Without damage	Types of damage					Total
			Top break	Breaking branches	Slope > 20 °	Peeling of the bark	Crown damage	
8-Krh	16.46	3.80	1.68	3.62	2.50	0.52	4.34	12.66
	100	23.1	10.2	22.0	15.2	3.1	26.4	76.9
1-Bat	9.08	0.22	2.30	0.52	5.04	0.36	0.64	8.86
	100	2.4	25.3	5.7	55.5	4.0	7.0	97.6
1-Blsh	25.6	9.40	1.10	4.00	2.60	-	8.50	16.2
	100	36.7	4.3	15.6	10.2	-	33.2	63.3
2-Blsh	26.80	9.70	1.00	5.10	5.20	-	5.80	17.10
	100	36.2	3.7	19.0	19.4	-	21.7	63.8

Note: in the numerator are thousands of plants·ha^{-1}, in the denominator, %.

growth was crown damage and stem slope of more than 20 ° from the vertical. To reduce damage to the young growth, skidding of wood should be carried out only along the technological corridor.

After the final stage of shelterwood cutting, the young growth of English oak (0.1–0.8 thousand plants·ha^{-1}) and silver birch (0.1–1.7 thousand plants·ha^{-1}) are also preserved. The frequency of occurrence of young growth of economically valuable species is 75–90 %, including 73–84 % of Scots pine. During the first year after the final stage of the cutting, a viable young growth of Scots pine prevails, aged 5 years, with an average height of 0.6–1.0 m. At PSP 1-Bat, the current annual growth in height of 5-year-old pine trees (18.2 ±1.02 cm) is more than 3 times greater than that of 3-year-old trees (5.3 ±0.48 cm). Plow furrows have been laid in the technological corridors and upper log yard to facilitate the subsequent regeneration of pine trees.

So, after carrying out two stages of shelterwood cutting in fresh and humid oak-pine relatively poor forest type in mature pine forests, successful natural regeneration and preservation of Scots pine young growth are ensured. Thinnings here in the future should form stable oak-pine stands.

Based on the results of shelterwood cutting, stands of mixed composition and natural origin are formed. After carrying out it in pine stands the diversity of tree species increases, structural diversity increases, the genetic intraspecific variability of trees is maintained and increases, and the resistance of trees to adverse biotic and abiotic factors increases, which corresponds to the principles of close-to-nature silviculture (Brang et al. 2014, Krynytskiy and Chernyavsky 2016).

Conclusions

As a result of the research, the following conclusions were obtained:

For the reproduction of stable pine stands of natural origin, shelterwood cutting is used, aimed at using the natural regeneration of Scots pine and valuable accompanying tree species. It is an important system of measures for close-to-nature forestry.

In pine stands of fresh oak-pine relatively poor forest type after the first stage of shelterwood cutting with a decrease

in density of stocking up to 0.5, the natural regeneration of Scots pine is mainly unsatisfactory. After reducing the relative density of the stocking of pine stands to 0.4–0.3 and implementing soil mineralisation on the eve of the seed year, the natural regeneration of pine trees is satisfactory. The number of 3–4-year-old young growth of Scots pine is 8.1–18.0 thousand plants·ha^{-1}. It is evenly distributed at the site and has a height of up to 0.5 m. Under such conditions, the final stage of cutting should be scheduled 4 to 5 years after the first stag.

In Scots pine stands at humid oak-pine relatively poor forest type after the 1st stage of shelterwood cutting with a decrease in relative density of stocking to 0.5 and soil mineralisation, during the first year, satisfactory regeneration of Scots pine occurs only at some sites, and for the next 2–3 years – at most sites. The largest amount of Scots pine young growth accumulates under the canopy of pine stands, thinned out to a relative density of stocking 0.4 (8.8–34.7 thousand young growth plants·ha^{-1}) and up to 0.3 (9.1–11.3 thousand plants·ha^{-1}). In some sites, poor and insufficient pine regeneration is explained by the suppression of self-sown seedlings by *Calamagrostis epigeios* and damage by cockchafer larvae.

Good and satisfactory natural regeneration was assessed at the sites with preserved pine young growth (2.7–3.2 thousand plants·ha^{-1}) after thinning the pine forests of fresh and humid oak – pine relatively poor forest type in the first stage of shelterwood cutting to a density of stocking of 0.4–0.5 and replenishment with individuals of accompanying regeneration.

During the final stage of shelterwood cutting, from 9.1 to 26.8 thousand plants·ha^{-1} (71.3–96.2 %) of Scots pine young growth trees are stored, 0.1–0.8 thousand plants·ha^{-1} of English oak, 0.1–1.7 thousand plants·ha^{-1} of silver birch. The frequency of occurrence of young growth of economically valuable species is 75–90 %, including pine – 73–84 %. During the first year after the final stage viable pine young growth aged 5 years prevails, with an average height of 0.6–1.0 m. In the future, it is necessary to form stable pine stands of mixed composition and natural origin.

It is necessary to assign shelterwood cutting in mature pine stands of fresh and humid oak-pine relatively poor forest types in case of undergrowth layer relative density below 0.3, and absence of grass cover. The first stage and measures to support the natural regeneration of Scots pine and other species should be carried out in the seed year before the start of opening cones. The share of soil mineralisation should be more than 60 % of the site area. In the presence of self-sown seedlings and young growth of pine trees under the canopy, it is necessary to ensure its maximum safety. In the final cutting stage, it is necessary to ensure the safety of more than 70 % of the young growth of Scots pine and other valuable species.

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INFLUENCE OF CLIMATIC FACTORS ON RADIAL GROWTH OF *PINUS STROBUS* L. AND *PINUS PEUCE* GRISEB. IN MOSCOW REGION

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Abstract

Most dendrochronological studies on conifers in Moscow region and on Russian plain in general focused to Scots pine (*Pinus sylvestris* L.) and Norway Spruce (*Picea abies* (L.) Karst). This study is focused on the chronology analysis in non-native pines from *Strobi* section: Eastern white pine (*Pinus strobus* L.) and Macedonian pine (*Pinus peuce* Griseb.) in Moscow city, Moscow region and some neighboring regions, with particular attention to climatic signal in tree-ring chronologies. The study revealed climatic factors that significantly correlate with the growth dynamics of the tested trees. The studied chronologies contained a drought-associated climatic signal, and the nature of the signal differed among the species and among chronologies of the same species obtained from various geographical areas. The most important effect had the climate conditions in May, both for different locations and for different species. The cluster analysis showed similarities in chronologies of the white pine for sites located in a closer proximity to each other, thus proving that site-specific ecological conditions influenced the growth dynamics in a specific manner. This regular pattern can be used as a basis for developing methods of wood origin identification.

Key words: dendrochronology, dendroecology, drought impact on radial growth, Eastern white pine, Macedonian pine, wood origin identification.

Introduction

Most dendrochronological and dendroecological studies on the conifers in Moscow region and on the Russian plain have been performed on Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst) (Solomina et al. 2017). Such kind of investigations may have importance for progress in the forestry practices and can provide unique information about the ecological patterns of growth, which often cannot be obtained from other sources (Rumyantsev 2010).

On the one hand, the impact of climatic variability on radial growth fluctuations is closely related to hereditary ecological properties of the studied species, mainly to such characteristics like tolerance to drought, heat, frost, and cold.

On the other hand, local growing conditions affect the formation of patterns of annual radial growth fluctuations. Consequently, being unmatched in time the tree

ring width fluctuation patterns appear to be similar in all trees of the same species growing in homogeneous site conditions. This regular pattern serves as a basis of many methods to identify the origin of logged timber, as shown in the publications devoted to this issue (Rozanov 1969, Palchikov and Rumyantsev 2009, Sinkevich 2014, Goncharuk and Mayorova 2015, Voronin et al. 2016).

In this study, we examined chronologies of Eastern white pine (*Pinus strobus* L.; called hereafter 'white pine') and Macedonian pine (*Pinus peuce* Griseb.) from Moscow city, Moscow region and some other regions for comparison. These species are evolutionarily closely related to each other (Eckenwalder 2009). White pine has long been considered a promising species for wide introduction in Russia for the purpose of timber producing plantations. However, the sensitivity of this species to the White pine blister rust (*Cronartium ribicola* Fisch) did not allow this program to be implemented (Tsarev et al. 2002).

Our knowledge of regularities of annual rings changes helps the better understanding of their ecological significance, and understanding the ecological conditions favorable for cultivation of a given species in the long-term perspective. Dendroecological study of these two species in the Russian regions has not been performed before. Therefore, the results of such study would be of general biological significance, revealing the effect of climatic factors on the growth of species cultivated far from their natural range and located in unusual (that is, stressful by definition) conditions.

Dendroclimatic investigations in the natural range of white pine performed with bootstrapped correlation analysis indicated that the radial growth was negatively associated with summer temperature (i.e., June and July) of the current growing season in both floodway and terrace sites (Chin et al. 2013).

In other part of the white pine natural range, dendroclimatic models revealed that radial growth responses to climate were complex and differed among sites (Chin et al. 2018). The key dendroclimatic relationships observed included sensitivity to high temperature in winter and summer, cold temperature in the spring and fall (i.e., beginning and end of the growing season), summer moisture stress, potential sensitivity to storm induced damage in spring and fall, and both positive and negative effects of higher winter snowfall. Separation of the loadings of provenances on principal component axes was mainly associated with temperature-related bioclimatic parameters of provenance origin at 5 of the 7 test sites close to the climate influence of the Great Lakes (i.e., Wabeno, Manistique, Pine River, Newaygo, and Turkey Point). In contrast, differences in radial growth response to climate at the Ganaraska test site were driven more by precipitation-related bioclimatic parameters of the provenance origin location, while radial growth at the easternmost Orono test site was independent of bioclimate at the provenance origin location. Study results suggest that genetic adaptation to temperature and precipitation regime may significantly influence radial growth performance of white pine populations selected for use in assisted migration programs to better adapt white pine to a future climate.

The great interest also has the results of the investigation of tree-ring chronology of *Pinus peuce* from treeline locations in the Pirin Mountains in Bulgaria showed the strong climatic signal (Panayotov et al. 2010). Climate-growth relationships

were computed with bootstrap correlation functions and their consistency over time assessed by calculating the correlations over shortened periods. In addition, climate situations in the years with unusually narrow or wide tree rings were reviewed and analyzed. The species is negatively influenced by previous summer drought conditions and cold winters. Early summer temperatures were positively correlated with *P. peuce* radial growth.

The comparison of radial growth models in the natural area with results the growth investigation in introduction is important for understanding the ecophysiological potential of the species. The purpose of our study was to investigate the interannual variability of tree rings width of Eastern white pine and Macedonian pine and to establish how climatic factors impact radial growth in time series and how this impact can be modified by genetical ecophysiologies features of the species or local environment condition.

Materials and Methods

This study involved materials collected in the Arboretum of Mytischi Branch of Bauman of the Moscow State Technical University (the university was known under the name Moscow State Forest University (MSFU) until 2016, so we use name “MSFU Arboretum” further in the article), the Main Moscow Botanical Garden of Russian Academy of Sciences, the Botanic Garden of Moscow State University, and the Pereslavl Arboretum (Yaroslavl region), Ahunsky Arboretum (Penza), Ugra National Park (Kaluga region), Poreczkoe Forestry Service (the west of Moscow region).

Wood samples were obtained using a Pressler increment borer; cores were taken from the trees at a height of 1.3 m with a spot on the stem being chosen at random and the samples were stored in paper envelopes until used. The following details were recorded for each core: test site, species, tree ID, sample ID, Kraft’s tree class (tree position in the stand social structure and its crown development and extent), height, diameter, and direction of sampling. Then, the collected and labeled samples were delivered to the Dendrochronological Laboratory of the Science and Education Center for Wood Investigation, Analysis and Expertise of MSFU to perform measurements with the LINTAB equipment in combination with the TSAP-Win software.

The cores were placed in a wooden background and the surface of the cores was wetted with water, cleaned with a razor blade and rubbed with chalk powder. This contributed to the clear recognition of the boundaries of annual rings. Tree ring widths were measured with a precision of 0.01 mm. Cross-dating was carried out to verify the measurement results in TSAP-Win program. The methodology is similar to one described in previous papers (Lovelius et al. 2013, Rumyantsev and Cherakshev 2013). The obtained radial growth series were indexed by dividing of tree ring width to the average tree ring width observed in the last five years. Next, a mean group chronology was calculated for each species from each geographic area based on individual indexed chronologies. The parameters of testing generalized chronologies are presented in Table 1.

The distribution of plots in the territory of Russian plain is shown in Figure 1. The main topic of scientific interest was the tree ring variability of Strobi pines in Moscow region, but for good understanding of its specific patterns it was necessary

Table 1. Parameters of testing chronologies.

Object	Species	Individual chronology with maximum length, years	Number of testing trees	Number of cores	Number of measured tree rings
MSFU Arboretum	White pine	1962–2013	5	10	481
	Macedonian pine	1978–2013	12	24	701
Main Botanical Garden of Russian Academy of Sciences	White pine	1963–2014	12	24	1115
	Macedonian pine	1965–2014	12	24	1060
Botanic Garden of Moscow State University	White pine	1963–2014	4	4	169
Pereslavl Arboretum	White pine	1979–2013	7	14	419
Poreczkoe Forestry Service	White pine	1918–2018	25	25	2364
Ugra National park	White pine	1915–2018	10	10	788
Ahunsky Arboretum	White pine	1920–2017	17	17	1216
Sum			104	152	8313

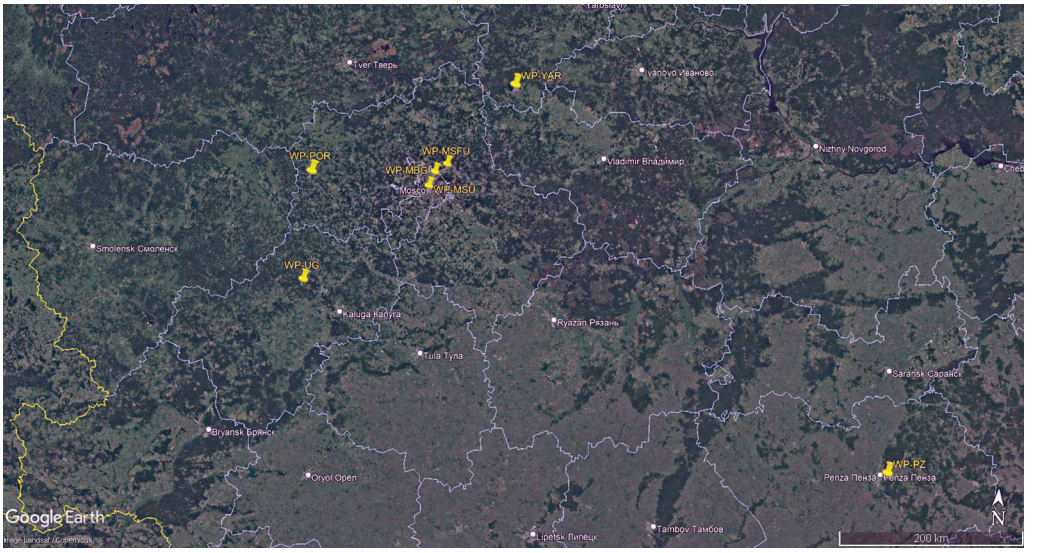

Fig. 1. Geographical location of sample sites (from Google maps).

Note: sample site locations: WP-PZ – Ahunsky Arboretum in Penza region; WP-YAR – Pereslavl Arboretum in Yaroslavl region; WP-MSU – MSU arboretum in Moscow; WP-MSFU – MSFU arboretum in Moscow region; WP-MBG – MBG arboretum in Moscow; WP-UG – Urge National Park in Kaluga region; WP-POR – Porezckoe forestry arboretum at the west border of Moscow region.

to investigate different plots situated at some distance from Moscow. Therefore, the possibilities for choice the study areas were not vast. Plots situated westward from Moscow (WP-PZ), south-west (WP -UG), north-east (WP-YAR), south-east (WP-PZ, the most remote site) were sampled.

Such kind of plot distribution allowed to study the possibilities of identifying the place of origin of felled wood according to dendrochronological data. Also, it was important for analyzing the specific patterns of the influence of climatic factors on the dynamics of radial growth. Only two of study areas had the stands formed by the Macedonian pine. They were located in Moscow and Mytischi town (near the border line of Moscow city and in fact, in Moscow from a biogeographic point of view). The analysis of the dynamics of radial growth of this species was compared with that of Eastern white pine, which was important in the light of their biological and ecological proximity, with considering the specific ecological requirements of Macedonian pine.

All calculations were performed in Microsoft Excel. STATISTICA 6.0 was used for cluster analysis. This application has a wide statistic possibility for cluster group construction. At this research stage the simplest variant: Euclidean distance calculation and association in clusters by the rule of ‘single linkage’ was used. The question of the best option for clustering of dendrochronological information in dendroecological studies requires further studies.

The climatic data (2004–2021) from several sources were used: specialized meteorological web portal (Weather and Climate 2021), Pereslavl-Zalessky meteorological station, Moscow meteorological station, Penza meteostation, and for Ugra national park the data from Kaluga meteorological station were used.

The period for statistical analysis was limited by the length of all chronologies and was set to 1987–2013, as the trees had different age and the sampling took place in different years.

The climate of Moscow city was characterized by using the Main Botanical Garden data (Plotnikova et al., 2005), which can be considered as a central point in relation to the other test sites. The date of transition of the average daily temperature through 0 °C is marked in spring 5th of April and in autumn 5th of November, and hence the frost-free period lasts 214 days. The transition through 5 °C conventionally taken as the beginning of the growing season is observed in spring at 20th of April and in autumn at 5th of November. The duration of the growing season is 173 days. The average annual air temperature is 3.7 °C, the absolute minimum is -40.8 °C, the absolute maximum is 35.8 °C. The soils are loamy sod-medium podzolic (Umbric Albeluvisols Abruptic).

The conditions of tree growth in plantings are similar to the conditions of their growth in natural stands. This was one of the goals for testing their growth in introduction in order to assess the possibilities of using species in the forestry practice. The stands had not experienced currently any intensive sylviculture treatment such as irrigation, fertilization and so on; however, for some sites there is lack of information about their treatment in the past.

Results and Discussion

The generalized indexed chronologies of white pine were analyzed using a cluster analysis method with the STATISTICA 6.0 software. Figure 2 shows the results.

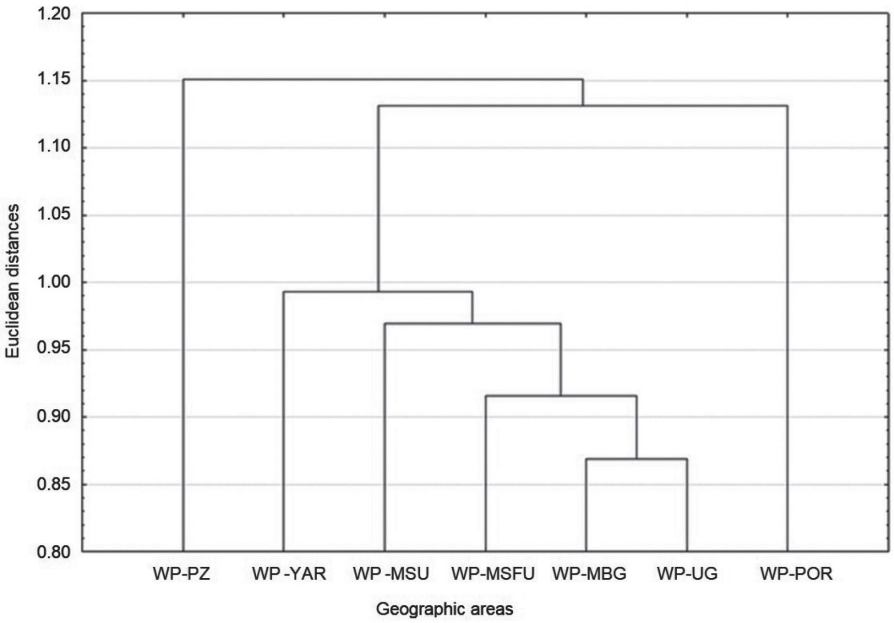

Fig. 2. Results of the cluster analysis of the indexed tree-ring chronologies of white pine in various geographic areas.

Note: the chronologies of *Pinus strobus* are plotted on the abscissa by regions: WP-PZ – from Ahunsky Arboretum in Penza region; WP-YAR – from Pereslavl Arboretum in Yaroslavl region; WP-MSU – from MSU arboretum in Moscow; WP-MSFU – from MSFU arboretum in Moscow region; WP-MBG – from MBG arboretum in Moscow; WP-UG – from Ugra National Park in Kaluga region; WP-POR – from Porezckoe forestry arboretum at the west border of Moscow region.

As shown in Figure 2, a similarity range of chronologies within one species as a whole is in direct relationship with the pairwise distance between the sites. The chronologies obtained from the MSFU Arboretum are more similar to the ones obtained from the Main Botanical Garden located nearby, in the northeastern part of Moscow, than to those from the Botanic Garden of Moscow State University located in the southwestern part of Moscow. However, together they form one cluster when compared to the chronology from Yaroslavl region (Pereslavl Arboretum, about 130 km from Moscow) and Porezckoe forestry service (about 77 km from Moscow). The chronology from the Penza region (about 550 km from Moscow) opposes the entire large cluster of chronologies as an equivalent cluster, which is expected in the light of its remoteness. Only the chronology of Ugra Park (about 180 km from Moscow) had a position in cluster, which is not correlating with its geographical location.

The cluster analysis really is a complex of methods, with different variants to organize the group. Some of groups may have biological interpretation, some of them no. Our results indicates that the established method of clustering gives a good biologically interpretable results, but does not fully meet the needs of dendroecological research yet and the statistical processing could be improved.

Another important and indicative indi-

cator is the correlation coefficient among the chronologies and time series of meteorological parameters (sum of monthly rainfall, average monthly temperature). In the present study we used both meteorological parameters of the year of tree ring formation and those of the preceding year (tables 2–6).

Table 2. The values of the correlation coefficients between chronologies and average monthly temperatures in the year of the formation of the annual ring.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0.04	0.04	0.32	-0.15	0.39*	0.31*	0.09	2
II	0.23	0.23	0.18	-0.27	0.53*	0.36*	-0.24	2
III	0.05	-0.11	0.07	-0.05	0.47*	0.10	-0.05	1
IV	0.21	0.15	0.26	-0.28	0.35*	0.02	0.14	1
V	-0.46*	-0.43*	-0.26	0.02	-0.44*	-0.41*	-0.31*	5
VI	-0.33*	-0.12	0.01	-0.21	-0.47*	-0.02	-0.24	2
VII	-0.10	-0.23	0.18	-0.19	-0.18	-0.04	-0.21	0
VIII	-0.17	-0.19	0.11	0.26	-0.05	0.02	-0.11	0
IX	-0.01	-0.20	0.13	0.05	-0.30	0.08	0.14	0
X	0.13	0.19	0.29	0.21	-0.02	0.23	0.26	0
XI	0.19	0.00	0.11	0.25	0.00	0.12	0.18	0
XII	0.19	0.25	0.25	0.39*	0.08	0.15	0.28*	2
NSCC	2	1	0	1	6	3	2	15

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Table 3. The values of the correlation coefficients between chronologies and average monthly temperatures in the year preceding the year of the formation of the annual ring.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0.25	0.20	0.05	-0.18	0.26	0.12	-0.06	0
II	0.29	0.10	0.02	-0.08	-0.02	0.17	-0.01	0
III	0.38*	0.20	-0.13	-0.05	-0.09	0.05	0.13	1
IV	0.18	0.01	0.00	-0.47*	-0.11	0.04	0.03	1
V	-0.03	-0.19	0.08	0.49*	-0.35*	0.04	-0.16	2
VI	0.21	0.21	0.19	-0.22	-0.02	0.27	-0.01	0
VII	0.14	0.05	0.35*	-0.08	0.00	0.12	0.04	1
VIII	-0.01	-0.09	0.21	0.15	-0.15	0.12	-0.04	0
IX	-0.02	-0.08	0.07	-0.03	-0.02	-0.11	0.02	0
X	0.25	0.14	0.40*	0.06	-0.03	0.23	0.35*	2
XI	-0.20	-0.39*	-0.01	0.22	-0.10	-0.13	-0.09	1
XII	0.29	0.19	0.50*	0.36	0.19	0.26	0.32*	2
NSCC	1	1	3	2	1	0	2	10

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Table 4. The values of correlation coefficients between chronologies and monthly precipitation sums in the year of the annual ring formation.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0.01	0.07	0.26	-0.03	0.13	-0.05	0.19	0
II	0.24	0.16	0.26	-0.07	0.10	0.11	-0.04	0
III	0.23	0.36*	0.28	-0.11	0.26	0.17	0.11	1
IV	-0.01	0.06	0.17	0.27	0.24	-0.15	0.12	0
V	0.50*	0.43*	0.22	0.22	0.20	0.05	0.01	2
VI	0.13	0.13	-0.05	0.14	0.55*	0.14	-0.13	1
VII	0.51*	0.51*	0.17	0.31	0.31	-0.01	0.02	2
VIII	0.14	0.26	0.02	0.19	-0.01	-0.13	0.15	0
IX	-0.26	-0.04	-0.14	-0.02	0.17	0.17	-0.20	0
X	-0.02	-0.15	0.28	-0.08	-0.06	0.02	0.02	0
XI	-0.08	-0.12	-0.02	0.19	0.07	0.06	-0.07	0
XII	0.13	0.11	-0.02	-0.15	-0.04	0.02	0.03	0
NSCC	2	3	0	0	1	0	0	6

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Table 5. The values of the correlation coefficients between chronologies and monthly precipitation sums in the year preceding the year of the formation of the annual ring.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0,06	0,20	0,08	-0,23	-0,25	0,12	0,05	0
II	0,12	-0,10	-0,07	-0,55*	-0,14	0,08	0,11	1
III	0,04	0,07	0,05	-0,48*	-0,07	-0,05	-0,04	1
IV	-0,09	-0,06	0,07	0,30	0,08	0,04	0,38*	1
V	-0,20	-0,30	-0,05	-0,08	-0,30	-0,30*	-0,33*	2
VI	-0,36*	-0,17	-0,17	0,22	0,36*	-0,08	-0,03	2
VII	0,26	0,02	0,02	0,19	0,04	-0,09	0,10	0
VIII	0,24	0,25	0,30	0,04	0,24	0,13	0,28*	1
IX	-0,04	-0,17	0,13	0,05	-0,07	0,19	-0,23	0
X	-0,15	0,04	-0,12	-0,28	0,00	-0,25	0,05	0
XI	-0,16	-0,10	-0,06	-0,16	0,06	-0,11	-0,24	0
XII	0,02	-0,05	0,09	0,02	0,23	-0,02	0,21	0
NSCC	1	0	0	2	1	1	3	8

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Tables 2–5 show that there were 24 meteorological parameters correlating significantly with the radial growth dynamics of white pine. The matrix of correlation coefficients includes 39 significant values out of 48 calculated as a whole. Some of them obviously do not have biological meaning and result from stochastic pro-

cesses (mutual correlation of time series of meteorological parameters as an example). So, for chronologies from Perslavl (WP-YAR) and Ugra (WP-UG), a significant correlation with December temperature of recent calendar year was identified. It cannot be interpreted in biological terms, as the ring formation in this time is already over. On our opinion, the parameters of October, November and December of the current year must be present in dendroclimatic investigation for good understanding the level of biologically significant values, which must be higher than parameters for this month.

When the distribution of significant values of correlation coefficients by month was analyzed, the maximum number of such values was found in May (Fig. 3).

It explains the specific effect of vegetation season periods on the cambium activity and xylem differentiation, which reflect integrally the ring width. It is important to consider that May is the period of the most active shoot growth and assimilation surface forming, which apparently predetermines photosynthetic activity and opportunities for the formation of xylem, and this factor influences the ring width in the current year, and also in the next year.

While analyzing the distribution of significant values of correlation coefficients by chronologies, it was found that chronology from Penza region (WP-PZ) demonstrates the maximum number (nine) of such values. This area has a dry climate. High temperatures of vegetation season negatively affect the ring width, while high amount of precipitation has positive affect. At the same time, this result has good comparability with data from the natural habitat in North America (Chin et al. 2013), taking into account the shifted growing season.

In our research, there was not a single meteorological parameter detected, for which a reliable correlation was found for all chronologies. Also, we did not reveal any reliable correlations that would be valid for all investigated sites. This is confirmed with the results of investigation within the natural area of species distribution (Chin et al. 2018). For five sites the greatest importance for annual ring formation of white pine had the temperature of May, which had negative effect on ring

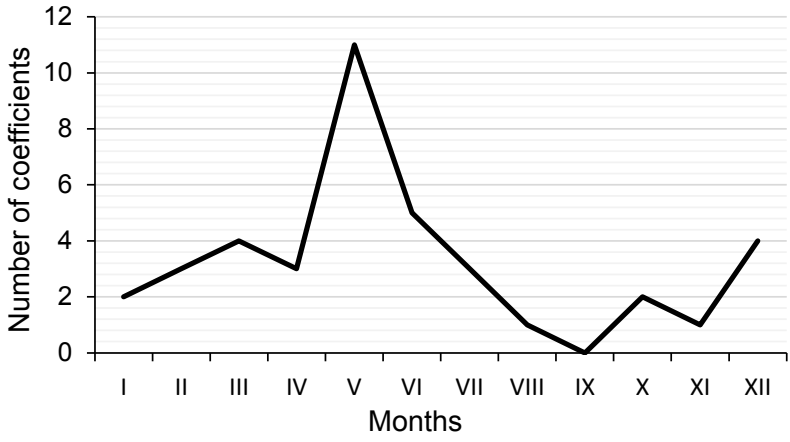

Fig. 3. The distribution of the number of significant correlation coefficient values by months.

width. Thus, if our hypothesis about irrigation the plantings of white pine in MSU and Pereslavl Arboretum on some time interval is right, that leads to conclusion that chronologies of white pine from Moscow region characterized the specific feature: express significant positive high-level correlation with the precipitation in May and July.

If we compare the effect of climate conditions of the current and the previous calendar year, it turns out that 21 reliable coefficients were found for the current year, and 18 for the previous one. The difference is not as great as one might expect, and we must consider that the influence of meteorological parameters on the tree ring formation continues also out of the vegetation period, when the cambium activity does not stop, as is well known from the Fritts (1976) models. The time of the period of the so-called 'winter rest' is in fact a period of stress state of the tree and has an integral indirect effect on its growth during the vegetation season.

The analysis the distribution of drought-related climatic signals in investigated chronologies is of particular interests, too. In this case, by drought-associated signals we mean significant positive correlations of the growth index with the total monthly precipitation of May, June, July and August, as well as reliable negative correlations with the monthly average temperatures over the same period. The coefficients of the current and previous year are taken into account. The calculations preformed for chronologies are presented in Table 6.

Thus, we can say that chronologies from two sites in urbanized environment contain a strong climatic signal caused by droughts, as does the chronology from the driest (of the investigated) region, which is situated in forest-steppe zone.

For Macedonian pine, a similar comparison of climatic signal distribution in chronologies taken from various areas was done only for the MSFU Arboretum and the Main Botanical Garden of Academy of Sciences. There were only a few Macedonian pine trees in Pereslavl Arboretum or the Botanic Garden of Moscow State University, and this species was not present at other sites. It is not appropriate to compare individual chronologies with the mean group chronologies based on ten or more trees. Table 7 presents the results of the correlation analysis.

As indicated in Table 7, the study revealed 12 meteorological parameters showing a reliable correlation with Macedonian pine radial growth indexes for at least one site under study. However, reliable correlations for both sites were observed only for the rainfall in May and in July of the current year. Higher rainfall has a positive impact on growth. These two meteorological variables were also the ones showing reliable correlations in white pine growing on the same two sites. The level of similarity in the short-term dynamics of growth among chronologies of the same species on different objects, and different species on the same object is of particular interest. One such graphical comparison is shown in Figure 4.

Table 6. Distribution of drought-associated signals in chronologies from different sample areas.

Code of chronology	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG
Number of coefficients	4	3	0	0	5	1	2

Table 7. Correlation coefficients between individual meteorological parameters for Macedonian pine.

Meteorological parameter with a detected reliable correlation for at least one site	MSFU Arboretum	Main Botanical Garden of Academy of Sciences
Rainfall in May of the current year	0.43*	0.32*
Rainfall in June of the current year	0.43*	0.07
Rainfall in July of the current year	0.52*	0.60*
Rainfall in May of the preceding year	-0.43*	-0.28
Average temperature in June of the current year	-0.42*	-0.19
Average temperature in July of the current year	-0.36	-0.32*
Average temperature in August of the current year	-0.45*	-0.17
Average temperature in October of the current year	0.21	0.37*
Average temperature in December of the current year	0.1	0.37*
Average temperature in September of the preceding year	-0.39*	-0.05
Average temperature in November of the preceding year	-0.30	-0.33*
Average temperature in December of the preceding year	0.19	0.41*
Number of significant coefficients	7	7

Note: * – significant correlation coefficient at confidence level of 0.95.

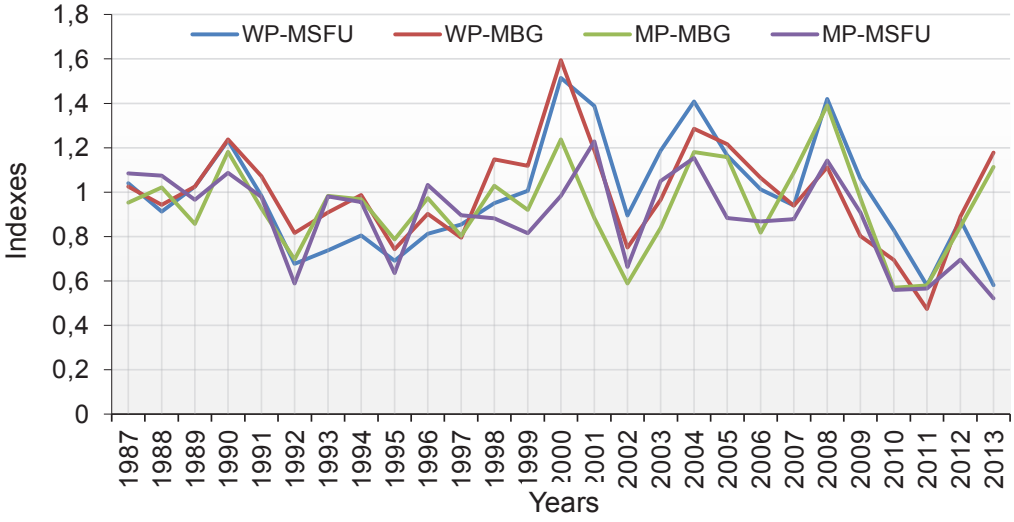

Fig. 4. Dynamics of radial growth indexes for two pine species.

Note: WP-MSFU – chronology of white pine from MSU arboretum in Moscow region; MP-MSFU – chronology of Macedonian pine from MSFU arboretum in Moscow region; WP-MBG – chronology of white pine from Main Botanical Garden arboretum in Moscow; MP-MBG – chronology of Macedonian pine from Main Botanical Garden arboretum in Moscow.

The time series presented in Figure 4 support the conclusion about great similarity of chronologies and high level of their synchrony, especially at the years of growth extrema. Also, the comparison of chronologies similarity is possible by using the results of the correlation analysis in Table 8. The coefficient was calculated between indexed chronologies for the period 1987–2013 years. At a confidence level of 0.95, the threshold values of significance were 0.38 or higher.

Table 8. Correlation coefficients between chronologies for White pine and Macedonian pine from different areas.

Code of chronology	WP-UG	WP-POR	WP-PZ	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	MP-MBG
WP-POR	0.23							
WP-PZ	0.54	0.28						
WP-MSFU	0.70	0.19	0.57					
WP-MBG	0.69	0.30	0.57	0.72				
WP-MSU	0.54	0.14	0.34	0.54	0.61			
WP-YAR	0.28	0.26	0.06	0.37	0.16	0.41		
MP-MBG	0.54	0.46	0.41	0.59	0.77	0.52	0.34	
MP-MSFU	0.42	0.45	0.44	0.74	0.54	0.30	0.46	0.59

The correlation analysis presented in Table 8 showed that chronologies of different species from the same location have greater similarity than these of the same species from different locations. Therefore, the local conditions impact prevailed over the genetical and eco-physiological features of species in the tree ring dynamic from year to year.

Conclusions

Local growing ecological conditions determine that radial growth dynamic formed by a different combination of limited meteorological parameters, and this creates a diversity in growth dynamics in chronologies of the same species it the located geographical sites. Being associated to various genetical and ecophysiological properties of the planting material, such as provenance, genetic factors may also contribute to dynamics diversity of time series of radial growth.

The correlation analysis of the generalized indexed chronologies of white pine and Macedonian pine compared to time series of meteorological parameters (monthly rainfall and average monthly temperature) shows reliable correlations for both pine species that are common for the test sites situated close to each other. The results of correlation and cluster analyses allow the conclusion that specific site conditions can be more important in terms of growth rate dynamics that specify genetical ecological properties of a species. The response to rainfall shortage in May and July represents a clear drought-associated signal in the chronologies of these species in Moscow. Also, May temperature is a significant factor for white pine chronologies from Moscow region, Kaluga region and Penza, and has negative impact on ring width.

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EFFECT OF TREE SHELTERS ON THE SURVIVAL AND GROWTH OF DECIDUOUS TREE SPECIES IN NORTH-WESTERN BULGARIA

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Abstract

The effects of tree shelters on the survival, height, and diameter growth of three deciduous tree species – common beech (*Fagus sylvatica* L.), sycamore (*Acer pseudoplatanus* L.) and sessile oak (*Quercus petraea* Matt. (Liebl.) were studied. The study was conducted in two experimental plantations, established in the spring of 2018 in the Training and Experimental Forest Range Petrohan (North-Western Bulgaria). Four experimental variants with tree shelters – Tubex Ventex Classic, Tubex Ventex Clear, Layflat Shelterguard, Layflat Treeguard and a control one (without tree shelters) were used. Twenty to twenty-seven seedlings in three replications of each variant and tree species were planted. The experimental plantation-1 was established on an east-facing flat terrain at an altitude of 600 m. The soil is Grey Luvisol mixture of sandy and clay, slightly stony, and very deep. The site class is medium rich to rich. The experimental plantation-2 is located in a high-density game area. The area is a meadow, aspect north, slope with gradient 8° and an altitude of 850 m. The soil is Dystric-Eutric Cambisol, mixture of sandy and clay, slightly stony and deep. The site class is medium rich to rich. In the autumn of the second and third year after the planting height, height increment and root collar diameter were measured. The survival in both experimental plantations was high but without any statistical significance of the tree shelter. The height growth of all tree species was better in tree shelter variants, with the highest average in that with Tubex Ventex Clear. The root collar diameter growth was not yet significantly affected by the use of tree shelters. As a result of research, ventilated tree shelters (Tubex Ventex Classic and Tubex Ventex Clear) may be recommended as suitable.

Key words: *Acer pseudoplatanus*, root collar diameter, *Fagus sylvatica*, height, *Quercus petraea*, plantation success.

Introduction

The issue of successful survival and growth of forest plantations is particularly important in the context of climate change (high temperatures and prolonged drought in summer and early autumn). The use of tree shelters for protection of seedlings from competing vegetation and browse damage is of particular interest. In addition, a specific microclimate is created around each plant, similar to that

in a greenhouse, which helps to accelerate growth and prolong the growing period due to the higher temperature of the growing environment of protected plants (Ponder 1994). In some cases, tree shelters help to better nutrients absorption (Ponder 1995).

The use of tree shelters was first evaluated in United Kingdom in 1978 (Tuley 1985). Later, they became popular in the Mediterranean, especially in dry and degraded site classes. The effect of their use has been the subject of a number of publications. Marques et al. (2001), Sharew and Hairston-Starng (2005), Mechergui et al. (2012), Defaa et al. (2015) proved a positive effect of different types of tree shelters on the survival and height growth of carob tree (*Ceratonia siliqua* L.), cork oak (*Quercus suber* L.), green ash (*Fraxinus pennylvanica*), northern red oak (*Quercus rubra* L.), pin oak (*Quercus palustris*), american sycamore (*Platanus occidentalis*), black walnut (*Juglans nigra* L.), flowering dogwood (*Cornus florida* L.), eastern white pine (*Pinus strobus* L.), *Quercus canariensis* Willd. and *Argania spinosa* (L.) Skeels. Better growth in height using tree shelters has been found also in *Quercus douglasii* Hook & Arn. (McCreary 2011), as well as sycamore, common beech, white oak (*Quercus alba* L.), shingle oak (*Quercus imbricaria* Michx.), bur oak (*Quercus macrocarpa* Michx.) (Bardon 1992, Lantagne 1997, Willoughby et al. 2009).

Different results have been obtained for the effect of tree shelters on diameter growth. According to Mechergui et al. (2012), Stuhlinger (2013), Defaa et al. (2015), it was weaker in the variants with protection and established insufficient stability of the stem.

In most studies, the effect was observed in all types of tree shelters. Bellot et al. (2002) studied the effect of five types of tree shelters (polypropylene – ventilated, unventilated, and made of biodegradable material) on the microclimate, survival, stem, and root growth of kermes oak (*Quercus coccifera* L.) and note that polypropylene tree shelters have significant advantages over those made of biodegradable material.

The territory of Training and Experimental Forest Range in Petrohan (North-Western Bulgaria) is characterised by its highly productive beech forests. The climate is temperate continental, but the annual rainfall is high and stimulates the vigorous development of weeds. In addition, there is a base for intensive management of fallow deer in the region. These are the main prerequisites that hinder successful afforestations. In order to overcome the difficulties, two experimental plantations with four types of tree shelters of the company Tubex (www.tubex-deutschland.de) were established in this territory.

The aim of the research was to study the effects of tree shelters on the survival and height, and root collar diameter growth of common beech, sycamore and sessile oak in the second and third year after the establishment of the plantations.

Material and Methods

The object of the research are two experimental plantations (EP1 and EP2), established in spring 2018 in the Training and Experimental Forest Range in Petrohan (North-Western Bulgaria). EP1 was established on an east-facing flat terrain at an altitude of 600 m (43.187247° N, 23.141207° E). The soil is Grey Luvisol mixture of sandy and clay, slightly stony and very deep. The site class is medium rich to rich (Table 1). The plantation

Table 1. Site classes of the experimental plantations.

Object number	Altitude, m	Aspect	Slope, °	Relief	Type of soil	Site index*
EP1	600	E	3	flat terrain	Gray Luvisol	CD_2
EP2	850	N	8	meadow	Cambisols	CD_2

Note: * In Bulgaria, the system used to evaluate the site classes is based on soil richness (A – very poor, B – poor, C – medium rich, D – rich) and a digital index for soil moisture (0 – very dry, 1 – dry, 2 – slightly moist, 3 – moist, 4 – very moist) (Raykov et al. 2011). CD_2 means medium rich to rich and slightly moist soil.

was established after windthrow in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantation. The stumps were pushed with a bulldozer and the area was cleaned and levelled. EP2 was located in high-density game area. It is a meadow, aspect north, slope with gradient 8° and an altitude of 850 m (43.177994° N, 23.133380° E). The soil is Dystric-Eutric Cambisol, mixture of sandy and clay, slightly stony and deep. The site class is medium rich to rich. The climate in the region is temperate with an average annual temperature of 10.2 °C and annual precipitation of 1004 mm. The duration of the growing season is about 6 to 6.5 months (Kyuchukova et al. 1983, Koleva and Peneva 1990).

During the three-year study period, the average annual temperature was in the range from 11.3 to 12.0 °C, and the annual amount of precipitation from 706 to 979 mm (Table 2). Most of the precipitation fell during the growing seasons. For all three years no minus temperatures in spring and in autumn were reported, i.e. no frost damage was found.

The soil in EP1 is Gray Luvisol, poor in humus, well stocked with nitrogen, poorly stocked with phosphorus and potassium and slightly acidic pH (Table 3). EP2 is located on brown forest soil (Dystric-Eutric Cambisol), poor in humus, moderately stored in nitrogen, poor in phosphorus, moderately stored in potassium and acidic pH.

Table 2. Air temperature and precipitation in the study period in the region of Berkovitsa town.

Year\Month	IV	V	VI	VII	VIII	IX	IV-IX	Annual
				Temperature, °C				
2018	14.9	17.4	19.3	20.8	20.8	16.5	18.3	11.3
2019	10.8	14.1	19.3	20.3	21.9	17.1	17.2	12.0
2020	9.1	15.0	17.9	20.6	21.3	18.7	17.1	11.8
				Precipitation, mm				
2018	27	120	163	154	84	20	568	979
2019	78	49	175	151	24	14	491	706
2020	59	108	91	91	148	25	522	972

Table 3. Soil properties of the study sites.

Object number	Humus, %	pH in H_2O	N, %	P_2O_5, mg/100 g	K_2O, mg/100 g
EP1	2.43	5	0.243	1.5	2.9
EP2	0.87	4.7	0.153	1.5	11

Method

Four experimental variants with tree shelters – Tubex Ventex Classic (A), Tubex Ventex Clear (B), Layflat Shelterguard (C), Layflat Treeguard (D) and a control one (without tree shelters) were used (Fig. 1). Twenty to twenty-seven seedlings in three replications of each variant and tree species were planted. All tree shelters are 120 cm high.

Tubex Ventex Classic (Fig. 1A) has a light green colour, is made of polypropylene and has a patented ventilation system. In the lower third of it there are 16 round holes with a diameter of 15 mm, which provide optimal supply of carbon dioxide and optimal growth conditions through a mini greenhouse effect, which accelerates growth and the plant is protected from extreme weather conditions – solar heat, humidity, danger of fungal pathogens. This tree shelter type protects against competing vegetation and animal damage. Its duration of use is about 10 years.

Tubex Ventex Clear (Fig. 1B) is similar to Tubex Ventex Classic, but is white and has greater transparency. It is intended for shade-tolerant species, such as common beech.

Layflat Shelterguard (Fig. 1C) protects plants from animal damage and at the same time offers better conditions for initial growth. It is made of recycled plastic mesh with holes of 12 mm and is additionally reinforced with a transparent polyethylene layer. The plant is protected from winds and herbicides as long as the access of light is not limited. The decomposition of this tree shelter type takes place in two phases – first the polyethylene layer decomposes (after about 3 years), the net remains to protect the plant from animals, and the plant successfully adapts to external conditions.

Layflat Treeguard (Fig. 1D) is a stable safety net, especially suitable for protection of seedlings, which grow very quickly in closed tree shelter and the crown becomes heavy and unstable. By using it, the tree can grow in natural conditions,

A B C D

Fig. 1. Tree shelters used in experimental plantations: A – Tubex Ventex Classic; B – Tubex Ventex Clear; C – Layflat Shelterguard; D – Layflat Treeguard.

being exposed to sunlight and rain. The durability of the tree shelter is about 10 years. At its upper end, the net is rounded to avoid injury to the shoots and stem.

The afforestation in EP1 was carried out on 17.04.2018 under the scheme 2.0×1 m, and the tree shelters were installed on 27 and 30.04.2018. In EP2 the afforestation was performed on 19.04.2018 and the installation of the tree shelters – on 03.05.2018. The planting of the seedlings in both experimental plantations was done with a motor drill. Common beech seedlings were 1-year-old, and those of sycamore and sessile oak – 2-year-old. In the autumn of the second and third year after the establishment (2019 and 2020), the height and root collar diameter of the seedlings were measured.

Statistical analysis

The influence of tree shelter type on the survival rate was modelled by beta regression (Mangiafico 2016). The statistical significance of the experimental variant on the growth in height within the tree species and experimental plantation, and for each year of measurement was studied according to GAM model (Wood 2017). The comparison of the effect of the type of tree shelter on the height growth of the individual tree species in EP1 and EP2 was performed using the nonparametric analogue of ANOVA – Kruskal – Wallis test (Mangiafico 2016). In this test, Games-Howell multiple comparisons method was applied.

Results and Discussion

Survival

Our results show that both in the second (2019) and the third (2020) year in both experimental plantations the average survival rate is relatively high – for sessile oak and sycamore – about and over 90 %, and for common beech – 85–80 % (Table 4).

The verification of the significance in the variants shows the following:

- In EP1 of common beech in both the second and the third year there are no significant differences among the variants of the experiment. The control variant (E) differs significantly from variants A and B by sycamore ($p < 0.05$) of the second year and only from variant A in the third year, and from variants A, B and C ($p < 0.05$) by sessile oak for both the second and the third year.

Table 4. Survival by site, species and treatment.

Object number	Treatment	Common beech		Sycamore		Sessile oak	
		2019	2020	2019	2020	2019	2020
EP1	A Tubex Ventex Classic	92	85	99 b	96 b	99 b	99 b
	B Tubex Ventex Clear	89	89	98 b	93 ab	99 b	99 b
	C Shelterguard	83	83	94 ab	88 ab	96 b	96 b
	D Tree guard	88	88	97 ab	96 ab	93 ab	93 ab
	E Control	86	85	82 a	77 a	80 a	80 a
EP2	A Tubex Ventex Classic	77 a	75 a	70	100 b	93	93
	B Tubex Ventex Clear	94 b	94 b	94	93 ab	92	90
	C Shelterguard	91 ab	91 ab	81	93 ab	98	92
	D Tree guard	78 ab	76 ab	73	98 b	95	93
	E Control	86 ab	81 ab	79	82 a	97	92

- In EP2 of the second year by sessile oak and sycamore no significant differences were found among the experimental variants on the survival, and by common beech differences were found only between variants A and B ($p < 0.01$). In the third year, there are no significant differences between the variants in sessile oak, in the case of common beech with sufficient significance only A differs from the B variant ($p < 0.01$), and in the sycamore – the control variant E differs from A and D at $p < 0.05$ (Table 4).

The influence of the tree shelter type on survival is reported in a number of studies, but the results are different. Defaa et al. (2015), Mechergui et al (2012), McCreary et al. (2011), Marques et al. (2001), West et al. (1999) established a positive effect of tree shelters on survival, but according to Stuhlinger (2013) and Sharew and Hairston-Strang (2005) the tree shelter type did not affect survival. Bellot et al. (2002) found that survival was affected by rainfall, not by tree shelter type.

In the present study, no significant differences in survival between protected and unprotected seedlings were observed in common beech in EP1 and sessile oak in EP2. In sycamore in EP1, the survival rate in the control variant was lower, but the differences were significant only with variant A and B of the second and with variant A of the third year.

In EP2, which is located in a high-density game area mass sycamore seedlings without shelters were heavily browsed, mainly by fallow deer. Common beech and sessile oak seedlings seem to be less preferred. In the same experimental plantation, damage to the top shoot was also observed in seedlings that had a height greater than the tree shelter (over 120 cm). With such a height in the third year are 30 seedlings of sycamore from all protected variants and three from sessile oak – two from B and one from C variant. Fallow deer browse probably contributed to stunted seedling growth but not to mortality. For browsing damage by deer to unprotected seedlings of green ash, and less of *Quercus pagoda* Raf. reported by Stuhlinger (2013).

In EP1, the browsing damage of unprotected seedlings were episodic, the problem was the lush grass vegetation, which competes significantly with the seedlings and this leads to the death of a large part of them. In contrast to EP2 in this plantation, the growth of sessile oak is significantly better than that of sycamore and common beech, as site class conditions are more suitable for sessile oak – lower altitude and richer sandy-clay soil (Table 3). The total number of seedlings with a height of more than 120 cm in the protected variants is 37. The mean part of them (21) were of variant B.

Height growth

In the second year after establishment of EP1 in sessile oak the highest seedlings were observed in variant B (Fig. 2), but statistically significance had the difference between B variant of D and E ($p < 0.0001$) and A variant of E ($p < 0.05$). No significant differences were found of the sycamore, and of the common beech with the highest statistical significance B variant differed from E (without tree shelter) at $p < 0.0001$. There was a significant influence of the variant in height increment of sessile oak and the common beech in the third year at $p < 0.0001$. In the sycamore, the differences in height increment were not statistically significant.

In the second year after the establishment of EP2 (Fig. 3), the highest seedlings of the sessile oak were observed in vari-

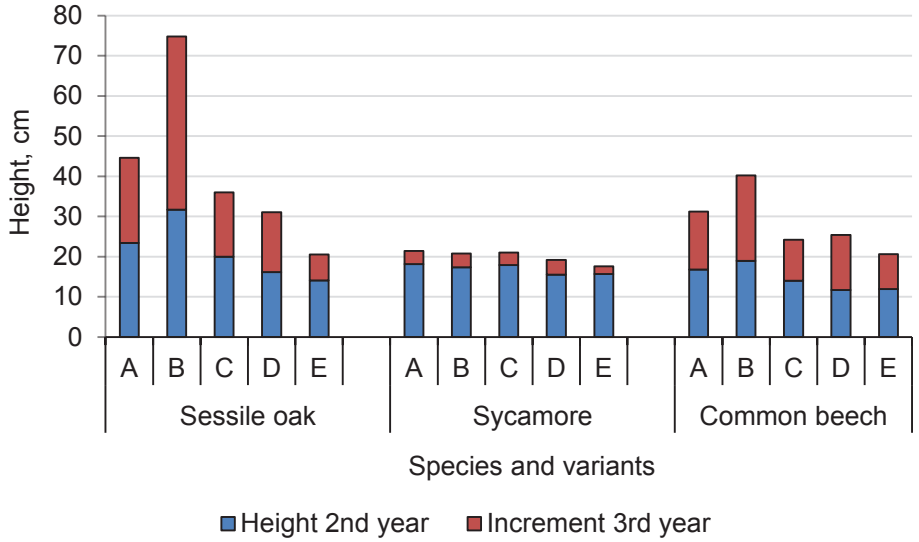


Fig. 2. Height growth at EP1.

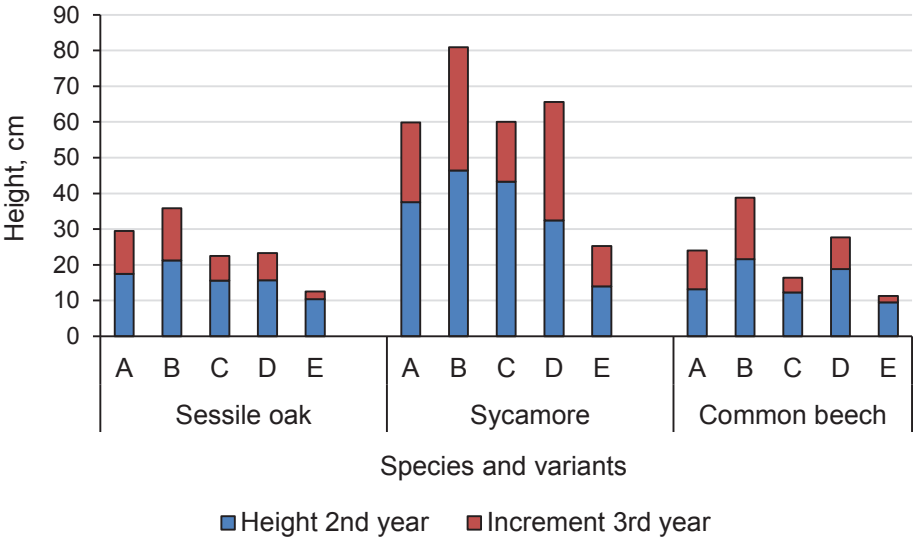


Fig. 3. Height growth at EP2.

ant B. The difference was significant only to variant D and control E at $p < 0.0001$. Of the sycamore, the variant was not statistically significant. Of common beech, variants B and D differed significantly from control E (B at $p < 0.0001$ and D at $p < 0.05$).

The differences in height growth in the third year for sessile oak and common beech were statistically significant, while

for sycamore were not significant.

Similar results confirming the positive effect of tree shelters on height growth were obtained for northern red oak (Bardon 1992), for northern red oak, sycamore and common beech (Lantagne 1997), for *Fraxinus excelsior* L. and *Acer pseudoplatanus* (Willoughby et al. 2009), for *Quercus douglasii* (McCreary et al. 2011).

Root collar diameter growth (RCD)

In EP1, the best RCD growth and increment was found of the sessile oak and common beech (Fig. 4), but the differences were not statistically significant. No differences were found between the variants of sycamore, as RCD increment in all variants was negligible.

In EP2 better RCD growth and increment was observed of the sycamore. Of the sessile oak and common beech its growth and especially increment in this indicator was negligible (Fig. 5). Of all three species, no statistically significant differences in RCD were found between the experimental variants.

The results of our studies on RCD growth of protected and unprotected seedlings were in agreement with the work of other researchers, who also found no significant differences by using tree shelters (Defaa et al. (2015). Some of them reported even weaker RCD growth of protected than unprotected plants (Mechergui et al. 2012, Sharew and Hairston-Starng 2005).

Comparison of height growth

In the second year (2019) statistically significant differences in common beech height growth were found in variants D (at $p < 0.0001$) and in the E variant (at $p < 0.05$). In variant D (Tree guard), the height growth was better in EP2, and in the control in EP1 (Fig. 6A).

In the third year (Fig. 6B), the average height of the common beech was higher and statistically significant in variants A (at $p < 0.05$), C (at $p < 0.001$) and control E

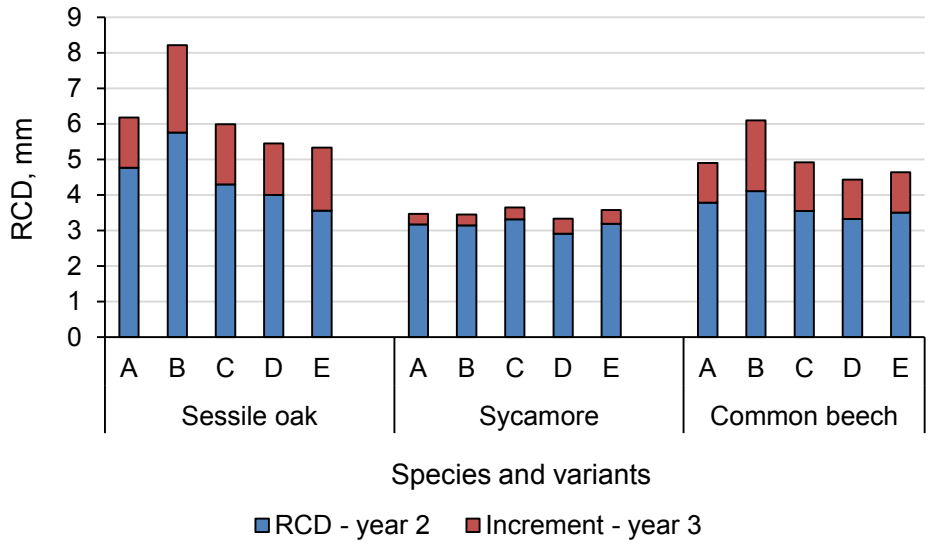


Fig. 4. RCD growth at EP1.

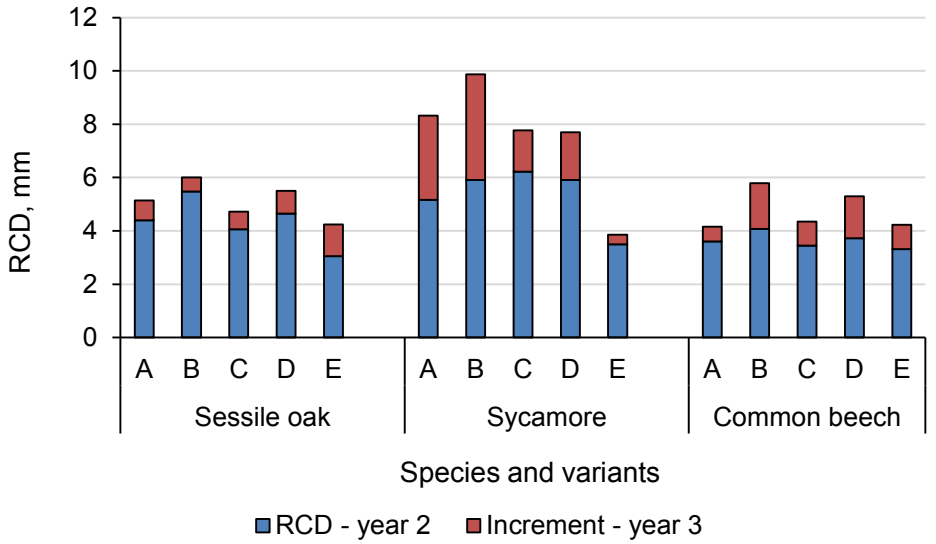
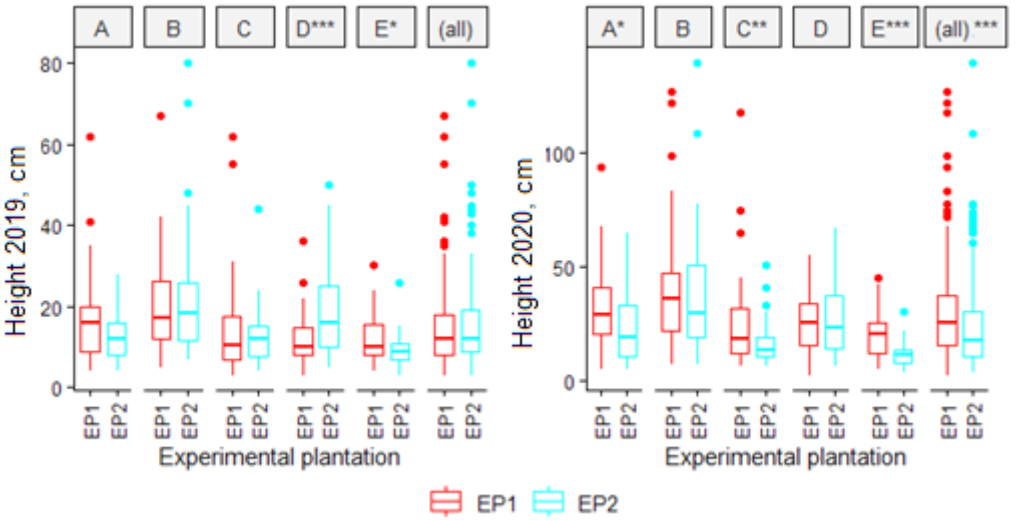


Fig. 5. RCD growth at EP2.



A **B**

Fig. 6. Comparison of the height growth of the common beech: A – in the second year (2019) and B – in the third year (2020).

Note: Significance codes: *** – 0.0001; ** – 0.001; * – 0.05.

(at $p < 0.0001$).

The weaker height growth in the variant E (without tree shelter) of EP2, both in the second (Fig. 6A) and in the third year (Fig. 6B) was due to the mass browsing damage, which led to a smaller growth.

Of the sycamore, in the second year, the average height was higher in all pro-

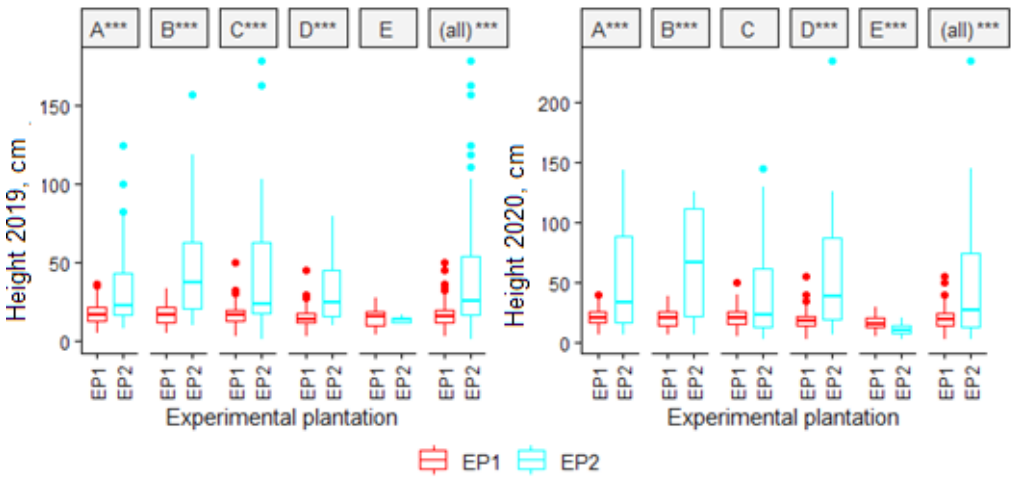
tected variants (A, B, C and D) in EP2, and the differences were of high statistical significance (at $p < 0.0001$) – Fig. 7A. In the third year the average height was higher in all protected variants (Fig. 7B), but the differences were statistically significant in variants A, B and D at $p < 0.0001$. In the control the difference is in favour of EP1. The better height growth of the sycamore in EP2 was due to the fact that the site class and climatic conditions in the middle mountain belt are more suitable for this tree species. The worse results in the control variant can be explained by the browsing damage in EP2, where the game concentration is especially high and without protection no seedling can grow and develop normally.

Of the sessile oak, the total height growth in both the second (Fig. 8A) and the third year (Fig. 8B) was better in EP1, but with different statistical significance. Statistically significant were the differences in variants B Tubex Ventex clear and control variant of the second year, and in the third – in variants B Tubex Ventex Clear, C Layflat Shelterguard and control E.

The better height growth of the sessile oak in EP1 could be explained by the ecological optimum of this tree species, which is mainly in the lower belt at lower altitudes.

Conclusions

In both the second (2019) and the third (2020) year after afforestation in both experimental plantations, the average survival rate is relatively high – for the sessile oak and sycamore – about 90 % and for the common beech – 85–80 %, but there are no significant differences between protected and unprotected variants. In addition, the root collar diameter growth is not yet significantly affected by the use of tree shelters.



A **B**

Fig. 7. Comparison of the height growth of the sycamore: A – in the second year, 2019 and B – in the third year, 2020.

Note: Significance codes: *** – 0.0001; ** – 0.001; * – 0.05.

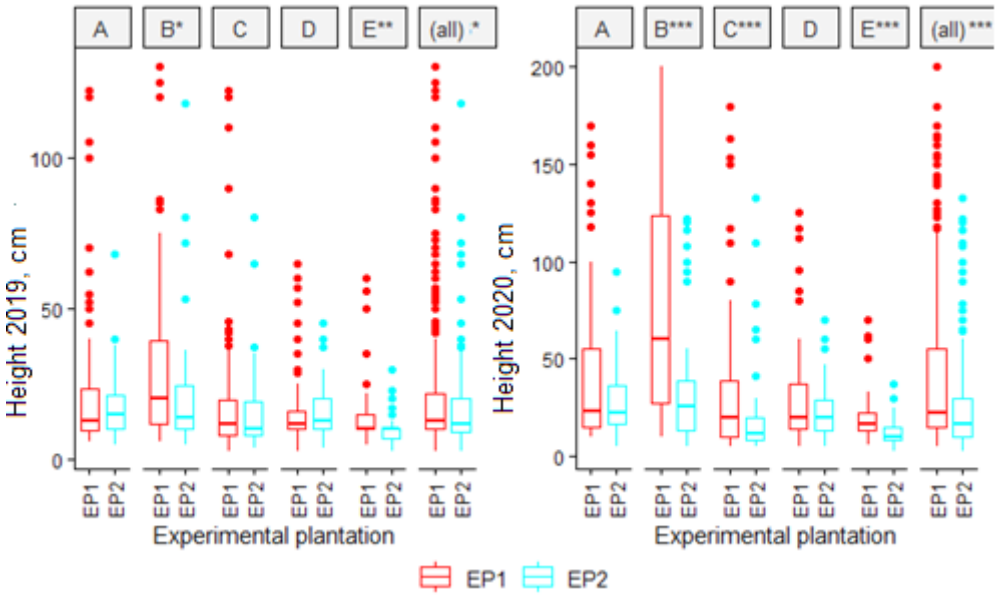


Fig. 8. Comparison of the height growth of the sessile oak: A – in the second year, 2019 and B – in the third year, 2020.

Note: Significance codes: *** – 0.0001; ** – 0.001; * – 0.05.

The tree shelters stimulate the height growth of all three tree species. The highest average height was found in variant B Tubex Ventex Clear in EP2 for all species, and in EP1 – for sessile oak and common beech.

The height growth of the sycamore in all variants in EP2 is significantly better than in EP1, which can be explained by the more suitable growth conditions for this species at higher altitudes. A similar explanation could be made for better height growth of the sessile oak in EP1 at lower altitudes but richer site class.

Ventilated protectors could be recommended as suitable at this stage. In the third year, of the sessile oak from EP1 12.5 % of the surviving seedlings in variant A and 26 % – from variant B and from 10 to 15 % of the sycamore seedlings from EP2 were higher of the tree shelters.

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ETHNOBOTANICAL AND SOCIO-ECONOMIC EVALUATION OF THE MEDICINAL AND AROMATIC PLANTS IN THE OUED BEHT WATERSHED, MOROCCO

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Abstract

This study was carried out in the Oued Beht watershed in Morocco, it aimed to inventory the wild medicinal and aromatic plants (MAPs) used and marketed in the study area and to calculate their economic value using the market price. The survey led with the local population in 2019, using face-to-face interviews and focus groups with 200 collectors and 5 cooperatives operating upstream of the sector of MAPs. This study used the Geographical Information System (GIS) tool to develop spatial maps covering medicinal plants prevalent in the Oued Beht watershed. The results permitted the identification of 23 species of MAPs collected, of which root and whole constitute the most used parts. Their economic value was estimated at 34,745,943 MAD·yr^{-1} distributed between collectors and cooperatives. The profits of the cooperatives exceed 61 %, with a supply of MAPs of only 24.63 % (700 t·yr^{-1}). This important economic value encourages the local population to depend on these resources. For this reason, we propose sustainable exploitation of the MAPs to provide their sustainability.

Key words: economic value, geographical information system, sustainability, wild MAPs.

Introduction

Recognized for its geographical location, Morocco benefits from specific natural ecosystems, which provide a wide range of ecosystem services (ES) defined as direct or indirect contributions of ecosystems to human well-being (MEA 2005, Braat and de Groot 2012).

However, most ES are provided by nature, and their economic values are often underestimated or ignored in commercial markets and decision-making processes (Pascual et al. 2010), which create serious problems for the conservation and the valorization of these resources.

Wild medicinal and aromatic plants (MAPs) represent an essential ecosystem services category described as provisioning services (MEA 2005), it constitutes a genetic reserve offering rich ecological and floristic diversity (Zrira 2017). On national level, MAPs are represented by 4200 vascular plants belonging to 940 genera and 135 families (MATUHE 2002, Fennane et al. 2014), including 900 endemic species

(Idm'hand et al. 2020). MAPs contain 9 % of the total flora of Morocco, of which the cedar ecosystem represents 31 % of all MAPs (Aafi et al. 2011). This diversity is highly recognized compared with other Mediterranean countries (Zrira 2017, Lamrani-Alaoui and Hassikou 2018).

The harvesting of wild species represents more than 90 % of national production (Zrira 2017). This sector of exploitation and use of aromatic and medicinal plants enjoys a privileged place in the national economy (Bellakhdar 1997, Benjilali et al. 2000, El Mansouri et al. 2011). It is estimated that 20 % of the population lives at least partially from these products (Ennabili et al. 2000). More than 500 medicinal plants are economically important (Bellakhdar 1997, Benjilali et al. 2000). The MAPs sector has a significant socio-economic value (Ghanmi et al. 2009), which enhances the value areas with limited economic potential (Chemli and Sid 2006).

Due to the traditional knowledge of the Moroccan population, MAPs represent a source of income and a means of creating new jobs for local communities (Eddouks et al. 2002, Benkhnigue et al. 2010, El Hafian et al. 2014, Akdime et al. 2015). The sector could also be one of the keys to promoting, developing and improving the livelihoods of unfortunate local population. Indeed, medicinal and aromatic plants give rise to two types of economic benefits. Thus, the calculation of the economic value of MAPs includes, on the one hand, the use-value of the quantities collected by local populations for immediate therapeutic, cosmetic, dietary, pharmaceutical, food and industrial uses (Kassel 2001). On the other hand, the option value constitutes a source of genes that can be commercially exploited in the future (Fadil et al. 2015). In the first case, it consists to estimate the in-situ use-value of these plants. In the second case, it involves assessing the expected future value of the option value of these genetic resources.

Nevertheless, the exploitation of this sector is not rational, most of the collections are irregular and uncontrolled, which affects negatively the sustainability of these resources. Over-collection of species had a significant threat to the most commercially valuable wild species (Lamrani-Alaoui and Hassikou 2018).

Despite the existence of several floristic and ethnobotanical studies describing the uses of MAPs in traditional medicine by the local population, few studies analyze the distribution, harvesting practices of the wild MAPs and their socio-economic values in the livelihood of the local population. That causes an underestimation of the economic value of these aromatic and medicinal plants and the attention they deserve (Maseyk et al. 2017).

The present study aimed to inventory the botanical species of wild MAPs picked in the study area and to estimate their economic value for the local populations. It also fixes as a goal to analyze the distribution of these MAPs, the collection practices, and the selling prices. This analysis will help raise the awareness of wild MAPs as an important natural resource and promote sustainable utilization.

Materials and Methods

Study area

The present study is conducted in Morocco, in the upstream part of the Oued Beht watershed, which covers an area of 1683.5 km^2 (Fig. 1). This area is a part of the Atlas Cedar Biosphere Reserve, which is recognised for its diverse vegetal

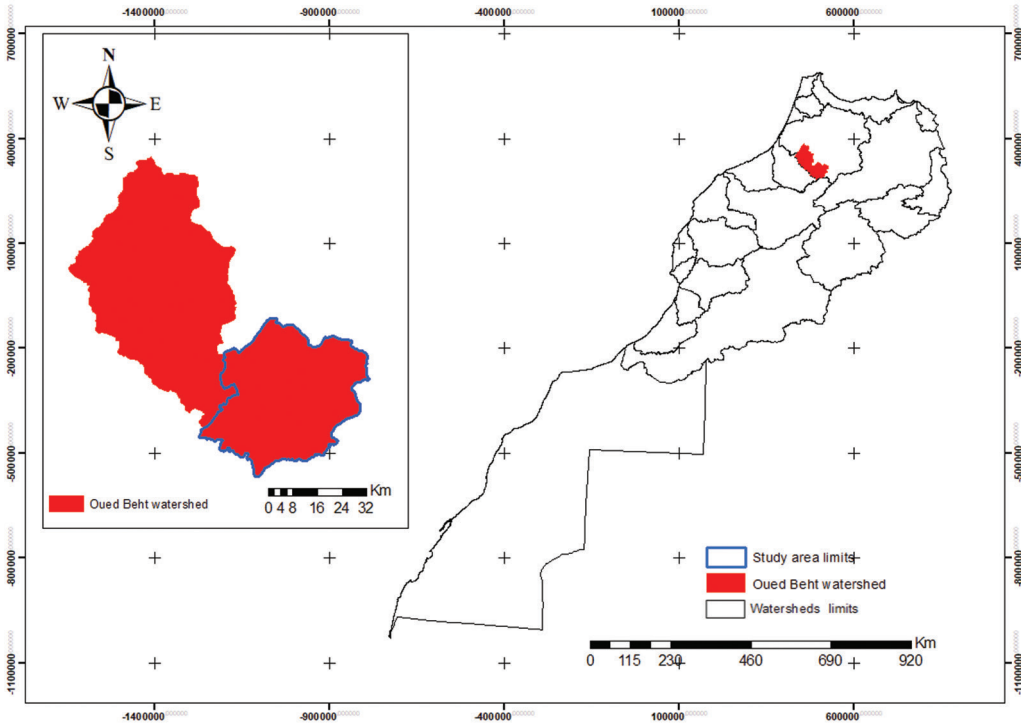

Fig. 1. Mapping representation of study area.

biodiversity.

Administratively, our study area is a part of two administrative regions, namely Fés-Meknes and Beni Mellal-Khenifra, it extends over three provinces and nine communes. The study area includes 76.76 % of the total area of Ifrane province and 17.32 % of Khenifra Province. The province of El Hajeb remains the least represented by a surface area not exceeding 6 %.

The study area is characterized by its Mediterranean climate with rainy winter and dry summer seasons. According to the National Census Report (HCP 2014), the total population is estimated at 41,647, and the number of households at 9330 with an average size of 4.46 inhabitants per household, which is lower than the national average (4.6 inhabitants/ household). The number of households is shared between rural households representing 88.54 % and urban households, which account for only 16.46 %. The unemployment average rate was 10.47 %. This rate is higher than the national average of 9.9 %, which reflects the poverty of households in the study area and consequently the intensity of exploitation of natural resources.

Data collection

The first step of this work is focused on the bibliographic exploitation of national and regional ethnobotanical studies on medicinal and aromatic plants (Benabid and Fennane 1994, Fennane et al. 1999, Benabid 2000, MATUHE 2002, Benjilali and Zrira 2005, Ghanmi et al. 2009, Akdime et

al. 2015, Jamaleddine et al. 2017). A GIS mapping approach is also used to determine the land use of the study area by exploiting and analyzing data from different regional and local maps. These data are integrated into ArcGIS 10.7.

In terms of land use, rangelands are the most dominant. They occupy 50.83 % of the total area of the target zone. Forests come in second place with 19.79 %, in the third place, we find denuded land with a percentage of 13.64 % and agricultural land, which is represented by 12.10 % (Fig. 2).

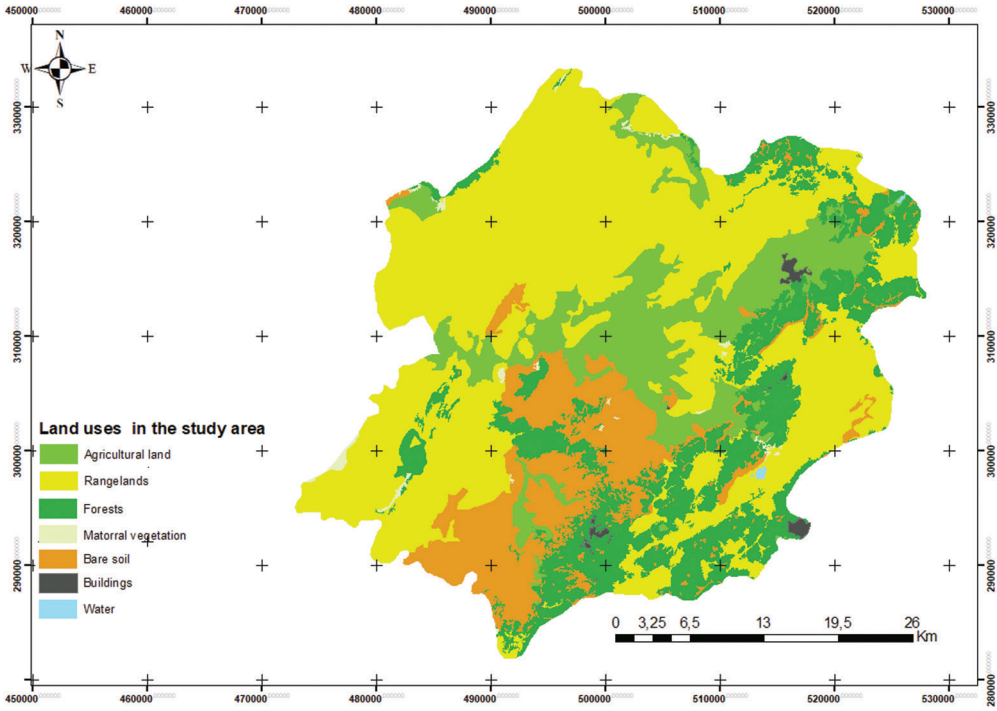

Fig. 2. Land uses of study area.

The results of the land use map are used to determine the survey sites and to ensure that most of the MAP exploitation areas are covered. The choice is guided by the distribution of the poverty rate in the study area, trying to cover the areas with high poverty rates located near the forests and rangelands and whose household living conditions are highly dependent on natural resources. We selected 47 sites (Fig. 3) to collect information on the most collected and commercialized wild medicinal and aromatic plants, locate them, quantify their removals, and estimate their economic values. A socio-economic survey was conducted between February and September 2019 at the above-selected sites.

Semi-structured questionnaires were conducted with 200 collectors and 5 cooperatives based on free listings submitted to respondents through face-to-face interviews and focus groups.

The collectors interviewed are local peasants living in the study area whose collected MAPs are sold to cooperatives

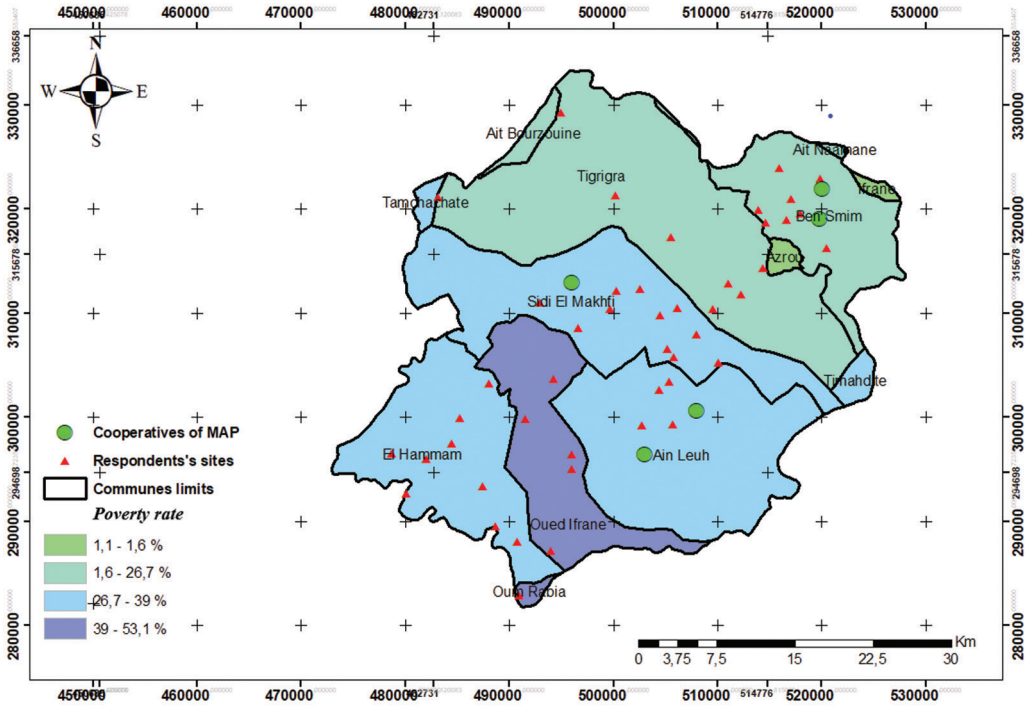

Fig. 3. Distribution of respondents site and cooperatives.

or other intermediaries. The selected cooperatives are those operating in the study area founded by practitioners from the population active in the MAPs sector. The collectors are randomly selected among the local populations. The questionnaire determines the profile of the collector (gender, age, level of education), the place of collection, the distance traveled to collect MAPs, harvesting season, the time passed per day and week, and the local name of each species and the part of the plant used. Other informations such as the quantities collected per day and per year, the place of supply, number of collection days, and the selling price was also requested from the collectors. For the five cooperatives operating upstream of the sector, the questionnaire aimed to determine the year of creation, the number of memberships, the quantities of each species marketed in dry form, the purchase price from collectors, and the selling price. The sample is developed using a stratified random sampling method. The interviewees are selected by the random sampling method.

To determine the species of MAPs, we referred to the following documents: the medicinal plants of Morocco (Sijelmassi 1993), Practical flora of Morocco (Fennane at al. 1999) and catalogs of vascular plants of northern Morocco, volumes I and II (Valdés 2002). The identification has been made at the Biodiversity and Resources Laboratory, Department of Biology, Faculty of Science, Ibn Tofail University Kenitra, Morocco. The identified plant species were arranged by family name, scientific name, collection location, quan-

tity and selling price. In order to develop spatial distribution maps of the prevalent medicinal plants in the area, the assessment was made using a GIS.

Results

Wild collection of medicinal and aromatic plants

Characteristics of the collectors

In total, 68 % of the respondents were female and 32 % - male. This predominance of females explains that this activity is largely practiced by women who collected plants while keeping their animals and collecting firewood in the forests. Regarding the age, the majority of the respondents were 45–55-year-old (60 %), followed by 33 % of 18–45-year-old, and by 5 % above 55-year-old. The least (3 %) were under 18-year-old. This shows that MAPs collecting is mainly practiced by the aged and that young people are not interested by this sort of activity. The interviewees status education is 77 % illiterate, 13 % primary school and 10 % secondary school. Many collectors collect MAPs without respect for their life cycle, which leads to overexploitation and negatively influences the regeneration of the resource and its future value to local people. As a result, if this overexploitation is not managed wisely, it can cause genetic erosion and ultimately species extinction (Bijlsma and Loeschcke 2011). In our study, 67.6 % of the interviewees were unemployed, 16.1 % had a monthly income between 500–900 Dirham marocain (MAD), 13.3 % had 900–1300 MAD, and 3 % had an income higher than 1300 MAD. Most collectors are shepherds or part-time employees. The distance traveled to collect MAPs varies from one collector to another, it can be estimated as 9 km for collectors who use collective tractors (18.2 %). However, almost 81.8 % of the distances, from 1 to 5 km, are covered either by foot or using a mule. The collection of MAPs is done either individually or in groups, the collectors prefer to go in groups (85 %) to reduce more risks during the collection.

Quantification of collected MAPs

Table 1 present the informations about the MAPs collected in our study area.

According to the results of the survey, 23 species belonging to 13 botanical families are identified, the most representative in terms of quantities collected were *Anacyclus pyrethrum, Crataegus laciniata*, *Evernia prunastri*, *Evernia furfuracea* and *Thymus algeriensis*. It is explained by the ecological factors that favor the growth of the majority of these species. The total collected quantity of medicinal and aromatic plants was 2141 $t \cdot yr^{-1}$, varying from one species to another (6 $t \cdot yr^{-1}$ to 400 $t \cdot yr^{-1}$). Root and whole plant were the most common parts used by collectors, which are considered the most destructive method that differs from the non-destructive method (Sharma and Kala 2022), which removes part of the plant without harming the plant or the environment (Cunningham 1993).

Collected quantities depend on the number of harvests and the area occupied by the MAPs, those marketed represent 90 % of those collected after the removal of the indiscernible part. Interviews with collectors indicate that the number of harvest days was five days per week, except the day dedicated to the market and the one of prayer. A day starts at 6 a.m. and ends around 3 pm, representing 9 h of work per day for four months. Most plants are collected between April and August of

Table 1. List of collected medicinal and aromatic plants by local population.

MAP species	Family	French name	Part used	Quantity collected, $t \cdot yr^{-1}$	Spatial distribution in habitats
Anacyclus pyrethrum L.	Asteraceae	Pyrèthre	root	380	rangelands and forests
Crataegus laciniata Ucr.	Rosaceae	Aubépine	flowers, fruits, leaves	400	forests
Salvia verbenaca L.	Lamiaceae	Sauge	whole plant	6	rangelands and forests
Evernia prunastri Ach.	Parmeliaceae	Lichen de chêne	whole plant	80	forests
Evernia furfuracea Mann.	Parmeliaceae	lichen de cèdre	flowers, fruits, leaves	100	forests
Thymus algeriensis Boiss. & Rent.	Lamiaceae	Thym	whole plant	200	forests
Mentha pulegium L.	Lamiaceae	Menthe pouliot	whole plant	52	forests
Saponaria vaccaria (L.) Sm.	Caryophyllaceae	Saponaire	leaves, roots	210	rangelands
Satureja alpina L.	Lamiaceae	Calament des Alpes	whole plant	17	rangelands and forests
Ferula communis L.	Apiaceae	Férule	flowers	84	rangelands and forests
Ruta chalepensis L.	Rutaceae	Rue d'Alep	whole plant	36	rangelands
Arbutus unedo L.	Ericaceae	Arbousier	fruit, leaves	32	and forests
Corrigila telephiifolia Pourr.	Caryophyllaceae	Corrigiole	root	82	rangelands
Calendula officinalis L.	Asteraceae	Souci	leaves, flowers	72	rangelands
Lavandula pedunculata (Mill.) Cav.	Lamiaceae	Lavande pédonculée	whole plant	50	rangelands
Fraxinus dimorpha Coss. & Durieu	Oleaceae	Frêne dimorphe	flower	42	forests
Origanum compactum Benth.	Lamiaceae	Origan	leaves	18	rangelands and forests
Silybum marianum L.	Asteraceae	Chardon marie	flower heads	24	rangelands and forests
Taraxacum atlantico H. Lindb.	Asteraceae	Pissenlit	Root, leaves	200	rangelands
Ceratonia siliqua L.	Fabaceae	Caroubier	Fruit	16	and forests
Zizyphus lotus Lam.	Rhamnaceae	Jujubier	Fruit	8	forests

MAP species	Family	French name	Part used	Quantity collected, t·yr^{-1}	Spatial distribution in habitats
Daphne gnidium L.	Thymelaeaceae	Garou	Leaves	20	rangelands
Inula viscosa L.	Asteraceae	Aunée visqueuse	Root	12	rangelands
Total collected, t·yr^{-1}				2141	

each year. The average quantity collected per day per collector is 12.6 kg·collector^{-1}·day^{-1}, if we consider that the average number of collection days is five days per week, the average quantity collected per week is 63 kg·collector^{-1}·week^{-1}. This quantity collected per day was low compared to the working hours (9 h·day^{-1}) explained by the size and weight of the collected plants (young plants) and the low density of species distributed over a large surface area of forest and/or rangelands.

Characteristics of the cooperatives

Five cooperatives in our study area covering three communes with 49 memberships were also surveyed. The Chifae cooperative is the old one (Table 2). The cooperatives are supplied by the collectors for the majority of species or by their collectors who had also a good experience in the sector.

Table 2. Presentation of the cooperatives opering in study area.

Name of cooperative	Commune	Year of creation	Membership
Chifae	Ben Smim	2006	8
Ajaabou	Ain Leuh	2013	8
Al amal	Tgrigra	2006	7
Konouz al atlas	ben smim	2016	16
Ittihad toufstlt	Ain Leuh	2012	10

The quantities of dried plants commercialized differ from one cooperative to another. The storage and packaging capacity of the plants also determine the quantities of MAP marketed by each cooperative. The quantity of the eleven (11) species marketed as dried plants by the cooperatives in the study area is listed in Table 3.

Table 3. List of collected medicinal and aromatic plants by cooperatives.

MAP species	Chifae	Ajâabou	Itihad tousftl	Al Amal	Kounouz Al Atlas	Totale commercealised, t·yr^{-1}
Anacyclus pyrethrum	0.00	0.00	10.00	0.00	75.00	85.00
Calendula officinalis	2.00	4.40	1.00	3.50	0.00	10.90
Corrigila telephiifolia	2.10	0.30	1.00	14.00	17.00	34.40
Crategus laciniata	0.00	1.00	0.00	3.00	11.00	15.00
Fraxinus dimorpha	2.30	2.00	0.40	2.70	10.00	17.40
Lavandula pedunculata	0.00	2.60	3.20	2.80	4.00	12.60
Mentha pulegium	3.70	2.00	2.80	3.00	12.00	23.50
Origanum compactum	1.70	2.40	2.00	3.10	11.60	20.80
Thymus algeriensis	3.00	5.00	3.50	4.00	100.00	115.50
Salvia verbenaca	2.70	1.90	1.00	1.30	8.00	14.90
Evernia furfuracea	0.00	0.00	0.00	0.00	350.00	350.00
Total, t·yr^{-1}	17.5	21.6	24.90	37.4	598.6	700.00

The maximum quantities commercialized as dry plants are 598.6 t by the Kounouz Al Atlas, and the minimum is 17.5 t by the Achifae cooperative. These quantities differ from one species to another, the most represented are *Evernia furfuracea* with 50 %, *Thymus algeriensis* coming in second place with 16.5 %. In the last position, we find *Calendula officinalis* with 1.5 %.

Mapping the distribution of wild MAPs

To develop spatial maps covering the most prevalent MAPs collected and marketed in the study area, we used the land-use map developed for the study area and the results of surveys with collectors and cooperatives indicating harvest locations. The result of the mapping is presented in Figure 4.

Analysis of the map shows that the total planimetric area of the various MAPs facies is 95,220 ha, which represent 69 % of the total area. Three classes of medicinal and aromatic plants are identified:

- Class 1: High potential and medium coverage, representing MAPs found in forests with high collection quantities, which represents17,139.6 ha;
- Class 2: Medium potential and high coverage, representing MAPs found in rangelands with medium quantities collected, which represents 30,470.4 ha;
- Class 3: Low potential, representing MAPs that are found at the same time in forests and adjacent rangelands and whose collected quantities are low, which represents 11,426.4 ha.

This floristic richness is explained by appropriate ecological conditions in the study area, characterized by a wide var-

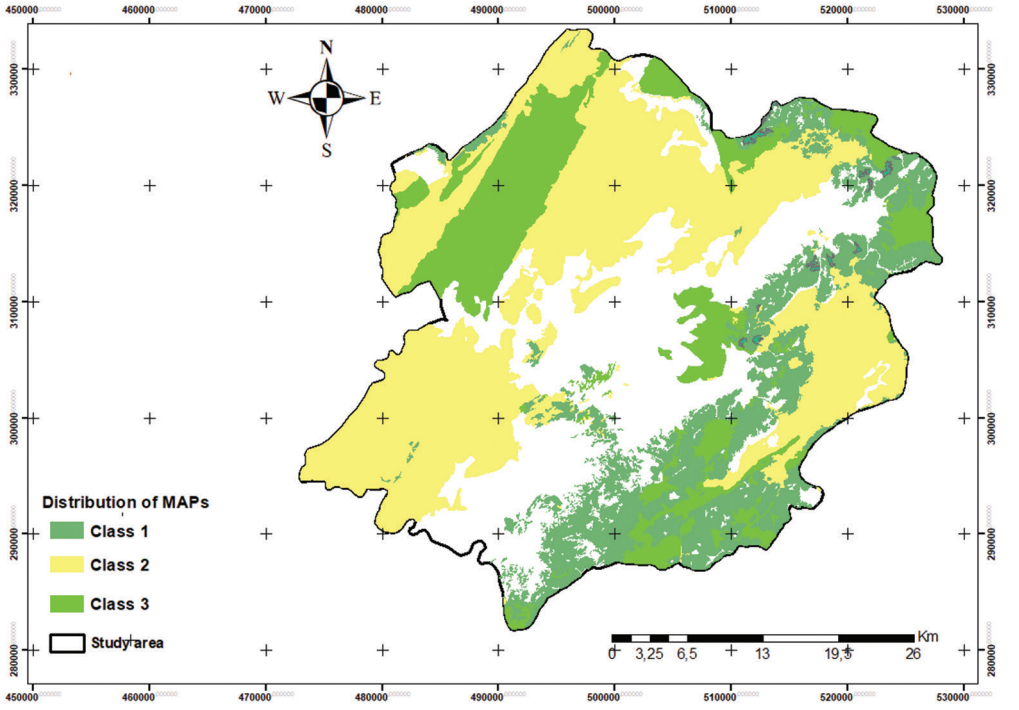

Fig. 4. Distribution of wild medicinal and aromatic plants in the study area.

iation in altitudes, high rainfall, rich soil conditions and a very high forest cover, which explains the large quantities of wild species.

Total economic value of medicinal and aromatic plants

Figure 5 shows that the total quantity of MAPs collected annually for the 23 species was 2141 t·yr^{-1}. The total quantity marketed after cleaning of the undesirable parts was 1930 t·yr^{-1}, giving an estimated value of 13,208,400 MAD, i.e. the collected MAPs are sold at the roadside or the tourist sites or the weekly souks by women having a good knowledge of the use of each plant.

The economic value of each species reflected its abundance in the study area

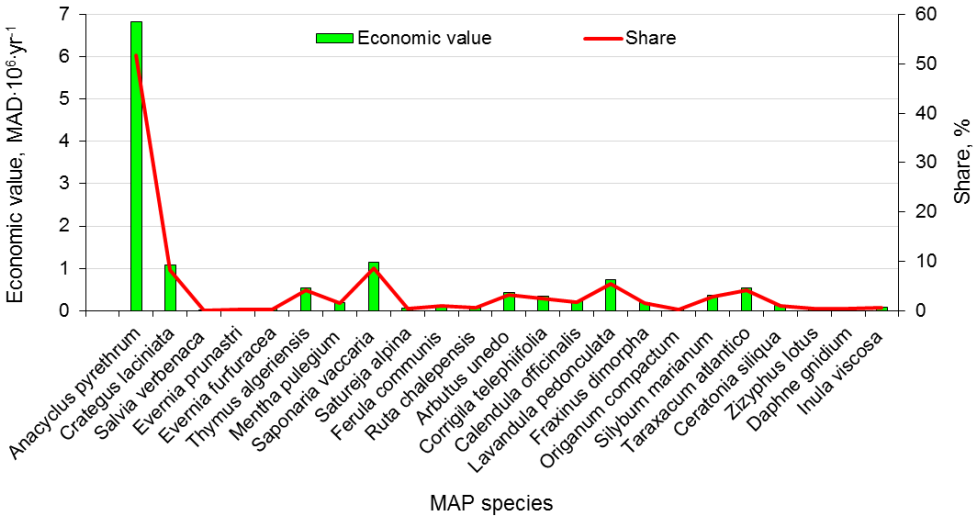

Fig. 5. Distribution of most frequently marketed MAPs for collectors.

and the unit selling price. Figure 6 shows that selling prices are mostly less than 5 MAD·kg^{-1}. Only 21 % of marketed plants had a price higher than 15 MAD·kg^{-1}, and 11.4 % between 5 and 10 MAD·kg^{-1}. This study showed that *Anacyclus pyrethrum* was the most expensive species, which makes it highly exploited and influences its suitability. This species is mentioned on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) list for Morocco as plant species subjected to trade authori-

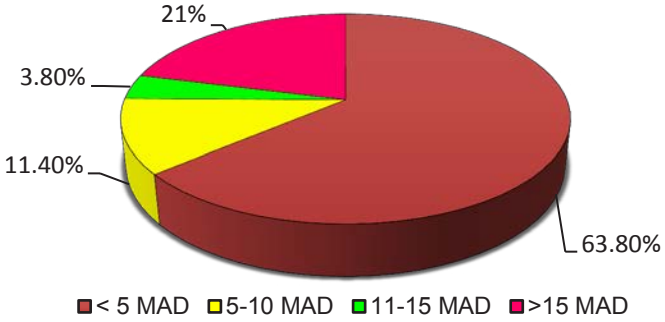

Fig. 6. Distribution of medicinal plants according to their selling price.

zation, it had also been demonstrated in Ait M'hamed Valley (Morocco) that it is suffering significant declines caused by poaching and premature root harvesting (Ouarghidi et al. 2017).

To determine the economic value of dried MAP marketed by the cooperatives, we are based on the selling price at the market after deducting the purchase price from the collectors (Table 4). Surveys with cooperatives show that cooperatives buy also from collectors in addition to collecting MAPs distributed on their land acquired for legal exploitation from the administration. The annual quantity of MAPs commercialized by the cooperatives is estimated at 700 $t \cdot y^{-1}$. This quantity generates an annual economic value of 24,661,500 MAD of which the annual value of purchases is estimated at 3,123,957 MAD giving a net value of 21,537,543 MAD. This value is realized by the cooperatives, which buy from collectors at very cheap prices, not exceeding 15 $MAD \cdot кg^{-1}$ except for pyrethrum (50 $MAD \cdot кg^{-1}$), and who were selling at high prices that exceeded 20 $MAD \cdot кg^{-1}$ and would in some cases go up to 90 $MAD \cdot кg^{-1}$.

The Upstream chain of the MAPs have two main actors, the collectors of the local population and the cooperatives. The results show that the MAPs collection and marketing chain offers an overall annual net value of 34,745,943 $MAD \cdot yr^{-1}$ distributed between collectors and cooperatives, representing a value of 365 $MAD \cdot ha^{-1}$. The cooperatives profits exceed 61 % with a MAPs supply of only 24.63 % (700 $t \cdot yr^{-1}$), showing that even if the collectors' harvests are more important (75.37 %), they receive the lowest value (38.01 % of the total economic value). These quantities underline the role of informal harvesting in the over-exploitation of MAPs in the study area. *Anacyclus pyrethrum*, *Crataegus laciniata*, *Evernia furfuracea*, *Evernia prunastri*, *Thymus algeriensis* are the most collected species generating important monetary values and which are susceptible to problems of overexploitation in the future.

Discussion

The wild medicinal and aromatic plants are a promising sector with enormous commercial purposes for the local popu-

Table 4. Distribution of most frequently marketed MAPs for cooperatives.

MAP species	Total quantity commercialised, $t \cdot yr^{-1}$	Unit selling price, $MAD \cdot kg^{-1}$	Gross annual value, MAD
Anacyclus pyrethrum	85	90	8,550,000
Calendula officinalis	10.9	35	381,500
Corrigila telephiifolia	34.4	30	1,032,000
Crataegus laciniata	15	25	375,000
Fraxinus dimorpha	17.4	25	435,000
Lavandula pedunculata	12.6	40	504,000
Mentha pulegium	23.5	40	940,000
Origanum elongatum	20.8	45	936,000
Thymus algeriensis	115.5	30	3 465 000
Salvia verbenaca	14.9	70	1,043,000
Evernia furfuracea	350	20	7,000,000
Total, $t \cdot yr^{-1}$	700,000		24,661,500

lations. Wild MAPs offer an overall annual net value of 34,745,943 MAD·yr^{-1} distributed between collectors and cooperatives. Generating an income for collectors who did not have permanent jobs, MAPs create financial capital that impacts positively the livelihood's collectors. However, these incomes are not representative of the real value of these MAPs, which explains the need to restructure the sector to increase the value of these resources.

The results show that the exploitation of wild MAPs is practiced by women and men (68 % against 32 %) and that exploitation increases with people's age (60 % of collectors were 45–55-year-old). Wild MAPs are collected mainly in forests or collective rangelands; private lands are always preferred over cultivated species (Schippmann et al. 2006). The collection of plants is often done by poor and illiterate collectors who influence the good collection practices, collectors pull up MAP species brutally and sometimes even during the flowering period. These results are similar to the bibliographic research that has been carried out in the region (Fadil et al. 2015, Rhafouri et al. 2015). Drying plants by cooperatives is also far from the modern way, plants dried directly in the sun are the most commonly used techniques.

The botanical analysis permitted the identification of 23 species collected and marketed by the local population. This number is less important than the one found in the Ifrane National Park. The exploited phytomass varies in the function of the biology of the plant and its use, it depends on the targeted part of the plant. When the whole plant is used, the quantities collected are significant (El Mansouri et al. 2011).

MAPs are considered by collectors as natural plants that are always available, and therefore harvested without any consideration for the regeneration of the resource. Therefore, the regeneration of natural resources is negatively correlated with sustainable exploitation, this causes a decrease in the reproductive capacity of species (Sharma and Kala 2018), which could lead to genetic erosion, extinction of certain species and the destruction of their natural habitats. Unsustainable harvesting threatens not only the survival of medicinal plant species but also the people that depend on them (Andel and Havinga 2008).

Thus, the future of medicinal and aromatic plants depends on today's ability to reconcile the conflicts between conservation and use. Proactive management policies are needed to mitigate biodiversity loss and ensure sound socio-economic development.

In technical terms, MAPs must be collected using the good practices, an appropriate harvesting plans specific to each species are necessary to ensure the sustainability of these precious species. The supervision and organization of the actors in this sector, their involvement in the whole development process, the technical modernization of collection and production will have positive repercussions on the management of the natural environment and the value of MAPs. These products can be promoted as representative products of territorial marketing initiatives give a label the geographical area.

Cultivation of wild MAPs, especially those of high economic value, is also a way to assure the conservation of these species and reduce the pressure on wild plants, and to increase their economic value. Though cultivated MAPs do not have the same quality of biomass or derived products and the wild MAPs are always preferred to cultivated species (Schippmann et al. 2006), wild nurseries can be

an appropriate option for the in-situ conservation of endangered, and in-demand medicinal plants (Liu et al. 2011). On the institutional level, appropriate regulations for the harvesting of wild MAPs need to be formulated. For example, each collection should only be done with a legally issued permit that indicates the amount to collect for each species and sustainable harvesting approaches that minimize biodiversity and ecosystem loss.

Conclusion

The MAP sector can be presented as a pillar for the socio-economic development of the poor rural population in the study area. However, the development of the sector faces several constraints like the excessive exploitation of spontaneous MAP and the limited use of modern production, harvesting, transformation and marketing techniques, which causes a loss of very important added value to the collectors

Our mapping and categorization of MAPs can contribute to the development of comprehensive scientific research on the theme to organize this informal sector.

The results provide a global and shared view of this type of ecosystem service in the study area and raise awareness among decision-makers and users to encourage the economic and environmental sustainability of the MAP sector without compromising the existing populations.

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Conflict of interest statement

There is no conflict of interest in the submission of this manuscript and all authors have given their approval for publication.

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GROWTH AND PRODUCTIVITY OF SYCAMORE (*ACER PSEUDOPLATANUS* L.) IN NATURAL STANDS AND FOREST PLANTATIONS IN BULGARIA

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Abstract

The sycamore (*Acer pseudoplatanus* L.) shows good adaptability to climate change and it could be used more widely in plantations in Europe and Bulgaria. The purpose of this study is to analyse and establish the condition, growth and productivity of plantations and natural stands under different habitat conditions in Bulgaria. All plantations and natural stands over 30 years of age, pure or dominated by sycamore, were evaluated on site. The volume of natural stands varies from 216 $m^3 \cdot ha^{-1}$ to 944 $m^3 \cdot ha^{-1}$. The plantations' growing stock at the age of 40 is 399 $m^3 \cdot ha^{-1}$, 70-year-old plantation has a stock of 810 $m^3 \cdot ha^{-1}$. At the age of 50–55, the Norway maple (*Acer platanoides* L.), the silver linden (*Tilia tomentosa* Moench.), the hornbeam (*Carpinus betulus* L.) and the European beech (*Fagus sylvatica* L.) reach and exceed the growth in height of sycamore, but not in diameter. Under optimal conditions, sycamore can produce amount of volume that meets the requirements for intensive crops.

Key words: diameter, height, increment, volume.

Introduction

In recent years, interest in the broad-leaved species used for afforestation has increased in Bulgaria. In order to conserve biodiversity, particular attention is paid to native species. In Bulgaria, a reserve in this regard are the species of genus *Acer*. The sycamore is one of the most important species of the genus in Bulgaria (Pandeva 2004). Spiecker et al. (2008) recommend that sycamore should be used more widely in forestry in Europe.

The sycamore habitat in Bulgaria covers most of the territory of the country and is naturally spread mostly in the northeast (Pasta et al. 2016) parts of the country. It occurs mainly in mixed deciduous forests, in smaller or larger groups in all mountains, in fresh sites with altitudes up to 1400 m a.s.l. (Pandeva 2004). It covers an area of 2324.4 ha (Varbeva 2019).

The regular and abundant fruiting, the high seed germination (El Kateb 1992), the wide range of tolerance to geographical and soil conditions and to altitude (Joyce et al. 1998) provide successful regeneration of sycamore in most forest

areas (Ammer 1996a) and good competitiveness, as well (Skovsgaard and Jørgensen 2004, Skovsgaard and Henriksen 2006).

Traditionally, the sycamore in Bulgaria is included in the composition of mixed forest plantations, such as some oaks (*Qurcus cerris* L., *Q. robur* L.), European beech (*Fagus sylvatica* L.), Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.) and other. Row schemes with spacing 2.0–3.0 m between rows and 1.0–1.5 m within the row or 3500–5000 pcs·ha^{-1} shall be applied. The method of mixing is single trees in rows and row-belt, rarely belt mixing (Varbeva 2019).

There are some recommendations regarding the management of the sycamore in Europe (Hein and Spiecker 2007, Hein 2008, Hein and Spiecker 2008a,b, Spiecker et al. 2008). Most of them are based on expertise and professional experience. Although very often these recommendations produce good results in local forestry practices, they are based on claims and hypotheses without being objectively examined. Therefore, their successful application in a wider geographical area should be verified (Hein et al. 2009).

Studies on the growth and productivity of sycamore show that the species grows intensively both in height and diameter at a young age up to 30 years (Kjølby 1958, Nagel 1985, Hamilton and Christie 1971, Spiecker 1991, Joyce et al. 1998, Hein et al. 2009). Some studies show that genetic origin influences height growth. Cundall et al. (1998), for example, found a significant difference in growth at a young age between British and continental origin. However, no significant difference in height growth was observed in the eight origins from Germany until the 31st year (Weiser 1971, 1981, 1996).

In Bulgaria the determination of the sycamore plantations' stock is carried out according to the European beech stemwood volume tables (respectively for high-stem and low-stem) by Nedyalkov (1960), Duhovnikov et al. (1963). Such a recommendation was made by Marschall (1975) for Austria. In Germany, the use of mountain ash volume tables is recommended (Hein et al. 2009). Hamilton and Christie (1971) propose to use general tables for calculating the stock of plantations of sycamore, ash (*Fraxinus excelsior* L., F. *angustifolia* Vahl) and silver birch (*Betula pendula* L.) for the conditions of Great Britain. Hein et al. (2009) emphasize that there are significant regional variations in growth rates and productivity of sycamore plantations.

For the calculation of the stem volume of plantations and stands of sycamore in Romania, Giurgiu (1974) proposes the equation (1):

$$v = a \cdot 10^{(b \cdot \log(D) + c \cdot \log(D)^2 + d \cdot \log(H) + e \cdot \log(H)^2} , \quad (1)$$

where: H is the average height, in m; D is the average diameter of the plantation, in cm; the values of the coefficients are respectively a = 0.00035375, b = 1.02, c = 0.3997, d = 0.666, e = 0.021.

According to Varbeva (2019), this equation shows the highest accuracy in calculating the stock of plantations.

The volume of the stands is affected by the intensity of thinning. Unfortunately, the results for the sycamore are few (Bryndum and Henriksen 1988, Henriksen and Bryndum 1989, Stern 1989, Jorgenensen 1992, Plauborg et al. 2004, Hein et al. 2009). The growth response of the sycamore to thinning is most rapid at a young age, but then slows significantly. There are three approaches of thinning plantations given in the literature. They differ in their assumptions and advantages (Hein

et al. 2009). Hein et al. (2009) conclude that although the sycamore is an attractive species for forestry, there is a lack of evidence-based research on its management.

The aim of this study is to determine the growth parameters of natural stands and plantations of sycamore in Bulgaria. Therefore, we outlined the following main tasks:

1. Creation and analysis of a database on the distribution of the species in Bulgaria.

2. Establishment of the condition, growth and productivity of plantations and natural stands under different habitat conditions.

Object and Methods

An analysis of the natural stands and forest plantations of the sycamore in Bulgaria was made. Six natural stands and sixteen plantations were selected as sample plots (Table 1).

Sample plots were identified by analysis of a sycamore source database, derived from the national database of the Executive Forest Agency (EFA). The selection of sites to set the sample plots is based on the analysis of the database.

All plantations and natural stands over 30 years of age, pure or with predominant participation of the sycamore, in good condition and homogenous structure were selected as sample plots.

The information on the habitat conditions (Table 1) in the studied sites was obtained from the forest management plans of the state forest enterprises.

The study conducted by Varbeva (2019) proved that there is no statistically significant difference between the growth parameters of natural stands and plantations, therefore the present study does not differentiate them according to their origin.

Data on the age of the stands were based on the current forest management plans of the forest enterprises, updated at the time of the survey. The size of the sample plots was determined based on the area, the condition of the stand and the configuration of the terrain. The diameters of all trees were measured by 2 cm diameter classes and the basal area (G) was calculated.

The species participation in the composition was calculated based on the total basal area of the plot. The density ($N \cdot ha^{-1}$) is calculated, and the average diameter (D_{cp}) is derived from the mean basal area. The dominant diameter was calculated as the average diameter of the hundred thickest trees per 1 ha.

The mean breast height diameter increment (Z_d) and the mean height increment (Z_h) were also calculated. Relative stocking is determined based on the actual stock of each species in the composition divided by the stock of the yield table of the species. For the sycamore, the Norway maple and the hornbeam, the tables for high-stem European beech stands were used (Poryazov et al. 2004). For plantations where the original afforestation scheme is clear, the survival rate is calculated.

The site index of the studied stands is determined according to a table for high-stem European beech stands (Poryazov et al. 2004).

The volume (V) per 1 ha is calculated using the equation (2):

$$V = a \cdot 10^{(b \cdot \log(D) + c \cdot \log(D)^2 + d \cdot \log(H) + e \cdot \log(H)^2)}, \quad (2)$$

where: H is the mean height, in m; D is the average diameter of the stand, in cm; the values of the coefficients are respectively: a = 0.00035375, b = 1.02, c = 0.3997, d = 0.666, e = 0.021 (Giurgiu 1974).

Table 1. Characteristics of the sample plots.

Forestry enterprise	Geographic coordinates	Area, ha	Altitude, m	Exposure	Relief	Slope, °	Soil characteristics				
							Soil type	Texture	Bulk density	Depth, cm	Humidity
Berkovitsa*	43°08'13.3" 23°17'03.4"	0.4	950	W	slope lower part	28	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Lesidren*	42°54'20.9" 24°27'23.6"	0.2	1400	E	hollow	11	Eutric Cambisols	Sandy clay	compacted	31–60	fresh
Kotel*	42°54'52.3" 26°20'49.0"	0.9	900	N	slope upper part	29	Eutric Cambisols	Loamy sand	loose	31–60	fresh
Gurkovo 1*	42°46'48.7" 25°39'26.2"	1.4	800	E	slope upper part	23	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Gurkovo 2*	42°46'41.0" 25°39'25.2"	0.3	750	E	slope upper part	30	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Preslav*	43°04'36.2" 26°51'28.2"	5.5	550	NE	ridge	12	Grey Luvisols	Sandy clay	loose	> 120	fresh to moist
Simitli	41°46'04.2" 23°01'44.5"	2.3	1300	N	slope lower part	21	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Karnobat 1	42°56'00.6" 26°55'40.1"	0.9	400	SE	hollow	9	Haplic Chromic Luvisols	Loamy sand	loose	61–120	fresh
Karnobat 2	42°56'04.8" 26°55'35.2"	0.2	400	SE	slope lower part	9	Haplic Chromic Luvisols	Loamy sand	loose	61–120	fresh
Varna	43°17'25.7" 27°54'53.4"	0.4	250	E	slope upper part	2	Grey Luvisols	Sandy clay	compacted	61–120	fresh to moist
Tsonevo	42°56'54.6" 27°27'29.7"	0.6	200	N	slope upper part	9	Grey Luvisols	Loamy sand	loose	61–120	fresh
Gabrovo 1	42°47'05.5" 25°19'38.9"	0.5	950	N	slope lower part	7	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Gabrovo 2	42°46'44.8" 25°20'04.5"	0.2	900	E	slope lower part	13	Dystric Cambisols	Sandy clay	loose	61–120	fresh to moist
Sofia	42°46'42.5" 23°18'47.9"	0.9	500	N	Riverside to 3 m.	2	Alluvial Fluvisols	Loamy sand	loose	> 120	fresh to moist

Pirdop	42°45'59.3" 23°55'06.5"	0.2	1200	SW	slope upper part	8	Eutric Cambisols	Loamy sand	loose	31–60	fresh
Kazanlak	42°43'55.6" 25°28'23.9"	5.4	1050	W	slope lower part	31	Dystric Cambisols	Loamy sand	loose	61–120	fresh
Varbitsa	42°55'58.6" 26°40'38.0"	4.5	850	NE	slope upper part	12	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Preslav	43°04'45.2" 26°51'06.5"	2.7	550	NE	ridge	12	Grey Luvisols	Sandy clay	loose	> 120	fresh to moist
Targovishte 1	43°10'07.0" 26°39'07.1"	0.7	400	N	slope lower part	6	Grey Luvisols	Sandy clay	loose	> 120	fresh to moist
Targovishte 2	43°08'30.1" 26°39'59.8"	1.6	600	N	hollow	2	Grey Luvisols	Sandy clay	compacted	61–120	fresh to moist
Cherni lom	43°24'47.8" 26°05'19.7"	0.5	400	NE	plateau	14	Chernozem	Sandy clay	loose	> 120	fresh
Shumen	43°14'50.1" 26°53'18.5"	0.3	450	NW	plateau	6	humus-carbonate	Sandy clay	loose	61–120	fresh

Note. The sample plots marked with asterisk (*) are natural stands.

The mean annual increment in volume is calculated in two variants – non-normalized, expressing the growth of the mixed plantation and normalized, calculated for pure full stocked sycamore stands with the specific height and diameter and area of 1 ha.

A one-way ANOVA test was used to determine if there are statistically significant differences between values of the mean annual increment (MAI) of four groups of sub-zones: I-2 (sub-zone of oak stands); II-3 (sub-zone of mixed deciduous stands; II-1 (sub-zone of sessile oak, European beech and silver fir) and II-2 (sub-zone of European beech, silver fir and Norway spruce). The results from ANOVA test showed that there is no statistical difference between the values of the groups.

Results and Discussion

The sycamore forms pure or with predominant participation in the composition of the plantations, which are small in area – from 0.2 to 5.5 ha (Table 2). They range from 550 to 1400 m a.s.l. The small areas of the sites give reason to assume that the emergence of pure stands or dominated by the sycamore occur in open spaces, in areas where clear cuttings of European beech stands were done or in small areas affected by natural disturbances.

Table 2. Characteristics of sample plots.

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1} ·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
Sofia	AP 9	2.0×2.0	680	30	40	20.6	24.0	0.52	1	24.5	28.5	0.63	38.81	365	9.12	10.13	1.13
	TT 1		70			20.0	23.0	0.50	1	20.0		0.50	2.99	34	0.86	-	
	Total		750			-	-	-	-	-		-	41.80	399	9.98	-	
Pirdop	AP 10	1.0×1.5	1257	19	45	24.5	2.07	0.54	1	23.8	34.6	0.53	55.93	596	13.25	13.25	1.9
Kazanlak	AP 10	1.0×2.0	744	15	50	20.0	24.0	0.40	1	24.4	33	0.49	34.75	321	6.42	6.42	1.1
Varbitsa	AP 6	1.0×1.5	333	5	50	21.0	24.0	0.42	1	28.8	38.6	0.57	21.53	211	4.22	7.03	0.95
	CB 3	-	144	-		20.0	22.0	0.40	1	20.0		0.40	4.85	56	1.12	-	
	FS 1		89	-		21.0	23.0	0.42	1	30.0		0.60	6.65	78	1.57	-	
	Total		566	-		-	-	-	-	-		-	33.03	345	6.91	-	
Simitli	AP 10	1.0×2.0	1214	24	50	22.0	24.0	0.55	1	18.1	29.4	0.45	31.19	301	7.54	7.54	1

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1} ·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
Karnobat 1	AP 6	unknown	483	-	50	22.0	23.0	0.44	1	22.2	29.7	0.44	18.74	189	3.79	5.34	0.71
	APt 3	-	233			23.0	24.0	0.46	1	20.0		0.40	6.77	83	1.67	-	
	TT 1		117			23.0	24.0	0.46	1	20.0		0.40	4.56	56	1.12	-	
	Total		833			-	-	-	-	-		-	30.07	329	6.58	-	
Karnobat 2	AP 5	unknown	583	-	50	22.0	24.0	0.44	1	20.0	30.8	0.40	18.32	178	3.56	7.12	0.84
	APt 3	-	333			23.0	25.0	0.46	1	22.0		0.44	12.07	149	2.97	-	
	FS 1		83			23.0	25.0	0.46	1	20.0		0.40	2.17	27	0.53	-	
	CB 1		133			23.0	24.0	0.46	1	16.0		0.32	2.37	29	0.58	-	
	Total		1132			-	-	-	-	-		-	34.93	383	7.64	-	
Preslav	AP 7	1.0×1.5	783	12	55	23.0	25.0	0.42	1	27.2	37.5	0.49	45.57	473	8.60	12.29	1.19
	CB 2		233				24.0	0.42	1	18.0		0.33	6.44	79	1.44	-	
	FS 1		83				23.0	0.42	1	24.0		0.44	3.23	40	0.72	-	
	Total		1099				-	-	-	-		-	55.24	592	10.76	-	
Shumen	AP 10	1.0×1.5	786	12	55	21.0	22.0	0.38	1	23.9	32.2	0.43	35.32	337	6.13	6.13	1.1
Tsonevo	AP 10	1.0×1.5	1417	21	60	20.0	23.0	0.40	1	21.7	30.8	0.43	52.79	479	9.59	9.59	1.7

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1} ·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
Gabrovo 1	AP 10	1.0×1.5	1140	17	60	23.0	25.0	0.38	1	25.7	36.4	0.43	59.02	607	10.12	10.12	1.8
Gabrovo 2	AP 10	1.0×1.5	1020	15	60	21.0	23.0	0.35	2	25.8	34.3	0.43	53.40	515	8.58	8.58	1.6
Targovishte 1	AP 10	1.0×1.5	533	8	60	25.0	27.0	0.42	1	27.4	35.1	0.46	31.43	346	5.78	5.78	0.9
Targovishte 2	AP 10	1.0×1.5	1011	15	60	22.0	25.0	0.37	1	23.3	30	0.39	43.18	425	7.08	7.08	1.3
Cherni Iom	AP 10	1.0×1.5	821	18	60	20.0	23.0	0.33	2	22.8	34.9	0.38	33.49	307	5.12	5.12	1
Varna	AP 10	unknown	650	-	70	27.5	29.0	0.39	1	34.7	48.8	0.50	61.52	765	10.93	10.93	1.8
Kotel	AP 8	-	622	-	45	20.0	23.0	0.44	1	22.6		0.50	24.89	228	5.06	6.41	
	FS 2	-	344	-	45	17.0	19.0	0.38	1	16.0	35.5	0.36	8.67	92	2.04	-	0.79
	Total	-	966	-	-	-	-	-	-	-		-	33.56	320	7.10	-	
Gurkovo 1	AP 9	-	592	-	45	20.0	22.0	0.44	1	20.8		0.46	20.07	182	4.05	4.5	
	CB 1	-	85	-	45	17.0	19.0	0.38	1	22.0	30.0	0.49	3.2	34	0.75	-	0.54
	Total	-	677	-	-	-	-	-	-	-		-	23.27	216	4.80	-	
Gurkovo 2	AP 5	-	1333	-	45	20.0	22.0	0.44	1	20.1		0.51	55.97	513	11.48	22.96	
	CB 4	-	1300	-	45	17.0	19.0	0.38	1	14.0	38.1	0.31	21.02	222	4.94	-	2.41
	APt 1	-	333	-	45	15.0	17.0	0.33	2	30.0		0.67	21.17	209	4.64	-	
	Total	-	2966	-	-	-	-	-	-	-		-	98.16	944	21.06	-	

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1} ·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
Preslav	AP 6	-	500	-	45	22.0	24.0	0.49	1	24.5	29.1	0.54	23.48	232	5.16	6.00	0.86
	CB 2	-	167	-	45	22.0	23.0	0.49	1	18.0		0.40	4.26	51	1.14	-	
	AC 2	-	150	-	45	22.0	23.0	0.49	1	20.0		0.44	4.77	58	1.28	-	
	Total	-	817	-	-	-	-	-	-	-		-	32.51	341	7.58	-	
Berkovitsa	AP 10	-	344	-	55	24.0	25.0	0.44	1	24.5	30.6	0.45	16.20	171	3.10	3.1	0.5
Lesidren	AP 10	-	2317	-	60	23.5	26.0	0.39	1	21.0	24.1	0.35	80.31	821	13.68	13.68	2.4

Note: *AP – *Acer pseudoplatanus* L.; CB – *Carpinus betulus* L.; TT – *Tilia tomentosa* Moench; FS – *Fagus sylvatica* L.; APt – *Acer platanoides* L.; AC – *Acer campestre* L.

The sycamore prefers shady exposure, with the only exception being the stand in the Berkovitsa State Forest Enterprise (SFE) located on a sunny exposure. It is noticeable that at lower altitudes (550–900 m) the plantations are located on convex relief forms – the upper portion of the slope and the hilly. At higher altitudes, they are in concave relief – a depression or a lower portion of the slope. The sycamore grows on slopes, as well as on steep terrains. The main soil types are Cambisols (Dystrict and Eutric) in the Middle Mountain Range of European beech and coniferous forests and grey forest soils (Gray Luvisols) in the lower plain-hilly and hilly-mountain ranges of oak forests. The texture of soil is sandy-clay in all sample plots. The maple prefers friable soils, with the exception of the plantation in Lesidren SFE growing on compacted soil. The demand of the maple is evident to the depth of the soil, which is at least medium deep (31–60 cm), most often deep (31–60 cm), and very deep (61–120 cm). In terms of soil moisture, the habitats are fresh and fresh to humid.

Sycamore plantations were created in the Moesian and Thracian forest areas (except the plantation at the Simitli SFE). They are situated in two forest zones – the plain-hilly and hilly-mountainous zone of oak forests at 200 m a.s.l. and the middle mountain zone of European beech and coniferous forests up to 1300 m a.s.l. (Table 2). The relief forms are varied – convex and concave, and the slope of the terrain varies from flat to steep. The soils are medium in mechanical composition, usually light, mostly deep and very deep. Soil moisture is good (fresh and fresh to moist soil).

The analysis of the stand characteristics of the natural stands shows that the sycamore can form stands pure in composition or with a predominant participation in the composition. Under natural conditions, the species may be mixed with the European beech, common hornbeam, Norway maple or field maple. The plantations are pure or mixed with European beech, hornbeam, silver linden, Norway maple, with a participation of 1/10 to 3/10 of the stand volume. For most plantations, the afforestation scheme applied is 1.0×1.5 m. Another scheme of afforestation is 1.0×2.0 m and the rarest scheme of afforestation is 2.0×2.0 m.

The density of 40-50-year-old plantations ranges from 677 (Gurkovo 1) to 2966 (Gurkovo 2) trees per ha. At the age of 55–60 the density is from 344 to 2317 trees per ha and 650 trees per ha at the age of 70. Self-thinning of the plantations was intense, survival was greatly reduced and ranged from 5 to 24 %. Intense self-thinning is an indicator of the great light-demanding nature of the species.

The density is lower than this in the normal yield table values (Poryazov et al. 2004) at the stands in Berkovitsa, Kotel and Gurkovo 1 and is an indicator of the relatively greater demand for light of the sycamore compared to the European beech. The density of the stands at the sites in Gurkovo 2 and Lesidren significantly exceeds the normal table values from 1.54 to 2 times, respectively. Hence it is an indicator of the species' biological potential in this regard.

The average height of the mean sample tree at the age of 40–50 is in the range of 20–22 m. At the age of 55–60 the height ranges from 20 to 25 m. In the 70-year-old plantation in Varna SFE, an average height of 27.5 m was calculated. The height of the average dominant tree at the age of 45–50 is from 22 to 24 m. At 55–60 years of age it is 22–26 to 29 m at the age of 70. According to Joyce et al. (1998),

sycamore shows excellent height growth during the first 30 years on appropriate site conditions. Significant decrease of its height growth occurs after 50 years of age. According to the growth models developed in Germany (Nagel 1986), sycamore plantations reach over 30 m in I yield class.

In the conditions of the middle mountain zone of European beech and coniferous forests, the sycamore outstrips in height the European beech, the hornbeam and the Norway maple, and in the lower plain-hilly and hilly-mountainous zone of the oak forests its growth is equalized with the common hornbeam. For the first 30 years, the Hamilton and Christie (1971) and Nagel (1986) growth models show better sycamore growth than the European beech, with European beech outgrows sycamore after 60, according to the Hamilton and Christie model (1971) and after 100 in the Nagel model (1986).

The height growth rate was characterized by the values of mean height increment. The increment ranges from 0.33 to 0.55 m per year. The most intensive growth is over 0.50 m / year and it is observed between 40 and 49 years of age. In general, there is a linear relationship between altitude and mean growth. The plantation in Simitli State Forest Enterprise is at altitude 1300 m a.s.l. and the increment is 0.55 m per year, and in Varna SFE it is at 250 m a.s.l. and the average increase in height is 0.39 m per year. Over the age of 60, the average height increment decreases. Hein et al. (2009) indicate that all height growth curves for the sycamore have one common feature – rapid growth at a young age (up to 20–25 years), which then slows down. In the best habitats, the species reaches 19.5 m by the age of 20 (Claessens et al. 1999).

The average diameter varies from 18.1 to 28.8 cm at the age of 40–50. At the age of 55–60, values range from 21.0 to 27.4 cm.

The studied objects showed the following relationship between density and mean diameter: at the age of 45–50 the average diameter is inversely related to the density. It reaches its maximum value (28.8 cm) for densities of 566 trees per ha and decreases to 18.1–20.1 for densities of 1214–2966 trees per ha. An exception to this trend are the plantations in Pirdop SFE.

At the age of 55–60 at densities from 344 to 1140 trees per ha there is no clear relationship between the average diameter and the density and it varies from 22.8 to 27.4 cm. A smaller average diameter was calculated at densities of 1417 trees per ha (21.7 cm) and 744 trees per ha (21.0 cm).

The relationship between size and density has been a topic of intense research for decades (Pretzsch 2005). However, for the time being, the exact correlations for the sycamore have not been established. Conditional results have been obtained in France comparing the self-thinning curves of the sycamore, the European beech, the mountain ash, the sessile oak and the common oak: the data on the sycamore is limited, but the relationship between size and density seems to have a steeper curve than this in the European beech (Le Goff and Ottorini 1999) and mountain ash, but close to that of the oaks. Therefore, a pure, even-aged stand of a sycamore would have a lower density than the same pure stand of a European beech or mountain ash, and the same density of the plantation of the sessile oak or common oak.

Growth in the average diameter of the sycamore is more intense than the European beech and the field maple, but lags behind at the age of 45 compared to the

Norway maple, which reaches an average diameter of 30 cm. In two of the plots with the participation of the hornbeam, the growth in diameter of the maple is more intense, and in Gurkovo 1 the growth in diameter of the two species is even. However, the experimental plots do not give basis for claiming that under these conditions the sycamore has a more intensive growth in diameter than the European beech and hornbeam because it is not known whether these co-occurrences are of the same age or settled in the stand at a later stage.

According to Nagel (1985), the sycamore reaches its maximum increment in diameter at the age less than 10 when open grown outdoors without competition. These results are in line with studies of its height growth: the species reaches maximum growth indicators both in height and diameter at an early age. Growth in diameter in the sycamore is most intense until the age of 20–25, after which it slows down (Spiecker 1991).

The diameter of the average dominant tree at the age of 40–50 ranges from 28.5 cm to 38.6 cm. At 55–60 years of age it is between 24.1 and 37.5 cm. Logically it does not show a relationship with the density of the stands, because dominant trees are less competing for growing space with other tree categories.

At the age of 40–45, the sycamore plantations exceed the growth in height and diameter of the natural European beech, silver linden, hornbeam and Norway maple stands. At the age of 50–55, Norway maple, silver linden, hornbeam, European beech reach and exceed the growth in the height of Sycamore, but not yet in diameter.

The average diameter increments at different ages were determined as follows: 40 years – 0.63 cm per year; 45 years – 0.44–0.53 cm per year; 50 years – from 0.40 cm per year up to 0.57 cm per year; 55 years – from 0.43 cm per year up to 0.47 cm per year; 60 years – from 0.35 cm per year up to 0.46 cm per year. The average growth in diameter of the 70-year-old plantation also has a high value of 0.49 cm per year.

A significant increase in the average diameter increment is observed for plantations with densities from 333 to 750 trees per ha, respectively 0.64 and 0.63 cm per year. After the age of 50, the mean diameter increment decreased from 0.43 to 0.37 cm per year. With respect to the average diameter increment, it can be summarized that the intensive diameter increment is up to 50–60 years of age, after which it slows down. Maximum height and diameter growth was observed at 40-45 years of age. When comparing the growth parameters of the studied stands with the normal table values (Poryazov et al. 2004), it is seen that the sycamore shows more intensive growth in height and diameter than the European beech at the age between 45 and 60.

The analysis of the basal area shows that at the age of 40–55 there is no correlation between density of up to 1214 trees per ha and the basal area as it varies from 23.26 to 41.8 $m^2 \cdot ha^{-1}$. At a density of 1257 and 2966 trees per ha the basal area increases to 55.93 and 98.16 $m^2 \cdot ha^{-1}$ respectively. At the age of 55–60 there is a linear relationship between the basal area and the density, which varies from 16.2 $m^2 \cdot ha^{-1}$ to 80.31 $m^2 \cdot ha^{-1}$.

The values of the stand volume vary from 171 $m^3 \cdot ha^{-1}$ (Berkovitsa density 344 trees per ha) to 944 $m^3 \cdot ha^{-1}$ (Gurkovo 2 density 2966 trees per ha). The total productivity of sycamore varies between 800

and 1000 $m^3 \cdot ha^{-1}$ at the age of 80 according to Germany and Denmark growth models, while in the UK, productivity reaches 766 $m^3 \cdot ha^{-1}$ at the same age (Joyce et al. 1998).

The productivity of the sycamore (~1050 $m^3 \cdot ha^{-1}$) is significantly higher than that of the European beech, which reaches only 546 $m^3 \cdot ha^{-1}$ at the age of 80 in first yield class (Schober 1995).

Henriksen and Bryndum (1989) indicate that for Danish sample plots on similar habitats where thinning of sycamore and beech stands has been made, the sycamore has a higher stock than European beech only until 40 years of age. The mean and current volume increment culminates earlier than in European beech. Although the height growth of mountain ash and sycamore is similar, the productivity of mountain ash is significantly lower (555 $m^3 \cdot ha^{-1}$) at the age of 80 at first site index class (Volquardts 1958). A comparison by Lockow (2004) of the influence of dominant heights on the volume increment of the sycamore, mountain ash and European beech in northern Germany reveals another model for the first site index class plantations of the three species: at a dominant height of 30 m the volume of plantations of the sycamore exceeds that of ash trees by 180 $m^3 \cdot ha^{-1}$ in terms of overall productivity, whereas European beech is superior to sycamore only at heights greater than 30 m, provided that they were equal in height at the last cultivation.

According to Kjølby (1958), the current annual increment in volume in Denmark is highest at 21 years of age – 19.5 $m^3 \cdot ha^{-1}$, and the mean annual increment in volume at 27 years of age is 15 $m^3 \cdot ha^{-1}$ for stands with I site index. The growing stock at 80 years of age ranges from 700 $m^3 \cdot ha^{-1}$ (for the fifth yield class) to 1050 $m^3 \cdot ha^{-1}$ (for the site index class V). The current annual increment in volume for the conditions of Germany is highest at the age of 20 (about 20 $m^3 \cdot ha^{-1}$) and the average growth at the age of 30 (15 $m^3 \cdot ha^{-1}$) (Spiecker 1991).

The average non-normalized volume increment increases from 3.10 (Berkovitsa) to 21.06 $m^3 \cdot ha^{-1}$ year (Gurkovo 2). The average normalized volume increment is from 3.10 (Berkovitsa) to 22.96 $m^3 \cdot ha^{-1}$ (Gurkovo 2) annually. According to Joyce et al. (1998), the maximum value of mean annual increment reaches about 20 $m^3 \cdot ha^{-1}$ per year for I yield class, and the age of biological maturity of maximum volume production for different yield classes varies between 20 and 30 years.

The results of Dunn's post hoc test for average normalized volume increment showed statistical significant difference between sub-zones II-1 and II-2. The boxplot of MAI by sub-zones is given of Figure 1.

The minimum and maximum values of the mean non-normalized and normalized increment in volume are observed in pure plantations and are respectively from 5.12 $m^3 \cdot ha^{-1}$ to 13.25 $m^3 \cdot ha^{-1}$ annually. Of the 22 sample stands and plantations, in 6 the mean normalized increment in volume exceeds 10 $m^3 \cdot ha^{-1}$ per year, which is considered sufficient to create intensive wood production crops.

When setting a production goal – sawtimber and special assortments – veneer, Joyce et al. (1998) recommend rotation period of 60–80 years on the best site conditions and 100 on less suitable sites.

The growing stock of the stands and plantations is high, despite of the intense self-thinning and low survival rate, and ranges from 0.5 to 1.9.

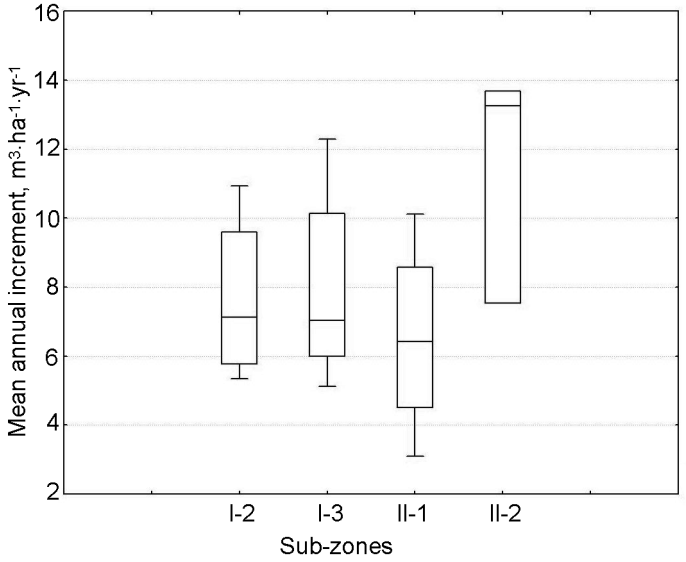

Fig. 1. Box-plot of mean annual increment for four groups of sub-zones.

Conclusions

The described above give the ground to draw the following important conclusions:

The highest values of stem volume are observed in the objects at altitudes between 550 and 1400 m a.s.l. on shade exposure.

Under optimal habitat conditions, sycamore can achieve productivity that meets the requirements for intensive plantations. It shows values from 13.25 to 21.96 $m^3 \cdot ha^{-1}$ at the age of 45; 13.68 $m^3 \cdot ha^{-1}$ at 60 years of age and 10.93 $m^3 \cdot ha^{-1}$ at the age of 70.

The studies carried out and the conclusions reached justify the following recommendations:

Areas located in the Middle Mountain zone of Beech and Coniferous Forests, Sub-zone of Low-altitude forests of Durmast oak, Common beech and fir (600–1000 m a.s.l.) and sub-zone of middle-mountain forests of beech, fir and spruce up to 1400 m a.s.l. Shady exposures and diverse habitats with fresh and moist soils are suitable.

Sycamore plantations can be created both pure and mixed. Suitable mixing species are: beech, Norway maple, linden, field maple, common cherry, mountain ash.

The obtained results, drawn conclusions and recommendations can help to improve and expand the future work with sycamore in Bulgaria.

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VOCAL ACTIVITY OF URAL OWL (*STRIX URALENSIS*, STRIGIFORMES, STRIGIDAE) IN THE MIDDLE VOLGA RIVER REGION

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Abstract

Both daily and seasonal year-round vocal activity of Ural owl were recorded in the Middle Volga River Region, Russia with the use of digital dictaphones. Two best-expressed peaks of long-term activity were revealed during the year: one starting in March and the other in September. In the spring, calls were recorded from 19:51 to 04:04. During this period, Ural owl's total length of calls varied from 1 to 35 min per day, on average 12 min. The second annual peak was restricted to brood dispersal. In this period, the total duration of calls varied from 1 to 32 min per day, on average 9 min. In the spring, Ural owls always started calling from 24 min to 4 h after sunset. Vocalisation began at an average of 2 h 34 min after sunset. Completion of morning vocal activity always ended from 1 h 30 min to 2 h 40 min before sunrise.

Key words: birds of Mordovia, diurnal activity, phenology of avian vocalisation, seasonal activity.

Introduction

Vocalisation of various species of animals carries a lot of scientific information about features of their biology and ecology (Catchpole and Slater 2003, Burgos and Zuberogoitia 2020). Most studies are devoted only to certain groups of animals (Catchpole and Slater 2003, Pukinsky and Pukinskaya 2011). The vocalisation of some owl species is of priority importance (Mikkola1970, Cramp 1985, Odom and Mennill 2010, Korpimaki and Hakkarainen 2012, Lourenço et al. 2013, Ševčík et al. 2019, Pérez-Granadoset al. 2020, Clément et al. 2021).

The calls of Ural owl (*Strix uralensis* Pallas, 1771) are used in the classical version for tracking when using the direction finding method (Voronetsky et al. 1990, Fischer et al. 1997, Haselmayer and Quinn 2000, González et al. 2008, Tutis et al. 2009).In descriptions of Ural owl vocalisations, the fundamental work by Scherzinger (1980) is of great importance. Pukinsky (1977) points out that the spring arrival of Ural owl on nesting sites, as a rule, is observed in the first days of March. But there are still big differences depending on the region and even on the habitat. Of important interest, at what hours of the day does the owl most vocal-

ise? As well as how it changes by season and month. What factors can affect vocalisation? We want to highlight one of the works in this sector of research. This is the work of Spanish zoologists on Eagle owl (*Bubo bubo* Linnaeus, 1758). For the South-Western part of Spain, it is shown that the beginning and end of the sound activity of owls are timed to sunset and sunrise, respectively. This circumstance is explained by the authors from the position of good visual contact between individuals (Penteriani 2002, Delgado and Penteriani 2007). Researchers highlight the influence of weather, climate, and trophic conditions on vocalisation (Southern 1970, Wijnandts 1984, Korpimaki 1987, Tome 1997, Clark and Anderson 1997, Lehikoinen et al. 2010, Sharikov and Shekhovtsov 2013).

The aim of our research is to determine the vocal activity of Ural owl (daily and seasonal rhythm) and the possible influence of weather and climatic factors on it in the Middle Volga Region. We consider the hypothesis that vocalisation does not depend on meteorological conditions.

Material and Methods

Voice activity of Ural owl was recorded in the period 2015–2019in various districts of the Republic of Mordovia (53º38' – 55º11' N and 42º11' – 46º45' E). The dictaphones were moved by car from one point to another. The climate of the region is moderate continental with pronounced seasons throughout the year. The average annual air temperature varies from 3.5 to 4.0 °C. The average annual precipitation in the territory is 480 mm (Andreychev 2017).

Ural owl is widespread in Mordovia (Lapshin et al. 2005, Andreychev and Lapshin 2017). It inhabits forests of various types, but is more common in ripe coniferous and mixed forests. The vocalisation was recorded in the following settlements and districts: Bolshebereznikovsky district (Nerley, Starye Naimany, Chernaya Promza, Sosnovy Gart, Russkie Naimany, Parakino, Shugurovo), Chamzinsky district (Michurino, Picheury, Kamenka, Chamzinka, Chkalovo), Dubensky district (Purkaevo, Engalychevo, Cheberchino, Kaybichevo, Nikolaevka), Atyashevsky district (Dyurki), Insarsky district (Luhmensky Maidan, Svistovka), Kochkurovsky district (Kochkurovo, Stary Turdaki), Staroshaygovsky district (Letki, Kuvay, Novoe Akshino, Kuldym, Lemdyay), Ichalkovsky district (Rezovatovo), city of Saransk (Fig. 1).

The acoustic material was collected through Olympus VN-416PC, VN-406PC, VN-712PC autonomous recording units. Voice recorders were installed in the daytime for 3–5 days. The maximum duration of continuous operation of voice recorders was about 140 h. By the time the previous recording was finished, we have moved the recorder to a different location (Andreychev et al. 2017, Lapshin et al. 2018, Andreychev 2019, Andreychev et al. 2020).More than 600 h of audio recordings were processed each year. Most of them were made during the spring-summer period (more than 400 h/1 year). Registration of the activity of Ural owl is, first of all, registration of the calls of males, as females call less often and mainly as a response to male calls. Therefore, most of the material was obtained from the vocalisation of male (Vrh and Vrezec 2006).

The resulting audio records were processed using AIMP (2007) and Audacity (2015) programs. We looked at the spectrograms (time on x-axis; frequency on y-axis; amplitude on z-axis visualized

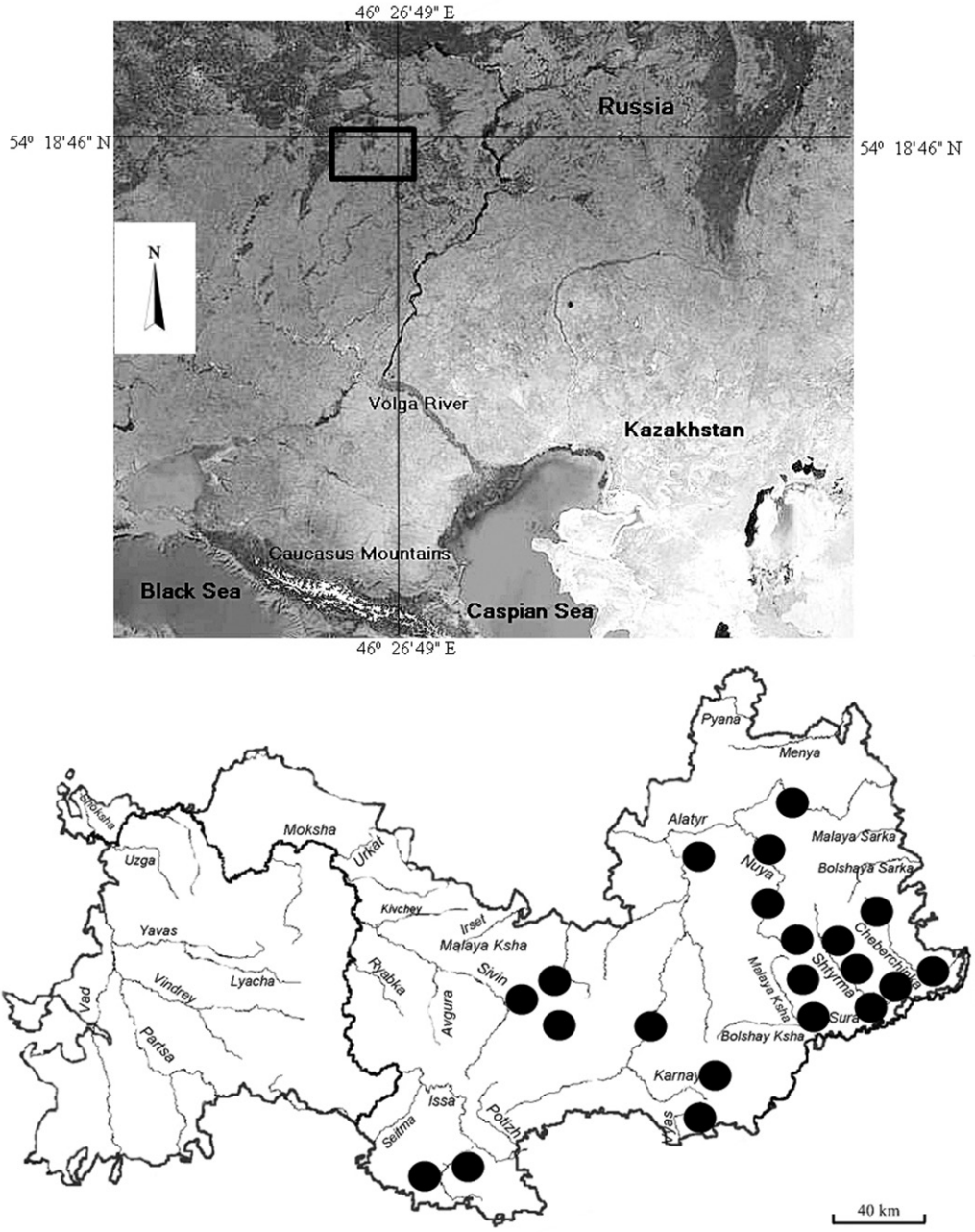

Fig. 1. Map of the Republic of Mordovia with vocalisation registration points (black circles).

as a colour) using software. Purpose of the spectrograms was to more effectively identify the calls and to easily check at what time the vocalisations started and

ended.

We singled out the beginning and end of vocal activity in the evening, night and morning hours when analysing the recordings. Evening vocal activity was restricted to two hours before and after sunset, while morning took place within two hours before and after sunrise. The beginning and end of night time activity was recorded in the remaining interval of the night between sunset and sunrise. The duration of individual periods of vocalisation was determined. When identifying the confinement of the beginning and end of calls, only those days were taken into account when Ural owl called in the interval up to 5 h relative to sunset and sunrise, respectively. Days with calls outside of these time limits were not taken into account. Comparison was made for the months and seasons of the year. Similarly, a possible dependence of vocalisation on moon phases was revealed. Ural owl calling activity was analysed for correlations with weather conditions (temperature (°C), force ($m \cdot s^{-1}$) and direction of the wind, precipitation in the form of rain or snow, cloud cover (%) and pressure (mm Hg). These variables were measured daily. To characterise climatic conditions, we used data from a weather station Bolshie Berezniki (Sun and Moon Wall Calendar 2021, rp5.ru 2021, Well and weather 2021, Phase of the Moon 2021).

Correlation analysis (r_s – nonparametric coefficient Spearman) was used to identify the relationship between vocalisation and variables. We tested the next aspects: number of calls per day, start or end of calling time and total length of calling time. All these variables were defined in the Audacity program. Comparison of the average number of calls per day for each month was made using One-way ANOVA. Statistical calculations were carried out by means of computer program AtteStat (2010), Past (Hammer et al. 2001).

Results and Discussion

During the research period, 116 sound recordings were obtained and processed, with a total length of about 3000 h. Ural owl can be attributed to moderately vocalising birds (Pukinsky1977), and calls were recorded for 5 months (January, March, April, May, and September).

A common version of the vocalisation of Ural owl males in Mordovia is a series of double calls, with the first one always louder than the second. The frequency range of male calls is 250–400 Hz. The intervals between calls are 5–8 s. A similar sound reaction of a female is rougher, hoarser, is uttered much less often. The frequency range of female calls is 550–900 Hz. A separate call of a female usually lasts 0.3–0.6 s and is issued at irregular intervals. The intervals between individual calls are from 4 or more seconds.

Analysis of vocalisation showed two of the clearest intense peaks of activity in the year: the whole of March and the second-third decades of September. In the spring months, calls of Ural owl were recorded from 19:51 to 04:04. During this period, Ural owl's total duration of calls varied from 1 to 35 min per day, with an average of 12 min. However, calls were mostly recorded in the evening hours (before 00:00 h). They account for 71.4 % of all spring calls. Calls after 00:00 h were recorded less frequently, mainly in the most active month (March). During the incubation period, owls were vocalising over the whole night. Vocalisation continued until May 14 (near the village of Sosnovy Garth Bolsheberezhnikovsky district). In summer, there is no vocalisation. Comparing the

timing of laying the first eggs in nests with the longest period of vocalisation during the day (276 calls/day) should be considered the period of mating calls the third decade of March.

The second peak of vocalisation in the year is timed to the period when broods usually break up. In September, calls of Ural owl were recorded from 19:54 to 04:24. In the warm and dry September, the birds did not call for long. During this period, Ural owl's total duration of calls varied from 1 to 32 min per day, with an average of 9 min. Other researchers also reported vocalisation during this period (Saurola 1992).

In the third decade of January, Ural owl rarely called. Calls were recorded from 23:40 to 00:23. The periods of series of calls were short.

Thus, it is shown that the vocalisation of Ural owl is high in the nesting and autumn periods, which can be used for census work. In the third decade of September, calls were heard only in the evening hours from 20:29 h to 21:02 h, that is, a short period.

Duration was significantly shorter in the evening that in the morning. Using the Mann-Whitney test, statistically significant differences between the first and second defined periods were revealed ($Z = -2.39$; $p < 0.05$) (Fig. 2). This was significantly influenced by statistical differences in the duration of vocalisation in autumn ($Z = -2.83$; $p < 0.05$) (Fig. 2). For the rest of the year, there are no differences ($p > 0.05$). There were differences between evening and morning hours.

As it was found out as a result of research, the vocalisation of Ural owl depends on some factors of the meteorological conditions. There is a statistically significant relationship between binary variable of vocalisation (yes –owl calls is present or no –owl calls is absent) and precipitation in the form of rain and snow ($r_s = -0.25$, $p = 0.01$). This is indirectly evidenced by the cessation of vocalisation of Ural owl with the beginning of rain. No statistically significant relationships were found with temperature ($r_s = -0.13$, $p = 0.94$) and pressure ($r_s = 0.08$, $p = 0.63$). It was observed in the temperature range

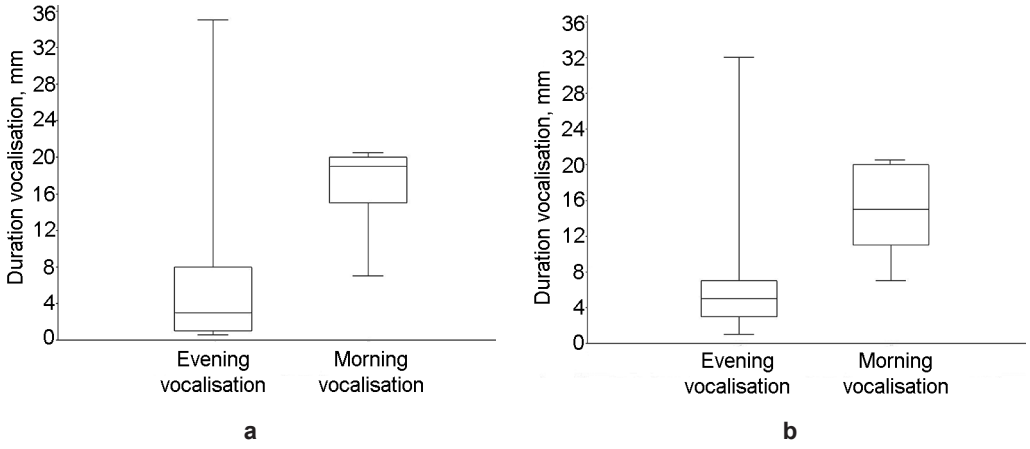

Fig. 2. Ranges of vocalisation based on materials for the autumn period (a) and for all the year (b).

Note: 'strip on box'is the median, the boundaries of the box are 25–75 % quantiles, whiskers – minimum and maximum values.

from -10 to +15 °C (+2 ±6.52 °C; *N* = 550). Calls of Ural owl in the region were recorded at cloud cover from 10 to 100 % (75 ±0.73 %; *N* = 550), at pressure from 744 to 762 mm Hg (752 ±3.92 mm Hg; *N* = 550). Calls were recorded equally in both the rising and waning phases of the moon. No calls were recorded during the full moon. Calls in the region were recorded at wind strength from 0 to 6 $m \cdot s^{-1}$ (3 ±1.11 $m \cdot s^{-1}$; *N* = 550). When the wind was strong (>6 $m \cdot s^{-1}$), they were not recorded. It was shown in some other related owls, that meteorological conditions have high influences on the owl vocalisations due to noise production (Lengagne and Slater 2002).

Comparison of the timing of vocalisation beginning in the evening and its completion in the morning did not reveal a statistically significant relationship. But, nevertheless, we consider it appropriate to give the results for the region. In the spring, Ural owl began to call always after sunset from 24 min to 4 h. Vocalisation started after sunset for an average of 2 h and 34 min (Fig. 3). It always ended before dawn (from 1 h 32 min to 2 h 46 min) (Fig. 4). In September, the overall trend continued. Vocalisation was absent before sunset and after sunrise, i.e.so in daytime. We explain this by the regional specific of the species, since the recorders work around the clock and did not record the daytime calls of the owl. In January, the calls were not timed to sunset or sunrise, as they were heard more than 5 h before and after.

In Sweden, vocal activity is at its highest level in late April and the first half of May (Lundberg 1980). In Mordovia, maximum vocalisation was noted in March. We believe that these differences may be influenced by the geographic latitude and climatic conditions. In Sweden, the winter and duration of the snow cover is longer

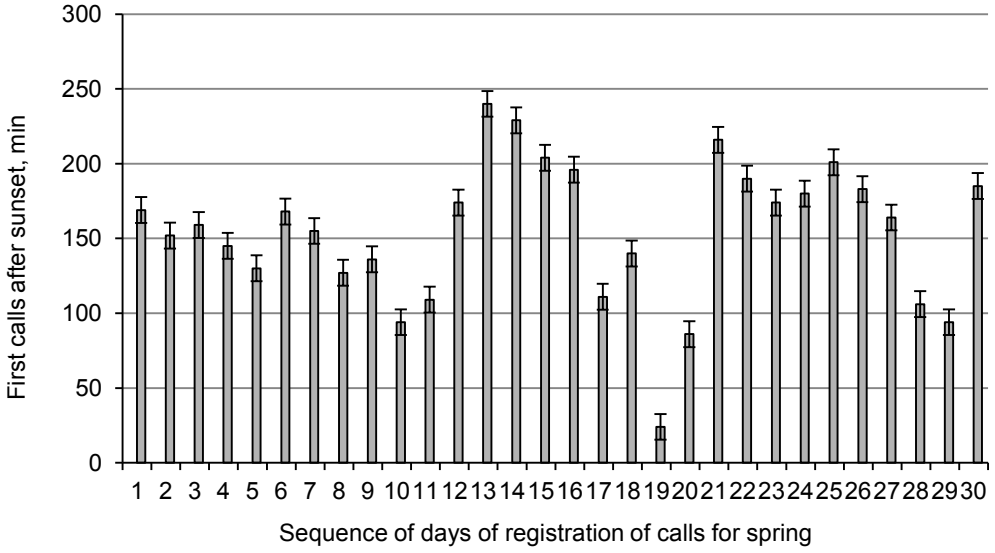

Fig. 3. Seasonal variation in the time of the first call to sunset.

Note: the number of columns corresponds to the number of days when Ural owl began vocalisation in the interval after 5 h relative to sunset.

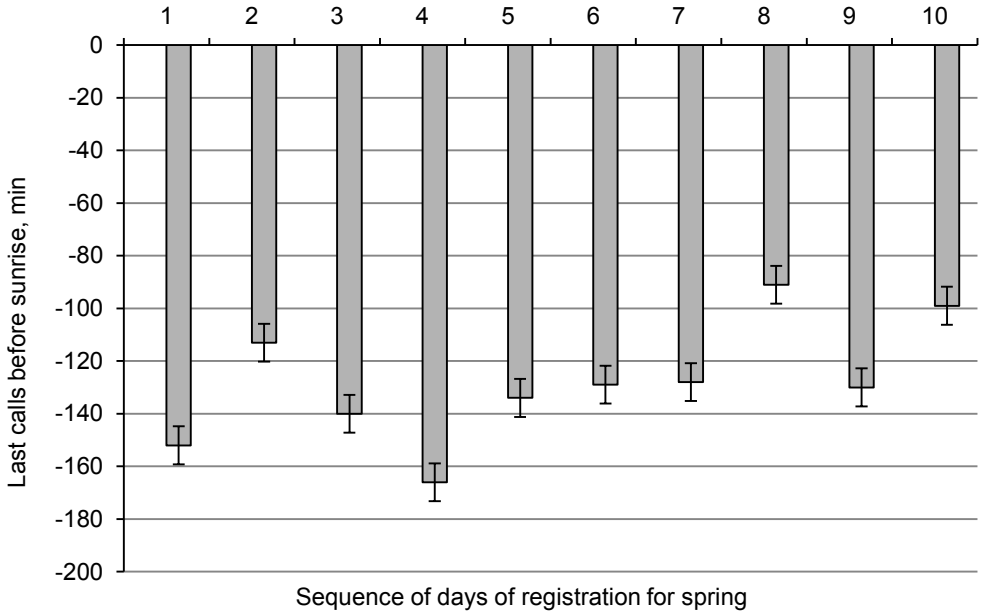

Fig. 4. Seasonal variation in the time of the last call to sunrise.

Note: the number of columns corresponds to the number of days when Ural owl finished vocalisation in the interval after 5 h relative to sunrise.

than in Mordovia. Our research covers the southern sections (approx. 54º N), in Sweden these are the northern sections (approx. 60º N), therefore the peak of vocalisation of Ural owl in Mordovia is earlier. In montane forests of Slovenia the first eggs in Ural Owl nests were found from 15 March to 21 June (Vrezec 2007), but in lowlands vocaling and breeding can start already in February (Vrezec and Tutiš 2003, Vrezec 2016).

There are slight differences between Mordovia and Sweden in daily activity with the general tendency of birds to start vocalising after sunset. So vocalisation in Mordovia began after sunset on average for 2 h 34 min. And in Sweden, this activity during incubation and the chick period was recorded on average one hour after sunset. A similar discrepancy in the vocalisation of owls was noted earlier on the example of Eagle owl in Mordovia (Lapshin et al. 2018) and Spain (Delgado and Penteriani 2007).

In terms of vocal characteristics, the recorded calls of Ural owl are similar to those recorded for other regions (Lundberg 1980, Cramp 1985, Tishechkin 1986, Shibnev 1989, Pukinsky and Pukinskaya 2011). In Finland, it shows the relationship between breeding and ambient temperature. Increasing late winter or early spring temperature advanced breeding at least as much as did high autumn abundance of prey (voles) (Lehikoinen et al. 2010).

The similarity of Ural owl with respect to the timing of vocalisation to sunset and sunrise in comparison with other species of owls is of significant interest. For Eagle owl in Mordovia, evening calls were recorded, as a rule, 1 h before sunset. Morning vocalisation usually ended 1.5 h

before sunrise (Lapshin et al. 2018). For Tawny owl (*Strix aluco* Linnaeus, 1758) in Moscow Region, voice responses were recorded mainly after sunset, and for the Pygmy owl (*Glaucidium passerinum* Linnaeus, 1758) 1.5 h before and after sunset (Sharikov and Shekhovtsov 2013). For Blakiston's fish owl (*Bubo blakistoni* Seebohm, 1884) in Primorye, voice responses were recorded 20–40 min after sunset (Andreev 2009, Pukinsky and Pukinskaya 2011). Thus, we can say that the timing of vocalisation to sunrise and sunset in different types of owls has a specific character. Spring and autumn distributions of calls of different species by time of day differ slightly.

Some differences in the number of calls of Ural owl per day in different regions can be explained by the results obtained by researchers in Spain on the example of Eagle owl. There is a lower intensity of vocalisation of single males by season compared to males which are in pairs (Martínez and Zuberogotia 2002). In areas with a high population density, calls are heard much more often in order to mark their sites from possible intruders (Martínez and Zuberogotia 2003). However, in Scandinavia, more often single males call more intensely than males in a pair bond (longer periods and longer time in spring) when calling for mates (for instance boreal owls). A possible explanation for the high vocal activity is that single males need to find a mate.

Conclusions

Thus, two best-expressed peaks of long-term activity were revealed during the year: one starting in March and the other in September. During the spring, calls were recorded from 19:51 to 04:04. During the incubation period, owls were vocalising over the whole night. In autumn, calls were recorded from19:54 to 04:24. Owls uttered calls for a duration longer in the evening than in the morning. We have identified the influence of the following meteorological factors in the form of rain, snow and wind on the vocalisation of Ural owl in Mordovia. The influence of temperature, pressure, cloudiness on the calls of an owl was not noted. Thus, the importance of this study in the priority of registration by acoustic signals, both for identifying the biology of the species in a particular area, and/or species monitoring, conservation, faunistics. A researcher in a certain area needs to know the periods of registration of a species and the conditions of environmental factors when it is better to identify a particular species.

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IMPROVED PERFORMANCE OF A MODIFIED YSD-UNIB SOLAR DRYER IN DRYING WASTE BRANCHES OF *ACACIA MANGIUM* WILLD. AND *FALCATARIA MOLUCCANA* (MIQ.) BARNEBY & J.W.GRIMES FOR CHARCOAL PRODUCTION

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Abstract

Waste in the form of bark and wood from branches of *Acacia mangium* and *Falcataria moluccana* trees is abundant in forest plantations in Indonesia. It is challenging to use these branches due to their high water content. Open sun drying (OSD) takes a long time and the resulting moisture content of 10–15 % reached still leaves the wood susceptible to microorganism attack. The objectives of this study were 1) to compare the performance of a modified YSD-UNIB mixed-mode solar dryer (MSD) with that of an earlier model and 2) to compare moisture content and drying time of bark and wood chips of *A. mangium* and *F. moluccana* branches in OSD and the MSD. MSD was 10 °C hotter and 14 % drier than the original YSD-UNIB model. MSD reduced the moisture content of wood and bark samples of *A. mangium* (to 4.52 % and 5.40 %, respectively) and *F. moluccana* (to 3.81 % and 5.38 %, respectively), significantly more than OSD (10.41 % and 12.11 % for *A. mangium* wood and bark samples, respectively, and 10.42 % and 11.82 % for *F. moluccana* wood and bark samples, respectively). OSD also took longer (10 days) to dry samples of both species than did MSD (20 h for *A. mangium* and 12 h for *F. moluccana*). The regression equations fitted to the drying curves for *A. mangium* (y = -8.746·ln(x) + 32.49) and *F. moluccana* (y = -4.7·ln(x) + 16.441) wood chips in MSD, estimated that air-dry moisture content of 10.4 % was achieved in 12 h for *A. mangium* and only 5.43 h for *F. moluccana*. For chipped bark samples of both species, the regression equation y = -8.322·ln(x) + 31.874 and y = -4.57·ln(x) + 18.517, respectively, estimated that *A. mangium* also took longer (11.12 h) than *F. moluccana* (6.79 h) to reach air-dry moisture content (of 12.11 % and 11.82 %, respectively).

Key words: bark, branchwood, drying curves, mixed-mode solar dryer.

Introduction

Acacia mangium Willd. and *Falcataria moluccana* (Miq.) Barneby & J.W.Grimes are two fast-growing species recommended and widely planted in industrial forest plantation programs in Indonesia (Marbun et al. 2019, Rahmawati et al. 2019, Yahya et al. 2020a). Harvesting timber of fast-growing species such as both leaves a lot of unutilised branches on site (Alamsyah et al. 2020). While branch trimmings of several timber species have been used as firewood (Reina et al. 2016, Ben et al. 2017), bark is still underutilised resource and has a great potential for energy production (Wang et al. 2018). Bark comprises 2 % to 10 % of the stem (Sette et al. 2020). The smaller the size of the trunk or branch, the greater the percentage of bark.

Conversion of branch wood and bark waste to charcoal can increase its calorific value. One of the obstacles in using the waste as a raw material for charcoal is its high moisture content. The calorific value of a product is inversely related to the moisture content of the raw materials (Verma et al. 2017), including charcoal production.

Solar radiation is received in abundance by the earth. In the context of sustainable development, solar energy is efficient and effective. The use of conventional energy from fossil fuels and natural gas can be replaced by solar energy (Lingayat et al. 2020).

Generally, open sun drying (OSD) of biomaterials will only reach 10 % to 15 % air-dried moisture content and takes more than a week depending on on-site drying conditions. The attack of microorganisms occurs on biomaterials with a moisture content greater than 10 % (Sulaiman et al. 2013). Technically, the best method to achieve quick drying to a targeted moisture content is by using a kiln dryer, which controls temperature, humidity and air flow. The drawback is the relatively expensive price of the equipment. Therefore, it is necessary to look for other drying alternatives.

The University of Bengkulu in the last decade developed a mixed-mode solar dryer called YSD-UNIB. It consists of a drying chamber, two heat collectors, a chimney equipped with an air outlet and inlet and a pair of doors. The dryer has successfully dried red pepper, mustard greens and cassava leaves (Yuwana and Silvia 2012), cassava (Silvia and Yuwana 2012) and catfish (Yuwana et al. 2017).

To improve its performance, the rectangular chimney running lengthwise to the dryer was replaced with a square, centered chimney, producing a modified YSD-UNIB solar dryer (hereafter referred to as MSD). The consequently smaller chimney (Fig. 1) was designed to concentrate the hot air in the chimney into a smaller space so that the hot air would be better distributed throughout the drying rack. Initial measurements show that chimney reached temperatures of up to 80 °C.

Solar-based drying for agro-products is quicker than wood (Simo-Tagne et al. 2020) because agricultural products are generally thinner and smaller. Because the waste size is relatively small, one of the recommended product sizes for energy production is in the form of chips (Moskalik and Gendek 2019). The thickness of the wood is directly proportional to the energy required for drying (Bentayeb et al. 2008). In our study, the bark and wood from waste branches were dried and subsequently used to produce charcoal (reported separately).

The novelty of this work is anticipated that MSD will dry the bark and wood chips

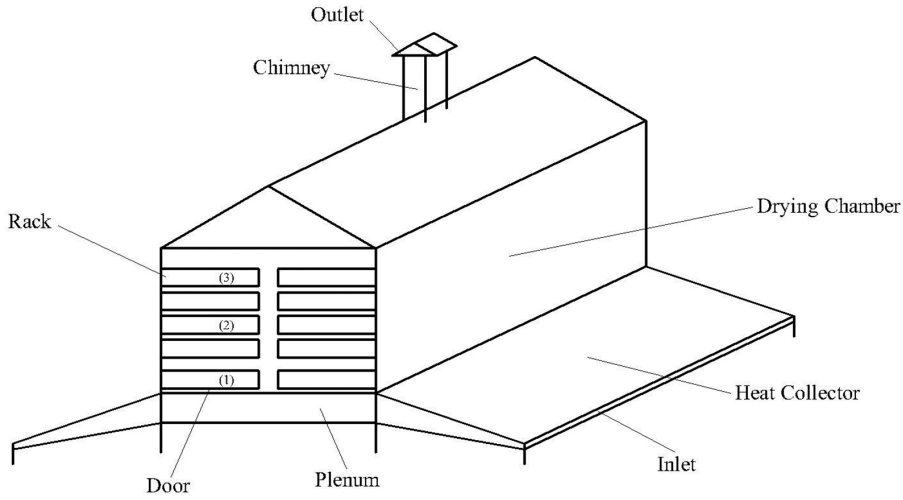

Fig. 1. Schematic diagram of modified YSD-UNIB solar dryer.

from branches more quickly than OSD. MSD is also expected to reach a higher temperature and lower humidity than other mixed-mode solar dryers, in which case it could be recommended for drying green wood for producing charcoal. Because the levels of chemical components that make up wood and bark from *A. mangium* and *F. moluccana* are different (Nawawi et al. 2018), and differing levels of chemical components in wood and bark may affect the quality of the resulting product (Park et al. 2017, Yahya et al. 2017), our study also aims at to compare moisture contents of the bark and wood of *A. mangium* and *F. moluccana* branches.

Material and Methods

Sample preparation

A 3–8 cm diameter branch was taken from each of twenty *A. mangium* and *F. moluccana* trees that had been randomly selected from a forest plantation in Bengkulu, Indonesia. Branches were immediately placed into polyethylene bags and brought to the laboratory. They were debarked and chips measuring 25×21×3 mm (length × width × thickness) were cut from the debarked branch and the bark itself. The thickness of bark chips varied according to bark thickness, which was in the range of 2.5–3.5 mm.

Drying methods

The bark and wood chips were dried in two ways namely OSD and MSD (Fig. 1). The working mechanism of the mixed-mode solar dryer including MSD is as follows. As long as sun rays strike the structure of the dryer, the drying chamber accumulates solar energy directly from the sun rays passing through its roof and the wall while the heat collector gathers solar energy from the sun rays passing through its roof and striking the upper surface plate. Solar energy obtained in the drying chamber increases the drying air while the absorbed energy by the surface plate escalates its temperature and uses it to heat the entering fresh air from the inlet and

the heated air flows into the drying chamber and further increases the drying air in it. Due to the enclosed system of drying air in the structure of the dryer, there is a pressure gradient between a point in the lower end of heat collector and a point in the upper end of chimney, then creates a continues flow of the drying air from the inlet passing through the trays to the outlet. The passing drying air heats the samples on the trays and evaporates its moisture content, and its content decreases during the drying process (Yuwana et al. 2017).

Samples of chips weighing 150 g per replicate were spread out on paper trays measuring 23×15 cm, with 20 replicates per treatment for a total of 80 samples. Samples were arranged in a nested design under the sun and in the drying chamber of solar dryer and were left to dry from 8 a.m. to 4 p.m. daily until a constant weight was reached (Montgomery 2013). Samples in the solar dyer were weighed every 4 h during the drying period but if rain was forecast, samples were weighed every 2 h. OSD samples were weighed once at the end of the day's drying period, i.e. at 4 p.m. daily. Drying the chips with OSD and MSD was carried out until the chips gained a constant weight. Temperature and humidity were recorded outside and inside the solar dryer throughout the experiment.

Five chips from each replicate sample that had reached constant weight with OSD and the solar dryer were measured their weight (IW), and further oven-dried to constant weight (ODW) to determine final sun- and solar dryer-dried moisture content (*MC*). *MC* was calculated according to the formula (1):

$$MC = \frac{IW - ODW}{IW} \cdot 100 \ , \% \qquad (1)$$

Volume of the oven-dried chips was measured using the water displacement method (Fan et al. 2012). The oven-dried density was determined as weight of the oven-dried chips divided by its volume.

An ANOVA of nested design, with species as the whole plots and branch components as subplots, was used to determine effect of species, branch component, moisture content level, and their interactions, on moisture content. Fisher Least Significant Difference (LSD) Method was used to compare treatment means at the 5 % significance level. The relationships between drying time and moisture content of wood and bark chips dried in the solar dryer were calculated using simple regression. The regression equations were used to predict the drying time needed by wood and bark chips to reach final air-dried (constant-weight) moisture content.

Results and Discussion

Moisture content of branch components in relation to tree species

The moisture content of bark and wood samples from MSD was significantly lower than that from OSD and of green wood (Table 1).

Table 1. Effect of interaction between branch component and moisture content level by ANOVA.

Interaction between branch componentand moisture content level	Average moisture content, %
Bark, wet basis (initial)	55.11a
Wood, wet basis (initial)	40.25b
Bark, air dry OSD	11.97c
Wood, air dry OSD	10.41c
Wood, dried in MSD	5.39d
Bark, dried in MSD	4.16d

Note: *Post hoc* Fisher's LSD significant differences at the 0.05 level are indicated with different letters.

Taken freshly harvested branches (wet basis), the moisture content of bark was significantly higher than that of wood (Table 1). The higher levels of extractives in the bark as compared with the wood may explain the differences in their initial moisture content. Nawawi et al. (2018) reported that hot water solubility of *A. mangium* wood and bark was 7.31 % and 16.41 % respectively, sodium hydroxide solubility was 20.60 % and 42.24 % respectively, and ethanol-benzene solubility was 8.01 % and 14.92 %, respectively; while for *F. moluccana* wood and bark, hot water solubility was 5.75 % and 12.68 % respectively, sodium hydroxide solubility was 17.26 % and 32.43 %, respectively, and ethanol-benzene solubility was 5.83 % and 8.01 %, respectively. The deposition of extractive substances in the pit prevents the release of water from the biomaterial in the drying process (Jankowska et al. 2017).

Comparing the two drying methods

MSD reduced the moisture content of the wood and bark chip samples of both *A. mangium* and *F. moluccana*, which was significantly lower than that of OSD (Table 2). OSD also took longer time (10 days) to dry the samples of *A. mangium* and *F. moluccana* to final constant moisture content than did MSD (20 h and 12 h, respectively). This result could be attributed to the very hot and dry conditions within MSD drying chamber. Mean temperature and humidity in the drying chamber were 52.8 ±1.5 °C and 21 ±4.4 % respectively, while 32.1 ±1.6 °C and 69.5 ±5.6 % respectively, outside.

With the modified smaller, centered chimney, MSD was also hotter and drier than the original YSD-UNIB solar dryer. The latter drying chamber reached mean temperature and humidity values of 43 ±2.8 °C and 35.3 ±2.7 % respectively, while it was 33.3 ±1.5 °C and 58.8 ±2.9 % outside (Yuwana et al. 2017). Reducing the chimney size appears to have increased MSD drying chamber temperature by 10 °C and reduced the humidity by 14 % compared with the original YSD-UNIB solar dryer.

MSD also performed better than other mixed-mode solar dryers. Ugwu et al.

Table 2. Moisture content and drying time of chipped branch components dried under OSD and MSD.

Branch component	Drying method	Moisture content, %			Drying time
		Initial (wet)	At constant (dry) weight	Difference	
		A. mangium			
Wood	OSD	41.73	10.41	31.32	10 days
	MSD	41.73	4.52**	37.21	20 h
Bark	OSD	51.70	12.11	39.59	10 days
	MSD	51.70	5.40**	46.30	20 h
		F. moluccana			
Wood	OSD	38.77	10.42	28.35	10 days
	MSD	38.77	3.81**	34.96	12 h
Bark	OSD	58.52	11.82	46.70	10 days
	MSD	58.52	5.38**	53.14	12 h

Note: ** – significantly different at the 0.01 level.

(2015) reported temperature and humidity values of 44–50 °C and 32–35 % respectively for their wood-drying solar dryer. Sulaiman et al. (2013) reported that the temperature in their mixed-mode dryer reached 35.86–45.22 °C. Efficient drying is driven by high temperature and low humidity in the dryer (Lingayat et al. 2020) and our results for MSD indicate good potential for efficiently removing moisture in green wood chips in the process of carbonisation (Verma et al. 2017). The heating value is inversely proportional to the moisture content of a material (Mohammed et al. 2019) thus the well-dried chips from MSD are suitable for producing charcoal with good burning quality. Additionally, the dried chips are resistant to attack by microorganisms, which need moisture levels above 10 % to actively deteriorate biomaterial (Sulaiman et al. 2013).

MSD can reduce the cost of transporting of these raw materials to charcoal-producing facilities. These transportation costs need to be considered particularly for *A. mangium* and *F. moluccana* because the charcoal kilns are typically far from forest plantations (Yahya et al. 2020b). Drying branch logs using MSD before transportation could reduce overall production costs. The energy required to dry wood in the wood processing industry can reach 70 % of the total production cost (Blanche et al. 2016) thus solar drying is beneficial because it reduces weight, transportation costs and packaging problems, and improves product stability (Chandramohan 2016, Bekkioui et al. 2020). Another advantage of using MSD is that the solar collector can reduce CO_2 emissions. The solar collector of an indirect hybrid solar dryer in Morocco helped to reduce annual CO_2 emissions by 34 % (Lamrani et al. 2019).

An alternative way to help reduce transportation costs could be siting the charcoal kiln with MSD to directly produce charcoal after drying the chips. The resulting charcoal will have a low moisture content that is relatively constant and stable because charcoal is hydrophobic (Leal et al. 2019) thus minimising transportation costs.

Predicted drying times of wood and bark chips in the solar dryer

It was predicted that *A. mangium* wood (equation $y = -8.746 \cdot \ln(x) + 32.49$, Fig. 2a) would require longer (12 h) to reach the air dry moisture content (10.41 %), whereas *F. moluccana* wood was predicted (equation $y = -4.7 \cdot \ln(x) + 16.441$, Fig.2b) to require only 5.43 h to reach air dry moisture content (10.42 %). Bark from the branches of the two species also required different drying times. Using the equations for the bark in figures 2c and 2d, *A. mangium* bark samples were predicted to take 11.12 h to reach the air dry moisture content (12.11 %) with OSD, while *F. moluccana* bark would only take 6.79 h to reach air dry moisture content (11.82 %) with OSD.

Extractive content and cell wall thickness is thought to influence drying time. The extractive content of bark and wood of *A. mangium* was higher than that of bark and wood of *F. moluccana*, respectively (Nawawi et al. 2018). The longer drying time for bark and the added production cost of debarking are factors that need to be considered when including bark in producing energy from *A. mangium* and *F. moluccana* branches.

Results of present study showed that the density of *A. mangium* wood (0.48 ±0.05 $g \cdot cm^{-3}$) was significantly greater ($p < 0.05$) than the density of *F. moluccana* wood (0.36 ±0.03 $g \cdot cm^{-3}$, Table 3). For *A. mangium* and *F. moluccana* density of the

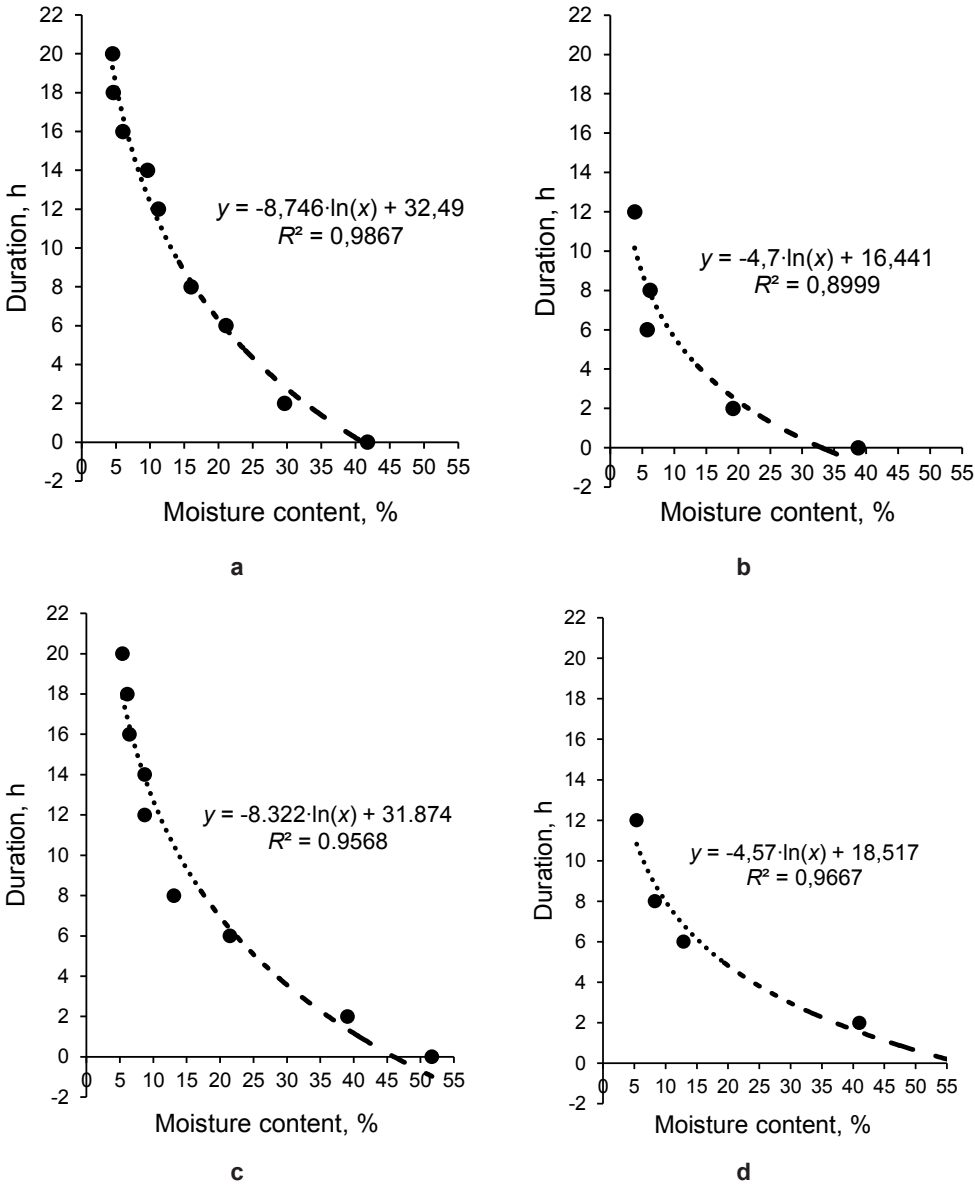

Fig. 2. Relationship between moisture content and drying time using the modified YSD-UNIB solar dryer for wood of: a) *A. mangium*; (b) *F. moluccana* and bark of (c) *A. mangium*; (d) *F. moluccana* branches.

bark is also higher than that of the wood. The density of wood is directly proportional to the cell wall thickness (Werdin et al. 2020). The thickness of the cell wall is directly proportional to the amount of bound water in the wood, and the bound water takes a longer time than free water in the drying process (Penvern et al. 2020).

Table 3. Density of wood and bark of *A. mangium* and *F. moluccana* branches.

No	Variables	Density, g·cm^{-3}
1	Branchwood of *A. mangium*	0.48*
	Branchwood of *F. moluccana*	0.36
2	Bark of *A. mangium* branches	0.62^{ns}
	Bark of *F. moluccana* branches	0.61
3	Branchwood of *A. mangium*	0.48
	Bark of *A. mangium* branches	0.62*
4	Branchwood of *F. moluccana*	0.36
	Bark of *F. moluccana* branches	0.61**

Note: ** – significantly different at the 0.01 level, * – at the 0.05 level, ^{ns} – no significantly different.

Conclusions

MSD was 10 °C hotter and 14 % drier than the original YSD-UNIB model. Its ability to dry wood chips to 10 % moisture content in 12 h and 5.43 h for *A. mangium* and *F. moluccana* wood respectively, while OSD took 10 days demonstrates its potential in pre-processing waste *A. mangium* and *F. moluccana* branches for subsequent charcoal production.

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ANALYSIS OF THE VALUE, VISITOR EXPENDITURE PATTERNS AND EMPLOYMENT BENEFITS FROM FOREST RECREATION IN MABIRA CENTRAL FOREST RESERVE, UGANDA

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Abstract

The contribution of forest recreation to national economy and the adjacent communities is rarely recognized and often overlooked. However, if assessed, it can help to justify the need to conserve forest resources. This study assessed the value, visitor expenditure patterns and employment benefits of forest recreation at the three recreation sites in Mabira Central Forest Reserve (CFR). Semi-structured questionnaires were administered to recreational visitors from July to December 2019. The zonal travel cost method was used to determine the annual recreational value of Mabira CFR and the direct tourism spend method to estimate tourists' expenditure. Employment income was assessed from questionnaires administered to all employees at the sites. The comparatively high annual forest recreational value of 577,446 USD was attributed to the forest's rich biodiversity and close proximity to densely populated urban areas. The most preferred recreational activity was canopy super skyway ziplining because it is relatively new. The annual income of employees at the three sites amounted to 28,034 USD, of which 78 % was attributed to employment at the sites. The total annual visitor expenditure amounted to 100,700 USD, of which 61,151 was attributed to the biodiversity of the forest. These results indicate the potential of forest recreation in job creation and income generation, which translate to improved standards of living for employees and surrounding communities. This calls for promotion of forest-based recreation in other high diversity forested areas of the country.

Key words: economic benefits, job creation, outdoor recreation, recreational value, site perceptions, tourism expenditure, travel cost method.

Introduction

Tourism industry has a major economic significance for any country through receipts from international tourists (Dwyer and Mistilis 1999). Worldwide, the pursuit for leisure has led to increased demand for recreational activities across many countries (Amalu and Ajake 2012). The interest in forest recreation is attributed to aesthetic experiences offered and relaxing environment provided by forests (Grilli et al. 2014, Mamat et al. 2020). An estimated 3.7 % of the world's forests are designated for recreation, tourism, education, cultural and spiritual heritage (FAO

2010). A few studies have been conducted to evaluate these benefits (Eagles et al. 2000, Shoo and Songorwa 2013). Recreation has been suggested as one of the solutions to overcome obstacles to community development (Lawson et al. 2006, Amalu and Ajake 2012) due to the high number of tourists who spend money at recreational facilities.

In Africa and many other parts of the world forests are important for tourism but their main function remains conservation of wildlife. Many goods and services provided by forest ecosystems are crucial, but not always measurable in monetary terms. Forested land has traditionally been considered to be of lower economic value than agricultural land. The main forest output is viewed as timber production and yet recreation is one of the numerous sustainable services provided by forest ecosystems. Forests are parts of the countryside that visitors enjoy, sometimes for relaxation and other recreational activities. The value that users attach to forest recreation can be substantial but this is not reflected by market prices. This attachment can improve in the management, conservation and planning options for recreational activities. In Uganda, the value of forest recreation is often ignored or accounted for in other sectors like tourism when valuing forests (MWE 2013). However, if public goods are to be managed in ways that provide maximum benefits to the community, these benefits should be recognized. As more people visit forested areas for tourism and recreation purposes, it becomes increasingly important to emphasize the values provided by these natural resources. Managing a forest to the maximum benefit of society involves the identification and estimation of all resource benefits on a common metric scale. In order to convince policy makers about the economic viability of forest conservation, it is essential to provide them with monetary gains from all forest benefits including recreational services.

The economic linkages between forests and adjacent communities are one of the important ways public lands contribute to the well-being of private individuals and communities (Mayer and Woltering 2017). Forests attract recreational visitors who spend money in communities and at forest recreation facilities (White et al. 2017). The importance of forests in recreation and leisure activities translates into other benefits to surrounding communities that ought to be assessed. Such benefits include income generation and job creation for both public and private sectors (Wagner 1997). Generally a change in tourism contribution leads to a multiplier effect in related industries (Harvath and Fretchtling 1999). The income multiplier is the most important indicator of the impact of spending in the local economy. Forest recreational visitors spend money on drinks, food, accommodation and recreational activities. This creates direct revenue for businesses and public organizations associated with forests. Direct employment relates to the number of jobs directly supported by expenditures of forest recreational users. The employment multiplier measures the increase in employment associated with a specific increase in initial expenditure or the number of full-time jobs equivalent with a specified amount of expenditure.

The analysis of the role of forests in recreation and tourism based employment and income is hampered by the lack of information on exactly how much the local economy derives from them (Kass and Okuba 2000). This limitation, coupled with the fact that amenity attributes are non-market inputs, results into inad-

equate policy decisions (Marcouiller and Deller 1996).

Tourist expenditure is scrutinized by policy makers, planning officials, marketers and researchers for monitoring and assessing the benefits of tourism to the local economy (Wang et al. 2006). Direct effects are indicative of the total tourist financial spending at a tourism facility. Data describing economic and employment contributions of forests typically focus on timber harvesting and processing because of the conviction that other forest benefits like recreation are worthless. Despite this shortcoming, the economic contribution of forest recreation is of interest to private businesses, public agencies and individuals living in tourist destination areas (Simpson et al. 2009). The study assessed the value, visitor expenditure patterns and employment benefits from Mabira CFR. Specifically, the study (i) assessed the value of Mabira CFR, (ii) estimated tourists' expenditure contribution to income generation and employment. Understanding the benefits of forest recreation to a local community can act as an incentive to support conservation of the forest resource.

Research Design

Study area

The study was conducted at three recreational sites within Mabira Central Forest Reserve, namely: Griffin Falls Camping Site, Mabira Ecotourism Site and Mabira Rainforest Lodge (Fig. 1). These sites are well-managed with a variety of recreational activities that attract tourists and offer support services to forest recreation. The reserve is located 20 km north of Lake

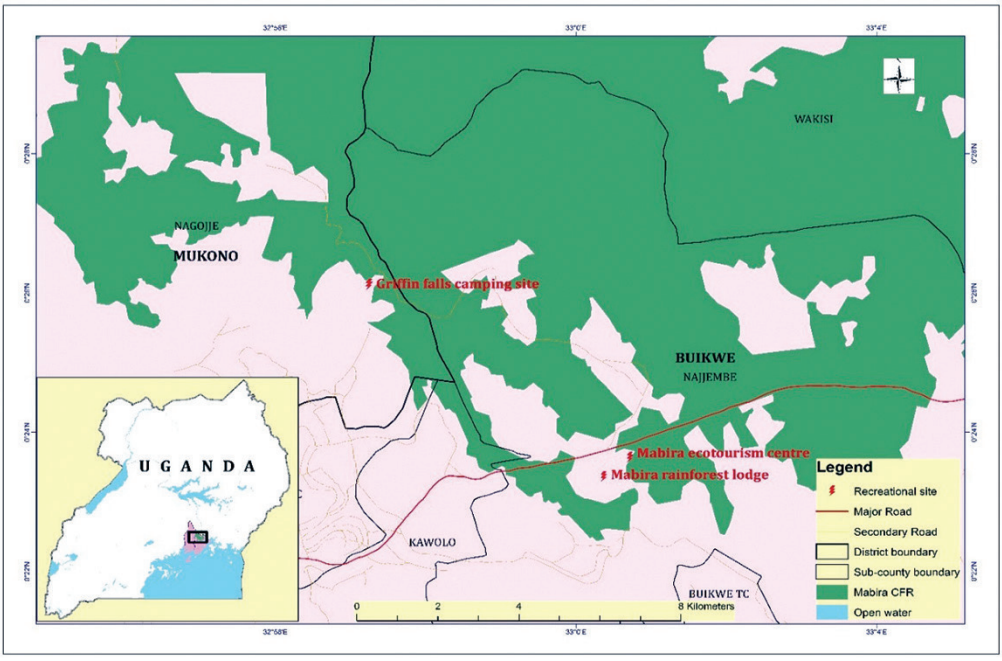

Fig. 1. Recreational sites within Mabira CFR.

Victoria shoreline to the west of Victoria Nile. It lies partly in Buikwe, Mukono and Kayunga districts and occupies an area of 306 km^2 with an altitudinal range of 1070–1340 m above sea level. It is situated between latitude 0°22′ and 0°35′ N and between longitude 32°56′ and 33°02′ E. The reserve is characterized by numerous flat-topped hills and wide shallow valleys (Howard 2001).

The soils are generally ferralitic sandy clay loams, with black waterlogged clays in the valley bottoms. The climate is tropical with two rainfall peaks from April to May and October to November with annual amounts ranging between 1250–1400 mm. The annual mean minimum and maximum temperature ranges are 16–17 °C and 28–29 °C, respectively (Tugume et al. 2016). Mabira CFR is an important ecosystem in Uganda and a watershed for Lake Victoria basin and Lake Kyoga.

The communities adjacent to the reserve comprise mainly the Bantu ethnic groups, namely: Baganda, Banyarwanda, Basoga, Bagisu, Bakiga, Banyankole, Bagwere and Batoro in addition to the minor Luo groups like the Samia, Ateso, Langi and Acholi (Galabuzi et al. 2014). The majority of the residents are subsistence farmers. Education and income levels of local people residing in the forest communities are low (Agea and Fungo 2009).

The forest is adjacent to large sugar cane plantations. Mabira CFR is located on the main Kampala-Jinja highway making it easily accessible even by public transport. Mabira CFR has a rich biodiversity, which, together with accessibility, makes it an important tourist destination area. It is one of the significant recreational places in Uganda that host local and foreign visitors.

Recreational value of the forest

The zonal travel cost method (ZTCM) (Clawson 1959) was used to estimate the recreational value of Mabira CFR. The ZTCM is an indirect approach used to estimate user benefits from visits to recreational sites (Liston-Heyes and Heyes 1999). It assumes that the value of a recreational site or its recreational services is reflected in how people pay to get to the site. The expenditure related to recreation travel was treated as travel costs (Englin and Shonwkiler 1995).

Travel cost is seen as derived demand for a recreation site that contributes to each individual's production of a recreational activity providing utility (Smith 1990). Since visitors must travel to a particular site with preferred attributes to derive the recreation experience, their travel behaviour provides important information to calculate the recreation demand.

An on-site survey of recreational visitors was carried out from July to December 2019 using pretested self-administered questionnaires at the three sites. The questionnaires were filled by 201 visitors who were present at the time of the survey.

Each respondent was allocated to a zone of origin according to the distance travelled to visit the forest using the web flyer mileage calculator (WebFlyer 2019). This resulted in 10 zones. Through the questionnaires it was possible to clarify how many people had visited the forest within a period of one year from the different zones. The population of each zone was obtained from Mapofworld.com (2019). The basic model used depicts the rate of visits per 1000 population as a function of factors such as the travel cost and the time spent travelling.

Using information on the number of

visitors from each of the 10 zones (0–9), total visitors per year and the population in each zone (Table 4), the visit rate per 1000 population (VR_{1000}) in each zone was determined by using the formula (1):

$$VR_{1000} = \frac{N_i \cdot 1000}{P_i}, \text{ number of 1000 per year} \quad (1)$$

where: N_i is number of visits per year from zone i and P_i is the total population in zone i.

Information on the round-trip travel cost and the average time for each trip was also collected. Round-trip distance to the forest by visitors from each zone was calculated using the web flyer mileage calculator and this was multiplied by the standard cost per mile for the period according to the American Automobile Association (AAA) as 0.608 USD per mile for 2019 to get the full travel cost per zone. This method assumes that all visitors from a particular zone have the same probability of visiting the forest at the same travel cost. The recreational value of Mabira CFR was determined by multiplying the total cost per trip for each zone with the number of visits per year, to get the total travel cost per zone. These figures were summed up for all zones to obtain the total travel cost for all the visitors to Mabira CFR per year, which was equal to the recreational value of Mabira CFR.

Analysis of economic benefits to employees at the recreational sites

Semi-structured questionnaires were administered to all employees at each of the three sites to capture data about the benefits they obtained from forest recreation. In total 33 employees responded, of whom six worked at the Mabira Ecotourism Centre, five at Griffin Falls Camping Site and 22 at Mabira Rainforest Lodge. Information was obtained about their demographic characteristics, net salary and wages, level of employment, other sources of income and other non-financial benefits received in the course of employment. The managers provided data about monthly revenues of the businesses, employment levels, charges for different recreational activities, the peak period, and the number of individuals employed at the recreation sites. Using the number of employees and monthly wages per head, an estimate of the total employment income from forest recreation was calculated and extrapolated to annual figures.

Visitor expenditure survey

User spending was used to measure the direct economic value of forest recreation (Carlsen and Wood 2004). The value was determined using a visitor expenditure survey, in which tourists were asked to record their expenditure on different items during their visit to Mabira CFR. The expenditure information was obtained using semi-structured questionnaires administered on the next come basis. Visitor expenditure was assessed by asking respondents to indicate i) The money spent on the trip with respect to travel, accommodation, food, drinks, entrance fees and recreational activities, ii) Whether expenditure figures were per day or for the whole trip, iii) The number of people covered by the expenditure figures and iv) The length of stay at the site. The survey data provided daily average expenditure per visitor using the average length of stay and adjustment for total expenditure to account for the number of persons the expenditure covered. Mean daily expenditure per person was calculated for each item. In case of accommodation, the number of nights

was determined by subtracting one (1) from the number of days visitors stayed at the site. The sum of each expenditure item separately was used to compute average expenditure per person per day. The average daily expenditure per person was extrapolated using estimates of total visitors to the study sites in 2019, the average expenditure per visitor and average length of stay to get the total annual expenditure (Crompton et al. 2001). The average expenditure per visitor per day on accommodation (*A*) and other expenses (*OE*) were calculated using the formulas (2) and (3).

$$A = MAE \cdot N \cdot MLS^{-1}, \quad (2)$$

$$OE = MNP \cdot LS, \quad (3)$$

where: *MAE* is mean accommodation expense, *N* is number of people, *MLS* is mean length of stay, *OE* is all other expenses (based on mean expense for each item), *MNP* is mean number of people, and *LS* is length of stay in days.

Total visitor annual expenditure (*TE*) was calculated using the formula (4).

$$TE = EDE \cdot ELS \cdot TLS, \quad (4)$$

where: *EDE* is average daily expenditure, *ELS* is average length of stay, and *TLS* is total number of visitors.

Regarding their perception of Mabira CFR in terms of environmental conditions for recreation and services offered, visitors were asked to respond to a set of seven questions structured to three categories using the five-point Likert scale **(**Ezeuduji and Mhlongo 2019). The questions also sought the visitors' perception about conservation issues that threaten the forest. The responses were coded as disagree or don't know or agree and used to calculate the mean scores.

The annual expenditure of the visitors attributed to Mabira CFR was estimated as follows: number of overnight visitors × visitor attribution to biodiversity × daily expenditure of the visitors × average length of stay.

Results and Discussion

Characteristics of visitors

Overall, 62 % of the respondents were female and the average age of visitors was 30 years. About 27 % of respondents were Ugandans and 73 % were foreigners. Resident foreigners comprised 10 % of the visitors, and the non-resident foreigners constituted 90%. Similar results were reported in a study in Brazil, where a majority of visitors to a protected forest were foreigners (Souza 2016). The low frequency of Ugandan visitors might be attributed to unaffordable costs and limited awareness about the variety of recreational activities available in Mabira CFR. Regarding education, 84 % of the visitors had attained at least tertiary education implying that education increases knowledge about the benefits associated with recreation. Therefore, people with higher levels of education appreciate environmental services, recreation and ecotourism (Kawsar et al. 2015). A similar trend was observed in a study conducted in Tanzania (Twerefou and Ababio 2012). The mean monthly household income of respondents was 954.52 USD; with a standard deviation of 1957.8 USD. About 26 % of the respondents earned above the mean income.

Forest recreation patterns

The study revealed that 48 % of the respondents visited Griffin Falls Camping Site, 28 % the Mabira Ecotourism Centre and 24 % the Mabira Rainforest Lodge.

The canopy super-skyway zip-lining activity at the Griffin Falls Camping Site attracted the highest frequency of visitors due to its uniqueness. At the Bavarian Forest in Germany visitor motivation for hiking was a small forest restaurant at the end of the trail and followed by tradition linked to forest visits every summer (Rathmann et al. 2020). About 75 % of the respondents visited Mabira CFR for the first time in the past 12 months and most of them were foreign tourists. An adult visitor made at least one trip to the site per year. The visitors were mainly interested in nature walks (43.5 %), canopy super-skyway zip-lining (34 %), bird watching (15 %) and camping (17 %). Other activities offered at the sites include biking and hiking. The months of July, August and November recorded the highest frequency of visitors because they coincide with the traditional holidays in countries of the temperate northern hemisphere where a majority of the visitors came from. Information regarding recreation patterns is important for business owners because it helps them to predict when to expect more visitors and plan for them in advance to avoid visitor dissatisfaction.

Site perceptions

Mabira CFR was regarded as having a good recreational space (92 %) with a high aesthetic value (89 %) by the majority of the visitors (Table 1). The parking facilities at the forest were considered adequate and the staff at the sites offered the necessary information to the visitors. The mean values for the seven site perception characteristics were above four (4) an indication that visitors regarded Mabira CFR as a good recreational space with conducive environmental conditions. However, 51 % of the visitors considered the forest threatened by encroachers. This might have a negative implication on recreational visits and revenue collected in the long run. Thus, visitor perceptions and site characteristics are important aspects for any tourist destination area (Staneva 2019).

Environmental attributes that attracted visitors to Mabira CFR were the rich biodiversity (60 %), conducive environment that stimulates relaxation and self-reflection (47 %) and canopy super skyway zip-lining that was recently introduced (9 %). Similarly, a study by Lupp et al. (2016) revealed that forest diversity was the major motivator of tourist visits. Visitors also reported having contact with nature, exercising and relaxation as the main motives for visiting Mabira CFR. Preference of different recreational activities provide a guide to private investors in the tourism sector on which activities are highly demanded and worth investing in.

Table 1. Visitors' perceptions of Mabira CFR recreational sites.

Characteristic	Mean score	Disagree	Don't know	Agree
		%		
Good recreational space	4.40	2.8	5.1	92.1
High aesthetic value	4.32	1.4	9.8	88.8
Good environmental conditions	4.40	2.8	5.9	91.3
Availability of guiding information	4.05	2.1	10.9	87.0
Adequate parking facilities	4.42	8.6	8.0	83.4
Safety	4.32	5.8	9.4	84.8
Encroachment threat to the forest	3.58	23.9	25.4	50.7

A majority of the visitors (45.5 %) preferred nature walks followed by 34.1 % that preferred zip-lining (Table 2). The popularity of canopy super skyway zip-lining is an indication of its potential to attract more tourists.

Table 2. Preferred recreational activity.

Activity	Frequency	Percentage
Nature walks	78	45.5
Bird watching	20	15.2
Zip-lining	45	34.1
Camping	22	16.7
Biking	11	8.4
Hiking	16	12.1
Viewing the water fall	3	2.2

Note: The percentages are inclusive of each other.

Recreational activities offered at the different sites provide a range of health benefits through reducing physical inactivity. White et al. (2016) indicated that recreational physical activity especially walking in natural environments promoted good health. Health benefits of walking have been reported as preventing high blood pressure, breast cancer, type 2 diabetes, hip fracture, colon cancer, osteoporosis and impotence (Godbey 2009). Outdoor recreation in forests reduces stress, helps people to connect with nature and experience calmness (Ohe et al. 2017, Taye et al. 2019), which are precursors to wellness. Forest recreational activities constitute part of health tourism, which has been suggested as a means to improve and maintain health conditions of aged tourists without necessarily obtaining medical treatment (Huang and Xu 2014).

The relaxation obtained by visitors promotes a good state of mind. Some studies reported exposure to nature as an important factor in mental health improvement by providing short term emotional benefits and recovery from stress (Holland et al. 2018, Buckley 2019, Buckley et al. 2019) and to improve happiness (Frumkin et al. 2017). Staneva (2019) reported that physical activity through outdoor recreation reduced the impact of electromagnetic fields on people's health through promotion of good sleep, improved immune system, stabilization of the cardiovascular system and provision of psycho-emotional comfort. From this discussion, it is evident that forest recreation not only promotes good health but also minimizes costs associated with management of wide range of health conditions. This is important in fostering improved health and wellbeing of citizens.

Forest recreational value

The total annual recreational value of Mabira CFR was 577,446 USD (tables 3 and 4). This value is higher than the previous estimates for the same forest at 91,035 USD (Muramira 2000). The in-

Table 3. Visitation rates per zone.

Zone	Population, number	Distance, miles	Visits, number	Visits per 1000
	a	b	c	$d=c \cdot b^{-1} \cdot 10^{-3}$
0	599,817	0	4	0.006669
1	2,050,370	189	86	0.041944
2	64,006,033	1,335	14	0.000219
3	6,219,150	4,550	9	0.001447
4	1,251,695,584	6,080	5	0.000004
5	8,584,926	6,900	3	0.000349
6	42,910,000	6,940	1	0.000023
7	35,563,007	8,123	27	0.000759
8	64,088,222	8,040	15	0.000234
9	34,368,864	14,580	28	0.000815
			∑=192	

Note: a – population per zone of visitors' origin, b – distance from zone of origin to Mabira CFR.

Table 4. Total travel cost estimates.

Zone	Round trip travel distance, miles	Visits, number	Round trip travel time, min	Distance × cost per mile, USD	Cost of travel time per minute, USD	Travel time × cost per min, USD	Total travel cost per trip, USD	Total travel cost per zone, USD
a	B	c	D	e=b·0.608	F	g=d·f	h=e+g	i=h·c
0	0	4	-	-	-	-	-	-
1	189	86	342.0	115	0.260	88.92	204	17,544
2	1532	14	300.0	931	0.997	299.10	1231	17,234
3	4550	9	480.0	2766	1.222	586.56	3353	30,177
4	6080	5	280.0	3697	0.370	103.60	3800	19,000
5	6900	3	120.0	4195	0.500	60.00	4255	12,765
6	6940	1	120.0	4220	1.110	133.20	4353	4353
7	7932	27	675.0	4823	0.577	389.48	5212	140,724
9	8123	15	614.0	4939	0.620	380.68	5319	79,785
10	14,580	28	323.0	8865	0.847	273.58	9138	255,864
							∑=36,865	∑=577,446

Note: Cost of distance travelled from each zone (column e), cost of travel time (column f) was obtained by averaging travel time reported by visitors from each zone and multiplied by their reported wages. The cost per mile = USD 0.608.

crease is attributed to the new facilities and activities that have been established like the Mabira Rainforest Lodge and the canopy super skyway zip-lining at Griffin Falls Camping Site respectively. There has been increased sensitization about tourist attractions by the Ministry of Tourism, Wildlife and Antiquities, which has resulted in increased numbers of foreign tourists per year, and local tourists who have begun to appreciate forest recreation. Naidoo and Adamowicz (2005) estimated the value of nature-based recreation of Mabira CFR at 7000 USD; but this focused only on bird diversity. The high recreational value revealed by this study could be attributed to the activities mentioned earlier. Additionally, the strategic geographical location of the forest reserve near the major urban centres of Kampala, Jinja and Mukono, also contributes to the desire of tourists to visit the forest. The immediate alternative to Mabira CFR would be Budongo Forest Reserve in Western Uganda; but this is likely to have a higher value based on travel cost method because of its remote location. This recreational value is much lower than values that were obtained for different forests in other countries. For instance, Srengsen Jakarta urban forest in Indonesia RM was valued at 0.44 $m \cdot yr^{-1}$ (Solikin et al. 2019), Belum-Temeng rainforest in Malaysia at RM 14.66 million per year (Gwee et al.

2019) and Swedish forest at $ 3,406,751 (Ezebilo 2016). The variation in values could be attributed differences in the number of forest recreational tourists in the different countries.

The value demonstrates the economic benefits of recreation in Mabira CFR and other associated benefits. The preservation of these benefits depends on conservation of the forest biodiversity through sustainable use. This would prevent substantial reduction in its value, thus improve the number of visitors per year. Despite empirical data generated from the survey, market failure has been identified as one of the major causes of undervaluation. To determine the economic value of the Mabira CFR, decision-makers have always put into account the easily quantifiable cost and benefits related to goods and services traded at the market. However, numerous functions of the Mabira CFR were identified for which markets are malfunctioning, distorted or simply non-existent. Markets only exist for some of the environmental functions of the forest reserve, such as eco-tourism. However, even if markets exist, market prices for these services are not reflected in the real value of these services due to distortion by subsidies. This study revealed that benefits were enjoyed and costs incurred but not directly realized in the supply and consumption of recreational services, hence externalities were observed.

The contribution of forest recreation to the local economy

Employment income

Forest recreation created 33 jobs for the local people at the three sites with 74 % being occupied by males and 26 % by females. Therefore, tourism related labour is more important to men than women in terms of employment. Local people were employed as guards, waiters, managers, accountants, cleaners, tour guides and receptionists. The total annual income received by the employees amounted to 28,074 USD, of which 21,863 USD was attributed to employment at recreational sites and 6211 USD (Table 5) to other sources like agriculture and business. These figures are very low compared to those generated from other forests worldwide. For instance, protected forests in Brazil generated $ 342 million and offered employment to 43,602 jobs (Souza 2019). Promotion of forest recreation brings about sustainable income that is dependent upon nature conservation. The high contribution of employment income underscores the importance of forest recreation to the rural community of Mabira CFR. Reliance on income from tourism related employment is characteristic of communities adjacent to other protected areas in East Africa (Shoo and Songorwa 2013). A similar scenario was

Table 5. Financial benefits that accrue to employees at the three recreational sites.

Tourist site	Annual recreational employment income, USD	Annual other income, USD	Total annual income, USD	Relative income from recreational employment, %
Mabira Ecotourism Centre	2833	1167	4000	70.8
Griffin Falls Camping Site	1567	2233	3800	41.2
Mabira Rain forest Lodge	17,463	2811	20,274	86.1
Total	21,863	6211	28,074	77.9

reported by Staneva and Marinov (2021). The local people preferred working in Mabira CFR recreational sites despite the proximity of large sugarcane plantations of Mehta Group of Companies. They attributed this to less pay in the sugarcane plantations.

The relative income from employment at Mabira Ecotourism Center and Mabira Rainforest Lodge was high at approximately 71 % and 86 % of total income respectively. These figures are higher than 9.6 % employment income attributed to ecotourism in Amani Nature Reserve (Shoo and Songorwa 2013). This indicates that forest recreation makes a positive contribution to the livelihoods of employees at the three sites. Griffin Falls Camping Site employed only four people hence the lowest employment income contribution of 41 %. The high relative income 77.9 % (Table 5) attributed to forest recreation activities reaffirms the fact that forest resources that were originally considered as only sources of raw materials for wood products are now valued for their recreational purposes. Therefore, promotion of forest recreational facility-based employment is a potential conservation strategy for forests. Additionally, it would enhance government revenue since it would increase the tax base. Mbaiwa and Stonza (2010) also revealed that employment at tourism facilities can improve livelihoods of communities.

Though employment can be regarded as an individual benefit, employees at the three sites financially support their families through payment of school fees, medical care and asset acquisition and accumulation. Other non-financial benefits derived from the forest by virtue of being employed at the sites include acquiring working experience that enhance employee skills in promoting teamwork and managing people, gaining reputation in the local community, making friends and travelling to different places. Employees also make statutory payments to the National Social Security Fund on behalf of employees that guarantees them some level of income on retirement in addition to offering them medical insurance. Apart from direct income from employers, employees reported receiving gifts in form of clothes and money from the tourists who appreciated their services. The economic returns generated from forest recreation and related activities also benefit investors in the tourism sector.

Visitor expenditure patterns

Expenditure on forest related recreational activities in addition to employment income generates revenue for the various businesses near the sites. The average period of stay for forest recreationists was two days and the average daily expenditure amounted to 136 USD. Total annual expenditure of visitors to the three tourist sites amounted to 138,442 USD (Table 6). This figure is far below 61.26 million USD estimates by Christie et al. (2006) and Carlsen and Wood (2004). This could be attributed to the limited number of visitors, an indication that forest recreation has not yet attained its full potential in Uganda to contribute high revenues to the economy.

The highest expenditure was attributed to airfare to Uganda. However, if this is excluded from the analysis the opportunity cost of travelling to Mabira CFR for recreation is the second biggest cost. This clearly illustrates the importance visitors attach to forest recreation. Amongst activities offered at the sites super skyway zip-lining was the most expensive activity per individual.

Table 6. Mean visitor expenditure to and on site.

Expenditure type	Amount, USD	Percentage
Local transport to site	2890.17	2.08
Fuel to site	512.72	0.37
Accommodation	7427.06	5.36
Meals	2811.42	2.03
Nature Walk	719.72	0.51
Entrance fees	652.78	0.47
Airfare to Uganda	107,113.20	77.37
Communication	297.36	0.21
Super skyway ziplining	112.22	0.81
Other costs	2132.22	15.59
Opportunity cost	12,762.72	9.212
Total	138,441.59	100.00

Note: The number of visitors that responded to the expenditure survey was 201.

The average daily expenditure on recreational sites aided in the generation of the direct tourist expenditure at the recreational sites in Mabira CFR (Table 7).

Table 7. Average daily expenditure per person in Mabira CFR.

Expenditure item	Average expenditure per person per day, USD
Transport to site	3.05
Fuel to site (use of private cars)	0.60
Accommodation	9.61
Meals	3.41
Recreational activities	1.42
Communication	0.31
Other expenses	0.81
Mean total expenditure	19.23

The average expenditure per day per person excludes costs for the airfare and entrance fees. The total average expenditure per person per day amounted to 19 USD. This figure is lower than what was estimated by Sun et al. (2002) an indication that forest recreation has not been fully appreciated and developed in Uganda. Tourists to the three sites in Mabira CFR directly contribute about 100,700 USD per year. This is quite low compared to tourism expenditure from day visits to other recreational sites (Christie et al. 2006). This may be attributed to the significantly lower number of visitors during the survey period. Irrespective of the low amounts spent by tourists at Mabira CFR sites, visitor expenditure provides an important reason to conserve the forest (Souza 2016). Thus, forest managers in Uganda should ensure that these natural areas are conserved in order to attract tourists whose expenditure might benefit forest adjacent communities and the country at large.

Attribution value

The visitor survey revealed that 60 % of visitors in Mabira CFR attributed their visits to the high biodiversity of the forest. It is therefore prudent to assume that 60 % of visitor expenditure is attributed to the forest to the tune of 61,151 USD annually. The high biodiversity attracts tourists with varied interests like game viewing, bird watching, nature walks, and zip lining among others. This supports the idea of forest conservation to generate income for countries and their citizens and particularly local communities living adjacent to forests. Realization of huge economic benefits is dependent on effective management and protection of forest biodiversity. Therefore, if countries and communities are to economically benefit from forest recreation, biodiversity of in such areas have to be preserved.

Conclusion

The visitors to Mabira CFR were mainly foreigners because the local tourists were discouraged by unaffordable costs of the recreational activities. Thus, a deliberate effort to attract local people through subsidization of the costs should be supported. The frequency of tourists coincided with holidays for European countries. The canopy super skyway zip-lining was popular due to its novelty and contributed to the increased number of tourists. Therefore, this activity can be introduced in other forested areas in Uganda in order to boost local revenue collection. Mabira CFR was perceived by most of the visitors as a good recreational space with conditions favourable for tourism. The rich forest biodiversity was singled out as the most important factor in attracting tourists. The forest contributed to a great extent to income generation for employees at recreational sites. Therefore, there is need for improvement of aesthetics of the recreational sites while preserving the naturalness of the area in order to attract more tourists. Results of this study may provide motivation to improve the quality of environmental services from Mabira CFR and to expand the variety of services offered based on the demand of the people.

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BREEDING DISTRIBUTION OF EUROPEAN TURTLE DOVE (*STREPTOPELIA TURTUR*) IN SARNENA SREDNA GORA MOUNTAIN, CENTRAL SOUTH BULGARIA

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Abstract

We monitored the abundance of European Turtle dove in 6 forest habitats. The present study identifies two variables that can affect the breeding distribution of European Turtle dove in Sarnena Sredna Gora Mountain. The arable land adjacent to the breeding habitats is a significant factor influencing its breeding distribution in the study area. The abundance is significantly higher in forest habitats adjacent to cereal, sunflower and sunflower/cereal crops. Second environmental variable which determines its breeding distribution is elevation. The study shows differences between the preferences of breeding sites of Turtle doves in Sarnena Sredna Gora and those found in lowland open habitats in Bulgaria. These results suggest that different approaches to habitat management need to be chosen for different parts of the breeding area of the species in Bulgaria.

Key words: abundance index, agricultural crops, breeding habitats, food source, habitat variables.

Introduction

European Turtle dove (*Streptopelia turtur* (Linnaeus, 1758)) is one of the most rapidly declining species in Europe. It falls under the category of vulnerable species (BirdLife International 2019). Threats in Europe include fragmentation and reduction of breeding habitats (Browne et al. 2004; Dunn and Morris 2012; Kleemann and Quillfeldt 2014), and changes in agricultural practices leading to a decrease in food availability (Browne and Aebisher 2003, 2004; Baptista et al. 2020).

In Bulgaria, the species was common and widespread at the end of the 20th century (Patev 1950; Simeonov 1971; Simeonov and Petrov 1977; Petrov 1981; Nankinov 1981, 1994). The species has been subject to several ornithological studies, some of which indicate a decrease in the population trend indices (Hristov and Petkov 2013, Spasov et al. 2017, Gruychev and Mihaylov 2019).

The distribution pattern of Turtle doves in Europe suggests that their breeding dis-

tribution is determined by latitude as well as the mean annual and monthly temperature during the entire breeding season (Keller et al. 2020). Similar results have been obtained in Germany but in relation to forest cover (Marx and Quillfeldt 2018). In many European regions, hedges and various coniferous and deciduous trees are of major significance for its breeding distribution (Browne and Aebisher 2005, Bakaloudis et al. 2009, Sáenz de Buruaga et al. 2012, Kleemann and Quillfeldt 2014). In some Mediterranean countries, Turtle dove nesting locations can also be found in olive, orange, eucalyptus and other plantations (Pina 1989, Peiro 1990, Boukhemza et al. 2008, Hanane and Baamal 2011). Although the primary breeding habitats of the species are various forest, shrub and plantation landscapes, it mainly feeds on seeds found in open areas (Browne and Aebisher 2003). The migratory specifics of Turtle doves, the large variety of breeding habitats, and the dependence of the birds on food availability often create a set of relationships difficult to comprehend.

The aim of this study is to provide data on the distribution and impact of certain habitat characteristics on European Turtle doves in Sarnena Sredna Gora Mountain.

Material and Methods

Study area

The studied area is Sarnena Sredna Gora Mountain (Fig. 1). It is part of Sredna Gora Mountain, situated in the central part of Bulgaria (Petrova 2020). Its area is 2280 km^2, mean altitude is 416 m a.s.l., and its highest peak is Bratan (1235.8 m) located in the western part of the mountain (Georgiev 2020). The terrain is mountainous hilly, the annual rainfall is between 550–700 mm, and the mean annual temperature is above 0 °C (Petrova 2020). The vegetation in the study area is comprised of forest and open habitats, which provide breeding and feeding sites for European

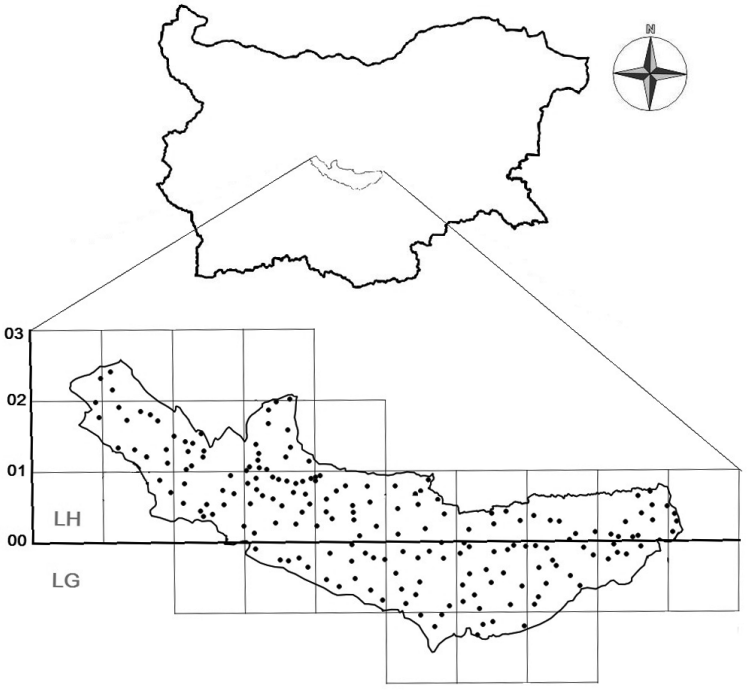

Fig. 1. Study area and distribution of points to determination of Turtle dove abundance index.

Note: the study area falls into quadrants LH and LG of 35T Universal Transverse Mercator, UTM.

Turtle doves. Based on the tree composition, forest habitats have been divided into the following species: broadleaf forest: includes Oriental hornbeam (*Carpinus orientalis* Mill.), Sessile oak (*Querqus petraea* (Matt.) Liebl.), Turkey oak (*Querqus cerris* L.), Hungarian oak (*Quercus frainetto* Ten.), Downy oak (*Quercus pubescens* Willd.), and oak of Virgil (*Querqus virgiliana* (Ten.) Ten.); oak forest (comprised only of oak species): includes Sessile oak, Turkey oak, Hungarian oak, Downy oak, and oak of Virgil (Bondev 1991); mixed oak/European beech forest: mixed forest comprised of various oak species and up to 50 % of European beech (*Fagus sylvatica* L.), with single Common hornbeam (*Carpinus betulus* L.) and European hop-hornbeam (*Ostrya carpinifolia* Scop.) trees; riparian forest: comprised of willows and poplars, and covering a small area around water within the study area; human-made Scots pine (*Pinus silvestris* L.) plantations which were planted 40–45 years ago; mixed broadleaf and coniferous forest comprised of deciduous trees and mostly artificially-planted conifers.

The open habitats in the southern part of the study area are occupied by arable lands mostly with cereal and oilseed crops, and small areas of alfalfa, vineyards and orchards. To the north, open areas at a higher altitude are occupied by grasslands, including pastures with occurrence of Bulbous bluegrass (*Poa bulbosa* L.), Perennial ryegrass (*Lolium perenne* L.), and Couch grass (*Cynodon dactylon* (L.) Pers.), Bothriochloa (*Dichantium ischaemum* (L.) Roberty), Chrysopogon (*Chrysopogon gryllus* (L.) Trin.) (Bondev 1991).

Field methods

In the period between 2018–2020 we monitored the presence of European Turtle dove in 6 forest habitats: broadleaf forest – 83 points; oak forest – 40; mixed oak/European beech – 5; Scots pine (*Pinus sylvestris* L.) plantations – 23; mixed broad-leaved/coniferous forest – 20; riparian forest – 21; a total of 192 points across 1084.1 km^2 (Fig. 1). The number of singing male birds within 100 m of the centre of each point was recorded twice a year (first report: 1–25 May; second report: 1–25 June). All the data was collected in quiet weather, no rainfall, between 04:30 and 08:30 am. The number of singing Turtle doves was reported over the course of 10 min, after a 2-min wait on the part of the observer before the onset of the measurement of each point. We calculated the abundance index as the average number of singing birds in each point by year (total number of singing birds in each point/number of observations per year). The following parameters were determined at each point in the 100-m radius: average tree height (m); elevation (m); distance to water sources (m); distance to road (m); distance to arable land (m); distance to villages (m); tree cover (%); shrub cover (%); type of arable land in the open area around the points. All distances were recorded as the shortest distances from each point to the point of beginning of the respective territory. We determined three main types of arable land: cereal crops; sunflower crops; pastures, and combination of sunflower/cereal, cereal/pastures, or sunflower/pastures. The remaining arable land was planted mainly with potatoes, alfalfa, orchards, and Damask rose (*Rosa damascena* Mill.) but as the latter occupied a very small area (several decares), it was not reported. A total of 1152 reports were made for the entire study period at 192 points with different types of arable land around them (Table 1).

Table 1. Distribution of observations during 2018–2020 by type of arable land.

Arable land around the point	Number of reports
cereal	286
sunf./cereal	137
pastures	312
sunflower	152
cereal/pastures	164
sunfl./pastures	101
Total	1152

Statistical methods

We used ANOVA main effects to examine the relationships between breeding habitats, type of arable land in the open area over every point every year, and abundance of Turtle doves within every fixed radius of points. Then we tested the significant categorical variable with other continuous predictors (tree height, elevation distance to water sources, etc.) using generalized linear models with log-link function and Poisson error distribution. Turtle dove abundance within the fixed radius was a dependent variable, the type of arable land in open areas over every point was the categorical variable, and all other variables measured were continuous predictors. All statistical analyses were performed with Statistica 10 StatSoft, Inc (2011).

Results

At 28 out of 192 points, Turtle doves were not reported for the entire study period. At 144 points the abundance index was between 0.1 and 0.4, and at 20 points it was higher than 0.4 (Fig. 2).

ANOVA analysis shows a high degree of significance of our model. It determines that the arable land adjacent to the breeding habitats is a significant factor influencing Turtle dove breeding distribution in the study area (Table 2).

The abundance of Turtle doves within the fixed radius is significantly higher in forest habitats adjacent to cereal, than in the other five types of open area surrounding the breeding sites (Table 3, Fig. 3).

Two environmental variables deter-

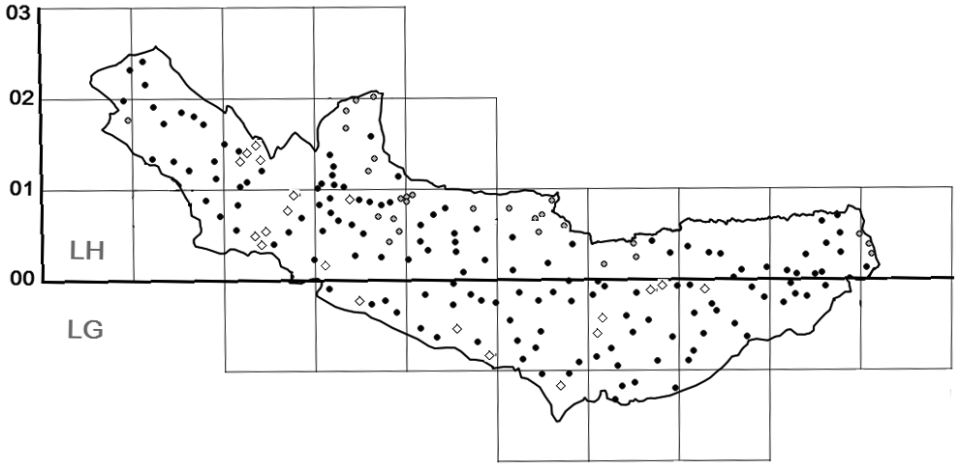

Fig. 2. Distribution of points in study area by abundance index, ○ – no reported birds; ● – points with abundance 0.1 – 0.4; ◊ – points with abundance higher than 0.4.

Table 2. Results from univariate test of significance for distribution of Turtle dove dependence two categorical predictors.

Variables	Sum of squares	Degree of freedom	Mean square	F	*p*
Intercept	**1.906**	**1.000**	**1.906**	**14.867**	**0.000**
Habitats	1.358	5.000	0.272	2.118	0.062
Arable land around point	**7.499**	**5.000**	**1.500**	**11.698**	**0.000**
Error	50.130	391.000	0.128		

Note: in bold are significant results.

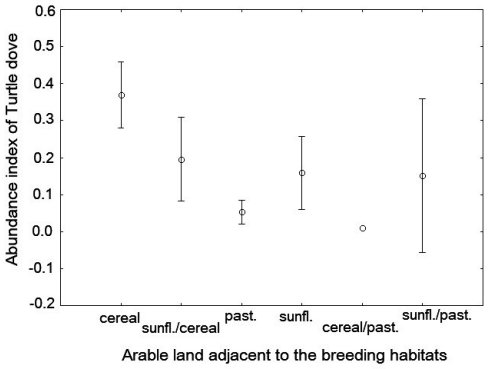

Fig. 3. Abundance index of Turtle dove in fixed radius by type of arable land around the counting point, mean (min-max).

mine Turtle dove breeding distribution in Sarnena Sredna Gora Mountain: type of arable land around the breeding sites, and elevation (Table 4).

Although the abundance index of Turtle doves decreases with increasing altitude, the significance of this variable is close to the limit value, unlike the other variable which has a high degree of significance (Table 4).

Discussion

The present study identifies two variables that can affect the breeding distribution of European Turtle dove in Sarnena Sredna Gora Mountain: elevation, and type of open areas around the breeding sites. Although the differences in altitude are not very large (381.5 m min-max 210-840 m), the number of singing birds decreases with increasing altitude. The distribution of European breeding population of Turtle doves is associated with higher temperatures and lower latitudes (Marx and Quillfeldt 2018, Keller et al. 2020). Probably the higher minimum temperatures in January determine the availability of food resources at the beginning of the breeding season (Marx and Quillfeldt 2018). In addition, with the increase of altitude, the forest cover also increases, and the share of open areas which Turtle doves can use for food decreases. Some studies (Sáenz de Buruaga et al. 2012) have found a decrease in Turtle dove abundance with the increase of forest cover. Therefore, altitude is the second probable reason for the decrease of Turtle doves.

The second factor that is significant for the breeding distribution in this study is type of open areas around the breeding sites. Although previous studies in other regions of Bulgaria (Gruychev and Mihaylov 2019, Gruychev 2020) found variations in breeding density associated with the type of breeding habitats, they did not test the significance of arable land in open areas around the breeding sites. In contrast to Sakar Mountain, where habitat heterogeneity is greater (Gruychev and Mihaylov 2019), in Sredna Gora Mountain there is a clearly marked differentiation

Table 3. Results from univariate test of significance for abundance of Turtle dove dependence type of arable land around the counting point.

Variables	Presence parameter	Standard error	*t*	*p*	-95.00% Cnf. Lmt	+95.00% Cnf. Lmt	β	Standard error	-95.00% Cnf. Lmt	+95.00% Cnf. Lmt
Intercept	**0.161**	**0.065**	**2.491**	**0.013**	**0.034**	**0.288**				
Cereal	**0.215**	**0.067**	**3.213**	**0.001**	**0.083**	**0.346**	**0.289**	**0.090**	**0.112**	**0.466**
Sunfl./cereal	0.065	0.075	0.869	0.386	-0.082	0.213	0.065	0.075	-0.082	0.212
Pastures	-0.119	0.066	-1.788	0.075	-0.249	0.012	-0.171	0.096	-0.359	0.017
Sunflower	0.022	0.074	0.299	0.765	-0.123	0.168	0.023	0.077	-0.128	0.174
Cereal/past.	-0.174	0.164	-1.059	0.290	-0.497	0.149	-0.096	0.090	-0.273	0.082
Sunfl./past.	-0.032	0.312	-0.103	0.918	-0.645	0.581	-0.016	0.156	-0.322	0.290

Note: in bold are significant results.

Table 4. Results from generalized linear model summary of all effects.

Variables	Degree of freedom	Wald-statistics	Log- likelihood	*p*
Intercept	**1.000**	**9.363**		**0.002**
Tree height	1.000	0.438	-175.670	0.508
Elevation	**1.000**	**4.029**	**-177.416**	**0.045**
Distance to water	1.000	0.182	-175.537	0.670
Distance to road	1.000	0.223	-175.551	0.637
Distance to food	1.000	0.290	-175.609	0.590
Distance to villages	1.000	0.940	-175.903	0.332
Tree cover	1.000	0.831	-175.772	0.362
Shrub cover	1.000	1.405	-176.167	0.236
Type of food	**5.000**	**33.231**	**-196.839**	**0.000**

Note: in bold are significance level.

between points in large forest complexes surrounded by pastures and points near arable land. No clear relationship to food resources in Sakar can be found due to the availability of food resources in close proximity to nearly all counting points, which is not the case in Sarnena Sredna Gora Mountain.

Variation in breeding density is associated with the type of breeding habitat. According to a number of studies (Simeonov et al. 1990, Nankinov 1994, Browne et al. 2004, Sáenz de Buruaga et al. 2012, Gruychev 2020), breeding density is high in the riparian and oak forests as well as in similar forest types; however, breeding density seems to depend to a large extent on the type of habitats found which provide the main food resources. In Europe, Turtle doves feed on large amounts of seeds, most of which occur naturally in the environment (Dunn et al. 2018). Studies of the food spectrum in Spain have recently reported a higher share of wild seeds, in contrast to older studies (Gutiérrez-Galán and Alonso 2016). In the United Kingdom, it has been found that it mainly uses grasslands as feeding habitats (Dunn et al. 2021). Nevertheless, our model shows a greater presence of Turtle doves in breeding habitats of the study area surrounded by open areas occupied by cereal and sunflower crops, and low presence around pastures, pastures and cereal crops combined. Two possible explanations of these results can be suggested: 1) pastures are located in high parts of the study area, with high forest cover and lower temperatures, which is why birds avoid these areas; 2) weed strips, which are often formed in arable land planted with wheat crops, could possibly provide food for Turtle doves at the beginning of their breeding season. In addition, the size of arable land in the study area is between 0.2 and 0.5 km^2, which probably contributes to increasing the diversity of food supply (Fig. 4).

Fig. 4. Arable land around the breeding sites of European turtle dove (*Streptopelia turtur*) in the lower part of the studied area (Foto Gradimir Gruychev, 17.05.2018).

Although Turtle doves can travel up to 10 km to feeding sites (Browne and Aebisher 2003, Gutiérrez-Galán and Alonso 2016, Vreugdenhil-Rowlands 2020), they also often feed near breeding sites (Browne et al. 2004, Fisher et al. 2018, Moreno-Zárate et al. 2020). During the second half of the breeding season, Turtle doves often use cereal and rapeseed crops as food resources (Browne and Aebisher 2003), which is likely to link the presence of Turtle doves in the present study to the availability of cereal crops. The relationship between Turtle dove occurrence and areas with sunflower crops might be due to the fact that at the beginning of the breeding season, areas occupied by these crops abound in numerous early-flowering weed species that the birds may feed on, but additional studies are needed in order to confirm this hypothesis.

The present study did not examine the species composition or the quantitative indicators of the potential feeding grounds; therefore, we have been unable to ascertain any definitive relationships between Turtle dove breeding distribution and these variables.

The study shows differences between the preferences of breeding sites of Turtle doves in Sarnena Sredna Gora and those found in lowland open habitats in Bulgaria. These results suggest that different approaches to habitat management need to be chosen for different parts of the breeding area of the species in Bulgaria, taking into account the food availability in early breeding season.

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IMPACT OF OAK WOOD BIOCHAR AND NITROGEN FERTILIZER ON SOIL PROPERTIES AND MAIZE BIOMASS GROWTH

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Abstract

The aim of study was to investigate the effect of wood biochar in combination with nitrogen fertilizer on soil properties and maize biomass. The experiment was conducted at the Tsalapitsa field (Plovdiv, Bulgaria) on Fluvisol. A randomised block design was established – three rates (0, 5 and 10 t·ha^{-1}) of biochar and two rates (130 and 260 kg·ha^{-1}) of N fertiliser (ammonium nitrate). Each treatment was in four replications. Biochar was obtained by pyrolysis (400 ºC) of oak bark. The plant samples (leaves, stems, cobs) were taken in three phases of maize growth. The soil samples were taken during growing period and after maize harvesting. The results showed that treatments with biochar in the presence of N fertilizer significantly increased yields in maize growth ($p \leq 0.05$) compared to the variants with fertilizer only. Greater positive effect of biochar application was observed in the combination of low-rate biochar (5 t·ha^{-1}) and low rate of fertilizer (130 kg·ha^{-1}) on crop biomass in different growing stages compared to controls and the variant with high N and low biochar rates (increases were +24 % and +44 %, respectively). Slight increases in pH, organic carbon and cation exchange capacity in the variants with both rates of biochar and low level of mineral fertilization were observed in the Fluvisol. When N fertilizer was applied at high rate, soil pH decreased (0.5–0.7 units) and exchangeable Al (1 cmol·kg^{-1}) appeared due to the fertilizer acidifying effect. The pH in these variants is not a limiting factor for maize production.

Key words: cation exchange capacity, N fertiliser, oak peels, pH, rich carbon amendment.

Introduction

The increasing anthropogenic impacts, such as incorrect agricultural practices (including unbalanced nitrogen fertilization), result in disturbing arable lands. They have a significant effect on the environment, which is a precondition for a number of environmental risks, such as soil acidification, surface and ground wa-

ter pollution, etc. A successful method for solving the above-mentioned problems is the use of biochar (BC) as soil organic amendment because of its physical and chemical characteristics (pH, high porosity, large surface area). Biochar is a final product of biomass burning at the absence of oxygen in the pyrolysis process.

A number of experiments have studied the maize growth responses to biochar, as a soil improver without additional organic or inorganic fertilization. In most of them, the application of biochar increased the yield of maize compared to the control (Islami et al. 2011, Sukartono et al. 2011, Cornelissen et al. 2013). Recently, some studies have noted its effect on soil fertility when combined with fertilizers by studying the chemical changes in soil, and effects on plants (Schulz et al. 2013, Glaser et al. 2015, Oladele et al. 2019, Akolgo et al. 2020). Another effect is improvement of soil physicochemical properties, including increasing soil pH, CEC and organic carbon (Paz-Ferreiro et al. 2014, Gao et al. 2016, Hussian et al. 2016). Biochar potential for increasing soil pH of acidic soils is demonstrated in many studies (Novak et al. 2014, Xu et al. 2014). Biochar application depends on soil type, biochar feedstock, biochar pyrolysis temperature, soil properties, plant species and the environmental and experimental conditions (Sohi et al. 2010, Al-Wabel et al. 2018, Muhammad et al. 2018). The application of biochar in fertile, alkaline soils in temperate climatic region is not so efficient (Karer et al. 2013, Jeffery et al. 2017), as adverse effect on yield were observed even at high biochar application rates. In a study involving the use of organic wood charcoal in the production of corn and grass in Wales, soil pH rose by 0.32 over two years (Jones et al. 2012), while electrical conductivity, soil moisture, total N, soluble C, soluble N, available P, exchangeable Na and Ca were not significantly affected by biochar compared to controls. Kloss et al. (2012) compared biochar produced from three raw materials pyrolyzed at different temperatures and found that the two wood-based biochars have lower concentrations of soluble elements, which are not suitable for use as soil fertilizer. Woody charcoal contains less degradable C than other biochars (Lehmann et al. 2006, Nelissen et al. 2015).

In our study we used locally produced wood biochar from oak (*Quercus* spp.) peels, which has the potential to improve soil properties, increase soil nutrient availability and crop biomass in a slightly acidic, loam sandy Fluvisol. The aim of the study was to investigate the effect of wood biochar in combination with nitrogen fertilizer on soil properties and maize biomass.

Materials and Methods

An experiment was conducted at the experimental field of Institute of Soil Science, Agrotechnology and Plant Protection 'Nikola Poushkarov' in the village of Tsalapitsa, Plovdiv region (42°10.8' N, 24°32.5' E) and climatic region of Eastern Central Bulgaria with suitable conditions for maize growing. The soil type is Alluvial-meadow soil (Fluvisol), which is slightly acidic, with light texture, low content of total N (0.072 %) and organic carbon (0.70 %). Oak woodchip biochar, produced through pyrolysis at 400 °C, was selected for this field study (Table 1).

A randomised block design was established with three levels of biochar (0, 5 and 10 $t \cdot ha^{-1}$) and 2 levels of N (ammonium nitrate) fertiliser (130 and 260 N $kg \cdot ha^{-1}$). Each biochar level was tested

Table 1. Basic characteristics of the Fluvisol and biochar.

Soil and biochar	pH H_2O	min N, mg·kg^{-1}	P_2O_5	K_2O	CEC	exch. Ca	exch. Mg	OC, %
			mg·100g^{-1}		cmol·kg^{-1}			
Fluvisol	6.1	20.2	17.1	22.4	16.7	11.5	1.8	0.70
BC	9.7	72.0	43.4	499.6	10.3	7.5	2.8	49.0

against each N level. Each treatment was in four replications. Maize hybrid 9903-X299 (according to FAO 430) was used with a plant density 85,000 plants·ha^{-1}. The area of the experimental plot of one variant was 25.2 m^2. The treatments were the following:

- Variant B_1 – K1N130 – control without BC and 130 kg·ha^{-1} nitrogen fertilization;
- Variant B_2 – B5N130 – with 5 t·ha^{-1} BC and 130 kg·ha^{-1} nitrogen fertilization;
- Variant B_3 – B10N130 – with 10 t·ha^{-1} BC and 130 kg·ha^{-1} nitrogen fertilization;
- Variant B_4 – K2N260 – control without BC and 260 kg·ha^{-1} nitrogen fertilization;
- Variant B_5 – B5N260 – with 5 t·ha^{-1} BC and 260 kg·ha^{-1} nitrogen fertilization;
- Variant B_6 – B10N260 – with 10 t·ha^{-1} BC and 260 kg·ha^{-1} nitrogen fertilization.

Phosphorus fertilization (300 kg·ha^{-1}) was done in autumn as triple superphosphate, and potassium fertilization was not applied due to the good soil supply. The biochar and nitrogen fertilizer were spread on the topsoil and were incorporated into the soil (to a depth about 0.20 cm) with a cultivator before maize sowing. Soil samples were taken during maize development (in phenophase '10–12th leaf'– about 45 days after the biochar and nitrogen fertilizer application) and after harvesting. Plant samples were taken from all variants of the experiment in dynamics (in three replications) in the following phenophases: '10–12th leaf'; 'Tasseling', 'Milky-wax ripeness', the absolutely dry biomass was determined. After drying the plant biomass to an air-dry weight, the plant samples were weighed, and the plant production was estimated.

The physicochemical soil properties were determined by the method of Ganev and Arsova (1980). Soil organic matter content and composition were obtained by a modified method of Turin (oxidation with dichromate and H_2SO_4 in a thermostat at 120 °C, 45 min., Ag_2SO_4 catalyst and back titration with $(H_4)_2SO_4.FeSO_4.6H_2O$ and Kononova-Belchikova method (Kononova 1966, Filcheva and Tsadilas 2002). Mineral nitrogen by the method of Kjeldahl (Methods of Soil Analysis 1982) and available P and K following the methods of (Ivanov 1984) were assessed.

Results and Discussion

Physicochemical characteristics

According to the physicochemical analysis of Alluvial-meadow soil in the experimental field Tsalapitsa, it can be classified as slightly acidic (pH = 6.1). The level of colloidal reactivity in the source soil according to the cation exchange capacity (CEC = 16.7 cmol·kg^{-1}) is defined as low. At a degree of base saturation of 78 %, the content of basic cations is about 68 % Ca and 11 % Mg in the source soil (Table 2). Monmorillonite - ilite minerals predominate (CECsa = 11.8 cmol·kg^{-1} about 71 % CEC), according to the size of the strongly acidic positions in the soil (Ganev 1990).

Table 2. Soil physicochemical characteristics by variants during development and after harvesting of maize.

Variants	pH	CEC	CEC_{SA}	CEC_A	exch. $H_{8.2}$	exch. Al	Ca	Mg	BS, %
		cmol·kg^{-1}							
Fluvisol	6.13	16.7	11.8	4.9	3.7	0	11.5	1.8	78.03
		In the stage '10–12th leaf'							
B_1 (K1N130)	5.80	17.1	13.8	3.3	3.5	0.2	11.8	1.8	79.53
B_2 (B5N130)	5.30	16.8	14.2	2.6	3.5	0.9	11.2	1.9	79.17
B_3 (B10N130)	5.70	17.0	14.4	2.6	2.8	0.2	12.2	1.8	83.53
B_4 (K2N260)	4.90	17.0	13.3	3.7	4.8	1.0	10.3	1.7	71.77
B_5 (B5N260)	5.20	16.8	14.1	2.7	3.6	0.9	11.2	1.8	78.57
B_6 (B10N260)	6.70	17.2	14.7	2.5	1.6	0.0	14.0	1.8	90.70
		After harvesting							
B_1 (K1N130)	6.15	18.0	14.5	3.5	2.3	0.0	14.3	1.70	87.2
B_2 (B5N130)	6.15	18.3	14.7	3.6	2.3	0.0	14.5	1.70	87.4
B_3 (B10N130)	6.15	18.3	14.7	3.6	2.2	0.0	14.6	1.70	85.0
B_4 (K2N260)	5.50	17.2	14.2	3.0	3.2	0.4	12.0	1.80	81.4
B_5 (B5N260)	5.70	17.9	15.1	0.8	3.0	0.3	13.5	1.70	83.2
B_6 (B10N260)	5.70	17.7	14.9	2.8	3.1	0.3	13.0	1.70	82.5

Note: CEC_{SA} – capacity value of strongly acidic ionexchanger of soil colloids; CEC_A – capacity value of weakly acidic ionexchanger; exch. $H_{8.2}$ – total acidity, exch. Al – exchangeable acidity.

Data about pH values of the Alluvial-meadow soil during the phase '10–12th leaf' of maize development (45 days after the nitrogen fertilizer and biochar application) and these after corn harvest are shown in Table 2. The application of nitrogen fertilizer only at a lower rate (N130) causes a slight acidification (up to 5.8 pH), which at the end of the experiment increases to 6.2 pH. The higher N rate (260 kg·ha^{-1}) acidifies soil to ~4.9 pH, but after corn harvesting this value rises to 5.5. Application of the low dose of N 130 kg·ha^{-1} in combination with the two rates of biochar mitigates soil acidification and at the end of the field experiment the value of pH is 6.2. A consequence of a combination of a high dose of nitrogen with a high dose of biochar was a short-term increase of this index (pH 6.7), but at the end of the experiment a decrease within 1.0 unit was observed.

Similar results were also obtained by Mukhina et al. (2019), where they used biochar of woody origin at a rate of 5 t·ha^{-1} in combination with 90 kg·ha^{-1} N fertilizer on Spodosol. Biochar can adsorb nitrogen from the applied fertilizer and reduce the acidity at the beginning of the experiments, but over time nitrogen is slowly released from BC, which can lead to a decrease in soil pH. The combination of biochar with nitrogen fertilizer leads to an increase in pH after the end of the experiment, but both doses (BC) are insufficient to neutralize the soil acidity caused by the high dose of fertilizer. Karer et al. (2013) observed a similar decrease in pH when applying a high rate of 72 t·ha^{-1} BC and a nitrogen fertilizer dose of 150 kg·ha^{-1} after a first year of a sunflower experiment on a Chernozem soil. After maize cultivation, an increase in the exchange capacity is observed in the variants, compared to

the CEC during the maize development, when the values did not change or slightly increased. The values after harvesting are higher (CEC 18.0–18.3 cmol·kg^{-1}) in the variants with a low rate of nitrogen fertilizer. During the experiment in almost all the variants, low exchange acidity between 0.2 and 1.0 cmol·kg^{-1} (Table 2) is observed due to the acidifying effect of the nitrogen fertilizer.

After corn harvesting, the application of the low dose of nitrogen only, as well as in combination with biochar, is relatively effective and the exchange acidity is not observed (exch. Al = 0 cmol·kg^{-1}). The total acidity tends to decrease and fluctuates between 1.6–4.8 cmol·kg^{-1}. Lower values of total acidity are maintained in the soil during the experiment, except for variant B_4 (K2N260) (exch. $H_{8.2}$ 4.8 cmol·kg^{-1}). In this variant, the amount of Ca is also the lowest (10 cmol·kg^{-1}). There is a certain tendency for Ca increase in the variants after maize harvesting, especially at the low nitrogen rate in combination with the two doses of biochar, which is reflected in the higher values of base saturation. The Mg content does not show significant differences in CEC either in variants or during sampling.

Alluvial-meadow soils are defined as the most vulnerable to nitrogen loading, which causes a change in the acid-base balance and leads to pollution of shallow groundwater with nitrates. Therefore, the application of nitrogen fertilizer in combination with biochar is effective because it improves the physicochemical status of the soil (increase in pH, basic cations, absence of exchange aluminum and increase in cation exchange capacity) compared to the use of nitrogen fertilizers only.

Agrochemical characteristics of Alluvial-meadow soil before and after the field experiments

It is well known that the processes of permanent acidification are most pronounced in carbonate-free soils with low sorption capacity, relatively low organic matter content and leaching water regime, as is the case with the Alluvial-meadow soil from the area of the experimental field in the village of Tsalapitsa, Plovdiv region. The content of mineral nitrogen is low (20.2 mg·kg^{-1}), the soil is low in P (P_2O_5 17.1 mg·100g^{-1}) and has moderate K content (K_2O 22.4 mg·100g^{-1}) (Table 1).

Mineral nitrogen content

The samples taken for agrochemical analysis during maize cultivation (in stage '10–12th leaf') show that the differences in the mineral nitrogen content in all variants depend on the fertilization doses and the combination with the two doses of biochar (Fig. 1). More significant differenc-

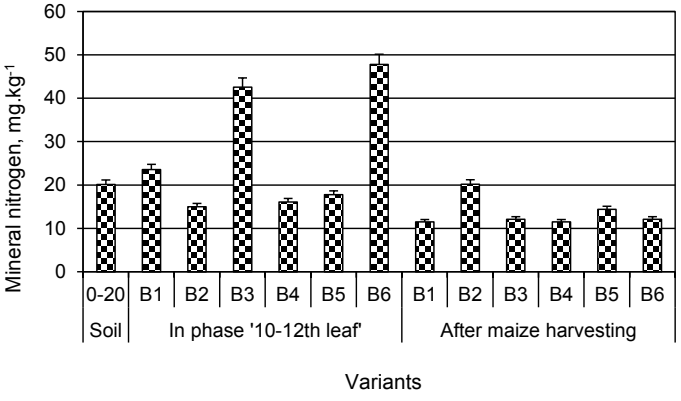

Fig. 1. Content of mineral nitrogen in Alluvial-meadow soil by variants in maize cultivation.

es are observed in the combination with the higher rate of biochar – variants B_3 (B10N130) and B_6 (B10N260), where the values reach 42–47 mg·kg^{-1}. In the other variants, the nitrogen content decreases in the ranges of 15 and 17 mg·kg^{-1}. Only in the variant B_1, with a low dose of N (130 kg·ha^{-1}), the content remains in the range of 23 mg·kg^{-1}, as in the control soil.

The results for the content of mineral nitrogen after maize harvesting (Fig. 1) show that within the experiment N decreases in the range between 11.0 and 14.4 mg·kg^{-1}, but the variant differences are not kept, even some alignment is observed. An exception is variant B_2, where the value of N is 20 mg·kg^{-1}. The results for the content of mineral nitrogen in the Alluvial-meadow soil in maize cultivation show that the application of high doses of BC improves the content of mineral nitrogen in the soil in the initial phase of maize development (45 days after application) in combination with nitrogen fertilizer. Intensive growth processes follow, in which a large part of the nitrogen content in the soil is consumed. The content of mineral nitrogen in the range between 10 and 15 mg·kg^{-1} for this soil can be considered as background, which shows that the crop has created a good precondition for the experiment conducting in the second year.

Content of mobile phosphorus and potassium

Data about the amount of mobile phosphorus during the experiment (Fig. 2) show almost double reduction compared to the control soil and equalization of the values between 7.78–9.4 mg·100g^{-1}. Data about the phosphorus content after maize harvesting show that it increases to 14 mg·100g^{-1} and values are higher compared to those during maize cultivation. Exceptions are the variants B_3 and B_6, where the content of mobile phosphorus remains low, but this is probably because of the low available phosphorus content in

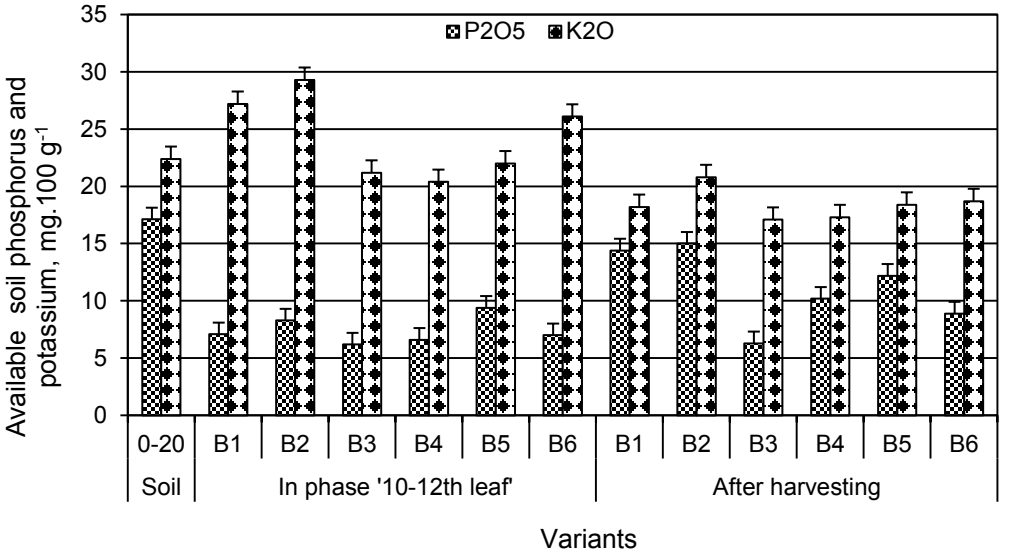

Fig. 2. Mobile phosphorus and potassium in Alluvial-meadow soil by variants in maize cultivation.

BC (Table 1). The decrease in pH, which was observed with increasing rates of N fertilizer at biochar – nitrogen amended variants, could also contribute to the lower values of available phosphorous in soil, due to fixation with sesquioxides in soil. The data obtained for the content of mobile potassium during the experiment (phase 10–12th leaf of maize) do not show high variability compared to the control soil. Only in the variants B_1 (K1N130), B_2 (B5N130) and B_6 (B10N260) is observed slight increase to 27, 26 and 29 mg·100g^{-1}, respectively. The content of mobile potassium after corn harvesting varies between 17–20 mg·100g^{-1} and reaches equal or lower values compared to the control soil.

Changes in the content and composition of organic matter

Total organic carbon is an important indicator of soil organic matter, which is widely used in estimating the total amount of organic compounds in soils. Due to its predominant aromatic structure, biochar is a relatively stable form of C (Purakayastha et al. 2015).

The composition of the organic matter of BC is dominated by humic and fulvic acids (Table 3), which determines the fulvic-humate type of humus (Ch/Cf = 1.12).

Table 3. Content and composition of the organic matter of the source soil, 45 days after nitrogen and biochar application (phase '10–12th leaf') and after maize harvesting.

Variants	TOC	Humus	OC, %			Ch/Cf	OC in HA fraction, %	
	%		Total	HA	FA		Free and bound to R_2O_3	Bound to Ca
Initial soil	0.68	1.17	0.18 23.62	0.10 13.55	0.08 10.08	1.0	0	100
Biochar	49.07		0.53 2.77	0.28 1.47	0.25 1.3	1.12	0.13 46.43*	0.15 53.57
In phase '10–12th leaf'								
B_1 (K1N130)	0.66	1.14	0.17 25.76	0.08 12.12	0.09 13.64	0.89	0	100
B_2 (B5N130)	0.71	1.22	0.19 26.76	0.13 18.31	0.06 8.45	2.17	0	100
B_3 (B10N130)	0.73	1.26	0.19 26.03	0.12 16.43	0.07 9.59	1.71	0	100
B_4 (K2N260)	0.66	1.14	0.19 28.79	0.1 15.15	0.09 13.64	1.11	0	100
B_5 (B5N260)	0.71	1.22	0.2 28.16	0.12 16.9	0.08 11.26	1.5	0	100
B_6 (B10N260)	0.80	1.38	0.53 66.25	0.27 33.75	0.26 32.5	1.03	0	100
After maize harvesting								
B_1 (K1N130)	0.75	1.29	0.17 22.67	0.17 22.67	0	-	0	100
B_2 (B5N130)	0.73	1.26	0.17 23.61	0.14 19.44	0.03 4.17	4.66	0	100
B_3 (B10N130)	0.73	1.26	0.18 24.66	0.14 19.18	0.04 5.48	3.5	0	100

Variants	TOC	Humus	OC, %			Ch/Cf	OC in HA fraction, %	
	%		Total	HA	FA		Free and bound to R_2O_3	Bound to Ca
B_4 (K2N260)	0.77	1.32	0.18 23.38	0.14 18.18	0.04 5.2	3.5	0	100
B_5 (B5N260)	0.66	1.14	0.16 24.24	0.16 24.24	0	-	0	100
B_6 (B10N260)	0.70	1.20	0.15 21.43	0.15 21.43	0	-	0	100

Note: TOC – total organic carbon; OC – organic carbon, exstracted with 0.1 M $Na_4P_2O_7$ + 0.1 M NaOH; HA – humic acids, FA – fulvic acids; underlined numbers are % of the soil sample, numbers below them are % of the TOC, and number with * is % of the total content of HA; Ch/Cf is ratio of humic acids to fulvic acids; R_2O_3 is cations of the third degree of oxidation.

Some of the humic acids (46 %) are represented by 'free' and bound with R_2O_3 forms, and most (53 %) are associated with Ca. Only a small fraction of biochar can be mineralized for a short time after application in soil, especially if it is produced at lower pyrolysis temperatures (Mukome and Parikh 2015). According to the classification of Orlov (Orlov 1985), the studied soil is characterized by a low content of humus (1.17 %) of humate-fulvic type (Ch/Cf = 1), low content of humic acids, 100 % bound with Ca and weak degree of humification (13.5 % of total carbon). For those soils that are low in organic carbon, it is beneficial to apply organic materials or composts, to increase the content of organic matter and their fertility. In the variants with nitrogen fertilizer only, during maize development (through 45 days) there is a slight decrease in the amount of total C. In the combination of nitrogen with biochar there is a slight increase in carbon, and this change is the highest (0.8 %) in the variant with high dose BC and nitrogen B_6 (B10N260). In this variant, the type of humus changes from humate-fulvic to fulvic-humate type (Ch/Cf > 1) compared to the variants without biochar. The humic acids present are 100 % bound to the alkaline earth elements. After maize harvesting, the content of organic C in the low-dose nitrogen variants in combination with BC does not change, and in the high-dose nitrogen combination there is a slight decrease. The application of N to the soil reduces the carbon content of organic matter due to a decrease in the C:N ratio (Yan et al. 2007) and probably mobilization of DOC due to increased microbial activity. But in all the cases the type of humus changes from fulvic-humate to humate compared to the variants during the experiment. The application of nitrogen in combination with biochar does not lead to significant changes in the total carbon content, but generally improves the humus condition of soil after corn harvesting: in all variants the type of humus changes to fulvic-humate or humate, increase in humic acids and a decrease in fulvic acids (increase in the Ch/Cf ratio).

The increase in the values of these indicators is associated with the improvement of the hydro-physical and physico-chemical soil properties and there is no risk of mobilization of organic matter. The most favorable humus condition in terms of soil is the variant with low content of BC and nitrogen B_2 (B5N130). The addition of BC to the soil generally favors the process

of humic acids formation. Similar results were obtained by Juriga et al. (2018). The higher rate of BC (20 t·ha^{-1}) used by them has a stronger effect on the C content in soil than the lower rate (10 t·ha^{-1}). The amount of C in soil also increases when using the combination of BC with 240 kg N·ha^{-1}.

Dry biomass

Regarding the accumulated dry biomass (Fig. 3) in all six variants of the experiment its value is highest in the phase 'Milky-wax ripeness', as the main amount is formed by the cobs. In variant B_5 the high rate of fertilization (N260) and the low rate of biochar (BC5) were applied. In all studied phases this variant belongs to the same homogeneous group with B_6 and there are no significant differences between them. In the variant B_2 (B5N130) it can be seen that in all the three phases the dry biomass (respectively 2592, 8438 and 17,768 kg·ha^{-1}) is quite high and proven to be equal to that of B_5 (2585, 9723 and 18,914 kg·ha^{-1}). There are no statistically significant differences between the biomass of B_2 and B_6 in '10–12th leaf' phase, which can be explained by the fact that the variant B_2 has the best ratio between nitrogen fertilizer and biochar. The lowest quantity of absolutely dry biomass is reported in the variants without biochar B_1, However, in the third phase, the biomass of the non-biochar variants is higher than those of variant B_3 (B10N130). These results show that, except the applied higher nitrogen norms in combination with BC, the combinations of low doses biochar in variant B_2 (B5N130) also affects the formation of higher biomass.

Statistical analysis was performed using ANOVA multi-factor analysis of variance, in order to assess the effect of nitrogen fertilizer and biochar on the dry biomass accumulation by phases of maize development (Fig. 4). The results show that both factors (biochar and N fertilizer) have a significant effect on the biomass

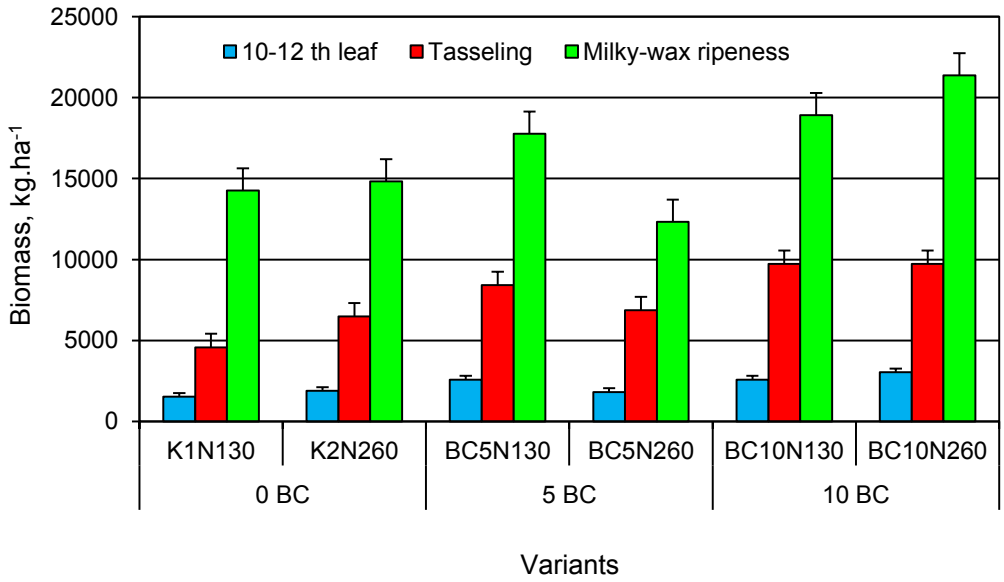

Fig. 3. Total maize biomass in stages of development.

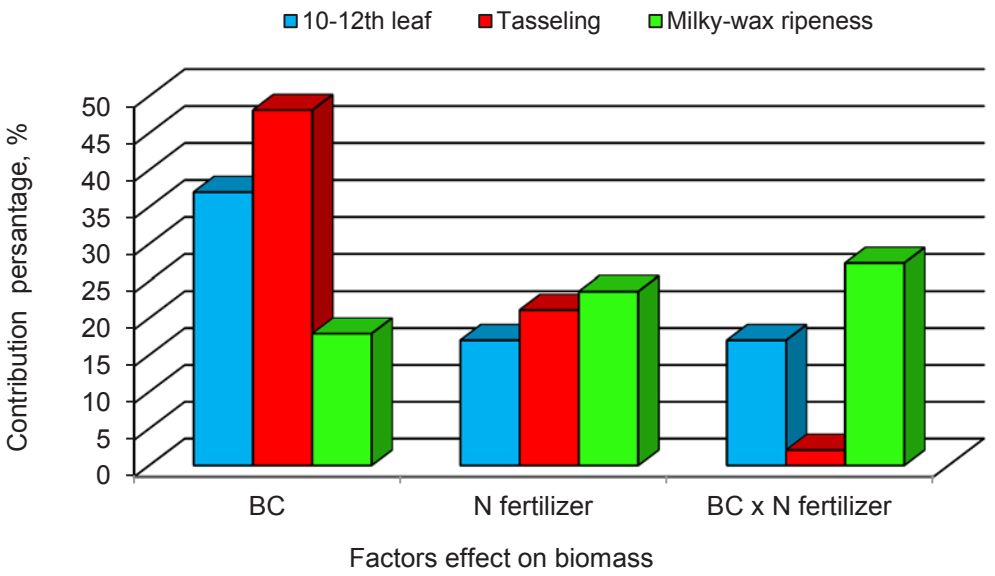

Fig. 4. Component contribution of biochar, N fertilizer, and biochar in combination with nitrogen fertilizer to maize biomass.

accumulation during different stages of maize growth. During 'Milky-wax ripeness', fertilization factor (B:N) contributes most to the variability of dry biomass – 23 %. The factor biochar (A:BC) has a significant effect in '10–12th leaf' (37 %) and 'Tasseling' (48 %). Combination of biochar and N fertilizer contributed over 27.4 % in 'Milky-wax ripeness'. In the 'Tasseling' stage the contribution of both factors on the variation of biomass is statistically insignificant (2.1 %).

In all the studied phases and all tested variants with biochar, the obtained biomass has higher values compared to the control (except for variant B_3 in the last phase). In the variants with nitrogen fertilizer rate of 130 kg·ha^{-1} (B_2, B_3) the plants biomass from the variant B_2 is higher. There are no significant differences between B_2 and B_5. This proves that biochar and N fertilizer, applied together have a beneficial effect on the accumulation of total biomass in maize. As optimal in this respect can be mentioned variant B_2, which has a lower rate of nitrogen fertilizer and yet the biomass is only 114 kg less, compared to the variant with higher nitrogen rate and the same amount of biochar (B_5) (Fig. 3). The reason for this is the ability of biochar to retain nutrients (in particular nitrogen) in the root zone, preventing it from leaching.

Conclusions

The results showed that treatments with biochar in the presence of N fertilizer significantly increased biomass in maize ($p \leq 0.05$) compared to the variants with fertilizer addition only. Greater positive effect of biochar application was observed in the combination of low-rate BC (5 t·ha^{-1}) and low-rate fertilizer (130 kg·ha^{-1}) on crop biomass in different growing stages compared to the controls and the variant with high N and low BC rates (increases were

+24 % and +44 %, respectively). Slight increases in pH, organic carbon and cation exchange capacity in the variants with both rates of biochar and low level of mineral fertilization were observed in the Fluvisol. The application of wood biochar in combination with low nitrogen fertilizer is more effective, because it improves the physicochemical status of soil (increases pH, basic cations and increase of cation exchange capacity) compared to the use of a nitrogen fertilizers only.

Acknowledgments

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VISCUM ALBUM L. IN PROTECTED AREAS OF THE UKRAINIAN POLISSYA

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Abstract

In our work we determined the representation of trees that serve as hosts to common mistletoe (*Viscum album* L.) in protected areas of the Ukrainian Polissya. Our research goal was to conduct a quantitative and qualitative inventory of tree taxa damaged by the mistletoe. The study was conducted in 57 protected areas of the Ukrainian Polissya with a combined area of 715.22 ha. We identified 455 trees hosting 8586 mistletoe plants in 36.8 % of the entities covering 51.5 % of studied areas. The total number of host-tree taxa was 64, belonging to 9 families and 16 genera, with 45 tree species being on IUCN Red List. By bio-morphological characteristics, these 64 taxa were distributed among moesophanerophytes (44), megaphanerophytes (11) and microphanerophytes (9). By ecological characteristics, the dominant taxa were heliophytes (60.9 %), followed by moesotrophs (57.8 %) and mesophytes (46.9 %). Based on damage to host trees, 46.2 % taxa had low, 31.9 % - moderate, 10.5 % – high and 11.4 % – very high levels of mistletoe damage. The highest damage was observed on five species, including *Tilia cordata* Mill., *Acer platanoides* L., *Populus simonii* Carrière, *Populus nigra* L. and *Juglans nigra* L. By origin, 72.3 % of damaged host trees were introduced species, whereas by number of damaged trees, 51.4 % of trees were native. On study sites, in southern section of Volyn and Zhytomyr Polissya, the rate of mistletoe infestation per plant was high and constituted 43 and 41 bushes per host tree, respectively.

Key words: dendrological park, infected trees, European mistletoe, monument of nature.

Introduction

Protected areas of the Ukrainian Polissya have not only historical, cultural and aesthetic values, but also healing, recreational, functional and ecological values (Markov 2014, Markov and Terelya 2019, Markov et al. 2020). However, due to the increase in air temperatures and the decrease in precipitation, tree growth may decrease (Petkova 2018). In order to effectively plan the protected area, all threats and factors that may adversely affect its functioning should be investigated (Prots et al. 2010). *Viscum album* L. can lead to decline of tree plantations, reduced tree growth, premature tree mortality and deterioration of the aesthetic appearance

of woody plants, including rare trees; as a result, it poses a threat to plantations in protected areas, protective strips along roads and fruit orchards (Taran et al. 2008, Yurel and Liakh 2019). This semi-parasitic plant can reduce the intensity of the assimilation apparatus of host trees by more than 20 % (Rybalka and Verheles 2017). Mistletoe is now an invasive plant species that is actively spreading (Yurel and Liakh 2019). European mistletoe has become an important agent of destruction of forest trees in Central Europe. During 2008–2018, an increase in infected trees was noted in the forests of Poland (Lech et al. 2020). In Hungary, since the beginning of the 20th century, area where mistletoe was widespread has tripled (Varga et al. 2014). Monitoring and control of mistletoe is becoming increasingly difficult as more and more new plant species become mistletoe hosts (Krasylenko et al. 2020). From the temperate to the tropical world, 464 species of mistletoe host trees are known (Ahmed and Dutt 2015). In Europe, mistletoe can infect over 380 taxa of trees (Varga et al. 2014). Spread of white mistletoe occurs as a result of stand thinning (Rybalka 2017). Growing on the edges, trees in groups with an open crown are most affected by mistletoe (Baltazár et al. 2013). Infecting of trees by *Viscum album* L. resumes after sanitary pruning (Bilonozhko et al. 2019). The density of white mistletoe is positively correlated with the density of the road network and the share of buildings (Rybalka 2017). *Viscum album* primarily inhabits large trees of the genus *Populus* L. and *Acer saccharinum* L. (Ivchenko et al. 2014). Trees that are most often infected are weakened old trees with soft wood and a thin cork layer, growing in river valleys, moist beams and ancient manor parks. Trees growing in urban plantations are infected less often (Dobrynia 2013, Yakymenko et al. 2019). Mistletoe mainly affects old trees (Tsopelas et al. 2004, Evstihneev and Fedotov 2005), prefers sparse plantations in which trees have sufficient light, as well as suppressed trees (Velichkin 2012). Among the environmental factors and landscape characteristics, the main ones influencing the spread of mistletoe in urban areas are tree age and relative humidity. Factors that reflect environmental pollution (content of heavy metals in the soil and the concentration of nitrogen dioxide in the air) do not statistically affect the spread of mistletoe (Skrypnik et al. 2020). To keep green area in proper condition, it is important to control the distribution of *Viscum album* (Barannik et al. 2010). Inventory and examination of positive and negative processes resulting from a decrease in the distribution of white mistletoe will allow avoiding unwanted biological effects (Yurel and Liakh 2019). The vast majority of research on the spread of white mistletoe was conducted in forest plantations (Tsopelas et al. 2004, Varga et al. 2014, Lech et al. 2020) and urban areas of different European countries (Kołodziejek et al. 2013, Rybalka 2017, Bilonozhko et al. 2019, Yakymenko et al. 2019, Krasylenko et al. 2020, Skrypnik et al. 2020), for example in the roadside forests of the Forest-Steppe zone (Vinnytsia and Cherkasy Regions) and Polissya (Zhytomyr Region) (Hnatyuk and Kavun 2017), in parks and recreation areas of the Forest-Steppe and Polissya (Hnatyuk and Kavun 2016). Therefore, there is a need to conduct research in the protected areas of the Ukrainian Polissya to study the spread of mistletoe.

The purpose of this study is to conduct an inventory of *Viscum album* in protected areas of the Ukrainian Polissya and to solve the following tasks: to analyze dis-

tribution of *Viscum album*, to assess the degree of impact on trees and to establish taxonomic, ecological and biomorphological characteristics of the host-trees.

Materials and Methods

A systematic approach and comparative analysis of the obtained empiric data were applied; inventory of species of woody plants affected by white mistletoe was carried out by route method (State Committee … 2014). The plant species were verified (Kokhno et al. 2001, Spohn and Spohn 2011), as well as species name, according to the international classification (WFO 2021). Tallied woody plant species were checked according to the Red List of the International Union for Conservation of Nature (IUCN Red List) (IUCN 2021). Also, the degree of damage to trees from the mistletoe was assessed. Classification of woody plants into four groups was done based on the level of infection, reflected as the number of mistletoe plants on one tree. Classes included low (less than 10 mistletoe plants per tree), medium (10–30 plants per tree), high (30–50 plants per tree) and very high (more than 50 plants per tree) (Skrypnik et al. 2020). The allocation of woody plants to the ecological groups was conducted based on main environmental factors. Classification of life forms was conducted based on Raunkiær (1934). Distribution of woody plant species by height classes was based on Kalinichenko (2003), where trees have height exceeding 25 m, between 20 and 25 m, between 15 and 20 and between 5(7) and 15 m, for trees of 1st, 2nd, 3rd and 4th height classes, respectively. Shrubs were also separated into height classes including 2.5 to 5 m, 1 to 2.5 m and 0.5 and 1 m for high, medium and low shrub height classes, respectively.

Study Area

We examined 57 protected areas of the Ukrainian Polissya, among them 3 dendrological parks (DP), 42 park-monuments of landscape art (PMLA), three botanical monuments of nature (BNM), six complex monuments of nature (CNM), zoo, and arboreta within the Natural National Parks and Landscape preserve). Plants of *Viscum album* were identified in 21 protected areas (Fig. 1).

Results and Discussion

Viscum album is distributed in Central Europe, Southwest-and-East Asia to Japan (Becker 2000), over most of the territory of Ukraine, western and southern Europe, the Caucasian Mountains, the Southwest, Central and Southern Russia and Belarus (Yurel and Liakh 2019). The area of distribution of white mistletoe over the past decade has expanded significantly to the northeast and east (Velichkin 2012, Yakymenko et al. 2019). In Ukraine, the area occupied by *Viscum album* ssp. *album* is characterized by uneven distribution of the population with gaps in the south and east of the country, whereas the distribution of the highly specialized *V. album* ssp. *abietis* (Wiesb.) Abr. and *V. album* ssp. *austriacum* (Wiesb.) Vollm. is mainly limited to the western and central regions and the mountainous part of the Crimean Peninsula.

Based on the conducted route analysis, mistletoe was found in 21 protected areas, covering 368.14 ha (Table 1).

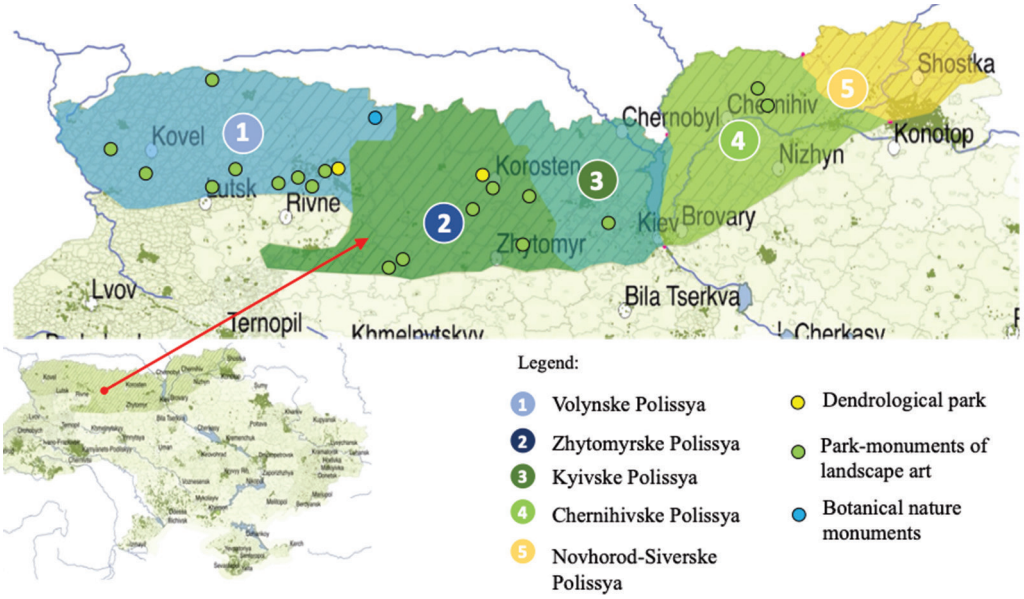

Fig. 1. Distribution of *Viscum album* in the protected areas of the Ukrainian Polissya.

Table 1. *Viscum album* in protected areas of the Ukrainian Polissya.

Protected areas	Absolute altitude, m	Area, ha	Number of host species/ hybrid/ ssp./ cultivar	Number of infected trees	Number of mistletoe specimens	Rate of mistletoe infes-tation*
Volynske Polissya (VP)						
PMLA 'Zdorovia'	195	13.6	2	2	6	3
PMLA 'Litynskyi'	196	8.4	1	2	10	5
PMLA 'Liubeshivskyi'	151	12.0	2	3	16	5.3
PMLA 'Makarevychivskyi'	191	0.9	3	25	969	38.8
PMLA 'Bairak'	192	13.6	1	1	5	5
PMLA 'Horodotskyi'	178	8.0	7	22	425	19.3
PMLA 'Zirnenskyi'	170	17.2	6	12	76	6.3
PMLA 'Oleksandriiskyi'	189	5.0	7	54	2280	43.0
PMLA 'Tuchynskyi'	178	10.0	3	11	176	16
DP 'Beresnivskyi'	165	29.5	46/4/3/3	162	2052	12.7
BNM 'Yuzefinska dacha'	152	100.0	1	2	9	4.5
Zhytomyrske Polissya (ZP)						
PMLA 'Vilkhivskyi'	247	11.2	1	2	40	20
PMLA 'Dvoryshchanskyi'	188	1.5	4	29	811	28
PMLA 'Korostyshivskyi'	180	12.9	2	12	491	40.9

Protected areas	Absolute altitude, m	Area, ha	Number of host species/ hybrid/ ssp./ cultivar	Number of infected trees	Number of mistletoe specimens	Rate of mistletoe infestation*
PMLA 'Ushomyrskyi'	187	12.91	8	24	554	23.1
PMLA 'Park imeni Miklukho-Maklaia'	172	29.63	5	23	489	21.2
DP 'Elita'	170	4.8	2	2	4	2
PMLA 'Polonskyi'	264	37.0	4	17	123	7.6
Kyivske Polissya (KP)						
PMLA 'Kopylivskyi'	185	8.0	11	41	325	7.9
Chernihivske Polissya (CP)						
PMLA 'Lyzohubivskyi'	158	22.0	1	3	16	5.3
PMLA 'Tupychevskyi'	138	10.0	3	5	93	18.6

Note: * the rate of mistletoe infestation presents the number of mistletoe bushes per tree.

In protected areas, *Viscum album* is distributed unevenly, mostly in Volynske Polissya (VP) and Zhytomyrske Polissya (ZP) on 11 and 7 sites, respectively. However, in terms of the number of host-tree species, two locations had the most, DP 'Beresnivskyi' (46 species, 4 hybrids, 2 ssp., 2 cultivars) (VP) and PMLA 'Kopylivskyi' (11 species) on Kyivske Polissya (KP). PMLAs 'Makarevychivskyi', 'Oleksandriiskyi' and DP 'Beresnivskyi' (VP) and PMLA 'Dvoryshchanskyi' (ZP) have the highest rate of damage from mistletoe (Fig. 1). In protected areas of Chernihivske Polissya (CP) white mistletoe plant count was between 16 and 96 plants per host-tree. Infected trees are distributed evenly throughout the parks area. Significant damage by mistletoe was observed on trees that are 100-year-old in historical parks, which were created in the second half of the 19th century (PMLAs 'Makarevychivskyi', 'Horodotskyi', 'Polonskyi', 'Tuchynskyi', 'Oleksandriiskyi' (VP), PMLAs 'Dvoryshchanskyi', 'Korostyshivskyi', 'Ushomyrskyi', 'Park imeni Miklukho-Maklaia' (ZP), PMLA 'Kopylivskyi' (KP).

Similar trend was observed by Evstihneev and Fedotov (2005), Velichkin (2012), Dobrynia (2013), Yakymenko et al. (2019), who also observed most frequent damage to ancient trees. In these studies damaged trees were thought to be associated with river valleys, wet beams and plantations with adequate lighting in ancient parks. The study sites located in the western part of Volynske Polissya showed much sparser distribution of the mistletoe, usually with 2–3 plants per one or two host trees (PMLAs **'**Zdorovia**'**, **'**Litynskyi**'**, **'**Liubeshivskyi**'**, **'**Bairak**')**.

Within the boundaries of studied sites, 455 host trees with 8586 specimens of mistletoe were discovered. The average host-tree was found to have more than 18 mistletoe plants per tree. Depending on the number of mistletoe plants per host-tree, four classes were identified, including low, medium, high and very high. The first class contained 46.2 % of host-plants (Fig. 2a, b), the second one contained 31.9 % (Fig. 3a, b), the third one contained 10.5 % (Fig. 4a, b), the fourth one contained 11.4 % (Fig. 5a, b). Five species

a) *Populus trichocarpa* Torr. & A.Gray ex. Hook PMLA 'Zdorovia'

b) *Malus domestica* Borkh. PMLA 'Zirnenskyi'

Fig. 2. Low degree of the mistletoe infection.

a) *Acer platanoides* PMLA 'Tuchynskyi'

b) *Betula litwinowii* Doluch. DP 'Beresnivskyi'

Fig. 3. Medium degree of the mistletoe infection.

a) *Tilia cordata* PMLA 'Horodotskyi'

b) *Robinia pseudoacacia* PMLA 'Polonskyi'

Fig. 4. High degree of the mistletoe infection.

a) *Acer platanoides* PMLA 'Dvoryshchanskyi'

b) *Tilia cordata* PMLA 'Makarevychivskyi'

Fig. 5. Very High degree of the mistletoe infection.

were most affected (with all four classes): *Tilia cordata* Mill., *Acer platanoides* L., *Populus simonii* Carrière, *Populus nigra* L., *Juglans nigra* L. (Table 2).

Table 2. Host of *Viscum album* in protected areas of the Ukrainian Polissya.

Tree scientific name	Number of infected trees	Number of mistletoe specimens	Rate of mistletoe infestation*	Number of host trees (% to total number of trees)			
				Low	Medium	High	Very high
Tilia cordata Mill.	85	1725	20.3	27 (31.8)	23 (27.1)	19 (22.4)	16 (18.7)
Robinia pseudoacacia L.	55	560	10.1	36 (65.5)	18 (32.7)	1 (1.8)	-
Acer platanoides L.	53	1640	30.9	15 (28.3)	17 (32.1)	9 (17.0)	12 (22.6)
Populus simonii Carrière	31	1008	32.5	8 (25.8)	11 (35.6)	4 (12.9)	8 (25.8)
Populus nigra L.	25	820	32.8	4 (16.0)	8 (32.0)	6 (24.0)	7 (28.0)
Fraxinus excelsior L.	15	167	11.1	8 (53.3)	7 (45.7)	-	-
Salix alba L.	15	145	9.7	8 (53.3)	7 (46.7)	-	-
Acer saccharinum L.	13	158	12.2	7 (53.8)	6 (46.2)	-	-
Juglans nigra L.	11	317	28.8	2 (18.2)	6 (54.5)	1 (9.1)	2 (18.2)
Betula pendula Roth.	11	156	14.2	4 (36.4)	6 (54.5)	1 (9.1)	-
Fraxinus angustifolia Vahl.	10	174	17.4	5 (50.0)	3 (30.0)	2 (20.0)	-
Betula occidentalis Hook.	9	176	19.6	3 (33.3)	4 (44.4)	2 (22.2)	-
Betula platyphylla ssp. *Mandshurica* (Regel) Kitag.	8	50	6.3	3 (37.5)	5 (62.5)	-	-
Betula albosinensis Burkill	7	57	8.1	5 (71.4)	2 (28.6)	-	-
Prunus pensylvanica L.f.	7	145	20.7	1 (14.2)	5 (71.4)	1 (14.4)	-
Betula litwinowii Doluch.	5	50	10	3 (60.0)	2 (40.0)	-	-
Tilia platyphyllos Scop	4	387	96.8	1 (25.0)	-	-	3 (75.0)
Juglans × intermedia Jacgues.	4	245	61.3	-	-	-	4
Fraxinus chinensis Rox.	4	56	14	3 (75.0)	-	1 (25.0)	-
Acer rubrum L.	4	37	9.3	3 (75.0)	1 (25.0)	-	-

Tree scientific name	Number of infected trees	Number of mistletoe specimens	Rate of mistletoe infestation*	Number of host trees (% to total number of trees)			
				Low	Medium	High	Very high
Betula turkestanica Litv.	4	32	8	3 (75.0)	1 (25.0)	-	-
Fraxinus pennsylvanica Marsh.	4	18	4.5	4	-	-	-
Betula×caerulea Blanch.	3	60	20	1 (33.3)	1 (33.3)	1 (33.3)	-
Carpinus betulus L.	3	28	9.3	2 (66.7)	1 (33.3)	-	-
Betula grossa Siebold & Zucc.	3	24	8	3	-	-	-
Acer tataricum ssp. Semenovii (Regel & Herder) A.E.Murray	3	18	6	3	-	-	-
Quercus rubra L.	3	14	4.7	3	-	-	-
Salix caprea L.	3	14	4.7	2 (66.7)	1 (33.3)	-	-
Sorbus aria (L.) Crantz	3	10	3	3	-	-	-
Malus zumi (Matsum.) Rehder.	3	8	2.7	3	-	-	-
Crataegus sanguinea Pall	3	7	2.3	3	-	-	-
Quercus palustris Muenchh.	2	37	18.5	1 (50.0)	1 (50.0)	-	-
Salix babylonica L.	2	29	14.5	-	2	-	-
Betula kenaica W.H.Evans	2	24	12	1 (50.0)	1(50.0)	-	-
Acer pseudoplatanus L.	2	12	6	2	-	-	-
Populus alba L.	2	9	4.5	2	-	-	-
Betula pubescens Ehrh	2	6	3	2	-	-	-
Betula schmidtii Regel	2	6	3	2	-	-	-
Tilia platyphyllos 'Laciniata'	2	6	3	2	-	-	-
Sorbus×thuringiaca (Ilse) Fritsch	2	4	2	2	-	-	-
Prunus cerasifera Ehrh	2	3	1.5	2	-	-	-
Malus pallasiana Juz.	2	2	1	2	-	-	-
Sorbus aucuparia L.	1	26	26	-	1	-	-
Aesculus hippocastanum L.	1	21	21	-	1	-	-
Juglans cinerea L.	1	18	18	-	1	-	-
Sorbus aucuparia 'Pendula'	1	17	17	-	1	-	-

Tree scientific name	Number of infected trees	Number of mistletoe specimens	Rate of mistletoe infestation*	Number of host trees (% to total number of trees)			
				Low	Medium	High	Very high
Betula lenta L.	1	15	15	-	1	-	-
Betula papyrifera Marshall.	1	10	10	-	1	-	-
Tilia amurensis Rupr.	1	8	8	1	-	-	-
Sorbus alnifolia (Siebold & Zucc.) K.Koch	1	5	5	1	-	-	-
Acer hyrcanum Fisch. & C.A.Mey.	1	3	3	1	-	-	-
Amelanchier spicata (Lam.) K.Koch	1	3	3	1	-	-	-
Tilia americana L.	1	3	3	1	-	-	-
Crataegus monogyna Jacq	1	2	2	1	-	-	-
Malus×purpurea (E.Barbier) Rehder	1	2	2	1	-	-	-
Betula microphylla Bunge	1	1	1	1	-	-	-
Betula dahurica Pall.	1	1	1	1	-	-	-
Betula pendula '*Youngii*'	1	1	1	1	-	-	-
Syringa reticulata ssp. *pekinensis* (Rupr.) P.S.Green & M.C.Chang	1	1	1	1	-	-	-
Crataegus arnoldiana Sarg.	1	1	1	1	-	-	-
Malus domestica Borkh.	1	1	1	1	-	-	-
Prunus maackii Rupr.	1	1	1	1	-	-	-
Populus trichocarpa Torr. & A.Gray ex. Hook.	1	1	1	1	-	-	-
Acer tataricum L.	1	1	1	1	-	-	-
Total	455	8586	18.9				

Note: *The rate of mistletoe infestation presents the number of mistletoe bushes per tree.

The largest numbers of affected trees were in species *Tilia cordata*, *Acer platanoides*, *Populus simonii*, *Populus nigra* and *Robinia pseudoacacia*, although the latter had a slightly lower degree of damage. *Juglans* × *intermedia* had a significant number of mistletoe plants exceeding 50 per tree (on average, more than 60 mistletoe bushes were found on one tree).

Viscum album was found on 64 taxa of woody plants belonging to 16 genera and 9 families, including 54 taxa in DP 'Beresnivskyi'. Among these, the most host-trees belonged to genus *Betula* L. (13 species and one hybrid, ssp., cultivar). Among different species of genus *Betula*, the largest number of mistletoe plants was found in *Betula pendula* (156 on 11 trees, on average 14 plants per tree) and *Betula occidentalis* (176 on 9 trees, on aver-

age about 20 mistletoe bushes per tree). Among trees that serve as host-trees for mistletoe, in total in Ukraine were identified 123 species and subspecies from 37 genera and 17 families. The majority of host-trees belong to *Rosaceae* (45 species), *Betulaceae* and *Salicaceae* (15 species each) and *Sapindaceae* (13 species) families (Krasylenko et al. 2020). In Hungary, in mistletoe-infected areas, grow 9–12 of the 18 most common host species; *Populus* spp., *Robinia pseudoacacia* L. and *Acer saccharinum* L. are frequently infected; no significant changes on mistletoe hosts have been observed over the past 90 years (Varga et al. 2014). In Poland, mistletoe is found on 12 species of forest trees, most often on silver fir and Scots pine, much less frequently on birches (Lech et al. 2020). In the castle park in Lednice (Poland), *Tilia cordata* Mill., *Juglans nigra* L. and *Acer saccharum* Marshall are intensively affected (Baltazar et al. 2013).

By presence of host-trees on IUCN Red List, it was determined that 45 species belong to the IUCN World Cup, with 68.5 % being in the category LC (Least Concern) and 7.4 % in category DD (Data Deficient). *Aesculus hippocastanum* L. belonged to category VU (Vulnerable), *Juglans cinerea* L. – to category EN (Endangered), *Fraxinus pennsylvanica* Marsh. – CR (Critically Endangered). Such a trend is alarming and requires not only the protection of these species, but also the identification of ways to preserve and restore them in protected areas.

According to the classification of life forms by Raunkiær (1934) in the studied protected areas of the Ukrainian Polissya, the host trees are mainly represented by moesophanerophytes (44 taxa), megafanerophytes (11 taxa) and microphanerophytes (9 taxa) (Fig. 6). The distribution of trees by height classes showed that the host trees of class four (37.5 %) and class one (32.8 %) prevailed, with class 2 and 3 trees (14.1 % each) having lower representations.

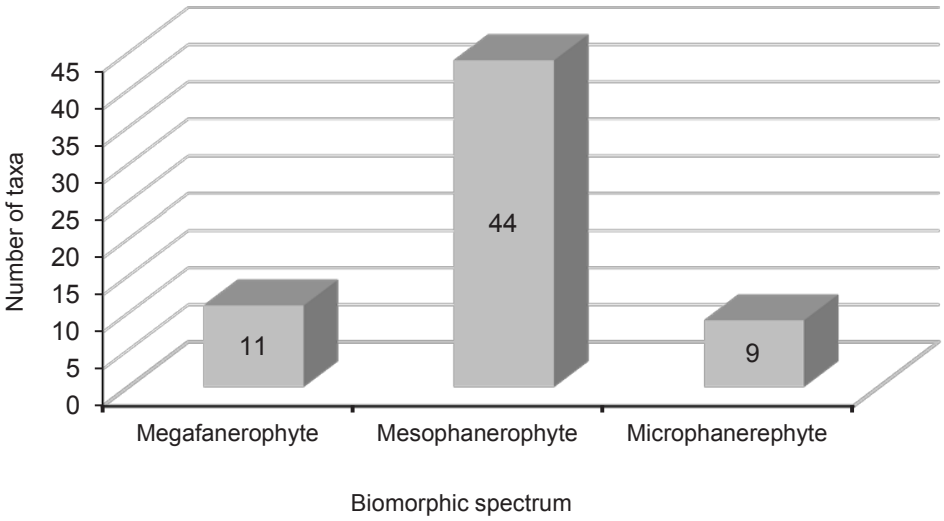

Fig. 6. Biomorphic spectrum of host trees.

After analyzing the ecology of host trees, it was determined that a significant proportion of them are heliophytes (39 taxa), moesotrophs (37 taxa) and mesophytes (30 taxa) (Fig. 7). Moesoxerophytes, oligotrophs and heliophytes such as *Robinia pseudoacacia* L. (10 mistletoe plants on average per tree) and *Betula pendula* Roth. (on average 14 mistletoe plants per tree) were significantly damaged by mistletoe (Table 2). The moesohygrophytes *Populus simonii*, *Populus nigra*, *Juglans nigra*, *Fraxinus angustifolia* and *Fraxinus excelsior* were also severely damaged with average number of mistletoe ranging between 11 and 33 plants per tree.

According to Bilonizhko (2019), mistletoe more readily damages introduced species. In contrast, our study showed that despite 72.3 % of the host trees in the Ukrainian Polissya are introduced, of which 33.3 % are of North American origin and only 27.7 % are native, the majority of trees (229 specimens with mistletoe) are native species. *Viscum album* is distributed via endozoochory, mainly by birds (Yakymenko et al. 2019). Such a phenomenon is observed in DP 'Beresnivskyi', where the spread of mistletoe occurs during the years of increasing population of *Bombycilla garrulus* L.

In most protected sites, in order to reduce the number of affected trees, they are removed mechanically. This method is quite effective when the number of host plants affected by mistletoe is small and their removal is timely. In PMLA 'Kmytivskyi' (ZP) in 1972, two 150-year-old *Populus* × *canescens* (Aiton) Sm. trees and one 80-year-old *Tilia cordata* had a high degree of mistletoe damage, so they were removed. As of 2018, the PMLA had no trees affected by mistletoe. The intensive spread of mistletoe in historical parks over the last ten years is a concern for the ancient dendroflora. Old trees are five times more likely to be affected by mistletoe than younger ones (Baltazar et al. 2013, Lech et al. 2020). In PMLA 'Kopylivskyi' (KP) during 2016–2017, the degree of damage to *Tilia cordata*, *Robinia*

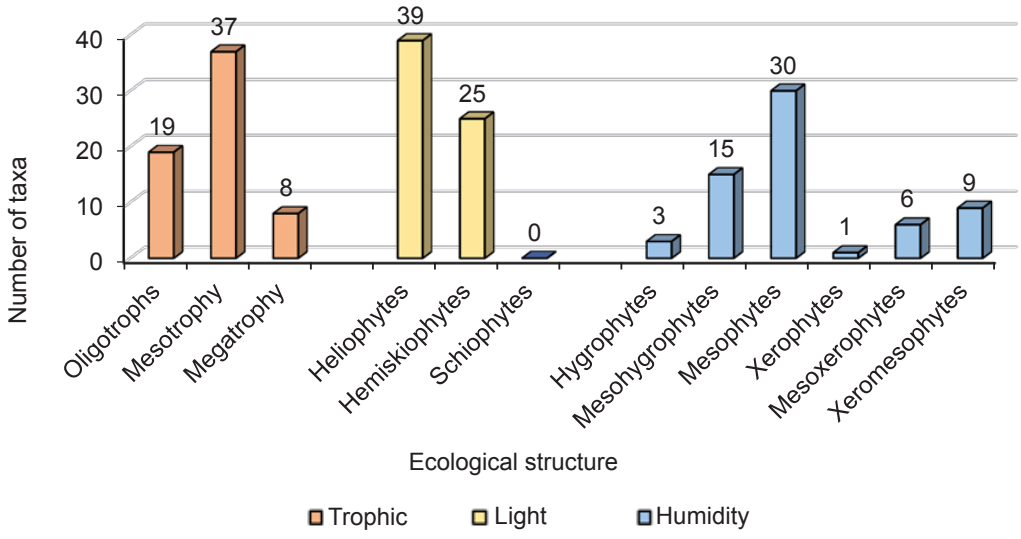

Fig. 7. Ecological structure of host trees.

pseudoacacia and *Acer platanoides* was very high. After pruning in 2018–2019 and removal of severely damaged trees, the situation temporarily improved with the number of mistletoe plants decreasing to eight per tree on average. The spread of mistletoe due to untimely removal and drought could be observed in PMLA 'Oleksandriiskyi', 'Horodotskyi', where two affected trees of species *Tilia cordata*, *Populus simonii*, *Robinia pseudoacacia* and *Tilia cordata* were present in 2015. In 2021, there were 22 to 54 woody plants affected by mistletoe, belonging to 7 species, with an average number of mistletoe plants between 29 and 43 per tree. Thus, in protected areas, especially in historic parks, one of the effective ways to stop the mistletoe spread is timely mechanical removal of mistletoe plants.

Conclusions

The first study of mistletoe distribution in the protected areas of the Ukrainian Polissya showed that the main tree species susceptible to mistletoe invasion are *Tilia cordata* (18.7 %), *Robinia pseudoacacia* (12.1 %) and *Acer platanoides* (11.6 %). It was established that the dendroflora of the Ukrainian Polissya had many host trees of white mistletoe, which include 64 taxa belonging to 16 genera and 9 families, among which the most common are *Betulaceae*, *Rosaceae*, *Salicaceae*, *Sapindaceae*. In terms of the number of affected trees, autochthonous species predominate. Moesoxerophytes, oligotrophs, heliophytes (*Robinia pseudoacacia*, *Betula pendula*) and moesohygrophytes (*Populus simonii, Populus nigra*, *Juglans nigra*, *Fraxinus angustifolia*, *Fraxinus excelsior*) suffer by significant damage. The highest level of damage from mistletoe was observed on trees of tree height class four (5(7) –15 m) (37.5 %) and trees of class one (greater than 25 m) (32.8 %).

In two PMLA ('Oleksandriiskyi', 'Makarevychivskyi') located in the southern part of Volyn and one in Zhytomyrske Polissya (PMLA 'Korostyshivskyi'), the average degree of mistletoe infestation was high with 38 to 43 mistletoe plants per host tree.

The trend towards the destruction of rare species is alarming and requires not only their protection, but also the determination of ways for their conservation and restoration in protected areas. One of the effective ways to stop the spread of mistletoe in protected areas, especially in historical parks, is the timely mechanical removal of mistletoe plants.

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ON THE RELICT OF THE FLORA IN INSULAR PINE FORESTS IN THE RUSSIAN PLAIN

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Abstract

The forests, located in the conditions of steppe and forest-steppe zones, represent insular massifs with an extrazonal type of vegetation. Based on the unanimous opinion of scientists about the origin of insular pine forests and the assumption that pine forests in the past formed a single array with the zonal northern taiga, the concept of relict flora of insular pine forests arose. Scientists note that, despite the high degree of steppe species, the core of the flora is boreal in nature. The purpose of the study was to test the assumption of the relict nature of flora found in insular pine forests in the Russian Plain in contemporary conditions based on the analysis of the spectrum of latitudinal groups. We have studied the flora of the pine forests in the Russian plain: Usmansky and Khrenovskoy – located in the subzone of the typical forest-steppe of the Oka and Don Rivers lowland; Buzuluksky and Krasnosamasrky – occupying an area in the steppe zone of the Volga region. The flora of the forests in the steppe and forest-steppe zones fully reflects the natural and climatic features of these areas, which is clearly visible in the spectra of the latitudinal groups of the studied flora. One-third of the species in the floristic core are forest groups, which confirms the previously stated assumptions about the relict nature of insular pine forests. This was also confirmed by the analysis of the spectrum of latitudinal groups of rare species in the flora. In the floristic core, among the rare ones, there was a high percentage of forest species that determine its forest character. The data obtained also indicate that for many steppe and forest-steppe regions, forests may be the only habitats of forest species. For example, *Drosera rotundifolia* L., *Calla palustris* L., *Lycopodium annotinum* L., and *Neottianthe cucullata* (L.) Schlehter.

Key words: floristic core, rare species, spectrum of latitudinal groups, steppe and forest-steppe zone.

Introduction

Pine forests are insular forests, where the main forming species is Scots pine occurring at the southern limit of distribution. Located in the steppe and forest-steppe zones along the left bank of rivers, pine forests represent an extra-zonal type of vegetation. They can stretch along the riverbeds from the taiga to the steppe zone, forming ribbon massifs, but in most cases, they are compact forest massifs.

Most scientists share the same opinion about the origin of the insular pine forests. According to them, the periodic Quaternary glaciations covered different areas and alternated with warming stages, and thus had a significant influence

on the formation of flora (Gerasimov and Markov 1939, Markov and Velichko 1967). The vegetation cover changed repeatedly under the influence of glacial dynamics. In the interglacial epochs during the melting of glaciers, troughs of ancient flow along the ancient riverbed were formed, on the bottoms of which there was an accumulation of ancient alluvial sand sediments, then rewetted. Pine trees settled on the deposited sands (Gvozdetsky 1968, Kazmin 2017).

The assumption that the pine forests, located in the depth of the steppe zone, in the past constituted a single massif merging with the zonal northern taiga, was suggested by Gordyagin (1897), on the example of the insular pine forests of Kazakhstan. His concept provided an explanation for the occurrence of some taiga and marsh plants. Later this concept was supported and developed by Krasheninnikov (1939), Pavlov (1948), Gribanov (1960) and other scientists. Gorchakovsky (1987), studying the flora of pine massifs in low mountains of the Kazakh small knoll topograph, noted that despite its high degree of steppification, the core of the flora is of boreal character. This provoked high botanical and geographical interest and provided grounds for the development of the concept of relict nature of flora in pine forests.

The history of the pine forests of the Russian Plain can be dated back to the late Pleistocene to the Holocene (Kremenetsky et al. 1998). The last blanket glaciation in the Late Pleistocene (Valdai) covered only the northwestern part of the Russian Plain; the areas where the studied pine forests are currently located were far from the boundaries of blanket ice in the periglacial zone. Nevertheless, the climate changes that occurred repeatedly throughout the Valdai time were reflected in the vegetation cover of the entire plain and beyond. During humid periods, boreal floristic complexes were more widespread. During the increasing aridization of the territory, periglacial, almost treeless spaces were actively formed, the vegetation cover of which was composed of species that are currently representatives of different zonal floristic complexes: boreal, nemoral steppe, desert-steppe. As a result of climate fluctuations, the ratio and role of these floristic complexes in the vegetation cover changed, alternately shifting from the dominant to the subordinate position and vice versa (Agafonov 2006).

According to the spore-pollen analyses carried out in the territories of modern bogs, there were few tree species in the Late Valdai time, and the vegetation cover was represented by cold dry steppes, dominated by species of Chenopodiaceae family (Agafonov 2006) and species of the genus *Artemisia* (Kremenetsky et al. 1998).

In the Holocene the climatic conditions changed towards softening, birch and pine actively penetrated into the river valley and spread over sandy terraces. This led to the formation of pine forests with an admixture of birch. From this time, the history of pine forests can be counted. In the Holocene pre-boreal period, the boreal floristic complex with the dominance of pine with an admixture of spruce and birch in the island massifs still prevails. Later on, the boreal floristic complex is confidently replaced by the desert-steppe floristic complex. The most powerful migration waves of steppe and desert species from the south and southeast occurred during the Atlantic Holocene (Agafonov 2006). Thus, the forest massifs dominated by *Pinus sylvestris* that emerged at the beginning of the Holocene underwent significant changes and are currently represented in the Russian Plain by compact island massifs in the steppe

and forest-steppe zones.

In the development of modern flora, in addition to the paleogeographical factor that determines the events of past years, the modern abiotic factor is taken into account, which makes it possible to state the features of the current state of the flora and predict its further development. Also, the most dynamic - anthropogenic factor, capable of fundamental changes in the landscape both as a whole and its individual components, is becoming increasingly important.

The forest ecosystems of the European part of the continent have been significantly destroyed as a result of human activity, which has led to a decrease in the forested area and the emergence of natural-anthropogenic complexes. However, scientists in many European countries are finding remaining forest areas that have a distinct identity and continue to play a vital ecological role in maintaining a habitat for biodiversity. Most often, these natural islands are the only habitat for many endangered species. One of these unique ecosystems are the island pine forests of the Russian Plain.

Modern scientists (Agafonov 2006, Chibilev 2008, Korchikov et al. 2009, Kliment'ev 2010, Matveev et al. 2012) note a change in the structure of the pine forests of the Russian Plain, expressed in a decrease in the area of natural forest tracts. This is primarily due to numerous fires and uncontrolled logging. Thus, in the pine forests of the Russian Plain located in the forest-steppe zone, natural pine forests account for less than half of the area of woodlands (Matveev et al. 2012).

The pine forests of the Russian Plain of the steppe zone, located in more extreme forest-growing conditions, have also historically experienced a powerful anthropogenic load, which led them to complete fragmentation (Pallas 1809, Darkshevich 1953, Chibilev 2008, Kliment'ev 2010). The connection between the pine forests has been preserved in floodplain forests, which have become ecological corridors for forest biota (Korchikov et al. 2009).

Modern researchers of the pine forests flora noted their floristic richness and diversity (Starodubtseva 1999, Grigorievskaya 2004, Kin 2009, Korchikov et al. 2009, Kin et al. 2012, Saxonov et al. 2012, Seregin 2015), indicating that these forests still remain unique natural landscapes.

In this regard, there is a hypothesis about the preservation of the relict nature of the flora of the pine forests despite the change in environmental conditions. To establish the validity of this hypothesis, we will rely on the opinion of Gorchakovsky (1987). He pointed out that the relict nature of the flora of the in low mountains of the Kazakh small knoll topograph, forest directly depends on the presence of boreal (in a broad sense) species in the core of the studied flora. The purpose of our work is to reveal the relict nature of the island forests that occur across the Russian Plain.

Materials and Methods

We carried out an inventory of the flora of the pine forests of the Russian Plain: Usmansky, Khrenovskoy, Buzuluksky, and Krasnosamarsky (Fig. 1).

In physiographic terms, the Usmansky and Khrenovskoy pine forests are located in the typical forest-steppe subzone of the Oka and Don Rivers lowland of the central part of the Russian plain (Milkov 1977). The Usmansky pine forest (51°41' – 52°02' N, 39°21' – 39°47' E) is located in the forest-steppe zone along the

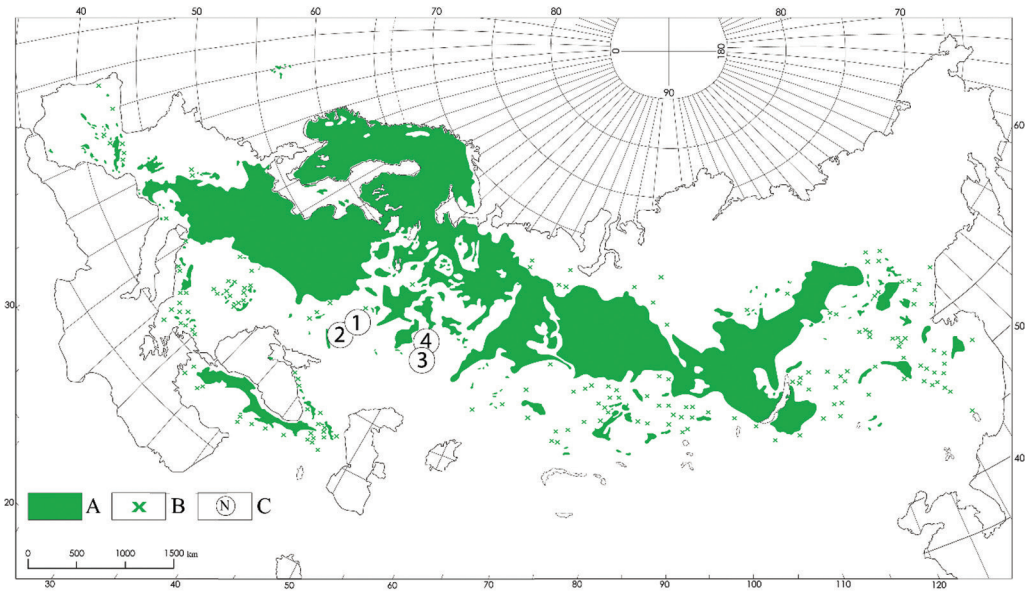

Fig. 1. Schematic map of the studied Scots pine forests location (Crichfield and Little 1966, in the authors' version).

Legend: A – Main range of *Pinus sylvestris* L.; B – Areas separated from the main range of *Pinus sylvestris*; C – Studied pine forests (1 – Usmansky, 2 – Khrenovskoy, 3 – Buzuluksky, 4 – Krasnosamarsky).

watersheds of the Voronezh and Usman rivers in Voronezh and Lipetsk regions. The total area is 70,700 ha (covered by forest – 63,100 ha), the reserve occupies 31,053 ha. Khrenovskoy pine forest is located on the left bank of the Bityug River (51°05' – 51°16' N, 40°06' – 40°25' E), on the border of steppe and forest-steppe zones in Voronezh oblast. The area of the Khrenovskoy pine forest is 40,210 ha. Buzuluksky and Krasnosamarsky pine forests are located in the southeastern part of the Russian Plain (Fig. 1), occupying a vast area in the western part of the Obshchesyrtovsko-Preduralskaya upland steppe province, in the steppe zone of Zavolzhye (Godnev et al. 1949). Buzuluksky pine forest is located between 52°53' – 53°19' N and 51°05' – 52°31' E within the Orenburg and Samara regions. Considering the numerous small isolated wood patches, the total area of the Buzuluk pine forest is about 350,000 ha.

The Krasnosamarsky pine forest (52°58' – 53°05' N and 50°59' – 51°07' E) is situated in the south-east of the Samara Region in the right-bank part of the valley of the middle course of the Samara River.

Krasnosamarsky pine forest occupies an area of 13,554 ha, including 1565 ha in the Samara river floodplain and 12,286 ha outside the floodplain, and the total area of the Krasnosamarsky forest together with open meadow and steppe areas is about 30,000 ha.

In the pine forests under study, there is an increase in continentality from the west (Usmansky and Khrenovskoy pine forests) to the east (Buzuluky and Krasnosamarsky pine forests), which manifests itself in the deterioration of hydrothermal conditions and other parameters (Table 1).

Table 1. Indicators of temperature regime and precipitation for the studied pine forests.

Pine forests	Average annual air temperature, °C	T_{max}, °C	T_{min}, °C	Amplitude, °C	Average annual precipitation, mm
Usmansky	+5.3	+38.9	-41.8	80.7	653
Khrenovskoy	+5.8	+35.0	-41.0	76.0	527
Buzuluksky	+3.6	+48.0	-50.0	98.0	530
Krasnosamarsky	+4.5	+41.0	-49.0	90.0	359

Note: T_{max} and T_{min} are absolute maximum and minimum temperatures.

Increasing aridization of the climate is also reflected in the taxonomic structure of pine forests (Kin et al. 2020). The floras of Usmansky and Khrenovskoy pine forests, located in more favorable climatic conditions, are represented by a large number of families, genera, and species, compared to the floras of Buzuluksky and Krasnosamarsky pine forests, located in extreme conditions for forest ecosystems (Table 2).

Table 2. Taxonomic diversity of higher plants in the studied pine forests.

Pine forests	Number				
	Families	Genera	Types		
			Indigenous	Alien	Introducers
Usmansky	123	508	852	219	12
Khrenovskoy	108	430	718	130	2
Buzuluksky	101	383	675	112	7
Krasnosamarsky	93	352	591	80	3

Species found in all floras pine forests are involved in the formation of the floras core.

It was noted that a part of species for some pine forests is indigenous and for others it is a part of alien fraction. Therefore, when counting taxa of the aboriginal and alien fraction of the pine forests of flora, only those that have the same origin for all the studied pine forests were considered.

The species involved in the formation of the floristic core of the studied pine forests are distributed by latitudinal geographical groups (Kulikov 2005). In order to establish the relict nature of the flora of pine forests, special attention was given to the 'boreal species in the broad sense', which are the species composing the boreal, boreo-nemoral, boreo-nemoral forest-steppe and nemoral groups. All they were classified in our work under the general name 'forest'.

Results and Discussion

It was found that 419 species from 281 genera of 89 families participate in the formation of the floristic core. The nucleus of the aboriginal fraction of the flora consisted of 358 species from 236 genera of 84 families. The core of the adventive fraction of the flora includes 25 families, 41 genera, and 44 species.

Obviously, the basis of the floras of the studied pine forests is formed by the aboriginal fraction. Considering this fraction of

the studied floras in the latitudinal spectrum, we revealed that almost one third of the species belong to the plurizonal group (Table 3). Otherwise, the order of the groups is individual for each of the studied floras. In the Usmansky pine forest, the boreo-nemoral group is second in the number of species, while the forest-steppe and steppe groups contain fewer species. In the flora of the other three pine forests, on the contrary, the forest-steppe and steppe group are richer in species and take second place in this ranking, leaving the boreonemoral group in a lower position.

In the Usmansky pine forest, the complex of latitudinal groups represented by forest species occupied the middle position in the spectrum and corresponded to 4–6 positions, in descending order: boreonemoral forest-steppe, nemoral, boreal. Forest-steppe, steppe groups are few in number. The smallest number of species belonged the nemoral forest-steppe and nemoral forest-steppe and steppe groups.

In the flora of the Khrenovskoy pine forest, only three groups with forest species wre highly significant, occupying 3–5 positions in the spectrum, in descending order: boreaonemoral, boreonemoral forest-steppe, nemoral. Boreal is the smallest of all groups. It occupies the last place in the spectrum, yielding by the number of species to steppe, forest-steppe, nemoral forest-steppe, and nemoral forest-steppe and steppe groups (Table 3).

The nature of the Buzuluksky pine forest flora is peculiar. Having a large area and a variety of landscapes, the pine forest forms favorable conditions for species belonging to different latitudinal groups. The forest character of the pine forest is also noticeable in the

Table 3. Spectrum of latitudinal groups of the native fraction of the flora of pine forest and the floristic core.

Name of groups	I. Total species, number/%				II. Species in the core, number/%			
	1	2	3	4	1	2	3	4
Boreal	64/7.5	33/4.6	36/5.5	16/2.7	9/14.0	9/27.3	9/25.0	9/56.2
Boreonemoral	122/14.3	89/12.4	96/14.2	65/11.0	46/37.1	46/51.7	46/47.9	46/70.8
Boreonemoral forest-steppe	69/8.1	57/7.9	61/9.0	46/7.8	33/47.8	33/57.9	33/71.7	33/71.7
Nemoral	66/7.7	55/7.7	41/6.1	28/4.7	19/28.8	19/34.5	19/46.3	19/67.8
Nemoral forest-steppe	40/4.7	35/4.9	26/3.9	21/3.6	15/38.5	15/ 42.8	15/57.7	15/71.4
Nemoral forest-steppe and steppe	37/4.3	35/4.9	30/4.4	27/4.6	22/61.1	22/62.8	22/73.3	22/81.5
Forest-steppe	54/6.3	43/6.0	22/3.3	22/3.7	12/22.6	12/27.9	12/27.3	12/54.5
Forest-steppe and steppe	99/11.6	94/13.1	102/15.1	115/19.5	56/56.6	56/59.6	56/54.9	56/48.7
Steppe	54/6.3	51/7.1	67/9.9	83/14.0	17/31.5	17/33.3	17/25.4	17/20.5
Plurizonal	247/29.0	226/31.4	193/28.6	168/28.4	129/52.9	129/57.3	129/66.8	129/76.8
Species in total	852	718	674	591	358	358	358	358

Note: 1 – Usmansky; 2 – Khrenovskoy; 3 – Buzuluksky; 4 – Krasnosamarsky pine forest.

spectrum, where the boreonemoral group keeps the third position by the number of species, and the boreonemoral forest-steppe, nemoral and boreal groups occupy 5th to 7th lines of the rating. Zonal location had a noticeable influence on the development of boreal flora. Here a significant number of species fall in the steppe group, which occupied the 4th position in the ranking. The least number of species (in descending order) belonged to the nemoral forest-steppe, nemoral forest-steppe and steppe, as well as forest-steppe groups (Table 3).

In the flora of the Krasnosamarsky pine forest, the steppe group was among the top three in terms of the number of species, followed by the boreonemoral, boreonemoral forest-steppe and nemoral groups. The boreal group contained the smallest number of species. A little more species were observed in the nemoral forest-steppe and steppe, forest-steppe and nemoral forest-steppe groups.

The spectrum of the latitudinal groups of the floristic core differed from the studied floras, with the exception of the first three leading groups in terms of the number of species, and the leading ones in the structure of flora (Table 3). Here a significant part of the species belonged to the plurizonal group – 36.0 %. This group consisted of species that have a wide distribution and are found in almost all zones. This includes a large number of weed species (apophytes), among which: *Tripleurospermum inodorum* (L.) Sch.-Bip., *Chenopodium album* L., *Erysimum hieracifolium* L. Also, in this group there were many representatives of aquatic flora: *Stratiotes aloides* L., *Nuphar lutea* (L.) Smith, *Sparganium emersum* Rehm. More than 2 times less, relative to the leading one, representatives of the forest-steppe and steppe (15.6 %) groups entered the floristic core. The species composing this group were found in ecosystems transitional between forest and steppe – forest-steppe zone and spread further south, finding habitats in the steppe zone, for example, species of the genus *Artemisia*: *A. abrotanum* L., *A. austriaca* Jacq., *A. marchalliana* Spreng. Species composing the boreonemoral (12.8 %) group were predominantly distributed in the zone of taiga and deciduous forests. The floristic core of this group included representatives of woody-shrub flora of pine forests: *Sorbus aucuparia* L., *Padus avium* Mill., *Populus tremula* L., *Ribes nigrum* L., *Frangula alnus* Mill. The herbaceous plants in this group was represented by *Lathyrus vernus* (L.) Bernh., *Scrophularia nodosa* L., *Impatiens noli-tangere* L., and some types of horsetails *Equisetum hyemale* L., *E. sylvaticum* L. Further, in descending order of the number of species in the latitudinal groups included in the floristic core of the studied pine forests, the groups were arranged in the following order:

- boreonemoral forest-steppe group (9.2 %), which included species of the family *Primulaceae*: *Lysimachia nummularia* L., *L. vulgaris* L., *Naumburgia thyrsiflora* (L.) Reichb. and *Humulus lupulus* L., *Verbascum thapsus* L., *Rubus saxatilis* L. and others;

- the nemoral forest-steppe and steppe (6.1 %) group combines plant species with their habitats both in the forest and steppe zones. Among them: *Allium rotundum* L., *Eupatorium cannabinum* L., *Inula helenium* L., *Senecio erucifolius* L., *Origanum vulgare* L., *Verbascum lychnitis* L., *Filipendula vulgaris* Moench, *Otites borystenica* (Grun.) Klok.;

- nemoral (5.3 %) group was represented in the floristic core largely by woody plants: species of the genus *Ulmus* (*U. glabra* Huds., *U. laevis* Pall., *U. mino*r

Mill.), *Tilia cordata* Mill., *Corylus avellana* L., *Quercus robur* L. *Euonymus verrucosa* Scop. and others;

- steppe (4.7 %) group included species such as: *Elytrigia intermedia* (Host) Nevski, *Chondrilla graminea* Bieb., *Salvia tesquicola* Klokov & Pobed., *Astragalus varius* S. G. Gmel., *Dianthus andrzejowskianus* (Zapal.) Kulcz., *D. campestris* Bieb. and others;

- the nemoral forest-steppe group (4.2 %) was represented in the floristic core of pine forests by such species as: *Carlina biebersteinii* Bernh. ex Hornem., *Pyrethrum corymbosum* (L.) Scop., *Vincetoxicum hirundinaria* Medik, *Aristolochia clematitis* L. and others;

- the forest-steppe group (3.4 %) was one of the small ones in the floristic core and included: *Tragopogon major* Jacq., *Leonurus quinquelobatus* Gilib., *Chamaecytisus ruthenicus* (Fisch. ex Wolosz.) Klask., *Prunus spinosa* L., *Geranium sanguineum* L. and others;

- boreal (2.5 %) group had the smallest share in the floristic core, but it included *Pinus sylvestris*, the edificator of the studied forests; other species in the group were: *Galium trifidum* L., *Spirodela polyrhiza* (L.) Schleid., *Lemna minor* L. and others.

It is interesting that of all groups, the largest number of species in the floristic core was retained by the nemoral forest-steppe and steppe group, which in the latitudinal spectrum of the flora of the studied pine forests occupied the last positions. Thus, 61.1 % of species from this group were included in the flora of the Usmansky pine forest. The largest number of species of this group was recorded in the core in the flora of Krasnosamarsky pine forest – 81.5 %.

More species ofthe forest-steppe and steppe and steppe groups were present in the core from the flora of the Usmansky and Khrenovskoy pine forests located in the forest-steppe zone than in the flora of the Buzuluksky and Krasnosamarsky pine forests located in the steppe zone. The opposite situation with the boreonemoral forest-steppe, nemoral forest-steppe, boreonemoral, nemoral and boreal groups, where a smaller proportion of species of the flora of Usmansky and Khrenovskoy pine forests entered the core than in the flora of Buzuluksky and Krasnosamarsky pine forests.

This is primarily due to the floristic structure of the Krasnosamarsky pine forest, which is located in the steppe zone, initially containing few forest species compared to the rest of the studied pine forests floras. On the other hand, in the floristic complex of the Usmansky pine forest, which is closest to the boreal flora among the studied ones, the number of forest-steppe, and steppe species is low. This, in turn, limits the presence of species of the respective groups in the core of the unified flora of pine forests.

Particularly important is the share of species groups containing representatives of forest floras and causing the greatest interest with respect to the relictness of the floras of the studied pine forests. These groups comprised from 37.6 % in the Usmansky, 32.6 % in the Khrenovsky, 34.6 % in the Buzuluksky, to 26.2 % in the Krasnosamarsky pine forests. Only 29.8 % of species from these groups participate in the floristic core.

Another important indicator of the value of flora is the presence of rare and endangered species, which are protected and/or listed in the Red Books of the regions. Territorially, the pine forests are located in different regions, and the Usmansky and Buzuluksky pine forests are located within two regions. Based on the information from the regional Red Data

Books (Shcherbakov 2014, Senator and Saksonov 2017, Agafonov 2018, Belov 2019), it is worth considering that species may have different protection status. In addition, being protected in the territory of one region, in another, these species may not have this status and be well distributed.

Almost half of the protected species of the Lipetsk Region were found in Usmansky pine forest (Table 4). For the Voronezh Region, the same pine forest is a refuge for one third of protected species of the region. About 20 % of protected species of the Voronezh Region occurred in the flora of Khrenovskoy pine forest.

Table 4. Number of species in the regional Red Data Books and their proportion in the flora of the studied pine forests.

Regions	Number of species in the Red Book of the region	Proportion of rare species in the flora of pine forests from those included in the Red Book of the region, %	
		Usmansky pine forest	Khrenovskoy pine forest
Voronezh	237	32.9	19.8
Lipetsk	175	45.7	-
		Buzuluksky pine forests	Krasnosamarsky pine forests
Samara	243	22.2	17.3
Orenburg	173	25.4	-

Approximately the same proportion of protected plants for the Samara and Orenburg regions is found in Buzuluksky pine forest.

In the flora of the Krasnosamarsky pine forest the share of protected species is not high and amounts to 17.3 % of all rare species included in the Red Book of the Samara region.

The proportion of protected species of all species accounted for in the flora of pine forests does not reach 10%. In the flora of the Usmansky pine forest, about 9% of species are protected in the Voronezh and Lipetsk regions. In the flora of Khrenovskoy pine forest, only 6.5 % of plant species included in the Red Book of the Voronezh region. The same percentage of protected species is noted in the flora of the Buzuluksky pine forest for the Orenburg region. The percentage of protected species in the flora of Buzuluksky pine forest for the Samara region is 8 %, and in the flora of Krasnosamarsky pine forest – 7 % of this region.

A compilation of a spectrum of latitudinal groups of protected species of flora of pine forests and floristic core was done (Table 5).

A high percentage of the species belonging to the forest group were protected.

The largest percentage of species from these groups falls on the flora of the Buzuluksky pine forest and totals 65.9 % for the Orenburg region and 61.1 % for the Samara region of all protected species accounted for in the flora of this pine forest.

In the flora of the Usmansky pine forest, protected species of the forest groups accounted for 60.3 % for the Voronezh region and 53.8 % for the Lipetsk region. The flora of Khrenovskoy pine forest contained 55.3 % of species of the forest groups for the Voronezh region among protected ones. Only 40.5% of species of the forest groups with a protection status in the Samara region entered the flora of Krasnosamarsky pine forest.

Of the protected species included in the floristic core, more than half (57.6 %)

Table 5. Spectrum of latitudinal groups of protected species of pine forests and core floras.

Latitudinal group	Number of species of flora of pine forests in the regions						Number of species in the floristic core of pine forests
	Lipetsk	Voronezh		Orenburg	Samara		
	1	1	2	3	3	4	
Boreal	24	27	15	7	16	4	5
Boreonemoral	7	10	8	9	9	7	7
Boreonemoral forest-steppe	5	4	2	6	4	2	5
Nemoral	7	6	1	7	4	4	2
Nemoral forest-steppe	6	4	1	2	2	1	2
Nemoral forest-steppe and steppe	3	2	1	1	2	2	2
Forest-steppe	8	6	6	1	1		1
Forest-steppe and steppe	8	5	6	5	6	6	6
Steppe	4	3	3		4	10	1
Plurizonal	8	11	4	6	6	6	2
Species in total	80	78	47	44	54	42	33

Note: 1 – Usmansky, 2 – Khrenovskoy, 3 – Buzuluksky, 4 – Krasnosamarsky pine forests.

belonged to the forest groups. From the boreal group here are marked: *Pyrola rotundifolia* L., *Adenophora liliifolia* (L.) A. DC., *Menyanthes trifoliata* L., *Juniperus communis* L., *Dryopteris carthusiana* (Vill.) H.P. Fuchs. Among the protected species from the boreonemoral group: *Carex bohemica* Schreb., *Listera ovata* (L.) R. Br., *Platanthera bifolia* (L.) Rich., *Paris quadrifolia* L., *Veratrum lobelianum* Bernh., *Dryopteris filix-mas* (L.) Schott, *Matteuccia struthiopteris* (L.) Tod. The composition of the floral core of the boreonemoral forest-steppe group includes such protected species as *Orchis militaris* L., *Iris pseudacorus* L., *Naumburgia thyrsiflora*, *Pulsatilla patens* (L.) Mill., *Thelypteris palustris* Schott. From the nemoral group in the floristic core, species with a protected status in the Orenburg region are *Euonymus verrucosa* and *Viola mirabilis* L.

Conclusions

The flora of the forests of the steppe and forest-steppe zones fully reflects the natural and climatic features of these areas, which is clearly visible in the spectra of the latitudinal groups. Nevertheless, one third of the floristic core is represented by species of forest groups. This is decisive in the character of the studied flora. The data obtained may be a confirmation of the concept on the relict nature of flora in insular pine forests due to the high representation of forest species in the core.

The obtained spectrum of latitudinal groups of protected species in the studied floras of pine forests and those included in the floristic core was also characterized by a high percentage of forest species determining the pine nature of the core.

In addition, the data obtained indicate

that for many steppe and forest-steppe regions, the pine forests may be the only habitats primarily for species from forest groups. For example, representatives of boreal flora: *Diphasiastrum complanatum* (L.) Holub., *Lycopodium annotinum* L., *L. clavatum* L., *Oxycoccus palustris* Pers., *Vaccinium myrtillus* L,. *V. vitis-idaea* L., *Chimaphila umbellata* (L.) W. Barton, *Orthilia secunda* (L.) House., *Pyrola chlorantha* Sw., *P. rotundifolia*, *Drosera rotundifolia*, *Hammarbia paludosa* (L.) O. Kuntze, *Neottianthe cucullata*, *Calla palustris*, *Maianthemum bifolium* (L.) F. W. Schmidt; boreonemoral *Botrychium virginianum* (L.) Sw. var. *europaeum* (Angstr.) Clausen; nemoral forest-steppe *Liparis loeselii* (L.) Rich.; nemoral *Salvia glutinosa* L. Examples of finding habitats on the territory of pine forests can also be species from other latitudinal groups: plurizonal *Hottonia palustris* L., steppe *Centaurea pineticola* Iljin.

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SPECIES COMPOSITION OF THE ICHTHYOFAUNA OF THE OGOSTA RIVER MIDDLE ZONE

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Abstract

Fish diversity is an important indicator of a healthy river ecosystem. The article presents a study examining the current state of fish composition of the Ogosta River, western Bulgaria. Data was obtained by electrofishing along the river's middle zone above the Ogosta Dam. The analysis recorded 12 fish species from 4 families. Most fishes are rheophilic. Four of it are specific for the North Bulgaria rivers and lower Danube basin. The fish fauna is strongly predominated by the *Squalius cephalus*.

Key words: fish fauna composition, Northwester Bulgaria, chub, Romanian barbel.

Introduction

The Ogosta River is the largest watercourse in the western part of Bulgaria. Its length is 144.1 km. The river springs below the Vrazha Glava peak (1935 m) in the Balkan Mountains and flows into the Danube River no far from the town of Oryahovo (Hristova 2012). Built in 1986, the Ogosta Dam divides the river into two parts.

Researchers studying the taxonomic composition and distribution of fish fauna in Bulgaria provide data about the fishes of the Ogosta River (Kovatcheff 1921, Morov 1931, Drensky 1951, Marinov 1986, Zhivkov and Karapetkova 1995, Peshev et al. 2003).

Maitland (1987) conducted an extensive study of freshwater fish of Europe and Britain, which was published in 1987 and which included data on fish from the Danube Basin. Data on the fishes in Ogosta River can also be found in Muus and Dahestrom (1991).

The study of the ichthyofauna of the Western Stara Planina Mountains Mihaylova (1970) includes the Ogosta River and its tributaries, above the town of Montana. The author gives the most complete description of the fish fauna in the middle zone of the river so far. In this study, 13 fish species from 3 families were identified.

Karapetkova and Dikov (1986) examined the composition, distribution and abundance of ichthyofauna of the Vit River, Danube River drainage. The authors have studied the entire length of the river. This allowed them to give an overall as-

sessment of the fish fauna in this water course and to cite 43 fishes found.

The revision of the data on the ichthyofauna of Europe of Kottelat and Freyhof (2007) allows specifying the systemic affiliation of the fishes in the Ogosta River.

Materials and Methods

This study was conducted along a stretch of the middle river zone, located above the Ogosta Dam. The studied part of the river course lies between 190 and 380 m a.s.l. (Fig. 1). Fieldwork was took place in the autumn of 2020 and 2021. For sampling via electrofishing a SAMUS 725G device with a 12 V accumulator and 5–65 Amps with an output of 640 W was used. Study sites were located along the middle zone of the Ogosta River, from the town of Chiprovtsi to the confluence of the Ogosta River with the Ogosta Dam (Table 1). The shallow depth of the river, less than 1.5 m, allowed the catch to be without a boat. Upstream, backpack electrofishing was carried out. Catch was performed according to the EN 14011:2004 instruction (Water quality Sampling of fish with electricity). Since the study focused on collecting material from *Squqlius cephalus* and *Barbus petenyi*, we used the method of partial, point, study (Belliard et al. 2008). This method is also suitable for studying the species composition of fish fauna. All available habitats of the river were examined in each transect.

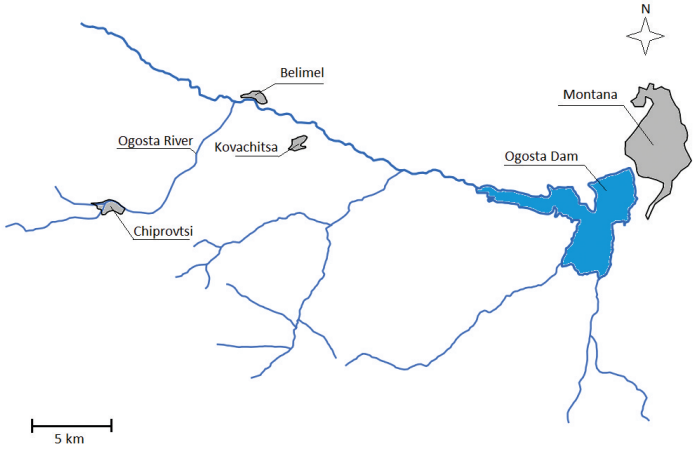

Fig. 1. Schematic map of Ogosta River middle zone, where the Romanian barbell was found.

Species' identification was carried out according to the methodological guidance of Berg (1948, 1949), Drensky (1951), Kottelat and Freyhof (2007).

Table 1. Sampling areas in the Ogosta River.

No	Location	Geographic coordinates		Altitude, m a.s.l.	Date of sampling
		N	E		
1	Near the confluence of the Ogosta River and the Ogosta Dam	43°23'49"	23°03'58"	195	19.11.2020 18.11.2021
2	Near the strawberry farm	43°24'20"	23°03'16"	221	22.10.2020
3	Near the village of Kovachitsa	43°25'20"	23°00'40"	250	19.11.2020
4	Near the village of Belimel	43°25'33"	22°57'30"	305	22.10.2020 18.11.2021
5	Near the town of Chiprovtsi	43°23'42"	22°55'26"	380	22.10.2020 18.11.2021

Results and Discussion

Twelve fishes, representative of 4 families were recorded (Table 2). This study did not aim to determine the abundance and the biomass of fish fauna, so only the specimens of the Chubs and the Romanian barbels were detained. However, by collecting material from these two species, using partial, points study, we also caught and identified other fish species present in the transects. The results clear-

Table 2. Fish fauna of the Ogosta River middle zone.

No	Family and species	Common name	Mihaylova (1970)	Our study (2022)	IUCN (2022)	Local fish fauna
	Family Salmonidae					
1	*Salmo trutta* (Linnaeus, 1758)	Brown trout	-	+	LC	IS
	Family Cyprinidae					
2	*Squalius cephalus* (Linnaeus, 1758)	Chub	+	+	LC	IS
3	*Barbus barbus* (Linnaeus, 1758)	Barbel	+	-	LC	IS
4	*Barbus petenyi* (Heckel. 1852)	Romanian barbel	+	+	LC	IS
5	*Gobio gobio* (Linnaeus, 1758)	Gudgeon	+	+	LC	IS
6	*Romanogomio kessleri* (Dybovski, 1862)	Kesler's gudgeon	+	-	LC	IS
7	*Alburnoides bipunctatus* (Bloch, 1782)	Schneider	+	+	-	IS
8	*Phoxinus phoxinus* (Linnaeus, 1758)	Eurasian minnow	+	+	LC	IS
9	*Alburnus alburnus* (Linnaeus, 1758)	Bleak	+	+	LC	IS
10	*Rutilus rutilus* (Linnaeus, 1758)	Roach	-	+	LC	IS
11	*Rhodeus amarus* (Bloch, 1782)	European bitterling	+	+	LC	IS
12	*Leuciscus aspius* (Linnaeus, 1758)	Asp	+	-	LC	IS
13	*Chonrostoma nasus* (Linnaeus, 1758)	European nase	+	-	LC	IS
	Family Nemachelidae					
14	*Barbatula barbatula* (Linnaeus, 1758)	Stone loach	-	+	LC	IS
	Family Cobitidae					
15	*Cobitis elongatoides* (Băcescu & Mayer, 1769)	Spined loach	+	+	LC	IS
16	*Sabanejewia balcanica* (Karaman, 1922)	Balkan spined loach	+	+	LC	IS

Note: LC – category Least Concern by IUCN (2022), IS – indigenous species (Berg 1948, 1949; Drensky 1951; Kottelat and Freyhof 2007).

ly showed that in almost all transects, the Chub strongly outnumbered all other fishes. In the transect 1 (Table 1) we caught only the Chub.

Although the explored river section falls within the middle river zone, or the so-called 'barbel zone', the number of Romanian barbel specimen was relatively small. Unlike the Ogosta River, this species is most abundant in the middle zone of the rivers of the Danube basin, such as: Vit (Karapetkova and Dikov 1986, Dikov et al. 1994), Palakaria, and Zlatna Panega (Dikov et al. 1994), Vâlsan (Truţă and Stancu 2016), Hășdate (Năstase and Tošić 2016). However, in a way similar to its abundance in the Ogosta River, a numerical dominance of the Chub in Valea Rocilor River has been reported (Năstase and Tošić 2016).

Lake Chub and Romanian barbel, Gudgeon is also numerous in the studied section of the river. This fish ranked third in species abundance amongst the fish fauna. Brown trout and Eurasian minnow were caught only in the upper part of the middle zone of the river, in vicinity of the town of Chiprovtsi.

The Sculpin (*Cottus gobio*), a species typical of the upper river zone of Northwestern Bulgaria have been recorded by Mihaylova (1970). The species also was found during the monitoring of the protected areas under NATURA 2000 (Ministry of environment and water of Bulgaria 2002, uunpublished data). Kolev (2000, unpublished data) also observed the Sculpin in the upper part of the river, above the town of Chiprovtsi. However, this species was not found in the current study of the river.

Mihaylova (1970) studied the ichthyofauna of the river's middle zone, prior to the construction of the Ogosta Dam. Data, collected by this study, now enable a comparative analysis. The present study found that the fish community is now characterised by fishes, typical of the river's lower zone, such as Roach. Probably this specie came here, escaping from the Ogosta Dam. The study also recorded the existence of Stone loach in the middle zone of the Ogosta River. This species is widely spread in Europe, but it was not reported by Mihaylova (1970). Apparently, after the construction of the Ogosta Dam, Common nase can no longer reach spawning areas, located in the upper zone of the river, above the dam. The studied stretch of the river is also not accessible nowadays for fishes, such as Asp and Barbel.

Conclusions

The results of the study indicate that the typical of this habitat ichthyofauna has been preserved. Nonetheless, the dam construction has interrupted fish migration from areas located below the dam to former spawning areas above it. Therefore, the dam has changed to a certain extent the ichthyofauna's composition in this part of the river.

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Authors' statement

The present study was conducted in accordance with the national legislation. Electrofishing was conducted with a permit 31/26.08.2020, issued by the Minister of the Ministry of Agriculture, Food and Forestry of Bulgaria. Most caught fish

were released back into the water. Only the quantity indicated in the electrofishing permit was detained.

Conflict of interest

The author declares no conflict of interest.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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