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## EFFECTS OF SURFACE FIRES ON SCOTS PINE FORESTS OF THE POLISKYI NATURE RESERVE

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### Abstract

The study presents the assessment of fire effect produced by surface forest fires on the herbal plants, the possibility of natural forest regeneration and Scots pine stands of the Poliskyi Nature Reserve. Five-year succession of forest herbs following the fire of 2009 was evaluated by analyzing its species' composition, coenotic structure, similarity, constancy and dominance of species in the burned area and comparison with similar unburned forest. The consequences for herbal plants mostly depend on the type and intensity of a wildfire. The response of the herbal layer to fire factor varies from small reversible short-term changes to degradation or even complete distinction. Surface fires stimulate emergence of Scots pine regeneration. On stand level, fires cause the deterioration of trees' health and the reduction of stand growth. The mathematical model for severity of fire and tree health was developed.

**Key words:** fire severity, natural regeneration, post-fire succession, species diversity, species similarity, surface fire.

### Introduction

Global climate change results in growth of intensity and areas of wildfires globally that, in turn, are drivers of significant changes in forest ecosystems and other types of landscapes (Pyne 1997, 2010; Goldammer et al. 2013). Nowadays there is a clear trend of wildfires increase that often becomes catastrophic in Australia, Greece, Portugal, Russia, Spain, USA, and other countries (Goldammer et al.

2013, Heyerdahl et al. 2014, Axelson et al. 2019, Lynn 2019, Roper 2020). Ukraine is no exception, in the first six months (January-June) 2020 in different landscapes of the country there were more than 1 thousand wildfires on a total area of more than 110,000 ha, of which 67,000 ha are in the Chernobyl Exclusion Zone (Zibitsev and Myroniuk 2020). Protected areas are most vulnerable to fires in Ukraine. During the last six years 27 % of the burned areas in the northern region of Polissya have been

nature reserves, the total burned area accounting for 87,500 ha (Gumeniuk 2015; Zibtsev and Myroniuk 2015, 2020). Under conditions of fire risks and burned areas growth it is important to have reliable data on the impact of fires on such important components as herbal plans, stand and regeneration.

Historically fires have been one of the important factors that determined biodiversity, composition and age structure of stands, vegetation dynamics and the biological cycles in forests (Goldammer and Furyaev 1996; Pyne 1997, 2010). Studies of post-fire dynamic in other regions of the world show that it is determined by the type of wildfires and their intensity (Furiaev et al. 2005, Kane et al. 2012, Lauvaux et al. 2015, Meng et al. 2015). After crown and peat fires, pine stands are completely destroyed as a result of the damage to their crowns and root systems (Hys 1973, Valendik et al. 2013). Post-fire dieback of trees after surface fires can vary essentially (5–100 %) which depends on fire dynamics and which in turn poses difficulties for the prediction of trees' survival rate. The trees' dieback after surface fires depends on the characteristics of forest components, for example, forest structure, age, height and diameter of trees, edaphic conditions and seasonal dynamics of wildfires (Usenia 2000, Furiaev et al. 2005, Hordei 2007). The wildfires in fire dependent ecosystems determine the spatial structure of the stands and changes on the landscape level, including the expansion of Scots pine (Hille 2006, Sokolov et al. 2011, McIvler et al. 2012). Dendrochronological studies of ancient trees in the United States (Stocks et al. 2001) show that the recurrence of large fires can range from tens to hundreds of years.

Controlled fire can be used as a tool

for shaping stand structure and dynamics close to a natural way within approaching sustainable forest management targets (Goldammer et al. 2013, Battipaglia et al. 2014, Douglas et al. 2015). Prescribed fires, widely used in the world, allow the stimulation of natural forest regeneration in order to obtain productive and sustainable stands in the future. In a similar study, Sannikova (1977, 1978) notes increased productivity of Scots pine seeds after surface fires and favourable conditions for the emergence of a new forest generation.

The impact of wildfires on the herbal plants underneath forest cover has been studied for more than a century, but mainly outside Ukraine (Clements 1910, Zhytlukhyna and Shubenko 2002). Perev-oznykova et al. (2005), Kovaleva and Ivanova (2013) found out that surface fires of low- to medium-intensity do not cause significant changes in the phytocoenosis, however, high-intensity fires can lead to prolonged succession of forest herbs. Another paper (Rabotnov 1978, Sakhnevych 2005) showed that in wet edatopes the herbs-moss cover recovers faster (3–5 years) than in dry ones (10–15 years), which significantly reduces the time of post-fire transformation of vegetation. Summarizing, it is necessary to state that the impact of surface fires on the forest dynamics in Ukraine has not been studied in detail and the existing studies (Gumeniuk 2013, 2015; Gumeniuk et al. 2015, Voron et al. 2017) are fragmented.

Therefore, this paper aims to study the effect of surface fires on the components of Scots pine forests such as forest ground vegetation, natural forest regeneration, and structural changes in the affected stands. The results will provide better understanding of the pyroecological properties of pine forests.



## Material and Methods

### Study area

The research was carried out in the Scots pine stands of Poliskyi Nature Reserve located in Zhytomyr region of Ukraine (North of the country), affected by different intensity surface fires in May 2009 (Fig. 1). The total area of the wildfires is over 1000 ha.

The experimental data were collected on 32 plots, including 18 plots in burned forest and 14 plots in unburned territories. The study is based on the approach of comparative ecology (Pogrebnyak 1993), under which the main parameters of similar by structure burned and unburned (control) forest were compared. The plots of burned forest were divided into three groups based on the intensity of the surface fires and the scorch height ( $S_{\text{height}}$ ) on a tree trunk (Cabinet of Ministers of

Ukraine 1995): low ( $S_{\text{height}} < 0.5$  m), medium ( $S_{\text{height}} 0.5\text{--}1.5$  m) and high ( $S_{\text{height}} > 1.5$  m).

### Input datasets

#### Dataset to assess the surface fires effect on the forest ground vegetation

The method described by Chasoven-na (1975) was used in the framework of the research. Twenty  $1 \times 1$  m subplots on each of 32 plots were selected. The species' composition, their projective cover, abundance and type (herbs-shrub, moss, lichens) were studied on both burned and unburned plots. The Myrkyn and Rozenberh (1978) asymmetric unequal distance scale was used to establish the abundance of plant species: + (up to 1 %), 1 (1–5 %), 2 (5–15 %), 3 (15–25 %), 4 (25–50 %), 5 (50–100 %). The indicators of dominance, constancy and species similarity were calculated.



Fig. 1. Study area.

The constancy of species was determined as a percentage, namely as the ratio of the number of the sites where these species occur, to the total number. The species' dominance is defined as the ratio of its projective cover sum to the site number on which this species was found (Chasovenna 1975).

The Jaccard similarity index was calculated by the formula:

$$K_j = \frac{c}{a + b + c}, \quad (1)$$

where:

$K_j$  is the Jaccard similarity index;

$a$  is the number of species in the first site ( $1 \times 1$  m);

$b$  is the number of species in the second site ( $1 \times 1$  m);

$c$  is the number of species common to the first and second sites.

Soil conditions were determined according to the forest types classification of Alexeev-Pogrebnyak (Pogrebnyak 1955) generally used in Ukraine. The soil conditions were analyzed according to two factors: soil fertility (A–D) and soil moisture (0–5). The degree of soil fertility and moisture was established based on the number of species present in a site. The coenotic structure of the herbal layer was studied based on Belhard's (1955) system of life forms (ecomorphs), which includes the following groups: Sil – forest species, St – steppe species, Pr – meadow species, Pal – wetland species, Ru – invasive species. The nomenclature of forest herbs and their taxonomy was determined using the international plant database (The Plant List ... 2013) and the Determinants of plants of Ukraine (Barbarich et al. 1965).

### **Dataset to assess the surface fires effect on the natural forest regeneration**

The natural forest regeneration was studied according to Pobedinsky's (1966) method on  $10 \times 2 \times 2$  m subplots (total 320 micro plots). Age, height and the number of trees undergoing natural regeneration were measured on both burned and unburned parts. The undergrowth age was determined by counting the whorls. Two years was added to the undergrowth to allow for the time between seedling germination and the evidence of branch whorls on the trunk. The height of the undergrowth was divided into groups: up to 10 cm, 11–25 cm, 26–50 cm, 51–100 cm, 101–150 cm; 151–200 cm; > 200 cm.

The success of natural forest regeneration and the Scots pine constancy were determined as the ratio of the number of sites where this species occurs to the total number of sites. Regeneration success was measured according to Gorshenin scale (Gorshenin and Shvidenko 1977).

The vital energy of seedlings and undergrowth was classified into the following categories: healthy, weakened, drying out and dried. The viability of coenopopulation's regeneration was determined by the ratio of every category. The viability index of coenopopulation was calculated according to Alekseev (Ivanova et al. 2002):

$$L = \frac{100n_1 + 70n_2 + n_3}{N}, \quad (2)$$

where:

$L$  is the relative viability of the coenopopulation;

$n_1$ ,  $n_2$ ,  $n_3$  are the numbers of healthy, weakened and drying out individuals on

the temporary sample plots (TSPs) or per ha;

$N$  is total number of undergrowth individuals, including dried, on the TSPs or per one ha.

At the value of  $L = 100-80\%$ , the viability of the coenopopulation of the undergrowth is assessed as healthy, at  $79-50\%$  the population is considered weakened, at  $49-20\%$  it is severely weakened and less than  $20\%$  the coenopopulation is completely destroyed.

### Dataset to assess impact of surface fires on Scots pine stands

The plots were selected based on Anuchyn's field methodology (Anuchyn 1982). The classification of burned Scots pine stands was carried out according to Sofronov and Volokytyna (2007). The trees on the TSPs were counted, standard

tree parameters, namely, height, diameter, sum of cross-sectional areas, wood stock, minimum and maximum scorch height on tree trunks were determined. The assessment post-fire condition of stands was carried out on a scale of tree condition categories according to 'Sanitary rules in the forests of Ukraine' (Cabinet of Ministers of Ukraine 1995). According to the rules, trees are evaluated by the shape of their crown, the presence and colour of needles in six categories: I – healthy, II – weakened, III – very weakened, IV – drying out, V – new dead wood, and VI – old dead wood. Crown defoliation was also assessed by the ICP forests method (ICP Forests 2010). The studies were carried out on 32 TSPs, out of which 18 TSPs were burned forest and 14 TSPs were unburned forest. Forestry and statistical characteristics of Scots pine stands on TSPs are given in Table 1.

**Table 1. Descriptive statistics of Scots pine stands' parameters.**

| Taxational parameters     | <i>n</i> | <i>M</i> | <i>M<sub>e</sub></i> | min  | max  | σ    | ν   | <i>As</i> | <i>Es</i> |
|---------------------------|----------|----------|----------------------|------|------|------|-----|-----------|-----------|
| Burned forest             |          |          |                      |      |      |      |     |           |           |
| A                         | 18       | 50       | 49                   | 20   | 125  | 26   | 51  | 1.46      | 3.14      |
| H                         |          | 18.2     | 18.5                 | 6    | 30   | 6.7  | 37  | -0.11     | -0.15     |
| DBH                       |          | 16.4     | 15.2                 | 5    | 41   | 8.5  | 52  | 1.43      | 3.40      |
| P                         |          | 0.66     | 0.65                 | 0.40 | 0.97 | 0.17 | 26  | 0.26      | -0.81     |
| <i>M</i>                  |          | 200      | 212                  | 22.9 | 449  | 118  | 59  | 0.48      | -0.10     |
| <i>Hsr</i> <sub>max</sub> |          | 1.43     | 0.96                 | 0.43 | 4.67 | 1.11 | 78  | 1.68      | 2.96      |
| <i>Hsr</i> <sub>min</sub> |          | 1.09     | 0.40                 | 0.24 | 4.16 | 1.20 | 110 | 1.97      | 3.99      |
| Unburned forest           |          |          |                      |      |      |      |     |           |           |
| A                         | 14       | 48       | 37                   | 20   | 125  | 29   | 59  | 1.60      | 2.83      |
| H                         |          | 17.3     | 16.2                 | 6    | 29   | 7.4  | 43  | 0.14      | -0.92     |
| DBH                       |          | 15.2     | 14.1                 | 5    | 35   | 8.2  | 54  | 1.27      | 1.70      |
| P                         |          | 0.65     | 0.59                 | 0.41 | 0.91 | 0.17 | 27  | 0.43      | -1.27     |
| <i>M</i>                  |          | 184      | 143                  | 23.3 | 391  | 120  | 65  | 0.53      | -0.68     |

Note: A – age of the stand, years; H – average height, m; DBH – diameter of tree at breast height (1.3 m), cm; P – relative density; M – stock volume, m<sup>3</sup>/ha;  $Hsr_{max}$  – maximum scorch height of the tree trunk, m;  $Hsr_{min}$  – minimum scorch height of the tree trunk, m;  $n$  – number of temporary sample plots;  $M$  – arithmetic mean;  $M_e$  – median;  $\sigma$  – standard deviation;  $\nu$  – variation coefficient; As – asymmetry coefficient; Es – excess coefficient.

Mathematical and statistical processing of the dataset was performed using Microsoft Excel and Statistica.

## Results

### Surface fires' effect on the forest ground vegetation

The analysis of the forest ground vegetation and its floristic composition 4 years after the fire in the Poliskyi Nature Reserve revealed that after a low-intensity surface fire ( $S_{\text{height}} < 0.5$  m), the abundance and species composition of both herbs and moss layers did not change ( $p$ -value  $< 0.05$ ), whereas after a surface fire of medium- ( $S_{\text{height}} 0.5$ – $1.5$  m) and high- ( $S_{\text{height}} > 1.5$  m) intensity there were significant changes in the floristic composition and structure of the forest ground vegetation. After the fire, the number of plant species in post-fire TSPs increased by 49 %. 39 species were found in the burned TSPs, 37 of which were vascular plants and 2 were species of mosses, and 19 species of plants belonging to five families appeared because of the fire – Asteraceae, Polygonaceae, Onagraceae, Scrophulariaceae and Rosaceae. In particular, there was a 93 % increase in projective coverage of herbs-shrub layer and a 95 % decrease in coverage of the moss-lichen layer. The following species of vascular plants appeared in the TSPs affected by medium and high intensity fires: *Chamaerion angustifolium* L., *Erigeron canadensis* L., *Rumex acetosella* L., *Agrostis tenuis* Sibth., *Calamagrostis epigeios* (L.) Roth., *Hieracium pilosella* L., *Solidago virgaurea* L., *Gnaphalium sylvaticum* L., *Taraxacum officinale* Webb. ex Wigg., *Echinochloa crusgalli* (L.) Beauv., *Helichrysum arenarium* (L.) Mo-

ench., which are dominant. The following species of mosses, namely *Dicranum polysetum* Swartz., *Polytrichum commune* Hedw. and lichen *Cladonia rangiferina* (L.) Web. did not recover. However, new species of mosses from Polytrichaceae – *Polytrichum piliferum* Hedw. family and *Polytrichum juniperinum* Hedw. emerged.

Dominant and co-dominant species of the forest ground vegetation on post-fire TSPs are characterized by high constancy (50–67 %) and low dominance (less than 25 %). In species which constancy is equal to or exceeds 50 %, the projective coverage varies between 5–9 %. On the unburned TSPs, the forest ground vegetation species with high constancy overwhelmingly dominant, which is typical of undisturbed plant communities (Fig. 2).

The analysis of coenotic structure of forest ground vegetation in the burned and unburned phytocenoses shows that its complete regeneration occurs only after a low-intensity surface fire ( $p$ -value  $< 0.05$ ). A medium-intensity surface fire decreases the participation of forest species (Sil) to 35 %, as well as the appearance of the meadow (Pr – 28 %) and invasive (Ru – 12 %) species. A high-intensity surface fire reduces the participation of forest species to 56 %, and the share of invasive species is about 19 %. Thus, the intensity of the fire is a key factor that determines the character of changes in the structure of the coenosis of the forest ground vegetation (Fig. 3).

To assess qualitative changes in species diversity in post-fire and unburned phytocenoses, the Jaccard floristic similarity index was used. The calculations showed that after a low-intensity surface fire there is a complete species regeneration, as  $K_j = 1.0$ . On the contrary, after a

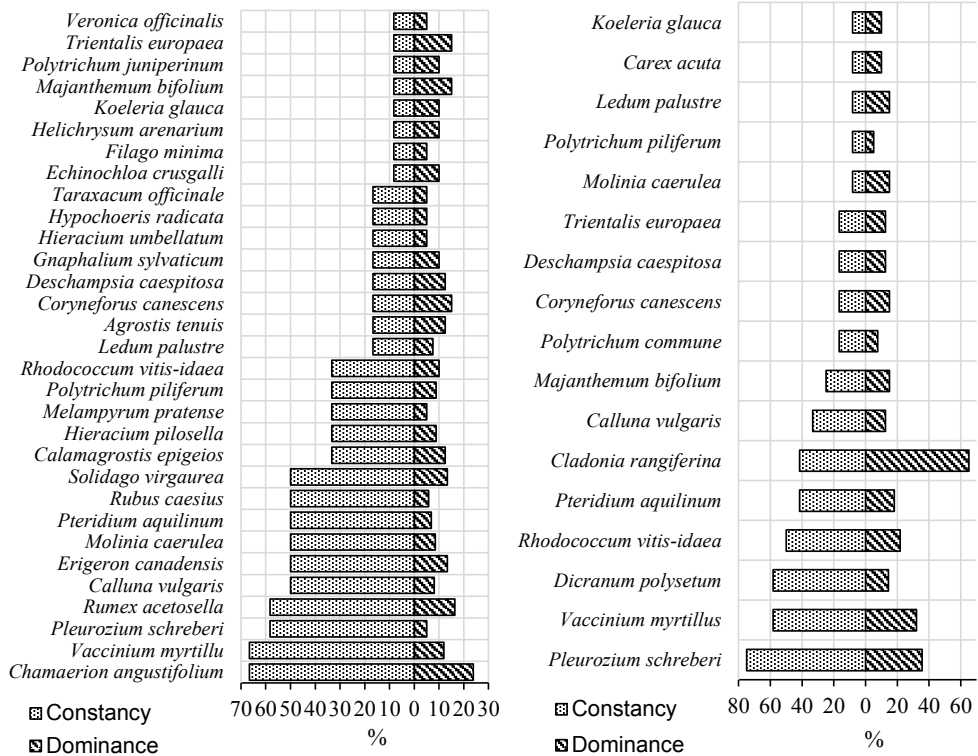


Fig. 2. Distribution of species on the burned (left) and in unburned phytocoenosis (right).

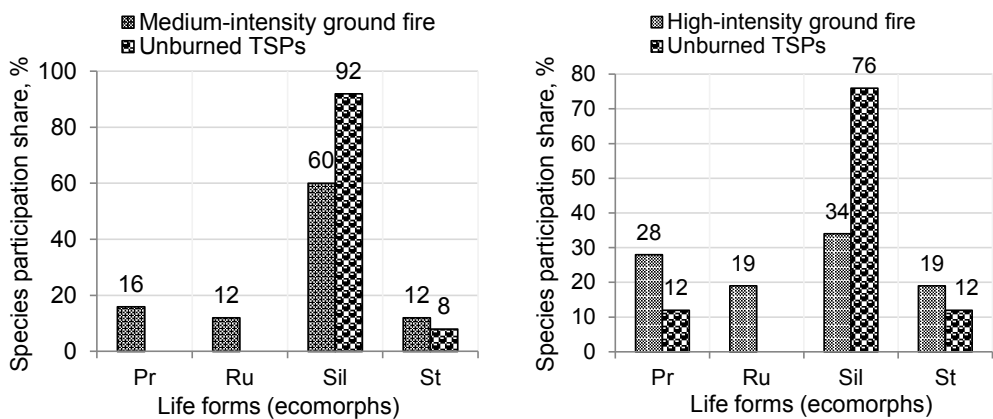


Fig. 3. Coenotic structure of forest ground vegetation after a surface fire of medium- (left) and high- (right) intensity on unburned TSPs.

fire of medium-intensity the value of the index ranged from 0.11–0.43, and after a

high-intensity – 0.13–0.15. The statistical analysis of the experimental data allowed



to establish a reliable inverse correlation between the floristic similarity index and the type of fire ( $r_s = -0.69$ ). Thus, an increase in the intensity of the surface fire leads to a decrease in the similarity of the forest ground vegetation on TSPs between the burned and unburned plant communities.

### Effect on the natural forest regeneration

The state of a post-fire forest is an important assessment factor for the success of its future natural regeneration. The study shows that after low- and medium-intensity surface fires the most successful forest regeneration occurs during the first and the second year when up to 90 % of trees' self-seeding appears. In all types of post-fire edaphic conditions satisfactory natural regeneration of pine and birch, and aspen in wet hygrotape was observed. The total amount of self-seeding and undergrowth on the burned TSPs is 78 % higher than

on the unburned ones. On both TSPs, Scots pine natural regeneration is higher (80 %) compared to other tree species (Fig. 4).

The constancy of Scots pine natural regeneration on TSPs after a surface fire of medium- and high-intensity is higher than the unburned stands and ranges from 75 to 100 %. Natural pine regeneration on the burned TSPs is uniform. The deciduous tree species constancy in all types of edaphic conditions is much lower (5–32 %), and these tree species are located in small groups. Pine regeneration on the burned stands during the first two years following a fire has a marked differentiation in a tree's height. The average height of the majority (61 %) of natural regeneration is 0.26–0.5 m, which allows it to compete with herbs vegetation.

To establish the viability of Scots pine natural regeneration, classification into viability categories was carried out. Healthy one-year old pine regeneration on burned TSPs is 36 %, two-year old is 53 %, three-

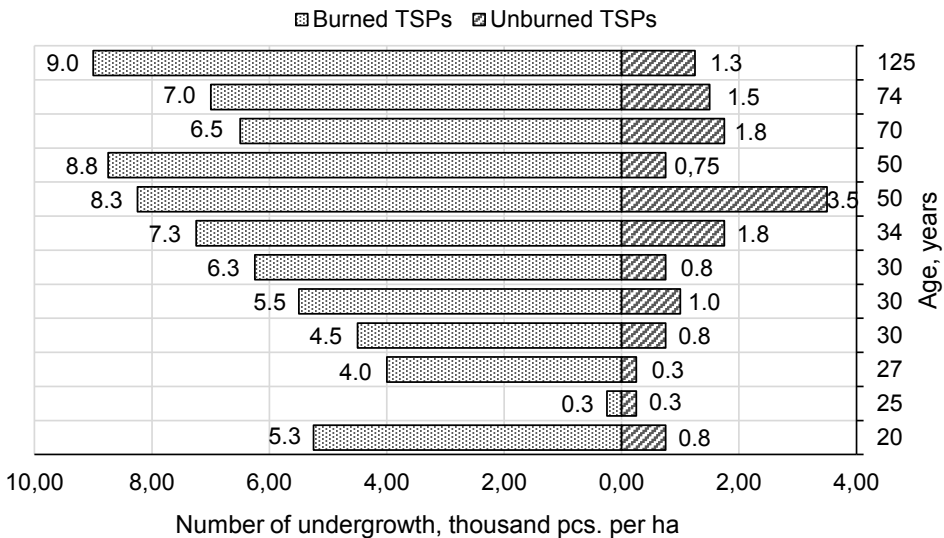


Fig. 4. Amount of Scots pine natural regeneration.

year old is 57 % and four-year old is 67 %. On the unburned TSPs, the number of healthy pine regeneration increases from the age of eight and above (81–100%). On the unburned TSPs the number of weakened pine regeneration decreases with age on starting from two years and above from 50 % to 22 %. Based on the experimental dataset statistically significant ( $p$ -value < 0.05) correlations between the viability of the natural pine regeneration and its height ( $r_s = 0.78$ ), age ( $r_s = 0.71$ ), and edaphic conditions ( $r_s = 0.68$ ) were established.

### Effect on Scots pine stands

The analysis of the collected data using descriptive statistics revealed significant variability of the obtained values in diameter (DBH), maximum ( $Hsr_{max}$ ), minimum ( $Hsr_{min}$ ), and average ( $Hsr_{avg}$ ) scorch height on the tree trunk (Table 2). The absence of normal distribution of the studied parameters (at  $p$ -value = 0.05 or  $p$ -value for every statistic) based on Shapiro-Wilk ( $W$ ) and Kolmogorov-Smirnov ( $\lambda$ ) tests were confirmed. Therefore, it is necessary to use non-parametric statistical criteria.

**Table 2. Main statistical indicators of trees in burned TSPs.**

| Indicators                         | <i>n</i> | <i>M</i> | <i>M<sub>a</sub></i> | <i>min</i> | <i>max</i> | <i>v</i> | <i>As</i> | <i>Es</i> |
|------------------------------------|----------|----------|----------------------|------------|------------|----------|-----------|-----------|
| DBH                                | 3506     | 15.9     | 14.3                 | 1          | 71         | 63       | 1.28      | 2.47      |
| <i>Hsr<sub>max</sub></i>           | 3477     | 135.5    | 95.0                 | 1          | 650        | 88       | 1.81      | 3.09      |
| <i>Hsr<sub>min</sub></i>           | 1974     | 106.8    | 43.0                 | 1          | 575        | 122      | 1.69      | 1.90      |
| <i>Hsr<sub>avg</sub></i>           | 1974     | 141.7    | 85.0                 | 1          | 600        | 91       | 1.51      | 1.48      |
| Category of tree health conditions | 3506     | 3.1      | 3.0                  | 1          | 6          | 41       | 0.59      | -0.62     |
| Crown defoliation, %               | 3506     | 51.7     | 40                   | 5          | 100        | 60       | 0.50      | -1.26     |

The nonparametric correlation analysis indicates a naturally close relationship between the category of tree health conditions and crown defoliation ( $r_s = 0.95$ ) (Table 3). As the assessment of tree viability in forestry practice is carried out according to the scale of the category of tree health conditions, further studies

were carried out for this indicator. There is a moderate, inverse correlation between the category of tree health conditions and the tree's diameter ( $r_s = -0.56$ ).  $Hsr_{min}$  has the closest connection with the category of tree health conditions ( $r_s = 0.54$ ). Thus, this indicator is better suited for predicting tree loss after surface forest fires.

**Table 3. The Spearman's rank correlation coefficients between trees' indicators in burned TSPs ( $r_s$  critical is < 0.01 at  $p = 0.05$ ).**

| Indicators                         | DBH          | <i>Hsr<sub>max</sub></i> | <i>Hsr<sub>min</sub></i> | <i>Hsr<sub>avg</sub></i> | Category of tree health conditions | Crown defoliation, % |
|------------------------------------|--------------|--------------------------|--------------------------|--------------------------|------------------------------------|----------------------|
| DBH                                | 1.00         | –                        | –                        | –                        | –                                  | –                    |
| <i>Hsr<sub>max</sub></i>           | <b>0.07</b>  | 1.00                     | –                        | –                        | –                                  | –                    |
| <i>Hsr<sub>min</sub></i>           | <b>-0.28</b> | <b>0.78</b>              | 1.00                     | –                        | –                                  | –                    |
| <i>Hsr<sub>avg</sub></i>           | <b>-0.16</b> | <b>0.98</b>              | <b>0.88</b>              | 1.00                     | –                                  | –                    |
| Category of tree health conditions | <b>-0.56</b> | <b>0.31</b>              | <b>0.54</b>              | <b>0.52</b>              | 1.00                               | –                    |
| Crown defoliation, %               | <b>-0.54</b> | <b>0.34</b>              | <b>0.55</b>              | <b>0.52</b>              | <b>0.95</b>                        | 1.00                 |

Note: here and further in the tables, statistically significant criteria are marked in bold.



Graphical interpretation of the dependency of tree health conditions' category on the tree's diameter and the minimum scorch height allows detecting significant deviations from the approximating curves (Fig. 5). Within the first category of tree health condition, the deviations of these indicators from the trend line are significant. Therefore, mathematical dependencies have been developed to establish the distribution of trees with certain health conditions according to DBH and  $Hsr_{min}$ . The following groups of categories were distinguished: I–II – no signs of weakening, III – significant lag in growth and crown development, IV–VI – drying out, and deadwood.

Analytical dependencies of the share of trees in the selected groups of the categories of THC on their DBH and  $Hsr_{min}$  are shown in formulas (3–5).

where:  $p_{I-II}$ ,  $p_{III}$ , and  $p_{IV-VI}$  are the share of trees in groups of categories of THC, %.

Power, exponential and logistic dependencies are used in the structure of formulas (3–5). Equation (4) shows the lowest percentage of oscillation of the independent variable and is characterized by the largest residuals.

Taking into account the equations 3 and 5, we created normative reference tables to estimate the percentage of trees in the selected groups of I–II and IV–VI categories of health conditions taking their DBH and  $Hsr_{min}$  as indicators. The table shows that four years after the fire for 16+ cm DBH and  $Hsr_{min}$  of 1.0 m the fall of the trees in the pine stands varies between 3–26 %. Thus, it is not critical for the further development of the stand.

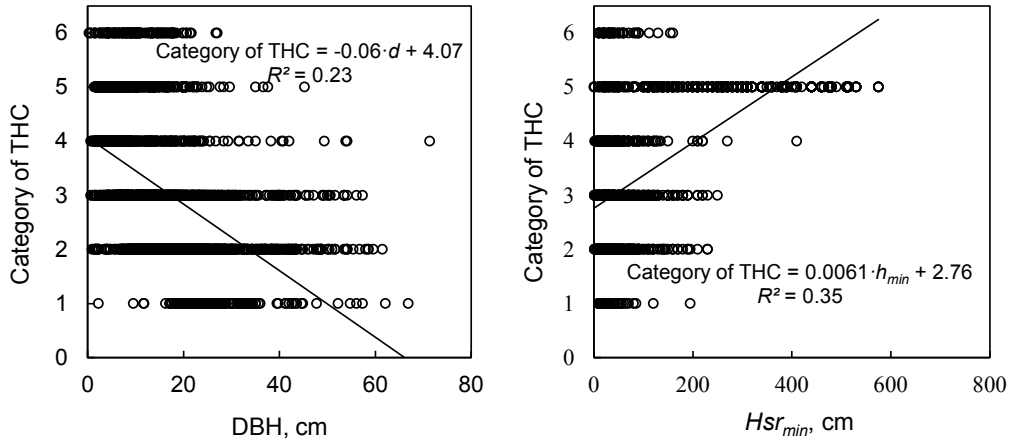


Fig. 5. Dependencies of the categories of tree health condition (THC) on DBH (left) and  $Hsr_{min}$  (right).

$$p_{I-II} = 1.061 \cdot \left( \frac{100}{1 + 10^{2.12 - 0.124 \cdot DBH}} \right) \cdot \exp(-0.508 \cdot Hsr_{min}), R^2 = 0.78, \quad (3)$$

$$p_{III} = DBH^{2.358} \cdot \exp(-0.081 \cdot DBH) \cdot Hsr_{min}^{2.048} \cdot \exp(-1.648 \cdot DBH), R^2 = 0.57 \quad (4)$$

$$p_{IV-VI} = 100 - 2.674 \cdot \left( \frac{100}{1 + 10^{1.21 - 0.116 \cdot DBH}} \right) \cdot \exp(-1.079 \cdot Hsr_{min}) \cdot Hsr_{min}^{0.683}, R^2 = 0.74, \quad (5)$$

## Discussion

### Effect on the forest ground cover

The study shows that impact of forest fire on the species composition and projective cover of forest ground vegetation is determined by its type and intensity. As we expected, the moss-lichen layer in the Scots pine phytocoenosis is the most sensitive one to surface fires. In the papers of Perevoznykova (2005), Kovaleva and Ivanova (2013), a similar replacement of mosses and lichens plant associations in the post-fire pine stands of the Middle Taiga subzone is observed. In particular, after surface fires of low- and medium-intensity the moss-lichen layer experienced a decrease of species diversity, and after high-intensity fires it faced total extinction. According to the authors, high-intensity surface fires caused the appearance of micro-groups with the dominating mosses *Polytrichum piliferum* Hedw. and *Polytrichum juniperinum* Hedw. on the burned pines. Their appearance in our research was also noted, however, they are not dominant, and the micro-groups are fragmentary.

Regeneration of herbs-shrub layer species composition and structure directly depends on the fire intensity and the burning depths of forest litter. In the paper of Kovaleva and Ivanova (2013) it is noted that at the initial stage of secondary post-fire succession after medium-intensity fire there is a decrease in the projective cover of the dominant species of shrubs *Vaccinium vitis-idaea* L. and *Vaccinium myrtillus* L. and their phytomass. The authors (Ivanova et al. 2002, Perevoznykova et al. 2005) argue that high-intensity surface fires lead to the changes in the horizontal structure of the ground cover which is dominated by micro-groups with a predominance of Poaceae and Fabaceae, especially *Chamer-*

*ion angustifolium* (L.) Scop. and *Calamagrostis epigejos* (L.) Roth. The results of similar studies in Belarus (Parfenov et al. 1985) show that after surface fires of medium- and high-intensity in a burned pine forest with relatively poor transitional soils more abundant and diverse species composition of the live ground cover is formed. This paper also notes that in pine stands on extremely poor soils the process of herbs' regeneration takes decades and goes through a series of successive stages, which are characterized by the predominance of different species of Poaceae, mosses, and lichens. Despite the fact that the abovementioned study areas are situated in different locations, it should be noted that they are still in the same climatic zone (temperate), and the course of post-fire successions of the forest ground cover is similar to our data for Northern Ukraine.

### Effect on the natural forest regeneration

A set of favourable conditions is important for the regeneration of natural Scots pines after forest fires (Buzykyn and Popova 1978, Usenia 2000). The emergence and continuity of natural pine regeneration depends on surface fire intensity, combustion of the forest floor layer (Furiaev et al. 2005, Perevoznykova et al. 2005), age, edaphic conditions, seed availability, seed years (Kalynyn 2002, Hille 2006, Meng et al. 2015), and the suppression of herbs-shrub vegetation (Ivanova et al. 2002).

In this paper, similar dependencies are observed, in particular, it was found out that 4 years after the surface fires on TSPs with significant (45–100 %) combustion of the forest floor layer there is a successful (7.7–9.5 thousand pcs. per ha) natural pine regeneration. It was established that these years were not seed ones. The scale



At  $Hsr_{min}$  up to 1.0 m and  $DBH \geq 28$  cm, the percentage of drying trees is similar to the one possessing no signs of drying, i.e. low-intensity surface fire have a negligible impact on the pine stands. Similar results were obtained in the researches in Northern Ukraine (Voron et al. 2017) and South Belarus (Usenia 2000).

In the paper of Usenia (2000), the prediction of tree losses share is underestimated by 42–68 %. This is explained by the author in a mathematical model in which the average stand values are used as a DBH, height scorch, and tree losses share, which is characterized by greater variability and lower accuracy. In our study, forecasting is based on the values of each tree in the pine stand. Comparing the results of our research with the abovementioned ones, we can state that the dynamics of the categories in the burned forest can vary, which complicates the prediction of post-fire effects. Thus, the study of the effects of varying intensity surface fires on Scots pine stands has great practical and economic importance and requires further research.

## Conclusions

Wildfires remain a constant and significant environmental factor influencing the formation and development of Scots pine forests in the Poliskyi nature reserve. The reaction of forest ground cover to the surface fire is manifested differently and can be represented by both small short-term changes, and the degradation and elimination of plant communities, which results in the emergence of secondary ecological successions. In particular, low-intensity surface fires ( $S_{height} < 0.5$  m) do not change the species composition, the pro-

jective cover, and the coenotic structure of the forest ground cover. At the same time the surface fires of increased intensity cause succession in the herbs-shrub and moss-lichen tiers with typical forest species being replaced by invasive ones. Therefore, the duration and the character of secondary ecological successions and the recovery of the unburned phytocoenosis directly depend on the type and intensity of the surface fire.

Surface fires are stimulating the emergence and development of the natural Scots pine regeneration. Natural regeneration in a burned forest is 78–81 % higher than in an unburned one. The most successful natural regeneration occurs during the first two years after a low- and medium-intensity surface fire in medium stand density with the trees aged 50–70. The undergrowth of aspen and birch is scarcely represented, whereas Scots pines prevail. Low competition of seedlings with the herbs cover during the first year after the fire helps to preserve more natural pine regeneration. The share of healthy pine regeneration grows from 36 to 67 % with the increased age and height of the regeneration.

Low- and medium-intensity surface fires do not cause losses or critical changes to the structure of pine stands with an average  $DBH \geq 16$  cm. In general, these types of surface fire do not cause statistical differences in the distribution of trees by DBH in both burned and unburned forest. The representatives of Environmental Resources Management may in some cases anticipate the use of the positive role of surface fires in the fire management system. Thus, the study of surface fire effects on the components of forest ecosystems is relevant and requires further research.

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## LOGGING EQUIPMENT IN BULGARIA – CURRENT STATE AND FUTURE PROSPECTIVE

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### Abstract

The results from survey of forestry equipment in 2019 show 1371 units in Bulgarian logging industry. Expectedly, the largest share is in the farm tractors adapted for timber skidding. The rate of cable skidders is more than three times lower. Cable skidders and yarders should prevail, given that most of the forests in Bulgaria are situated on steep terrains with complex forms. A fundamental problem in logging industry in Bulgaria is the huge predominance of old equipment (in operation over 10 years), and their lower production rates and higher maintenance and repair costs. A major renewal of the logging machinery is expected, due to its physical wear and lack of manpower in the logging industry as well as in the industry as a whole, which is becoming increasingly tangible. The retrofit must be done with new high-performance equipment that, while more expensive, will ensure efficiency and lower unit costs. Facilitating access to EU programs will encourage the purchase of modern logging equipment. The density of the forest road network is insufficient and investment is needed to build new forest roads to reduce the average skidding distance and unit costs, and to rise the productivity of primary transport. Increasing the maximum allowable felling intensity will lead to the possibility of mechanized logging. The increasing the intensity of cutting will expand the use of harvesters and forwarders in coniferous forests. Another driver for the rapid introduction of new logging equipment are the long-term contracts of companies for better predictability and sustainability of investments. Barriers are the oncoming recession in the demand for timber and the supply of large volumes of cheap timber damaged by natural disasters from other European countries.

**Key words:** forwarders, harvesters, mechanization improvement, skidders, yarders, years in operation.

### Introduction

In Bulgaria forests account for about 4.5 million hectares, corresponding to 37 % of the land area and are mainly located in hilly and mountainous areas (EFA 2020). Over the last 5 years, an average of about 8.0–8.3 million cubic meters timber (over bark) per year has been produced, and

about 6.6–7.0 million cubic meters timber (under bark) per year (EFA 2019). The mentioned volumes are significantly under annual increment of Bulgarian forests of 16.7 million cubic meters (over bark). Deciduous tree species predominate – 70.5 % from forest territory, but their share from total growing stock is lower – 55.5 %.

Bulgarian forest territories are characterized by steep terrains, small dimensions of most cutting areas, and predomination of deciduous timber. The traditional harvesting system in Bulgaria is motor-manual tree felling and processing and extraction mostly by skidder, yarder, and animal force, which corresponding to an early stage of mechanization. Traditional extraction methods are based mainly on adapted agricultural tractors with related logging equipment such as winches, as well as wheel cable skidders.

In the 20th century large areas with coniferous plantations were created at very low altitudes. While coniferous plantations have usually served their primary purpose of helping to control erosion, numerous waves of mortality have been observed in recent decades due to the combined negative effects of drought, aging and lack of opportunities for regular thinnings (Milev et al. 2017, MoEW 2019).

From an economic point of view, the total output at basic prices of forestry and logging in 2017 in Bulgaria is approximately EUR 707 million, which is an increase of 2.7 times compared to EUR 266 million in 2005. However, persons employed of forestry and logging in 2017 are approximately 12000 and have decreased by 1300 employees (9.8 %) compared to 2005 (Eurostat statistics explained 2020).

The beginning of the development of the mechanized timber extraction is considered to be the operation of the first two Wyssen sledge yarders in 1949. During the period 1958–1961 between 85 and 97 % of the mechanized timber extraction is carried out by cable yarders and their number reaches 248 units (Vasilev 2013). Several models of cable yarders have been developed and produced in Bulgaria. Currently, only about 5 % of the timber extraction in Bulgaria is carried out by ca-

ble yarders, although 60 % of the forests are located on terrains with large slopes.

In the second half of the 1960s, the use of cable yarders gradually narrowed with the introduction of rubber-tired tractors. They have higher mobility, a simpler technological process and can transport timber over longer distances. In the middle of the 70s of the XX century the production of the Shipka ShT-80 four-wheel-drive articulated cable skidders began in Bulgaria (Manolov et al. 2009).

In the early 80's of the twentieth century, environmentally friendly logging was realized by foresters and loggers, and tractor-mounted tower yarders began to be imported. Later tractor-mounted tower yarders began to be produced in Bulgaria. During the same period in Bulgaria the MSI-100 4WD forwarder and MBI-100 4WD clambunk skidder were developed. Later, production of the Shipka TG-50G tractor log trailer began (Manolov et al. 2009). Forwarders manufactured by leading world companies, gradually began to enter the forestry in Bulgaria at the beginning of the new millennium. Hundreds of 4WD and 6WD old high-mobility military trucks have been used in logging in Bulgaria as low-cost substitutes of forwarders since the early 1990s.

Motor-manual tree felling and processing is among the most used options in timber harvesting operations and it is formally known to be a heavy job exposing the workers to safety hazards and harmful factors (Cheța et al. 2018).

Adapted agricultural tractors are the most widely used means of timber extraction in Bulgaria, as well as the Balkans, the Carpathians, Italy, etc. (Borz et al. 2013, 2015; Moskalik et al. 2017; Proto et al. 2018a; Cataldo et al. 2020).

Wheel cable skidders are used in many harvesting systems due to their better lon-

gitudinal and lateral stability, mobility and long winch cable (60–100 m) giving a better opportunity to access to marked trees and enhanced productivity (Georgiev and Stoilov 2007).

Forwarders are a mechanized alternative to agricultural tractors and horse logging (Proto et al. 2017, Borz et al. 2019). Modern forwarders are an effective extraction option for timber harvesting operations that provide the opportunity for higher levels of mechanization. With their ability to carry logs from the forest to the roadside or processing areas, they have an established lower environmental impact in comparison to tree-length skidding options (Proto et al. 2018b). In Austria, whose forests are predominantly on mountainous terrain, the distribution of timber extraction machines from stand to landing in 2009 is as follows: cable yarders – 20 %, skidders – 49 %, forwarders – 26 %, and other means – 5 % (Holzleitner et al. 2011). Ten years later, in 2019, this ratio has changed in favour of forwarders: cable yarders – 19 %, skidders – 37 %, forwarders – 43 %, and other means – 5 % (Prem and Bauer 2020).

Fully mechanized timber harvesting systems are generally characterized by a high operational performance being widespread and used across many regions. Such systems are adaptable to different levels of operational integration, enabling also the recovery of energy wood, but given integration configurations affect their performance (Apăfăian et al. 2017). In a survey in neighbouring Romania evaluated the perception of state forest managers, contrary to expectations, the mechanized harvesting systems were rated as highly preferred. In particular, cable systems were among the first preferences of the respondents, being followed by those

systems involving forwarding operations (Munteanu and Borz 2018).

About 65 % of the timber extraction in Bulgaria in the 90s of the last century were mechanized, and in loading operation the degree of mechanization is about 85 %. There has been significant regression in this regard in recent decades. About 550 units of adapted tractors and no more than 60 others worked in logging. The tractor skidding has very obsolete equipment with expired depreciation period. The cable yarders were about 40 sledge yarders and 20 tower yarders, of which a little more than half worked constantly. The most common are Pirin and Koller (Dinev 2009).

It should be noted that in recent years new modern logging machines have started to enter the Bulgarian forests – forwarders and cable skidders, cable yarders, as well as second-hand ones. So far, this update is not enough. Mechanization may change this situation, by offering fewer, better jobs, which may prove attractive to the new and more educated generations. Mechanization allows multiplying operator productivity and for this reason achieves an overwhelming superiority over traditional technology, which makes it a better choice even when utilization rates and labour cost are comparatively low (Spinelli and Magagnotti 2011).

Currently, there are no reliable data on the number and state of logging equipment in Bulgaria, and various sources indicate contradictory data. All this makes the study of logging equipment in Bulgaria actual, relevant and necessary.

The aims of the present study are: i) to establish the number and years in operation of available logging equipment; ii) to analyse the current state, influencing factors and future prospects for development.

## Materials and Methods

The study of logging equipment in Bulgaria was conducted in the spring of 2019. A questionnaire (see Table 1) was sent to the six state forest enterprises, two training and experimental forest ranges of University of Forestry, municipal forest enterprises, forestry production cooperatives. The questionnaire was accompanied by detailed instructions and an example to be completed. The six state forest enter-

prises sent the questionnaire to their territorial divisions. To avoid duplication, as one machine is reported to neighbouring territorial divisions, the number and type of equipment are determined on a specific date, 3rd of May 2019.

Data were collected from 160 territorial divisions of state forest enterprises, two training and experimental forest ranges of University of Forestry, municipal and private structures in which mechanized logging was currently carried out.

**Table 1. Questionnaire used for the survey.**

Questionnaire

for logging equipment, working on the territory of state forest/hunting range, municipal forest enterprise, forestry production cooperatives ..... as of May 3rd 2019

| No     | Brand and model of the machine             | Age classes |           |            |               | Owner |
|--------|--------------------------------------------|-------------|-----------|------------|---------------|-------|
|        |                                            | new         | 1–5 years | 5–10 years | over 10 years |       |
| 1.     | <b>Ground-based extraction</b>             |             |           |            |               |       |
| 1.1.   | Adapted agricultural tractors for skidding |             |           |            |               |       |
| 1.2.   | Purpose-built machine                      |             |           |            |               |       |
| 1.2.1. | Skidders                                   |             |           |            |               |       |
| 1.2.2. | Forwarders                                 |             |           |            |               |       |
| 1.2.3. | Tractor log trailers                       |             |           |            |               |       |
| 2.     | <b>Cable-based extraction</b>              |             |           |            |               |       |
| 2.1.   | Sledge yarders                             |             |           |            |               |       |
| 2.2.   | Tower yarders                              |             |           |            |               |       |
| 3.     | <b>Harvesters</b>                          |             |           |            |               |       |
| 4.     | <b>Timber loading machines</b>             |             |           |            |               |       |
| 4.1.   | Tractor mounted knuckle-boom               |             |           |            |               |       |
| 4.2.   | Front loaders                              |             |           |            |               |       |
| 5.     | <b>Mobile chippers</b>                     |             |           |            |               |       |

The data were processed and classified by type of machine, type of running gear and age.

## Results

The data of logging equipment by number, type, age classes, and percentage is

shown in Table 2 and Figure 1.

From the Figure 1 it can be seen that in Bulgarian forestry timber extraction equipment (80 %) is widespread. Skidding operations with the adapted agricultural tractors, numbering 750 (55 % of all logging equipment), predominate. Followed by cable skidders – 233 units (17 %), tower yarders (3 %), and sledge yarders (1 %).

Table 2. Data of logging equipment in Bulgaria.

| Type of machine                | Age classes |           |            |               | Total       |
|--------------------------------|-------------|-----------|------------|---------------|-------------|
|                                | new         | 1–5 years | 5–10 years | over 10 years |             |
| Adapted cable skidders         | 2           | 19        | 22         | 707           | 750         |
| Cable skidders                 | 7           | 17        | 18         | 191           | 233         |
| Forwarders                     | 2           | 9         | 9          | 28            | 48          |
| Tractor log trailers           | 0           | 4         | 1          | 2             | 7           |
| Sledge yarders                 | 1           | 0         | 0          | 19            | 20          |
| Tower yarders                  | 1           | 1         | 0          | 38            | 40          |
| Harvesters                     | 1           | 2         | 0          | 9             | 12          |
| Tractor mounted cranes         | 3           | 13        | 6          | 210           | 232         |
| Front loaders                  | 2           | 7         | 2          | 13            | 24          |
| Chippers                       | 1           | 1         | 0          | 4             | 5           |
| <b>Logging equipment total</b> | <b>20</b>   | <b>73</b> | <b>58</b>  | <b>1221</b>   | <b>1371</b> |

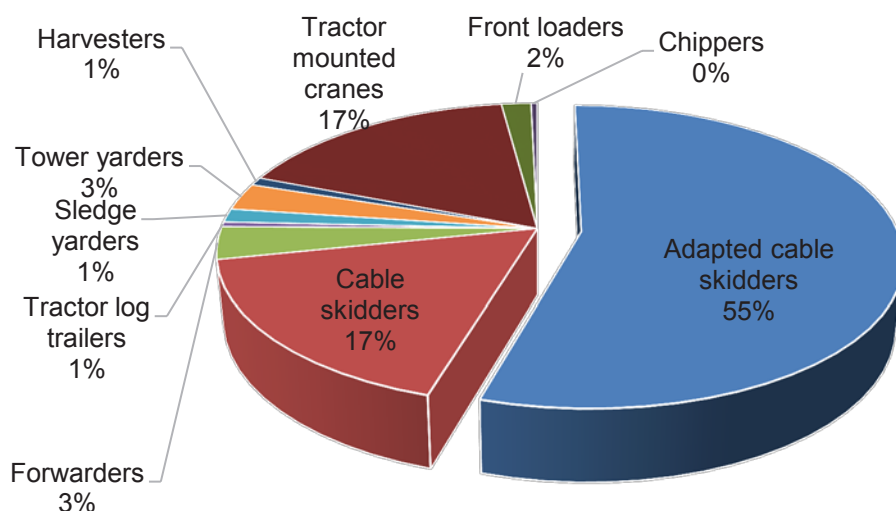


Fig. 1. Percentage of logging equipment by type.

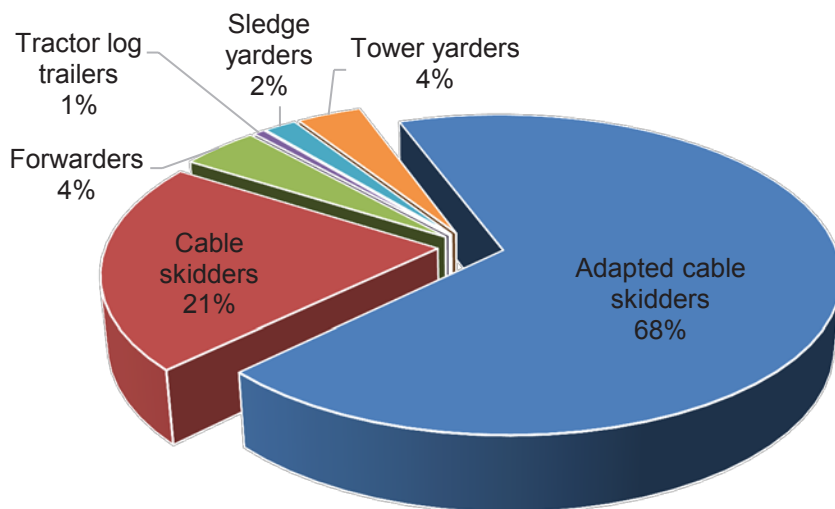
The forwarders are 48 units (5 %) of timber extraction equipment (Fig. 2). In general, ground-based equipment for transport of assortments has a relatively small share – as mentioned, 48 forwarders and 7 tractor log trailers, i.e. 6 %.

As expected, among the timber extraction machines the largest share of 68 % belongs to adapted agricultural tractors for skidding in a semi-suspended position, as 750 units were reported. Adapted trac-

tors widely used in Bulgaria do not fully meet the operating conditions in forestry, but they have a relatively low cost as mass-produced 4WD agricultural tractors (Fig. 2).

The purpose-built cable skidders – 233 units (21 %) are less than adapted ones. The ratio between adapted agricultural tractors and cable skidders is about 3:1. However, cable skidders should prevail, given that most of the forest areas of Bul-





**Fig. 2. Percentage of timber extraction equipment by type.**

garia are located on steep terrain with complex shapes. The most common cable skidders used in Bulgaria are middle – sized from brands LKT-80/81T/82 (100 units) and TAF-658/690/2010 (44 units).

It is noteworthy that in general the forwarders work independently, not only with harvesters, which are 12 units, i.e. ratio of 4:1. The most common forwarders used in Bulgaria are heavy – sized from brands John Deere (25 units) and Komatsu Forest (6 units). Two of harvesters, John Deere 1170E and 1270E, two John Deere 1510E and one 1510G forwarders operate mainly in poplar plantations (Novakov 2020).

Ground-based timber extraction vehicles (adapted cable skidders, cable skidders, forwarders, tractor log trailers) are a total of 1038, versus 60 cable-based machines, i.e. ratio of 17:1. It is important to note that there are 3 mountain harvesters among the forty tower yarders.

A very serious problem is obsolete and depreciated equipment (Fig. 3). The largest share of machines over 10 years

belongs to the group of sledge and tower yarders (95 %), followed by adapted agricultural tractors (94 %), tractor mounted cranes (91 %), and cable skidders (82 %).

The share of machines over 10 years of age is relatively lower among harvesters (75 %), forwarders (58 %) and front loaders (54 %). Only tractor log trailers up to 5 years (57 %) predominate, while those over 10 years are 29 %.

In ground-based extraction the more environmentally friendly wheel skidders predominate (91 %), while the tracked ones are 9 % in total.

## Discussion

A fundamental problem in logging industry in Bulgaria is the huge predominance of equipment in operation over 10 years (89 %), and hence, their lower production rates and higher maintenance and repair costs. Bulgarian forestry needs for new modern logging equipment, which is a prerequisite for increasing productivity

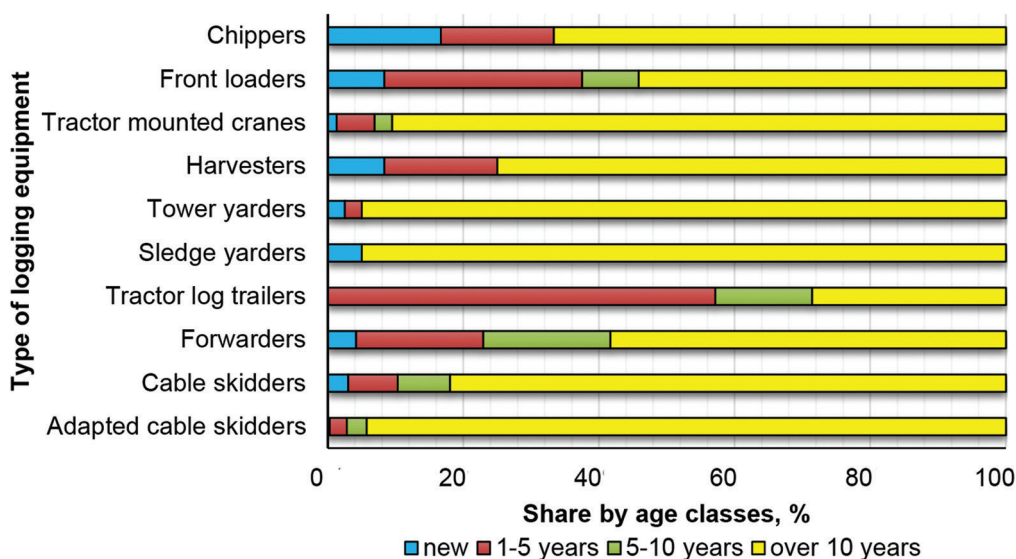


Fig. 3. Share of logging equipment by age classes.

and improving working conditions. Given that the backbone of logging equipment in Bulgaria are cable skidders and adapted agricultural tractors, which are a total of 783, there is a significant aging (average 91 %). For example, the most common adapted agricultural tractors used in logging in Bulgaria are Universal-651M (331 units) and Bolgar TK-82N (93 units), both are no longer produced by over 20 years and factories no longer work.

The drivers toward renewal of logging equipment are several.

A major renewal of the logging machinery is expected, due to its physical wear and lack of manpower in the logging industry as well as in the industry as a whole, which is becoming increasingly tangible. Modernization must be done with new high-performance equipment that, while more expensive, will ensure efficiency and lower unit costs.

There is a sustainable demand for wood, both for heating and from wood-working and pulp and paper mills. Tem-

porary barriers are the oncoming recession crisis in the demand for timber due to COVID-19 and the supply of large volumes of cheap timber damaged by natural disasters from Central-European countries. The effective use of forest biomass is set as a priority objective in the European Union Forest Strategy and is a key part of the strategy of the European Commission for Sustainable Energy Union with a future-oriented policy on climate change. In recent years limiting the dependency on imported fossil fuels and their replacement by renewable energy sources has gained strategic importance. In Bulgaria the majority of forest biomass is used locally, making it a major factor in ensuring the energy independence and stability in rural and mountainous areas (EFA 2019).

Increasing the maximum allowable felling intensity over 30 % will lead to the possibility of mechanized logging. Coniferous species are preferred for timber harvesting in Bulgaria because they are better suited for the pulp and paper

mills. Only 29 % of the forests by area are coniferous, but they provide 45 % from growing stock. Increasing the intensity of logging will expand the use of harvesters and forwarders, which now work mainly in clearcutting in coniferous plantations affected by natural disturbances. At higher cutting intensity harvesters and forwarders will be able to operate effectively on moderate slopes and their numbers and production rates will increase. It can be expected that forwarders, based on their advantages, will gradually replace military off-road trucks and have the greatest potential to increase their number and share. This is prompted by the increasingly noticeable lack of skilled and even unskilled labor force. An important advantage of new equipment is the comfortable working environment in the cab of the machine and the ergonomic control devices. Such a machine can retain more skilled workers in the forestry industry.

Facilitating access to European Union programs will encourage the purchase of modern logging equipment.

Variation in slope reflects the difficulty, and thus costs, of accessing forest stands. Road density has a positive effect and has the largest impact of all factors. The magnitude of this effect reflects the fact that forest road network in Bulgaria is a limiting factor for the forestry and in particular logging industry. The density of the forest road network ( $7.9 \text{ m} \cdot \text{ha}^{-1}$ ) (MoAF 2014) is insufficient and investment is needed to build new forest roads to reduce the average skidding distance and unit costs, and to rise the productivity of primary transport.

Another driver for the rapid introduction of new logging equipment are the long-term contracts of companies (5–7 years) for better predictability and sustainability of investments.

## Conclusions

The predominance of adapted agricultural tractors in Bulgarian forestry does not correspond to the fact that most of the forest areas are located on steep terrains with complex shapes, despite this feature requires the use of purpose-built skidders and cable yarders. Therefore, the use of harvesters is limited, as well as by the predominance of deciduous forests. The number of forwarders which otherwise work in conjunction with harvesters is 4 times greater than that of harvesters, and it can be expected that forwarders will gradually replace military off-road trucks and have the greatest potential to increase their number and share.

Both physical wear and lack of manpower in the logging industry leads to renewal of the logging machinery, which while more expensive, will ensure efficiency, higher productivity and lower unit costs. Facilitating access to European programs will encourage the purchase of modern logging equipment. Increasing the maximum allowable felling intensity will improved the possibility of mechanized logging. Another driver for the rapid introduction of new logging equipment are the long-term contracts of companies for better predictability and sustainability of investments.

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# INFLUENCE OF CLIMATIC FACTORS ON THE FORMATION OF SCOTS PINE (*PINUS SYLVESTRIS* L.) AND NORWAY SPRUCE (*PICEA ABIES* KARST.) RADIAL GROWTH ELEMENTS IN THE BOREAL ZONE OF RUSSIA

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## Abstract

We studied the influence of average temperatures and precipitation of the growing season on the formation of macrostructural elements of radial growth in Scots pine and Norway spruce stands of Leningrad region located in the boreal zone of the European part of Russia. Denro-climatic studies were carried out using the results of wood samples analysis from forest stands on two-layer soils collected during 60 years. The digitized parameters of wood samples were processed in a GIS system, which made it possible to obtain an array of generalized dendrochronologies. A rank correlation analysis of the data obtained was carried out using the Spearman's test. To simulate the combined effect of the amount of precipitation and average temperatures on the formation of the structural elements of radial growth, the method of the quadratic function was used. Depending on the composition of a stand, there was a different response to the selected meteorological factors during the study period. In pine stands, the effect of the average temperature of the growing season on the amount of annual radial growth was greater than in spruce stands. In spruce and pine stands with the participation of deciduous species, the structural elements of wood were more meteosensitive. The use of the quadratic function method made it possible to assess the combined effect of the total precipitation and average temperature of the growing season on the elements of radial growth of pine and spruce in the stands under study over the period of the experiment. Stands with various proportions of pine predominantly responded in the same way to changes in external factors associated with the climatic features of the region, which indicates the priority of their use in dendrochronological studies.

**Key words:** amount of precipitation, annual ring width, average temperature, early and late wood, statistical analysis.

## Introduction

A great number of researchers noted the ability of annual growth rings to retain in-

formation about changes in the action of environmental factors (Byusgen 1906, Mikola 1962, Vikhrov and Protasevich 1965, Dergachev and Chistyakov 1993,



Makinen et al. 2002, Grippa and Potakhin 2016). The obtained information, on one hand, is chronological, that is, it represents the variability of annual growth in time, the presence of temporary cyclical changes, and the direction of changes (Mielikäinen et al. 1996). On the other hand, this information is associated with exogenous and endogenous environmental factors (Eckstein et al. 1989).

Radial growth of stem wood of forest-forming woody plants is a complex integral indicator, to the formation of which the genotype of each particular plant and a complex of environmental factors contribute. Radial growth of trees is a bioindicator, and the characteristics of tree growth rings can show changes in the environment (Babushkina et al. 2010).

A large number of publications have been devoted to the variability of tree growth, but many issues remain debatable or poorly understood, due to the diversity of both forest biogeocoenoses and the nature of environmental impacts, as well as the differences in research methods (Henttonen 1990, Demakov 2005, Vaganov et al. 2006, Zaytsev et al. 2020).

Climatic factors have a particularly strong effect on the growth rate. By deviating from the long-term average they produce response in plants (Mitryajkina 2005).

Since a complex of factors affects growth and development of plants during their life cycle, the relationship between the width of annual growth rings and climatic parameters is not always unambiguous.

Meteorological values such as air temperature and precipitation directly influence the development of dendrocoenoses (Miina 2000). However, the growth of the trunk mass of trees also depends on soil nutrients, moisture, depth of groundwater,

vital state of a stand, etc. For this reason, the revealed correlations between the current radial growth and meteorological factors are, in fact, statistical, reflecting their influence on the intensity of the use of water-mineral soil resources in accordance with the vital state of the stand.

It has been noted that the growth rate of annual rings of Scots pine and Norway spruce of the same age growing in the Baltic region in different habitat conditions was not the same against the background of changes in weather factors (Bitvinskas 1974, 1984).

Variability in radial growth of coniferous trees in Central and Eastern Europe and in Northern Fennoscandia was mainly associated with changes in the sum of positive temperatures of the growing season (Mikola 1962; Makinen et al. 2000, 2001, 2002, 2003). In contrast, in Central Europe variation in growth of conifers was mainly correlated with precipitation (Eckstein et al. 1989, Kahle 1994, Kahle and Spiecker 1996). Studies of precipitation effect on annual radial growth of Norway spruce carried out in southern and central Finland have also revealed that damage and dying off of spruce in drought-sensitive areas in the southern part of the country could be primarily related to low precipitation rather than temperature fluctuations (Mikola 1962; Henttonen 1990; Mielikäinen et al. 1996; Miina 2000; Makinen et al. 2000, 2001, 2002, 2003).

Makinen et al. (2002, 2003) studied changes in radial growth of Norway spruce (*Picea abies* (L.) Karst.) and its dependence on various climatic variables. The researchers compared forest stands in southwestern and eastern Germany, Norway and Finland. Climate models included local temperature and precipitation, and temperature anomalies. Trees growing in moderate conditions

have been found to be less responsive to climate change. Changes in spruce growth were clearly correlated with temperature.

When the Baltic countries were considered, on moist soil growth of Scots pine was more sensitive to precipitation of the previous year (Daukane and Elferts 2011).

Studies of interannual differences in growth of Scots pine tree rings at the northern border of the range under the conditions of the European North have revealed consistency in long-term growth and the same response to changes in environmental conditions (Tyukavina and Lezhneva 2014, Tyukavina 2015). In different growing conditions, pine reacted to unfavourable factors more synchronously than to optimal ones.

According to a number of authors, in the taiga geocomplexes of the European North of Russia, the amount of radial growth of wood is limited by the ratio of heat and moisture, both in the atmosphere and in the soil, especially during the growing season (Grippa and Potakhin 2016, Chudakov et al. 2020).

The analysis of wood samples collected from large territories by scientists from different countries made it possible to consider tree growth as an indicator of the dynamics of biological systems in space and time in connection with changes in natural conditions and anthropogenic influences at the local, regional and global scales (Martínez-Sancho et al. 2020).

In connection with the above, it is necessary for forestry practice to determine stands with less dependence on variations of limiting meteorological factors. The aim of the study was to analyse the influence of meteorological parameters on the formation of annual growth and its structural elements in Norway spruce and Scots pine stands of various compositions.

## Material and Methods

To correctly identify the consequences of the influence of meteorological parameters on tree growth, only forest stands on similar soils and in similar hydrological conditions should be considered. The selection of sampling points is a key issue in dendroclimatic research. It determines sensitivity of trees under study to various environmental factors.

To study the influence of meteorological factors on annual growth of Scots pine and Norway spruce, studies were carried out in pure and mixed coniferous stands of the same age class (85–100 years) of the bilberry (*Vaccinium myrtillus* L.) series of forest types in the conditions of Oredezh plateau of Luga-Oredezhsky landscape region of Leningrad region located in the Northwest of the European part of Russia. Geographic coordinates of study area are 59°16'58" N and 30°14'24" E.

The natural stands under study have not been affected by human activities and grow on soils with two-layer structure. The landscape types under consideration are widespread in the boreal zone of Valdai glaciation area: within the moraine plain and along the tops and slopes of north-facing moraine hills. Two-layer sediments are rocks of a loamy or sandy composition of low thickness (30–70 cm) occurring on loams, which serve as the first impermeable horizon from the surface. The main distinguishing feature of the hydrological regime of drained soils on two-layer sediments is the presence of a surface soil-groundwater horizon in April-May and September-November which screens the loam located below (Chertov 1981).

The climate of the area is Atlantic-continental, with relatively mild winters with thaws and moderately warm summers. The prevailing winds are westerly and

southerly. The average temperature is minus 8 °C in January and plus 17 °C in July. The annual amount of precipitation is 650–700 mm. The study used data from Belogorka meteorological station (Gatchinsky district of Leningrad region, Russia) located within a radius of 1–5 km from the study sites. The growing season lasts five months, from May 1 to September 30.

On 9 test sites with predominance of Scots pine, on 12 test sites with predominance of Norway spruce and on 1 mixed site with Scots pine and Norway spruce dominated by a deciduous species the growing stock, average heights and diameters of the forest forming species were measured and the species composition of stands determined. For dendroecological studies, 10–30 wood samples were taken from each tree species in experimental plots. The sample cores were taken at the height of 1.3 m from the root collar at least from 2 trees of each diameter class, taking into account the quantitative representation of the diameter class in the stand.

For the macroanatomical analysis of radial growths of Scots pine and Norway spruce the data from 60 years were used. On the basis of selected core samples, the anatomic structure was investigated and the dependences of changes in the annual structure of xylem on the main meteorological factors were calculated.

Previously prepared and sanded wood sample was glued into the holder and placed in the high-resolution scanner; the surface of the sample was scanned with an accuracy of 1200 dpi in full colour mode (16.7 million colours). The brightness and contrast of the digitized scans was then adjusted to ensure better differentiation of early- and latewood areas in the sample (Chudakov et al. 2020, Zaytsev et al. 2020).

To measure the wood macrostructure

parameters, the obtained image was converted into a geo-information system (GIS) with a resolution equal to the scanning resolution (a relative 1 m on an electronic map was considered equal to 1 mm).

Using GIS tools, a line was drawn along the longitudinal axis of the core sample. The limits of the late- and earlywood areas were set at each annual growth ring. All measurements were done to the middle of the sample (center of the wood). The obtained data were verified using a high-precision electronic caliper with digital screen; the difference in measurement results between the two methods statistically was not significant. The created line was used to prepare a report in GIS, containing information on the distance between the points, i.e. in this case, values of late- and earlywood widths in mm.

Thus, as indicators characterizing the macrostructure of wood, we measured the average width of the annual layers and the content of the late and early xylem in the annual layer during the life of the tree. These indicators were determined for all wood samples taken from model trees in study plots. Later, the Microsoft Excel spreadsheet processor was used to systematize the obtained quantitative and qualitative data on the macrostructure of Scots pine and Norway spruce wood.

The obtained values of the amount of growth of trees were transformed into a generalized dendrochronological series characterizing the main features of the growth variability on the study sites, by using the method of averaging. This is the simplest and most reliable way to study the relationships between the amount of annual growth of wood and meteorological variables (Vaganov et al. 2006, Matkovsky 2015). To create a generalized dendrochronological series, the most representative undamaged trees were used.

The process of removing the age trend (standardization of tree-ring series) was not applied due to the conditional same age of the studied stands within 15 years. To study the influence of meteorological factors on the macrostructure of wood, data from 1960 to 2016 were used.

The main statistical characteristics of dendrochronological series were calculated for each stand from the width of annual growth rings using the STATGRAPHICS Centurion XVI, STATISTICA-11, Microsoft Excel 2007 programs.

To reflect the combined effect of the amount of precipitation and average temperature of the growing season on the amount of annual growth, we used the smoothing of point values of the function by the least squares method (Freedman 2005, Illowsky and Dean 2017). The method is based on minimizing the sum of squares of difference between an observed value and the fitted value provided by a model (Freedman 2005). By using this method, surface plots were created, reflecting the influence of meteorological parameters on the structural elements of Scots pine and Norway spruce xylem.

To assess the quantitative relationship between the studied phenomena, the Spearman's rank correlation analysis was used. The rank correlation coefficients were calculated using the formula (1):

$$r_s = 1 - \frac{6 \cdot \sum d_t^2}{n \cdot (n^2 - 1)}, \quad (1)$$

where:  $d_t$  is the difference in the ranks of each pair of compared values;  $n$  is the number of measurements, pcs.

$r_s$  coefficient reflects the directionality of the relationship between two variables measured on a rank scale (Illowsky and Dean 2017). When using the coefficient of rank correlation, the strength of the association between two variables is

conditionally estimated. Specifically, the values of the  $r_s$  coefficient equal to 0.3 or less indicate a weak association between variables; the values of 0.4–0.7 are indicators of a moderate association, and the values of 0.7 and above indicate a strong association (Mitzel 2013, Zang and Biondi 2013). A negative value of the  $r_s$  coefficient indicates the possible presence of inverse correlation.

## Results and Discussion

Abrupt changes in the annual growth rate of coniferous species of the boreal zone are most pronounced over a period of many centuries. In general, abnormal changes in the radial growth of wood on the background of fluctuations in meteorological factors during the observation period in the studied stands were not observed, which is associated with a period of observation less than 100 years.

Using the obtained data set on the macrostructural elements of Scots pine and Norway spruce wood, Spearman's rank correlation analysis was carried out of the effect of the sum of temperatures and precipitation over the growing season on the parameters of wood macrostructure (Table 1).

In Scots pine stands, the strongest relationship was observed between air temperature and the amount of annual growth and the early wood zone. When the proportion of latewood was considered, statistically significant relationship was observed only in mixed forest stands with participation of deciduous species. With a decrease in the proportion of pine in stand composition, the influence of average temperature of the growing season on the formation of the elements of radial growth increases, which is probably associated

with an increase in phytocoenotic tension from other tree species. At the same time, in a forest stand with 20 % of pine trees the relationship between the amount of

annual growth of pine and temperature was not significant, which probably indicates a strong influence of other species on the habitat.

**Table 1. Spearman's rank correlation coefficients  $r_s$  for wood macrostructure indicators and weather conditions on double layer soils.**

| Stand composition         | Early wood             |                    | Late wood        |                    | Annual growth rate |                    |
|---------------------------|------------------------|--------------------|------------------|--------------------|--------------------|--------------------|
|                           | Meteorological factors |                    |                  |                    |                    |                    |
|                           | Tempe-<br>rature       | Precipi-<br>tation | Tempe-<br>rature | Precipi-<br>tation | Tempe-<br>rature   | Precipi-<br>tation |
| Pine-dominated stands     |                        |                    |                  |                    |                    |                    |
| 90P10S                    | -0.31                  | -0.05              | -0.25            | -0.21              | -0.30              | -0.08              |
| 80P20S                    | -0.31                  | -0.14              | -0.23            | -0.14              | -0.30              | -0.13              |
| 80P10S10B                 | -0.35                  | -0.09              | -0.32            | -0.06              | -0.33              | -0.07              |
| 40P40S10B10A              | -0.37                  | -0.08              | -0.34            | -0.04              | -0.35              | -0.07              |
| 20P10S60B10A              | -0.19                  | -0.13              | -0.13            | -0.10              | -0.17              | -0.12              |
| Spruce-dominated stands   |                        |                    |                  |                    |                    |                    |
| 100% Spruce               | 0.13                   | 0.01               | 0.02             | 0.37               | 0.14               | 0.10               |
| 90S10P+B,A                | 0.24                   | -0.09              | 0.20             | -0.03              | 0.26               | -0.08              |
| 80S20P+B,A                | -0.25                  | 0.02               | -0.03            | 0.09               | -0.23              | 0.05               |
| 80S10B10A+P               | -0.25                  | -0.13              | -0.26            | -0.07              | -0.26              | -0.13              |
| 70S20P10B+A               | 0.20                   | 0.21               | 0.23             | 0.17               | 0.19               | 0.20               |
| 60S(10P20A10B/<br>30B10A) | 0.35                   | -0.03              | 0.32             | -0.01              | 0.35               | -0.03              |
| 50S50P                    | 0.19                   | -0.04              | 0.15             | -0.06              | 0.17               | -0.03              |
| 40S30P20A10B              | -0.18                  | 0.04               | -0.29            | 0.06               | -0.22              | 0.05               |

Note: S – Norway spruce, *Picea abies* Karst.; P – Scots pine, *Pinus sylvestris* L.; B – silver birch, *Betula pendula* Rott.; A – aspen, *Populus tremula* L. Here and further marked bold coefficients are statistically significant at  $p = 0.05$ .

According to the results of the Spearman's analysis, the influence of the amount of precipitation of the growing season on the formation of elements of annual radial growth was not statistically significant at  $p < 0.05$  level.

Similarly to pine stands, in forest stands with various shares of spruce, the main factor influencing radial growth of spruce wood was the average temperature of the growing season.

There was a tendency to an increase in its importance for the formation of zones of early spruce wood with a decrease in

the share of spruce in the composition of a dendrocoenosis from 100 to 60 %.

In contrast to pine stands, the influence of the average temperature on the width of annual growth rings in spruce stands was noted only in two variants of the composition of spruce stands (80S10B10A+P, 60%S10P20A10B/60%S30B10A).

In spruce stands with a share of deciduous species (60%S10P20A10B/60%S30B10A), the contribution of positive temperatures over the growing season was significant for all studied elements of annual radial growth.

The influence of precipitation on the macrostructure of spruce wood was manifested only in pure stands at the level of the latewood zone, in contrast to pine stands with no significant correlations.

The study carried out using the apparatus of nonparametric statistics showed that the effect of the amount of precipitation on the formation of the macrostructure of annual growth rings of pine and spruce was weak and insignificant at the level of  $p < 0.05$  in most variants of the stands. At the same time, the influence of the average temperature had a greater influence on radial growth of these species. Concurrently, both positive temperatures and moisture supply are required for the formation of wood during the growing seasons. This contradiction can be explained by the fact that the combined effect of the amount of precipitation and the average temperature of the growing season is nonlinear. To reflect this complex mutual directionality, the quadratic function equations were used to construct a surface plot reflecting the effect of both meteorological parameters on the structural elements of pine xylem. By the shape of the surface and its slope, one can visually investigate the combined influence of the parameters on the elements of annual radial growth in tree-ring chronologies.

For forest stands with various proportions of pine, the surface plots of the quadratic function showed different nature of the combined effect of the total precipitation and average temperature on the formation of elements of the macrostructure of annual growth rings. The bending of the surface reflects the fluctuations in the thickness of the structural elements of the xylem, depending on the amount of precipitation and the average temperature in the compared variants of dendrochronology.

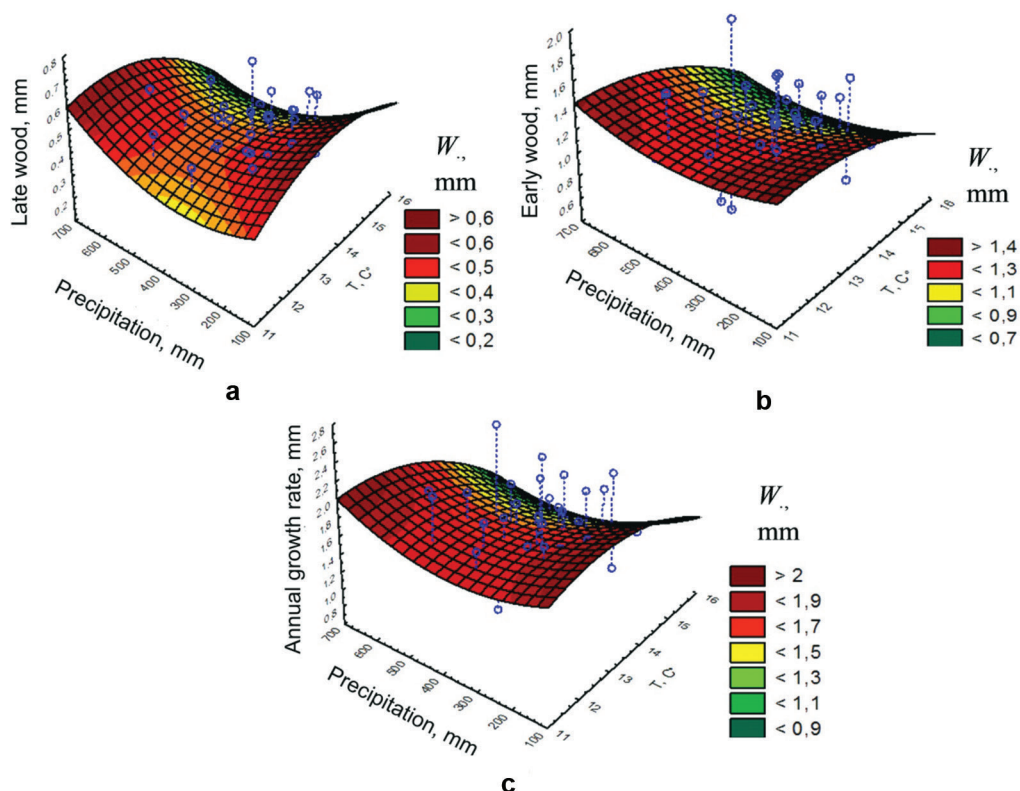
In pine stands with various proportions of accompanying species in the same hydrological conditions on the same two-layer soils, the directionality of the influence of meteorological parameters on the formation of radial growth and the zone of earlywood in pine was nearly the same. However, the influence of meteorological factors on the formation of the latewood zone was different. The surface plots differ in the influence of average temperatures on its formation.

In forest stands with 90 % of pine, an increase in the increment of all elements of pine xylem was observed at the average temperature in the range of 12–13 °C, regardless of the amount of precipitation during the growing season (Fig. 1). In these forest stands, a decrease in all elements of radial growth was observed at high values of the average temperature and precipitation.

When the composition of a forest stand was 80 % pine and 20 % spruce (80P20S), with a smaller share of pine in the stand, an increase in the amount of annual growth of pine was more noticeable at low values of precipitation (Fig. 2). When the latewood zone was considered, the effect of the average temperature of 12–13 °C on its growth against the background of precipitation of the growing season of 200–300 mm was observed. In a stand with an admixture of silver birch under similar soil conditions, the influence of meteorological factors on pine growth was similar to that in a pure pine stand.

In forest stands with 20–40 % of pine and 30–60 % of deciduous species, a different reaction of width formation of zones of late- and earlywood under the influence of meteorological factors was observed (Fig. 3). With 40 % of pine, the maximum increment was observed at a minimum of average temperatures and maximums





**Fig. 1. Relationship between pine wood growth and meteorological parameters in forest stands with 90 % share of pine (90%P10%S).**

and minimums of the amount of precipitation of the growing period. In forest stands with 20 % of pine and a predominance of deciduous species, a different relationship between the development of the elements of radial growth and weather conditions was observed. The share of latewood increased at a maximum amount of precipitation against the background of a minimum of the average temperature. The contribution of the average temperature to the formation of earlywood zone against the background of a minimum amount of precipitation was insignificant.

For forest stands with various proportions of spruce, the graphs of the quadratic function showing the relationship between

the parameters of the macrostructure of spruce wood and meteorological factors demonstrated different nature of the effect of weather conditions, depending on the share of spruce in the stand. Pure spruce stands were characterized by a maximum radial wood growth at high average temperatures (Fig. 4). When spruce latewood was considered, the greatest increase was observed at a maximum of the average temperature and the total precipitation of the growing season of 400–500 mm. When the spruce early wood was considered, the greatest increase was observed at a maximum precipitation.

In a spruce stand with the participation of other species, the nature of the joint

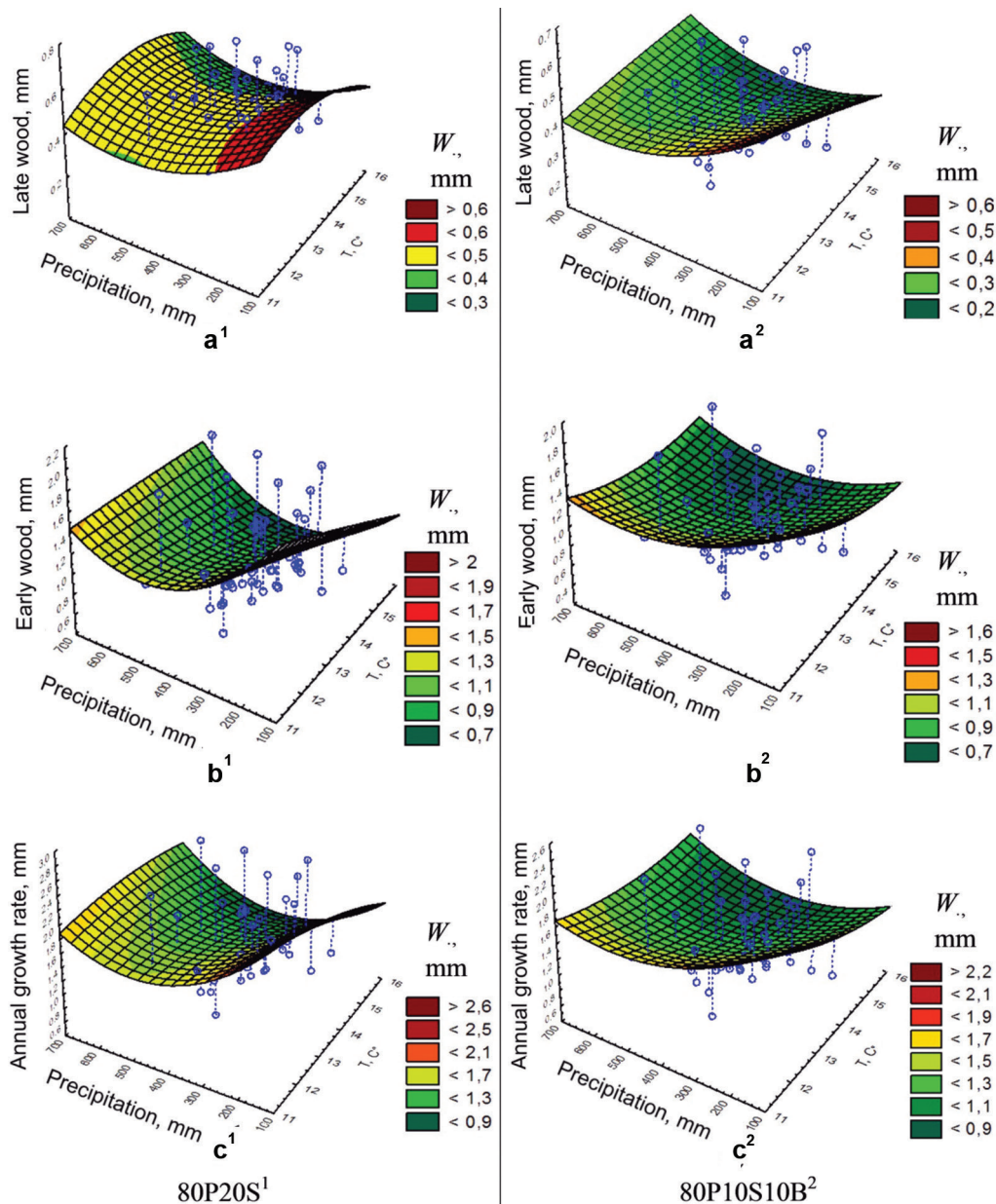
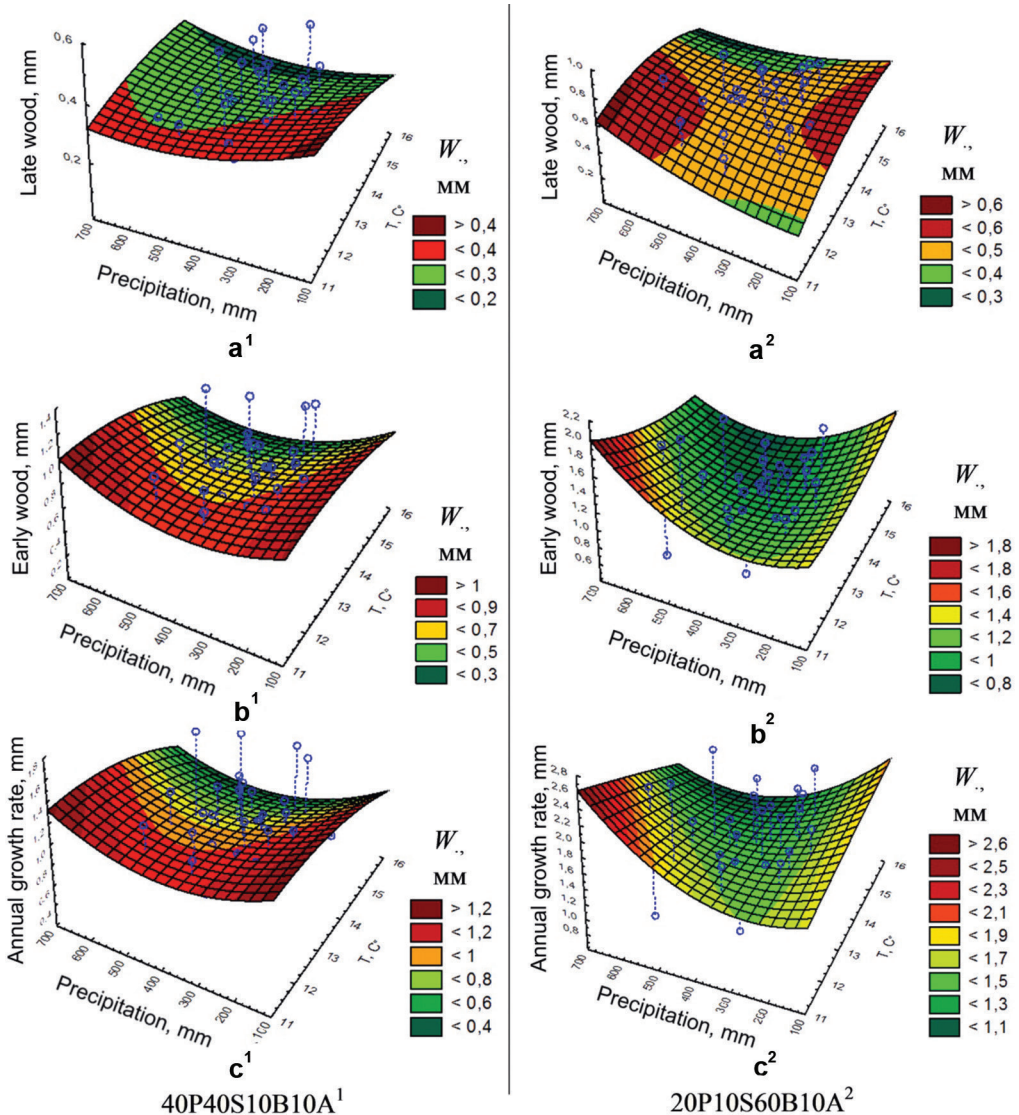


Fig. 2. Relationship between pine wood growth and meteorological parameters in forest stands with 80 % share of pine.

influence of meteorological factors was different. The greatest radial growth was recorded at a maximum average tempera-

ture and the total precipitation of the growing season of 200–350 mm (Fig. 5). However, in these stands an increase in the



**Fig. 3. Relationship between pine wood growth and meteorological parameters in forest stands with the different share of pine in the stand composition.**

size of radial growth elements of spruce wood was also observed at lower average temperatures.

Forest stands with a 70 % share of spruce and various shares of accompanying species responded differently to meteorological factors acting during the

formation of annual growth rings (Fig. 5).

In the stands with composition 80S20P, the greatest increase in spruce diameter was observed at the total precipitation of 300–500 mm and a minimum and maximum average temperature of the growing season. However, in contrast to the early-

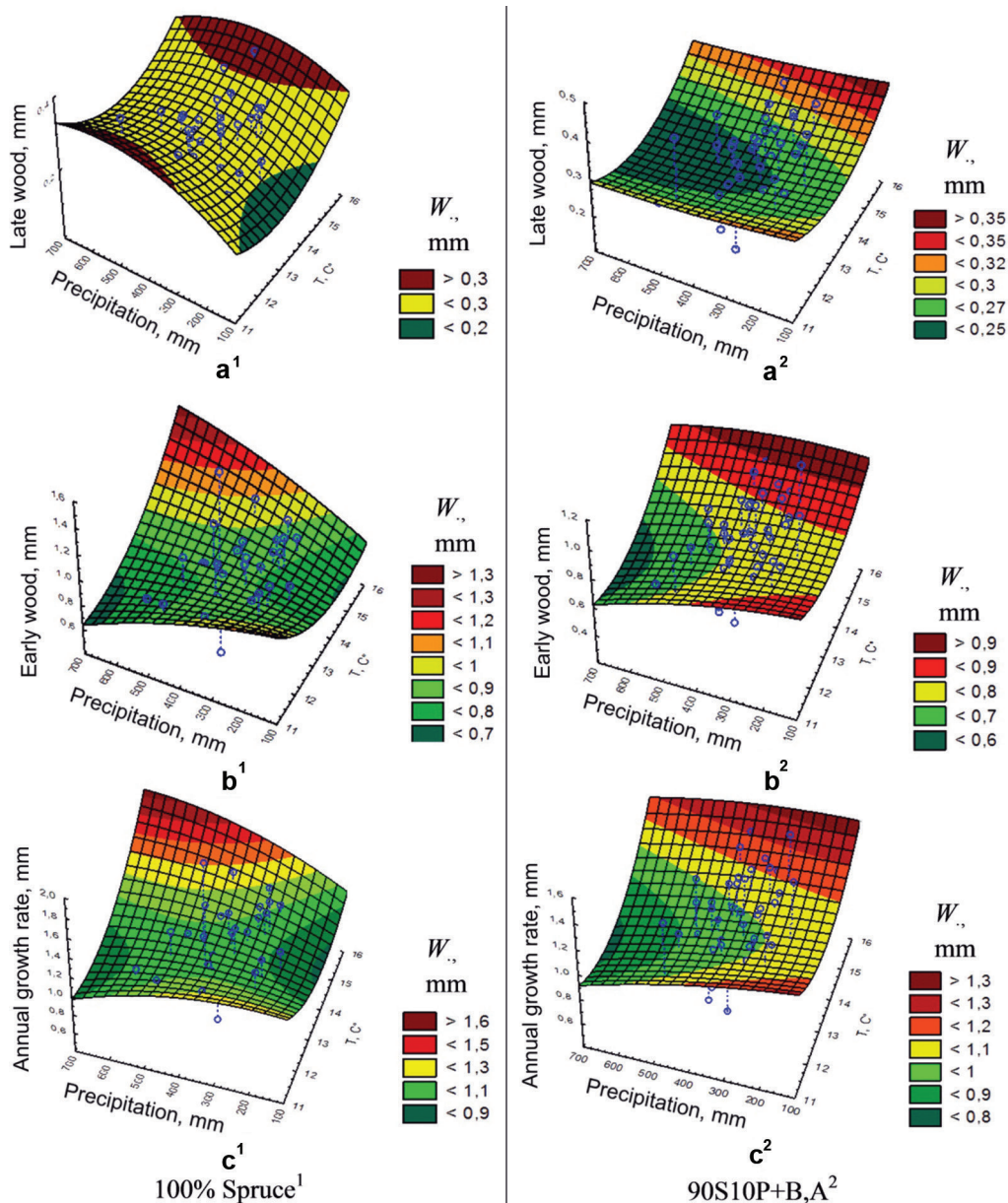


Fig. 4. Relationship between spruce wood growth and meteorological parameters in forest stands with a 90–100 % share of pine.

wood zone, an increase in the late wood zone was associated with an increase in the average temperature and precipitation.

In a spruce stand with the participation

of deciduous species (80S10B10A+P), a maximum amount of annual growth was observed at lower average temperatures against the background of the entire in-



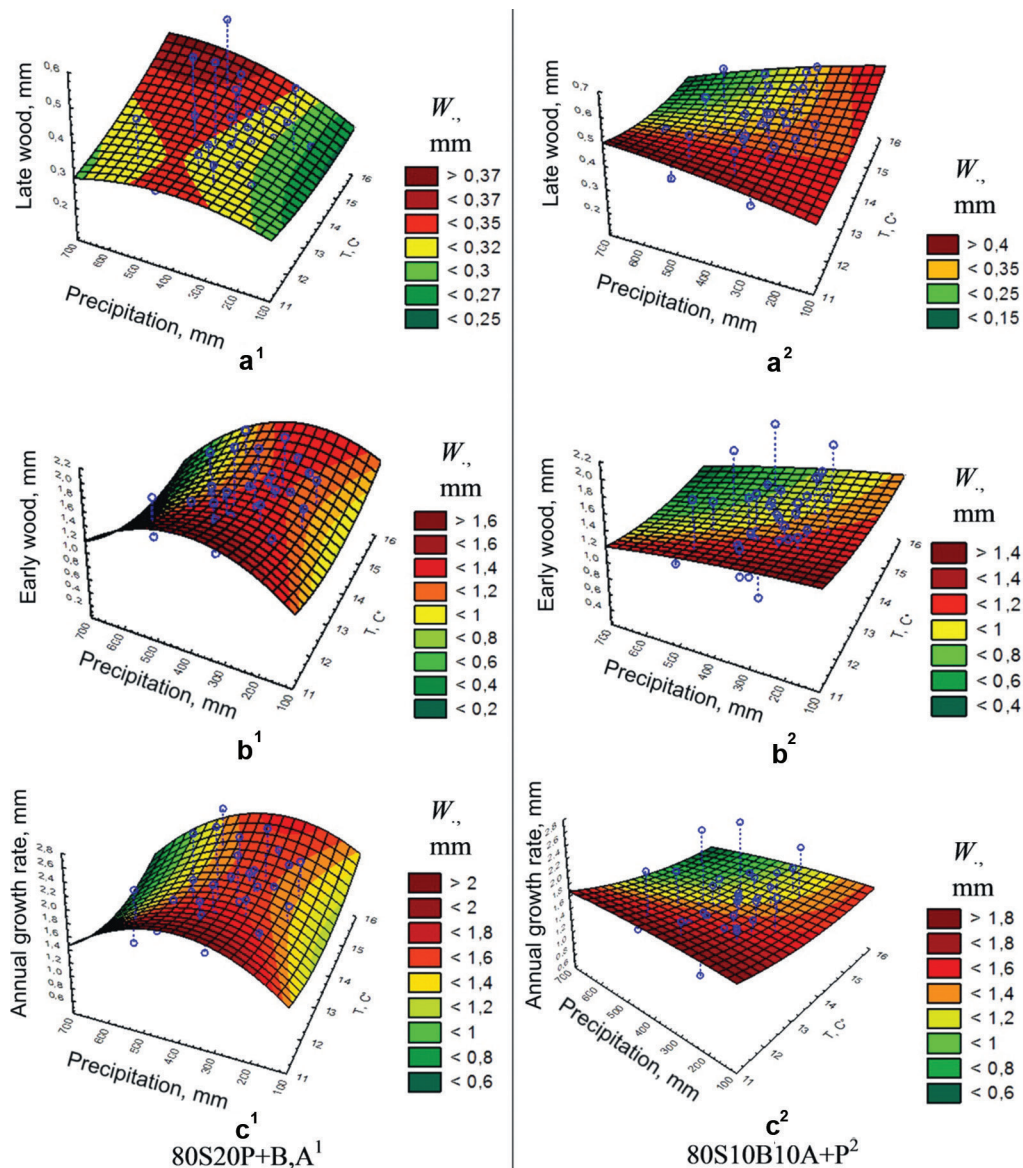


Fig. 5. Relationship between spruce wood growth and meteorological parameters in forest stands with 80 % share of spruce.

terval of the amount of precipitation. A maximum size of the latewood zone was reached at a high average temperature and the amount of precipitation of 200–300 mm.

In spruce stands with various proportions of deciduous species, there was a different response of annual growth rings to meteorological parameters (Fig. 6).

A stand with 70 % of spruce and 20 %

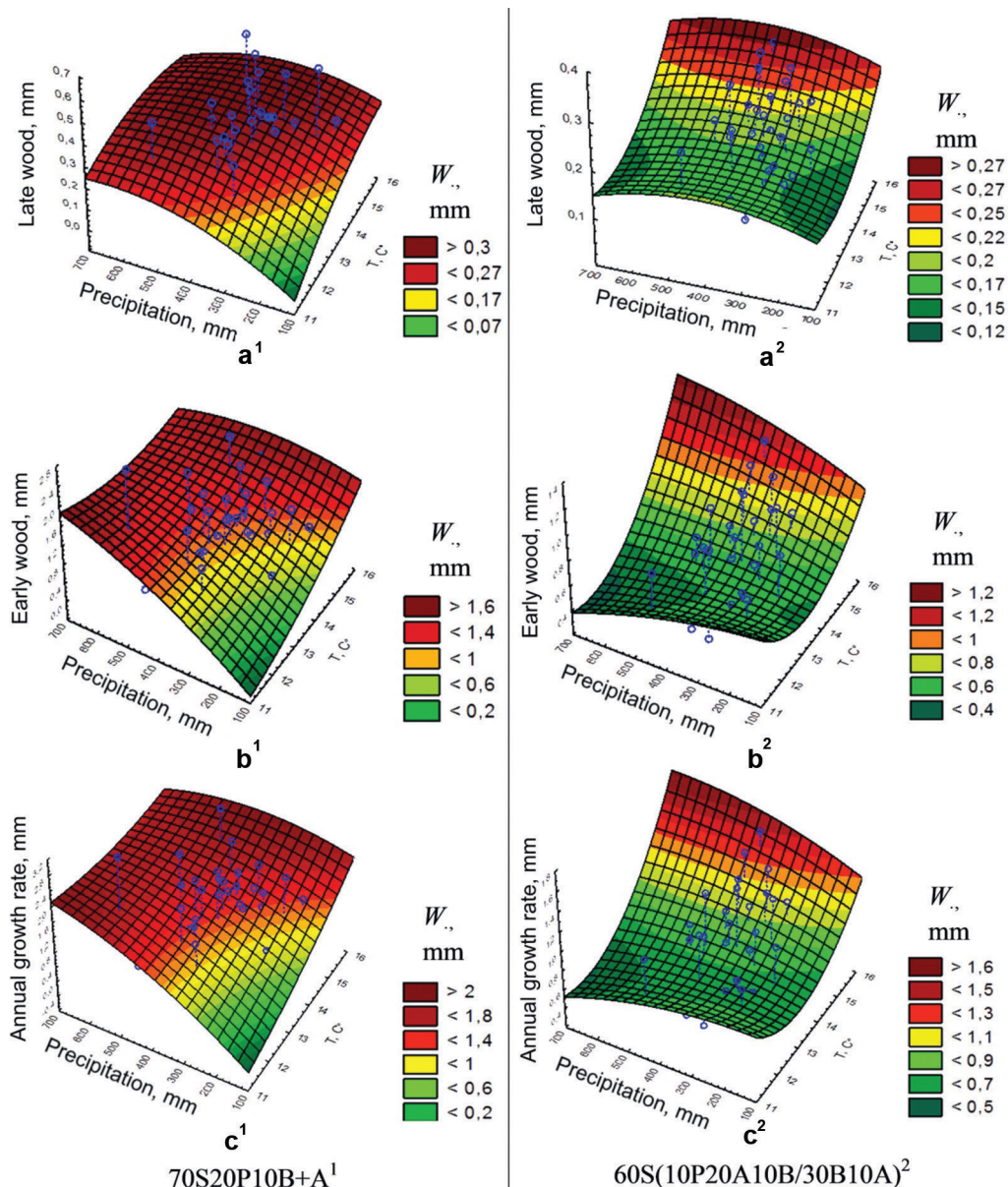


Fig. 6. Relationship between spruce wood growth and meteorological parameters in forest stands with 60–70 % share of spruce.

of pine and a lower percentage of deciduous species (70S20P10B+A) had a maximum amount of radial annual growth at an increase in the average temperature and

precipitation of the growing period.

In a spruce stand with a large share of deciduous species, a more pronounced dependence of the amount of the annual



radial growth and its elements on an increase in the average temperature was observed, with a lesser importance of the amount of precipitation.

In stands with equal proportions of spruce and pine (50S50P), a maximum

amount of annual radial growth in spruce was observed under the influence of maximums and minimums of the average temperature against the background of the total amount of precipitation of 300–500 mm (Fig. 7).

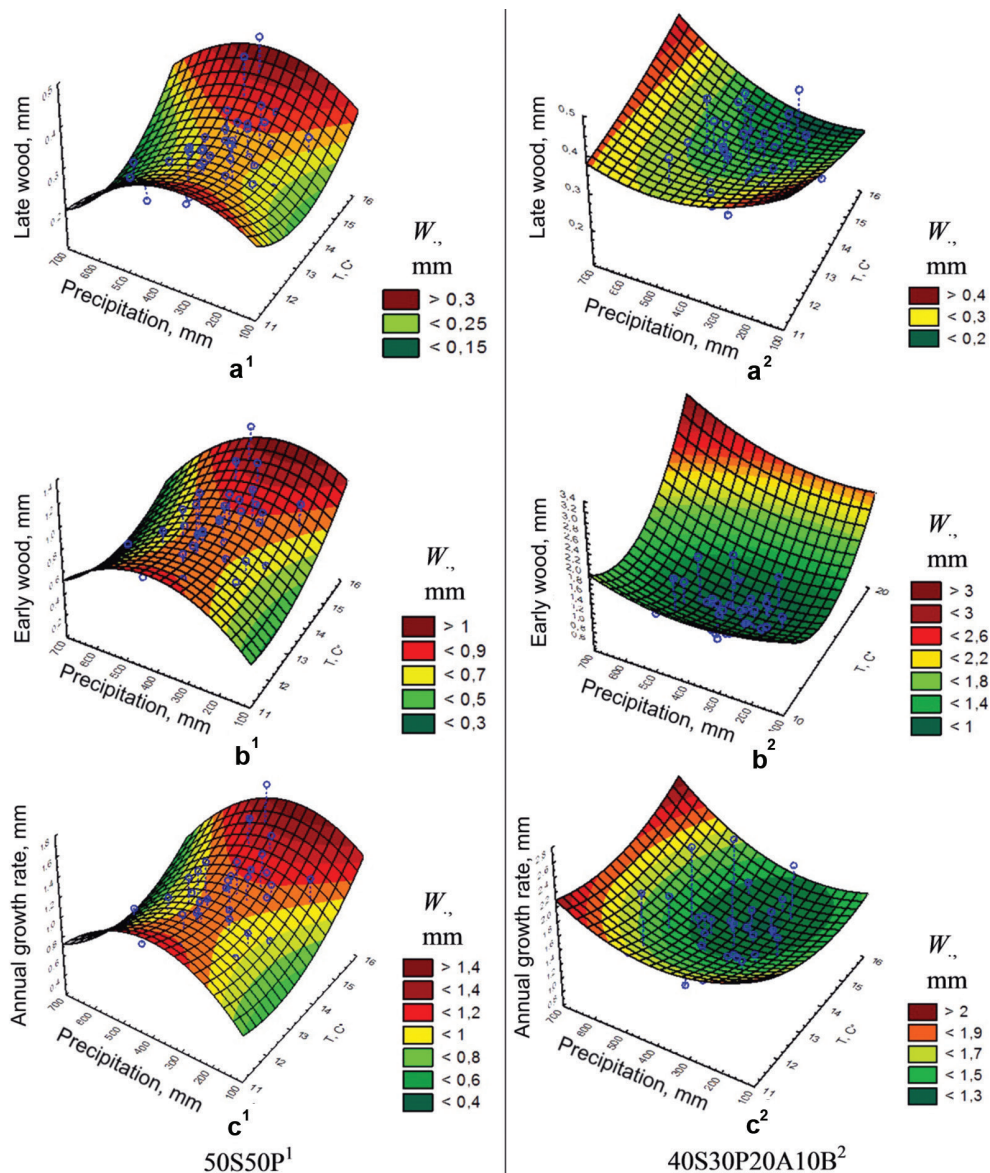


Fig. 7. Relationship between spruce wood growth and meteorological parameters in forest stands with 40–50 % share of spruce

In a stand with 40 % of spruce, 30 % of pine, 20 % of aspen, and 10 % of birch (40S30P20A10B), the greatest amount of annual radial growth in spruce was observed at a maximum amount of precipitation and an increase in the average temperature. In spruce, the average temperature had a greater influence on the formation of the zone of earlywood than the zone of latewood.

## Conclusion

The study revealed the nonlinear nature of the influence of the total precipitation and average positive temperature of the growing season on the formation of macrostructural elements of Scots pine and Norway spruce wood in forest stands with various species composition growing on two-layer soils. The response of pine and spruce to the combined effect of weather factors manifested in the formation of zones of earlywood and latewood was different. In the boreal zone, the study of the influence of climatic factors using methods of dendrochronological observations is most preferably carried out by studying changes in the annual growth of Scots pine, as this species is most sensitive to the fluctuations of weather changes in the region.

In the case of spruce, a significant effect of precipitation on the growth of macrostructural elements of wood was observed only in pure stands. The greatest meteosensitivity was observed in stands with the share of spruce below 60 % under the given soil conditions. The largest number of statistically significant values of Spearman's correlation coefficient for the relationship between the width of macrostructural elements of spruce and meteorological parameters was observed

in spruce stands with the participation of deciduous species.

In stands with various proportions of pine, the influence of the average temperature of the growing season on the formation of structural elements of wood was more pronounced than in spruce stands. The influence of precipitation alone, i.e. without taking into account positive temperatures during the growing season, on the formation of the elements of annual radial growth was practically unnoticeable.

The modelling of the combined influence of the meteorological factors under study using graphical representation of the quadratic function allows us to visually investigate the influence of those factors on the formation of macrostructural elements of pine and spruce wood.

The tree-ring chronologies of pine growing in mixed stands obtained from a set of trees mainly react to changes in external factors associated with the climatic features of the region in the same way, which indicates the priority of their use in dendrochronological studies.

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## CHAIN OF CUSTODY AND LABELLING OF FOREST PRODUCTS IN ROMANIA

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### Abstract

The aim of this paper is to analyse the history and the current situation of FSC CoC certified companies in Romania, to present an overview of the distribution of those companies in the country's regions, to highlight the FSC product category adopted by Romanian companies and which label type is the most common. In addition, the paper will outline a brief comparison between FSC CoC and PEFC CoC. The FSC database was accessed for the analysis. Then an excel spreadsheet was created starting from the name of the certified company, its location, the certification code, FSC certificate period of validity, the standard utilized for certification, types of certificated products traded, claims of the products, primary and secondary activity at certification. The data were processed using STATISTICA 7.0. Normality of distribution was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests. Compared with Europe, Romania is the third country by number of the FSC CoC certified companies. Their distribution shows a high concentration in North Romania. The main activity is primary processing (32 %) and the dominants FSC certified products found in Romania are part of the following categories: W1-Rough wood, W5-Solid wood (sawn, chipped, peeled), W3-Wood in chips or particles, W12-Indoor furniture, P5-Packaging and wrappings of paper. Among all FSC products types sold, the most frequent is FSC 100%. Therefore, the companies' efforts must be appreciated in this respect. These efforts require the use of a range of resources, including financial ones, to demonstrate the fulfilment of all the requirements of the voluntary FSC standard.

**Key words:** forest certification, FSC, standards, sustainability, wood products.

### Introduction

United Nation Conference on Environment and Development (ONCED) held in 1992 in Rio de Janeiro, Brazil was the official starting point toward sustainable forest management (SFM) (Diaz-Balteiro and de Jalón 2017). The principal output after the summit was to highlight the deforestation

in the tropics by SFM means. The aim of SFM is to provide the necessary information to customers about the forest and forest products (wood and non-wood products). SFM also assures that all the processes are held into environment, social and economic considerations (Marx 2010, Lewis and Davis 2015, Michal et al. 2019, Santoso et al. 2019), and to the bene-

fits of next generations (Clark and Kozar 2011). SFM is dealing with subjects related to deforestation in the tropics, maintenance of biodiversity, the quality of forest management (Rametsteiner and Simula 2003), circular economy (Näyhä 2019), and resources efficiency (Husgafvel et al. 2018).

The first forest certification label appeared with the establishment of Forest Stewardship Council in 1993. The following were Sustainable Forestry Initiative (SFI) in 1995, the Canadian Sustainability Association – Sustainable Forestry Management System (CSA) in 1996 and the Programme for the Endorsement of Forest Certification (PEFC) in 1999 (Ozinga 2010, Klarić et al. 2016, Halalisan et al. 2019). A number of certification schemes appeared at national level such as China Forest Certification Council (CFCC) in China, the Japanese Sustainable Green Ecosystem Council (SGEC), and Indonesian Ecolabelling Institute and Indonesian Forestry Certification Cooperation (IFCC) (Halalisan et al. 2018). The purpose of the certification system is to guarantee that all products are certified (Clark and Kozar 2011). Therefore, forests, as well as all processes, from timber extraction to the final product, are certified. The certified area has dramatically increased in the last decade. However, almost 90 % of the globally certified area is in the northern hemisphere (Kraxner et al. 2017). FSC has two types of certification. One of them is responsible for forest management (FM) certification and the other one is responsible for chain of custody certification (CoC) (Owari and Sawanobori 2008, Paluš et al. 2018).

The most important and widespread forestry certification schemes are FSC and PEFC. There are 320 million ha globally certified by PEFC (PEFC 2020), 212

million ha globally certified by FSC (FSC 2020a), and 92 million ha certified by both FSC and PEFC (FSC and PEFC 2020). Hence, 10 % of the global forests is certified by those two certification schemes (Enescu et al. 2019).

In stark contrast with this world perspective, Romania applied for FSC forest management certification and there are 2.8 million ha certified by FSC (FSC 2020a), and that represents 43.1 % from the forested area. Hence, there are no certified areas by PEFC in Romania (Gavrilut et al. 2015, Enescu et al. 2019). Our further analysis will focus on FSC. The FSC certification process is completely voluntary and provides, among other advantages, some benefits to stakeholders (Auld et al. 2008, Paluš and Kaputa 2009, Guan et al. 2019, Michal et al. 2019). The CoC process requires a level of coordination among all the parts involved in the process (Vidal et al. 2005). The certification procedure represents a 'third party audit' (Masters et al. 2010, Halalisan et al. 2018) and implies an independent certification body (CB) that carries out the assessment. Furthermore, those CB are controlled and periodically verified by Accreditation Service International (ASI). The most important features of audits are transparency, objectivity and efficiency (Cook et al. 2016).

FSC (2004) defines 'Chain of Custody' as 'an information trail about the path taken by products from the forest or, in the case of recycled materials, from the reclamation site to the consumer including each stage of processing, transformation, manufacturing, and distribution where progress to the next stage of the supply chain involves a change of ownership'. In order to sell products as FSC-certified or FSC-labelled and promote it with the FSC trademark, the organization must hold a



valid FSC CoC certificate and a signed trademark license agreement with FSC (Paluš and Kaputa 2009, Paluš et al. 2017, Brotto and Pettenella 2018). FSC CoC can be applied alone (FSC CoC certificate is issued) or along with Forest Management (Combined FSC FM/CoC certificate is issued) (Galati et al. 2017, Halalisan et al. 2019).

The aim of this paper is to analyse the history and the current situation of FSC CoC certified companies in Romania, to present an overview of the distribution of those companies on the country's regions, to highlight the FSC product category adopted by Romanian companies and which type of label is the most common. In addition, the paper will outline a brief comparison between FSC CoC and PEFC CoC.

## FSC certification process

FSC CoC includes all the processes, from the certified forest to the final product, which included all the steps (e.g. primary manufacture, secondary manufacture etc.). Two types of wood are eligible to be used in FSC CoC certification process. The first one is the FSC-certified wood (origin is from FSC-certified forests) and the second one is FSC controlled wood. FSC controlled wood is described by FSC (2004) as a 'Virgin material originating in non FSC-certified forests or plantations supplied with an FSC claim by a supplier which has been assessed by an FSC-accredited certification body for conformity with FSC CoC and/or FSC Controlled Wood requirements (FSC-STD-40-005 or FSC-STD-30-010)'. Each FSC certified products might differ from each other; they can have different composition of FSC-certified wood, as FSC forest

certified material (FSC 100%), controlled wood or recycled material.

There are three FSC label types: FSC Mix, FSC 100% and FSC Recycled (FSC 2016). FSC 100% refers only to wood originating from FSC-certified forests. Within FSC Mix there can be a combination between wood coming from FSC-certified forests and FSC controlled wood. Within FSC Recycled there is only recycled material.

The five FSC controlled wood categories of unacceptable sources (referred to as 'controlled wood categories') are: i) Illegally harvested wood; ii) Wood harvested in violation of traditional and human rights; iii) Wood from forests in which high conservation values are threatened by management activities; iv) Wood from forests being converted into plantations or non-forest use; v) Wood from forests in which genetically modified trees are planted (FSC 2016).

## Materials and Methods

The FSC database (FSC 2020a) was accessed for the FSC CoC analysis in Romania. Information was collected regarding the name of the certified company, location of the certified company and FSC certification code, FSC certificate period of validity, use standard utilized for certification, types of certified products traded, FSC products' claims, primary and secondary activity.

Available data on all 800 FSC CoC certified companies (with active certificate on 31 December 2019) were analysed together with all the annual reports (FSC certification situation – November 2019 Facts and figures) published at [www.fsc.org](http://www.fsc.org). An excel database was created based on the official data from FSC website. Ac-

cumulated data were processed by use of program product STATISTICA 7.0.

Normality of distribution was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests. Normality tests were used to determine if a set of data is well shaped by a normal distribution. Moreover, these were used to calculate how likely it is that a random variable underlying the dataset will be distributed normally. Kolmogorov-Smirnov test allows comparison of empiric distribution with theoretic distribution, usually a normal one, starting from the null hypothesis that the two distributions do not differ. Value resulting from the test is reported to critical threshold of 0.05. Thus, if the resulting value is greater than 0.05 the test is insignificant, null hypothesis is accepted and the distribution can be considered normal.

## Results and Discussions

### FSC CoC evolution

Even though the FSC appeared in 1993, the global interest for FSC certification started mostly after 1999 (Tuppura et al. 2016). The first FSC CoC certification of a Romanian company happened in 2001 (Halalisan et al. 2013). As a general trend, Romania followed the global one, as the first certified company appeared just two years after the global company was established. Between 2001 and 2012, the number of the FSC certified companies constantly rose, albeit slowly. In 2012, the number of companies hit 93 (Fig. 1). Since then, a significant increase was observed and by the end of 2019, the number of certified companies was 800.

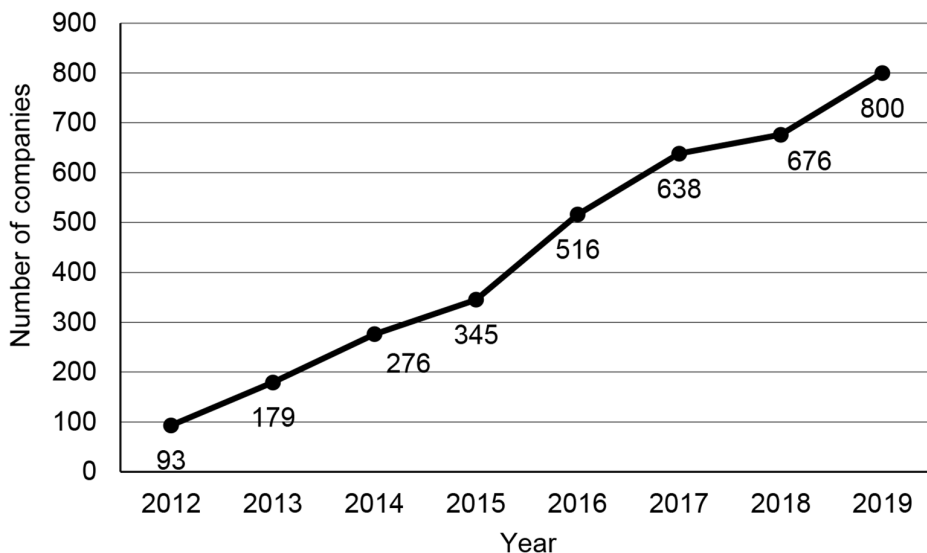


Fig. 1. FSC CoC evolution in Romania.

The increase interest for FSC begun in 2012, when there were 93 FSC CoC certified companies and 717,055 ha of FSC certified forest (Table 1). The interest in

the FSC certified forest area skyrocketed between 2012 and 2013. This is mostly due to the fact that the National Forest Administration ROMSILVA started to certi-

fy their forest districts under FSC scheme. Currently, there are just 27 private companies or forest districts, which have certified their FM (FSC 2020b). Now, there are more than 2.8 million ha of forest certified by FSC (FSC 2020a).

**Table 1. Correlation between FSC-certified area and the number of FSC CoC certified companies.**

| Year | FSC certified area, ha | No. of FSC CoC companies |
|------|------------------------|--------------------------|
| 2012 | 717,055                | 93                       |
| 2013 | 2,445,082              | 179                      |
| 2014 | 2,552,563              | 276                      |
| 2015 | 2,529,605              | 345                      |
| 2016 | 2,591,243              | 516                      |
| 2017 | 2,659,538              | 638                      |
| 2018 | 2,820,078              | 676                      |
| 2019 | 2,836,078              | 800                      |

The area was somehow limited and the development of companies was limited, too. In contrast, the forest certificated area in 2019 was four times higher (2,836,078 ha) and the companies have enough area to expand and enough experience in the certification process.

The connection between the FSC certified forest area and the number of FSC CoC certified companies was analysed using Spearman correlation, applying the two nonparametric variables. The results (Table 2) show a strong connection between the two variables: the increase of certified forest area is followed by an increase of the number of certified companies. This is reasonable, since when the source of FSC-certified wood (certified forest area) increases, the interest of companies for this segment (FSC-certified products) also rises.

**Table 2. Spearman correlation between FSC forest certified area and the number of FSC CoC certified companies in Romania.**

| Indicator                             | Certified area | Number of FSC CoC certified companies |
|---------------------------------------|----------------|---------------------------------------|
| Certified area                        | 1.000          | 0.976                                 |
| Number of FSC CoC certified companies | 0.976          | 1.000                                 |

Note: Spearman correlation (significant for  $p < 0.05$ ).

### Comparison between FSC CoC certification in Romania and other European countries

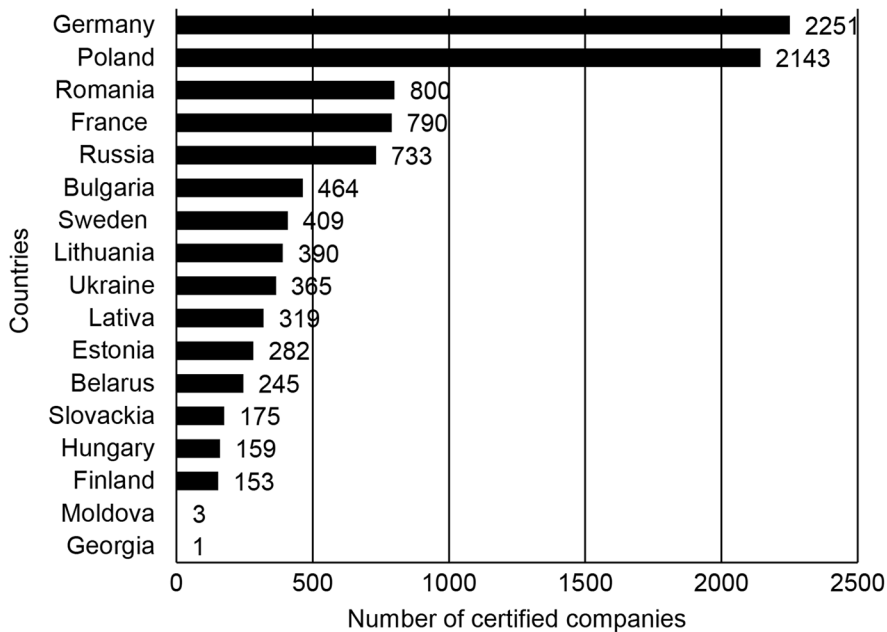
Romania has the most certified companies from Eastern Europe (Fig. 2). It even has more than France, but France has significantly more PEFC certified companies (PEFC 2020).

Germany and Poland are the top of the list because their certified forest area is much higher than in Romania, therefore the number of the companies is very high too. However, such a comparison

is somehow biased, because there are countries that have applied for other certification schemes (e.g. PEFC). Therefore, this analysis is just from the FSC CoC certified companies' point of view.

### FSC CoC vs PEFC CoC in Romania

The trend for the global PEFC certification did not affect Romania, since by the end of 2018 there were only 43 PEFC CoC certified companies in the country. Since then, a slow increase in the number of companies PEFC CoC certified compa-



**Fig. 2. FSC CoC companies in some European Countries.**

panies can be observed. There are 73 PEFC CoC certified companies on the official website. Therefore, the number increased with 20 companies in the last year and a half (from mid 2018 to 2020) despite that there is no PEFC certified area. As presented, there are 800 FSC CoC certified companies in Romania, and the FSC certified forest area is 2.8 million ha. The PEFC CoC certification had a slow adoption process, but should the PEFC certification scheme appear in Romania,

there will be a gradual increase in the number of the PEFC CoC certified companies, as they will have the actual PEFC certified forest and the proper PEFC certified wood to use for processing.

### Distribution by region

For a detailed analysis of the distribution, we grouped the companies in the eight development regions of Romania (Table 3).

The analysis of the number of compa-

**Table 3. Development regions.**

| Development region | County                                                               |
|--------------------|----------------------------------------------------------------------|
| North-East         | Bacau, Botosani, Iasi, Neamt, Suceava and Vaslui                     |
| South-East         | Braila, Buzau, Constanta, Galati, Tulcea and Vrancea                 |
| South-Muntenia     | Arges, Calarasi, Dambovita, Giurgiu, Ialomita, Prahova and Teleorman |
| South-West Oltenia | Dolj, Gorj, Mehedinti, Olt and Valcea                                |
| West               | Arad, Caras-Severin, Hunedoara and Timis                             |
| North-West         | Bihor, Bistrita-Nasaud, Cluj, Maramures, Satu-Mare and Salaj         |
| Centre             | Alba, Brasov, Covasna, Harghita, Mures and Sibiu                     |
| Bucharest-Ilfov    | Bucharest municipality and Ilfov county                              |

nies depending on the development regions (Fig. 3), shows that 30 % of them are situated Northwest region, 21 % are in the Central region and 12 % are in the Northeast region. The region with the smallest number of certified companies is

the Southwest Oltenia.

All of the counties were grouped into development regions. The mean of FSC CoC certified companies represent the number of companies from that region divided by the number of the counties

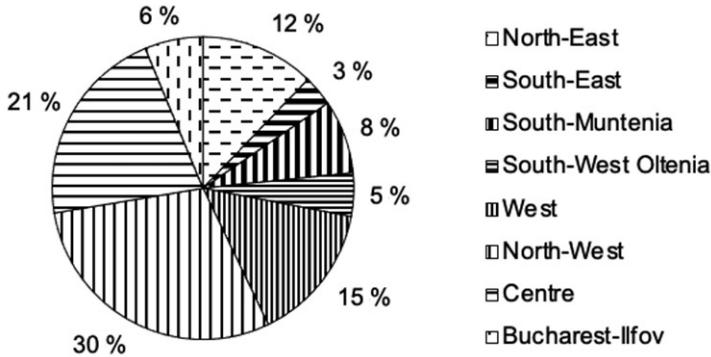


Fig. 3. FSC certified company distribution by development regions.

within that region. North-West and West regions present the greater means (32.5, and 32 respectively) of the certified companies. The following is the centre one

(25.5) (Fig. 4).

Northwest region has the maximum number of FSC certified companies in one county (120), Maramures county.

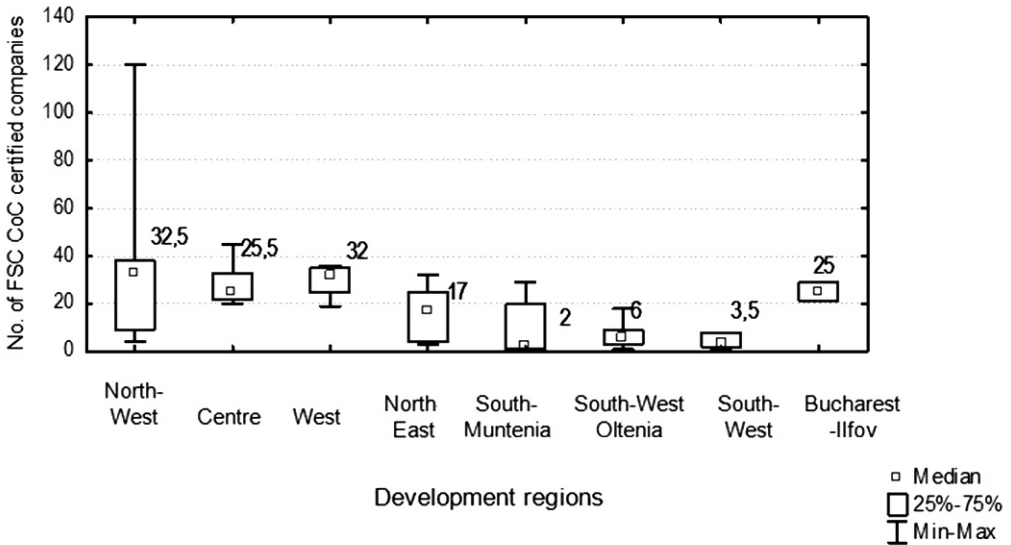


Fig. 4. FSC CoC certified companies statistic depending on the development regions.

Kruskal-Wallis ANOVA was used (Table 4) to test the statistic differences between regions (considered groups). The

results show that the statistic differences between the groups (those 8 development regions) are significant.

**Table 4. Statistic difference test between groups and the number of the FSC CoC certified companies.**

| Region             | Cod | Valid – N (county) | The sum of the ranks |
|--------------------|-----|--------------------|----------------------|
| North-West         | 101 | 6                  | 181.0                |
| Centre             | 102 | 6                  | 184.5                |
| West               | 103 | 4                  | 131.0                |
| North-East         | 104 | 6                  | 133.0                |
| South-Muntenia     | 105 | 7                  | 89.5                 |
| South-West Oltenia | 107 | 5                  | 65.0                 |
| South-East         | 108 | 6                  | 61.5                 |
| Bucharest-Ilfov    | 109 | 2                  | 57.5                 |

Note: Kruskal-Wallis ANOVA  $H(7, N = 42) = 21.52, p = 0.0031$ .

The certified companies are unevenly distributed within the country's territory. The Spearman correlation between the number of CoC FSC certified companies per county and certified forest area was conducted. The results ( $r = 0.63$ , significant for  $p < 0.05$ ) show that the distribution of certified companies is moderate depending on the FSC certified forest area.

The north part of the country is leading with the highest number of companies. In Maramures county alone, there are 120. The next one has almost one third of the number of the first county, Mures county has 45 companies. The gap between the second and the third one, Bistrita-Nasaud (38) is not as wide. After that, the number of companies per count slowly decreases. Olt, Teleorman, Tulcea, Vaslui, Ialomita, Giurgiu, Galati, Dolj, Constanta, and Calarasi have no more than 3 each. The small number of certified companies in Giurgiu, Ialomita, Olt, Teleorman counties is due to the lack of certified forest area. Meanwhile, the high number of companies in the north part is due to a high demand of FSC-certified products (e.g. from IKEA, which started to purchase only FSC-certi-

fied wood) and the available certified forest area.

### Distribution by activity type

Primary processing is the main activity (32 %) of the certified companies and the least represented is the paper making industry (6 %) (Fig. 5).

### FSC product types

One of the FSC CoC certification outcome is the sale of FSC-certified products. The type of products determined according to the standard FSC-STD-40-004a (V2-1), EN which serves for product classification (FSC 2013). The percentage distribution of offered FSC-certified products by Romanian companies is presented in Figure 6.

The prevailing part of offered products is represented by W1 – rough wood (39 %), W5 – Solid wood (sawn, chipped, peeled) (22 %), W3 – Wood in chips or particles (6 %), W12 – Indoor furniture (6 %) and P5 – Packaging and wrappings of paper (5 %). The rest of the products is not so well represented in Romania.



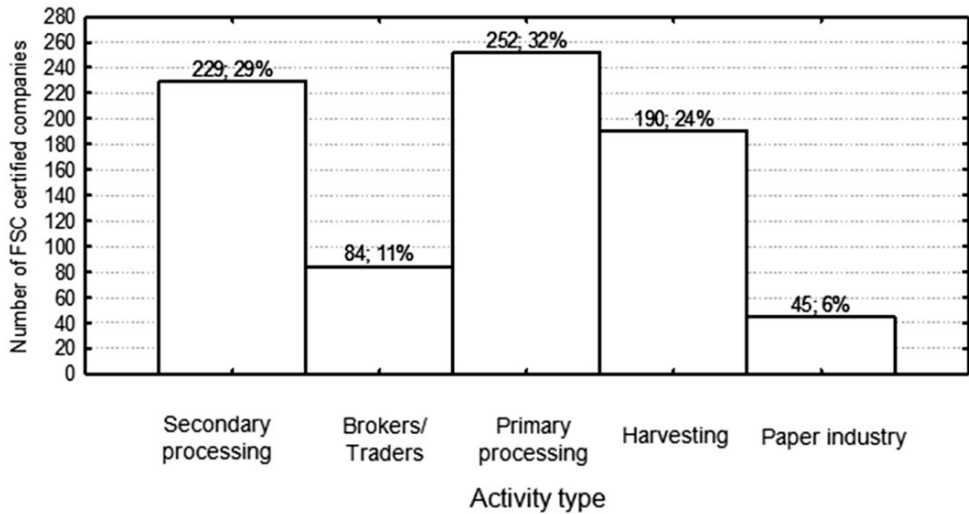


Fig. 5. Distribution by activity type.

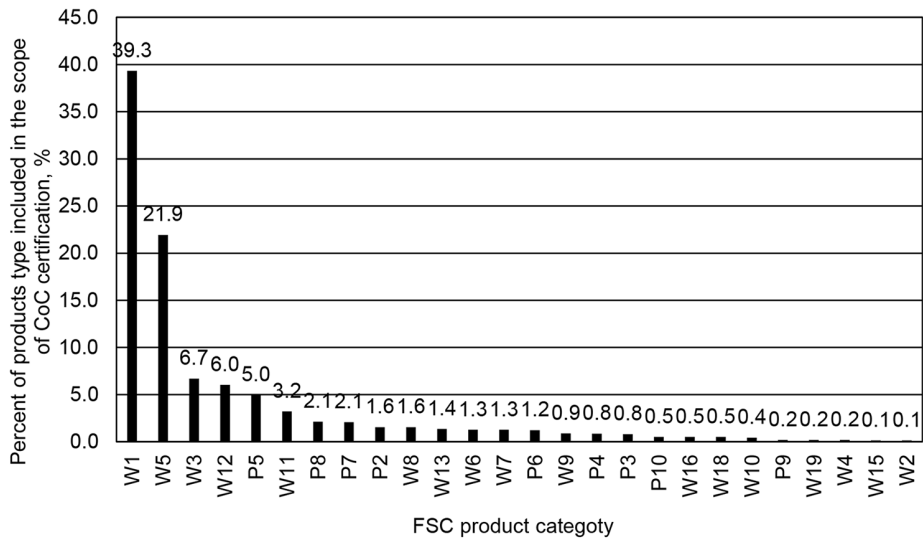


Fig. 6. Product categories.

FSC product categories: W1 – Rough wood; W5 – Solid wood (sawn, chipped, peeled); W3 – Wood in chips or particles; W12 – Indoor furniture; P5 – Packaging and wrappings of paper; W11 – Wood for construction; P8 – Printed materials; P7 – Stationery of paper; P2 – Paper; W8 – Wood panels; W13 – Outdoor furniture and gardening; W6 – Products from planning mill; W7 – Veneer; P6 – Household and sanitary pulp and paper products; W9 – Engineered wood products; P4 – Corrugated paper and paperboard; P3 – Paperboard; P10 – Other pulp and paper products not elsewhere classified; W16 – Household articles; W18 – Other manufactured wood products; W10 – Wood package and similar; P9 – Bobbins, spools, rolls and similar; W19 – Other wood products not elsewhere classified; W4 – Impregnated/treated wood; W15 – Recreational goods; W2 – Wood charcoal.

Companies are not restricted to only one product type and can choose different products, listed in the standard depending on their processing/trade capacities; they can choose a wide range of products.

### FSC output categories

Applicable FSC output categories' (FSC 100%, FSC Mix, FSC Recycled and FSC controlled wood) percentage distribution is presented in Figure 7.

The prevailing part of offered certified products are FSC 100% claimed (66 %), followed by FSC Mix claimed (22 %). The FSC Recycled and FSC Controlled wood claims are both represented by less than 10 %. FSC 100% claimed is the raw material, which comes from FSC certified forests and which has not been mixed with material from another category. It is eligible to be used in all FSC product groups, however other materials cannot be used for FSC 100% product groups (FSC 2015).

### Conclusions

FSC certification in Romania has become a reality in the forestry sector. Both the

customers' demand (Howe et al. 2005) from the external markets and the interest in demonstrating compliance with an international standard have contributed to the increased interest in FSC certification. Following up the area distribution of the certified companies, we noted that those are concentrated close to large processors, which demand the FSC certified products. The results show a strong correlation (Spearman correlation was used) between the evolution of the FSC forest certified area and the number of FSC CoC certified companies. The comparison with the other European countries is strictly from the FSC point of view, because there can be other certification schemes of even other standards, which ensure compliance with the environmental requirements (e.g. ISO 140001), which were not the purpose of this study. Similarly, there is just a brief comparison between Romanian certified companies (FSC CoC vs PEFC CoC), just to highlight the fact that FSC is currently leading at the national level. However, PEFC has certified some companies even without having any PEFC certified forest area, if PEFC starts to certify forest area, the number of PEFC CoC certified companies can dramatically increase.

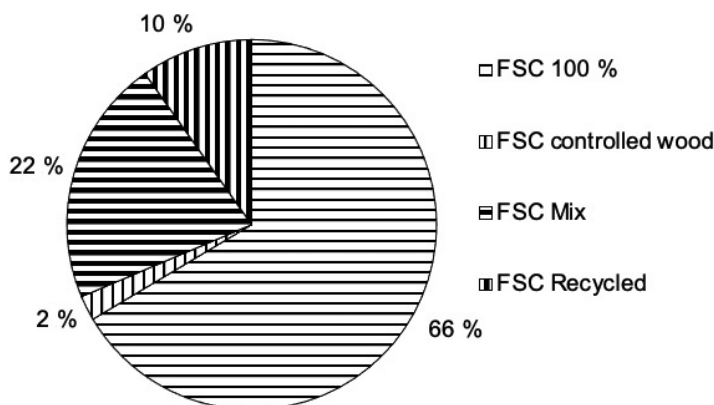


Fig. 7. Output categories percentage distribution.

The North-western part of Romania has the highest proportion of the certified companies and the highest number of FSC CoC certified companies in one country only. The three largest regions have 66 % of the Romania FSC CoC certified companies. Most of the certified companies focus their activity on secondary processing. The main FSC-certified products offered by Romanian companies are: W1 – Rough wood, W5 – Solid wood (sawn, chipped or peeled), W3 – Wood in chips or particles, W12 – Indoor furniture, P5 – Packaging and wrappings of paper. The most frequent claim is for the FSC 100%.

The companies' efforts for FSC CoC certification must be highly appreciated. These efforts require many resources, including human and financial ones, in order to demonstrate the fulfilment of all the requirements of the voluntary FSC CoC standards.

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## ACTIVITY OF THE EUROPEAN MOLE *TALPA EUROPAEA* (TALPIDAE, INSECTIVORA) IN ITS BURROWS IN THE REPUBLIC OF MORDOVIA

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### Abstract

A new method of studying the activity of European mole *Talpa europaea* (Linnaeus, 1758) with use of digital portable voice recorders is developed. European mole demonstrates polyphasic activity pattern – three peaks of activity alternate three peaks of relative rest. Moles are found to have activity peaks from 23:00 to 3:00 h, from 6:00 to 9:00 h and from 15:00 to 18:00 h, and three periods of rest: from 3:00 to 6:00 h, from 9:00 to 15:00 h and from 18:00 to 23:00 h. Mole's rest is relative since animals show low activity during periods of rest. Average daily interval between mole passes is 2.5 h. Duration of audibility of continuous single European mole pass by the microphone varies from 11 to 120 seconds. On average, it is 37.5 seconds.

**Key words:** animals, daily activity, day-night activity, voice recorder.

### Introduction

In many countries, the European mole *Talpa europaea* (Linnaeus, 1758) is an object of constant modern research (Komarnicki 2000, Prochel 2006, Kang et al. 2009). It inhabits mixed and deciduous forests, forest-steppes of Europe and Western Siberia to the east to Irtysh (Pavlinov et al. 2002, Zaytcev et al. 2014). For a long time, systematic researches on the ecology and biology of this species have not been conducted in Russia.

The biological activity of animals is corresponding and consistent with the level of daily and seasonal cycles in changing the complex of environment conditions

where light factor is essential (Shilov 2001). Activity of many mammals is investigated under various conditions of the light regime. For underground animals, especially for the different mole species, such information is fragmentary.

Individual moles occupied a well defined home range, which varied in size from an average of 4300 m<sup>2</sup> for males to an average of 1658 m<sup>2</sup> for females. Range overlap was observed between animals of different sex, while home ranges patrolled by animals of same sex were largely exclusive. Overlap was highly reduced when core areas of activity were considered. Daily activity rhythms showed a regular alternation between periods of rest and



activity, each lasting about four hours. Activity patterns of females were better synchronized than those of males, a feature probably related to mating activity (Loy et al. 1992, 1994).

Mole shows more activity at night than during the day (Kuzynkin 1935), although Stein (1950) reported there was no difference. A lot of studies showed that the activity of moles alternates every three to four hours (Gorman and Stone 1990, Loy et al. 1992). Individual area and rhythms of activity were investigated using radio telemetry and radioactive isotope (Godfrey 1955, Gorman and Stone 1990, Loy et al. 1992, Macdonald et al. 1996). Analysis of daily and seasonal activity of North Caucasian mole (*Talpa caucasica* Sat., 1908) demonstrates that this species is active year-round, day and night (Dzuyev et al. 2015).

Studies by Macdonald et al. (1996) show that moles had a triphasic pattern of activity, but this became tetraphasic under drought conditions. These differences could be related to seasonal differences in soil moisture. On average, each mole spent only 0.9 % of its time within 6 m of another mole, and only 3 out of 46 dyads showed evidence of being attracted to each other; there was no evidence from the simultaneous movement patterns of neighbouring moles that they avoided each other. Although moles tended to return to the same part of their range at the same time on successive days, there was also some indication of gradual changes in the spatial pattern of daily home range use.

In the Middle Volga, the activity of European mole has not been studied before, so there was a hypothesis about the applicability of the polyphase activity rhythm of the animal in our conditions. Aim of this study is to assess activity of the European

mole in its burrows. This paper presents the results of research in this area and describes the method that can be used to study other underground animals.

## Material and Methods

The work was carried out in two districts of Republic of Mordovia – located in the centre of the European part of Russia. The study area belongs to the forest-steppe natural zone. The climate of the region is moderately continental with pronounced seasons throughout the year. The influx of direct solar radiation varies from 5.0 in December to 58.6 kJ/cm<sup>2</sup> in June. Total radiation throughout the year is 363.8 kJ/cm<sup>2</sup>, the radiation balance is 92.1 kJ/cm<sup>2</sup>. The average annual air temperature varies from 3.5 to 4.0 °C. The average temperature of the warmest month, July, is in the range of +18.9 to +19.8 °C. Extreme temperatures in June reached 33 °C (in 2019). Extreme temperatures in July reached 35 °C (in 2020). Extreme temperatures in August reached 32 °C (in 2016, 2019). The average annual precipitation is 480 mm. Over the course of observation lasting for many years, periods of more and less humidification were noted, ranging between the minimum and maximum values of 120–180 mm. Distribution of precipitation across the territory is not very diverse. The average long-term value of evaporation is calculated to be in the range of 390–460 mm (Yamashkin 1998, Andreychev 2017).

The study was conducted at the biological station (village Simkino) of Mordovian University in Bolshebereznykovsky district (54°17' N and 46°16' E) and in Saransk city district (54°16' N and 45°11' E) in 2016–2020. In the first section, the biotope is a mixed forest, and in the sec-

ond section, the biotope is a broad-leaved forest. Moles are distributed unevenly in the region because it is quite close to the southern border of their habitat which goes across Penza oblast, to the south of Penza (Zaytcev et al. 2014). In Volga Region the European mole is a common widespread species (Sokolov 1984). In the forest, where its activity was investigated, were registered 6 to 9 burrows per 1 km. According to the assessments of European mole habitats in the North-West of Russia (Rusakov 1965, Nesterkova 2014), favourable ones are defined as areas containing 15 or more burrows per 1 km, areas containing 5–10 burrows considered to be satisfactory, and areas containing less than 5 burrows are mediocre. Thus, the study was conducted in satisfactory European mole areas.

Before studying the mole, the method with the use of voice recorders was tested and improved in the study of the activities of different animal species (Russian desman, greater mole-rat, Eagle owl) (An-

dreychev et al. 2017, Lapshin et al. 2018, Andreychev 2019a). I looked for near-surface burrows of 50–55 mm in diameter that crossed dirt roads. I opened mole's burrows along the roadside and installed Olympus voice recorders perpendicular to burrow's direction. Each recorder was placed in a 0.3–0.5 liter water plastic bottle used as a container. The catch of moles after studying their activity at the end of August was performed with cylinders. It was done to determine the number of animals living in burrows. The total absence of moles was then established by means of voice recorders, which records were assessed for the absence or presence of moles' noises (Fig. 1). Up to five moles were caught from each of the burrows at the end of the summer, a total of 24 individuals were caught during the work.

Activity for certain months (June, July, August) was detected as follows: initially, activity of the animals was fixed at each place where a voice recorder was installed by registering the number of ani-

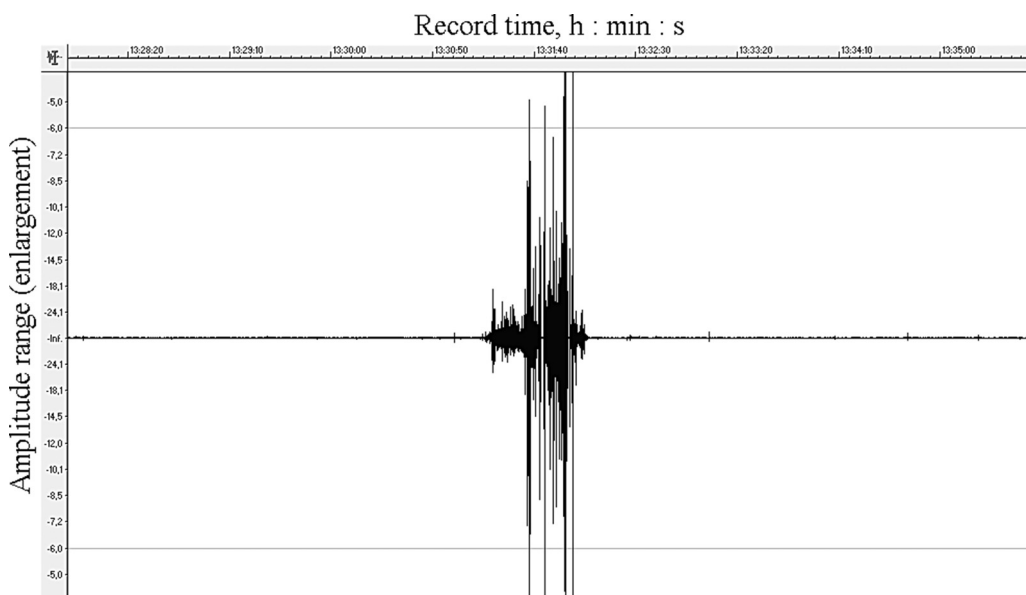


Fig. 1. Oscillogram obtained by recording noises by voice recorder in a burrow.

mal passes through main (transit) passages near the recorder per day (24-hour period); this number was taken as 100 %. In total, 14 voice recorders were used. The studies were conducted on both sites in 7 burrows each. The area of each plot was 1 km<sup>2</sup>. Then activity rate (%) was evaluated for certain hours, e.g. 15.00 to 16.00 h. To make description more convenient, days were conditionally divided by hours into periods of activity and relative rest. As a rule, the following record schedule was used: 3–4 days in each decade of each month. The duration of voice recorder usage in burrows depended on expediency. In continuous network of burrows with a

small amount of fresh ground emissions, we kept microphones until alkaline batteries run out (completely discharged) so that to make objective assessment of activity. And, on the contrary, in continuous network of burrows with a lot of fresh molehills under changing weather conditions (long-lasting rains), in order to save voice recorders from moisture, working time was reduced to 48 h (2 days). Sound recordings were carried out in the same mole burrows. During the study, 123 sound records were received and processed with the total duration of 10,670 h (Table 1). More than 19,000 moles passes by microphones were recorded.

**Table 1. The volume of material on the activity of the European mole.**

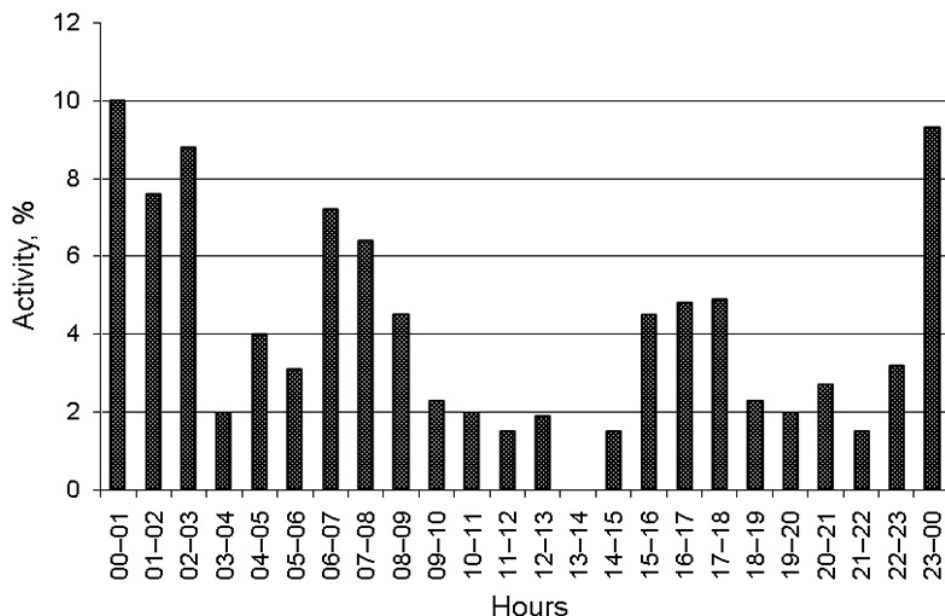
| Parameters                              | Months |      |        | Total |
|-----------------------------------------|--------|------|--------|-------|
|                                         | June   | July | August |       |
| Bolshebereznykovsky district            |        |      |        |       |
| Number of sound records                 | 27     | 28   | 18     | 73    |
| Number of days recording                | 95     | 102  | 76     | 273   |
| Average number of sound records per day | 8      | 9    | 8      | 8     |
| Saransk city                            |        |      |        |       |
| Number of sound records                 | 18     | 20   | 12     | 50    |
| Number of days recording                | 60     | 68   | 43     | 171   |
| Average number of sound records per day | 8      | 10   | 8      | 8     |

Office processing of the audio recordings obtained was carried out using AIMP (2007) and Audacity (2015). This software allows identification and subsequent listening to the noises of moving mammals along the burrows by frequency characteristics in visual mode. Alternative software, in particular, SONY ELECTRONICS INC. (2019), was used to convert audio files from WMA to WAV and divide them into short sections for easy analysis in Audacity. Comparison of the average number of mole passes at a microphone 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

Our data suggest that there are three periods of pronounced activity and three periods of relative rest in mole's daily activity (Fig. 2). They are found to have the first activity peak from 23:00 to 3:00 h, the second one from 6:00 to 9:00 h, and the third from 15:00 to 18:00 h. The last period is less pronounced than the previous two. Duration of rest periods is three to six hours. The first period of rest occurred



**Fig. 2.** Daily activity of the European mole in summer months.

from 3:00 to 6:00 h, the second – from 9:00 to 15:00 h, and the third – from 18:00 to 23:00 h. The mole's rest is relative since animals show low activity during periods of rest. For one hour, from 13:00 to 14:00 h, no passing of the animal through main passages was observed.

During periods of pronounced activity, moles travel along main passages 3–4 times per hour. The maximum registered number is five passes per hour from 00:00 to 1:00 h on July 11, 2016 and June 21, 2017. During periods of relative rest, moles travel through the main passages up to two times per hour. Most often we registered one pass per hour or no movement at all. The interval between single mole passes varies from 10 min to 15 h. The average daily interval between mole passes is 2.5 h. Duration of audibility of a continuous single mole pass by the microphone varies from 11 to 120 s. On av-

erage, audibility of mole passage by the voice recorder is 37.5 s.

The maximum activity in June is observed during certain periods: 23:00 to 00:00 h, 2:00 to 3:00 h, and 6:00 to 7:00 h. Moles are active for 23 h a day. High burrowing activity is probably caused by active search for food and patrolling individual area. The high activity of moles is also indicated by land activity, and by rates of molehills appearance in particular.

In July periods of activity shift to night hours. In the general rhythm of animals' activity, the number of daily passes is significantly reduced. For one hour, from 13:00 to 14:00 h, no passing of the animal through main passages is observed. From 9:00 to 13:00 h sporadic passes are registered. The highest activity is observed from 00:00 to 1:00 h. Evening activity (15:00 to 18:00 h) is slightly less than the night one. Morning activity (6:00

to 9:00 h) is even less pronounced during this month. The tendency to shift activity to nighttime is still observed in August. The number of moles' passes through the main passages is reduced. The maximum number of registered passes is fifteen per day.

Analysis of the number of mole passes per day in summer months (June, July, August) reveals that their average number varies from 8.15 to 9.62 (Fig. 3). In June the average number is 8 (min 3 – max 28) per day. In July it is 9 (min 2 – max 33), in August 8 (min 3 – max 15). It is important to note that the registered activity rate does not refer to a single animal living in a burrow. It is an indicator characterizing activity of all animals in the burrow. The burrow is inhabited by several animals. This fact is demonstrated by full catching

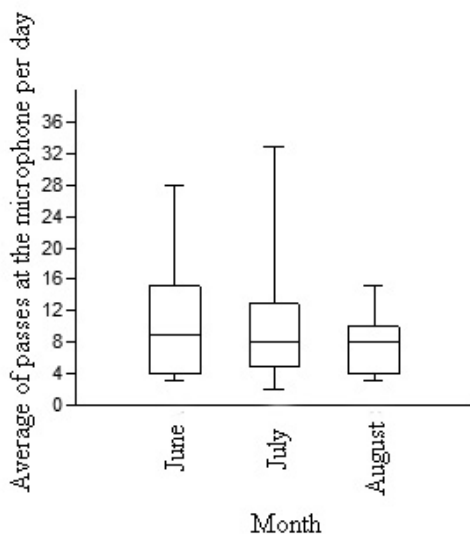
of moles at a number of selected burrows after studying their activity. We caught two to five animals in one burrow.

Besides the moles, the activity of other animals (shrew, vole, etc.) was recorded in burrows. This information will be presented in a separate article. The noises of the studied moles are clearly distinguished from the noise of their commensals. Differences in the waveform of the sounds produced by these animals are discussed in previous articles (Andreychev 2018, 2019b). Each year, moles demonstrated polyphasic activity pattern when three peaks of activity alternate with three peaks of relative rest. Thus the mole also has polyphase activity in the region as does its closest relative the Russian desman *Desmana moschata* (Andreychev et al. 2020).

Comparison of the average number of mole passes near the microphone per day for each month was made using One-way ANOVA. It did not reveal statistically significant differences between the three months ( $F = 0.58$ ,  $df = 31, 63$ ,  $p > 0.05$ ).

Experimental data can serve as a confirmation of our results on the polyphase rhythm of mole activity with three rest periods. Like wild moles, captive moles have a period of sleep lasting three to five hours followed by a period of activity of about the same duration. This activity pattern was usually repeated three times every 24 h (Mellanby 1967).

Other scientists have identified slightly different periods of mole activity. However, this can be explained by the fact that the differences are sexual in nature. Males are active at some time intervals, while females are active at other times. In females, the most pronounced periods of activity are observed in the morning (from 06:00 to 12:00 h) and in the afternoon (from 15:00 to 18:00 h), while the rest periods are



**Fig. 3. Ranges of passes of European mole in a burrow per day.**

Note: 'A strip in a box' – a median, a rectangle – dispersion of values of rather main trend (25–75 % quantiles), pieces around (above and below) a rectangle – the minimum and maximum values.

concentrated before sunrise (from 3:00 to 6:00 h) and around the noon (from 12:00 to 15:00 h) (Loy et al. 1992). As part of the discussion of differences and similarities in the activity of individuals of different sexes, a general trend can be found. A common feature of both males and females is the presence of three to four periods of activity during each 24 h, although the length of these periods is highly variable. However, despite the tendency to alternate periods of rest and activity, it is difficult to determine a certain pronounced period that differs from the others by the type activity (Loy et al. 1992, 1994).

Our results of research in nature are consistent with the results of previous experimental studies in our country. Using a MAG-8M tape recorder, it was shown that moles exhibit mainly nocturnal activity (Alexandrova and Frolova 1967). X-ray examination of the gastrointestinal tract showed the peculiarities of the animals' digestion, the cycle of which is completely over within 4–5 h (Spiridonova 1949). Such a short period of digestion creates the need for frequent food intake and makes prolonged fasting impossible. This information explains the reason for the three-phase activity of a mole, identified in our studies.

The presence of differences between activity rhythms of *T. europaea* males and females during the breeding season has already been noticed (Stone and Gorman 1985, Stone 1986). Studies of the mole in Mordovia revealed a partial coincidence of rest periods from 3:00 to 6:00 h and from 12:00 to 15:00 h as well as coincidence of activity periods from 6:00 to 12:00 h and from 15:00 to 18:00 h. In Scotland and in Mordovia, moles have slightly different periods of activity; these differences may be associated with geographical zoning of the area where the moles live.

## Conclusions

Thus, the daily rhythm of the European mole has a polyphase character with frequent changes of activity and rest. It is active both during daylight hours and at night. But if during the day the activity is subject to fluctuations, then at night a stable high activity is recorded. In many regions of Russia, the mole is a malicious pest of gardens and kitchen gardens, so the periods of activity identified by us can be used to catch them. Periods of rest are characterized by a length of three to six hours. On average, the interval between mole passes per day is 2.5 h. This interval is important to know in order to catch all possible inhabitants of the burrows. The duration of audibility of a continuous single pass of a mole past the microphone ranges from 11 s to 120 s.

It is of undoubted interest whether there are differences in the studied aspect of the common mole in one of the populations on the southern border of the range compared to the populations that are located in good and mediocre land.

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## PROTEIN CONTENT IN BEE-COLLECTED POLLEN OF SOME PLANTS IN FORESTRY REGION

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### Abstract

Proteins are one of the main components of honey bee-collected pollen. In present days pollen is of great interest as food supplement. The objective of this research was to determine the protein content of pollen in some floral species in semi-mountain area and to analyse the length of life of bees fed on different protein content in the pollen. The analysis of 30 samples showed that bee pollen was described by a content of protein, which depends on the botanical origin of bee-collected pollen. The percentage of the total protein content in the bee pollen grains ranged from 14.83 % for *Helianthus annuus* L. to 26.14 % for that of *Prunus cerasifera* Ehrh., and the average value was 20.90 %. In this research Rosaceae floral species had the highest levels of protein content of all studied representatives. The impact of the protein food on the length of life of worker bees was found. The average lifespan of worker bees fed on pollen from *P. cerasifera* was 24.74 days, whereas it was 16.92 days for the worker bees fed on pollen from *H. annuus*. Lifespan of honey bees consumed pollen with higher protein content is prolonged compared to those that consumed pollen with lower protein content.

**Key words:** honey bee, monoflora pollen, protein.

### Introduction

Pollen plays a key role in the development, reproduction and productivity of honey bees (*Apis mellifera* L.) (Radev et al. 2014), as it is rich in nutritional components (Dietz 1975, Brodschneider and Crailsheim 2010). Pollen also plays a major role in the development of honey bee larvae and vitality of colony (Schmidt et al. 1987, Roulston and Cane 2000). In present time the researches in bee pollen are under deep studies, because it is a rich source of proteins and amino acids. Bee pollen is also used by humans (Ianuzzi 1993, Campos et al. 1997).

According to previous studies protein content in pollen depends on the plant species (Roulston and Cane 2000). Protein content in pollen grains collected by honey bees from different plant species in USA ranges from 7 % to 30 % (Todd and Bretherick 1942), from 8 % to 40 % (Herbert 1992), and from 9.5 % for *Pinus radiata* D. Don to 36.9 % for *Banksia ornata* F. Muell ex. Meisn. in Australia (Rayner and Langridge 1985). In another study in the USA, Roulston et al. (2000) found protein content ranging from 2.5 % for *Cupressus arizonica* Greene to 61.7 % for *Primula clevelandii* (Greene) A. R. Mast et Reveal. Research conducted by Liolios

et al. (2016) in the region of Thessaloniki, Greece showed that it ranged from 12.8 % of *Smilax* sp. L. to 30.1 % for *Fallopia* sp. Adans., with an average of 20.8 %. Radev (2018) determined protein content in pollen in fifty plants in Central Thracian lowland. He discovered a range from 11.5 % for *Chondrilla juncea* L. to 27.4 % for *Cucumis melo* L., and the average value was 19.9 %. Maurizio (1960) classified pollen in four groups upon the influence on honey bee physiology. The first group with high quality pollen includes willow, fruit trees, white clover, and corn. The second group includes less contained nutritious pollen from elm, dandelion and cottonwood. The third group includes pollen with a fair nutritional value from hazelnut and alder. The fourth group includes plants with the poorest nutritive value in pollen – species of pine trees. The protein content in pollen of *Acacia* on the Australian coast is 16 %, whereas the protein content in pollen of *Acacia* inside the continent is 26 % – 29 % (Kleinschmidt and Kondos 1977). According to a study by Taranov (1986) pollen from anemophilous plants is poorer in protein than the entomophilous.

The objective of this research was to determine the protein content of pollen in some floral species in semi-mountain area. Also, it is analysed the length of life of bees fed on pollen from a taxa with different protein content in it, to give a light on the impact of the protein on the vitality of honey bees.

## Materials and Methods

Bottom pollen traps were used at five beehives and the pollen grains were collected every second day during the apicultural season in region of Saedinenie (42°36'96" E and 25°30'95" N), Bulgaria.

The area is located at the end of the central part of the mountain of Sredna gora, part of the administrative district of Stara Zagora, 308 m a.s.l.

Four hundred and twenty samples of mixed pollen were collected. The pollen loads of each hive were carefully mixed and a sample of 10 % was taken (Dimou and Thrasyvoulou 2007). Pollen pellets were separated over white sheets according to the physical characteristics – colour, shape and structure. Palynological analysis was carried out using a similar methodology as described by Louveaux et al. (1978). To identify the pollen database of plants from the area was created.

For nitrogen content determination, pollen was analysed using Kjeldahl method. The crude protein content was estimated using factor 5.60 (Rabie et al. 1983), applying formula (1).

$$0.791—, \quad (1)$$

where:  $P$  is crude protein content, %;  $V$  is the volume, mL of HCl used for titration; and  $m$  is the amount of pollen, g.

Three replicates from each sample were analyzed, and the results were averaged.

They were made into two groups with five cages 10×10×10 cm each. One hundred newly emerged worker bees were placed in each cage and fed on 50 % sugar syrup. In the quantity of 20 mL sugar syrup for the first group, two grams of pollen from *P. cerasifera* and for the second group, two grams of pollen from *H. annuus* were added. The syrup was changed daily with new one. The experimental cages were covered for darkness in a room at a temperature of 28 °C. Worker bees were viewed every day and the last dead was taken out.

The results were statistically processed by using Excel and Anova to compare the

protein content between identified pollen grains and the lent of life of worker bees.

## Results and Discussion

The protein contents of bee-collected pollen grains from 10 identified floral species in the studied area are represented in Fig. 1. The percentage ranged from 14.83 % for *H. annuus* to 26.14 % for that of *P. cerasifera* and the average value was 20.90 %. Other protein contents of pollen are reported in Fig. 1 as well.

The results confirmed other studies – the fact that pollen grains from different plants have different protein con-

tents. In this study results of some honey bee plants belonging to the families: Asteraceae, Rosaceae, Chenopodiaceae, Juglandaceae, Fabaceae, Salicaceae, Papaveraceae and Brassicaceae are presented.

No significant difference in the protein content between entomophilous compared to entomophilous floral species ( $F \leq F_{crit}$ , Anova: Single factor) was found in this study. *Salix* sp. was called as wind-pollinated floral species in the present study. It is noted that entomophilous plants especially *Juglans regia* L. provided very high protein content – 18.24 %, and *Salix* sp. – 19.94 %.

In this study significant difference was

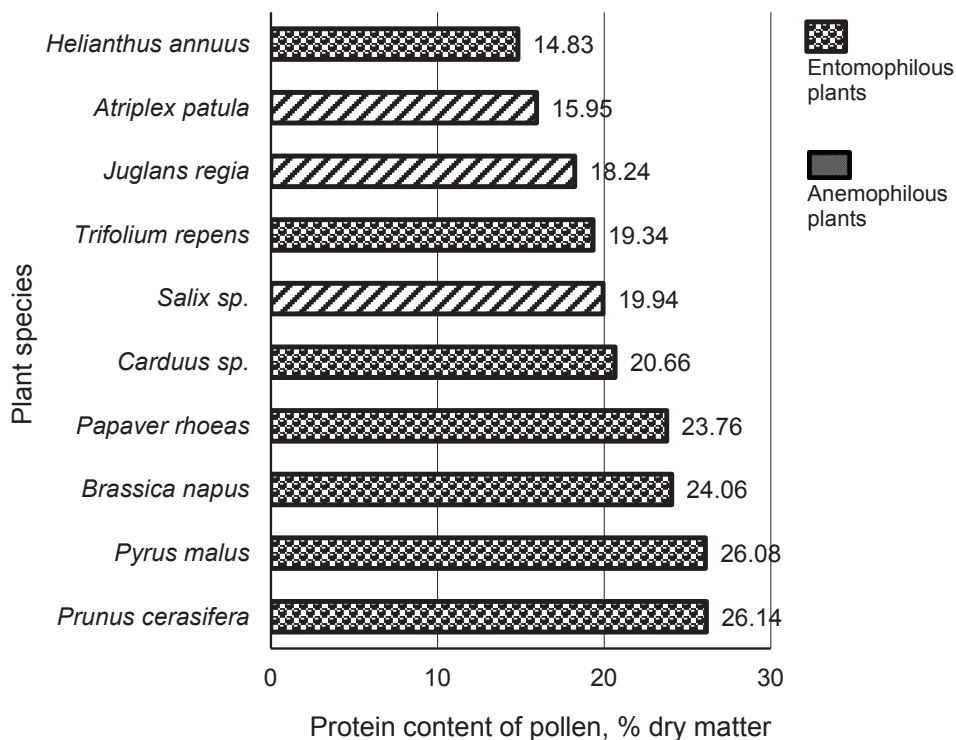


Fig. 1. Protein content of 10 pollen species.

found between the lifespan of worker bees fed on pollen from *H. annuus* (14.83 % protein content) compared to the lifespan of worker bees fed on pollen from *P. cerasifera* (26.14 %) (Table 1). For worker bees fed on pollen from *P. cerasifera* it was 24.74 days, whereas it was 16.92 days for those fed on pollen from *H. annuus* ( $F > F_{crit}$ , Anova: Single factor). The lifespan of honey bees that consumed pollen with higher protein content is prolonged compared to those that consumed pollen with lower protein content. There has been a highly significant positive correlation ( $r = 1$ ,  $p \leq 0.05$ ).

**Table 1. Average length of life of worker bees.**

| Fed worker bees                                                         | Average length of life in days | Means $\pm$ std  |
|-------------------------------------------------------------------------|--------------------------------|------------------|
| Worker bees fed on sugar syrup and pollen from <i>Prunus cerasifera</i> | 24.74                          | 24.74 $\pm$ 1.06 |
| Worker bees fed on sugar syrup and pollen from <i>Helianthus annuus</i> | 16.92                          | 16.92 $\pm$ 0.87 |

In this research Rosaceae plant species showed the highest levels of protein content of all studied representatives. The one frequently cultivated crop *H. annuus* produces pollen with the lowest protein content. The other frequently cultivated crop *Brassica napus* L. produces pollen with the third highest protein content. The protein content levels of the cultivated plants may be due to hybrid influences and further researches are recommended.

In the present study protein content value is much higher for: *Carduus* sp. with 2.86 %; *Pyrus malus* with 2.88 %; *P. cerasifera* with 3.74 %; especially *J. regia* with 4.84 %, and much lower for *Trifolium repens* with 4.76 % compared to Radev (2018) previous results for Central Thracian lowland.

The protein content results are compared for the species given in Table 2.

The varied results among the studies may be due to many reasons – different methods of analysis, climate, geographical region, soil composition and for the cultivated plants the hybrid variety. Further researches could give more light for the protein supply available to honey

**Table 2. Comparing pollen protein contents results in %.**

| Species                  | Our present results | Our previous results (Radev 2018) | Results of other authors |
|--------------------------|---------------------|-----------------------------------|--------------------------|
| <i>Prunus cerasifera</i> | 26.14               | 22.4 ↓                            |                          |
| <i>Pyrus malus</i>       | 26.08               | 23.2 ↓                            |                          |
| <i>Brassica napus</i>    | 24.06               | 25.1 ≈                            | 31.9 <sup>2</sup> ↑      |
| <i>Papaver rhoeas</i>    | 23.76               | 24.3 ≈                            | 24.51 <sup>5</sup> ≈     |
| <i>Carduus</i> sp.       | 20.66               | 19.9 ≈                            |                          |
| <i>Salix</i> sp.         | 19.94               | 17.8 ↓                            | 22.2 <sup>5</sup> ≈      |
| <i>Trifolium repens</i>  | 19.34               | 24.1 ↑                            | 35.4 <sup>1</sup> ↑      |
| <i>Juglans regia</i>     | 18.24               | 13.4 ↓                            | 25.1 <sup>4</sup> ↑      |
| <i>Atriplex patula</i>   | 15.95               | 13.1 ↓                            | 17.1 <sup>3</sup> ≈      |
| <i>Helianthus annuus</i> | 14.83               | 14.5 ≈                            | 29.8 <sup>4</sup> ↑      |

The sources of other authors: Robertson (1929)<sup>1</sup>, Rayner and Langridge (1985)<sup>2</sup>, Proctor et al. (1996)<sup>3</sup>, Roulston et al. (2000)<sup>4</sup>, and Liolios et al. (2016)<sup>5</sup>. Comparison with our present results: ≈ – similar result, ↑ – higher result, ↓ – lower result.



bees. This information about nutritional value of pollen could be used by specialists for further research studies.

## Conclusions

The percentage of the total protein content in the bee-collected pollen grains ranged from 14.83 % for *H. annuus* to 26.14 % for that of *P. cerasifera* and the average value was 20.90 %. In this research Rosaceae floral species had the highest levels of protein content of all studied representatives. It is noted that anemophilous plants especially *J. regia* provide very high protein content. The average length of life of worker bees fed on pollen from *P. cerasifera* was 24.74 days, whereas it was 16.92 days for the worker bees fed on pollen from *H. annuus*. Lifespan of honey bees that consumed pollen with higher protein content is prolonged compared to those that consumed pollen with lower protein content.

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## SPECIES COMPOSITION, STRUCTURE AND QUALITY STATUS OF HEDGES IN BUKOVYNIAN CARPATHIAN REGION OF UKRAINE

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### Abstract

Object of the study are hedgerows in settlements of Ukrainian Bukovynian Carpathian region (Chernivtsi region of Ukraine). The species and quality composition, spatial, age and ecological structure and ornamental value of hedges. The formation of hedges as an element of landscaping the urban ecosystems of the Ukrainian Bukovynian Carpathian region occurred due to the influence of a number of objective (natural and anthropogenic) and subjective factors (traditions, socio-economic conditions and long-term plans for the development of the region, financing of activities for the formation and care of plantings in green spaces). The dendroflora of hedges of urban areas is represented by 32 species of woody plants from 24 genera and 15 families. *Carpinus betulus* L., *Buxus sempervirens* L., *Cornus alba* (L.) Opiz. and *Ligustrum vulgare* L. are most often used to form hedges. The vast majority of hedges is formed from one species (Chernivtsi – 98.3 %, other towns and villages – 71.1 %), and they are mainly single-row (Chernivtsi – 83.8 %, other towns – 58.2 %, villages – 70.2 %). In the settlements of the region, trimmed hedges predominate (Chernivtsi – 92.1 %, other towns and villages – 75.5 %). Most hedges are mean-height hedges (Chernivtsi – 65.8 %, other towns and villages – 66.9 %). For the formation of a curb hedge, *Spiraea media* Schmidt., *Buxus sempervirens*, *Ligustrum vulgare* are most often used. For first time, comprehensive studies of hedges in the settlements of Chernivtsi region of Ukraine (Bukovynian Carpathian region) were carried out according to their species composition, system, age and environmental structure, height and constitution. The features of functioning in urban ecosystems are established. A comprehensive assessment was made regarding the quality status and ornamental value of hedges in the green zones.

**Key words:** dendroflora, decorativeness, functionality of hedges, landscaping, urban.

### Introduction

In the general structural and functional organization of urban ecosystems, a special environment-creating and recreational role is played by complex green zones.

The formation of aesthetically attractive urban landscapes and street plantings involves the creation of hedges of various species composition, spatial structure and functional purpose, as an integral part of urban gardening (Myronchuk 2018, Carli-

er and Moran 2019).

The historical development of hedge use as an element of urban green spaces, including improvement of the environment, is directly related to urbanization processes, human economic and industrial activities, as well as the development of landscaping.

Hedgerow is one of the oldest elements of landscape gardening art, the history of which dates back thousands of years, and the first records date back to about 2000 BC (Bilous 2001, Aleksandrova 2003, Kucheryavyi 2018, Myronchuk 2018). It is an integral part of urban green spaces and plays an important role in protecting various objects and structures from the negative effects of both natural and anthropogenic factors, which is confirmed by other authors (Bilous 2001, Kucheryavyi 2001, Kurnytska and Myronchuk 2011).

The issues of the vitality of hedges of various species composition and spatial structure, as well as the analysis of their adaptive features in the urban environment, are highlighted in a number of scientific works (Hill 1979, Brooks and Agate 1998, Bird and Robson 1999, Chernyshenko 2001, Gutsulyak et al. 2006, Avramenko 2012, Larionov et al. 2015, Carlier and Moran 2019).

The role of hedges in solving environmental problems of urban environment has been studied by a number of scientists, who, among the most important environmental functions of hedges, generally distinguish sanitary-hygienic, barrier, and phytocidal functions (Uleiskaya and Komar-Temnaya 2002, Sapelin 2011, Avramenko 2012, Myronchuk 2018).

Hedges in urban ecosystems, like all other vegetation, experience adverse effects by urban development, which consists, first of all, in the violation of the technology of creation and mechanical dam-

age, as well as in the untimely carrying out agrotechnical measures for the care of woody plants. As a result of this, a reduction in the vitality of plants and their resistance to adverse natural and anthropogenic factors occurs (Burda 1991, Brooks and Agate 1998, Bird and Robson 1999, Chernyshenko 2001, Avramenko 2012, Larionov et al. 2015, Myronchuk 2018).

Impairment of the vital functions of plants in an urban environment occurs due to changes in the physical and mechanical properties of soils, diminishing of their fertility, and the presence of a high content of building inclusions in the soil profile. Soil contamination and the presence of asphalt pavement lead to a change in the temperature, air and water regimes of the soil, which negatively affects the vital activity of soil microflora and the state of vegetation cover – inhibition of growth and development, and sometimes complete destruction (Oreszczyn and Lane 2000, Larionov 2015, Logachyova and Soldatova 2015, Myronchuk 2018). A study of the growth, development, and vital functions of various woody plants under urban conditions and which can be used in hedges showed changes in morphological parameters, ecological plasticity, functional and vital condition (Uleiskaya and Komar-Temnaya 2002, Sapelin 2011, Myronchuk 2018, Carlier and Moran 2019).

Scientific studies of green areas in urban environment prove the significant natural landscape potential of hedges. However, the lack and inadequacy of measures for maintenance and care of hedges lead to a loss of ornamental value, sanitary-and-hygienic functions, and the appearance of less valuable plant species in their composition (Hill 1979, Oreszczyn and Lane 2000, Chernyshenko 2001, Hessayon 2007, Kurnytska and

Myronchuk 2011).

The development of effective environmental and rehabilitation agrotechnical measures and timely care of hedges in urban ecosystems will contribute to improving their qualitative condition and ornamental value, increasing resistance to adverse conditions of an urban environment (Hill 1979, Kucheryavyi 2003, Myronchuk 2018).

Scientists have not analysed the species composition, bioecological and spatial structure, and the quality status of hedges in urban ecosystems of Ukrainian Bukovynian Carpathian region, either.

The purpose of the study is to assess (determine) the ecological and biological features, functionality of hedges in urban ecosystems of Chernivtsi region of Ukraine (Bukovynian Carpathian region) and to suggest recommendations for the formation of hedges in the urban

environment.

## Object

The objects of the studies are hedges of urban ecosystems in Chernivtsi region of Ukraine (Bukovynian Carpathian region) (Fig. 1). It is divided into three physical-geographical regions: Prut-Dniester elevated lowland forest-steppe, Prut-Sirets elevated hilly forest meadow and Pokut-Bukovynian Carpathians. According to the peculiarities of the relief, these physical-geographical regions represent plain, foothill and mountainous parts (Gutsulyak et al. 2006).

The climatic conditions are influenced by surface nature, therefore, in the mountains it is always colder and with more precipitations, in the plains – warmer and drier. The average annual air tempera-



Fig. 1. Bukovynian Carpathian region of Ukraine.

ture is +6 °C (from +8 °C in the northeast to +3 °C in the southwest). In winter it is cold, the average temperature in January is -5 °C. In the plains it can reach -32 °C, and in the mountains frosts below -40 °C are observed.

The average rainfalls in winter are 100–250 mm, which is almost three times less than in summer. During the whole cold period of the year in the east of Chernivtsi region less than 125 mm of precipitations falls, in the central part – 125–150 mm, in the foothills – 175–200 mm, and in the mountains – 250–300 mm and more. In winter in the plain part winds blow in different directions, but are dominated by north-western, western, south-eastern, eastern, which account for about 80 % of winds in all directions.

Summer is moderately warm. The average air temperature does not change much in July – from +15 °C (in the mountains) to +19 °C (in the east). The highest recorded air temperature reached 38 °C. The lowest ones in summer were recorded in the plain in June +3 °C, in July – +7 °C, in August – +4 °C, and in the mountains – -3 °C, 1 °C and -2 °C, respectively.

In summer there is a lot of precipitation (400–700 mm and more). Most precipitation falls in the mountains. At the same time, there are often showers and thunderstorms. Especially heavy rainfall falls from June to August.

The average annual temperature for Chernivtsi is +7.9 °C. The average temperatures of the warmest and coldest months – July and January – are 19.3 °C and 5.0 °C, respectively. The period without frosts lasts mostly 153 days.

The average annual rainfall in Chernivtsi is 712 mm. Precipitation falls mainly in the form of rain during the warm period in an average of 505 mm. From November to March precipitation is about 207 mm

(Antonov 1999, Gutsulyak et al. 2006).

The growing season in Chernivtsi region ranges from 224 to 253 days (Myronchuk 2013).

In total, an inventory and accounting of 283 hedges along the main streets and in the plantings of 95 settlements of Ukrainian Bukovynian Carpathian region was carried out (11 towns – Chernivtsi, Novodnistrovsk, Khotyn, Storozhynets, Vyzhnytsa, Novoselytsia, Kitsman, Hertsa, Vashkivtsi, Zastavna, and Sokyriany, 7 townlets – Berehomet, Vartykivtsi, Hlyboka, Kelmentsi, Nepolokivtsi, Luzhany, and Kostryzhivtsi, and 77 villages). Species composition, systematic, spatial, age and ecological structure, quality status and ornamental value of hedges were investigated.

## Methods

In the city of Chernivtsi, an inventory was carried out and the species composition and structure of 117 hedges were analysed, and in other settlements of Bukovynian Carpathian region – 166.

The inventory was carried out on the basis of cartographic documents by route method in accordance with the requirements of 'Instructions for the technical inventory of green spaces ...' (Verkhovna Rada of Ukraine 2001). Following data was recorded: item number, date of study, geographical area, settlement and street, length, average height and width, species composition and age of plants, rows, spatial structure and method of formation, decorative value and quality condition.

The species composition of hedge plants was identified in accordance with the domestic nomenclature (Dobrochaeva et al. 1987, Zayachuk 2014). Their eco-



logical structure was analysed in accordance with the 'Guide to plants ...' (Yelin et al. 1984, Myronchuk 2018). The quality of hedges of urban ecosystems was classified as 'good', 'satisfactory' and 'unsatisfactory'. The qualitative condition was established on the following signs:

'Good' – trees or shrubs that are part of the hedge are healthy, normally developed, thick foliage, evenly distributed on the branches, normal size and colour without signs of disease and wounds, damage to trunks and skeletal branches, the type of hedge – integral without breaks. 'Satisfactory' – trees or shrubs are healthy, but with signs of slow growth, with unevenly developed crown, few leaves on the branches, there is little mechanical damage, the appearance of the hedge – openwork or with breaks. 'Unsatisfactory' – trees or shrubs are much weakened, trunks are crooked,

crowns are underdeveloped, there are dry and withering branches, the growth of annual shoots is insignificant, technically damaged trunks, presence of phytopathological diseases, the hedge is not intact, fragmentary.

It is known that the hedge is a normal planting of trees and shrubs, so the assessment of its ornamental properties begins with an assessment of the structural unit that forms it. A score for the ornamental value of hedges was carried out on a modified scale for assessing the ornamental characteristics of shrubs (Andrushko and Tereshkin 2012, Myronchuk 2014). To assess ornamental plants which influence its attractiveness, first of all, indicators such as crown density, shoot colour, leaf shape and colour, time and duration of flowering, the size, colour, and aroma of fruit are taken into account (Table 1).

**Table 1. Determination of hedge decorative value.**

| <b>Signs of decorativeness</b> |                                          | <b>Points</b> |
|--------------------------------|------------------------------------------|---------------|
| <b>1.</b>                      | Architectonics of shrubs or tree         |               |
|                                | Openwork                                 | 3             |
|                                | Dense                                    | 6             |
| <b>2.</b>                      | Colour of shoots                         |               |
|                                | Common (gray, brown, black)              | 1             |
|                                | Original (red, brown, light brown, buff) | 3             |
| <b>3.</b>                      | Foliage                                  |               |
| <b>3.1.</b>                    | Terms of leafing                         |               |
|                                | End of May                               | 1             |
|                                | Late April – Early May                   | 2             |
|                                | Until the beginning of April             | 3             |
|                                | Evergreen leaves                         | 4             |
| <b>3.2.</b>                    | Timing of leaf fall                      |               |
|                                | Early leaf fall (September)              | 1             |
|                                | Average duration (October)               | 2             |
|                                | Preservation of leaves before frost      | 3             |
|                                | Evergreen leaves                         | 6             |
| <b>3.3.</b>                    | Texture of leaves                        |               |
|                                | Matte                                    | 1             |
|                                | Glossy                                   | 3             |

| Signs of decorativeness |                                                                | Points |
|-------------------------|----------------------------------------------------------------|--------|
| <b>3.4.</b>             | Colour of leaves                                               |        |
|                         | Green                                                          | 1      |
|                         | Another (red, yellow) with a shade                             | 4      |
| <b>3.5.</b>             | Seasonal foliage colour change                                 |        |
|                         | Does not change                                                | 1      |
|                         | Colour changes in autumn                                       | 2      |
|                         | Colour changes throughout the growing season                   | 3      |
| <b>4.</b>               | Flowering                                                      |        |
| <b>4.1.</b>             | Duration of flowering                                          |        |
|                         | Flowering inconspicuous, absent                                | 0      |
|                         | Short-term (1–2 weeks)                                         | 1      |
|                         | Medium-term (up to 4 weeks)                                    | 2      |
|                         | Long-term (more than a month)                                  | 3      |
| <b>4.2.</b>             | Size of inflorescences, flowers                                |        |
|                         | Flowering inconspicuous, absent                                | 0      |
|                         | Small                                                          | 1      |
|                         | Large                                                          | 2      |
| <b>4.3.</b>             | Inflorescence colour set-off against the background of foliage |        |
|                         | Missing                                                        | 0      |
|                         | Weakly expressed                                               | 1      |
|                         | Pronounced                                                     | 2      |
| <b>5.</b>               | Fruiting                                                       |        |
| <b>5.1.</b>             | Preservation of fruits                                         |        |
|                         | Fruits are invisible, absent                                   | 0      |
|                         | Fruits fall off quickly                                        | 1      |
|                         | Fruits are stored until winter                                 | 2      |
|                         | Fruits are stored until the next season                        | 3      |
| <b>5.2.</b>             | Nature of fruit type                                           |        |
|                         | Fruits are solitary                                            | 1      |
|                         | Fruits are collected in clusters                               | 2      |
| <b>5.3.</b>             | Fruit size                                                     |        |
|                         | Small (up to 3 cm)                                             | 1      |
|                         | Large (more than 3 cm)                                         | 2      |
| <b>5.4.</b>             | Contrast colour of fruits on a background of leaves            |        |
|                         | Missing                                                        | 0      |
|                         | Weakly expressed                                               | 1      |
|                         | Pronounced                                                     | 2      |
| <b>6.</b>               | Aroma                                                          |        |
|                         | Missing                                                        | 0      |
|                         | Weak                                                           | 1      |
|                         | Strong                                                         | 2      |

To determine the exact number of points of ornamental hedge, the decorativeness of the species that are part of it is first determined. Further, we propose to evaluate such ornamental features as: type of hedge – moulded, unformed; assessment of species decorativeness, score; deviation from the specified form, %; distance of structural units per 10 m; height of the hedge exposure from below, m; hedge shape – straight, natural, wavy, stepped, chaotic, combined; perception of the hedge against landscape background; living wall and complex hedge (Myronchuk 2018).

Based on the modified scale (Myronchuk 2018), were distinguished green hedges of various degrees of decorative value: very high degree – 40–49 points; high degree – 36–40; medium degree – 30–35; low degree (less than 23 points).

## Results and Discussion

The formation of hedges as an element of landscaping of settlements of Ukrainian Bukovynian Carpathian region was due to the influence of a number of objective – natural and anthropogenic, and subjective

factors – long-term plans for settlements' development, the amount of funding for the formation of urban green areas and planting care, traditions and socio-economic conditions of the region's development.

The study of hedges during 2010–2016 (283 hedges along the main streets and in plantings with a length of 35,231 m in 95 settlements of the region) showed the popularity of this element of gardening in the formation of green urban areas and their diversity in many ways.

The results of the inventory showed that the majority of hedges were formed in public areas – 64.3 %. In the territories of limited use, their share is 33.6 %, and in the territories of special purpose – 2.1 %.

The dendroflora of hedges is represented by a total of 32 species of woody plants from 24 genera and 15 families (Table 2). The following families lead in taxonomic composition: Rosaceae Juss. – 7 species, Sapindaceae Juss. – 3 species, and Oleaceae Lindl. – 3 species. The rest of the families are represented by only one or two woody species.

The diversity of species composition of hedges primarily depends on their functional purpose and the cost of

**Table 2. Systematic composition.**

| Group                                                                   | Class         | Number of |          |        |         |
|-------------------------------------------------------------------------|---------------|-----------|----------|--------|---------|
|                                                                         |               | orders    | families | genera | species |
| City of Chernivtsi                                                      |               |           |          |        |         |
| Pinophyta                                                               | Pinopsida     | 1         | 1        | 1      | 1       |
| Magnoliophyta                                                           | Magnoliopsida | 8         | 10       | 13     | 15      |
| -----                                                                   |               |           |          |        |         |
| Other settlements of the region                                         |               |           |          |        |         |
| Pinophyta                                                               | Pinopsida     | 1         | 2        | 3      | 4       |
| Magnoliophyta                                                           | Magnoliopsida | 10        | 10       | 16     | 23      |
| -----                                                                   |               |           |          |        |         |
| In total, in the settlements of Bukovynian Carpathian region of Ukraine |               |           |          |        |         |
| Pinophyta                                                               | Pinopsida     | 1         | 2        | 3      | 4       |
| Magnoliophyta                                                           | Magnoliopsida | 10        | 13       | 21     | 28      |
| -----                                                                   |               |           |          |        |         |
| In total                                                                |               | 11        | 15       | 24     | 32      |

planting material. Hedges with *Buxus sempervirens*, *Physocarpus opulifolius* (L.) Maxim., *Cornus alba*, *Spiraea media*, and *Spiraea vanhouttei* (Briot) Zabel are usually formed near enterprises and government institutions (urban landscaping). Less commonly used are *Symphoricarpos albus* Blake, *Cornus sanguinea* (L.) Opiz., *Thuja occidentalis* L., and *Picea abies* (L.) Karst., there occur hedges formed from *Parthenocissus quinquefolia* (L.) Planch. In suburban landscaping, cheaper species – *Carpinus betulus*, *Ligustrum vulgare* and *Syringa vulgaris* L. – are often used (Fig. 2).

An analysis of the species composition of hedges showed that the following species are more often used: *Carpinus betulus* – 19.4 %, *Buxus sempervirens* – 19.1 %, *Cornus alba* – 17.0 %, *Ligustrum vulgare* – 12.0 %, *Physocarpus opulifolius* – 6.7 %. Less common are hedges from *Spiraea media* – 5.0 %, *S. vanhouttei* – 3.5 %, and *Symphoricarpos albus* – 2.8 %. Individually used are *Robinia pseudoacacia* L., *Tilia cordata* Mill., and *Tilia platyphyllos* Scop.

The vast majority of hedges are formed from one tree species – 98.3 % in Chernivtsi and 71.1 % – in other settlements of the region. The share of mixed hedges in small towns and villages is 28.9 %, and

in Chernivtsi – only 1.7 %. Sometimes in hedges, there are tree species uncharacteristic for their formation – *Acer negundo* L., *Tilia cordata*, *Acer platanoides* L. This is due to the close proximity of the location of such hedges to protective forest belts or forest stands, which can give a natural renewal of woody plants.

The city of Chernivtsi is characterized by single-row hedges – 83.8 %. The proportion of two-row hedges is 13.7 %, and that of three-row hedges is only 2.5 %. In other settlements, the share of two-row hedges is higher – 35.4 % in towns, and 29.8 % in rural areas. Four-row hedges in the green spaces are practically absent – only 0.9 % in small towns (Table 3). This is due to the density development of the city of Chernivtsi and the lack of necessary space for formation of multi-row hedges.

In the settlements of the region, trimmed hedges predominate – 92.1 % in Chernivtsi and 75.5 % in other towns and villages. Hedges from tree species such as *Spiraea media*, *S. vanhouttei* and *Symphoricarpos albus* predominate among the untrimmed ones. Due to the lack of proper care, some trimmed hedges passed into the untrimmed category – those from *Carpinus betulus*, *Physocarpus opulifolius*, *Picea abies* and even with *Buxus sempervirens*.

**Table 3. Number of hedge rows in settlements.**

| Number of rows | Number of hedges, % |                          |                       |
|----------------|---------------------|--------------------------|-----------------------|
|                | Chernivtsi          | Other settlements        |                       |
|                |                     | cities, district centres | townlets and villages |
| 1              | 83.8                | 58.2                     | 70.2                  |
| 2              | 13.7                | 35.4                     | 29.8                  |
| 3              | 2.5                 | 5.5                      | -                     |
| 4              | -                   | 0.9                      | -                     |
| In total       | 100                 | 100                      | 100                   |

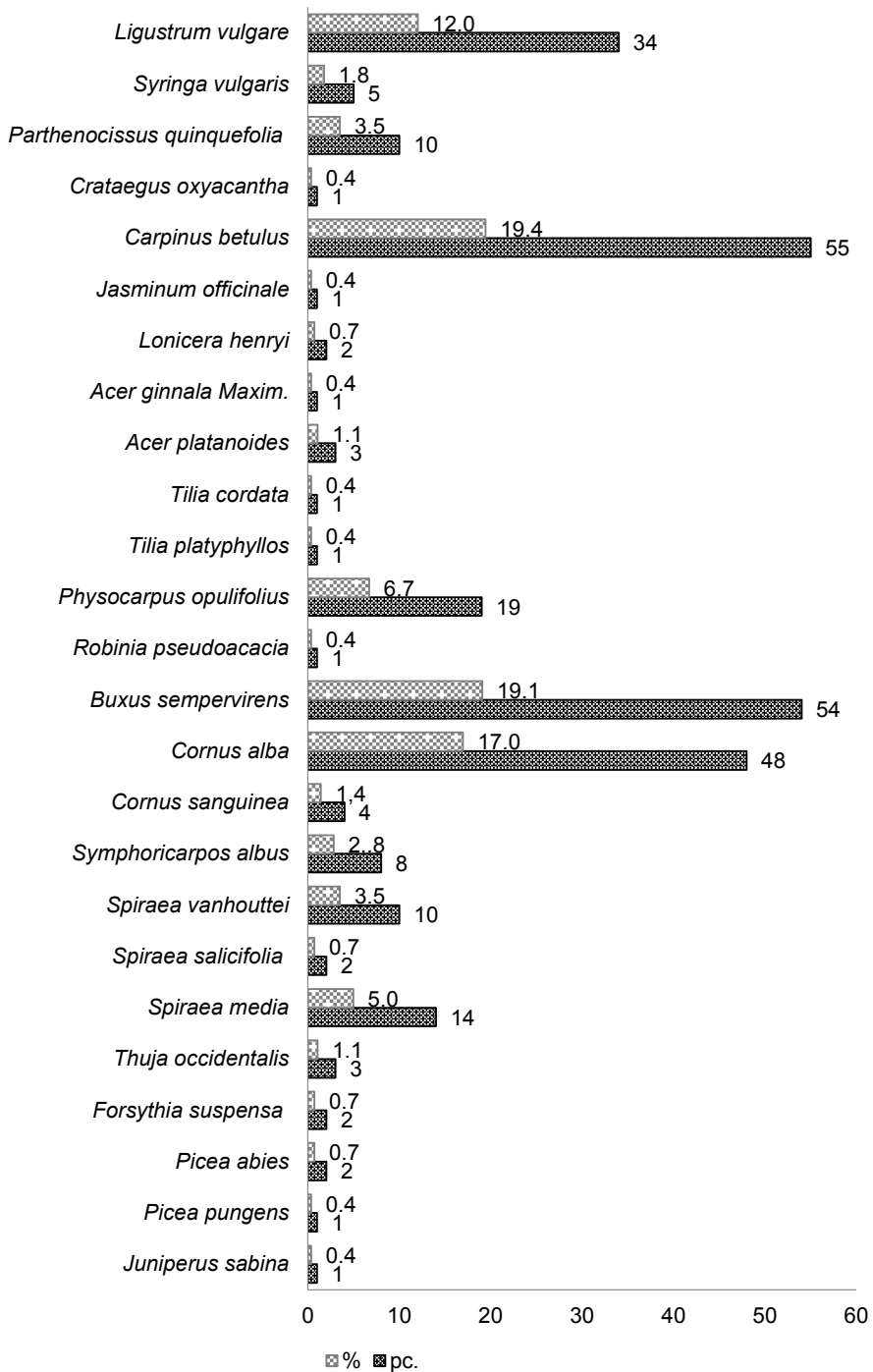


Fig. 2. Number of hedges by plant species.

Mean-height hedges are predominant in towns and villages – 65.8 % in Chernivtsi and 66.9 % in other settlements. This is primarily due to the significant number of hedges created from *Carpinus betulus*. The share of curb hedges is insignificant – 7.7 % in Chernivtsi and 4.8 % in other settlements (Fig. 3).

In Chernivtsi, the following shrub species are most often used to form a curb hedge: *Spiraea media*, *Buxus sempervirens*, *Ligustrum vulgare*, which makes up 44.4 % of all hedges in the city.

According to the age structure, hedges in the age group of 11–30 years dominate in the settlements, the share of which in urban areas is 82.0 %, while in rural – 51.8 %. In small towns and villages, a significant portion of hedges is 31–40 years old – 38.5 %, while those over 50 years old are practically absent – only 0.6 % in rural areas (Fig. 4).

An analysis of the ecological structure of hedges, which makes it possible to determine the dependence of plants on en-

vironmental factors, showed that in terms of substrate nutrient status, the most common is the group of mesotrophic woody plants – 56.2 %. The share of megatrophic ones is 37.5 %, and the share of undemanding for soil conditions oligotrophic tree species is insignificant – 6.3 % (Fig. 5A). In terms of soil substrate moisture content, the group of mesophytic woody plants predominates in the region's hedges – 43.8 %. The proportion of hydrophytic plants here is the smallest and amounts to only 1.6 % (Fig. 5B).

An analysis of the quality status of hedges showed that most of them can be classified as 'good' – 41.0 % in Chernivtsi and 40.4 % in other settlements. Partial or complete reconstruction is required for 22.2 % of hedges in Chernivtsi and 28.3 % in other towns and villages (Table 4). Poor quality ones are characterized by the presence of dry twigs and leaves, bareness of leaves and reduction in the fence density, mechanical damage to woody plants.

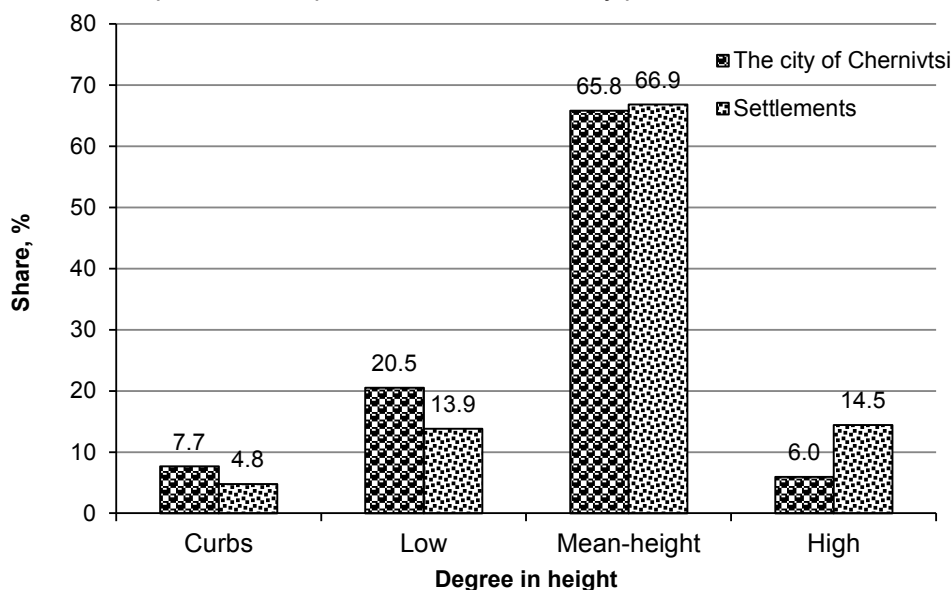


Fig. 3. Height structure of hedges.



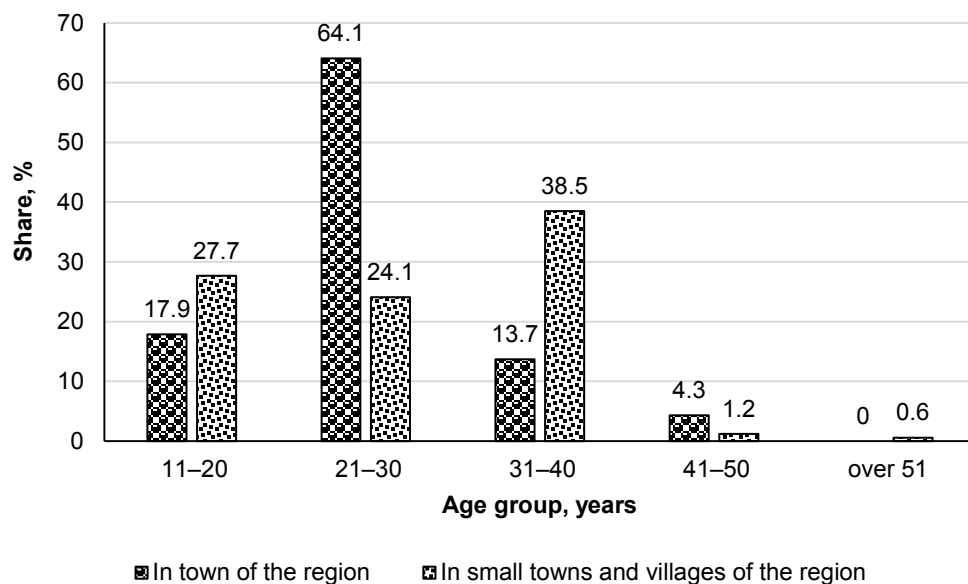


Fig. 4. Age structure of hedges.

Table 4. Quality status of hedges.

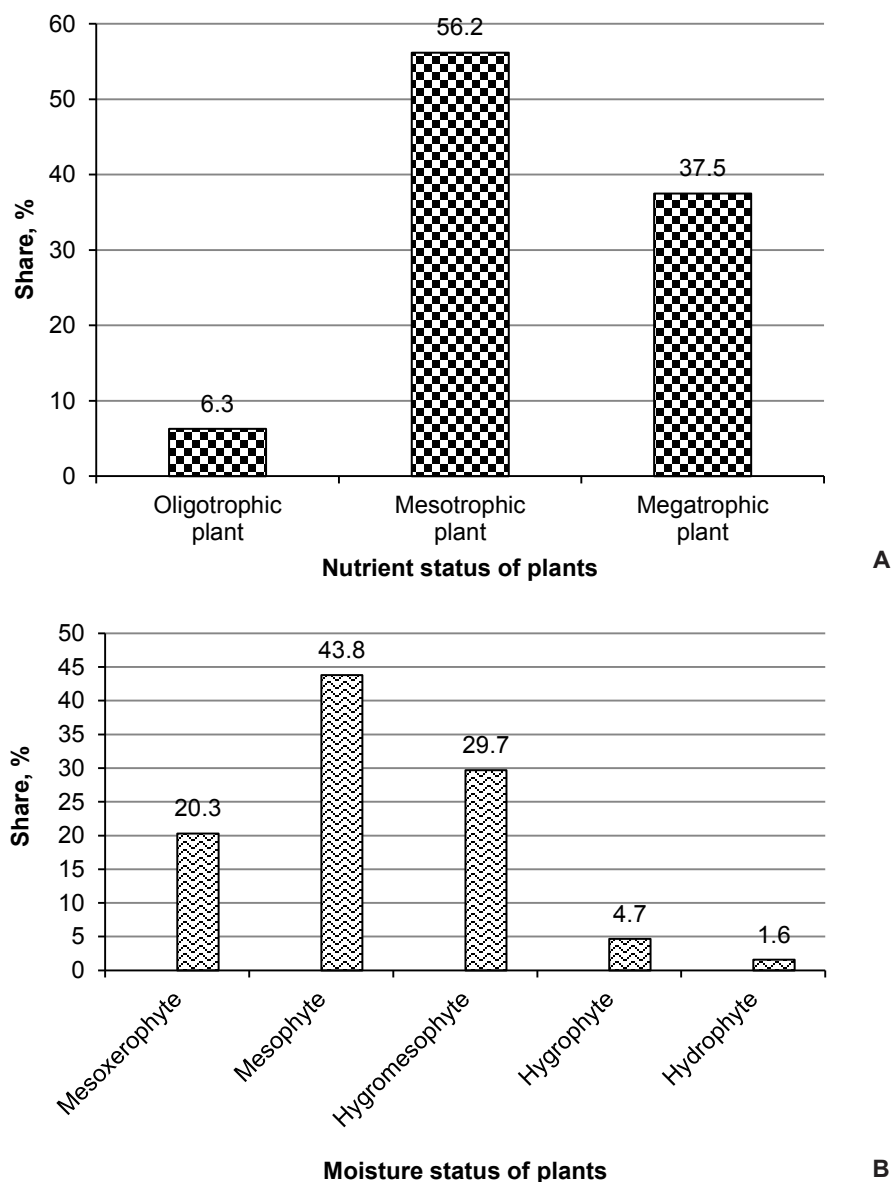
| Quality status | City of Chernivtsi  | Other settlements of the region |
|----------------|---------------------|---------------------------------|
|                | Number of hedges, % |                                 |
| Good           | 41.0                | 40.4                            |
| Satisfactory   | 36.8                | 31.3                            |
| Unsatisfactory | 22.2                | 28.3                            |
| Total          | 100                 |                                 |

Table 5. Quality of hedges depending on the level of illumination.

| Quality status | Illuminated |                    | Half-shade  |                    | Shade       |                    |
|----------------|-------------|--------------------|-------------|--------------------|-------------|--------------------|
|                | number, pcs | % within the group | number, pcs | % within the group | number, pcs | % within the group |
| Good           | 84          | 55.3               | 30          | 28.8               | 3           | 11.1               |
| Satisfactory   | 41          | 27.0               | 47          | 45.2               | 8           | 29.6               |
| Unsatisfactory | 27          | 17.7               | 27          | 26.0               | 16          | 59.3               |
| In total       | 152         | 100                | 104         | 100                | 27          | 100                |

Quality of hedges directly depends on the intensity of illumination of plants. With good lighting, the proportion of hedges with an unsatisfactory quality rating is 17.8 %. But in the shade, the proportion of such hedges increases to 59.3 % (Table 5).

In addition, major causes for 'unsatisfactory' quality of hedges are problems of agrotechnical nature both at the stage of creation and in the process of care and operation (non-compliance with the technology of creation, schedule of care and formation, incorrect or not systematic prun-



**Fig. 5. Ecological structure of hedges: A. regarding substrate nutrient status; B. regarding substrate moisture content.**

ing, untimely implementation of measures for protection against phyto-diseases and insect pests, lack of proper financing of works).

The ornamental value of a particular

woody plant depends both on the inherited ornamental features and on individual characteristics. An integral assessment of the above-mentioned signs made it possible to determine the ornamental value

of the formed hedges. In general, hedges formed from *Ligustrum vulgare*, *Lonicera xylosteum* L., *Philadelphus coronaries* L., *Symphoricarpos albus*, *Spiraea media*, *S. vanhouttei*, *Cornus alba*, *C. sanguinea*, *Buxus sempervirens*, *Picea abies* and *P. pungens* are characterized by the highest ornamental value in the settlements (more than 30 points).

One can single out hedges formed from *B. sempervirens*, which do not lose their ornamental value throughout the year and emit a pleasant aroma during flowering. The hedges from *Cornus alba* and *C. sanguinea* look exotic. Eye-catching and attractive are hedges with *L. vulgare* and *S. albus*.

## Conclusions

Hedges, as a component of landscaping of urban areas of Bukovynian Carpathian region of Ukraine, are mostly formed in public areas (64.3 %) and perform mainly the functions of delimiting space and improving the attractiveness of urban green areas.

The dendroflora of the settlements is represented by 32 species of plants from 24 genera and 15 families. In the taxonomic composition the leading families are Rosaceae Juss., Sapindaceae Juss., and Oleaceae Lindl.

Most hedges in the region are formed from one tree or shrub species (Chernivtsi – 98.3 %, other towns and villages – 71.1 %). *Carpinus betulus*, *Buxus sempervirens*, *Cornus alba* and *Ligustrum vulgare* are most often used for their creation.

In the settlements single-row hedges predominate (Chernivtsi – 83.8 %, other towns – 58.2 %, villages – 70.2 %). Most hedges are trimmed ones (Chernivtsi – 92.1 %, other towns and villages

– 75.5 %). In the absence of proper care, they pass into the category of untrimmed ones (with *Carpinus betulus*, *Physocarpus opulifolius*, *Picea abies* and *Buxus sempervirens*). In untrimmed hedges, species such as *Spiraea media*, *Spiraea vanhouttei* and *Symphoricarpos albus*, etc. are predominant.

Mean-height hedges are predominant (Chernivtsi – 65.8 %, other towns and villages – 66.9 %). The share of curb ones is insignificant (Chernivtsi – 7.7 %, other towns and villages – 4.8 %). *Spiraea media*, *Buxus sempervirens*, *Ligustrum vulgare* are most often used for curb hedge formation.

Most hedges in the settlements of Bukovynian Carpathian region belong to the category of 'good' in terms of quality status (Chernivtsi – 41.0 %, other towns and villages – 40.4 %). A significant number of them are characterized by 'unsatisfactory' condition (Chernivtsi – 22.2 %, other towns and villages – 28.3 %), which indicates the need for their partial or complete reconstruction. Under conditions of sufficient lighting, hedges with 'unsatisfactory' state make up 17.8 % compared to the share of ones growing in the shade (59.3 %).

It is advisable to use the research results in order to: solve issues of improving the process of forming new hedges in urban ecosystems; development of measures to improve their structure and functionality; choose an assortment of woody plants for creating hedges; form hedges that are complex in structure and rich in species diversity; enhance the ornamental value of landscape gardening compositions; develop landscape-architectural models for creating hedges of various functional purpose in an urban environment. Therefore, the aspects of systematic composition, structural features, condition and ornamental value of hedges in the

plantings of the city of Chernivtsi and other settlements of Bukovyna will contribute to the processes of creation and formation of resistant, steady-state and aesthetic plant communities in the urban environment.

The formation of new hedges must be carried out with the help of trees or shrubs that have high aesthetic qualities and environmentally friendly to microclimatic and soil conditions of the urban environment: *Aronia melanocarpa* (Michx.) Elliott, *Berberis thunbergii* DC, *Euonymus europaeus* L., *Euonymus fortunei* L., *Ulmus glabra* Huds., *Weigela hybrida* Jaeg. f. 'Variegata', *Viburnum opulus* L., *Cotoneaster lucidus* Schldl., *Acer japonicum* Thunb., *Prunus laurocerasus* L., *Mahonia aquifolium* (Pursh) Nutt., *Cotinus coggygia* Scop., *Prunus spinosa* L. and others.

To increase the area of greenery in cities, it is advisable to create new hedges – mobile hedges (Myronchuk 2018), living walls and wallpaper, using the latest technology. For formation of mobile hedges in the settlements of Chernivtsi region it is advisable to use the following species of woody plants or shrubs: *Pinus mugo* Turra., *Spiraea japonica* L., *Taxus baccata* L., *Thuja occidentalis* f. 'Danica', f. 'Timy Tum', *Berberis thunbergii*, etc.

The development of the scientific foundations for creating and forming hedges, proper financing and timely implementation of hedge care activities will contribute to the processes of creating aesthetically attractive and highly decorative elements of landscape gardening art in an urban environment.

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## FRACTIONAL COMPOSITION AND FORMATION OF FOREST LITTER IN SCOTS PINE PLANTATIONS ON RAVINE-GULLY SYSTEMS AND THE PLAIN OF THE CENTRAL PART OF UKRAINE

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### Abstract

The fractional composition of forest litter was studied in pure and mixed plantations with a predominance of Scots pine aged 14–85 years. The study was conducted in anti-erosion plantations of ravine-gully systems of Dnieper Upland, in parks on Kyiv slopes of Dnieper River, Ovruch Ridge, as well as in the plains of Kyiv and Zhytomyr Polissia. Forest litter is with a thickness of 2.2–2.5 cm in mixed stands and 2.5–3.5 cm in pure stands with a stock of 20.8 and 27.8 t·ha<sup>-1</sup>, respectively. The mass of litterfall in the studied areas is different and ranges from 2.9 t·ha<sup>-1</sup> in mixed plantations to 14.1 t·ha<sup>-1</sup> in pure pine ones. Analysis of the fractional composition of litter showed that its active part (leaves, crumbs, fruits) in all experimental areas is in the range from 65 to 82 %, while the inactive part (branches, bark, cones) is 18–45 % of the total mass. The active part in mixed plantations is 73–82 %, pure ones – 65–67 %, and the inactive part is 18–27 and 34–45 %, respectively. The rate of destruction and mineralization of freshly dead phytomass was determined by analysis of litterfall-litter index – the ratio of litter mass to the mass of annual litterfall. Plantations of ravine-gully systems are characterized by strongly inhibited intensity of litter mineralization with an index of 6.2–7.9. The index ranges from 2.9 to 4.5 in park plantations and from 1.1 to 5.5 in the plantations of the plain sites. The mass of water absorbed by litter is 11.0–50.8 t·ha<sup>-1</sup> and its moisture capacity is in the range of 134–319 %, which is equivalent to 1.6–4.8 mm of precipitation.

**Key words:** litterfall-litter index, mineralization, moisture capacity, organic litterfall, stock, water permeability.

### Introduction

Forest litter is a supersoil formation formed under forest canopy from the litterfall of organic remnants of aboveground

forest layers and partially grassy plants (Bogatyrev 1990). Litter decomposition is widely recognized as a vital link between aboveground and underground environmental processes, including soil organic



matter formation and nutrient cycling in forest ecosystems (Novák et al. 2013, Semenyuk et al. 2020).

Svyrydenko et al. (2005) consider forest litter to be an independent natural body that is spatially located on the boundary between soil and phytocoenosis, through which dynamic connections and relationships between vegetation and soil take. Forest vegetation properties of the soil are largely determined by the speed of circulation of substances in the soil-plant system. Litter is the main source of returning to soil of organic and ash substances removed from it by plants in the process of life.

Annual litterfall is considered to be fallen leaves, twigs, branches, bark, cones, seeds and other organic residues of forest vegetation. Along with litterfall, the soil surface receives a significant amount of organic matter and nutrients that are in them (Svyrydenko et al. 2005). The amount of litterfall depends on the species composition, age, canopy structure of the forest (Yakuba 2004, Solomatova 2013). Litterfall replenishes the reserves of organic and mineral substances in the litter and affects its physical properties and the formation of various genetic types of forest soils, their productivity.

The proportion of leaves in the litter decreases because they decompose rapidly, the proportion of twigs, fruits, scales and other components (organic residues), which decompose more slowly increases (Parsons et al. 2014). The amount of litter depends on the ratio between its arrival, during litterfall, and consumptions, due to decomposition, which in turn depends on: climate, soil conditions, position, and composition of planting, age and density (Svyrydenko et al. 2005).

Depending on the species composition of stands, different types of forest lit-

ter are formed, which differ in power and rate of mineralization (Bogatyrev 1990). It performs a number of different important functions, in particular significantly affects the water regime of soils, delays and retains much of the precipitation, prevents surface runoff and evaporation of water from the soil and thus affects the water, air, temperature, redox regimes of soils (Zhytska 2009). Forest litter plays a significant anti-erosion role, it absorbs 2–6 times more water than its mass; restrains the kinetic energy of rain and protects the soil from destruction; the rough surface of the litter slows down the flow rate and clogs the soil. With the removal of litter, runoff increases and soil water permeability decreases 5–10 times (Gomyo and Kuraji 2016).

Obviously, its thermoregulatory role is no less important for forest soils and for the cycle of mineral nutrients. In the process of its decomposition and mineralization, the upper soil horizons are enriched with nutrients (Novák and Slodičák 2009), and therefore are a constant source of modified organic compounds that form humus – the main part of organic compounds that determine the level of forest soil trophic (Brovko et al. 2020, Wei et al. 2020).

The main anti-erosion properties of the litter also include water-absorbing and water-retaining (moisture capacity) ability, which contributes to the transfer of surface destructive runoff into subsoil (Zhou et al. 2018). These properties depend on its thickness and stock. It is known that the litter acts as mulch. The presence of a continuous layer of organic precipitation reduces its heating, evaporation of moisture, inhibits the mechanical pressure exerted by humans and large animals on the upper layers of forest soil, which prevents its excessive compaction.

The main source of trace elements for the forest is organic rainfall. From the point of view of forest productivity, rapid decomposition of precipitation and forest litter is beneficial, because under such conditions the mineral compounds of nitrogen, phosphorus, potassium and other elements are formed.

According to Swift et al. (1979) the rate of mortal decomposition is determined by three groups of factors: physicochemical characteristics of the environment in which the decomposition takes place, the composition of litterfall and the activity of destructive organisms. Thus destruction can be limited both by one factor, and their complex. Excessive accumulation of mortmass indicates incomplete biogeochemical cycles, which is accompanied by a significant decrease in productivity and resilience of forests due to inhibition of the biogeochemical cycle (Chornobay 2000). Studying the rate of circulation through the litterfall-litter index is a potential way to assess changes in ecosystems, a priority tool in terms of being able to analyze the cycle, identify changes in individual links, and influence its course by practical measures (Sizer et al. 2000). One of the main indicators of forest litter is its capacity, layer-by-layer analysis of which allows us to assess the rate of accumulation or decomposition of plant precipitation.

Litter plays an important role not only in the processes of circulation of substances in ecosystems, but also in the processes of soil formation and reflects the zonal features of the geographical location of plantations. The meliorate role of forest litter is especially multifaceted, which determines water regulation, water retention, water cleaning, soil protection, anti-erosion and other functions (Yukhnovskiy et al. 2013).

The aim of the study was to analyze the fractional composition of forest litter

and the processes of its formation in protective forest stands of Scots pine in the central part of Ukraine.

## Material and Methods

The objects of research were Scots pine (*Pinus sylvestris* L.) stands of pure and mixed artificial origin, created in the conditions of ravine-gully territories of Dnieper upland in Forest-Steppe zone, in parks of Kyiv on the slopes of Dnieper River, Ovruch ridge of Polissia. For comparison, plantations growing in the plain conditions of Kyiv and Zhytomyr Polissia were studied (Fig. 1).

Plantations of ravine-gully Rzhyshchiv-Kaniv erosive area are represented by trail plots (TP) 1–4. Plantations are aged from 14 to 38 years. The conditions for the growth of anti-erosion plantations are quite close: slopes' steepness from 12° to 26°, the exposition from south-west to south-east with the location in the middle part of slopes.

On the ravine-gully lands of Ovruch-Slovechna ridge of Polissia zone TP 5 and 6 were chosen in anti-erosion plantations, which grow on sod-podzolic sandy soil. Plantations occupy slope upper part.

Two trial plots (7 and 8) are laid in the park plantations of Kyiv, located in conditions of complex relief. The composition of the mixed plantation is represented by the formula 4Qr3Ps3Ap, pure – 10Ps. Their age is 70 years and they grow on the slopes of the southern and northern expositions with a steepness of 20° and 10°, respectively.

To identify differences in the formation of litter in ravine-beam systems and plain conditions, trial plots 9–12 were laid. Trial plots 9–10 are the pine plantations in Kyiv

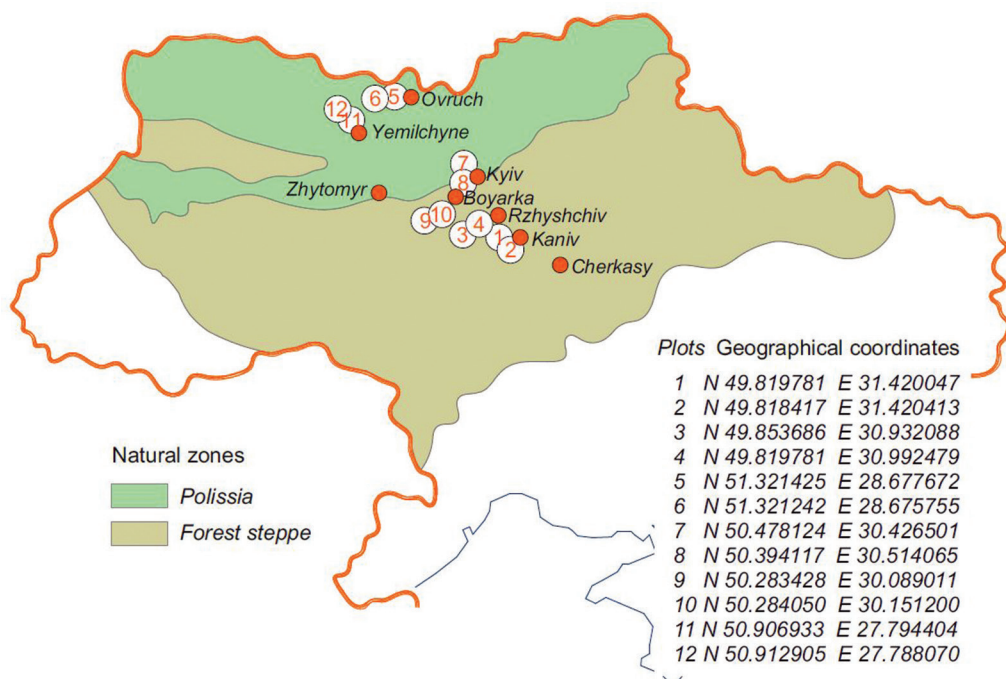


Fig. 1. Locations of research objects.

Polissia, which have reached the V age grade. The plantations are pure in composition, only the stand in TP 9 contains an admixture of red oak (up to 5 % of the total stock).

We also examined water-protected pine plantations growing in Zhytomyr Polissia in TP 11–12. Forest litter was researched in both mixed (9Ps1Bp) mature plantations and pure pre-mature pine stands growing in TP 11 and 12, respectively.

Trial plots of 11–12 are represented by water protection pine plantations, growing in Zhytomyr Polissia.

The biometric characteristics of plantations were obtained based on the results of processing the 12 test plots, which also described the undergrowth, understory, living above-ground cover and litter. The anti-erosion properties of the litter were studied in the spring (March). Litterfall and

litter samples were measured on each trial plot in autumn 2019 in late October or early November. They were collected at the accounting sites using metal trays-in-takes measuring 330×140 mm. Litter was taken in 10-fold replicate (a total of 120 samples). According to the recommendations of Karpachevskiy (1981), active and inactive litter fractions were distinguished.

Moisture capacity was determined by soaking the litter intact in water for 8 h. After soaking it was dried to a completely dry state and weighed with an accuracy of 0.01 g, pre-disassembled into active (leaves/needles, crumbs, mummified particles) and inactive (cones, branches, bark) part of the fractions (Hordienko et al. 2000). The capacity, stocks and fractional composition were studied according to the methods of Karpachevskiy (1981) and Vorobeychik (1997). The obtained data were averaged and recalculated per 1 ha.

As an indicator of the speed of destructive processes was used the ratio of litter stock to the annual inflow of litterfall or so-called litterfall-litter index (LLI). It objectively estimates the initial rate of destruction and mineralization of freshly dead phytomass (Basylevich 1983, Ivanyuk 2009). Thus, the higher the indicator, the weaker the intensity of the biological cycle (Rozhak and Kozlovskiy 2013). The turnover intensity was determined by the scale of the biological cycle in plant groups (Ivanyuk 2009). According to this scale, the process of decomposition of litter is divided into stagnant, severely inhibited, inhibited, intense and quite intense, the LLI being in the range of  $21 >$ ;  $6-20$ ;  $1.6-5.0$ ;  $0.1-1.5$  and  $<0.1$ , respectively.

## Results

Experimental plantations with the participation of the main forest-forming species of Scots pine, both pure and mixed in composition with different proportions of related species of woody plants: birch, maple, oak have an age range from 14 to 85 years. All plantations have high quality performance indicators – I–I<sup>b</sup> productivity classes. The range of basal areas of all presented plantations is from 5.1 (at 16 years) to 50.8 m<sup>2</sup>·ha<sup>-1</sup> (at 66). Quantitative indicators of productivity of experimental plantations taking into account the sums of basal areas of stands range from 38 (at 16 years) to 568 m<sup>3</sup>·ha<sup>-1</sup> (at 66 years) (Table 1).

**Table 1. Biometric indicators of plantations in different regions.**

| No of trial plot                              | Stand composition* | Age, years | Average   |              | Number of trees, ha <sup>-1</sup> | Sum of basal areas, m <sup>2</sup> ·ha <sup>-1</sup> | Class productivity | Stock, m <sup>3</sup> ·ha <sup>-1</sup> |
|-----------------------------------------------|--------------------|------------|-----------|--------------|-----------------------------------|------------------------------------------------------|--------------------|-----------------------------------------|
|                                               |                    |            | Height, m | Diameter, cm |                                   |                                                      |                    |                                         |
| Rzhyskchiv-Kaniv dislocations (Forest-steppe) |                    |            |           |              |                                   |                                                      |                    |                                         |
| 1                                             | 5Ps5Bp             | 16         | 7.2       | 8.8          | 837                               | 5.1                                                  | I                  | 38                                      |
| 2                                             | 10Ps               | 14         | 5.9       | 7.6          | 2750                              | 12.5                                                 | I                  | 42                                      |
| 3                                             | 8Ps2Ap             | 36         | 17.0      | 20.0         | 1120                              | 35.2                                                 | I <sup>a</sup>     | 291                                     |
| 4                                             | 10Ps               | 38         | 17.2      | 21.0         | 1218                              | 42.2                                                 | I <sup>a</sup>     | 348                                     |
| Ovruch-Slovenian ridge (Polissia)             |                    |            |           |              |                                   |                                                      |                    |                                         |
| 5                                             | 9Ps1Bp             | 35         | 16.0      | 17.0         | 1830                              | 41.5                                                 | I <sup>a</sup>     | 330                                     |
| 6                                             | 10Ps+Bp            | 20         | 12.0      | 14.0         | 1761                              | 27.1                                                 | I <sup>b</sup>     | 160                                     |
| Park plantings of Kyiv (Forest-steppe)        |                    |            |           |              |                                   |                                                      |                    |                                         |
| 7                                             | 4Qr3Ps3Ap          | 70         | 25.0      | 47.0         | 210                               | 36.4                                                 | I                  | 370                                     |
| 8                                             | 10Ps               | 70         | 23.9      | 30.2         | 570                               | 40.8                                                 | I                  | 437                                     |
| Kyiv Polissia                                 |                    |            |           |              |                                   |                                                      |                    |                                         |
| 9                                             | 10Ps+Qr            | 43         | 19.5      | 20.6         | 481                               | 16.0                                                 | I <sup>a</sup>     | 153                                     |
| 10                                            | 10Ps               | 40         | 17.0      | 16.5         | 987                               | 21.1                                                 | I                  | 178                                     |
| Zytomyr Polissia                              |                    |            |           |              |                                   |                                                      |                    |                                         |
| 11                                            | 9Ps1Bp             | 85         | 27.0      | 31.5         | 300                               | 23.4                                                 | I                  | 290                                     |
| 12                                            | 10Ps               | 66         | 25.0      | 32.1         | 628                               | 50.8                                                 | I <sup>a</sup>     | 568                                     |

\*Ps – *Pinus sylvestris* L., Bp – *Betula pendula* Roth., Qr – *Quercus robur* L., Ap – *Acer platanoides* L.

Given the fact that to study the anti-erosion properties of the litter presents a wide geographical range of experimental material, the analysis of the presented in-

dicators, which are obtained by the same method, we will consider differentiated. The characteristics of forest litter of protective stands are given in Table 2.

**Table 2. Characteristics of forest litter of protective stands.**

| No of trial plot | Stand composition* | Relief    |            |               | Litter        |                           |                   |          |
|------------------|--------------------|-----------|------------|---------------|---------------|---------------------------|-------------------|----------|
|                  |                    | Steepness | Exposition | Part of slope | Thickness, cm | Stock, t·ha <sup>-1</sup> | Part of litter, % |          |
|                  |                    |           |            |               |               |                           | active            | inactive |
| 1                | 5Ps5Bp             | 26°       | N-S        | middle        | 2.2           | 20.8                      | 82                | 18       |
| 2                | 10Ps               | 16°       | S-W        | middle        | 2.5           | 22.5                      | 67                | 33       |
| 3                | 8Ps2Ap             | 15°       | S-E        | middle        | 2.5           | 27.8                      | 73                | 27       |
| 4                | 10Ps               | 12°       | S          | middle        | 3.5           | 23.5                      | 66                | 34       |
| 5                | 9Ps1Bp             | 10°       | N-W        | upper         | 2.6           | 27.4                      | 69                | 31       |
| 6                | 10Ps+Bp            | 3°        | E          | upper         | 1.3           | 12.2                      | 65                | 35       |
| 7                | 4Qr3Ps3Ap          | 20°       | S          | upper         | 1.5           | 19.0                      | 80                | 20       |
| 8                | 10Ps               | 10°       | N          | upper         | 1.0           | 20.9                      | 70                | 30       |
| 9                | 10Ps+Qr            |           |            | plain         | 2.4           | 13.5                      | 65                | 35       |
| 10               | 10Ps               |           |            | plain         | 1.5           | 8.4                       | 55                | 45       |
| 11               | 9Ps1Bp             |           |            | plain         | 6.0           | 77.0                      | 72                | 28       |
| 12               | 10Ps               |           |            | plain         | 6.0           | 64.8                      | 64                | 36       |

Note: \*as in Table 1.

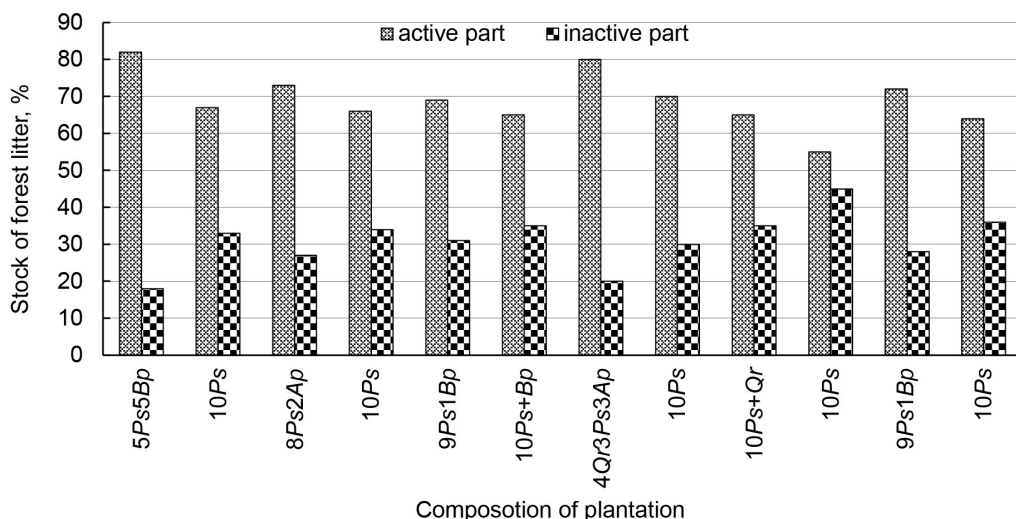
The thickness of the litter in mixed plantings is slightly less than in pure ones and represents 2.2–2.5 cm and 2.5–3.5 cm, respectively. The stock of litter, taking into account its capacity, composition and age of plantations, is from 20.8 to 27.8 t·ha<sup>-1</sup>. The active part of the fractional composition of mixed plantations is 73–82 %, pure – 66–67 %, and the inactive part – 27–18 % and 34–33 %, respectively (Fig. 2).

According to the species composition of woody plants on TP 5 and 6, the difference is small (9Ps1Bp and 10Ps+ Bp), but the age is 15 years, which affected the indicators of litter. Thus, the thickness of forest litter of mixed and pure pine stands is 2.6 and 1.3 cm, respectively, and the stock of litter is 27.4 and 12.2 t·ha<sup>-1</sup>. The fractional difference is insignificant.

Mixed planting on TP 7 has a slight-

ly greater thickness of the litter than pure planting on TP 8, which is 1.5 and 1.0 cm, respectively. However, the stock of litter has a different pattern and reaches 19.0 and 20.9 t·ha<sup>-1</sup>, respectively, which is caused by the difference in the composition of the litter. Mixed planting also has a higher percentage of the active part.

The water-regulation functions of litter play an important role in the plantations in the ravine-gully areas of Rzhyshchiv-Kaniv dislocations (TP 1–4) and Ovruch-Slovechno ridge (TP 5, 6). In some pine curtains of water protection plantations (TP 11 and 12), which grow in lowland wet conditions, a large share of forest litter accumulates. As for melioration, anti-erosion and water protection functions of pine plantations are more than obvious, as the litter provides water



**Fig. 2. The ratio of litter fractions depending on the plantations' composition.**

collection from adjacent slopes, transferring surface runoff into deep, and most importantly – is the primary stage of soil formation processes (Novak and Slodičák 2009, Gomyo and Kuraji 2016, Brovko et al. 2020, Wei et al. 2020).

In the plain conditions of Polissia zone at TP 9–12, the difference in capacity and stock of litter is caused mainly by plantations' age. The tendency regarding the fractional composition of the litter persists – in pure plantations its active part is inferior to the mixed ones.

The mass of litterfall in anti-erosion plantations of Rzhyschiv-Kaniv dislocations (TP 1–4) is from 2.9 to 3.8 t·ha<sup>-1</sup>. A similar value of precipitation mass was also observed in the plantations of Ovruch-Slovechna ridge on TP 5, 6. Here, the annual litterfall in mixed and pure plantations acquires values of 4.0 and 3.7 t·ha<sup>-1</sup>, respectively. In park plantations on complex relief the difference turned out to be bigger. Here the litterfall in the mixed plantation was 4.2 t·ha<sup>-1</sup>, and in the pure – 7.2 t·ha<sup>-1</sup> (Table 3).

It is known that the increase in litter ca-

capacity in forest stands is due to the receipt of dead plant remains during the extinction of aboveground plant phytomass. Decomposition and movement of litter material in the lower soil horizons reduces the capacity of the litter, which depends on the ratio of litterfall and removal of mineralization products in the lower soil horizons (Novák et al. 2014).

The intensity of litter decomposition in TP 1–4 is set as strongly inhibited with the LLIs from 6.2 to 7.9. The same intensity of litter decomposition was determined at TP 5 with the LLI 6.8. Trial plot 6 has an inhibited intensity of decomposition of the litter with a rate of 3.3. In park plantations on complex terrain, the intensity of decomposition is considered to be inhibited with fluctuations of LLI from 2.9 to 4.5 at TP 8 and 7, respectively.

In the plain conditions of Polissia zone, the mass of litterfall in 43- and 40-year-old plantations was 10.1 and 7.6 t·ha<sup>-1</sup>, respectively. The mass of litterfall in 66-year-old pure plantations in TP 12 was 12.2 t·ha<sup>-1</sup>, and its maximum was recorded in 85-year-old plantations in TP 11.



**Table 3. Water-physical indicators for protective plantations.**

| No of trial plot | Stand composition* | Mass of litterfall, t·ha <sup>-1</sup> | LLI | Mass of absorbed water, t·ha <sup>-1</sup> | Moisture capacity of litter, % | Precipitation retained by litter, mm |
|------------------|--------------------|----------------------------------------|-----|--------------------------------------------|--------------------------------|--------------------------------------|
| 1                | 5Ps5Bp             | 2.9                                    | 7.2 | 48.3                                       | 319                            | 4.8                                  |
| 2                | 10Ps               | 3.6                                    | 6.2 | 22.5                                       | 189                            | 2.2                                  |
| 3                | 8Ps2Ap             | 3.5                                    | 7.9 | 26.4                                       | 235                            | 2.6                                  |
| 4                | 10Ps               | 3.8                                    | 6.2 | 22.2                                       | 190                            | 2.2                                  |
| 5                | 9Ps1Bp             | 4.0                                    | 6.8 | 19.7                                       | 156                            | 2.0                                  |
| 6                | 10Ps+Bp            | 3.7                                    | 3.3 | 15.6                                       | 134                            | 1.6                                  |
| 7                | 4Qr3Ps3Ap          | 4.2                                    | 4.5 | 45.2                                       | 375                            | 4.5                                  |
| 8                | 10Ps               | 7.2                                    | 2.9 | 29.4                                       | 244                            | 2.9                                  |
| 9                | 10Ps+Qr            | 10.1                                   | 1.1 | 11.0                                       | 246                            | 1.1                                  |
| 10               | 10Ps               | 7.6                                    | 4.1 | 23.1                                       | 133                            | 2.3                                  |
| 11               | 9Ps1Bp             | 14.1                                   | 5.5 | 50.8                                       | 420                            | 5.1                                  |
| 12               | 10Ps               | 12.2                                   | 5.3 | 46.7                                       | 386                            | 4.7                                  |

Note: \*as in tables 1 and 2.

As for the experimental plots of Polisia zone, with the exception of TP 9, the intensity of decomposition is also inhibited. Forest litter is formed according to certain patterns, at a certain age of young plantations it is formed, gradually its mass accumulates, then stabilizes, and after felling it disappears (Voron et al. 2018). The reason for the intensive decomposition of litter at TP 9 can be explained by the thinning in 2016 with a pulling out of 15 % of the stock, the active role of undergrowth of mountain ash and buckthorn brittle.

The mass of absorbed water by all experimental plots ranges from 11.0 to 50.8 t·ha<sup>-1</sup>. In terms of anti-erosion, the role of litter in the absorption and retention of moisture is extremely important. Thus, its moisture content in those plantations, which are 14–38 years old, ranges from 134 to 319 %, which in terms of delayed precipitation is 1.6–4.8 mm. Park plantings on difficult terrain at the age of 70 provide a moisture content of 244–375 % or 2.9–4.5 mm. The litter of the plantations of the plain relief is characterised by a moisture

content of 133–420 % or 1.1–4.7 mm of precipitation.

## Discussion

The capacity of the litter, the rate of its decomposition and release of chemical elements depends on the type of forest, its age, the density of the stand, climatic and soil conditions, edaphotope features (soil conditions, water and heat regime, etc.), participation in the stand, except conifers, deciduous tree species, the presence or absence of grass or moss cover, the amount of annual precipitation. In contrast to deciduous forests, a characteristic feature of the rhythm of litter accumulation in coniferous forests is its year-round and uniform replenishment throughout the year due to litterfall. At the same time, according to Chornobay (2000), winter litterfall can be from 39 to 82 % of its total annual mass. Litterfall and litter formation are key parts of the substance cycle in the forest ecosystem (Meentmeyer et al. 1982). The amount of litterfall depends primarily on

the species composition of the stand, level of productivity, density and closure of the crowns and physic-chemical properties of the soil.

Differences in the conditions of litter formation are manifested in the late stages of decomposition of organic matter, which is reflected in the thickness of soil horizons, and organic matter is significantly reduced. Researchers (Voron et al. 2018) when studying the fractional composition of forest litter layers in sections emphasize that the proportion of twigs predominates near the trunks and under the crowns, and the leaves – in the inter-crown zone.

According to Minder et al. (2019) the middle and lower parts of the slope with 10° have approximately the same litter stock compared to the plain conditions (respectively 25.2 and 24.9 t·ha<sup>-1</sup>), and in the upper part of the slope there is a smaller litter stock – 20.9 t·ha<sup>-1</sup> (Table 3).

Litter in pine stands decomposes slowly and the rate of its mineralization decreases with age, as evidenced by the studies of Çömez et al. (2020), Corter (1998), Voron (2004) and others.

Accelerated process of litter mineralization is observed in plantations of Scots pine with an admixture of common oak and related species – Hornbeam and Maple, which cannot be said about the litter of red oak plantations (TP 9). There is a slowing down of the mineralization process of litterfall due to the lack of specific mycorrhizal fungi that occur in the forests of North America (Dickie et al. 2020) and the presence of dense litterfall from the leaves of single red oak trees.

It is known that the rate of decomposition of organic matter of forest litter depends on the ratio of its active and inactive parts, and therefore we calculated the reserves of these parts of forest litter pro-

tective plantations in comparison with the composition of plantings, which are given in Table 3, and their percentage is illustrated in Figure 2.

As can be seen from Figure 2, the active part of the litter of pure plantations is inferior to mixed, which indicates the positive role of impurities of deciduous species and significantly depends on their participation in the composition of plantations. A review of litter decomposition in forest ecosystems in Krishna and Mohan (2017) showed that the mineralization of litter of deciduous plant species occurs faster than coniferous and hardwood. Moreover, the litter of leaves disappears much faster than twigs and branches, i.e. the inactive part of the litter.

The inactive part of the litter of clean stands in most of the experimental plots is in the range from 30 to 36 %, which does not indicate a significant discrepancy. The exception is pure pine plantation in TP 10, where this figure reaches 45 %. This flow of organic matter was caused by intensive thinning of the stand and the removal of a significant amount of phytomass from the site. The effect of thinning on the reduction of organic matter in the litter is indicated in the works of Czech scientists Novák and Slodičák (2009), Novák et al. (2020).

Thus, the studied pine stands with an admixture of birch, oak, maple in Polissia and Forest-Steppe of Ukraine form significant reserves of forest litter, and their meliorate properties significantly improve the ecological and edaphic conditions for the development of biogeocenotic processes in these ecotopes.

## Conclusion

Regardless of the region and research conditions, the trend regarding the frac-

tional composition of litter persists – in pure plantations, its active part is inferior to mixed stands; most of it in the fractional composition of the litter had a positive effect on increasing its moisture content.

In different climatic conditions and under the cover of different plants, as well as under different conditions of natural drainage of the terrain, the intensity indices of the biological cycle of organic-mineral substances vary very significantly from 1.1 to 7.9.

It is established that the studied protective forest plantations are characterized by inhibited and very inhibited types of biological cycle (litterfall-litter index is 2.9–7.9 in plantations on complex relief, and 1.1–5.5 in plain conditions).

In experimental plantations on complex terrain, which perform anti-erosion functions, the moisture capacity of forest litter varies in the range from 134 to 319 %, and depending on the species composition of woody plants and their age, the litter can hold from 1.6 to 4.8 mm of precipitation.

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## EXPORT COMPETITIVENESS OF NAMIBIA'S TIMBER SECTOR: IMPLICATION FOR FORESTRY SECTOR

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### Abstract

Analysing and understanding the timber sector export performance is essential for value chain role players to formulate strategies and policies to enhance the competitive export position and ensure forest sustainability. This study's main objective was to measure the export competitiveness of the Namibian timber (HS440799, HS4401, HS4402, and HS4403) and assess its implication for Forestry using secondary data (2001–2018), Revealed Comparative Advantage (RCA), and Revealed Symmetric Comparative Advantage indices (RSCA). The result shows that Namibia had a revealed comparative advantage for 17 years; however, all below one (except for commodity HS4402 from 2010–2018) means that Namibia timber exports are not internationally competitive. Comparing the four categories of timber, in 2007, the sub-sector (HS4402) recorded the lowest RCA (0.00001) and the lowest RSCA (0.99998) for timber (HS4402) in 2007, the same year. On the other hand, the same categories of timber (HS4402) score the highest RCA with a value of 2.73 in 2015 and the highest RSCA (0.46) for timber (HS4402) in the same year compared to the other categories of timber. RSCA indices results for all commodities show that Namibia's timber exports are not competitive for the study period. Timber's comparative export pattern heavily depends on export volumes and values of timber exports. Timber export competitiveness is not sustainable, given the heavy dependence on natural forests. Namibia should re-structure timber harvesting protocols to include replacement or replanting every tree species harvested for timber production to ensure timber and forest sustainability. The country's timber export sub-sector should focus more on adding value to timber than exporting to improved competitiveness. Further, the government should regulate the harvested wood and protect over-grazing, to promote timber and forest resources' sustainable utilization.

**Key words:** harvesting protocols, replanting, Reveal Comparative Advantage, Revealed Symmetric Comparative Advantage indices, sustainability.

### Introduction

Forest plays an essential role in our environment, biodiversity, and Gross Domestic Product. (Brockerhoff et al. 2017). The contribution of agriculture and forestry to

Gross Domestic Product declined from 7.4 % in 1980 to 3.3 % in 2015. Agriculture and forestry's sector contribution increased from 3.4 % in 2016 to 4.6 % in 2018 (Laubscher et al. 2019). The forest asset of Namibia is estimated at US\$



288 million; it is high compared to other resources of Namibia. Overharvesting of forest was observed at the national level; however, at the national level, underutilized. Community forest management and trade-in products play an essential role in ameliorating over-harvesting (Barnes et al. 2010).

Namibia exports agricultural commodities to international partners in raw form such as timber and charcoal (Bojnec and Ferto 2014). Despite the precise rules and regulations (the Forest Act, 2000-indicated that it may not export any unprocessed forest produce without authorization of the director and relevant documents provided as a prerequisite for cultural and disease identification, education, and research), Namibia continues to export unprocessed or semi-processed timbers to Western countries. The ignorance of the law is an indication that the ministry officials are not ready to uphold and defend the Forest Act to protect Namibia's rare and slow-growing trees and fight climate changes.

Competitiveness is a measure of countries' advantage or disadvantage in selling its products in international markets (OECD 2015, Miteva-Kacarski 2018). Timber resources are part of Namibia's significant natural resources, which must be exploited for national benefits such as creating employment and mainly contributing to economic growth. Over the past few years (2015–2019), Namibia experienced a substantial increase in timber export. The country exported 3200 t of timber to China and 10,000 blocks of wood from northern Namibia to Vietnam since November 2018. According to Brandt (2019), in 2019, approximately 75,000 t of timber was exported from Namibia, and the government received 231 timber harvesting license applications to cut 47,847 trees per annum, 195,550, in

5 years for exportation (Shinovene 2019). The harvesting of timber could generate an income of approximately N\$24 million a year for local farmers. Due to irregularities in issuing permits and lobbying, local farmers lose N\$24 million per year instead.

The Namibian government has implemented several policies and strategies geared towards improving the competitive market performance and taking advantage of the global open market for the Namibian agriculture sector, including timber, based on its perceived competitive advantage. Despite the policies, capital investment, and agriculture and forestry projects (including timber) that were implemented, little research has been conducted to assess the timber sector's export competitiveness and its implication for natural resources. Existing studies such as by Barnes et al. (2010), Propper and Volla (2013), Nott et al. (2020) and others focused on evaluating timber industry economic and environmental sustainability; examine export taxes applied to the forest industry; assess the value and account of forest resources and awareness and self-governance of illegal harvesting of the forest. None of them consider the export competitiveness of the timber sector and its implication for natural resources. Therefore, the present study attempts to fill this gap in knowledge and literature.

## Material and Methods

### Revealed Comparative Advantage (RCA) and the Revealed Symmetric Comparative Advantage (RSCA)

The competitiveness of the Namibian timber sector export was measured by applying two indexes, i.e., the: Revealed

Comparative Advantage (RCA) and the Revealed Symmetric Comparative Advantage (RSCA). The RCA proposed by Balassa (1965) calculates if the export participation of a certain product (in this case, timber) on the export schedule of the analysed country is (in this case Namibia) higher or lower for the participation of the country in the global market. The RCA index represents the comparative advantage or disadvantage of an exporting country and its competitiveness. In other words, RCA demonstrates whether the input of a certain product reveals an advantage or disadvantages regarding the export schedule of Namibia.

RCA index, which is measured by the product's share in the country's exports with its stake in the world trade, was calculated using the RCA model – equation (1):

$$RCA_{ij} = \frac{\frac{Y_{ij}}{\sum_i Y_{ij}}}{\frac{\sum_j Y_{ij}}{\sum_i \sum_j Y_{ij}}}, \quad (1)$$

where:  $RCA_{ij}$  country  $j$ 's revealed comparative advantage for good  $i$ ;  $Y_{ij}$  is the exports of sector  $i$  of county  $j$ ;  $\sum_i Y_{ij}$  is the total exports of country  $j$ ;  $\sum_j Y_{ij}$  is the world exports of sector  $i$ ; and  $\sum_i \sum_j Y_{ij}$  is the total world export.

The results of indicator RCA mean:

- $RCA < 0$  indicates revealed comparative disadvantages in the sector or commodity group;
- $RCA > 0$  indicates that there are revealed comparative advantages in the country for export commodities for that sector or commodity group; and
- $RCA > 1$  identifies the commodity and sector as internationally competitive.

The Revealed Symmetric Comparative Advantage, an RCA index, is modified

to normalize the RCA's very high values. The RSCA is calculated using the following model – equation (2):

$$RSCA_{ij} = (RCA - 1) / (RCA + 1) \quad (2)$$

RSCA values vary in the interval from -1 to +1. RSCA index measuring more than '0' reveals a competitive advantage of  $i^{\text{th}}$  product being exported by  $j^{\text{th}}$  country and indicates a competitive disadvantage if RSCA is -1. It provides information to how much extent a country is specialised in exporting a particular commodity.

## Data sources

The study employed time series secondary data from 2001 to 2018 obtained from U.N. Comtrade statistics (2019) and Namibia Statistics Agency (2019). The study used export trade data classified according to Harmonized Commodity Description and Coding (HS) system, HS440799 that includes wood, sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end-joined, of a thickness > 6 mm (excluding tropical wood, oak *Quercus* spp., beech *Fagus* spp., maple *Acer* spp., cherry *Prunus* spp., ash *Fraxinus* spp., birch (*Betula* spp.), poplar and aspen *Populus* spp.); Harmonized Commodity Description and Coding (HS) system, HS4401 that includes fuel wood in logs, billets, twigs, faggots or similar forms; wood in chips or particles; sawdust and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms; Harmonized Commodity Description and Coding (HS) system, HS4402 that includes wood charcoal (including shell or nut charcoal), whether or not agglomerated, and Harmonized Commodity Description and Coding (HS) system, HS4403 includes wood in the rough, whether or not stripped of bark or sapwood, or roughly squared.

## Results and Discussion

### Namibia's timber export (net weight and export value)

In recent years (2014–2018), a high number of trees were harvested in Namibia. Table 1 presents volumes in tons and values in US Dollar thousand of all categories of timber. In 2002, Namibia HS 440799 exported 11.2 tons of timber: the lowest volume exported, followed by 22.8 t in 2001 and 62.5 t in 2003. From 2004–2018 export of timber exceeded 100 t. The volume of timber (HS 440799) increase steadily by 99 %  $((1668-11.2)/1668 \cdot 100)$  from 2002 to 2018.

Timber (HS4401), the lowest volume (335 t) export was observed in 2003, followed by 695 t in 2002, and the highest volume of export (20,513 t) took place in 2016. The volume of timber (HS 4401) increase steadily by 107 %  $((20,513-1451)/20,513 \cdot 100)$  from 2001 to 2016.

Timber HS 4402, the lowest export takes place in 2007 with 0.18 t followed by in 2008 with 18 t, and the highest export volume takes place in 2017 with 124436 t. The volume of timber (HS 4402) increase by 77 %  $((109337-25143)/109337 \cdot 100)$  from 2001 to 2018.

Timber HS4403, the lowest export volume, takes place in 2002 with 778 t, followed by 828 t in 2002, and the highest volume export takes place in 2018 with 22651 t. The volume of timber (HS 4402) increase by 97 %  $((22651-778)/22651 \cdot 100)$  from 2002 to 2018.

In a comparison of the four types of timber, commodity HS4402 have the highest volume export with 124436 t in 2017, followed by timber HS4403 with volume export of 22651t in 2018, timber HS4401 followed by 20513 t in 2016, the commodity HS440799 the lowest volume export of

1668 t in 2018 (Table 1).

Namibian annual timber export value growth calculated using Table 1. Annual timber export value growth (HS440799) decline by 20 %  $((50-40)/50 \cdot 100)$  from 2001 to 2002; this was caused by import and export bans of timber export by Namibia, global demand, and supply. Namibia's annual timber export growth from 2017 to 2018 increased by 290 %  $((1250-320)/320 \cdot 100)$ , this directly and directly closely linked to an increase in export of timber from Namibia in general and increase timber harvesting activities in Zambezi district municipality and the two Okavango district municipality of northern Namibia in particular.

Regarding HS4401, timber export growth increase steadily from 2001 to 2011 by 95 %  $((2648-128)/2648 \cdot 100)$ . Consequently, export growth declined from 2011 to 2015 by 23 %  $((2648-2027)/2648 \cdot 100)$ , then increase in 2016. From 2016 to 2018 timber (HS4401) decrease by 88 %  $((2748-342)/2748 \cdot 100)$ .

Namibia, annual timber export growth (HS4402) decline by 14 %  $((1164-1001)/1164 \cdot 100)$  from 2001 to 2002. However, Namibia's annual timber export growth of HS 4402 from 2017 to 2018 increase by 19 %  $((31,928-25901)/31,928 \cdot 100)$ . Further, different export growth trends were observed from one year to another. For commodity HS4403, the highest export value observed in 2017 and 2018, the trend increased by 54 %  $((3564-1642)/3564 \cdot 100)$  from 2017 to 2018. One of the reason could be the Namibian government lifted the ban on the harvesting, transport, and export of timber.

As indicated in Table 1, the trend of growth in timber export is not consistent, possibly due to the global recession of 2007–2009 and the Namibian government

Table 1. Namibia's Timber quantity net weight and export value (2001 to 2018).

| Years | HS440799         |                                      |                  | HS4401                               |                  |                                      | HS4402           |                                      |                  | HS4403                               |                  |                                      |
|-------|------------------|--------------------------------------|------------------|--------------------------------------|------------------|--------------------------------------|------------------|--------------------------------------|------------------|--------------------------------------|------------------|--------------------------------------|
|       | Net weight,<br>t | Export value,<br>USD 10 <sup>3</sup> | Net weight,<br>t | Export value,<br>USD 10 <sup>3</sup> | Net weight,<br>t | Export value,<br>USD 10 <sup>3</sup> | Net weight,<br>t | Export value,<br>USD 10 <sup>3</sup> | Net weight,<br>t | Export value,<br>USD 10 <sup>3</sup> | Net weight,<br>t | Export value,<br>USD 10 <sup>3</sup> |
| 2001  | 22.8             | 50                                   | 1451.227         | 128                                  | 25142.89         | 1164                                 | 828.043          | 89                                   |                  |                                      |                  |                                      |
| 2002  | 11.2             | 40                                   | 695.157          | 195                                  | 20871.07         | 1001                                 | 778.399          | 117                                  |                  |                                      |                  |                                      |
| 2003  | 62.5             | 344                                  | 335.006          | 134                                  | 22422.63         | 2968                                 | 924.273          | 74                                   |                  |                                      |                  |                                      |
| 2004  | 150.5            | 425                                  | 2222.502         | 352                                  | 12630.08         | 5299                                 | 1463.044         | 230                                  |                  |                                      |                  |                                      |
| 2005  | 195.5            | 285                                  | 3872.953         | 612                                  | 12913.28         | 5418                                 | 1205.288         | 190                                  |                  |                                      |                  |                                      |
| 2006  | 176.6            | 269                                  | 7962.397         | 737                                  | 50441.48         | 6690                                 | 3631.524         | 302                                  |                  |                                      |                  |                                      |
| 2007  | 110.7            | 590                                  | 8098.118         | 1158                                 | 0.18             | 0.107                                | 6888.801         | 868                                  |                  |                                      |                  |                                      |
| 2008  | 109.4            | 1234                                 | 11227.24         | 1527                                 | 18               | 7                                    | 6275.46          | 919                                  |                  |                                      |                  |                                      |
| 2009  | 667.3            | 1803                                 | 14788.29         | 1759                                 | 84.358           | 11                                   | 6457.379         | 1298                                 |                  |                                      |                  |                                      |
| 2010  | 356.3            | 844                                  | 14729.06         | 2163                                 | 92958.48         | 19,413                               | 3513.064         | 755                                  |                  |                                      |                  |                                      |
| 2011  | 247.4            | 400                                  | 14819.76         | 2648                                 | 83172.4          | 17,266                               | 2428.037         | 619                                  |                  |                                      |                  |                                      |
| 2012  | 146.9            | 503                                  | 15391.36         | 2396                                 | 84756.54         | 17,410                               | 4089.897         | 1001                                 |                  |                                      |                  |                                      |
| 2013  | 431.3            | 567                                  | 15468.43         | 2188                                 | 100376.2         | 23,505                               | 3663.098         | 851                                  |                  |                                      |                  |                                      |
| 2014  | 1007.6           | 706                                  | 16455.99         | 2138                                 | 109526.6         | 25,070                               | 4860.428         | 598                                  |                  |                                      |                  |                                      |
| 2015  | 700.7            | 755                                  | 19800.29         | 2027                                 | 119297           | 25,386                               | 3139.921         | 363                                  |                  |                                      |                  |                                      |
| 2016  | 406              | 125                                  | 20513.28         | 2748                                 | 117651.8         | 24,241                               | 3423.216         | 423                                  |                  |                                      |                  |                                      |
| 2017  | 951.8            | 320                                  | 6978.005         | 1103                                 | 124436.1         | 25901                                | 10433.39         | 1642                                 |                  |                                      |                  |                                      |
| 2018  | 1668             | 1250                                 | 2777.561         | 342                                  | 109337.4         | 31,928                               | 22651.14         | 3564                                 |                  |                                      |                  |                                      |

Source: Author's computation based on Namibia Statistics Agency (2019) and U.N. Comtrade data (2019).

issues a ban on the harvesting, transport, and export of timber. A significant spike in export value was observed in 2018 for commodity HS440799. For commodity HS4401, a considerable increase was observed in 2011 and 2016; for commodity HS4402 and HS4403, significant growth was observed from 2017 to 2018, respectively. These findings were consistent with the findings of Lukumbuzya and Sianga (2017).

### RCA and RSCA

Tables 2 to 5 presents the RCA and RSCA indexes of the timber sector (HS440799, HS4401, HS4402, and HS4403) exports from Namibia, respectively. The results of Table 2 shows that Namibia had a comparative advantage over the past 17 years for the timber sector's export commodities (HS440799). In 2001, the sub-sector (HS440799) recorded the lowest RCA (0.010), and the lowest RSCA (-0.98) was observed in 2001, 2002, and 2016. The highest RCA value of 0.16 was recorded in 2009 and an RSCA -0.73 in the same year. For a 17-year retrospective, the Namibia timber sector recorded an average RCA value of 0.062, revealing competitiveness. Comparative advantage and competitive advantage are inextricable; thus, they both affect each other. The timber sector had a comparative advantage at the national level from 2001 to 2018, and it had a competitive disadvantage for the same period. The timber sector had no revealed competitive advantage throughout the analysis period. Namibia has had a revealed comparative disadvantage for the past 17 years on the international market. This implies that Namibia does not maintain Timber's share in the global market; thus, Namibia loses competitiveness. These findings concurred with Almeida et

al. (2010) and de Souza et al. (2018); they found that Brazil did not enjoy a comparative advantage.

Table 3 indicates RCA and RSCA indexes of the timber sector (HS4401). In 2018, Namibia recorded the lowest RCA of 0.021 and RSCA of -0.96 (2018), respectively. The highest RCA value of 0.263 was recorded in 2012 and an RSCA -0.58 in the same year. For a 17-year retrospective, the Namibia timber sector recorded an average RCA value of 0.14, revealing competitiveness. Comparative advantage and competitive advantage are inextricable; thus, they both affect each other.

Table 4 indicates RCA and RSCA indexes of the timber sector (HS4402). Namibian timber (HS4402) have a noticeable advantage in the regional and global market from 2010–2018. In 2007, Namibia recorded the lowest RCA of 0.00001 and RSCA of -0.99998 in the same year. The highest RCA value of 2.73 was recorded in 2015 and an RSCA of 0.46 in the same year. For a 17-year retrospective, the Namibia timber sector recorded an average RCA value of 1.22, revealing competitiveness. Comparative advantage and competitive advantage are inextricable; thus, they both affect each other.

Table 5 indicates RCA and RSCA indexes of the timber sector (HS4403). In 2003, Namibia recorded the lowest RCA of 0.01771 and RSCA of -0.97 the same year. The highest RCA value of 0.222 was recorded in 2018 and an RSCA -0.64 the same year. For a 17-year retrospective, the Namibia timber sector recorded an average RCA value of 0.069, revealing competitiveness. Comparative advantage and competitive advantage are inextricable; thus, they both affect each other.

RCA changes are caused by import and export bans of timber export by Namibia, global demand, and supply. To deal

Table 2. Namibia's Timber RCA and RSCA (2001 to 2018) (HS440799).

| Year | World export, USD 10 <sup>3</sup> |                 | Namibia export, USD 10 <sup>3</sup> |                 | Ratios        |             |       | RCA of Namibia    | RSCA of Namibia |
|------|-----------------------------------|-----------------|-------------------------------------|-----------------|---------------|-------------|-------|-------------------|-----------------|
|      | World timber                      | All commodities | Timber                              | All commodities | Namibia ratio | World ratio |       |                   |                 |
| 1    | 2                                 | 3               | 4                                   | 5               | 6=4/5         | 7=2/3       | 8=6/7 | 9=(8-one)/(8+one) |                 |
| 2001 | 21,732,755                        | 6,127,467,761   | 50                                  | 1,362,662       | 0.00004       | 0.00355     | 0.010 | -0.98             |                 |
| 2002 | 22,471,983                        | 6,424,391,781   | 40                                  | 1,282,913       | 0.00003       | 0.00350     | 0.090 | -0.98             |                 |
| 2003 | 24,036,779                        | 7,486,202,969   | 344                                 | 1,303,668       | 0.00026       | 0.00321     | 0.082 | -0.85             |                 |
| 2004 | 29,367,976                        | 9,099,996,891   | 425                                 | 2,544,642       | 0.00017       | 0.00323     | 0.052 | -0.90             |                 |
| 2005 | 30,619,164                        | 10,340,858,415  | 285                                 | 2,725,999       | 0.0001        | 0.00296     | 0.035 | -0.93             |                 |
| 2006 | 32,838,531                        | 11,956,256,558  | 269                                 | 3,375,927       | 0.00008       | 0.00275     | 0.029 | -0.94             |                 |
| 2007 | 35,887,349                        | 13,832,342,053  | 590                                 | 4,040,274       | 0.00015       | 0.00259     | 0.056 | -0.89             |                 |
| 2008 | 30,964,513                        | 15,969,594,225  | 1234                                | 4,729,337       | 0.00026       | 0.00194     | 0.135 | -0.76             |                 |
| 2009 | 23,821,353                        | 12,346,656,501  | 1803                                | 5,870,620       | 0.00031       | 0.00193     | 0.159 | -0.73             |                 |
| 2010 | 28,788,442                        | 15,095,502,449  | 844                                 | 5,848,292       | 0.00014       | 0.00191     | 0.076 | -0.86             |                 |
| 2011 | 31,932,703                        | 18,103,987,370  | 400                                 | 5,900,941       | 0.00007       | 0.00176     | 0.038 | -0.93             |                 |
| 2012 | 31,193,788                        | 18,395,803,866  | 503                                 | 5,376,995       | 0.000094      | 0.00170     | 0.055 | -0.90             |                 |
| 2013 | 35,264,192                        | 18,881,587,009  | 567                                 | 6,337,216       | 0.000089      | 0.00187     | 0.048 | -0.91             |                 |
| 2014 | 37,761,001                        | 18,878,970,324  | 706                                 | 5,983,840       | 0.00012       | 0.00200     | 0.059 | -0.89             |                 |
| 2015 | 32,943,620                        | 16,399,773,904  | 755                                 | 4,628,292       | 0.00016       | 0.00201     | 0.081 | -0.85             |                 |
| 2016 | 34,640,029                        | 15,881,855,749  | 125                                 | 4,815,846       | 0.00003       | 0.00218     | 0.012 | -0.98             |                 |
| 2017 | 38,554,446                        | 17,550,866,220  | 320                                 | 5,229,361       | 0.00006       | 0.00220     | 0.028 | -0.95             |                 |
| 2018 | 41,333,460                        | 19,284,580,098  | 1250                                | 7,488,296       | 0.00017       | 0.00214     | 0.078 | -0.86             |                 |

Note: The last column is addition and subtraction of number one from RCA and to RCA (please refer equation number 2).

Source: Author's computation based on U.N. Comtrade data (2019).



Table 3. Namibia's Timber RCA and RSCA (2001 to 2018) (HS4401).

| Year | World export, USD 10 <sup>3</sup> |                      | Namibia export, USD 10 <sup>3</sup> |                      | Ratios  |         |       | RCA of Namibia    | RSCA of Namibia |
|------|-----------------------------------|----------------------|-------------------------------------|----------------------|---------|---------|-------|-------------------|-----------------|
|      | World timber                      | All commodi-<br>ties | Timber                              | All commodi-<br>ties | 6=4/5   | 7=2/3   | 8=6/7 |                   |                 |
| 1    | 2                                 | 3                    | 4                                   | 5                    |         |         |       | 9=(8-one)/(8+one) |                 |
| 2001 | 21,732,755                        | 6,127,467,761        | 128                                 | 1,362,662            | 0.00009 | 0.00355 | 0.026 | -0.95             |                 |
| 2002 | 22,471,983                        | 6,424,391,781        | 195                                 | 1,282,913            | 0.00015 | 0.00350 | 0.043 | -0.92             |                 |
| 2003 | 24,036,779                        | 7,486,202,969        | 134                                 | 1,303,668            | 0.00010 | 0.00321 | 0.032 | -0.94             |                 |
| 2004 | 29,367,976                        | 9,099,996,891        | 352                                 | 2,544,642            | 0.00014 | 0.00323 | 0.043 | -0.92             |                 |
| 2005 | 30,619,164                        | 10,340,858,415       | 612                                 | 2,725,999            | 0.00022 | 0.00296 | 0.076 | -0.86             |                 |
| 2006 | 32,838,531                        | 11,956,256,558       | 737                                 | 3,375,927            | 0.00022 | 0.00275 | 0.079 | -0.85             |                 |
| 2007 | 35,887,349                        | 13,832,342,053       | 1158                                | 4,040,274            | 0.00029 | 0.00259 | 0.110 | -0.80             |                 |
| 2008 | 30,964,513                        | 15,969,594,225       | 1527                                | 4,729,337            | 0.00032 | 0.00194 | 0.167 | -0.71             |                 |
| 2009 | 23,821,353                        | 12,346,656,501       | 1759                                | 5,870,620            | 0.00030 | 0.00193 | 0.155 | -0.73             |                 |
| 2010 | 28,788,442                        | 15,095,502,449       | 2163                                | 5,848,292            | 0.00037 | 0.00191 | 0.194 | -0.68             |                 |
| 2011 | 31,932,703                        | 18,103,987,370       | 2648                                | 5,900,941            | 0.00045 | 0.00176 | 0.254 | -0.59             |                 |
| 2012 | 31,193,788                        | 18,395,803,866       | 2396                                | 5,376,995            | 0.00045 | 0.00170 | 0.263 | -0.58             |                 |
| 2013 | 35,264,192                        | 18,881,587,009       | 2188                                | 6,337,216            | 0.00035 | 0.00187 | 0.185 | -0.69             |                 |
| 2014 | 37,761,001                        | 18,878,970,324       | 2138                                | 5,983,840            | 0.00036 | 0.00200 | 0.179 | -0.70             |                 |
| 2015 | 32,943,620                        | 16,399,773,904       | 2027                                | 4,628,292            | 0.00044 | 0.00201 | 0.218 | -0.64             |                 |
| 2016 | 34,640,029                        | 15,881,855,749       | 2748                                | 4,815,846            | 0.00057 | 0.00218 | 0.262 | -0.59             |                 |
| 2017 | 38,554,446                        | 17,550,866,220       | 1103                                | 5,229,361            | 0.00021 | 0.00220 | 0.196 | -0.82             |                 |
| 2018 | 41,333,460                        | 19,284,580,098       | 342                                 | 7,488,296            | 0.00005 | 0.00214 | 0.021 | -0.96             |                 |

Note: The last column is addition and subtraction of number one from RCA and to RCA (please refer equation number 2).

Source: Author's computation based on U.N. Comtrade data (2019).

Table 4. Namibia's Timber RCA and RSCA (2001 to 2018) (HS4402).

| Year | World export, USD 10 <sup>3</sup> |                      | Namibia export, USD 10 <sup>3</sup> |                      | Ratios           |             |         | RCA of Namibia    | RSCA of Namibia |
|------|-----------------------------------|----------------------|-------------------------------------|----------------------|------------------|-------------|---------|-------------------|-----------------|
|      | World timber                      | All commodi-<br>ties | Timber                              | All commod-<br>ities | Namibia<br>ratio | World ratio |         |                   |                 |
| 1    | 2                                 | 3                    | 4                                   | 5                    | 6=4/5            | 7=2/3       | 8=6/7   | 9=(8-one)/(8+one) |                 |
| 2001 | 21,732,755                        | 6,127,467,761        | 1164                                | 1,362,662            | 0.00085          | 0.00355     | 0.24084 | -0.61             |                 |
| 2002 | 22,471,983                        | 6,424,391,781        | 1001                                | 1,282,913            | 0.00078          | 0.00350     | 0.22306 | -0.64             |                 |
| 2003 | 24,036,779                        | 7,486,202,969        | 2968                                | 1,303,668            | 0.00228          | 0.00321     | 0.70906 | -0.17             |                 |
| 2004 | 29,367,976                        | 9,099,996,891        | 5299                                | 2,544,642            | 0.00208          | 0.00323     | 0.64526 | -0.22             |                 |
| 2005 | 30,619,164                        | 10,340,858,415       | 5418                                | 2,725,999            | 0.00199          | 0.00296     | 0.67124 | -0.20             |                 |
| 2006 | 32,838,531                        | 11,956,256,558       | 6690                                | 3,375,927            | 0.00198          | 0.00275     | 0.72151 | -0.16             |                 |
| 2007 | 35,887,349                        | 13,832,342,053       | 0.107                               | 4,040,274            | 0.00000003       | 0.00259     | 0.00001 | -0.99998          |                 |
| 2008 | 30,964,513                        | 15,969,594,225       | 7                                   | 4,729,337            | 0.000001         | 0.00194     | 0.00076 | -0.9985           |                 |
| 2009 | 23,821,353                        | 12,346,656,501       | 11                                  | 5,870,620            | 0.000002         | 0.00193     | 0.00097 | -0.9981           |                 |
| 2010 | 28,788,442                        | 15,095,502,449       | 19,413                              | 5,848,292            | 0.00332          | 0.00191     | 1.74058 | 0.27              |                 |
| 2011 | 31,932,703                        | 18,103,987,370       | 17,266                              | 5,900,941            | 0.00293          | 0.00176     | 1.65886 | 0.25              |                 |
| 2012 | 31,193,788                        | 18,395,803,866       | 17,410                              | 5,376,995            | 0.00324          | 0.00170     | 1.90946 | 0.31              |                 |
| 2013 | 35,264,192                        | 18,881,587,009       | 23,505                              | 6,337,216            | 0.00371          | 0.00187     | 1.98594 | 0.330             |                 |
| 2014 | 37,761,001                        | 18,878,970,324       | 25,070                              | 5,983,840            | 0.00419          | 0.002       | 2.09464 | 0.35              |                 |
| 2015 | 32,943,620                        | 16,399,773,904       | 25,386                              | 4,628,292            | 0.00548          | 0.00201     | 2.73049 | 0.46              |                 |
| 2016 | 34,640,029                        | 15,881,855,749       | 24,241                              | 4,815,846            | 0.00503          | 0.00218     | 2.30781 | 0.40              |                 |
| 2017 | 38,554,446                        | 17,550,866,220       | 25901                               | 5,229,361            | 0.00495          | 0.00220     | 2.25472 | 0.39              |                 |
| 2018 | 41,333,460                        | 19,284,580,098       | 31,928                              | 7,488,296            | 0.00426          | 0.00214     | 1.9893  | 0.331             |                 |

Note: The last column is addition and subtraction of number one from RCA and to RCA (please refer equation number 2).

Source: Author's computation based on U.N. Comtrade data (2019).

Table 5. Namibia's Timber RCA and RSCA (2001 to 2018) (HS4403).

| Year | World export, USD 10 <sup>3</sup> |                      | Namibia export, USD 10 <sup>3</sup> |                      | Ratios           |             |        | RCA of Namibia        | RSCA of Namibia |
|------|-----------------------------------|----------------------|-------------------------------------|----------------------|------------------|-------------|--------|-----------------------|-----------------|
|      | World timber                      | All commodi-<br>ties | Timber                              | All commod-<br>ities | Namibia<br>ratio | World ratio |        |                       |                 |
| 1    | 2                                 | 3                    | 4                                   | 5                    | 6=4/5            | 7=2/3       | 8=6/7  | 9=(8-one)/<br>(8+one) |                 |
| 2001 | 21,732,755                        | 6,127,467,761        | 89                                  | 1,362,662            | 0.00007          | 0.00355     | 0.0184 | -0.96                 |                 |
| 2002 | 22,471,983                        | 6,424,391,781        | 117                                 | 1,282,913            | 0.000091         | 0.00350     | 0.026  | -0.949                |                 |
| 2003 | 24,036,779                        | 7,486,202,969        | 74                                  | 1,303,668            | 0.00006          | 0.00321     | 0.0177 | -0.97                 |                 |
| 2004 | 29,367,976                        | 9,099,996,891        | 230                                 | 2,544,642            | 0.00009          | 0.00323     | 0.028  | -0.946                |                 |
| 2005 | 30,619,164                        | 10,340,858,415       | 190                                 | 2,725,999            | 0.00007          | 0.00296     | 0.024  | -0.954                |                 |
| 2006 | 32,838,531                        | 11,956,256,558       | 302                                 | 3,375,927            | 0.000089         | 0.00275     | 0.033  | -0.94                 |                 |
| 2007 | 35,887,349                        | 13,832,342,053       | 868                                 | 4,040,274            | 0.00021          | 0.00259     | 0.083  | -0.85                 |                 |
| 2008 | 30,964,513                        | 15,969,594,225       | 919                                 | 4,729,337            | 0.00019          | 0.002       | 0.100  | -0.82                 |                 |
| 2009 | 23,821,353                        | 12,346,656,501       | 1298                                | 5,870,620            | 0.00022          | 0.0019      | 0.115  | -0.79                 |                 |
| 2010 | 28,788,442                        | 15,095,502,449       | 755                                 | 5,848,292            | 0.00013          | 0.0019      | 0.068  | -0.87                 |                 |
| 2011 | 31,932,703                        | 18,103,987,370       | 619                                 | 5,900,941            | 0.000105         | 0.0018      | 0.059  | -0.89                 |                 |
| 2012 | 31,193,788                        | 18,395,803,866       | 1001                                | 5,376,995            | 0.00019          | 0.0017      | 0.110  | -0.80                 |                 |
| 2013 | 35,264,192                        | 18,881,587,009       | 851                                 | 6,337,216            | 0.00013          | 0.0019      | 0.072  | -0.87                 |                 |
| 2014 | 37,761,001                        | 18,878,970,324       | 598                                 | 5,983,840            | 0.00010          | 0.002       | 0.050  | -0.90                 |                 |
| 2015 | 32,943,620                        | 16,399,773,904       | 363                                 | 4,628,292            | 0.00008          | 0.002       | 0.039  | -0.925                |                 |
| 2016 | 34,640,029                        | 15,881,855,749       | 423                                 | 4,815,846            | 0.000088         | 0.0022      | 0.040  | -0.923                |                 |
| 2017 | 38,554,446                        | 17,550,866,220       | 1642                                | 5,229,361            | 0.00031          | 0.0022      | 0.143  | -0.75                 |                 |
| 2018 | 41,333,460                        | 19,284,580,098       | 3564                                | 7,488,296            | 0.00048          | 0.00214     | 0.222  | -0.64                 |                 |

Note: The last column is addition and subtraction of number one from RCA and to RCA (please refer equation number 2).

Source: Author's computation based on U.N. Comtrade data (2019).

with the asymmetry problem in RCA, the index was transformed into a Symmetric Reveal Comparative advantage (RSCA). The main advantage of RSCA is it adjusted the weight and unity Hoang et al. (2017).

Namibia's RSCA over 17 years shows Namibia exports of timber showed varying levels of comparative disadvantage for all categories of timber. This finding concurred with Petrauski et al. (2012).

## Conclusions

The results showed that Namibia's timber sector has revealed comparative advantage or competitiveness for the past 17 years but not internationally competitive. Namibia's annual timber export (HS440799) growth declined by 20 % from 2001 to 2002; this was caused by import and export bans of timber export by Namibia, global demand, and supply. Namibia's annual timber export growth from 2017 to 2018 increased by 290 %; this is directly and directly closely linked to an increase in timber export from Namibia in general and an increased timber harvesting activities in northern Namibia in particular.

The result shows that Namibia had a revealed comparative advantage for 17 years; however, all below one (except for commodity HS4402 from 2010–2018) means that Namibia timber exports are not internationally competitive. In 2001, the sub-sector (HS440799) recorded the lowest RCA (0.010), and the lowest RSCA (-0.98) was observed in 2001, 2002, and 2016. The highest RCA value of 0.16 was recorded in 2009 and an RSCA -0.73 in the same year. The highest RCA and RSCA of 0.263 and -0.58 respectively was achieved in 2018 for commodity

(HS4401), Namibia recorded the lowest RCA of 0.021 (in 2018) and RSCA of -0.96 (2018), in the same year. Namibian timber (HH4402) have a noticeable advantage in the regional and global market from 2010–2018. In 2007, Namibia recorded the lowest RCA of 0.00001 and RSCA of -0.99998 in the same year. The highest RCA value of 2.73 was recorded in 2015 and an RSCA of 0.46 in the same year. For timber HS4403, in 2003, Namibia recorded the lowest RCA of 0.01771 and RSCA of -0.97 the same year. The highest RCA value of 0.222 was recorded in 2018 and an RSCA -0.64 the same year.

Namibia's RCA and RSCA over 17 years shows Namibia exports of timber showed varying levels of comparative disadvantage for all categories of timber commodities, except for commodity HS4402 from 2010–2018). Thus, it can be concluded that Namibia's timber sector is not internationally competitive, and the country does not specialize in international exports, especially when considering the results of RSCA. This implies that Namibia does not maintain Timber's share in the global market; thus, Namibia loses competitiveness.

Timber exports are a natural-resource-intensive sector based on renewable commodities. RCA and RSCA prove that, overall, timber comparative export pattern heavily depends on export volumes and timber exports' values. Timber export competitiveness is not sustainable, given the heavy dependence on natural forests. This implies that unsustainable timber harvesting will deplete natural forests; the country will lose out on timber export earnings.

Namibia should re-structure timber harvesting protocols to include replacement or replanting every tree species harvested for timber production to ensure

the sub-sector's sustainability. The country's timber export sub-sector should focus more on adding value to timber than exporting for improved competitiveness. Further, the government should regulate the harvested timber to promote timber and forest resources' sustainable utilization and stimulate ongoing and sustainable economic growth and employment creation.

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## SUGAR CONTENT OF HONEY BEE-POLLEN FROM ASTERACEAE SPECIES COLLECTED FROM FORESTRY AREA

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### Abstract

In the research, HPLC method was used to determine the composition of sugar profile of identified honey bee-pollen from Asteraceae species spread in a forestry area. The analysis showed that bee-pollen is described by a high content of glucose and fructose, which depends on the origin of bee-collected pollen. They constitute from 60.0 % of the total sugar content for *Centaurea cyanus* L. to 100 % for *Carduus* sp., *Centaurea* sp., *Centaurea calcitrapa* L., *Centaurea solstitialis* L. and *Chondrilla juncea* L. bee-pollen. The content of fructose ranged from 13.3 % for *C. juncea* to 20.3 % for *C. calcitrapa*, average 16.8 %. Glucose was the second highest content from 10.2 % for *Echinops ritro* L. to 21.4 % for *C. cyanus*, average 15.5 %. Of all analyzed samples the presence of trisaccharide melezitose was not detected.

**Key words:** *Apis mellifera*, carbohydrates, monofloral pollen.

### Introduction

Till nowadays no scientific evidence has been cited to disprove the claimed properties of bee-pollen (Campos et al. 1997). Sugars constitute the main component of bee-collected pollen grains, and they vary among different pollen taxa according to their origin and the surrounding vegetation (Dimou et al. 2020). Pollen contains a wide variety of sugars (Stanley and Linskens 1974). Several authors (Cirnu et al. 1969, Rosenthal et al. 1969, Herbert and Shimanuki 1978) made first studies on reducing and non-reducing sugars. Studies between hand-collected and bee-collected pollen have shown the importance of the added nectar during pollen load formation to sugar content (Dimou et al. 2020).

Sugar composition of pollen are nectar carbohydrates, mostly fructose and glucose, arabinose, xylose, sucrose, dextrans, starch and cellulose – from 15 % to 60 % (Mladenov 1989). Cellulose is contained in large quantities in exine of pollen grains, but in total amount of all components it is small – from 1 % to 3 %. The starch content reaches up to 7 %. The pollen from *Zea mays* contains up to 22 % starch (Shkenderov and Ivanov 1983). According to other researches sugar content of pollen is about 27 % (Todd and Bretherick 1942, Weygand and Hofmann 1950, McLellan 1977).

The present research aimed to determine the sugar profile of identified honey bee-collected pollen grains from Asteraceae species spread in a forestry area.

These plants provide pollen in autumn, used in early spring next year by honey bees (*Apis mellifera* L.) and is important for honey bee's nutrition diet.

## Material and Methods

Pollen traps were used in 5 bee hives and pollen pellets were harvested every 1–2 days from April till September in forestry area of Bratya Daskalovi Municipality (Bulgaria) (42°30'08" E and 25°21'03" N). The area is located at the end in the central part of the mountain Sredna gora, 671 m a.s.l.

Over four hundred samples of bee-pollen pellets are separated over white sheet, according to colour, shape and structure. Distinguishment of morphology of pollen grains and colour of pellets during their collection by bees was made, which helped to separate and identify them. The plant species of each pollen pellet was identified through microscopic examination of grains. Melissopalynological analysis was carried out using methodology of Louveaux et al. (1970). To identify the pollen database of plants from the area was created.

Sugar analysis of bee-pollen was performed by HPLC method (Liolios et al. 2018) in laboratory of Apiculture-Sericulture of Aristotle University, Thessaloniki. All the results were expressed as percentage.

The results were statistically processed by using Anova.

## Results and Discussion

Eleven pollen types belonging to Asteraceae were analysed for sugars. Analysis

of monosaccharides was made – fructose and glucose (reducing sugars); disaccharides – saccharose and trehalose (non-reducing sugars), maltose, turanose and melibiose (reducing sugars); and trisaccharide – melezitose (non-reducing sugar). Of all analysed samples the presence of melezitose was not detected (Table 1).

The results of sugars' analysis showed that their percentage varied among the plant species (Table 1). The average percentage content of total sugars was 35.69 % and ranged from 25.1 % for *C. juncea* to 59.7 % for *C. cyanus*. Most quantity of sugars in all identified bee-pollen pellets were the monosaccharides fructose and glucose. They constituting from 60.0 % of the total sugars content for *C. cyanus* to 100 % for *Carduus* sp., *Centaurea* sp., *C. calcitrapa*, *C. solstitialis* and *C. juncea* bee-pollen. Fructose was present in highest concentration of all the analysed sugars, only pollen from *C. cyanus* and *Helianthus annuus* L. contain more glucose. Fructose content ranged from 13.3 % for *C. juncea* to 20.3 % for *C. calcitrapa*, average 16.8 %, and glucose ranged from 10.2 % for *E. ritro* to 21.4 % for *C. cyanus*, average 15.5 %.

Saccharose was found in 2 out of 11 taxa and its highest content 2.1 % was recorded for *H. annuus*. Turanose was detected only in 1 sample, with content 4.8 % for *C. cyanus*. Maltose was found in 3 out of 11 taxa with content ranged from 1.6 % for *Cichorium intybus* L. to 4.3 % for *Taraxacum officinale* (L.) Weber ex F. H. Wigg. Trehalose was detected in two species. The average highest content of it was found in bee-pollen of *E. ritro* – 3.5 %. In the rest of the samples melibiose was only detected in *C. cyanus* with content 12.1 %. Trisaccharide melezitose was not found at any sample (Table 1).

**Table 1. Sugar composition of 11 identified bee-collected pollen species in %.**

| Taxa                          | Fructose | Glucose | Saccharose | Turanose | Maltose | Trehalose | Melibiose | Melezitose | Total |
|-------------------------------|----------|---------|------------|----------|---------|-----------|-----------|------------|-------|
| <i>Carduus</i> sp.            | 16.7     | 14.2    | NF         | NF       | NF      | NF        | NF        | NF         | 30.9  |
| <i>Centaurea</i> sp.          | 18.9     | 15.6    | NF         | NF       | NF      | NF        | NF        | NF         | 34.5  |
| <i>Centaurea calcitrapa</i>   | 20.3     | 19.6    | NF         | NF       | NF      | NF        | NF        | NF         | 39.9  |
| <i>Centaurea cyanus</i>       | 15.4     | 21.4    | 1.8        | 4.8      | 4.2     | NF        | 12.1      | NF         | 59.7  |
| <i>Centaurea solstitialis</i> | 15.7     | 15.1    | NF         | NF       | NF      | NF        | NF        | NF         | 30.8  |
| <i>Chondrilla juncea</i>      | 13.3     | 11.8    | NF         | NF       | NF      | NF        | NF        | NF         | 25.1  |
| <i>Cichorium intybus</i>      | 17.3     | 15.7    | NF         | NF       | 1.6     | NF        | NF        | NF         | 34.6  |
| <i>Cirsium</i> sp.            | 15.8     | 14.4    | NF         | NF       | NF      | 2.6       | NF        | NF         | 32.8  |
| <i>Echinops ritro</i>         | 18.9     | 10.2    | NF         | NF       | NF      | 3.5       | NF        | NF         | 32.6  |
| <i>Helianthus annuus</i>      | 18.7     | 20.6    | 2.1        | NF       | NF      | NF        | NF        | NF         | 41.4  |
| <i>Taraxacum officinale</i>   | 13.9     | 12.1    | NF         | NF       | 4.3     | NF        | NF        | NF         | 30.3  |
| Maximal value                 | 20.3     | 21.4    | 2.1        | -        | 4.3     | 3.5       | -         | -          | 59.7  |
| Minimal value                 | 13.3     | 10.2    | 1.8        | -        | 1.6     | 2.6       | -         | -          | 25.1  |

Note: NF – not found.

According to Szczesna (2007) fructose ranged from: 15.51 % to 19.22 % in samples from Poland; 12.09 % to 22.06 % for Korean samples; 9.74 % to 17.90 % for samples from China. Fructose content of present study was similar. In sugar profile of bee-pollen species from Asteraceae was found that *C. calcitrapa* and *H. annuus* pollen had much higher monosaccharide content, while *C. juncea* and *T. officinale* bee-pollen had fructose and glucose content lower than the rest. *C. cyanus* contains the most variety of sugars. *C. intybus*, *Cirsium* sp., *E. ritro*, *H. annuus*, *T. officinale* contain three types of sugars, and *Carduus* sp., *Centaurea* sp., *C. calcitrapa*, *C. solstitialis*, *C. juncea* contain only monosaccharides. Disaccharides were not always detected (Table 1). Asteraceae plants provide pollen to bees

from early spring till late autumn. In this study it is confirmed that sugars' profile of bee-pollen is characterised mainly by monosaccharides, found by Todd and Bretherick (1942), Stanley and Linskens (1974) and Nicolson (2011).

The average content of fructose is 16.80 % and glucose – 15.51 %. Other sugar contents of pollen are reported in Table 2 as well.

The statistical analysis according to sugar content showed that the monosaccharides are the main sugar ingredients in pollen  $y=2.0358x+4.0991$  and  $R^2=0.6652$  (Fig. 1).

Author's results for sugars in *C. intybus* are similar to Liolios et al. (2018), while fructose and glucose are much lower for *T. officinale* but maltose is double higher (Table 3).

Table 2. Average sugar content.

| Indicator        | Fructose  | Glucose    | Saccharose | Maltose   | Trehalose | Total sugars |
|------------------|-----------|------------|------------|-----------|-----------|--------------|
| Average value, % | 16.80     | 15.51      | 1.95       | 3.36      | 3.05      | 35.69        |
| Means±std        | 16.8±2.23 | 15.51±3.66 | 1.95±0.21  | 3.36±1.53 | 3.05±0.64 | 35.69±9.14   |

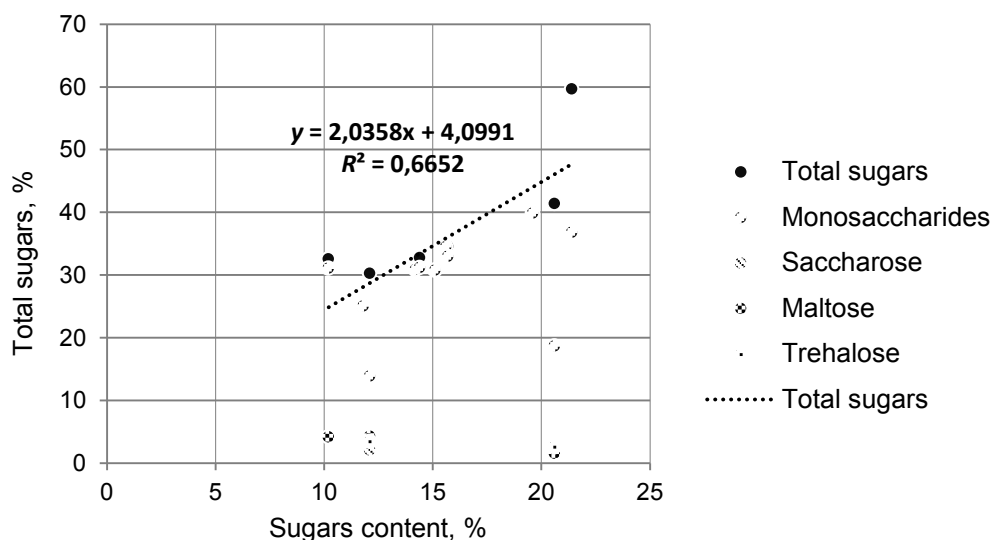


Fig. 1. Sugar content to total sugars.

Table 3. Comparing pollen sugar contents results in %.

| Species           | Source | Fructose | Glucose | Saccharose | Maltose | Melezitose | Total sugars |
|-------------------|--------|----------|---------|------------|---------|------------|--------------|
| <i>Cichorium</i>  | 1      | 17.3     | 15.7    | 0          | 1.6     | 0          | 34.6         |
| <i>intybus</i>    | 2      | 18.5     | 15.39   | 0.19       | 0.86    | 0.09       | 35.03        |
| <i>Taraxacum</i>  | 1      | 13.9     | 12.1    | 0          | 4.3     | 0          | 30.3         |
| <i>officinale</i> | 2      | 20.89    | 18.68   | 0          | 2.05    | 0          | 41.62        |

Note: 1 – author's results; 2 – Liolios et al. (2018) results.

## Conclusions

The studies for sugars content of identified bee-pollen are very limited. Obtained results give information and knowledge on sugar content in identified bee-pollen samples from the most popular and important plant family Asteraceae for honey bees. Bee-collected pollen is characterised by a

high content of monosaccharides glucose and fructose.

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## BREEDING BIRDS IN NORTHWESTERN SAKAR MOUNTAIN, BULGARIA

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### Abstract

The study area is a low mountain; nevertheless it has substantial biodiversity, due to its specific location, xerothermic vegetation and positive average monthly temperatures. The study was conducted in the period 2014–2020. It determinates 35 percent of the avifauna and 58 percent of the breeding birds of Sakar Mountain. This study reports two new species for the area. It informs about 89 species assigned to a specific breeding category. Seven species assigned to a breeding category are new to the quadrant and have not been reported by previous studies. The breeding density of 13 bird species was established. The density decreases in two common birds in study area.

**Key words:** breeding density, Common Tern, Common Quail, European Turtle Dove, Ruddy Shelduck.

### Introduction

Birds are often used as indicators of biodiversity. The trends and dynamics of bird populations are often associated with other taxa, which allows the identification of important warnings for upcoming changes (Gregory et al. 2008, Gregory and van Strien 2010). Sakar Mountain is a low mountain; nevertheless it has substantial biodiversity. It has been the subject of a number of ornithological studies (Borisov 1988, Petrov et al. 1997, Milchev and Kovachev 1998, Stoychev et al. 2007). There are 253 bird species found in Sakar region, and a more extensive study conducted at the beginning of the new century

has confirmed 232 of them (Stoychev et al. 2007).

Due to its specific location between Maritsa River and Tundzha River, its xerothermic vegetation as well as the positive average monthly temperatures throughout the year, Sakar Mountain is characterized by diverse fauna and the presence of southern species (Bondev 1991, Kopralev 2002, Stoychev et al. 2007).

Despite the availability of information about Sakar avifauna, the northwestern part of the mountain within which the present study falls remains relatively poorly studied. According to Iankov (2007), 98 species have been registered in the study area.



The aim of the study is to offer an overview of the breeding birds in Northwestern Sakar Mountain and provide data on the density of some of them. The results obtained should be compared with the diversity of the birds in the rest of the Mountain in order to identify what share of the breeding birds of Sakar is located within the study area.

## Materials and Methods

The study area (UTM square MG14, 35T) encompasses the northwestern slopes of Sakar Mountain, and a small part of Maritsa River valley. Parts of two Natura protected areas fall within the scope of this study: Reka Maritsa BG 0000578 and Radinchevo BG 0002020.

The study was conducted in the period 2014–2020 (average 30 days per year). Data were collected by means of two methods: the point count method and the transect method (Bibby et al. 1992). The point count method was used in the period from April 20 to August 1 (Gruychev and Mihaylov 2019) (Fig. 1). This method was used to count the breeding density of Eurasian Collared Dove (*Streptopelia decaocto* (Frivaldszky, 1838)), European Turtle Dove (*Streptopelia turtur* (Linnaeus, 1758)), Eurasian Golden Oriole (*Oriolus oriolus* (Linnaeus, 1758)) and Common Nightingale (*Luscinia megarhynchos* (Brehm CL, 1831)). The breeding density reported by point count method was determined by 106 points in MG 14. Hundred points were positioning in the center of the 100 one-kilometer squares of MG 14. Another 6 points were

placed at the locations where the birds' song was heard less clearly (Fig. 1). Every point was visited 7 times per year. All the data from point counts method were collected in clear and quiet weather, with no rainfall, between 4:00 and 8:30 am. The breeding density by point counts was calculated by maximum number of singing birds in all annual reports (Bibby et al. 1992). Data on other species were collected from 10 transects of a total length of 44.39 km and a width of 50 m (Fig. 1).

Transects were selected in a way that represents the distribution of habitat types in the quadrant as described by Gruychev and Mihaylov (2019). Each transect was visited four times between February 15 and July 15. They were visited in the morning between 7:00 and 10:30 am. The breeding density in transects was calculated by average number of breeding pairs reported in all transects by years. The criteria used to assess breeding evidence follow Hagemajr and Blair (1997). The taxonomy of birds used is according to Clements et al. (2019). One-way Anova was used to establish the breeding density trend of all birds.

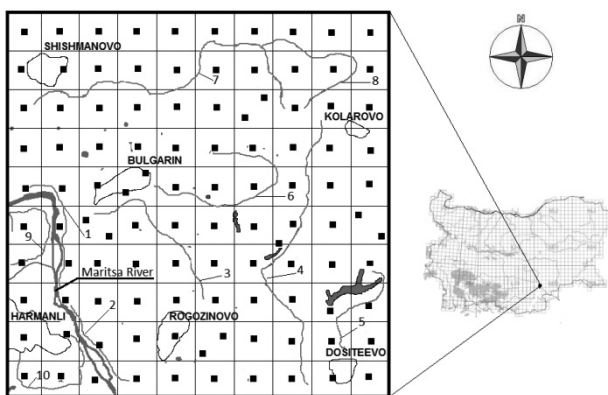


Fig. 1. Study area, points of count and transects in MG 14 (35T).

## Results

### Breeding category

The present study reported 89 species assigned to a specific breeding category (Table 1). Of these, 22 species are in the Red Data Book of the Republic of Bulgaria (Golemaki 2015), and seven species assigned to a breeding category are new

to the UTM square and have not been reported by previous studies (Stoychev et al. 2007, Iankov 2007). Ruddy Shelduck (*Tadorna ferruginea* (Pallas, 1764)) has not been reported for Sakar Mountain to this moment. A pair of birds was observed for first time on 03.04.2020. They remained in a 5.65-ha body of water characterized by shoreline vegetation overgrowth for 4 days following the date of the initial observation.

Table 1. Breeding birds in MG 14 (T35) UTM.

| No | Species                                           | RDB/IUCN<br>category<br>BG | SPEC/EU<br>population<br>status | Breeding<br>cat. by<br>Iankov<br>(2007) | Breeding<br>cat. this<br>study |
|----|---------------------------------------------------|----------------------------|---------------------------------|-----------------------------------------|--------------------------------|
| 1  | <b><i>Tadorna ferruginea</i> (Pallas, 1764)</b>   | RDB/CR                     | 3/D                             | x                                       | PrB                            |
| 2  | <i>Anas platyrhynchos</i> Linnaeus, 1758          | -                          | -                               | CB                                      | CB                             |
| 3  | <i>Coturnix coturnix</i> (Linnaeus, 1758)         | -                          | 3/D                             | CB                                      | CB                             |
| 4  | <i>Alectoris chukar</i> (Gray, JE, 1830)          | RDB/EN                     | 3/NT                            | CB                                      | CB                             |
| 5  | <i>Phasianus colchicus</i> Linnaeus, 1758         | RDB/EX                     | -                               | CB                                      | CB                             |
| 6  | <i>Perdix perdix</i> (Linnaeus, 1758)             | -                          | 2/Dec                           | CB                                      | CB                             |
| 7  | <i>Tachybaptus ruficollis</i> (Pallas, 1764)      | RDB/VU                     | -                               | CB                                      | CB                             |
| 8  | <i>Columba livia domestica</i> Gmelin, 1789       | -                          | -                               | CB                                      | CB                             |
| 9  | <i>Columba palumbus</i> Linnaeus, 1758            | -                          | -                               | CB                                      | CB                             |
| 10 | <i>Streptopelia turtur</i> (Linnaeus, 1758)       | -                          | 1/VU                            | CB                                      | CB                             |
| 11 | <i>Streptopelia decaocto</i> (Frisvaldszky, 1838) | -                          | -                               | CB                                      | CB                             |
| 12 | <i>Cuculus canorus</i> Linnaeus, 1758             | -                          | -                               | PrB                                     | CB                             |
| 13 | <i>Caprimulgus europaeus</i> Linnaeus, 1758       | -                          | -                               | PrB                                     | PrB                            |
| 14 | <i>Apus apus</i> (Linnaeus, 1758)                 | -                          | -                               | CB                                      | CB                             |
| 15 | <i>Crex crex</i> (Linnaeus, 1758)                 | RDB/VU                     | 2/D                             | PB                                      | PB                             |
| 16 | <i>Gallinula chloropus</i> (Linnaeus, 1758)       | -                          | -                               | CB                                      | CB                             |
| 17 | <i>Burhinus oedipnemos</i> (Linnaeus, 1758)       | RDB/VU                     | 3/D                             | PB                                      | x                              |
| 18 | <i>Haematopus ostralegus</i> Linnaeus, 1758       | RDB/CR                     | -                               | PrB                                     | PB                             |
| 19 | <i>Vanellus vanellus</i> (Linnaeus, 1758)         | -                          | 1/VU                            | PB                                      | x                              |
| 20 | <i>Charadrius dubius</i> Scopoli, 1786            | RDB/VU                     | -                               | PrB                                     | CB                             |
| 21 | <b><i>Scolopax rusticola</i> Linnaeus, 1758</b>   | RDB/EN                     | -                               | x                                       | PrB                            |
| 22 | <i>Ciconia nigra</i> (Linnaeus, 1758)             | RDB/VU                     | -                               | CB                                      | CB                             |
| 23 | <i>Ciconia ciconia</i> (Linnaeus, 1758)           | RDB/VU                     | -                               | CB                                      | CB                             |
| 24 | <i>Circaetus gallicus</i> (Gmelin, JF, 1788)      | RDB/VU                     | -                               | CB                                      | PrB                            |
| 25 | <b><i>Clanga pomarina</i> (Brehm, CL, 1831)</b>   | RDB/VU                     | -                               | x                                       | PB                             |
| 26 | <i>Hieraetus pennatus</i> (Gmelin, JF, 1788)      | RDB/VU                     | -                               | PB                                      | PrB                            |
| 27 | <i>Accipiter brevipes</i> (Severtsov, 1850)       | RDB/VU                     | 2/R                             | CB                                      | PB                             |
| 28 | <i>Accipiter nisus</i> (Linnaeus, 1758)           | RDB/EN                     | -                               | PrB                                     | CB                             |

| No | Species                                                  | RDB/IUCN<br>category<br>BG | SPEC/EU<br>population<br>status | Breeding<br>cat. by<br>lankov<br>(2007) | Breeding<br>cat. this<br>study |
|----|----------------------------------------------------------|----------------------------|---------------------------------|-----------------------------------------|--------------------------------|
| 29 | <i>Accipiter gentilis</i> (Linnaeus, 1758)               | RDB/EN                     | -                               | PrB                                     | CB                             |
| 30 | <i>Milvus milvus</i> (Linnaeus, 1758)                    | RDB/CR                     | -                               | PB                                      | x                              |
| 31 | <i>Milvus migrans</i> (Boddaert, 1783)                   | RDB/VU                     | 3/D                             | CB                                      | CB                             |
| 32 | <i>Buteo buteo</i> (Linnaeus, 1758)                      | -                          | -                               | CB                                      | CB                             |
| 33 | <i>Buteo rufinus</i> (Cretzschmar, 1829)                 | RDB/VU                     | -                               | CB                                      | CB                             |
| 34 | <i>Tyto alba</i> (Scopoli, 1769)                         | RDB/VU                     | 3/D                             | PrB                                     | x                              |
| 35 | <i>Otus scops</i> (Linnaeus, 1758)                       | -                          | 2/D                             | CB                                      | PrB                            |
| 36 | <i>Bubo bubo</i> (Linnaeus, 1758)                        | RDB/EN                     | 3/D                             | PB                                      | x                              |
| 37 | <i>Athene noctua</i> (Scopoli, 1769)                     | -                          | 3/D                             | CB                                      | CB                             |
| 38 | <i>Strix aluco</i> Linnaeus, 1758                        | -                          | -                               | PB                                      | x                              |
| 39 | <i>Asio otus</i> (Linnaeus, 1758)                        | -                          | -                               | CB                                      | x                              |
| 40 | <i>Upupa epops</i> Linnaeus, 1758                        | -                          | -                               | CB                                      | CB                             |
| 41 | <i>Alcedo atthis</i> (Linnaeus, 1758)                    | -                          | 3/VU                            | PrB                                     | PrB                            |
| 42 | <i>Merops apiaster</i> Linnaeus, 1758                    | -                          | -                               | CB                                      | CB                             |
| 43 | <i>Coracias garrulus</i> Linnaeus, 1758                  | RDB/VU                     | 2/Dec                           | PrB                                     | PrB                            |
| 44 | <i>Jynx torquilla</i> Linnaeus, 1758                     | -                          | 3/D                             | PrB                                     | x                              |
| 45 | <i>Dendrocopos major</i> (Linnaeus, 1758)                | -                          | -                               | PrB                                     | CB                             |
| 46 | <i>Dendrocopos syriacus</i> (Hemprich & Ehrenberg, 1833) | -                          | -                               | CB                                      | CB                             |
| 47 | <b><i>Dryobates minor</i> (Linnaeus, 1758)</b>           | -                          | -                               | x                                       | PrB                            |
| 48 | <i>Picus canus</i> Gmelin, JF, 1788                      | RDB/EN                     | -                               | PB                                      | x                              |
| 49 | <i>Picus viridis</i> Linnaeus, 1758                      | -                          | -                               | CB                                      | CB                             |
| 50 | <i>Falco tinnunculus</i> Linnaeus, 1758                  | -                          | 3/Dec                           | CB                                      | CB                             |
| 51 | <i>Falco subbuteo</i> Linnaeus, 1758                     | RDB/VU                     | -                               | CB                                      | x                              |
| 52 | <i>Oriolus oriolus</i> (Linnaeus, 1758)                  | -                          | -                               | CB                                      | CB                             |
| 53 | <i>Lanius collurio</i> Linnaeus, 1758                    | -                          | 2/D                             | CB                                      | CB                             |
| 54 | <i>Lanius minor</i> Gmelin, JF, 1788                     | -                          | 2/Dec                           | CB                                      | CB                             |
| 55 | <i>Lanius nubicus</i> Lichtenstein, MHC, 1823            | RDB/VU                     | 2/Dec                           | CB                                      | CB                             |
| 56 | <i>Lanius senator</i> Linnaeus, 1758                     | -                          | 2/Dec                           | CB                                      | CB                             |
| 57 | <i>Garrulus glandarius</i> (Linnaeus, 1758)              | -                          | -                               | PrB                                     | PrB                            |
| 58 | <i>Pica pica</i> (Linnaeus, 1758)                        | -                          | -                               | CB                                      | CB                             |
| 59 | <i>Coloeus monedula</i> Linnaeus, 1758                   | -                          | -                               | CB                                      | CB                             |
| 60 | <i>Corvus cornix</i> Linnaeus, 1758                      | -                          | -                               | CB                                      | CB                             |
| 61 | <i>Corvus corax</i> Linnaeus, 1758                       | -                          | -                               | PrB                                     | CB                             |
| 62 | <i>Cyanistes caeruleus</i> (Linnaeus, 1758)              | -                          | -                               | PrB                                     | PrB                            |
| 63 | <i>Parus major</i> Linnaeus, 1758                        | -                          | -                               | CB                                      | CB                             |
| 64 | <i>Remiz pendulinus</i> (Linnaeus, 1758)                 | RDB/VU                     | -                               | CB                                      | x                              |
| 65 | <i>Calandrella brachydactyla</i> (Leiser, 1814)          | RDB/VU                     | 3/D                             | PrB                                     | PrB                            |
| 66 | <i>Melanocorypha calandra</i> (Linnaeus, 1766)           | RDB/EN                     | 3/Dec                           | CB                                      | CB                             |
| 67 | <i>Lullula arborea</i> (Linnaeus, 1758)                  | -                          | 2/D                             | PrB                                     | PB                             |

| No  | Species                                               | RDB/IUCN<br>category<br>BG | SPEC/EU<br>population<br>status | Breeding<br>cat. by<br>lankov<br>(2007) | Breeding<br>cat. this<br>study |
|-----|-------------------------------------------------------|----------------------------|---------------------------------|-----------------------------------------|--------------------------------|
| 68  | <i>Alauda arvensis</i> Linnaeus, 1758                 | -                          | 3/Dec                           | CB                                      | CB                             |
| 69  | <i>Galerida cristata</i> (Linnaeus, 1758)             | -                          | 3/Dec                           | CB                                      | CB                             |
| 70  | <i>Iduna pallida</i> (Hemprich & Ehrenberg, 1833)     | -                          | -                               | PrB                                     | PrB                            |
| 71  | <b><i>Hippolais olivetorum</i> (Strickland, 1837)</b> | RDB/VU                     | -                               | x                                       | PrB                            |
| 72  | <i>Acrocephalus arundinaceus</i> (Linnaeus, 1758)     | -                          | -                               | PrB                                     | PrB                            |
| 73  | <i>Riparia riparia</i> (Linnaeus, 1758)               | -                          | 3/D                             | CB                                      | x                              |
| 74  | <i>Hirundo rustica</i> Linnaeus, 1758                 | -                          | 3/Dec                           | CB                                      | CB                             |
| 75  | <i>Cecropis daurica</i> (Laxmann, 1769)               | -                          | -                               | CB                                      | CB                             |
| 76  | <i>Delichon urbicum</i> (Linnaeus, 1758)              | -                          | 2/Dec                           | CB                                      | CB                             |
| 77  | <i>Phylloscopus collybita</i> (Vieillot, 1817)        | -                          | -                               | PrB                                     | x                              |
| 78  | <b><i>Aegithalos caudatus</i> (Linnaeus, 1758)</b>    | -                          | -                               | x                                       | PB                             |
| 79  | <i>Sylvia atricapilla</i> (Linnaeus, 1758)            | -                          | -                               | PrB                                     | x                              |
| 80  | <i>Curruca curruca</i> (Linnaeus, 1758)               | -                          | -                               | PrB                                     | PrB                            |
| 81  | <i>Curruca hortensis</i> (Gmelin, JF, 1789)           | RDB/VU                     | -                               | PB                                      | x                              |
| 82  | <i>Curruca communis</i> (Latham, 1787)                | -                          | -                               | PrB                                     | PrB                            |
| 83  | <i>Sturnus vulgaris</i> Linnaeus, 1758                | -                          | 3/Dec                           | CB                                      | CB                             |
| 84  | <i>Turdus merula</i> Linnaeus, 1758                   | -                          | -                               | CB                                      | CB                             |
| 85  | <i>Erithacus rubecula</i> (Linnaeus, 1758)            | -                          | -                               | PrB                                     | PB                             |
| 86  | <i>Luscinia megarhynchos</i> Brehm, CL, 1831          | -                          | -                               | PrB                                     | PrB                            |
| 87  | <b><i>Phoenicurus ochruros</i> (Gmelin, SG, 1774)</b> | RDB/VU                     | -                               | x                                       | PB                             |
| 88  | <i>Saxicola torquatus</i> (Linnaeus, 1766)            | -                          | -                               | CB                                      | PrB                            |
| 89  | <i>Oenanthe oenanthe</i> (Linnaeus, 1758)             | -                          | 3/D                             | CB                                      | CB                             |
| 90  | <i>Oenanthe isabellina</i> (Temminck, 1829)           | -                          | -                               | CB                                      | x                              |
| 91  | <i>Oenanthe hispanica</i> (Linnaeus, 1758)            | -                          | -                               | PrB                                     | PrB                            |
| 92  | <i>Passer domesticus</i> (Linnaeus, 1758)             | -                          | 3/Dec                           | CB                                      | CB                             |
| 93  | <i>Passer hispaniolensis</i> (Temminck, 1820)         | -                          | -                               | CB                                      | CB                             |
| 94  | <i>Passer montanus</i> (Linnaeus, 1758)               | -                          | 3/D                             | CB                                      | CB                             |
| 95  | <i>Motacilla flava</i> Linnaeus, 1758                 | -                          | 3/Dec                           | PrB                                     | PrB                            |
| 96  | <i>Motacilla alba</i> Linnaeus, 1758                  | -                          | -                               | PB                                      | PB                             |
| 97  | <i>Fringilla coelebs</i> Linnaeus, 1758               | -                          | -                               | PrB                                     | PB                             |
| 98  | <i>Coccothraustes coccothraustes</i> (Linnaeus, 1758) | -                          | -                               | PrB                                     | PB                             |
| 99  | <i>Chloris chloris</i> (Linnaeus, 1758)               | -                          | -                               | PrB                                     | PB                             |
| 100 | <i>Linaria cannabina</i> (Linnaeus, 1758)             | -                          | 2/Dec                           | PrB                                     | PB                             |
| 101 | <i>Carduelis carduelis</i> (Linnaeus, 1758)           | -                          | -                               | PrB                                     | PB                             |
| 102 | <i>Emberiza melanocephala</i> (Scopoli, 1769)         | -                          | -                               | CB                                      | CB                             |
| 103 | <i>Emberiza calandra</i> Linnaeus, 1758               | -                          | 2/D                             | CB                                      | CB                             |

| No Species                                   | RDB/IUCN<br>category<br>BG | SPEC/EU<br>population<br>status | Breeding<br>cat. by<br>Iankov<br>(2007) | Breeding<br>cat. this<br>study |
|----------------------------------------------|----------------------------|---------------------------------|-----------------------------------------|--------------------------------|
| 104 <i>Emberiza cirius</i> Linnaeus, 1766    | -                          | -                               | PrB                                     | PrB                            |
| 105 <i>Emberiza hortulana</i> Linnaeus, 1758 | -                          | 2/Dec                           | PrB                                     | PrB                            |

Note: In bold – the new species from MG14; x – species that were not registered; RDB – species in the Red Data Book of the Republic of Bulgaria/category by IUCN for Regional level (Golemanski, 2015); SPEC/EU population status according to Staneva and Burfield (2017), D – depleted, Dec – declining, NT – near threatment, R – rare, VU – vulnerable. CB, PB, PrB is breeding evidence by Hagemajier and Blair (1997), were CB is Confirmed Breeding, PB is Possible Breeding and PrB is Probable Breeding.

Eurasian Woodcock (*Scolopax rusticola* (Linnaeus, 1758)) was often observed in the UTM square during wintering, and a mating flight was observed on 05.05.2018. In May 2015, 2016 and 2017, single birds were reported from groups of oaks.

Lesser Spotted Eagle (*Clanga pomarina* (Brehm, CL, 1831)) – a pair was observed on 10.06.2015, 13.06.2016 and 03.06.2020.

Lesser Spotted Woodpecker (*Dryobates minor* (Linnaeus, 1758)) was observed along Maritsa River on 29.06.2015, 03.06.2016, 07.06.2019 and 13.06.2020.

Olive-tree Warbler (*Hippolais olivetorum* (Strickland, 1837)) – singing birds were registered in the northwestern part of the quadrant on 04.06.2016 and 28.06.2020.

Long-tailed Tit (*Aegithalos caudatus* (Linnaeus, 1758)) – the species was registered regularly from May to July, but mostly single individuals.

Black Redstart (*Phoenicurus ochruros* (Gmelin, SG, 1774)) – registered song on 03.04.2020, on the edge of tree and shrub strips near vineyards. Nearby (100 m) there is a rocky ravine, due to which breeding is possible.

No distinct breeding category was established for 17 species, in contrast with

the findings of Stoychev et al. (2007) and Iankov (2007) (Table 1). Another six species were identified in the category of Confirmed breeding (Table 1). Two species were observed in the study area but no breeding category was established for them: Common Tern (*Sterna hirundo* (Linnaeus, 1758)) was first observed for Sakar Mountain in this study as passing. Three birds were observed on May 5 2020 perched on low trees in the middle of a pond. Two Red-footed Falcons (*Falco vespertinus* (Linnaeus, 1766)), male and female, were observed on May 17 and 18, 2017. The species is new for the UTM square; it is also registered as migrant and has not been assigned to a specific breeding category.

### Breeding density

The breeding density of 13 bird species was established (Table 2).

The breeding density decreased significantly in Common Quail ( $F = 7.67$ ,  $p = 0.0008$  (mean 1.61, SD 1.49)) and European Turtle Dove ( $F = 2.86$ ,  $p = 0.035$  (mean = 1.86, SD = 0.93)) within the research period. For the other species, no reliable trend could be observed in the study area.

Table 2. Breeding density of 13 common bird species in MG14.

| Species                                     | Breeding density, pairs/100 ha |                       |                      |                   |                   |                     |                      |
|---------------------------------------------|--------------------------------|-----------------------|----------------------|-------------------|-------------------|---------------------|----------------------|
|                                             | 2014                           | 2015                  | 2016                 | 2017              | 2018              | 2019                | 2020                 |
| <i>Coturnix coturnix</i>                    | 3.2 ±0.9<br>(1.5–4.3)          | 2.3 ±1.5<br>(1.2–4.5) | 0.79 ±0.6<br>(0–1.4) | -                 | -                 | 0.7 ±1.1<br>(0–2.3) | 0.32 ±0.5<br>(0–1.1) |
| <i>Phasianus colchicus</i> <sup>4</sup>     | -                              | 0.5 ±1<br>(0–2)       | 0.8 ±2.3<br>(0–6)    | 0.9 ±1.4<br>(0–3) | 1.3 ±2<br>(0–5)   | 0.5 ±0.9<br>(0–2)   | 2.1 ±0.9<br>(1–4)    |
| <i>Perdix perdix</i>                        | 0.8 ±0.5<br>(0–2)              | 0.9 ±0.9<br>(0–2)     | 1.1 ±0.9<br>(0–3)    | 1.1 ±1<br>(0–3)   | 2.8 ±1.5<br>(2–5) | 1.7 ±1.4<br>(0–5)   | 1.02 ±1<br>(0–2.1)   |
| <i>Streptopelia turtur</i> <sup>3</sup>     | 4.4                            | 2.4                   | 1.6                  | 2.1               | 2.7               | 2.4                 | 3                    |
| <i>Streptopelia decaocto</i> <sup>3</sup>   | 3.49                           | 2.91                  | 1.45                 | 1.65              | 1.73              | 2.23                | 2.65                 |
| <i>Streptopelia decaocto</i> <sup>1,3</sup> | 18.5                           | 15.45                 | 7.68                 | 8.74              | 9.2               | 11.83               | 14.04                |
| <i>Buteo buteo</i> <sup>2</sup>             | 3                              | 4                     | 4                    | 5                 | 5                 | 6                   | 4                    |
| <i>Oriolus oriolus</i> <sup>3</sup>         | -                              | 4.2                   | 3.3                  | 2.6               | -                 | -                   | 1.5                  |
| <i>Melanocorypha calandra</i>               | -                              | -                     | -                    | -                 | 2.7 ±3.1<br>(0–5) | 10.4 ±3<br>(0–14)   | 7.8 ±5.2<br>(3–16)   |
| <i>Alauda arvensis</i>                      | -                              | -                     | -                    | -                 | 1.9 ±2.8<br>(0–6) | 3 ±0.9<br>(2–4)     | 4.9 ±2.4<br>(2–9)    |
| <i>Galerida cristata</i>                    | -                              | -                     | -                    | -                 | -                 | 1.8 ±0.8<br>(0–3)   | 1.9 ±1.9<br>(0–5)    |
| <i>Turdus merula</i>                        | -                              | -                     | -                    | -                 | 5.3 ±1.3<br>(4–7) | 3.7 ±1.5<br>(2–6)   | 3.1 ±2.3<br>(1–7)    |
| <i>Luscinia megarhynchos</i> <sup>3</sup>   | -                              | -                     | 6.9                  | 2.8               | -                 | -                   | 2.4                  |
| <i>Emberiza calandra</i>                    | -                              | -                     | -                    | -                 | 3.9 ±1.9<br>(2–7) | 4.5 ±2.6<br>(2–9)   | 5.2 ±2.3<br>(2–9)    |

Note: Average ±stdev. (min–max) according to data collected in all transects; <sup>1</sup> – breeding density pairs/100 ha inside Harmanli town and villages in MG14; <sup>2</sup> – reported confirmed breeding pairs in study area MG 14; <sup>3</sup> – maximum breeding pair/100 ha. <sup>4</sup> – reported birds/100ha. – insufficient data for density calculation are available. Breeding density of European Turtle Dove 2014–2016 is according to Gruychev and Mihaylov (2019).

## Discussion

The studied area covers part of the north-western slopes of Sakar Mountain and part of the Thracian lowlands (Maritsa River valley). The area has been fairly understudied in earlier research (Borisov 1988, Milchev and Kovachev 1998, Stoychev et al. 2007). During this study were reported 89 species out of a total of 253 for Sakar Mountain and 98 for the quadrant (according to Iankov 2007). Stoychev et al. (2007) reported 153 bird species assigned to a particular breeding category. In the study area 35 percent of the avifauna and 58

percent of the breeding birds of Sakar Mountain have been found. The current study reports two new species for the area, the first of which, Ruddy Shelduck, has been assigned to a breeding category, and the other one, Common Tern, has been recorded as a migrant. Common Tern is on the Endangered Species List for Bulgaria (Golemanski 2015). Today the main breeding sites of the species in Bulgaria are along Black Sea coast and along Danube (Iankov 2007, Golemanski 2015). In the past it used to breed in the Thracian lowland and along Maritsa River around Plovdiv, Harmanli and Svilengrad



(Boev et al. 1964, Mihov et al. 2007). The observation is from a small dam, 4.5 km in a straight line from Maritsa River. MG32 and LG95 squares were the closest localities of the species up until 2003 according to Iankov (2007). It is possible for the species to return to some of its old breeding sites.

The development of the breeding population of Ruddy Shelduck in Bulgaria has been in a positive direction. Many of the previous breeding sites in the northwestern part of the country have been re-occupied, and new ones are appearing in Southeastern Bulgaria (Shurulinkov et al. 2020). The present location is close to a known site (Shurulinkov et al. 2020) within the adjacent UTM square MG03. Red-footed Falcon is a new species for the quadrant registered as passing, but previous studies (Stoychev et al. 2007) have reported it as a rare breeding bird for Sakar Mountain with breeding population of 1–3 pairs. The species has been reported as common during migration.

The present study failed to record several owl species (Table 1) which have been assigned to a breeding category by Iankov (2007). No methodology for registering and counting owls was used in the study, which resulted in their rather accidental registration.

Breeding density of Common Quail and European Turtle Dove showed decrease. Stoychev et al. (2007) reported Common Quail as a common species on these sites. The breeding density of both species has been declining in Bulgaria in recent years (Spasov et al. 2017). Common Quail requires more extensive density studies in Bulgaria. The average breeding density of Turtle Dove has a continuous downward trend in the studied square, similar to that indicated for the period 2014–2016 by Gruychev and Mihaylov (2019). The trend

observed is similar to the one in the large area of the species' habitat (Wassink and Oreel 2008, Kleemann and Quillfeldt 2014, Harris et al. 2015).

## Conclusion

The present study describes the breeding avifauna in parts of Northwestern Sakar Mountain and part of Lower Thracian lowlands. It compares the results obtained to those of recent reports on this territory. This allows us to trace how the bird species composition in the studied UTM square changes. The breeding density data provided by us constitute valuable information for future research in Sakar Mountain and the region, which will make possible a comparison of density change in future.

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## SMALL MAMMALS AS RESERVOIRS OF TULAREMIA AND HFRS IN THE FOREST ZONE OF SARANSK

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### Abstract

Small mammals are important reservoirs for zoonotic pathogens that cause significant morbidity in humans. Of these, tularemia and hemorrhagic fever with renal syndrome (HFRS) are among of the most widespread zoonotic diseases worldwide. Despite the fact that both pathogens have great epidemiological significance in Russia, epizootological data for urbanized areas are still scarce. This study was conducted to investigate the occurrence and prevalence of tularemia and hantaviruses in small mammals living in close proximity to humans. Altogether, 425 small mammals (278 from urban environment and 147 from natural environment) representing nine species (*Myodes glareolus*, *Microtus arvalis*, *Cricetus cricetus*, *Apodemus flavicollis*, *Apodemus agrarius*, *Apodemus uralensis*, *Mus musculus*, *Sorex araneus* and *Neomys fodiens*) were captured in the Russian Republic of Mordovia and screened for pathogens using different serological and bacteriological methods. Red bank vole (*M. glareolus*) and yellow-necked wood mouse (*A. flavicollis*) are among species in the forest zone of the city of Saransk and are the source of a number of zoonotic diseases. In the non-urban environment, the main role as carriers of zoonotic diseases was played by house (*M. musculus*) and striped field (*A. agrarius*) mice. A total of 23 % of the small mammals sampled in Saransk were positive for tularemia, whereas 9.7 % were positive for HFRS. Furthermore, dual infections with both tularemia and hantaviruses were shown in 1.4 % of animals, suggesting that the same small mammal host can be infected with several pathogens at the same time, therefore representing a serious threat to public health. Small mammal ecology is a primary determinant of zoonotic pathogens dynamics in rodent populations and the risk of pathogen transmission to people.

**Key words:** epidemiology, hantavirus, Mordovia, rodents, urbanization.

### Introduction

It is known that epidemics coincide with urbanization, geographic expansion, and migrant movement over time (Taylor et al. 2008, Kang et al. 2012, Halliday et al. 2015, Houéménou et al. 2019). Research

results in China revealed the interrelatedness of urbanization, migration, and hantavirus epidemiology, potentially explaining why urbanizing cities with high economic growth exhibit extended epidemics (Tian et al. 2018). However, different types of animals can act as carri-

ers in different cities. For example, Urban Norway (*Rattus norvegicus* (Berkenhout, 1769)) and black (*Rattus rattus*) rats are reservoirs for a variety of zoonotic pathogens (Himsworth et al. 2015).

Republic of Mordovia in Russia is a historical focus for HFRS, tularemia and rabies (Boyarova et al. 2020). Among the small rodents in the wild natural environment, the red bank vole *Myodes glareolus* (Schreber, 1780), the common vole *Microtus arvalis* (Pallas, 1779) and the house mouse *Mus musculus* Linnaeus, 1758 play an important role as carriers of zoonotic diseases (Andreychev et al. 2019). One of our latest studies concluded that the forest dormouse *Dryomys nitedulla* (Pallas, 1779) in Mordovia was identified as a pathogen reservoir causing infectious diseases in humans (Andreychev and Boyarova 2020). However, this type of small mammal is found only in wild natural environment (Andreychev and Kiyaykina 2020, Andreychev and Kuznetsov 2020).

Most researchers of zoonotic diseases choose rats (Himsworth et al. 2013, 2014, 2015; Firth et al. 2014; Wang et al. 2017; Murray et al. 2020; Su et al. 2020; Yashina et al. 2021). This is of course logical, as there are quite a lot of rats. This is not the case in Saransk, so we assumed that the main vectors may be other small mammals (mice, voles, shrews). We set out to study these to determine their possible role in the transfer of zoonotic diseases in Saransk.

The purpose of this article is to highlight the role of small mammals as carriers or reservoirs of zoonotic diseases in the city forest zone. In addition to the main carriers in the natural environment, there is a high probability that other small mammals account for the circulation of zoonotic disease pathogens in urban environments.

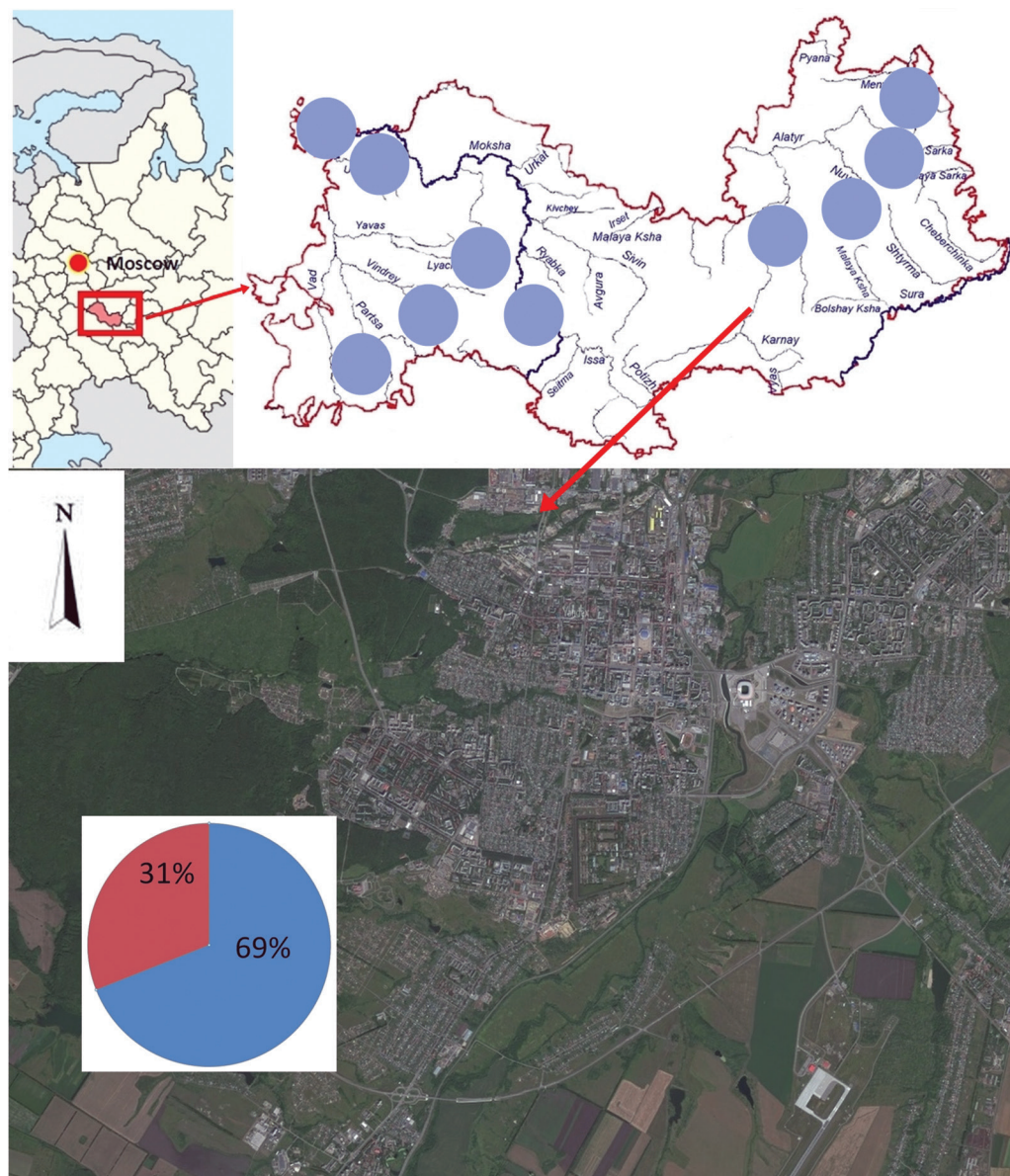
## Material and Methods

The work was carried out in the forest zone of Saransk and some districts of Mordovia (Fig. 1). The Republic of Mordovia is located in the centre of the European part of Russia. Its extreme points are defined by geographical coordinates 42°11' – 46°45' E and 53°38' – 55°11' N. The maximum distance from west to east is 298 km and the distance from north to south is 57 to 140 km. The area of the republic is 26,200 km<sup>2</sup>. Features of the geological structure are determined by its location in the central part of Russian Platform and north-western slopes of Volga Upland. In the western part, Volga Upland reaches Oka-Don Lowlands (Yamashkin 1998, Andreychev 2017).

The work is based on the materials of our own surveys of rodents and insectivorous mammals conducted in the urban environments and natural environments of Mordovia, using traditional methods of trap lines and trap grooves (Karaseva and Telicina 1996). Field work was carried out during the snow-free period (May to November). The snap traps were set in the typical habitats of the small mammals for several days and then transferred to the next site. Their number in each line was 25. Traps were checked for material every morning. Bread soaked in sunflower oil was used as bait.

During the research period of 2020, a total of 425 specimens (278 from urban environments and 147 from natural environments) of the following rodents were trapped: red bank vole *M. glareolus* – 55.2 %, common vole *M. arvalis* – 6.4 %, common hamster *Cricetus cricetus* (Linnaeus, 1758) – 0.5 %, yellow-necked mouse *Apodemus flavicollis* (Melchior, 1834) – 9.9 %, Ural field mouse *Apodemus uralensis* (Pallas, 1811) – 3.8 %, and





**Fig. 1. Geographical position of Saransk.**

Note: for the region, blue circles – collection points of the material, for the satellite image of city the red sector is the percentage of all infected (tularemia + HFRS) small mammals, the blue sector is the percentage of uninfected small mammals.

striped field mouse *Apodemus agrarius* (Pallas, 1771) – 11.8 %, house mouse *M. musculus* – 7.5 %, Eurasian common

shrew *Sorex araneus* Linnaeus, 1758 – 4.7 %, and Eurasian water shrew *Neomys fodiens* (Pennant, 1771) – 0.2 %. The

captured mammals were transported to the laboratory of the Center for Hygiene and Epidemiology of Republic of Mordovia. ELISA, using 'Huntagnost' test system for pathogen presence, was the main method used to detect HFRS antibodies in homogenized rodent organs (lung). Tests for tularemia were performed using a serological method.

## Results and Discussion

A total of 23 % of small mammal samples in Saransk were positive for tularemia while a total of 9.7 % were positive for HFRS. Furthermore, dual infections with both tularemia and hantaviruses were detected in 1.4 % of animals, suggesting that the same small mammal host can be infected with several pathogens at the same time, therefore representing a serious threat to public health. In the natural (non-urban) habitat, only house mouse and striped field mouse were infected with HFRS (Table 1).

Comparing the range of mouse rodent

species infected with tularemia in urban environments with data obtained for natural environments in previous years (Andreychev and Boyarova 2020), a similar pattern was noted insofar as red bank vole played a primary role as carrier of this disease (75 % in urban environments compared to 42 % in natural ones). Yellow-necked mouse, ranked second in urban environment for presence of tularemia bacteria (25 %). In natural environment of Mordovia, Ural field mouse was found positive for the same bacteria (25 %).

Comparing results obtained in urban environments for mouse rodent species infected with HFRS (Table 1) with data obtained for natural environments in previous years (Andreychev and Boyarova 2020), it should be noted that while red bank vole was primary in urban environments – 85 %, house mouse was primary in natural environment – 41 %. *A. flavicollis* ranked second in urban environments for presence of HFRS (15 %); and red bank vole (23 %) and common vole (23 %), were found positive for HFRS in natural environment.

**Table 1. Small mammal population structure involved as reservoirs of tularemia and HFRS in urban and non-urban environments in 2020.**

| Species                     | City of Saransk    |     |      |            | Other districts        |     |      |            |
|-----------------------------|--------------------|-----|------|------------|------------------------|-----|------|------------|
|                             | $n_{\text{urban}}$ | TUL | HFRS | TUL + HFRS | $n_{\text{non-urban}}$ | TUL | HFRS | TUL + HFRS |
| <i>Myodes glareolus</i>     | 219                | 48  | 23   | 4          | 16                     | 0   | 0    | 0          |
| <i>Microtus arvalis</i>     | 2                  | 0   | 0    | 0          | 25                     | 0   | 0    | 0          |
| <i>Cricetus cricetus</i>    | 1                  | 0   | 0    | 0          | 1                      | 0   | 0    | 0          |
| <i>Apodemus flavicollis</i> | 30                 | 16  | 4    | 1          | 12                     | 0   | 0    | 0          |
| <i>Apodemus uralensis</i>   | 2                  | 0   | 0    | 0          | 14                     | 0   | 0    | 0          |
| <i>Apodemus agrarius</i>    | 10                 | 0   | 0    | 0          | 40                     | 0   | 1    | 0          |
| <i>Mus musculus</i>         | 1                  | 0   | 0    | 0          | 31                     | 0   | 3    | 0          |
| <i>Sorex araneus</i>        | 12                 | 0   | 0    | 0          | 8                      | 0   | 0    | 0          |
| <i>Neomys fodiens</i>       | 1                  | 0   | 0    | 0          | -                      | -   | -    | -          |

Note:  $n_{\text{urban}}$  – number of specimens from Saransk,  $n_{\text{non-urban}}$  – number of specimens from natural environments, TUL – number of positive tests for tularemia, HFRS – the number of positive tests for HFRS, TUL+HFRS – simultaneous detection of positive tests for tularemia and HFRS.



Our study also showed that in 2020, some striped field mice in natural environment were infected with HFRS, which confirmed that this species may be active in the epizootic process in Mordovia (Trankvilevsky et al. 2007, 2011).

Suburban forest zone of Saransk in 2020 was potentially dangerous in relation to zoonotic diseases. It is known that HFRS and tularemia are widespread in many other Russian cities as well. The increase in the incidence of HFRS in Voronezh Region took place in 2007 when 154 people were infected. More than 50 % of cases involved people who were infected in the city (Gaponov 2017).

We also compared our results with the infection rates of small mammals in urban environments of Switzerland (Adler et al. 2002), where there is also a significant proportion of infected small mammals from the genera *Apodemus* and *Myodes*.

The large proportion of yellow-necked mice testing positive for zoonotic diseases in urban environments of Mordovia is understandable, since scientists have previously noted their role as carriers in other countries. Dobrava–Belgrade virus strain (DOBV) which causes HFRS in humans has been found in *A. flavicollis* (Weidmann et al. 2005). A previous study in Greece showed that approximately 10 % of *A. flavicollis* carried DOBV (Papa et al. 2000). In Albania, it was identified as primary reservoir causing HFRS in humans (Rogozi et al. 2013, Papa et al. 2016). In Slovenia, the yellow-necked mouse, the striped field mouse (*A. agrarius*), and the red bank vole (*M. glareolus*) were all found to play an important role in zoonotic circulation of HFRS (Stanko et al. 2004). Positive results for tularemia in the Republic of Moldova were recorded in species *M. glareolus*, *A. flavicollis* and *A. uralensis* (Chicu et

al. 2010). Thus, the yellow-necked mouse may be one of the most important carriers of zoonotic diseases. However, in Mordovia, it is in urban environments that its role has become more pronounced. This may be due to the smaller distribution across the region of other mouse species (*A. uralensis*, *A. agrarius*) (Andreychev 2020).

Our data on the higher incidence of double infections in small mammals in urban environments of Saransk are consistent with the results from Hungary. Dual infections with both *Leptospira* spp. and hantaviruses were shown in 2.6 % of mammals (Kurucz et al. 2018).

## Conclusions

There are clear differences in the role played by different small mammal species as reservoirs for zoonotic pathogens in the forest zones of urban environments versus the non-urban environments of Mordovia. The importance of red bank vole and of yellow-necked mouse in urban environments and of house mouse and striped field mouse in non-urban environments in relation to zoonotic diseases was confirmed. In addition, evidence of dual infection by tularemia and hantavirus was found, suggesting that the same small mammal host can be infected with several pathogens at the same time, therefore representing a serious threat to public health.

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## MICRONUTRIENTS IN CALCAREOUS FOREST SOILS

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### Abstract

The relations and the statistical comparisons of the available micronutrients Mn, Zn, Cu and Fe (DTPA extractable) were examined in alkaline soils of three forest ecosystems, i.e. pine, fir and maquis forest. Through a Principal Components Analysis (PCA) it was found that Mn and Zn had identical dependence on soil parameters. Both concentrations of these metals had negative relationship with pH, percentage of  $\text{CaCO}_3$  and positive one with the concentrations of organic C, N and Cation Exchange Capacity (CEC) values. With the exception of  $\text{CaCO}_3$ , Fe had the same dependence. Copper had a negative relation with  $\text{CaCO}_3$  and a positive one only with clay content and not with the organic carbon as would be expected. The Analysis of Variance (ANOVA) showed that the soil under fir had the highest concentrations of Mn probably due to the lowest pH values and  $\text{CaCO}_3$  percentages. The soil in the maquis plot had the lowest concentrations of Zn and Fe because of the highest pH and lowest amount of organic C. Despite the lowest amount of organic C, the soil in the maquis plot had the highest concentration of Cu because of the nature of parent material.

**Key words:**  $\text{CaCO}_3$ , DTPA, fir, maquis, pH.

### Introduction

The study of micronutrients was firstly carried out in agricultural soils. The general rules governing the behaviour of manganese (Mn) and iron (Fe) are the redox potential (i.e. oxidizing or reducing conditions) and pH (Porter et al. 2004; Colombo et al. 2014). Forest soils are usually aerobic and therefore the pH is the most important factor for these elements. Low pH values bring about dissolution of Fe and Mn oxides and enrichment of soil solution with Fe and Mn ready for plant uptake. The same dependency on pH exists with zinc (Zn). Its deficiency is limiting

crop production in  $\pm 30$  % of the world's soils (Sillanpää and Vlek 1985). Most of these soils are calcareous. Copper (Cu) also depends on soil pH although not as much as the previous mentioned metals (Sims 1986). It is the soil organic matter that Cu is strongly connected through chelation (McLaren et al. 1981). Soils with neutral to alkaline pH values may generally have lower Cu availability relative to acid soils, which can be explained by the presence of carbonates favouring Cu precipitation and adsorption (Bradl 2004). Forest plants have received less attention in this respect but there are some works on the subject. In northern Europe, the

motivation, initially, was to ameliorate the acidification of forest soils through liming. Grønflaten and Steinnes (2005) used four extractants to predict metal uptake by understorey forest vegetation in Norway. In the same country, Grønflaten et al. (2005) determined the concentration of trace elements in soils and plants in Scots pine stand after liming. In other regions having an appreciable percentage of alkaline forest soils, the deficiency problem can be intense. In a review, Will (1990) quoted that pines growing in alkaline soils in New Zealand presented deficiencies (chlorotic symptoms) of Mn and Fe. Soil scientists have developed tests involving a single extractant to draw conclusions on the availability of micronutrients in soils. In agricultural calcareous soils, some thresholds concentrations have been established below which plant growth is retarded. Başar (2009) in Turkey, used 14 extractants to predict uptake of micronutrients and heavy metals in peaches grown on alkaline soils and Michopoulos et al. (2004) used 7 extractants to assess Mn uptake by fir in calcareous soils. It is a little risky to adopt threshold values for forest species. At most, these values can be an indication for micronutrient deficiencies, which have to be verified through fertilization trials.

The aims of this work were: 1) to identify the soil parameters affecting the content of the available micronutrients in calcareous forest soils in three ecosystems and 2) using this piece of information to compare the average concentrations in the selected ecosystems. The forests chosen were a pine and a fir forest in the mountain of Parnitha and maquis forest in the area of Corinth. When reforestations take place in calcareous soils, usually having low concentrations of available micronutrients, such information will be of avail.

## Materials and Methods

### Study sites and sampling

#### Mountain of Parnitha

Two sampling areas were located in the national park of the Mountain of Parnitha 40 km north of the city of Athens, capital of Greece. The Parnitha Mountain has a Mediterranean climate with frequent snowfalls in winter and pleasant temperatures in summer. The average temperature range is 8–13 °C and the yearly precipitation height was calculated 1231 mm (Michopoulos et al. 2007). The coordinates of the Parnitha Mountain are: latitude 38°10'24" and longitude 23°43'2.6".

The first sampling area was in the zone of Aleppo pine (*Pinus halepensis* (Mill.)) and the second in the zone of Greek fir (*Abies cephalonica* Loudon).

Pine forests extend from the foot of the mountain, where they mix with shrubs (kermes oaks, strawberry trees, etc.), to 800 m a.s.l. In higher altitudes (800–1000 m), the Aleppo pine mixes with the Greek fir. Apart from the Aleppo pine the flora comprises kermes oak (*Quercus coccifera* L.), green olive trees (*Phyllirea latifolia* L.), holm oak (*Quercus ilex* L.), strawberry trees (*Arbutus unedo* L.), junipers (*Juniperus* sp.), olives (*Olea europea* L.), garden sage (*Salvia officinalis* L.) and thorns (*Crataegus* sp.).

The fir zone extends from 900 to 1400 m a.s.l. The dominant plant species with ecological significance in that zone are: prickly juniper (*Juniperus oxycedrus* L.) wild roses (*Rosa canina* L., *Rosa sempervirens* L.), barberry (*Berberis cretica* L.), hawthorns (*Crataegus heldreichii* Boiss., *Crataegus monogyna* Jack.). In addition, several trees species are included such as wild almonds (*Prunus webbii* Vierh., *Prunus spinosa* L.), wild pears



(*Pyrus amygdaliformis* Vill.) and naturally numerous herbs, like different kinds of daisies (*Bellis sylvestris* L., *Doronicum orientale* Hoffm.).

The soils of the sampling areas in both species zones are derived from hard limestone and tertiary deposits.

Soil samples were collected in a random way from a network of plots meant to monitor forest health in 2006. In total 40 sites of pine and 19 sites of the fir zone were selected for soil collection. In each collecting point, a composite sample was created by collecting soils in equal volumes from two orientations, north and east distancing 5 m each at a depth of 20 cm after the L layer was removed.

### Maquis zone

The third sampling area is close to the city of Corinth (41 km) and 120 km southwest from the city of Athens. It is included in the *Quercetalia ilicis* vegetation zone, and *Quercion ilicis* and *Oleo-Ceratonion* subzones. The climate is typical Mediterranean with dry and warm summers and mild winters with a mean annual air temperature of 16.0 °C and mean annual rainfall of 560 mm (National Meteorologi-

cal Service of Greece 2010). The altitude range is 360 to 500 m. The coordinates of the area are: latitude 37°48'22", longitude 22°40'19".

Maquis is an area covered dominantly by shrub vegetation of the Mediterranean region primarily of leathery, broad-leaved evergreen shrubs or small trees (Dallman 1998). The dominant species here are woody plants, i.e. mastic trees (*Pistacia lentiscus* L.), *Quercus coccifera*, *Arbutus unedo*, and *Olea europaea*. In addition, the herbaceous plants Greek cyclamen (*Cyclamen graecum* Link), and Bulbous dandelion (*Leontodon tuberosus* L.) are found.

Soil samples from this zone were collected in a systematic way at a depth of 20 cm (0–20 cm) after the L layer was removed. In a straight, line every 10 m a soil sample was collected. The first five samples made a composite sample and so on until there were 15 composite samples.

In terms of classification according to the WRB system (IUSS Working Group WRB 2015), the soils in the mountain of Parnitha are Regosols, whereas the maquis soil is a Luvisol.

Table 1 contains concise information of the ecosystems.

**Table 1. Information on the forest ecosystems from which soil was collected.**

| Area     | Altitude, m | Soil parent material              | Rain height, mm | Main forest species |
|----------|-------------|-----------------------------------|-----------------|---------------------|
| Parnitha | 430–1000    | Hard limestone, Tertiary deposits | 1230            | Aleppo pine         |
| Parnitha | 900–1400    | Hard limestone, Tertiary deposits | 1230            | Greek fir           |
| Korinth  | 360–500     | Hard and soft limestone           | 560             | Maquis              |

### Soil analysis

All soil samples were air dried and passed through a 2 mm sieve prior to analysis. Subsamples of sieved soils were pul-

verized in a ball mill for the determination of organic C, calcium carbonate and Kjeldahl N.

The texture of soils was determined by the hydrometer method, while the CaCO<sub>3</sub>

content was determined by a calcimeter.

The pH of soils (1:2.5 soil:water, ratio per weight) was measured by a glass electrode. Exchangeable cations (Ca, Mg, K and Na) were extracted with 1 M  $\text{NH}_4$ -acetate solution at a pH of 7. Cation exchange capacity (C.E.C.) of the samples was determined by the Na-acetate method (Bower et al. 1952).

Organic C was measured by wet oxidation with potassium dichromate ( $\text{K}_2\text{Cr}_2\text{O}_7$ ), organic plus ammonium N was extracted with concentrated sulphuric acid ( $\text{H}_2\text{SO}_4$ ), and its concentration was measured by the Kjeldahl distillation method (Jones 2001). Available trace elements (Fe, Zn, Mn and Cu) in soils were extracted with DTPA (Lindsay and Norvell 1978). In calcareous soils, the presence of calcium carbonate ( $\text{CaCO}_3$ ) can result in higher concentrations of extracted micronutrients due to the dissolution of  $\text{CaCO}_3$  particles where the metals are occluded. The use of DTPA depresses that dissolution and that is the reason it is suitable for calcareous soils (Mahashabde and Patel 2012, Al Jaloud et al. 2013, Chavda et al. 2018).

All results were expressed per dry weight of soil (105 °C).

### Data handling and statistical analysis

The Statistical dependence of the available micronutrients were examined for some soil parameters in the mineral soil layers by means of the Principal Component Analysis (PCA). The PCA was conducted with the ordination software CANOCO (Ter Braak and Smilauer 2002). The parameters chosen were the pH, the percentages of  $\text{CaCO}_3$ , clay and organic C, the concentrations of N, the CEC value and the ratio of C/N. The first principal component is the linear combination of x-variables that has maximum vari-

ance (among all linear combinations). It accounts for as much variation in the data as possible. The second principal component is the linear combination of x-variables that accounts for as much of the remaining variation as possible, with the constraint that the correlation between the first and second component is 0 (Zar 1999). Values around 0.600 or higher are considered satisfactory as they explain at least 40 % of the parameters' variability (Comrey 1962).

The average values, the ranges and coefficients of variation (percentages of standard deviations over the means) were calculated for all soil parameters measured. The latter were compared with an analysis of variance (ANOVA). Before the ANOVA test a logarithmic transformation was applied to the data (apart from pH) to conform to normality requirement.

### Results and Discussion

In Table 2, the component 1 represents the horizontal axis of Figure 1, whereas the component 2 the vertical one. In addition, the PCA axes and the vectors of the parameters are combined with the calculated values of the micronutrients. We can see that Mn, Zn and Fe have values higher than 0.600 in the component 1 column, whereas Cu in the component 2 column.

The PCA figure and Table 2 showed that the Mn and Zn had identical dependence on soil parameters. Both the concentrations of these metals had negative relationship with pH,  $\text{CaCO}_3$  and positive ones with organic C, N and CEC. Similar behavior of these two metals, with regard to solubility ( $\text{CaCl}_2$ -extractability) was also found by Haynes and Swift (1985) in a greenhouse experiment. With the exception of  $\text{CaCO}_3$ , Fe had the same depend-

Table 2. Values of soil parameters derived from PCA analysis.

| Component 1       |            |            |            |            |
|-------------------|------------|------------|------------|------------|
| Soil parameter    | Mn (0.768) | Zn (0.705) | Cu (0.25)  | Fe (0.849) |
| CaCO <sub>3</sub> | -0.683     | -0.557     | -0.459     | -0.452     |
| pH                | -0.849     | -0.778     | -0.743     | -0.742     |
| CEC               | 0.839      | 0.887      | 0.844      | 0.871      |
| C                 | 0.696      | 0.811      | 0.866      | 0.864      |
| N                 | 0.656      | 0.791      | 0.868      | 0.830      |
| C/N               | 0.056      | -0.009     | -0.085     | -0.024     |
| Clay              | 0.141      | -0.061     | -0.243     | -0.210     |
| Component 2       |            |            |            |            |
| Soil parameter    | Mn (0.278) | Zn (0.315) | Cu (0.660) | Fe (0.222) |
| CaCO <sub>3</sub> | -0.291     | 0.410      | -0.698     | 0.535      |
| pH                | -0.059     | 0.282      | -0.294     | 0.381      |
| CEC               | -0.151     | -0.081     | 0.127      | -0.197     |
| C                 | -0.444     | 0.164      | -0.239     | 0.097      |
| N                 | -0.686     | 0.505      | -0.081     | 0.373      |
| C/N               | 0.510      | -0.617     | -0.075     | -0.530     |
| Clay              | 0.861      | -0.852     | 0.790      | -0.866     |

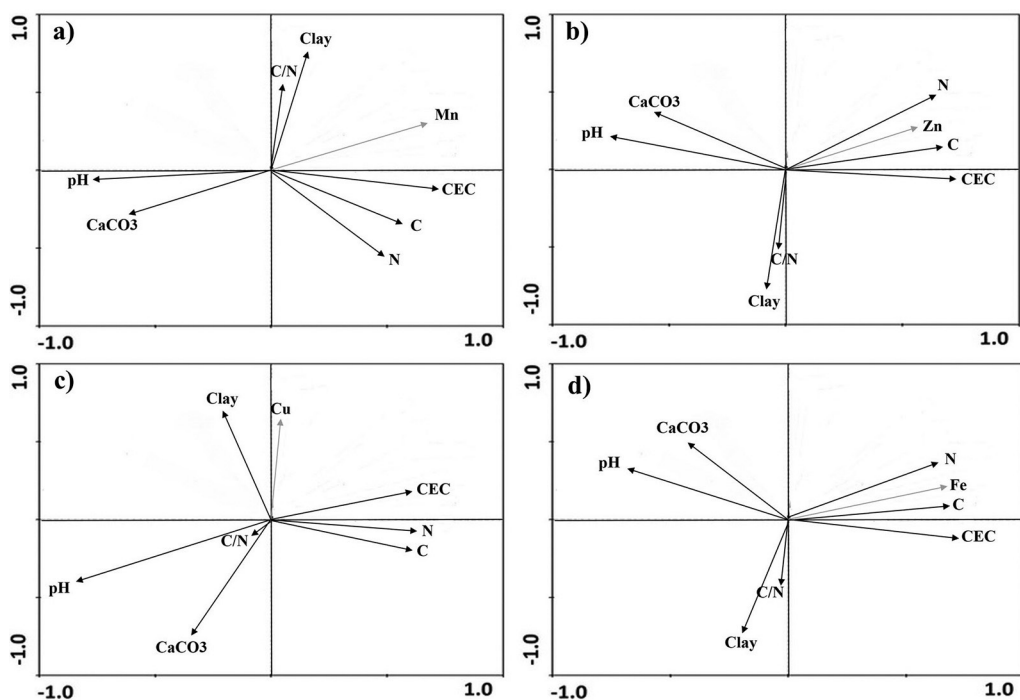


Fig. 1. Ordination diagrams for the relation of available micronutrients – Mn (a), Zn (b), Cu (c) and Fe (d) with the soil properties.

ence. Copper had a negative relation with the  $\text{CaCO}_3$  and a positive relation only with clay and not with the organic matter as would be expected because of the strong bonds it usually forms with organic compounds. Not all researchers have found significant dependency of pH with DTPA extractable micronutrients. Mahmoud-abadi et al. (2015) found negative relationships of the four micronutrients under consideration with  $\text{CaCO}_3$  but not with pH in urban forest soils in Iran. Similarly, to this study they did not find significant relationship of Cu with organic matter. Copper was not found to correlate with pH. Likewise, Grønflaten and Steinnes (2005) did not find any effect on extractable (with  $\text{NH}_4\text{NO}_3$ ) Cu after liming in a forest soil under Scots pine in Norway. In contrast, in agricultural soils in Spain Navarro-Pedreño et al. (2018) found that Cu, Mn, Fe (DTPA extractable) had a negative relationship with pH and Zn a positive one. The Organic C content of those soils was very low in comparison with the soils in this work and that fact was probably influential. It seems that different soils do not have the same behavior so relationships between available micronutrients and soil parameters should be examined separately for each soil type.

The deficiency limits for micronutrients extracted with DTPA have been defined for agricultural soils and have a range depending on the crop they refer to. So for Mn it is 3–3.5  $\text{mg}\cdot\text{kg}^{-1}$ , for Cu 0.2–1.0  $\text{mg}\cdot\text{kg}^{-1}$ , for Zn 0.5–0.54  $\text{mg}\cdot\text{kg}^{-1}$  and for Fe 4.5–4.8  $\text{mg}\cdot\text{kg}^{-1}$  (Lindsay and Norvell 1978, Nayyar et al. 1985, Sharma and Mukhopadhyay 2006). Table 3 shows the ranges of all soil parameters. With regard to the micronutrients, Cu seems to be the micronutrient in shortest supply. More specifically, the three ecosystems have some soil samples below the limit

Table 3. Averages, ranges and coefficients of variation (in parenthesis) of soil parameters.

| Sites  | C                    | N               | C/N            | Sand          | Clay           | Silt            | CEC            | $\text{CaCO}_3$ | pH               | Mn              | Zn                   | Cu              | Fe             |
|--------|----------------------|-----------------|----------------|---------------|----------------|-----------------|----------------|-----------------|------------------|-----------------|----------------------|-----------------|----------------|
| Pine   | 7.36a                | 3.48a           | 22.7a          | 50.5a         | 23.9a          | 25.6a           | 47.5a          | 20.2a           | 7.66a            | 39.5a           | 7.33a                | 1.21a           | 67.6a          |
|        | 3.9–15<br>(33)       | 1.6–8.9<br>(45) | 11–43<br>(29)  | 29–69<br>(18) | 15–44<br>(28)  | 16–33<br>(13)   | 18–96<br>(37)  | 2.5–45<br>(57)  | 6.9–8.1<br>(3.5) | 17–77<br>(36)   | 1.0–58<br>(126)      | 0.7–2.8<br>(32) | 30–183<br>(54) |
| Fir    | 7.51a                | 4.39a           | 18.4b          | 55.7a         | 20.3a          | 24.0ab          | 60.8b          | 5.11b           | 7.37b            | 68.1b           | 9.09a                | 1.82b           | 82.8a          |
|        | 1.17–15<br>(43)      | 0.7–11<br>(51)  | 12–31<br>(30)  | 32–85<br>(24) | 5.4–39<br>(48) | 9.4–31<br>(200) | 29–116<br>(28) | 0.2–44<br>(196) | 6.7–7.7<br>(3.5) | 21–126<br>(42)  | 0.6–72<br>(170)      | 0.9–4.0<br>(47) | 20–163<br>(46) |
| Maquis | 4.43b                | 3.58a           | 12.8c          | 54.1a         | 24.5a          | 21.4b           | 24.8c          | 13.9c           | 7.93c            | 43.8a           | 2.01b                | 3.02c           | 12.0b          |
|        | 0.80–<br>8.0<br>(45) | 0.9–5.6<br>(46) | 6.7–16<br>(26) | 28–78<br>(23) | 8.0–48<br>(45) | 14–26<br>(18)   | 6.4–44<br>(37) | 1.6–48<br>(108) | 7.4–8.5<br>(4.6) | 9.2–106<br>(71) | 0.25–<br>7.2<br>(92) | 0.5–6.7<br>(52) | 3.3–22<br>(39) |

Note: Values in the same column followed by different letters differ significantly for at least 0.05 probability level.

of  $1.0 \text{ mg}\cdot\text{kg}^{-1}$  in Cu. The soil in the pine stand has nine cases, the maquis two and the fir one. In addition, in the maquis plot the soil has low concentrations (below the limits) of Zn (four cases) and of Fe one. It must be taken into account that these ranges refer to the bulk soil and not to the rhizosphere one. Plants exude a variety of organic compounds and inorganic ions (protons, phosphate, etc.) to change the chemistry and biology of the rhizosphere (Rengel 2015). In any case, when reforestation takes place these low concentrations should be considered carrying out, for example, an experiment with fertilization trials.

The parameter that had the lowest coefficient of variation was the pH (Table 3). This is due to the strong buffer capacity calcareous soils have to withstand pH changes. Interestingly the micronutrient with the highest coefficient of variation was Zn.

Although the focus is on the micronutrients, the ANOVA was applied to all soil parameters to draw conclusions on the differences among the three ecosystems. Significant differences were found among the parameters on which the micronutrient concentrations depend. It is obvious that the soil in the maquis plot has striking differences with the soils in the two high forests of Parnitha. The first difference is the low content of organic matter (Table 3). This is due to the fact that the decomposition of needles in the high forests in a mountainous environment is slower and organic matter accumulates in soils. In addition, the C/N ratio had the lowest values in the maquis stand, a sign of rapid decomposition of the litterfall. The magnitude of the CEC followed that of the organic C in the three stands. The percentage of  $\text{CaCO}_3$  and the pH had the highest values in the maquis plot as the result

of the nature of the parent material (soft limestone). The low amount of organic matter and the high pH contributed to the low concentrations of Zn and Fe in the maquis stand. The pH had the lowest value in the soil of the fir stand. Consequently, the soil had the highest concentration of available Mn and relatively high concentrations of Zn and Fe (Table 3). The highest concentration of Cu in the soil of the maquis stand is a little difficult to explain. The maquis plot had the least concentration of organic C. In addition, the clay content in soils with which Cu had a good relationship did not differ significantly among the three forest stands. Probably the explanation lies in the nature of the parent material of the soil in the maquis plot. Okoli et al. (2019) stressed the importance of parent material in soil fractionation in four different locations in Imo State, Southeastern Nigeria. They found significant differences with regard to Cu concentrations among almost all the different fractions in the various types of parent material.

## Conclusion

The pH was a decisive factor for the mobility of Mn, Zn and Fe in the calcareous soils in this work. Despite this similarity, the Zn concentration had very high variability compared with the two other metals. The relationships of available Cu with soil parameters did not always follow the patterns mentioned in literature, especially with regard to the close relation of the metal with the organic matter. The parent material seems to be an additional important factor to affect the Cu content in soils. The Mn concentration was satisfactory in all stands but the Cu content was low especially in the pine stand and Zn in

the maquis stand. Grown plants can overcome the low concentrations of micronutrients in soils with root exudation. In case of reforestation young plants may need some fertilization which can nevertheless be proved through trial.

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## ASSESSMENT OF SOIL AND LITTER PARAMETERS IN YUNDOLA STATIONARY SAMPLE PLOT FOR INTENSIVE MONITORING OF FOREST ECOSYSTEMS

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### Abstract

Litterfall is an essential part of forest ecosystems. We assessed obtained data about aboveground litterfall (as input for nutrients in the ecosystem) and chemical composition of soil waters (as an output of the ecosystem). In addition, total microbial number of heterotrophic microflora and the structure of microbial communities were investigated. The aboveground litterfall had an average  $\text{pH}_{\text{H}_2\text{O}}$  value 4.2. Concentrations of Ca, Mg and P were high in the foliar fraction. The C/N ratio in the Litter fraction was high – 65 and in the Wood fraction – 60. In contrast to the *L* layer, *FH* layer showed an increase in microorganisms' activity. The total microbial number decreased in the *A* horizon compared to that in the foliar litter. The total microbial number for layer *L* was  $1.2 \times 10^7$  cfu/g DsM (dry soil mass), increased in the fragmented *FH* layer to  $1.4 \times 10^7$  cfu/g DsM and sharply decreased to  $9.0 \times 10^5$  cfu/g DsM in *A* horizon. The dominance of non-spore-forming bacteria was established in the litter and *A* horizon of the soil profile. Actinomycetes increased significantly in the soil depth. In the *L* layer they were only 1 % and in *A* horizon – they reached 16 %. The percentage of micromycetes was 1 % and increased up to 3 % in *A* horizon. The group of Spore-forming bacteria was 9 % of the total microflora. The reaction of soil solution sampled by tension lysimeters was assessed as slightly acidic to neutral. The electrical conductivity varied between 21 and 140  $\mu\text{S}/\text{cm}$ , which characterized waters as slightly mineralized. From 2011 to 2019, there was a balanced ratio of cations with basic and acidic functions. There was a slight tendency for the removal of basic cations outside the soil profile and this process should be observed over time.

**Key words:** aboveground litterfall, lysimeter, microflora, soil solution chemistry.

### Introduction

The concentration of nutrients in soils are determined by rock weathering, amount of litterfall (depending on tree species), forest management practices, chemical composition of the atmospheric deposition and others (Zimmermann et al. 2002,

Starra et al. 2003, Berg et al. 2006). Litterfall introduces org. C into the soil (Sayer 2006), which allows forecasting the retention of org. C in the soils (Liski et al. 2005). The parameters of aboveground litterfall (total mass and chemical composition) are important for assessing the nutrients in forest ecosystems (Schleppi et

al. 2007). Soil microorganisms as a part of forest ecosystems play a key role in the transformation of organic matter (Schloter et al. 2018). The decomposition of litterfall is a main process of biogeochemical cycles in the forest (Bani et al. 2018). The degradation of the litterfall is influenced by the type of plant litter, the quantitative and qualitative composition of the microbial community, as well as external factors, such as temperature, humidity and others (Li et al. 2017).

The 'input' of substances influences the pH of soils due to the formation of organic acids (Máthé-Gáspár et al. 2005). The chemical composition of litterfall of deciduous trees changes during the vegetation period Finér (1996). In autumn, the concentrations of nitrogen, phosphorus and potassium are lowest, and the concentrations of calcium and manganese are highest. In recent decades, the natural cycle of the elements has been disrupted by the influence of atmospheric depositions, as reported by several authors. Increased return of nitrogen, calcium, magnesium and potassium with the wood fall in soils was observed, in the range of 3.8–5.1 times more than the concentrations of the natural cycle (Zimmermann et al. 2002). According to Asi et al. (2008), increased return was also found for sulphate sulphur, magnesium and other elements.

The export of nutrients from the forest ecosystem is driven by biomass removal (logging) and leaching (Smidt et al. 2012).

The relationship between litter chemical composition of deciduous trees, soil and chemical composition of soil waters is contradictory because it is associated with a wide variation in their values. It has been found that the values of chemical composition of soil waters are most dynamic, captured right below the litter (Merila and Derome 2008).

In Bulgaria, the parameters of aboveground litterfall and soil solution sampled by tension lysimeters are measured at 3 stationary sample plots for intensive monitoring – 'Yundola', 'Vitinya' and 'Staro Oryahovo' (Kolarov et al. 1997–1998, Kolarov et al. 1999–2002, Malinova et al. 2003, Pavlova et al. 2004–2008), as part of the European Forest Ecosystem Monitoring Network (ICP Forest Manuals 1986–2016).

The aim of the study was to evaluate the amount of aboveground litterfall, the concentration of nutrients in the litterfall and chemical composition of soil waters from the intensive monitoring stationary sample plot in Yundola area, obtained for 2019. Further, we investigated their annual dynamics for the period of 2013 to 2019. In addition, we characterized the soil microbial community in the litterfall and in A horizon (upper mineral horizon) of the soil.

## Subject and Method

Yundola stationary sample plot is in the Western Rhodopes, on the territory of Yundola Training and Experimental Forest Range (41°55'34" N and 23°53'40" E). The experimental site is located in the Middle Mountain Subarea (Koleva-Lizama 2002) and is characterized by a mountain climate.

It was selected as representative for the Norway spruce (*Picea abies* (L.) Karst.) forests in the country (Kolarov et al. 2002). The altitude is 1550 m. The soil type is *Dystric* Cambisols, formed on granite.

Aboveground litterfall was collected in 5 traps, each with an area of 1 m<sup>2</sup>. It was collected every two weeks. After the collection, aboveground litterfall is sorted into

different fractions – foliar litter fraction (L), wood fraction (WF, bark, branches, twigs and others) and fruits and seeds fraction (FS) (ICP Forests Manual 2016a).

Eight sites were used to collect soil solution samples, in which lysimeters were pre-installed. Soil solution was sampled by tension lysimeters. The collected samples from A horizons in each site were mixed into one pooled sample. Same applies to the samples collected for Bw horizons. The samples of lysimeters were collected every two weeks according to ICP Forests Manual (2016b) requirements. Sampling and laboratory analyses of the observed parameters were carried out by the Executive Agency for the Environment at the Ministry of Environment and Waters in connection with the implementation of 'The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests under the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe' (ICP Forests 1986–2016). The obtained data are compared to the indicated minimum and maximum values of the different parameters of litterfall in ICP Forests (1986–2016). These parameters are monitored in the ICP Forests intensive Programme across Europe.

Microbiological assays were performed for L, FH layers and A horizon. The assays were performed under indirect cultural method. This method includes successive dilutions of the initial soil suspension (Koch method), subsequent inoculation on elective solid media. Nutrient agar for non-spore forming bacteria and spore forming bacteria (after pasteurization), actinomycete isolation agar for actinomycetes and Czapek-Dox Agar for micromycetes) were used. Germinated colonies were counted (Bonnet et al.

2020). The microbiological assays included determination of spore-forming bacteria and non-spore-forming bacteria, micromycetes and actinomycetes and subsequent determination of total microbial number. The measurement was carried out in colony forming unit under lg logarithm per gram dry soil mass (cfu lg/DsM soil).

## Results and Discussion

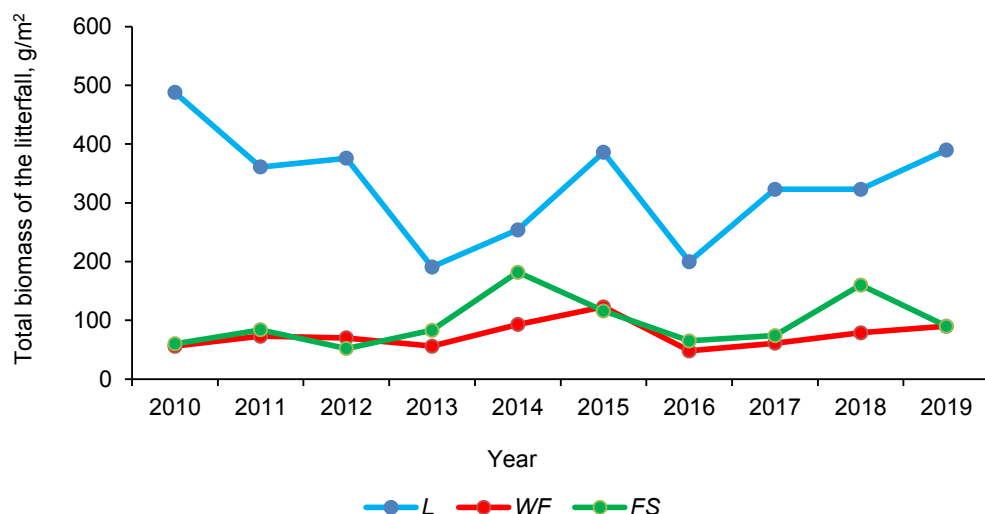
The mass of litterfall has been observed for the period 2010–2019 (Fig. 1). The obtained data showed that annual total biomass of aboveground litterfall varies widely between 200 and 488 g/m<sup>2</sup>. Similar results have been described by some other authors (Berg et al. 2006). The amount of different litter fractions determines the value fluctuation of aboveground litterfall total biomass.

The amounts of wood fraction (WF) and fruit and seeds fraction (FS) varied much less due to the almost equal amounts of bark, twigs, reproductive organs, and others that fall into the litter traps every year.

The maxima of aboveground litterfall for the coniferous tree species are in different seasons. For example, most abundant needle litterfall of the Norway spruce (*Picea abies*) is in the spring (Zimmermann et al. 2002). In Yundola stationary sample plot the maxima of the aboveground litterfall were measured in October.

There were also periods when the amount of aboveground litterfall was steady – for 2 months, mainly October and November. The data show that wood fraction was in high amounts at the beginning of the vegetation season – April, and in the end – October. For the fruits and seeds fraction, this period was in September–October.

Table 1 presents the chemical char-



**Fig. 1. Total biomass of the aboveground litterfall for the period 2010–2019.**

Note: L – litter, WF – wood fraction, FS – fruits and seeds.

acteristics of the aboveground litterfall by fractions in 2019.

The obtained data (Table 1) show that  $\text{pH}_{\text{H}_2\text{O}}$  of the aboveground litterfall for 2019 is in strongly acidic spectrum. Over time, values continue to show stability (Fig. 2). The pH of fraction L changes very slightly.

The reaction of the FS fraction showed a wider range of variation but is in the acidic spectrum throughout the observed period.

The nitrogen content of the aboveground litterfall for 2019 was assessed as average – it was in the range between the minimum and maximum values specified in the ICP Manual for Norway Spruce litterfall (Table 1). Its quantity was relatively equal in the observed period, which forms a lasting trend (Fig. 3). The org. C/N ratios differed in the individual fractions. The highest value was in WF – 86, which corresponds to the slow decomposition of organic matter. It was also high in fraction L – 65. Fraction FS was subject to the fastest decomposition

– org. C/N = 51.

The concentrations of sulphur in deciduous trees are monitored in the forest ecosystem monitoring system (ICP Forests 1986–2016) due to increased air pollution in the recent past and associated acidic atmospheric depositions (Koptsik et al. 1998, Michel and Seidling 2017). In some areas, soil acidification also extends to deeper soil layers (Iwald 2016). After 2000, recovery processes have been registered in some parts of Europe (Vanguelova et al. 2008). For Eastern Europe, however, these processes are reported to be delayed due to the later development of industrialization (Lorenz et al. 2007).

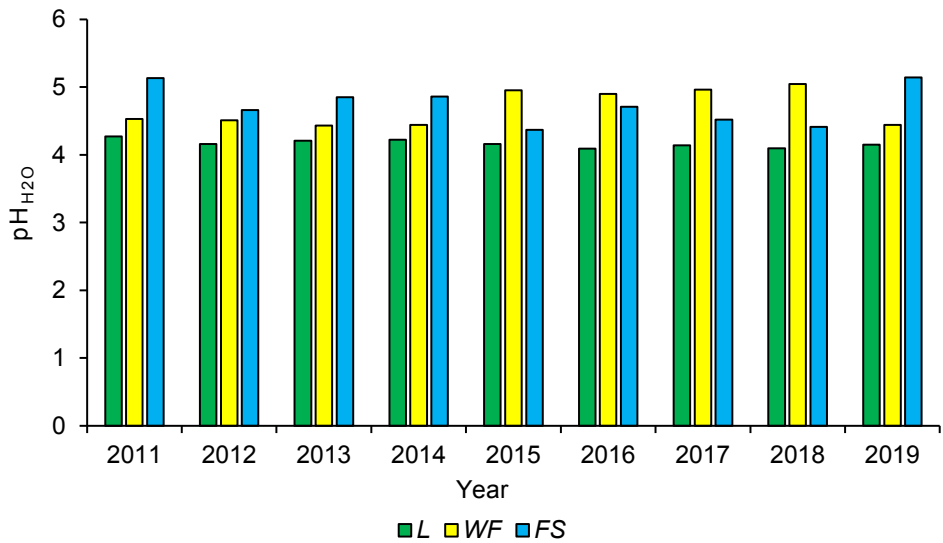
The available data show that the sulphur concentration in the aboveground litterfall from Yundola stationary sample plot in 2019 was low (Table 1). Figure 4 shows the decreasing trend of sulphur concentrations.

In 2019 the concentrations of macroelements – calcium, potassium and magnesium were assessed as high and as av-

Table 1. Concentrations of trace elements in aboveground litterfall from Yundola stationary sample plot – 2019.

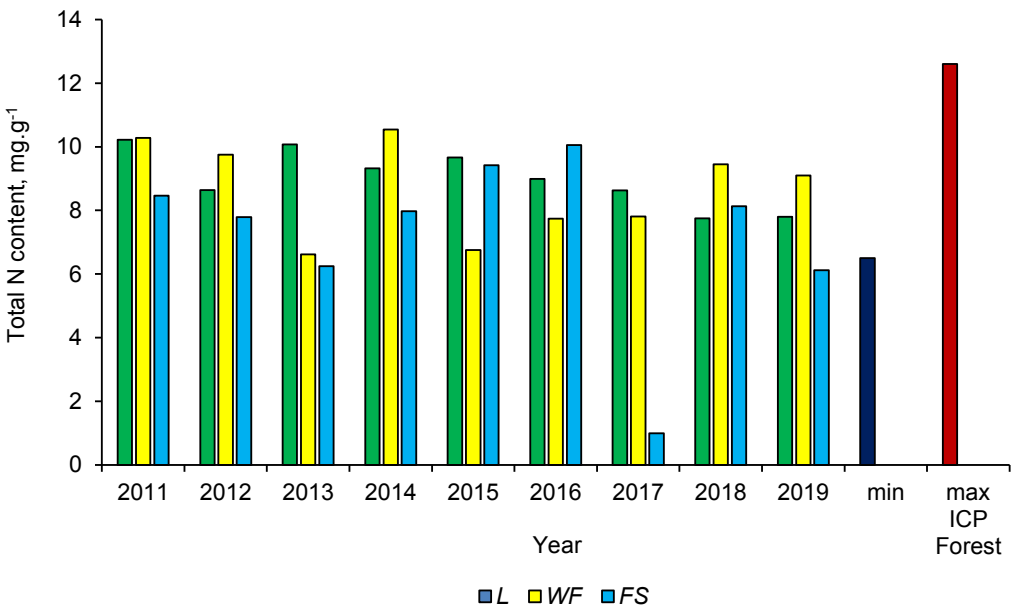
| Litter traps No | Frac-tion        | pH <sub>H2O</sub> | Org. C, g/100g | Fe, µg/g | mg/g  |      |      |       |      |      |       |         |      |       |
|-----------------|------------------|-------------------|----------------|----------|-------|------|------|-------|------|------|-------|---------|------|-------|
|                 |                  |                   |                |          | N     | S    | P    | Ca    | Mg   | K    | Zn    | Mn      | Cu   | Pb    |
| 1               |                  | 4.06              | 51.56          | 206.81   | 7.39  | 0.78 | 0.61 | 7.72  | 1.01 | 2.48 | 28.66 | 1173.13 | 1.47 | 1.90  |
| 2               |                  | 4.13              | 50.21          | 224.57   | 7.32  | 0.95 | 0.80 | 7.45  | 0.98 | 1.86 | 39.36 | 1356.61 | 3.38 | 1.90  |
| 3               |                  | 4.14              | 51.06          | 256.40   | 8.38  | 1.10 | 0.87 | 16.65 | 1.88 | 2.55 | 40.76 | 1394.83 | 0.75 | 0.11  |
| 4               |                  | 4.19              | 51.66          | 161.02   | 7.81  | 0.93 | 0.67 | 15.09 | 1.45 | 2.46 | 35.57 | 1672.88 | 2.14 | 0.96  |
| 5               |                  | 4.22              | 50.97          | 267.64   | 8.12  | 0.91 | 0.72 | 9.36  | 1.17 | 2.20 | 39.56 | 1290.10 | 2.03 | 1.82  |
| Mean            | Litter           | 4.15              | 51.09          | 223.29   | 7.80  | 0.93 | 0.73 | 11.25 | 1.30 | 2.31 | 36.78 | 1377.51 | 1.95 | 1.34  |
| St. dev.        |                  | 0.06              | 0.58           | 42.47    | 0.46  | 0.11 | 0.10 | 4.31  | 0.37 | 0.28 | 4.94  | 185.33  | 0.97 | 0.79  |
| 1               | Wood fraction    | 5.17              | 52.56          | 84.20    | 4.42  | 0.63 | 0.65 | <3.00 | 0.49 | 3.28 | 26.72 | 69.36   | 5.20 | 3.08  |
| 2               |                  | 5.16              | 53.08          | 65.09    | 6.66  | 0.70 | 0.53 | <3.00 | 0.54 | 3.31 | 29.36 | 66.60   | 4.64 | 3.99  |
| 3               |                  | 5.12              | 52.28          | 55.45    | 6.73  | 0.87 | 0.74 | <3.00 | 0.58 | 3.45 | 27.78 | 76.04   | 4.96 | 2.53  |
| 4               |                  | 5.18              | 52.46          | 54.52    | 4.92  | 0.73 | 0.37 | <3.00 | 0.56 | 2.97 | 25.25 | 96.37   | 3.17 | 2.64  |
| 5               |                  | 5.05              | 54.05          | 91.90    | 7.89  | 0.81 | 0.45 | <3.00 | 0.57 | 3.19 | 35.35 | 103.47  | 4.39 | 1.82  |
| Mean            | Wood             | 5.14              | 52.89          | 70.23    | 6.12  | 0.75 | 0.55 |       | 0.55 | 3.24 | 28.89 | 82.37   | 4.47 | 2.81  |
| St. dev.        |                  | 0.05              | 0.72           | 17.00    | 1.42  | 0.09 | 0.15 |       | 0.04 | 0.18 | 3.91  | 16.58   | 0.79 | 0.80  |
| 1               | Fruits and seeds | 4.43              | 51.27          | 702.08   | 8.65  | 0.80 | 0.77 | 4.99  | 0.71 | 2.10 | 52.28 | 336.53  | 7.86 | 9.95  |
| 2               |                  | 4.43              | 50.91          | 617.51   | 8.66  | 0.90 | 0.79 | 9.13  | 0.63 | 1.86 | 78.57 | 344.51  | 7.80 | 12.08 |
| 3               |                  | 4.43              | 51.27          | 748.92   | 8.73  | 0.88 | 0.73 | 5.71  | 0.71 | 1.66 | 43.63 | 257.85  | 7.71 | 6.65  |
| 4               |                  | 4.47              | 51.31          | 689.85   | 9.05  | 0.80 | 0.69 | 8.74  | 0.76 | 1.79 | 46.33 | 464.38  | 8.81 | 9.57  |
| 5               |                  | 4.42              | 51.03          | 773.01   | 10.42 | 0.90 | 0.51 | 5.52  | 0.69 | 2.10 | 55.96 | 277.43  | 8.15 | 12.33 |
| Mean            | Fruits and seeds | 4.44              | 51.16          | 706.28   | 9.10  | 0.86 | 0.70 | 6.82  | 0.70 | 1.90 | 55.35 | 336.14  | 8.07 | 10.12 |
| St. dev.        |                  | 0.02              | 0.18           | 60.08    | 0.76  | 0.05 | 0.11 | 1.96  | 0.05 | 0.19 | 13.85 | 80.76   | 0.45 | 2.29  |





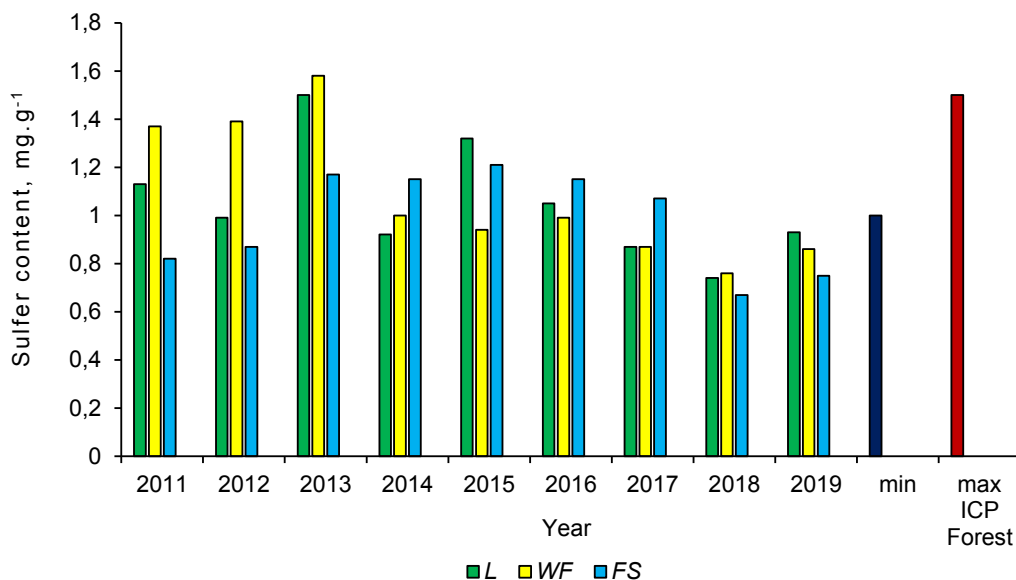
**Fig. 2. Reaction (pH<sub>H2O</sub>) of the aboveground litterfall fractions for the period of 2011–2019.**

Note: L – Litter, WF – wood fraction, FS – fruits and seeds.



**Fig. 3. Total nitrogen content in aboveground litterfall fractions for the period of 2011–2019 and ICP Forest criteria.**

Note: L – Litter, WF - wood fraction, FS – fruits and seeds.



**Fig. 4. Sulphur concentration in aboveground litterfall fractions for the period of 2011–2019 and ICP Forest criteria.**

Note: L – Litter, WF – wood fraction, FS – fruits and seeds.

erage for phosphorus (Table 1). They are a continuation of already formed trends in the reviewed period.

The trace elements were high throughout the period. There was an even distribution of their quantities between the different fractions. It should be noted that in 2019 the lead concentration was high in the WF fraction.

The degradation of the litter reflects the activity of the microbial community (Golebiewski et al. 2019). The obtained data showed a higher microbiological activity in the litter formed by the litterfall, compared to the A horizon, due to the higher total microbial number. This decrease in the total microbial number was a result of a decrease in the amount of organic matter in the A horizon.

As pointed by Prescott and Grayston 2013 and Bach et al. (2010), different tree species have different chemical composition and affect the development of soil

microorganisms in different ways.

Due to the slow decomposition of *Picea abies* needles, the organic matter in the surface L layer of the litter is in a steady state. This is explained by the presence of persistent substances, such as lignin, resins, and waxes, which are degraded by a smaller spectrum of microorganisms. In contrast to the L layer, the FH layer shows higher microbial activity. The C/N ratio remained high and determined the slow decomposition of organic matter on the soil surface.

Table 2 presents the reported microbiological indicators of the studied soils (lg cfu/g DsM).

The change of the total microbial number was characterized by a decrease in the A horizon compared to litter. In the L layer it was  $1.2 \times 10^7$  cfu/g DsM, increased in the fragmented FH layer to  $1.4 \times 10^7$  cfu/g DsM and sharply decreased to  $9.0 \times 10^5$  cfu/g DsM in A horizon.

Table 2. Microbiological indicators.

| Layers/<br>horizon | Total microbial<br>number | Spore-forming<br>bacteria | Non-spore-<br>forming<br>lg cfu/g DsM | Micromycetes | Actinomycetes |
|--------------------|---------------------------|---------------------------|---------------------------------------|--------------|---------------|
| <i>L</i>           | 7.08 ±0.67                | 6.03 ±0.66                | 7.03 ±0.72                            | 0 ±1.49      | 4.99 ±0.43    |
| <i>FH</i>          | 7.14 ±0.67                | 6.09 ±0.66                | 7.07 ±0.72                            | 2.27 ±1.49   | 5.83 ±0.43    |
| <i>A</i>           | 5.95 ±0.67                | 4.91 ±0.66                | 5.79 ±0.72                            | 4.39 ±1.49   | 5.23 ±0.43    |

The proportion of microbial groups in the soil microbial community is one of the main indicators of the degree and rate of transformation of soil organic matter (SOM) (Perfanova et al. 2015). Amount and variety of substrates available for decomposition influence soil and litterfall microflora (Gomoryova et al. 2013). The percentage share of microbial groups (Fig. 5) shows that the *L*, *FH* layers and *A* horizon were dominated by the group of non-spore-forming microorganisms. Their percentage of the total microflora decreased in depth – from 90 % in the *L* layer to 69 % in the *A* horizon. Contrary to this trend

was the percentage of actinomycetes. It increased significantly in depth. In the *L* layer it is 1 %, in the *A* horizon it reaches 16 %. Micromycetes were not reported in *L* layer, which may be due to specific micro conditions of the environment. Their percentage participation in *FH* layer was 1 % and increased up to 3 % in *A* horizon. With a constant amount in the whole studied profile was the group of spore-forming bacteria – 9 % of the total microflora.

The main microorganisms that carried out the initial stages of mineralization of organic compounds were non-spore-forming bacteria, due to which their per-

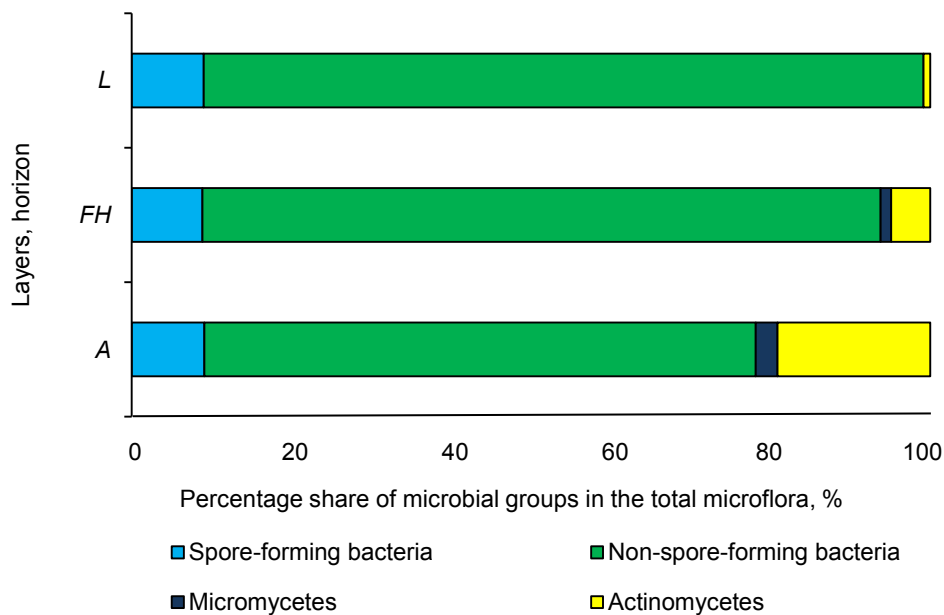


Fig. 5. Proportion of microbial groups.

centage was highest in the *L* layer.

The loss of nutrients from the soil was carried out in an acidic environment, as this was monitored by the pH of the soil solution sampled by tension lysimeters in 2019 (Table 3). In the studied period their reaction was characterized by some variation but does not differ significantly.

In comparison to the criteria specified in the ICP Forest Manual (2016b), the values of all indicators were assessed as low. They were close to the lower limit of the established values in soil solution. Soil solution sampled by tension lysimeters had low mineralization. The electrical conductivity of the soil solution varied in a wider range compared to pH but was assessed as low. For example, in the metamorphic horizon it was between 23 and 72  $\mu\text{S}/\text{cm}$ .

The conductivity of the solution was also very low. It was dominated by chlorine ions, sulphates, nitrates, phosphates, and ammonium ions. The basic cations were in low concentrations.

## Conclusions

The reaction of the aboveground litterfall had stable values for the period 2011–2019. The microbial proportion in the litter, as well as in the *A* horizon, showed a dominance of the group of non-spore-forming bacteria, which are responsible of the processes of transformation of more easily degradable soil organic matter. The trend in chemical composition of soil waters sampled by tension lysimeters is also stable – they were slightly mineralized. There was a balanced ratio between the cations with basic and acidic functions. The results showed that a small part of the studied elements has been lost in the soil substances cycle process. There is

Table 3. Chemical composition of soil waters in *A* and *Bw* horizons for 2019.

| Horizons | pH <sub>H2O</sub> | Alka-<br>linity,<br>μmol/l | Electrical<br>conduc-<br>tivity,<br>μS/cm | Dis-<br>solved<br>organic<br>matter | mg/dm <sup>3</sup> |      |      |                   |                   |                   |      |            |      |        | μg/dm <sup>3</sup> |       |       |      |      |  |
|----------|-------------------|----------------------------|-------------------------------------------|-------------------------------------|--------------------|------|------|-------------------|-------------------|-------------------|------|------------|------|--------|--------------------|-------|-------|------|------|--|
|          |                   |                            |                                           |                                     | K                  | Ca   | Mg   | N-NO <sub>3</sub> | S-SO <sub>4</sub> | N-NH <sub>4</sub> | Cl   | Total<br>N | Na   | Fe     | Mn                 | Zn    | Cu    | Pb   | Cd   |  |
| A        | 4.61              | 32                         | 64.35                                     | 7.26                                | 2.52               | 5.50 | 0.71 | 0.07              | 6.24              | 0.03              | 4.20 | 0.71       | 1.65 | 421.37 | 288.00             | 64.00 | 13.00 | 1.00 | 0.03 |  |
| Bw       | 5.48              | 32                         | 72.43                                     | 5.72                                | 1.84               | 4.62 | 1.05 | 0.16              | 7.20              | 0.03              | 4.00 | 0.59       | 2.12 | 109.60 | 544.75             | 29.75 | 2.00  | 1.00 | 0.03 |  |

a slight tendency to export basic cations outside the soil profile, a process that needs to be traced over time.

## Acknowledgements

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## **PINUS STROBUS L. IN PROTECTED AREAS OF THE UKRAINIAN POLISSYA**

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### **Abstract**

The paper considers the introduction of *Pinus strobus* L. to the Ukrainian Polissya for 200 years. The purpose of the study was to conduct an inventory of *P. strobus* in protected territories of the Ukrainian Polissya and to analyze its distribution, stand age structure, regeneration patterns, and application in different types of plantings. The study covers 26 protected man-made objects and natural areas and objects (botanical garden, 3 dendrological parks, 6 parks-monuments of landscape art, 8 natural monuments, 3 national natural parks, regional landscape park, 3 reserves, protected tract) in Ukrainian Polissya (Volyn, Rivne, Zhytomyr, Chernihiv, Khmelnytsky regions). The age of *Pinus strobus* ranges from 35 to more than 200 years. In the protected areas grow 120- to 200-year-old ancient *Pinus strobus* trees, with a number of its specimens ranging from 1 to 16. In 80 % of protected entities, *Pinus strobus* was represented by one specimen as a solitary or in groups mainly mixed with *Pinus sylvestris* L.; in 5 objects *Pinus strobus* grows in pure and mixed plantations of natural monuments. The condition of plants in 19 objects is good, in 5 – satisfactory, in two – unsatisfactory (harmed by the pest *Pineus strobi* Htg.). By self-seeding, *P. strobus* regenerated on 24 % of the territories of nature-protection entities; in one entity it has naturalized. It is proposed to use the best specimens of *Pinus strobus* as genetic material for further application in forestry and park gardening.

**Key words:** biodiversity conservation, eastern white pine, introduction, man-made objects.

### **Introduction**

Conservation of biodiversity is currently a hot topic discussed on both global and national levels, including Ukraine (Prots et al. 2011). Particular attention is paid to endangered and vulnerable species, protection of which requires combined efforts of several countries. For their protection, the state of endangered species is monitored and controlled (Verkhovna Rada of

Ukraine 1996).

Among the top 5 global risks identified for the next ten years are the significant loss of biodiversity and the destruction of terrestrial and aquatic ecosystems with irreversible consequences for the environment (WWF Ukraine 2020). Therefore, the preservation and protection of rare species of woody plants to be enjoyed by future generations represent important tasks for current natural resources scien-

tists and managers. Over the last few decades, significant efforts have been made by European countries to preserve a genetic diversity of woody plants. According to EUFGIS1, there are more than 3200 genetic conservation units that represent more than 4000 populations of about 100 tree species (de Vries et al. 2015).

White pine (*Pinus strobus* L.) is on the International Red List of Nature Conservation and belongs to the LC (low risk) category (Farjon 2013). Historically, the species dominated the eastern and western parts of North America and was an important commercial tree species (OECD 2006, Thompson et al. 2006, Mehes et al. 2009). *P. strobus* populations significantly declined since the 1600s following the white settlement of eastern North America. White pine felling in eastern Ontario, Canada, began in the late 1700s. During the 18th century, the number of *P. strobus* plantations within the natural range of the United States decreased (Thompson et al. 2006), yet owing to species' high growth rate they were eventually restored (Mandák et al. 2013). In the 19th and 20th centuries, within Canada's natural range, *P. strobus* underwent sharp decline due to excessive logging, fires, and the introduction of a pathogen *Cronartium ribicola* J.C.Fisch., which played an important role in forming the genetic structure of *P. strobus* populations (Mehes et al. 2009). First appearing in Europe in early 1865 in Estonia, *C. ribicola* eventually spread to France and Germany, and few years later to New England (1909) and Canada (1914) (Radu 2008). In North America in the early 20th century, the mortality from *C. ribicola* in mature pine groves was often 50–80 % (Ling 2003).

The rate of growth, high wood quality, ability to adapt to various climatic and growing conditions, and highly ornamental

appearance were the main reasons for *P. strobus* introduction into the plantations of Europe. The species was first introduced to Europe in 1705 in Great Britain (Radu 2008, Krumm and Vítková 2016, Adamenko et al. 2020). During the 18–19th centuries, *P. strobus* was introduced in the following European countries: Germany (1770), the area currently occupied by the Czech Republic and Slovakia (1773), Switzerland (1850), Romania (1861), Poland (1876), Austria (1886) and Bulgaria (1903). In Germany, *P. strobus* was one of the species used for reforestation in the early 20th century (until 1927, when it was banned due to *C. ribicola*) (Radu 2008).

Mandák et al. (2013) reported that *P. strobus* had naturalized in the Outer Western Carpathians subdivision of the Carpathian Mountains in the Czech Republic and southern Poland. However, in Central Europe mainly in sandstone areas of the Czech Republic *P. strobus* is an invasive tree species (Hadincová et al. 2008, Mandák et al. 2013).

On the territory of Ukraine, *P. strobus* was first planted between 1796 and 1800 in the dendrological park 'Sofiyivka' (Lypa 1952). At the beginning of the 19th century, Czartoryska (1805) (who owned estates in the Polish-Lithuanian Commonwealth, now Ukraine), recommended creating in gardens mixed groups of domestic and exotic trees and shrubs, including *P. strobus*. Nowadays in Ukraine, the area of plantations where *P. strobus* predominates, amounts to 165.6 ha, whereas the area of plantations where *P. strobus* is not the dominant species is 2542.0 ha (Musiienko 2015). The share of *P. strobus* in mixed plantations ranges from 10 to 90 %. Lukash (2008) indicated that within the areas of the Desniansko-Starohudskyi NNP (Eastern Polissya) the group of the class *Viccinio-Piceetea* Br.-Bl 1939

and Pulsatillo-Pinetea sylvestris Oberd 1992 is a place of growth of *P. strobus*, which is self-healing. To improve the aesthetics and increase the dendrodiversity of ancient parks in the Zhytomyr region, Markov et al. (2020) recommended the introduction of white pine in the plantations of four PMLA (Yulino, Miklouho-Maclay, Korostyshivskiyi, Vilkhivskiyi), which are concentrated in the Ukrainian Polissya. Anisimova (2020) noted that *P. strobus* pollen has low allergic potential (allergenicity level 3–4 out of 10 with 10 being the most severe). Therefore, based on the allergenicity of pollen, there is no reason to restrict further creation of *P. strobus* plantations in Ukraine.

The purpose of the study was to conduct an inventory of *P. strobus* in protected territories of the Ukrainian Polissya and to analyze its distribution, stand age structure, regeneration patterns, and application in different types of plantings.

## Materials and Methods

The study was conducted in several stages. The first stage included work in archives and examination of tree stand inventory materials in order to identify *P. strobus* in the protected areas of Ukrainian Polissya. The next stage was inventory of *P. strobus* by detailed route method depending on size, landscape features and structure of plantings. During the study, the condition of *P. strobus* was evaluated (good – trees are healthy and well developed, have no presence of pathogens or pests, wounds, or signs of physical damage to the trunk or skeletal branches, and no hollows, the needles are dense, evenly distributed on the branches, of regular size and colour; satisfactory – trees are healthy, but with signs of slow growth, with

unevenly developed crown, have small needles on branches, there is a presence of minor mechanical damages and small hollows; unsatisfactory – trees are very weak, trunks are crooked, crowns are poorly developed, with dry branches, and insignificant growth of annual shoots, trunks are mechanically damaged, with hollows) (State Committee ... 2014). During field studies, the diameter was measured with a measuring fork 1.3 m up the bole from the ground surface (DBH). Tree length was measured with an altimeter Suunto PM-5/1250. In some trees, the circumference of the trunk was measured with a measuring tape. The age of these trees was determined by the formula for ancient trees of at least 100 years:  $L = C \cdot K \cdot 100$ , where  $L$  is the age of the tree,  $C$  is the tree bole circumference length (girth) at DBH, and  $K$  is the coefficient for *P. strobus* (0.7 – for moist fertile soils, 1.5 – for dry rocky soils) (Boreiko 2001). To determine the natural regeneration of *P. strobus*, plots of  $1 \times 1$  m<sup>2</sup> (for seedlings of 1–5-years-old) and  $5 \times 5$  m<sup>2</sup> (for saplings of 6–10 years, 11–15 years, 15–20 years, and more) were laid at 0,5 % of the total area of the stands. The total number (pcs/ha) was determined by the formula  $N = 10000 \cdot n/P$ , where  $n$  is the number of seedlings and saplings on all accounted plots,  $P$  is the area of all accounted plots, m<sup>2</sup> (Hirs et al. 2004). For the information obtained from the literature, we applied a systematic approach and comparative analysis. We assessed if *P. strobus* was on the International Union for Conservation of Nature Red List (Farjon 2013).

## Study Area

We examined 26 entities representing protected territories in five regions of Ukrainian Polissya (Volyn, Rivne, Zhyto-

myr, Chernihiv, and Khmelnytsky). Among them were 8 nature protection areas (three National Natural Parks (NNP), a regional landscape park (RLP), a botanical reserve (BR), two landscape reserves (LR), a protected tract (PT)), and 18 man-

made entities (a botanical garden (BG), 3 dendrological parks (DP), 6 park-monuments of landscape art (PMLA), six botanical monuments of nature (BNM), and 2 complex monuments of nature (CNM)) (Fig. 1).

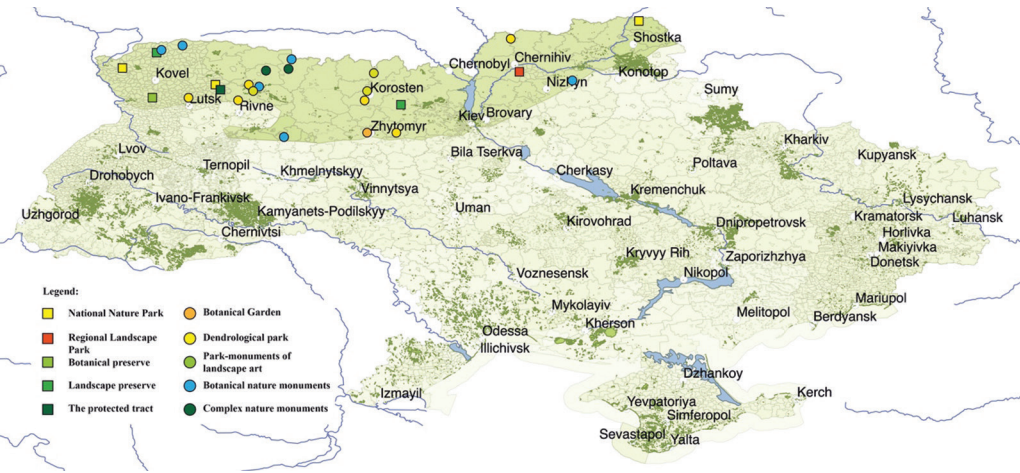


Fig. 1. Nature protection entities of Ukrainian Polissya containing *Pinus strobus*.

Results and Discussion

The introduction of *P. strobus* in Ukrainian Polissya took place in three stages with the first stage encompassing a period from the second half of the 19th century to the beginning of the 20th century; the second stage encompassing a period from the beginning of the 20th century until 1941, and the third stage encompassing

a period between the second half of the 20th century and the beginning of the 21st century (Fig. 2).

Within the area of 26 nature protection entities of Ukrainian Polissya, *P. strobus* grows in different types of plantings, namely: as a solitary specimen, in pure and mixed groups, and in pure and mixed plantations (Fig. 3). In 80 % of protected entities, *P. strobus* is represented by a sol-

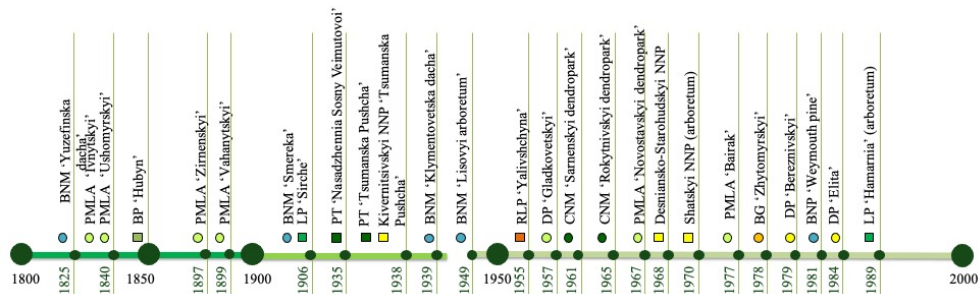
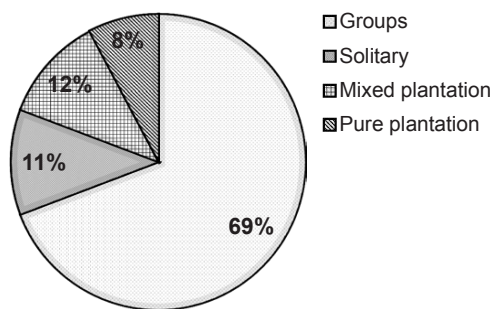


Fig. 2. Stages of the introduction of *P. strobus* in Ukrainian Polissya.



**Fig. 3. Types of plantings with *Pinus strobus*.**

itary specimen or in groups mainly mixed with *Pinus sylvestris* L. As a solitary specimen *P. strobus*, aged 120 to 180 years and in good condition, was found in three PMLAs: 'Ushomyrskyi'; 'Ivnytskyi' (Zhyto-

myr region); 'Vahanytskyi' (Chernihiv region) (figs 4–6; Table 1).

In 18 objects, *P. strobus* was represented in pure and mixed groups by one to 16 specimens. One 120-year-old specimen of *P. strobus* (good condition) grew in a group with *Larix decidua* Mill. in LNZ 'Sirche' BNM 'Smereka' (Volyn region) (Fig. 7, Table 1). In BP 'Hubyn' (Volyn region) two 170-year-old specimens of *P. strobus* were found. The first one was in good condition, whereas the second one had a bifurcation of the trunk located at a height of 2 m and was in an unsatisfactory condition (broken top). Sixteen 120-year-old *P. strobus* grew in groups of 3–5 specimens (Table 1) in a mixed plantation in PMLA 'Zirnenskyi' (Rivne region) (Fig. 8). Fourteen trees of them were in good con-

**Table 1. Characteristics *Pinus strobus* L. in protected areas of the Ukranian Polissya.**

| Protected areas                                  | Number of specimens/ area, ha | Age, years | Height /HT, m    | Diameter (DBH), cm |
|--------------------------------------------------|-------------------------------|------------|------------------|--------------------|
| 'Ushomyrskyi' PMLA                               | 1                             | 180        | 30.0             | 81.0               |
| 'Ivnytskyi' PMLA                                 | 1                             | 180        | 33.5             | 82.0               |
| 'Vahanytskyi' PMLA                               | 1                             | 120        | 26.0             | 64.0               |
| LNZ 'Sirche'                                     | 1                             | 120        | 23.5             | 70.0               |
| BNM 'Smereka'                                    | 1                             | 120        | 23.5             | 70.0               |
| BP 'Hubyn'                                       | 2                             | 170        | 28.0, 22.0       | 83.0, 60.0         |
| PMLA 'Zirnenskyi'                                | 16                            | 120        | 26.4 ±0.5        | 55.7 ±4.3          |
| BNM 'Nasadzhennia Sosny Veimutovoi'              | 14                            | 85         | 24.3 ±0.6        | 39.4 ±2.8          |
| PMLA 'Bairak'                                    | 3                             | 46         | 16.0, 11.5, 15.0 | 53.0, 39.0, 32.0   |
| LP 'Hamarnia' (arboretum)                        | 1                             | 36         | 13.0             | 21.0               |
| DP 'Elita'                                       | 1                             | 35         | 18.0             | 22.0               |
| DP 'Hladkovytskyi'                               | 7                             | 65         | 23.2 ±0.9        | 51.0 ±2.6          |
| DP 'Beresnivskyi'                                | 11                            | 41         | 19.0 ±0.6        | 43.5 ±3.0          |
| Botanical garden of Poliskyi National University | 7                             | 43         | 22.3 ± 0.5       | 41.5 ± 2.4         |
| Shatskyi NNP (arboretum)                         | 2                             | 45         | 12.0, 14.0       | 22.0, 23.0         |
| PMLA 'Novostavsky dendropark'                    | 1                             | 55         | 24.0             | 32.0               |
| BNM 'Forest Arboretum'                           | 1                             | 70         | 26.0             | 49.0               |
| CNM 'Sarnenskyi dendropark'                      | 3                             | 60         | 16.5, 23.0, 16.0 | 40.0, 46.0, 34.0   |
| BNM 'Weymouth pine'                              | > 30/0,5                      | 41         | 19.4 ±0.3        | 21.2 ±1.0          |





**Fig. 4. *P. strobus*, PMLA 'Ushomyrskyi' (Zhytomyr region).**



**Fig. 5. *P. strobus*, PMLA 'Ivnytskyi' (Zhytomyr region).**



**Fig. 6. *P. strobus*, PMLA 'Vahanytskyi' (Chernihiv region).**



**Fig. 7. *P. strobus*, BNM 'Smereka' (Volyn region).**



**Fig. 8. *P. strobus*, PMLA 'Zirnenskyi' (Rivne region).**



**Fig. 9. *P. strobus*, BNM 'Nasazhennia Sosny Veimutovoi' (Rivne region).**

dition, whereas two were in satisfactory condition. The trees were fruiting, however, self-seeding was not observed. The optimal age of fruiting was from 50 to 150 years (Wilson and McQuilckin 1963).

A *Pinus strobus* plantation in BNM 'Nasazhennia Sosny Veimutovoi' (Rivne region) was established in 1935. In 1993, 32 specimens were still growing. In 2015, some trees were felled because they were

drying, leaving 14 specimens (satisfactory condition) (Fig. 9, Table 1). *P. strobus*, aged 36 to 70 years, grew by one to 7 specimens in pure and mixed groups. In PMLA 'Bairak' (Volyn region) (Fig. 10), the botanical garden of Poliskiy National University, and DP 'Elita' (Zhytomyr region) plants were in good condition, whereas in LP 'Hamarnia' (arboretum) (Zhytomyr region), Shatskyi NNP (arboretum) (Volyn

region), and BNM 'Forest Arboretum' (Chernihiv region) the condition of the plants was satisfactory. Characteristics of *P. strobus* in the above-protected areas of the Ukrainian Polissya are shown in Table 1.

A group of 13 *P. strobus* trees was created at the CNM 'Sarnenskyi dendropark' (Rivne region) in 1961. Currently, from that group, there are 3 trees remaining (Fig. 11, Table 1): two of them have satisfactory conditions; one tree affected by *Pineus strobi* has an unsatisfactory condition.

In BNM 'Weymouth pine' (Volyn region), a 41-year-old pure plantation of *P. strobus* was found to grow in the area of 0.5 ha (Table 1). This plantation is damaged by *Pissodes strobi* W. D. Peck. (Fig. 12), with tree condition being unsatisfactory. According to research on *Pineus strobi* (Fora and Lauer 2008) the pathogen begins to attack trees when they are 25–30-years-old, especially when their sensitivity to pathogen increases due to urban pollution. Past the age of 30 years, the trees exhibit high sensitivity to the

pathogen and are subject to moderate and high intensity of infestation.

*P. strobus* was found to grow in pure and mixed stands in DP 'Hladkovytskyi', 'Bereznivskyi', RLP 'Yalivshchyna', in protected tracts 'Tsumanska Pushcha' Kivertsivskyi NNP 'Tsumanska Pushcha', BNM 'Juzefinska dacha', 'Weymouth pine', and 'Klymentovetska dacha'. Regeneration of *P. strobus* in Ukrainian Polissya was observed in six nature protection areas ('Tsumanska Pushcha' tract Kivertsivskyi NNP 'Tsumanska Pushcha' (Partizanske forest management enterprise (FME) (Fig. 13), quarter 21, stand 6, Berestianske FME, quarter 29, stand 2, Desnyansko-Starogudskyi NNP, DP 'Bereznivskyi', DP 'Hladkovytskyi' (Fig. 14), BNM 'Yuzevinska dacha' (Fig. 15).

'Tsumanska Pushcha' tract Kivertsivskyi NNP 'Tsumanska Pushcha' (Berestianske FME, quarter 29, stand 2) in Volyn Region is characterized by western and north-western winds. Several 80-year-old *P. strobus* ( $n = 29$ , mean diameter at breast height (DBH) =  $39.6 \pm 2.0$  cm), mean total tree height (HT) =  $27.9 \pm 0.4$  m)



Fig. 10. *P. strobus*, PMLA 'Bairak' (Volyn region).

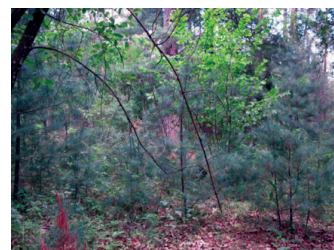
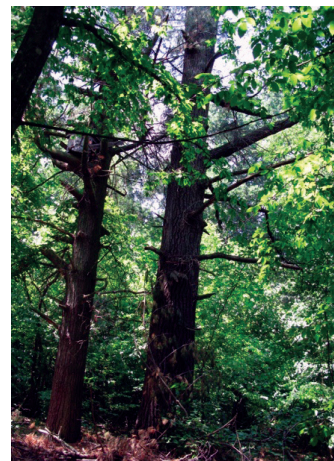


Fig. 11. *P. strobus*, CNM 'Sarnenskyi dendropark' (Rivne region).



Fig. 12. *P. strobus*, BNM 'Weymouth pine' (Volyn region).





**Fig. 13.** *P. strobus*, Kivertsivskyi NPP 'Tsumanska Pushcha', PT 'Tsumanska Pushcha' (Volyn region).

**Fig. 14.** *P. strobus*, DP 'Hladkovytskyi' (Zhytomyr region).

**Fig. 15.** *P. strobus*, BNM 'Yuzefinska dacha' (Rivne region).

were found to grow in a stand mixed with *P. sylvestris*, *Picea abies* (L.) Karst., *Quercus robur* L., occupying an area of 0.3 ha. Trees are naturally regenerating. In the study area, the natural regeneration was absent, however, it was present 100–150 m west and north-west from the seed trees, within a 4-m wide strip running along the road. Natural regeneration is viable. Two-three-year-old seedlings are 20 cm in height (3 seedlings). Six-year-old saplings are 6 cm in diameter and 6.0 m in height. Thirteen-year-old saplings are 6.0 and 8.0 cm in diameter and 3.0 and 4.0 m in height. Fifteen and twenty-year-old trees are 8 cm and 16 cm in diameter and 7.0 m and 10.0 m in height, respectively.

Wilson and McQuilckin (1963) indicated that seed dispersal is dependent on growing conditions and a dominant wind direction. Maximum distance for seed dispersal could be up to 60 m and 200 m in closed and open stands, respectively. According to Hadincová et al. (2008), *P. strobus* seeds could be dispersed up to 752 m from the source.

In Partyzansky FME (quadrant 21, stand 6, area 2.1 ha) in a mixed stand with *P. sylvestris*, *Picea abies*, *Quercus robur* and *Alnus glutinosa* (L.) Gaertn., 80-year-old *P. strobus* ( $n = 36$ , mean diameter at breast height (DBH) =  $39.9 \pm 1.9$  cm), mean total tree height (HT) =  $27.5 \pm 0.3$  m) regenerate naturally (Fig. 13). Natural regener-

ation is concentrated in a 3 m<sup>2</sup> gap, created by a fallen tree. Ten young pines range in age from 1 to 7 years. The majority of seeds are distributed within a distance equivalent to the height of the seed tree (Horton and Bedell 1960). In pure stands, *P. strobus* forms twice as many cones as in stands where it is a co-dominant species (Wilson and McQuilckin 1963).

DP 'Hladkovytskyi' (Zhytomyr region) was created in 1957 (Hladkivske FME, quadrant 38, area 4.0 ha). A mixed stand of *P. strobus* (12 specimens) and *Juglans cinerea* L. (5 specimens) was created in the western section of the park. Seven 65-year-old *P. strobus* from that stand still exist today ( $n = 7$ , mean diameter at breast height (DBH) =  $51.0 \pm 2.6$  cm, mean total tree height (HT) =  $23.2 \pm 0.9$  m)). All trees are in good condition. Species can regenerate via self-seeding in the north-eastern and western sections of the park within 10–12 m from the seed trees. Thirteen viable *P. strobus* specimens were found with an age ranging between 1 and 15 years (Fig. 14).

In 1979, 41 *P. strobus* seedlings were planted in DP 'Beresnivskyi' (Rivne region). By 2017, eleven 41-year-old trees remain ( $n = 11$ , mean diameter at breast

height (DBH =  $43.5 \pm 3.0$  cm), mean total tree height (HT) =  $19.0 \pm 0.6$  m). A total of four trees are damaged by pathogens, two by *Cronartium ribicola* and two by *Pineus strobi*. The trees are in good and satisfactory condition. Ten 2–7-year-old *P. strobus* seedlings and saplings were located within 12–18 m from the seed trees, with three from ten succumbed to mortality.

BNM 'Yuzefinska dacha' (Rivne region) covers an area of 100 ha (Hlynnivske FME quadrants 14 (except for stands 5, 7, 8, 10, 12, 12.1, 13, 14, 33, 35, 36, 63)). The nature preserve was created to protect old oak stands (Andryenko and Sheliah-Sozonko 1983). *P. strobus* (mean diameter at breast height (DBH) =  $63.3 \pm 6.4$  cm, mean total tree height (HT) =  $28.9 \pm 0.8$  m)) grows here in mixed stands with *Pinus sylvestris* L., *Picea abies* (L.) Karst., *Quercus robur* L., *Alnus glutinosa* (L.) Gaertn., *Betula pendula* Roth., *Populus tremula* L., with an understory of *Corylus avellana* (L.) H.Karst., *Rhododendron luteum* Sweet., *Euonymus europaeus* L. and *Frangula alnus* Mill. The oldest *P. strobus* trees are found in Hlynnivske FME, quadrant 14, stand 47 (Fig. 15) and have the following characteristics: DBH 131, 86, and 90 cm; height 37, 31, and 30 m, respectively. In

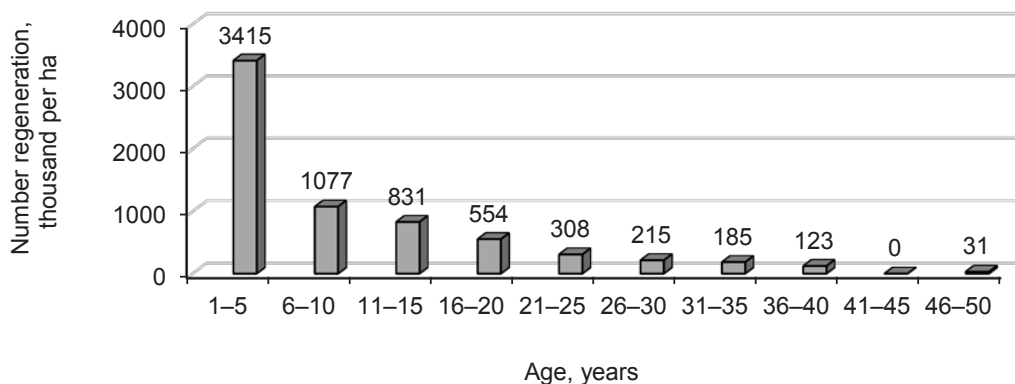


Fig. 16. Regeneration *P. strobus* in BNM 'Yuzefinska dacha', Hlynnivske FME quadrants 14.

1975, the proportion of *P. strobus* in a stand was 0.5 %. After 40 years, its distribution extended in north-eastern, eastern, and western directions (which corresponds with the prevalent wind direction). Regeneration is via self-seeding, in good condition, and of high density in quadrant 14, stands 45 (11.2 thousand per ha), 46 (4.1 thousand per ha), 47 (6.6 thousand per ha), 48 (4.0 thousand per ha), and 49 (2.2 thousand per ha), whereas in stands 21, 22, 23, 24, 25, 26 it is relatively sparse. Natural regeneration is viable ranging in age between 1 and 40 years (sometimes older) (Fig. 16) and dispersed at a distance of over 100 m from seed trees. *P. strobus* trees in these stands are in good condition.

## Conclusions

Lasted for the past 200 years, the introduction of *Pinus strobus* to the forest plantations and parks in Ukrainian Polissya occurred in three stages. It became most widespread in the second half of the 20th century. *P. strobus* grows in 26 protected areas and in 19 areas (73.1 %) it is in good condition; 7 locations contain ancient trees aged 120 to 200 years. In 80% of protected areas, *P. strobus* is represented as a solitary or in groups with *Pinus sylvestris*.

In 6 protected areas (located between 51 and 52 degrees northern latitude) *P. strobus* regenerates naturally by self-seeding. Most seeds are dispersed immediately under or within 200 m from the seed tree. The count of natural regeneration varies between 162 and 11.2 thousand seedlings per ha. *P. strobus* has naturalized in stands where it is mixed with *Pinus sylvestris*, *Picea abies*, *Quercus robur*, *Alnus glutinosa*, *Betula pendula* and

*Populus tremula*.

The study of *P. strobus* L. in protected areas provides information on its further use in parks and forests of Ukrainian Polissya. Although *P. strobus* is damaged by two pathogens (*Cronartium ribicola* and *P. strobil*), it is a valuable ornamental tree; therefore for creating groups, solitaires, and mixed plantings one should utilize specimens that are resistant to fungal diseases. 'Tsumanska Pushcha' tract Kivertsivskiyi NNP 'Tsumanska Pushcha', BNM 'Yuzefinska dacha', DP 'Hladkovytskyi', 'Bereznivskiyi', PMLA 'Bairak' can serve as a centre of genetic material for further breeding of trees resistant to fungal diseases. We propose to grant the status of a monument of nature to individual ancient trees as valuable historical, natural, scientific and cultural objects.

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## PRODUCTIVITY MODELS AND COSTS OF COMBINED SKIDDER – HARVESTER IN CONIFEROUS FORESTS

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### Abstract

In addition to natural pine forests in Bulgaria, there are also large artificial plantations (over 1.5 million ha), created in the period of 1950–1990. Large areas with non-thinned coniferous plantations located at low altitudes are associated with a high probability of reduced growth and significant health problems. Traditionally, adapted agricultural tractors are the most widely used equipment for timber extraction in Bulgaria. The shortage of work force due to labor-intensive and unattractive logging work is one of the reasons for making efforts to introduce more advanced, multipurpose equipment. However, in Bulgaria the use of harvesters is limited by the predominance of deciduous forests, steep terrains and by the maximum allowed harvesting intensity of 30 %. The latter requirement often makes modern logging equipment unprofitable. In an attempt to overcome some of these limitations, the use of a combined wheeled skidder-harvester (SH) has been introduced in the eastern Rhodopes Mountains in the last few years. The SH works as a harvester and fells the accessible trees located on the skid roads and on the corridors. The remaining marked trees are felled manually by chainsaw. The felled trees are dragged to the machine by a two-drum winch equipped with a remote control, skidded to the landing where they are delimbed, bucked and piled by the SH. The mean productivity of the SH which stands for a mean skidding distance of 69 m, a mean bunching distance of 14 m, a mean load volume of 4.06 m<sup>3</sup>, was estimated at 9.38 m<sup>3</sup>·PMH<sup>-1</sup> (8.27 m<sup>3</sup>·SMH<sup>-1</sup>) timber piled at landing, which is comparable to two typical logging teams with adapted tractors and 4–5 workers in each team. The gross costs per unit done by the SH (14.24 €·m<sup>-3</sup>) are within the regional level for coniferous stands.

**Key words:** cycle time, economic evaluation, shelterwood system, work elements.

### Introduction

The area of forests in Bulgaria is over 4.23 million ha (including 3.858 million ha of woodlands). The total stock is 681 million cubic meters (over bark). The share of deciduous and coniferous tree species by area is 71 % and 29 %, respectively, while the share in the total stock is 55.5 % and 44.5 %, respectively (EFA 2020). Bulgaria annually produces on average about

8.0–8.3 million cubic meters (over bark) of the stock or about 6.6–7.0 million cubic meters (under bark) timber (EFA 2019).

In addition to natural pine forests, there are also large artificial plantations (over 1.5 million hectares), created in the period of 1950–1990. They consist mainly of Scots pine (*Pinus sylvestris* L.) (48 %) and Austrian pine (*Pinus nigra* Arn.) (41 %) (EFA 2019). Most of the forest plantations were created to ensure anti-erosion func-

tions and to improve degraded forests; accordingly, due to their scale, they have a significant environmental function (Milev et al. 2017). Large areas with artificially created non-thinned coniferous plantations located at low altitudes are associated with a high probability of reduced growth and significant health problems, which present a serious challenge for the Bulgarian foresters. About 30 % of the Scots pine plantations are located at lower altitudes compared to their natural distribution in Bulgaria. 35 % of them are located between 700 and 1000 m a.s.l., where only 8 % of the natural forests of these tree species are found. The distribution of Austrian pine plantations is similar in terms of altitude, with 76 % of them being distributed below 700 m a.s.l., where only 5 % of natural forests of these species are found. These two species provide valuable wood with a wide application in the wood processing and construction industries. In the recent decades, there has been an increased drought stress due to higher recorded temperatures and long rainless periods during summer and autumn, which contributed to reducing the growth and deteriorating the health of many artificial plantations, especially those of Scots pine, located at low altitudes (MOEW 2019).

The selection of the most suitable machines is crucial for the assessment of technical, economic and environmental indicators during the harvesting operations in artificial coniferous plantations.

Traditionally, adapted agricultural tractors are the most widely used equipment for timber extraction in Bulgaria, as well as in the Balkans, the Carpathians, Italy, etc. (Borz et al. 2013a, 2013b, 2015; Spinelli et al. 2013; Moskalik et al. 2017; Bodaghi et al. 2018; Proto et al. 2018; Cataldo et al. 2020).

Wheel cable skidders are used in many

harvesting systems due to their long winch cable (60–100 m) giving a better opportunity to reach otherwise inaccessible trees. Worldwide the wheel skidder is one of the most used machines in mountain logging for slopes under 10–20° (Georgiev and Stoilov 2007).

Skidding distance had been found to be one of the most relevant independent variables for modeling the work time consumption (Sabo and Poršinsky 2005; Öztürk 2010a, 2010b; Gallis and Spyroglou 2012; Borz et al. 2013; Ghaffariyan et al. 2013; Vusić et al. 2013). The greatest amount of studies have been conducted for skidding distances up to 400 m (Sabo and Poršinsky 2005; Gallis and Spyroglou 2012). Borz et al. (2014) adds to the most significant independent variables for the time consumption estimation in a group shelterwood system also winching distance and number of logs forming a load.

Skidders may successfully replace modified farm tractors without requiring any substantial changes in the conventional harvesting methods, thus making innovation less traumatic for the logger's mind and wallet (Spinelli et al. 2021).

While the total productivity of the wood harvesting methods is comparable across EU countries, unit cost, particularly with the less mechanized technologies, differs greatly between countries due to the different cost of labor cost. The lowest level of mechanization for logging processes is observed in Bulgaria, Romania, Slovakia and Ukraine. This is mainly due to the availability of relatively cheap labor (Moskalik et al. 2017).

The productivity of a harvester depends on the harvested tree volume. As soon as the trees volume increases, the productivity of the harvester increases as well. Closer to the technological corridors, stands are thinned more intensively than

in more distant areas; the most common reason for such difference is the insufficient accessibility of trees located far from the strip roads (Pētersons 2010). The time consumption per cubic meter is also higher in sparse shelterwoods than in dense shelterwoods. Most of this increase is due to a longer driving time because fewer trees are harvested (Hånell et al. 2000).

The productivity of a John Deere 1270 D harvester operated in southeastern Bulgaria during clearcutting after forest fires and calamities in Scots pine and Austrian pine plantations was 51 m<sup>3</sup> per day. The distribution of the harvester work cycle by elements was: 50 % – time for trees processing, 13 % for trees felling, 13 % for moving in the stand, and 24 % for the remaining time, while the distribution of the forwarder work cycle is: 33 % of the time for loading, 12 % for unloading, 28 % for traveling, 13 % for moving in the cutting area and 14 % for the remaining time (Dinev and Vardunski 2014).

The longer time and higher logging cost in the shelterwood system (compared with the clearcutting system) were mostly related to the establishment of the shelterwood (Hånell et al. 2000).

The economic challenges faced by the Bulgarian forester are very severe. The shortage of work force due to labor-intensive and unattractive logging work justifies an effort to introduce more multipurpose equipment. In Bulgaria, the introduction of harvester technology is limited by the predominance of deciduous forests, steep terrains and by the maximum allowed harvesting intensity of 30 % (in poplar plantations – up to 50 %). The latter requirement often makes modern logging technologies with harvesters unprofitable.

In an attempt to overcome some of these limitations, the use of a combined skidder-harvester (SH) has been intro-

duced in Bulgaria for the last few years. The combined machine works as a harvester and fells the accessible trees located by the skid road and the corridor. The remaining marked trees in the midst of the stand are felled manually by chainsaw. The felled trees are pulled to the skid road by a two-drum winch with remote control and then skidded to the landing where they are delimbed, bucked and piled by the combined machine.

Currently, there are no studies on the time consumption, productivity and cost of the combined skidder – harvester used in different silvicultural systems and under different terrain conditions; therefore, one cannot assess the influence of different operational and technical parameters on its productivity and costs. Such studies are needed to evaluate the application of this type of combined machinery in logging from a silvicultural, technical and economic point of view.

The aims of the present study were: (i) to determine productivity rates and costs using combined wheel cable skidder – harvester, (ii) to develop cycle time and productivity prediction models, and (iii) to estimate the application in logging operation for such type of combined machine in Bulgaria and the eastern Rhodopes in particular, as well as in many European countries' coniferous plantations.

## Material and Methods

### Study site and work organization

The study was carried out in the Krumovgrad State Forest Range (subsidiary of South Central State Enterprise, Smolyan), located in the eastern Rhodopes, Kardzhali Province, Bulgaria. Stand and operation characteristics are shown in Table 1.

**Table 1. Characteristics of the test site.**

| Parameter               | Characteristics                                             |
|-------------------------|-------------------------------------------------------------|
| Location                | Egrek                                                       |
| Elevation               | 550 m a.s.l.                                                |
| Species composition     | Scots pine – 80 % and Austrian pine – 20 %                  |
| Stand age               | 55 years                                                    |
| Stand type              | High forest plantation                                      |
| Total area              | 22.2 ha                                                     |
| Stand density           | 929 trees per ha                                            |
| Relative stocking       | 0.8                                                         |
| Harvesting method       | Combined regular and shelterwood cutting, intensity 25 %    |
| Average tree height     | Scots pine – 17 m, Austrian pine – 16 m                     |
| Average DBH of a tree   | Scots pine – 24 cm; Austrian pine – 30 cm                   |
| Average slope gradient  | 19° (34 %)                                                  |
| Growing stock           | 7260 m <sup>3</sup> (336 m <sup>3</sup> ·ha <sup>-1</sup> ) |
| Allowable cut           | 1860 m <sup>3</sup> (84 m <sup>3</sup> ·ha <sup>-1</sup> )  |
| Number of trees for cut | 5154 (232 trees·ha <sup>-1</sup> )                          |

The Scots pine (*Pinus sylvestris* L.) and Austrian pine (*Pinus nigra* Arn.) trees were transported by a wheel cable skidder – harvester (SH) as semi-suspended full trees (except the stumps). Skidding direction was downhill and trees were felled manually by a chainsaw or by a harvester head.

The combined wheel cable skidder – harvester (SH) operated in sub-compartment 592-v (41°19'54.56" N, 25°36'39.25" E). Field observations were carried out on 31 work cycles (turns) of the SH.

The SH work team consisted of two

people, one of which was the skidder and harvester operator, the second one was the chainsaw operator and chokerman. The work team had more than 2 years of experience with studied machine and they were 30–45-years-old.

An articulated four-wheel-drive HSM 805 ZL (HSM Hohenloher Spezial-Maschinenbau GmbH & Co. KG, Neu Kupfer, Germany) double-drum wheeled cable skidder, equipped with a knuckle-boom loader and a Woody 50 harvester head (Konrad Forsttechnik GmbH, Preitenegg, Austria), as shown in Table 2, was used for the tests.

**Table 2. Technical data of the studied HSM 805 ZL double-drum cable skidder – harvester.**

| Parameter       | Characteristics                                                                 |
|-----------------|---------------------------------------------------------------------------------|
| Engine          | IVECO NEF, 4 cyl. Common Rail Turbo / TIER 3B                                   |
| Engine output   | 125 kW (170 DIN horsepower) at 2200 rpm                                         |
| Max. torque     | 700 Nm at 1500 rpm                                                              |
| Engine capacity | 4.5 liters                                                                      |
| Transmission    | HSM High Speed Drive, 2-step NAF transfer gearbox                               |
| Axles           | Planetary axles, 100% separately selectable differential locks, front and rear  |
| Brake           | 2-circuit brake, disk brake running in an oil bath, spring-loaded parking brake |

|                             |                                                                                                                                                                                                                                                                                                    |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Steering                    | Articulated steering with 2 cylinders, 45° steering angle                                                                                                                                                                                                                                          |
| Tank capacity               | Diesel: 175 l; AdBlue: 25 l; Hydraulic fluid: 90 l                                                                                                                                                                                                                                                 |
| Hydraulics                  | Load sensing                                                                                                                                                                                                                                                                                       |
| Pump output                 | Flow rate: 232 liters/min at 1600 rpm, pressure: up to 350 bar                                                                                                                                                                                                                                     |
| Hydraulic fluid             | Saturated, synthetic ester                                                                                                                                                                                                                                                                         |
| Cabin                       | <ul style="list-style-type: none"> <li>• HSM Panorama comfort cab;</li> <li>• ROPS, FOPS, OPS tested safety cab;</li> <li>• Swivel seat device, air-suspended comfort seat;</li> <li>• Heating/air-conditioning.</li> </ul>                                                                        |
| Logging equipment           | <ul style="list-style-type: none"> <li>• Fixed front polder shield, 2000 mm wide;</li> <li>• Lowerable straight shield;</li> <li>• Adler HY 20 (2×100 kN) double-drum winch, max. cable take-up of Ø14 mm, 100 m;</li> <li>• Epsilon crane M80 R59, lifting moment 114 Nm, range 8.0 m.</li> </ul> |
| Harvester head              | Woody 50                                                                                                                                                                                                                                                                                           |
| Chain tensioner system      | Hydraulic                                                                                                                                                                                                                                                                                          |
| Chain speed                 | 40 m·s <sup>-1</sup>                                                                                                                                                                                                                                                                               |
| Length of the saw guide bar | 750 mm                                                                                                                                                                                                                                                                                             |
| Max. cutting diameter       | 550 mm                                                                                                                                                                                                                                                                                             |
| Delimbing diameter          | 40–550 mm                                                                                                                                                                                                                                                                                          |
| Max. grapple opening        | 1030 mm                                                                                                                                                                                                                                                                                            |
| Dimensions                  |                                                                                                                                                                                                                                                                                                    |
| Length                      | 6986 mm                                                                                                                                                                                                                                                                                            |
| Wheel base                  | 3820 mm                                                                                                                                                                                                                                                                                            |
| Height                      | 3170 mm                                                                                                                                                                                                                                                                                            |
| Width                       | 2360 mm                                                                                                                                                                                                                                                                                            |
| Weight                      | 12,800 kg                                                                                                                                                                                                                                                                                          |

## Productivity study and costs

A detailed time and motion study was conducted to estimate the duration of work elements and productivity of the SH in the given conditions. A work cycle was assumed to be composed of repetitive elements (Stokes et al. 1989, Olsen et al. 1998).

The work cycle of the SH was composed of the following repetitive components:

- travel unloaded (TU) along the skid road;

- felling (F) – time for cutting standing trees by the harvester head causing them to fall as a result of the cutting;

- bunching – time for winching and gathering the tree load including the time for maneuvers and choice of position. Bunching can be divided into maneuvering (M), outhaul of the main cable and hook (OH), and load inhaul (I) to the skidder;

- travel loaded (TL) along the skid road;

- processing (P) – time for delimbing (removing branches from a tree) and bucking (cutting felled and limbed trees into sections) by the harvesting head;

- sorting and piling (SP) – time for picking up the logs or bolts and depositing in large piles by knuckle-boom so the logs are horizontal and parallel to each other and the ends are approximately in the same vertical planes;



- delays (D) include the rest, personal delays, organizational delays, service, and repair.

The time-motion study was designed to evaluate the duration of work elements and productivity of the SH and to identify those variables that are most likely to affect it. Each work cycle was individually measured by a stopwatch. The productive time was separated from the delay time. Skidding distance, slope gradient of the skidding road, and outhaul distances were measured with a professional laser range-finder with clinometer. Load volume was determined by measuring the length and the mid-length diameter of all logs in each load.

Machine costs were calculated using the COST model (Ackerman et al. 2014). In order to calculate the production cost for 1 m<sup>3</sup> timber, the cost analysis employed the following parameters: the number of operators, the hourly cost for an operator, the hourly cost of the machine, the volume of extracted timber and productive machine hours (excluding all delay times). The machine cost per hour was reported both as productive machine hours excluding delays and scheduled machine hours including delays. The purchase price and operator wages required by the cost calculations were obtained from the accounting records (Proto and Zimbalatti 2016). Labor cost was set at 11.55 €·SMH<sup>-1</sup> (both for the SH operator and the chainsaw operator) including the indirect salary costs. Diesel fuel consumption was calculated using diesel fuel consumption norms. A salvage value of 10 % of the purchase price was assumed and the Value Added Tax (VAT) was excluded.

Cost calculations were based on the assumption that companies worked for 150 working days in a year and the depreciation period is 10 years. For extraction

work, this amounts to 130–150 working days per year (20–21 working days per month) at an average of 6–7 scheduled working hours per day (assuming one to two hours spent on lunch, rest and other breaks). Thus yielded annual working hours are 910–1050 SMHs with a 70 % use coefficient (Spinelli and Magagnotti 2011, Spinelli et al. 2014, Proto et al. 2018).

## Data analysis

Regression analysis was performed on the experimental data of the SH in order to develop prediction equations for estimating time consumption and productivity. The variables used in the modeling approach included skidding distance  $L$ , bunching distance  $l$ , load volume per cycle  $V$ , slope gradient of the skidding road  $s$ , the number of trees in a load  $n_{tr}$ , and the number of processed assortments and logs  $n_{as}$ . The statistical analysis consisted of identification and exclusion of outliers, correlation analysis for independent variables with a correlation coefficient set at  $R \geq 0.75$  as an acceptable threshold to exclude the independent variables from regression analysis for reasons such as the inflation of determination coefficients. The descriptive statistics of the variables were computed and a stepwise backward regression procedure was used to model the variability of the cycle time and productivity as a function of independent variables.

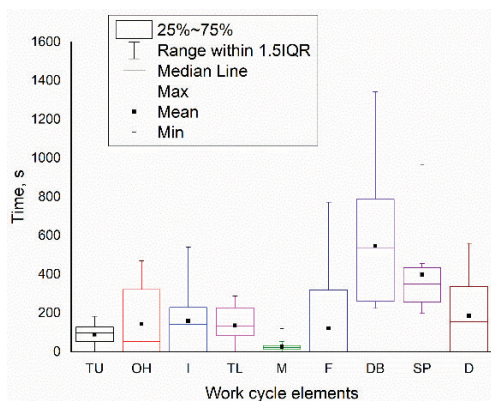
The confidence level used for regression analysis was 95 % ( $\alpha = 0.05$ ) and the assumed probability  $p < 0.05$ . Independent variables are significant at  $p < 0.05$ , i.e. strong presumption against neutral hypothesis. To process the experimental data Statistica 8 (StatSoft Inc., Tulsa, OK, USA) software was used.

## Results and Discussion

### Work cycle time

Tables 3 and figures 1 and 2 show the main descriptive statistics related to the time consumption and skidding and bunching distances during the field observations carried out on 31 work cycles (turns) of the SH.

Processing, including delimbing and bucking, accounted for the largest share (34 % and 31 %, by excluding and including delays, respectively), followed by the piling (25 % and 22 %, by excluding and including delays, respectively), load inhaul (10 % and 9 %, by excluding and including delays, respectively), outhaul and



**Fig. 1. Elemental time consumption.**

hook and loaded travel (8 % and 7 %, by excluding and including delays, respectively), felling (7 % and 6 %, by excluding

**Table 3. Descriptive statistics of the time consumption and operational distances.**

| Variables                             | Duration, s       |      |       | Distance, m       |     |     |
|---------------------------------------|-------------------|------|-------|-------------------|-----|-----|
|                                       | Mean value<br>±SD | min  | max   | Mean value<br>±SD | min | max |
| Travel Unloaded (TU)                  | 92 ±38            | 0    | 184   | 69 ±38            | 0   | 131 |
| Maneuvering (M)                       | 27 ±21            | 0    | 119   |                   |     |     |
| Outhaul and hook (OH)                 | 133 ±149          | 0    | 410   | 14 ±9             | 0   | 31  |
| Load inhaul (I)                       | 165 ±155          | 0    | 541   | 14 ±9             | 0   | 31  |
| Travel Loaded (TL)                    | 140 ±88           | 0    | 288   | 69 ±38            | 0   | 131 |
| Felling (F)                           | 114 ±224          | 0    | 773   |                   |     |     |
| Processing (P)                        | 557 ±305          | 224  | 1342  |                   |     |     |
| Sorting and Piling (SP)               | 404 ±198          | 198  | 967   |                   |     |     |
| Delays (D)                            | 192 ±184          | 0    | 560   |                   |     |     |
| Total cycle time                      | 1824 ±687         | 680  | 3572  |                   |     |     |
| Delay-free cycle time                 | 1632 ±701         | 680  | 3421  |                   |     |     |
| Number of trees per cycle             | 4.07 ±1.01        | 3    | 6     |                   |     |     |
| Number of assortments per cycle       | 35.67 ±10.06      | 24   | 66    |                   |     |     |
| Cycle load volume, m <sup>3</sup>     | 4.06 ±1.40        | 2.4  | 7.04  |                   |     |     |
| Productivity, m <sup>3</sup> per PMH* | 9.38 ±1.50        | 7.37 | 13.76 |                   |     |     |
| Productivity, m <sup>3</sup> per SMH* | 8.27 ±1.62        | 5.78 | 13.76 |                   |     |     |
| Number of cycles per SMH*             | 2.29 ±0.95        | 1.05 | 5.29  |                   |     |     |
| Mean speed, km·h <sup>-1</sup>        | 1.88 ±0.96        | 0    | 3.21  |                   |     |     |
| Speed loaded, km·h <sup>-1</sup>      | 1.59 ±0.88        | 0    | 2.98  |                   |     |     |
| Speed unloaded, km·h <sup>-1</sup>    | 2.35 ±1.16        | 0    | 3.97  |                   |     |     |

Note: \* SD – standard deviation, PMH – productive machine hour, SMH – scheduled machine hour.

and including delays, respectively), and unloaded travel (6 % and 5 %, by excluding and including delays, respectively); the smallest share was that of maneuvering (2 % and 1 %, by excluding and including delays, respectively).

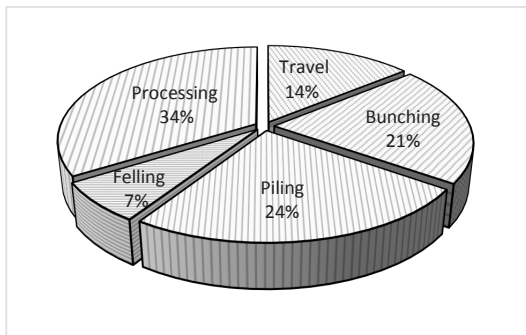
The breakdown of operations in delay-free cycle time by main groups (Fig. 2a) shows the predominance of processing, followed by piling at landing, bunching, travel, and felling trees by harvester head.

During the study 33.2 m<sup>3</sup> of the 124.3 m<sup>3</sup> by volume, and 33 of the 125 felled trees by number respectively were felled by harvester (Fig. 2b, c). The mean time for harvester felling is 114 s per tree (see Table 3).

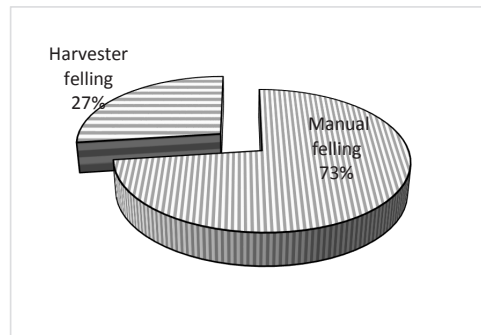
By time the SH works mostly as harvester and processor (65 %), whereas skidder operations occupy 35 % of its delay-free cycle time (Fig. 2d).

The SH productive time was 89 % from the scheduled time. The delays of 11 % are due to organizational reasons (waiting for the manual felling of trees in the cutting area, personal communications and breaks, phone calls) (7 %), and mechanical delays (4 %).

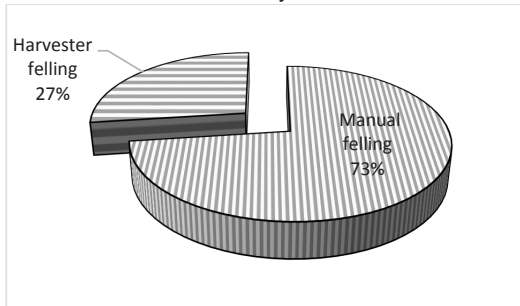
The regression analysis was performed on the time-study data (Table 3) in order to develop prediction equations for estimating the cycle time of the SH by excluding and including delays both shown in Table 4.



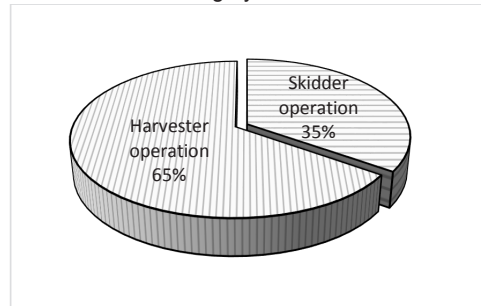
a) main groups of work elements in a delay-free work cycle



b) percentage of motor-manual vs. processing head felling by tree volume



c) percentage of motor-manual vs. harvester head felling by number of the tree felled



d) percentage of skidder vs. harvester operations by time

**Fig. 2. Summary statistics of HSM 805 ZL.**

**Table 4. Summary of the work cycle time models**

| Equations                                                                                |     | <i>F</i> | <i>R</i> <sup>2</sup> | <i>R</i> <sup>2</sup> <sub>adj</sub> | Std.<br>Error | <i>p</i> -Value |
|------------------------------------------------------------------------------------------|-----|----------|-----------------------|--------------------------------------|---------------|-----------------|
| $T_{\text{net}} = 0.056 \cdot L + 3.70 \cdot V + 5.94 \cdot n_{\text{tr}} - 13.73$ , min | (1) | 69.54    | 0.93                  | 0.92                                 | 3.30          | $p < 0.05$      |
| $T = 0.0764 \cdot L$ , min                                                               | (2) | 31.32    | 0.86                  | 0.83                                 | 4.70          | $p < 0.05$      |

The delay-free cycle time  $T_{\text{net}}$  regression equation containing the significant variables given in equation (1).

In equation (1) the minimum duration of delay-free cycle time  $T_{\text{net}}$  may be attained in the case of short skidding distances  $L$ , decreased load volumes  $V$  and number of trees  $n_{\text{tr}}$  in a cycle.

The regression equation (2) presents a cycle time including delays  $T$ .

Consequently, cycle time including delays of the SH depends only on skidding distance  $L$  and minimum duration may attain in case of minimal skidding distances. Probably, the difference between the two equations could be caused by the effect of included delays which follows different statistical laws (Spinelli and Visser 2008) and, therefore, could mask other important effects (Borz et al. 2014b).

### Travel speed and inhaul speed

The mean travel speed of the SH is  $1.88 \text{ km} \cdot \text{h}^{-1}$  (Table 3). The mean speeds with and without load are  $1.59 \text{ km} \cdot \text{h}^{-1}$  and  $2.35 \text{ km} \cdot \text{h}^{-1}$ , respectively. The difference is small –  $0.76 \text{ km} \cdot \text{h}^{-1}$ , due to the fact that loaded travel is downhill, and unloaded travel – uphill, as well as terrain and skid road conditions.

For comparison, Orlovský et al. (2020) found mean speeds with and without load at  $5.27 \text{ km} \cdot \text{h}^{-1}$  and  $4.67 \text{ km} \cdot \text{h}^{-1}$ , respectively, for HSM 805HD four-wheel cable skidder with knuckle-boom with round wood grapple, which were much higher than the studied SH. However, Spinelli and Magagnotti (2012) reported empty and

loaded travel speeds of  $96 \text{ kW}$  agricultural tractor at  $8.1 \text{ km} \cdot \text{h}^{-1}$  and  $7.3 \text{ km} \cdot \text{h}^{-1}$ , respectively, which were significantly higher than those determined in this study. The average speed of John Deere 548H was higher: for unloaded travel was  $8.58 \text{ km} \cdot \text{h}^{-1}$ , whereas for loaded travel, the average speed –  $6.02 \text{ km} \cdot \text{h}^{-1}$  (Proto et al. 2018). The higher speeds mentioned above may be the result of a better prepared skid road surface.

Theoretically, the movement time of a cable skidder could be reduced by increasing the travel speed loaded and unloaded. Unfortunately, the terrain conditions practically do not allow significant increase in travel speed.

The mean speed of a cycle load during winching was  $0.09 \text{ m} \cdot \text{s}^{-1}$  ( $0.324 \text{ km} \cdot \text{h}^{-1}$ ).

The mean duration of winching operations is long due to extraction of 1–2 trees at once with the winch line. Actually, this is because the worker does not use chokers to attach trees to a winch line.

### Productivity analysis

The mean productivity of the SH obtained at mean skidding distance of  $69 \text{ m}$ , mean bunching distance of  $14 \text{ m}$ , mean load volume of  $4.06 \text{ m}^3$  and  $4.07$  mean number of trees per cycle (turn) is  $9.38 \text{ m}^3 \cdot \text{PMH}^{-1}$  and  $8.27 \text{ m}^3 \cdot \text{SMH}^{-1}$ , respectively (Table 3). These productivity rates are not remarkable, comparing the results reported only for skidding operations, but they have also included harvester operations, i.e. these are the rates of timber piled at landing. For

comparison, Orlovský et al. (2020) found that HSM 805HD four-wheel cable skidder with knuckle-boom and round wood grapple (winching distance of 8.8 m, skidding distance of 87 m, and a load volume of 3.02 m<sup>3</sup>) the net and gross production rates were similar (4.69 m<sup>3</sup>·h<sup>-1</sup> and

3.33 m<sup>3</sup>·h<sup>-1</sup>, respectively).

Delay-free productivity of the SH was defined by the regression equation (3) shown in Table 5. From equation (3), to increase delay-free productivity of the SH, skidding distance  $L$  and number of skidded trees  $n_{tr}$  should be reduced.

**Table 5. Summary of the productivity models.**

| Equations                                                                             | $F$  | $R^2$ | $R^2_{adj}$ | Std. Error | $p$ -Value |
|---------------------------------------------------------------------------------------|------|-------|-------------|------------|------------|
| $P_{PMH} = 14.59 - 0.018 \cdot L - 2.16 n_{tr}$ , m <sup>3</sup> ·h <sup>-1</sup> (3) | 6.50 | 0.57  | 0.49        | 1.08       | $p < 0.05$ |
| $P_{SMH} = 12.21 - 0.029 \cdot L$ , m <sup>3</sup> ·h <sup>-1</sup> (4)               | 2.98 | 0.37  | 0.25        | 1.51       | $p < 0.05$ |

From equation (4) shown in Table 5, it can be seen that productivity including delays depends moderately on skidding distance  $L$ , which should be reduced for better output rates of the SH. This form of the equation may be the effect of including the delays which are known to follow different statistical laws (Spinelli and Visser 2008) and, therefore, to mask other important effects (Borz et al. 2014b).

### Cost analysis

Cost calculations were based on the assumption that companies worked all year round with the exception of adverse weather conditions (heavy rain, deep snow, thick fog), when cutting areas are not normally accessible by a wheel skidder.

The hourly fixed operating (variable)

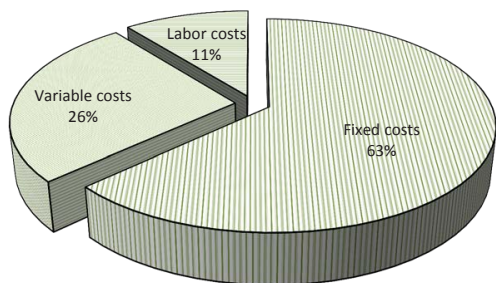
costs of the studied SH, and the labor cost of the operator and a chainsaw operator are shown in Table 6 and Figure 3. The gross costs for HSM 805 ZL team were calculated at 132.97 € per productive machine hour (PMH). Thus, when the SH was productive, the cost was at 14.24 €·m<sup>-3</sup>. The increase in productive time of the SH would lead to decrease in gross costs.

In the distribution of the net costs (Fig. 3), fixed costs predominate; they are more than two times higher than the variable costs and about six times higher than the labor costs. Generally, the fixed cost is around 2/3 of the net cost due to high rate of purchase cost of the SH.

The SH is about 2 times more productive than a logging team of 4–5 people with an adapted agricultural tractor for skidding.

**Table 6. Characteristics of costs of the studied skidder.**

| Costs                          | Costs per PMH, € | Costs, €·m <sup>-3</sup> |
|--------------------------------|------------------|--------------------------|
| Fixed costs                    | 70.36            | 7.50                     |
| Variable costs                 | 28.36            | 3.11                     |
| Labor costs                    | 11.94            | 1.27                     |
| Net costs (excluding profit)   | 110.93           | 11.88                    |
| Overheads and management costs | 9.95             | 1.06                     |
| Profit                         | 12.09            | 1.29                     |
| Gross costs (including profit) | 132.97           | 14.24                    |



**Fig. 3. Percentage distribution of net costs.**

When operating in deciduous stands, the harvester unit can be used for felling and cutting the self-pruned part of the tree trunk, especially in soft deciduous tree species. The knuckle-boom can be completely dismantled or the harvester head can be replaced with a log grapple for sorting and piling.

The disadvantage of the SH is that the harvester unit changes the load distribution between drive axles, increasing that of the rear axle. The increased load on the rear axle can result in deep rutting and high soil compaction.

The productivity of a SH could be increased by using chockers for collecting more trees within the same winching cycle. Currently, chockers are not used to attach trees to the winch line and trees are pulled out one by one to the SH, which results in longer bunching time.

Given the average load volume of  $4.06 \text{ m}^3$ , it can be concluded that the tractive (drawbar) force of the machine is not fully used.

The SH harvesting cost ( $14.24 \text{ €} \cdot \text{m}^{-3}$ ) fits well within the regional harvesting rates for coniferous stands, which range between  $13.50$  and  $15.00 \text{ €} \cdot \text{m}^{-3}$ .

Consequently, the combined skidder-harvester is highly productive and cost-effective, compared to the traditional motor-manual technique used today. The use of this type of machine is recommend-

ed because it allows to overcome the persistent labor shortage in the logging industry.

## Conclusions

The combined machine works as a harvester and it can fell the accessible trees located around the skid road and the corridor. The remaining marked trees in the midst of the stand are felled by chainsaw. Felled trees are pulled to the skid road using the two-drum winch with remote control, and then they are skidded to the landing, where they are delimbed, bucked and piled.

The SH is about two times more productive than a logging team of 4–5 people using chainsaws and an adapted agricultural tractor for felling, processing and skidding the trees.

The productivity of the SH could be increased by using chockers for collecting more trees within the same winching cycle. Currently, chockers are not used to attach trees to the winch line and trees are pulled one by one, which reflects in increased bunching time.

Harvesting cost per unit of the SH is within the range spanned by regional harvesting rates for coniferous stands.

The disadvantage of the SH is that the harvester unit changes the load distribution between the drive axles, increasing the load on the rear axle and causing deep rutting and heavy soil compaction.

## Acknowledgements

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## STATISTICAL JUSTIFICATION OF THE REQUIRED SAMPLES' SIZE OAK SAWN TIMBER BATCH

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### Abstract

The task of the study is to establish and justify the required amount of sawn timber, which must be measured to determine the conformity of the entire batch of sawn wood to the specified size on the basis of statistical processing of a sample of sawn timber from the total batch. It is established that the batch is homogeneous in width and thickness, and differs in length of a sawn timber. The values of variation coefficients for length of a sawn timber are much lower than similar values for thickness and width. Given the nature of the grouping of sawn timber particles around the central stage in terms of thickness, width and length, it can be argued that the samples are similar. Student's *t*-test was used at the *p*-level to check the difference between the mean values of individual samples. Measurement error (ME) for almost all indicators of the studied sawn timber is in the range of 0.1–5.0 %, which indicates that the experiment was performed with sufficient accuracy. In fact, 144 units of lumber were selected from 5 packages, which is more than 125 of the minimum required to establish the batch conformity of size and quality characteristics. Using the values of SE, ME and SD, calculated for individual samples, it was found that to correctly determine the deviations, including measurement accuracy and appropriate moisture content errors, it is sufficient to use from each individual sample no more 24 pieces of the appropriate sawn timber types. Using the recommendations for checking the conformity of sample to acceptable quality level for the total batch of a sawn timber, which was 2207 pcs in 5 packages, was confirmed the sufficiency of usage of the sample of 125 pieces from 5 packages.

**Key words:** oak sawn timber, regulatory documents, statistical indicators, wood moisture content.

### Introduction

According to the implementation of the Program of Activities of the Cabinet of Ministers of Ukraine, approved by Resolution

No. 695/09.12.2014, the State Enterprise 'Ukrainian Research and Training Center of Standardization, Certification and Quality' (State Enterprise 'UkrNDNC') have cancelled, with certain dates of cancel-

lation (from 2016, 2017, 2018 and 2019) all the valid interstate standards (GOST) in Ukraine, which were developed up to 1992 – order number 184/14.12.2015. This is due to the fact that in the national legislation of Ukraine as a member state of the World Trade Organization (WTO) were implemented the provisions of WTO Agreement on technical barriers to trade, in particular the Code of devout practice on the development, adoption and appliance of standards, and have been implemented international and European standards of standardization (Welling 2010). First of all, this relates to the principle of the voluntary application of national standards, except of cases where the obligatory application of them is established by regulatory acts. National standards are used directly or by reference to them in other documents.

Almost all regulatory documents on determining the dimensional and qualitative characteristics of sawn wood, which in practice are widely used in the forestry complex enterprises got under the action of the State Enterprise 'UkrNDNC' order No. 184. About 14 interstate standards only in the area of measurement, classification, sorting, acceptance and storage of sawn wood were cancelled from January 1, 2019. Therefore, it is expedient to use international experience during the selection process of sampling of sawn timber batch to assess compliance with the dimensions, moisture and quality of the researched sawn timber.

Evaluation of sawn timber batches, including statistical methods, is used mainly during wood processing: to the size control of sawn timber, their quality and size determining (Cochran 1963; Brown 1979, 1982, 1986, 2000; Buchanan 2000) or control of size changing in the course of drying (Pinchevska et al. 2016), or drying quality (Guzenda et al. 2002).

In addition, in determining the quality or quantitative parameters are mainly used homogeneous sawn timber batches (Buchanan 2000, Pinchevska et al. 2016). At the same time, when exporting sawn timber, they are often of different sizes in one batch. In this case, a justification for the choice of the minimum required number of sample measurements is required. Such studies, especially if they relate to export-import operations with sawn timber with reference to the updated standards, are currently non-existent. Therefore, the relevance of our research is caused both by theoretical foundations of the use of statistical evaluation of homogeneous samples, and application of the obtained justification.

### **Aim of the study**

The wood is exploited to the appropriate moisture content, which is achieved by drying. For the possibility of unification and technical acceptance of the batch, the dimensions of sawn timber are indicated by moisture content of 20 %. Under influence of external factors moisture content may change. On this cause, appropriate corrections are used. Corrections are defined, calculated and accepted for different moisture content and for different types of wood by normative tables. Often, there are conflicts regarding the acceptance of sawn timber batch associated with the moisture content changes and, consequently, with change of its size. In this case, there is often an increase or, conversely, a decrease in the nominal dimensions of wood that corresponds to the volume of sawn timber.

Different sizes of lumber in individual packs and in the general batch may cause difficulties in establishing the selection of

the required minimum number of samples for analysis. To do this, it is necessary to statistically confirm the possibility of selecting a certain amount of lumber from appropriate packages, in which collected materials of the same size, and in general for the whole party. An additional difficulty in carrying out this analysis is the change in moisture content of the lumber. During their manufacture, according to technological operations, the moisture content may have the same values, but during transportation and storage they may change. To be able to establish compliance with the lumber to the specified dimensions, it is also necessary to establish permissible changes in these dimensions to accepted limits with changes in humidity by the climatic characteristics of the region.

The research objective is to establish and justify the required amount of sawn timber that needs to be measured to determine the accordance of the whole batch of sawn wood to the indicated sizes based on the statistical processing of a sampling from the total. For this purpose in the case of export operations, valid international and Ukrainian normative documents must be used to appropriateness on the size and volume of sawn timber.

To solve the study purpose it is necessary to solve the following tasks:

- to establish the criterion of parameters compliance of lumber batch with the accompanying technical documentation;
- to establish grouping features of the shares of number lumber around the central stage of the relevant indicator and the decisiveness of this indicator to establish the similarity of lumber of different packages to the whole party;
- to investigate the influence of statistical indicators on the homogeneity characteristics of the lumber in different packages to the total volume of the party;

- to establish the minimum number of selected samples of lumber from packages within the party based on the analysis of statistical indicators of their sizes and humidity.

## Materials and Methods

Quality control and sawn timber batches size involves determining indicators of the units selected in the sample. The selection of pieces in the package for control was carried out randomly (for example, throwing cubes e.g. by throwing a dice), while from the outer layers of lumber were not selected. Random selection means that at each step of the sample, the elements that remain in the party are equally likely to be selected (Montgomery and Runger 2003).

The research used the results of processing the actual batch of sawn timber. The declared dimensions and technical parameters are: oak sawn timber, moisture content 8–10 %, grade Q-F 3-4 (according EN 975-1:2009), size: 27×190×2030 mm – 943 pcs (7 packages) (code 06-2030), 27×190×2230 mm – 615 pcs (5 packages) (code 08-2030; 09-2230), 27×190×2780 mm – 309 pcs (2 packages) (code 13-2780), 27×190×3000 mm – 340 pcs (3 packages) (code 17-3000); in total 2207 pcs in 17 packages.

In grade the first character represents the initial of the Latin name 'Q' for *Quercus* = oak. The second character indicates the type of product. 'F' means strips and square-edged timber. The quality of every sawn piece is assessed by the appearance of its faces and, if applicable, its edges, while taking account of the presence, extent, position and distribution of any features, specific sawing and deteriorations resulting from it. In case of failure to

meet any one of the specified conditions, the piece in question will be downgraded. Size defects due to sawing (irregular thicknesses and widths) are disregarded when appearance grading pieces (standard EN 1313-2). Such products may not be subjected to width and/or length reduction. The third character refers to the quality grade. A means exceptional quality, 1-2-3-4: in decreasing order of quality.

For all lumber samples were taken measurements of the actual dimensions of thickness and width, using an electronic caliper with accuracy of 0.01 mm, length – a metal measuring tape with accuracy of 0.01 m according to EN 1309-1: 2001. The smallest value of the three thickness and width values was recorded. These values were measured in the direction perpendicular where there is no wane. Of these, two dimensions are as close as possible to the ends, but not closer than 150 mm from the end, the third – at a random point between them. The length of the most possible rectangular parallelepiped inscribed in the lumber was taken as lumber length.

Actual moisture content of lumber was determined using an electric moisture meter Logica LG-43 according to DSTU EN 13183-2:2004 (2004). To reduce the effect of the way the meter is used, standard SS-EN 13183-2 describes how the insulated hammer electrodes should be inserted into the piece of wood. The average moisture content of wood is measured as follows: measure 300 mm from the end. Insert the insulated hammer electrodes into the face of the wood, in the direction of the grain, and along an imaginary line running 0.3 times the width of the wood from the edge. The measurement depth should be 0.3 times the thickness of wood.

Measurements of the visual charac-

teristics parameters of wood were carried out according to DSTU EN 1310:2005 (2005). Biological damage (by insects, fungi, etc.) – according to DSTU EN 1311-2001 (2001). The value of lumber drying for nominal dimensions was set by taking into account its moisture content according to DSTU 4920:2008 (2008). The permissible deviations from the nominal dimensions according to DSTU EN 1313-2:2018 (2018).

To test the difference between the mean values of individual samples, at  $p$ -level Student's  $t$ -test was used. To do this, we compared the arithmetic mean  $x_1$  and  $x_2$  of samples taken from different types of samples. In the case when  $n_1 \neq n_2$ , the standard error ( $s_d$ ) between standard deviation (SD) is determined by the formula (1) (Lakin 1980).

$$s_d = \sqrt{\frac{s_1^2 + s_2^2}{n_1 + n_2 - 2} \cdot \left( \frac{n_1 + n_2}{n_1 n_2} \right)} \quad (1)$$

Having accepting that  $s_1^2 = \sum (x_i - \bar{x}_1)^2$  and  $s_2^2 = \sum (x_i - \bar{x}_2)^2$ . The value of Student's  $t$ -test ( $t_f$ ) for such case is determined by the formula (2).

$$t_f = \frac{\bar{x}_1 - \bar{x}_2}{s_d} \quad (2)$$

Zero hypothesis is refuted if  $t_f \geq t_{st}$ , where:  $t_{st}$  – tabular value of Student's  $t$ -test (Lakin 1980).

We calculated the amount of required number of samples by the formula (3) (Lakin 1980).

$$n = \frac{t^2 s_x^2}{\Delta^2}, \quad (3)$$

where:  $n$  – number of samples;  $\Delta = t s_{\bar{x}}$ ;  $s_x$  – standard deviation (SD);  $t$  – normalized deviation of Student's  $t$ -test, with which is probability volume ( $p$ ).



## Results and Discussion

The results of statistical processing of experimental data of sawn timber of investigated packets are given in tables 1–5.

For the ability to set the average index of quality, the following encoding of this indicator is used in numerical values: Q-F-1a – 1; Q-F-1b – 2; Q-F 2 – 3; Q-F 3 – 4, Q-F 4 – 5.

**Table 1. Statistical characteristics of testing material for sampling from the package 06-2030.**

| Index                         | Thickness, mm | Width, mm | Length, mm | Quality | Moisture content, % |
|-------------------------------|---------------|-----------|------------|---------|---------------------|
| Arithmetic mean (AM)          | 29.6          | 193.1     | 2030.6     | 3.0     | 12.21               |
| Standard deviation (SD)       | 1.33          | 3.77      | 1.01       | 0.65    | 0.84                |
| Coefficient of variation (CV) | 4.51          | 1.95      | 0.05       | 21.92   | 6.90                |
| Min                           | 26.9          | 187.0     | 2030.0     | 1.0     | 11.1                |
| Max                           | 32.3          | 203.0     | 2034.0     | 4.0     | 14.9                |
| Skewness (Sk)                 | -0.07         | 1.13      | 1.82       | -0.88   | 1.48                |
| Kurtosis (Ku)                 | -0.55         | 1.20      | 3.53       | 2.63    | 3.02                |
| Standard error (SE)           | 0.26          | 0.72      | 0.19       | 0.12    | 0.16                |
| Measurement error (ME)        | 0.87          | 0.38      | 0.01       | 4.22    | 1.33                |
| Total number (N)              | 27            | 27        | 27         | 27      | 27                  |

**Table 2. Statistical characteristics of testing material for sampling from the package 08-2230.**

| Index                         | Thickness, mm | Width, mm | Length, mm | Quality | Moisture content, % |
|-------------------------------|---------------|-----------|------------|---------|---------------------|
| Arithmetic mean (AM)          | 29.05         | 194.13    | 2230.80    | 2.90    | 11.97               |
| Standard deviation (SD)       | 1.36          | 3.13      | 1.37       | 0.61    | 0.52                |
| Coefficient of variation (CV) | 4.67          | 1.61      | 0.06       | 20.95   | 4.33                |
| Min                           | 26.1          | 190.0     | 2230.0     | 1.0     | 11.0                |
| Max                           | 33.1          | 205.0     | 2235.0     | 4.0     | 12.8                |
| Skewness (Sk)                 | 0.30          | 1.27      | 1.92       | -0.95   | -0.07               |
| Kurtosis (Ku)                 | 1.81          | 3.64      | 3.02       | 2.91    | -1.11               |
| Standard error (SE)           | 0.25          | 0.57      | 0.25       | 0.11    | 0.09                |
| Measurement error (ME)        | 0.85          | 0.29      | 0.01       | 3.82    | 0.79                |
| Total number (N)              | 30            | 30        | 30         | 30      | 30                  |

**Table 3. Statistical characteristics of testing material for sampling from the package 09-2230.**

| Index                         | Thickness, mm | Width, mm | Length, mm | Quality | Moisture content, % |
|-------------------------------|---------------|-----------|------------|---------|---------------------|
| Arithmetic mean (AM)          | 29.17         | 193.26    | 2230.93    | 2.85    | 11.94               |
| Standard deviation (SD)       | 1.05          | 5.36      | 1.52       | 0.60    | 0.45                |
| Coefficient of variation (CV) | 3.60          | 2.77      | 0.07       | 21.09   | 3.75                |
| Min                           | 26.6          | 186.0     | 2230.0     | 2.0     | 11.2                |
| Max                           | 31.3          | 205.0     | 2235.0     | 4.0     | 12.8                |

| Index                  | Thickness,<br>mm | Width,<br>mm | Length,<br>mm | Quality | Moisture<br>content, % |
|------------------------|------------------|--------------|---------------|---------|------------------------|
| Skewness (Sk)          | -0.25            | 0.63         | 1.70          | 0.05    | 0.24                   |
| Kurtosis (Ku)          | 0.46             | -0.23        | 1.71          | -0.08   | -0.71                  |
| Standard error (SE)    | 0.20             | 1.03         | 0.29          | 0.12    | 0.09                   |
| Measurement error (ME) | 0.69             | 0.53         | 0.01          | 4.06    | 0.72                   |
| Total number (N)       | 27               | 27           | 27            | 27      | 27                     |

**Table 4. Statistical characteristics of testing material for sampling from the package 13-2780.**

| Index                         | Thickness,<br>mm | Width,<br>mm | Length,<br>mm | Quality | Moisture<br>content, % |
|-------------------------------|------------------|--------------|---------------|---------|------------------------|
| Arithmetic mean (AM)          | 28.59            | 191.77       | 2780.67       | 2.80    | 12.19                  |
| Standard deviation (SD)       | 1.06             | 3.71         | 0.96          | 0.48    | 0.54                   |
| Coefficient of variation (CV) | 3.70             | 1.94         | 0.03          | 17.29   | 4.42                   |
| Min                           | 26.1             | 185.0        | 2780.0        | 2.0     | 11.3                   |
| Max                           | 30.1             | 200.0        | 2784.0        | 4.0     | 13.5                   |
| Skewness (Sk)                 | -0.62            | 0.53         | 1.75          | -0.55   | 0.44                   |
| Kurtosis (Ku)                 | 0.16             | 0.31         | 3.66          | 0.50    | -0.37                  |
| Standard error (SE)           | 0.19             | 0.68         | 0.18          | 0.09    | 0.10                   |
| Measurement error (ME)        | 0.67             | 0.35         | 0.01          | 3.16    | 0.81                   |
| Total number (N)              | 30               | 30           | 30            | 30      | 30                     |

**Table 5. Statistical characteristics of testing material for sampling from the package 17-3000.**

| Index                         | Thickness,<br>mm | Width,<br>mm | Length,<br>mm | Quality | Moisture<br>content, % |
|-------------------------------|------------------|--------------|---------------|---------|------------------------|
| Arithmetic mean (AM)          | 28.23            | 192.47       | 3000.53       | 3.10    | 12.34                  |
| Standard deviation (SD)       | 2.33             | 2.76         | 0.82          | 0.31    | 0.80                   |
| Coefficient of variation (CV) | 8.25             | 1.44         | 0.03          | 9.84    | 6.50                   |
| Min                           | 18.2             | 187.0        | 3000.0        | 3.0     | 11.2                   |
| Max                           | 31.7             | 200.0        | 3003.0        | 4.0     | 14.7                   |
| Skewness (Sk)                 | -2.77            | 0.46         | 1.50          | 2.81    | 1.19                   |
| Kurtosis (Ku)                 | 11.80            | 0.64         | 1.63          | 6.31    | 1.60                   |
| Standard error (SE)           | 0.42             | 0.50         | 0.15          | 0.06    | 0.15                   |
| Measurement error (ME)        | 1.51             | 0.26         | 0.00          | 1.80    | 1.19                   |
| Total number (N)              | 30               | 30           | 30            | 30      | 30                     |

It was found that the average value varies from 28.2 to 29.6 mm by analyzing statistical indicators of sawn timber thickness. The highest value was determined for the package 06-2030, and the lowest – for 17-3000. The coefficient of variation of this indicator is in the range from 3.60

to 8.3 %. The lowest value was found for the package 09-2230, and the highest – for 17-3000.

The value of width of the sawn timber varies from 191.8 to 193.3 mm. The lowest average was found for the package 17-3000, and the highest – for 09-2230.

The coefficient of variation for width is lower, in comparison to the same indicator for thickness, which indicates lower variability of width. The lowest value of this indicator was found for package 17-3000 and is 1.44 %, and the highest – for 09-2230 and is 2.77 %.

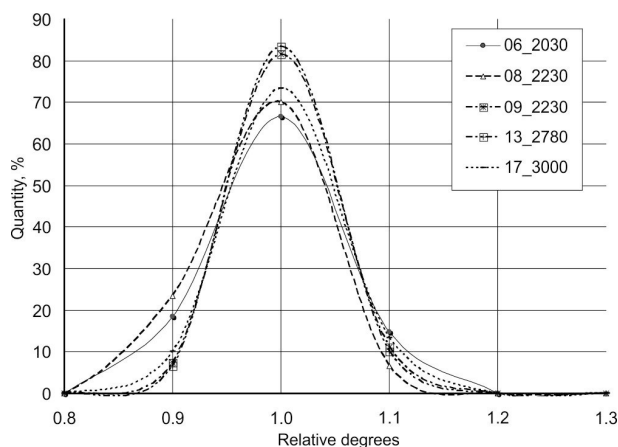
The value of the length of sawn wood in the packages of this batch is different: in 06-2030 the average is 2030.6 mm, for 08-2230 – 2230.8 mm, for 09-2230 – 2230.9 mm, for 13-2780 – 2780.7 mm, and for 17-3000 – 3000.5 mm. It is thus established that the batch is homogeneous in width and thickness, but differs by length of the sawn timber. The values of variation coefficients for length are significantly lower than the similar values of the indicator for thickness and width of the sawn timber. The lowest value of the coefficient of variation is 0.03 % for the package 17-3000, and the highest – 0.07 % for 09-2230. The value of moisture content of sawn timber is not significantly different. The lowest value was found in the package 09-2230 and is 11.9 %, and the highest – in 17-3000 and is 12.3 %. The lowest value of the variation coefficient was found for package 09-2230 and is 3.75 %, and the highest is 6.90 % for 06-2030.

The quality assessment is carried out by replacement of indicator value on its digital counterpart and graded in the reverse order – the best quality class is assigned 1, and the worst one is 5. Thus, with a decrease in the average value, the average quality class for sawn timber in the corresponding package increases. The highest value of quality is 2.80 for the package 13-2780, and the lowest is 3.10 for 17-3000. The value of the coefficient

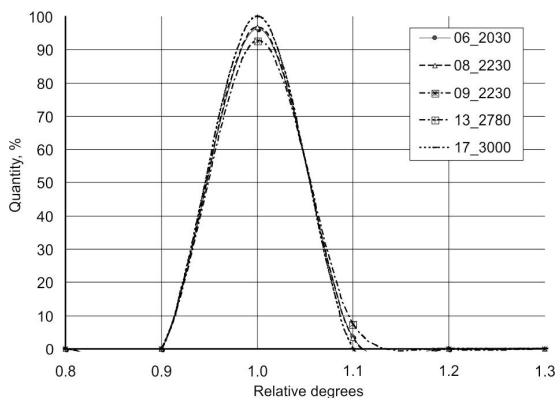
of variation is the lowest for 17-3000 and is 9.84 %, and the highest for 06-2030 and is 21.92 %. The variability of this indicator is the highest among all the indicators of researched sawn timber.

For the graphical representation of the research material, relative degrees of relevant indicators of the sawn timber were used: that is, separately, for the samples taken from different packs, the share grouping (in %), which were obtained by dividing the actual values by its average, was made according the relative degrees of the corresponding index. The results are shown in figures 1–4. Graphical representation of distributions by relative degrees of length is not given, since for all packages there is one hundred percent grouping at relative level of 1.0.

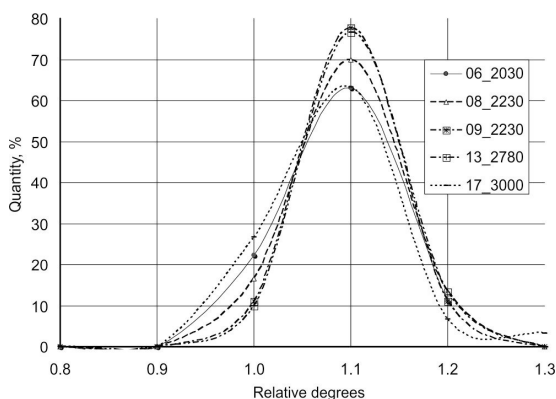
Given the nature of the share grouping of sawn timber pieces around the central degree by thickness, width and length, it can be argued that the samples are similar to each other. Generally, similarity is also observed in the distribution for the average value of wood moisture content – the difference is only in the percentage grouped around the central degree. The



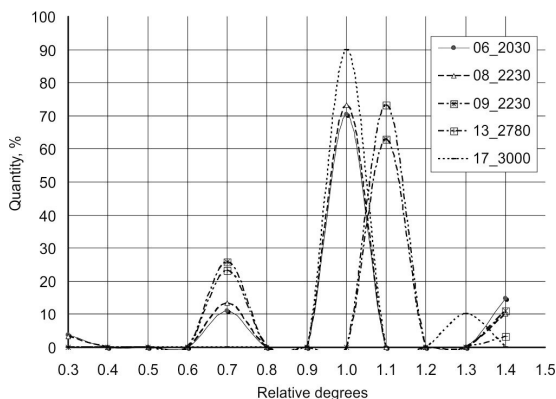
**Fig. 1. Share distribution of sawn timber pieces by relative degrees of thickness.**



**Fig. 2. Share distribution of sawn timber pieces by relative degrees of width.**



**Fig. 3. Share distribution of sawn timber pieces by relative degrees of moisture content.**



**Fig. 4. Share distribution of sawn timber pieces by relative degrees of quality.**

difference in distributions by relative degrees of quality classes is explained by different values of the minimum and maximum values of this indicator in different samples, selected from packages: 06-2030 and 17-3000 had an average quality lower and it was 3.0 and 3.10 accordingly, and 08-2230, 09-2230 and 13-2780 had an average value of less than 3.0, 2.90, 2.85 and 2.80, accordingly. Therefore, for 06-2030 and 17-3000, the formation of peak distributions is observed at a relative degree of 1.1, and for the rest of the samples – by 1.0.

The results of measurement error calculating between comparisons of the arithmetic mean of experimental data, determined by formulas 1 and 2, are shown in Table. 6.

Since the obtained indexes of the measurement error of arithmetic mean values of experimental data between the corresponding samples for all, without exception, the sample pairs are less than the table data's, one can assert the homogeneity of the selected research material.

Measurement error (ME) is practically for all indicators of researched sawn timber in the range of 0.1–5.0 %, which suggests that the experiment has been conducted with sufficient accuracy. It should be noted that the measurement error of dimensional indicators is actually the lowest, comparing them with the quality and moisture content. The highest measurement error values were found to evaluate the quality of timber, which is quite logical, given the high value of the coefficient of variation. At the same time, the value of the measurement error indicator for quality is quite high and does not exceed 5 %.

**Table 6. Calculation of ME comparing AM of experimental data between the corresponding samples.**

| Index           | Thickness, mm | Width, mm   | Length, mm  | Quality     | Moisture content, % |
|-----------------|---------------|-------------|-------------|-------------|---------------------|
| $s_{06-2030}^2$ | 46.2          | 368.7       | 26.3        | 11.0        | 18.4                |
| $s_{08-2230}^2$ | 53.5          | 283.5       | 54.8        | 10.7        | 7.8                 |
| $k_1$           | 57            | 57          | 57          | 57          | 57                  |
| $t_1$ value     | <b>0.36</b>   | <b>0.91</b> | <b>0.32</b> | <b>0.17</b> | <b>0.18</b>         |
| $s_{06-2030}^2$ | 46.2          | 368.7       | 26.3        | 11.0        | 18.4                |
| $s_{09-2230}^2$ | 28.7          | 747.2       | 59.9        | 9.4         | 5.2                 |
| $k_2$           | 54            | 54          | 54          | 54          | 54                  |
| $t_2$ value     | <b>0.33</b>   | <b>1.26</b> | <b>0.35</b> | <b>0.17</b> | <b>0.18</b>         |
| $s_{06-2030}^2$ | 46.2          | 368.7       | 26.3        | 11.0        | 18.4                |
| $s_{13-2780}^2$ | 32.4          | 399.4       | 26.7        | 6.8         | 8.4                 |
| $k_3$           | 57            | 57          | 57          | 57          | 57                  |
| $t_3$ value     | <b>0.32</b>   | <b>0.99</b> | <b>0.26</b> | <b>0.15</b> | <b>0.19</b>         |
| $s_{06-2030}^2$ | 46.2          | 368.7       | 26.3        | 11.0        | 18.4                |
| $s_{17-3000}^2$ | 157.1         | 221.5       | 19.5        | 2.7         | 18.6                |
| $k_4$           | 57            | 57          | 57          | 57          | 57                  |
| $t_4$ value     | <b>0.51</b>   | <b>0.87</b> | <b>0.24</b> | <b>0.13</b> | <b>0.22</b>         |
| $s_{08-2230}^2$ | 53.5          | 283.5       | 54.8        | 10.7        | 7.8                 |
| $s_{09-2230}^2$ | 28.7          | 747.2       | 59.9        | 9.4         | 5.2                 |
| $k_5$           | 57            | 57          | 57          | 57          | 57                  |
| $t_5$ value     | <b>0.32</b>   | <b>1.15</b> | <b>0.38</b> | <b>0.16</b> | <b>0.13</b>         |
| $s_{08-2230}^2$ | 53.5          | 283.5       | 54.8        | 10.7        | 7.8                 |
| $s_{13-2780}^2$ | 32.4          | 399.4       | 26.7        | 6.8         | 8.4                 |
| $k_6$           | 60            | 60          | 60          | 60          | 60                  |
| $t_6$ value     | <b>0.31</b>   | <b>0.89</b> | <b>0.31</b> | <b>0.14</b> | <b>0.14</b>         |
| $s_{08-2230}^2$ | 53.5          | 283.5       | 54.8        | 10.7        | 7.8                 |
| $s_{17-3000}^2$ | 157.1         | 221.5       | 19.5        | 2.7         | 18.6                |
| $k_7$           | 60            | 60          | 60          | 60          | 60                  |
| $t_7$ value     | <b>0.49</b>   | <b>0.76</b> | <b>0.29</b> | <b>0.12</b> | <b>0.17</b>         |

| Index            | Thickness, mm | Width, mm   | Length, mm  | Quality     | Moisture content, % |
|------------------|---------------|-------------|-------------|-------------|---------------------|
| $s_{09-2230}^2$  | 28.7          | 747.2       | 59.9        | 9.4         | 5.2                 |
| $s_{13-2780}^2$  | 32.4          | 399.4       | 26.7        | 6.8         | 8.4                 |
| $k_8$            | 57            | 57          | 57          | 57          | 57                  |
| $t_8$ value      | <b>0.28</b>   | <b>1.21</b> | <b>0.33</b> | <b>0.14</b> | <b>0.13</b>         |
| $s_{09-2230}^2$  | 28.7          | 747.2       | 59.9        | 9.4         | 5.2                 |
| $s_{17-3000}^2$  | 157.1         | 221.5       | 19.5        | 2.7         | 18.6                |
| $k_9$            | 57            | 57          | 57          | 57          | 57                  |
| $t_9$ value      | <b>0.49</b>   | <b>1.11</b> | <b>0.32</b> | <b>0.12</b> | <b>0.17</b>         |
| $s_{13-2780}^2$  | 32.4          | 399.4       | 26.7        | 6.8         | 8.4                 |
| $s_{17-3000}^2$  | 157.1         | 221.5       | 19.5        | 2.7         | 18.6                |
| $k_{10}$         | 60            | 60          | 60          | 60          | 60                  |
| $t_{10}$ value   | <b>0.47</b>   | <b>0.84</b> | <b>0.23</b> | <b>0.10</b> | <b>0.18</b>         |
| $t_{st}(P 0.05)$ | <b>1.96</b>   | <b>1.96</b> | <b>1.96</b> | <b>1.96</b> | <b>1.96</b>         |

Note: Comparison code between samples: 1 – 06-2030 i 08-2230; 2 – 06-2030 i 09-2230; 3 – 06-2030 i 13-2780; 4 – 06-2030 i 17-3000; 5 – 08-2230 i 09-2230; 6 – 08-2230 i 13-2780; 7 – 08-2230 i 17-3000; 8 – 09-2230 i 13-2780; 9 – 09-2230 i 17-3000; 10 – 13-2780 i 17-3000;  $k_n$  – total number of options for pairs of samples.

In fact, 144 pieces of sawn timber from 5 packages were selected, which is more than the minimum 125 required to determine batch consistency with dimensional and qualitative characteristics (Welling 2010).

The amount of required number of samples was calculated by the formula (3). Using the values of SE, ME, and SD, calculated for individual samples, it was found that to correctly determine the deviations, including measurement accuracy and errors at the appropriate humidity, it is sufficient to use no more than 24 pcs. from each sample of the appropriate type of lumber. To receive an odd number from each package from the randomly selected package it is expedient to use for the general account one additional piece of a sawn timber (Lakin 1980).

So, it is proved that in general for the

selected batch of sawn timber it is enough to use a sample of 125 samples – 25 samples from 5 packages.

The next stage of the study was to determine the size indicators and their changes by fact moisture content. These data are compared with the declared moisture content.

According to DSTU EN 1313-2:2018 (2018) the permitted deviations at moisture content of 20 %, are as follows:

- thickness ( $t_{nom}$ ) at  $t \leq 32$  mm: – 1 mm, + 3 mm; at  $t_{nom} > 32$  mm: – 2 mm, + 4 mm;
- width ( $b$ ) at  $b \leq 100$  mm: – 2 mm, + 6 mm; at  $b 100 \text{ mm} < b < 200$  mm: – 3 mm, + 9 mm;  $b > 200$  mm: – 4 mm, + 12 mm;
- length ( $l$ ) – 0, + 3 % of nominal length, but not more than 90 mm.

DSTU EN 1313-2:2018 (2018) also contains a list of the most common nomi-



nal sizes of hardwood sawn timber (20 % moisture content): 20, 27, 32, 40, 50, 60, 65, 70, 80, 100 mm by thickness; by width – from 50 to 90 mm in steps of 10 mm and from 100 mm with a step of 20 mm.

The actual moisture content of wood was within 11–16 %. Permitted thickness and width of sawn timber for this moisture content are given in Table 7.

**Table 7. Permitted thickness and width of sawn timber by fact moisture content (DSTU EN 1313-2:2018 2018).**

| Nominal<br>size of<br>thickness<br>and width,<br>mm | Moisture content of sawn<br>timber, % |       |       |       |
|-----------------------------------------------------|---------------------------------------|-------|-------|-------|
|                                                     | 11–13                                 |       | 14–16 |       |
|                                                     | Permitted thickness and<br>width, mm  |       |       |       |
|                                                     | min                                   | max   | min   | max   |
| 27                                                  | 25.4                                  | 29.4  | 25.6  | 29.6  |
| 32                                                  | 30.3                                  | 34.3  | 30.4  | 34.4  |
| 190                                                 | 184.3                                 | 192.3 | 185.7 | 193.7 |
| 200                                                 | 193.1                                 | 205.1 | 194.5 | 206.5 |

Definition of the volume of sawn timber was carried out at nominal dimensions in accordance to EN 1312:1997 (1997) – formula (4).

$$V = t_{nom} \cdot b_{nom} \cdot l_{nom}, \quad (4)$$

where:  $V$  – volume of sawn timber,  $m^3$ ;  $t_{nom}$  – nominal thickness of sawn timber, mm;  $b_{nom}$  – nominal width of edged timber, mm;  $l_{nom}$  – nominal length of sawn timber, m.

Due to the proof of a sufficient number of samples (125), it was from this number that samples were taken at random by analysis.

The results of the control show that the number of sawn timber, which by size does not correspond to the declared in the shipping documents, is 57 pcs of the 125 selected in the sample. Since it is larger than the acceptance number 21, such a batch is considered to be ineligible for technical characteristics stated in the shipping documents (ENV 12169:2008

2008). Exceeding the dimensional characteristics is +4.0–8.7 mm in thickness and +9.0–18.7 mm in width at 58.4 % of the sawn timber from the total in the batch. Of these, 44.8 % of boards have nominal dimensions of 32 mm in thickness and 200 mm in width. The length does not exceed the permitted deviation of +0–90 mm. The results of selective control expressed in volumetric units (4.22 % over by volume) were distributed to the entire lot of sawn timber. Thus, the fact volume of the lot of sawn timber will amount to 28.255  $m^3$ , which is 1.759  $m^3$  (4.22 %) higher than the volume declared in the shipping documents. According to the qualitative characteristics, the results of the control show that the higher grade Q-F 3-4 according to EN 975-1:2009 (2009) – there are 7 pcs sawn timber from 125 pcs, which is below acceptance number 21. In this case, the batch of sawn timber corresponds to the information in shipping documents by quality.

## Conclusions

It was confirmed the sufficiency of usage of the sample of 125 pieces from 5 packages by using the recommendations for checking the conformity of the sample to the acceptable quality level for the total batch of a sawn timber, which was 2207 pcs in 5 packages.

The criterion for determining the batch conformity of accompanying technical documentation is the corresponding value of acceptance number, which depends on the acceptable quality level (AQL) for the appropriate batch size: this is usually defined as the worst quality level, the percentage of non-compliant parts still acceptable. In this study, we considered a partial case for a total batch of 1201 to

3200 pcs (total number of pieces in the batch).

According to the results, it is established that the features of grouping the number of sawn timber particles around the central stage by degrees of thickness, width and length are crucial for establishing similarity. The distribution of particles by degree of wood moisture content also confirms the established patterns and differs only in the values of the particles of sawn timber grouped around the central stage of the index.

For the characteristics of homogeneity of the material, it is advisable to use indexes of the significance of difference in the comparison of average values of experimental data between the appropriate samples. In the case of our study, ME for almost all indexes of the studied sawn timber is in the range of 0.1–5.0 %, which indicates that the number of samples taken for measurement is sufficient, and the experiment was conducted with sufficient accuracy. It was also found that MEs of dimensional indicators (width, length and thickness of the wood blanks) are actually the lowest, compared with the quality and moisture content of sawn timber. The highest values of measurement error were found to assess its quality, which is quite logical, given the high value of variation coefficient. However, the value of measurement error for quality is quite high and does not exceed 5 %.

In fact, by analyzing the distributions by relative degrees and statistical indicators of the experimental material by dimensional indexes, less sawn timber could be used in the sample. But due to the fact that the moisture content is uneven even within one package, and the quality is more variable than the rest indexes, we will stop on the confirmed choice of the set quantity of pieces for measurement.

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## FLORISTIC ANALYSIS OF PLANT COMMUNITIES WITH THE PARTICIPATION OF A NARROW TIEN SHAN EN- DEMIC, *TARAXACUM KOK-SAGHYZ* L.E.RODIN

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### Abstract

*Taraxacum kok-saghyz* L.E.Rodin is a promising natural rubber source and an alternative to *Hevea brasiliensis* (Willd. ex A. Juss.) Müll.Arg. At the same time, *T. kok-saghyz* is a narrow endemic and a rare species with decreasing population size due to degradation of its natural habitat. Therefore, it is listed in the Red Data Book of Kazakhstan. Despite a large number of studies addressed various characteristics of this plant, the data on the floristic composition of plant communities it is part of are limited. The aim of our studies was to assess the floristic composition of plant communities with the participation of *T. kok-saghyz*. The article presents the most complete, up-to-date list of the flora comprising 169 species belonging to 110 genera and 35 families. We present the results of an analysis including taxonomic, chorological and ecological data, identified the basic spectrum consisting of 29 species which are the most characteristic indicators of the plant communities studied. For the first time, the 'core' of the flora was determined, consisting of 14 species. According to the habitat type, most of the basic spectrum was formed by mountain species (14) including one narrow endemic (Ketmentau), followed by Palaearctic species (8). According to ecological preferences, the following groups were distinguished: mesophytes (9 species), mesoxerophytes (7 species), and halophytes of various types (9 species). The share of species preferring saline habitats (halophytes) was 31.4 %. The most similar (Koch's index of biotal dispersity of 23.1 %) were communities at the western border of the surveyed area, and the value of the index gradually decreased towards the eastern border (from 22.7 % to 18.7 %). The results obtained can be important in the further studies on the populations of *T. kok-saghyz*, in searching for potential habitats and organizing population monitoring.

**Key words:** Asteraceae, ecotypes, floristic 'core', halophytes, rubber plant, Russian dandelion.

## Introduction

There is a growing interest in *Taraxacum kok-saghyz* L.E.Rodin as a source of natural rubber (NR). The demand for this raw material is also growing, which is explained, first of all, by its superior elasticity, impact and abrasion resistance, in comparison with the synthetic analogue made from oil. Most globally produced NR (over 60 %) is used in the manufacture of car tires. The remaining approx. 40 % is used in the manufacture of high-strength conveyor belts, anti-corrosion coatings for boilers and pipes, glue, thin-walled high-strength small items, and medical equipment. The ever-growing demand for NR is also due to the replacement of petroleum products as sources of synthetic rubber with renewable natural resources (Kuluyev et al. 2015). Currently, the main source of NR is *Hevea brasiliensis* (Willd. ex A.Juss.) Müll. Arg. Plantations of this species in its native South America are in decline due to the spread of a dangerous disease caused by the fungus *Microcyclus ulei*. As a result, the cultivation of *H. brasiliensis* is currently concentrated in Southeast Asia and some African countries. The probability of loss of *H. brasiliensis* plantations in these regions due to the spread of the pathogenic fungus is quite high; therefore, there is a growing scientific interest in alternative natural sources of rubber, such as *T. kok-saghyz*, also called 'Russian dandelion'. It is worth mentioning that the roots of the species contain another valuable product, inulin. Moreover, the rubber obtained from the roots of *T. kok-saghyz* is hypoallergenic, while the one obtained from *H. brasiliensis* is not (van Beilen and Poirier 2007, Baitulin 2010, Baitulin and Baitulin 2010, Kuluyev et al. 2015, Kutuzova et al. 2015, Luo et al. 2017).

The search for an alternative to *H. brasiliensis* began in Europe and the USA before and during World War II (Whaley and Bowen 1947) and intensified in the 2000s. In the past 10–15 years, several authors addressed such issues as the history of the study of *T. kok-saghyz* as a source of NR and inulin, as well as the problems and prospects of its cultivation (Rakhmankulov et al. 2006; Baitulin 2010; Baitulin et al. 2012; Kuluyev et al. 2015; Kutuzova et al. 2015; Kreuzberger et al. 2016; Arias et al. 2016a, 2016b; Garshin et al. 2016). Additional studies addressed population genetics of the species and genome structure (Collins-Silva et al. 2012, Arias et al. 2016c, McAssey et al. 2016, Lin et al. 2017, Luo et al. 2017), the biochemical composition of roots (Ramirez-Cadavid et al. 2017), plant morphology in nature and in cultivation (Baitulin et al. 2011, Abidkulova et al. 2015), and the internal structure of vegetative organs (Akhmetova et al. 2015). Several publications on the current state of *T. kok-saghyz* populations in Kazakhstan have stressed the need to revive NR production in the Republic of Kazakhstan (Volis et al. 2009, Baitulin and Baitulin 2010, van Dijk et al. 2010, Ametov et al. 2015, Mukhitdinov et al. 2015, Magzieva et al. 2016). Despite the numerous recent studies on *T. kok-saghyz*, the floristic composition of its natural plant communities has received little attention. In addition to a short list of co-occurring species (Lipschitz 1934, Pavlov 1948, Golovkova 1959), comprehensive species lists are available only in the publication by Ametov et al. (2015) describing populations in the Tekes River Valley.

For further search and identification of new habitats of this local endemic listed in the Red Data Book of Kazakhstan (2014), it is important to have a detailed information of its plant communities, in-



cluding the constantly occurring and less frequent species. This information is also necessary for monitoring the state of populations, since a change in the floristic composition can be an indicator about the status of its populations.

The objective of our study was to reveal the basic species composition of plant communities with the participation of *T. kok-saghyz*, i.e. identification of species that are found almost universally co-occurring with *T. kok-saghyz* in all suitable habitats.

## Materials and Methods

*T. kok-saghyz* (Fig. 1) is one of 62 species of the genus *Taraxacum* growing in Kazakhstan (Abdulina 1999). It is a perennial plant, up to 15 cm tall, with a thick root. Inflorescences (capitulae) contain bisexual ray florets with a yellow corolla; receptacles are 8–11 mm long; achenes are furrowed with a crest of white bristles. Flower arrows are usually numerous (up to 38), and sometimes are solitary. Leaves are



Fig. 1. *Taraxacum kok-saghyz* in the surroundings of Lake Tuzkol.

up to 10 cm long and 3 cm wide, shallow toothed along the edge or entire. The species is characterized by a long growing season: the first rosettes of leaves appear in early May, and yellowing and drying usually happens in early August. It blooms throughout the summer. It is found in the Kegen, Saryzhaz and Tekes valleys of the Northern Tien Shan (Fig. 2) in salinized meadows, together with *Achnatherum spp*, on pebbles and in river valleys, floodplain and piedmont meadows, and on



Fig. 2. The study area (marked by black dots).



northern mountain slopes at an altitude of almost 2000 m above sea level.

Its natural distribution range is a small area of up to 10,000 km<sup>2</sup> in three inter-mountain valleys in the southeast of the Almaty region at an altitude of 1800–2100 m a.s.l., the soils of which are characterized by different degrees of salinization (Volis et al. 2009, Baitulin and Baitulin 2010, Kutuzova et al. 2015, Garshin et al. 2016).

Our studies were conducted in 2009 and in 2014 in the Raiymbek district of the Almaty Region (Fig. 2). Over the course of the field trips, seven *T. kok-saghyz* habitats were examined; largest populations in the vicinity of Lake Tuzkol, in the Saryzhaz, Tekes, and Kegen valleys were examined in the most detail.

Sampling plots were established to study the vegetation cover, as well as 1×1 m census plots on which virgin and generative individuals of *T. kok-saghyz* were counted.

Geobotanical descriptions were carried out according to generally accepted methods (Korchagin and Lavrenko 1964), and species were identified according to botanical references (Komarov 1934–1964, Pavlov 1956–1966, Handbook for identification of plants of Central Asia 1968–1993). The habitat types were identified according to Goloskokov (1984), and the nomenclature of species according to Abdulina (1999) and POWO (2020). To determine the similarity coefficient of the floristic compositions at several locations of the distribution range studied we used the Koch's index (*IBD*) of biotal dispersity (Koch 1957) by formula (1).

$$IBD = \frac{T - S}{S(n - 1)} \cdot 100, \quad (1)$$

where: *S* is the total number of species in an area; *n* is the total number of sub-areas; *T* is the sum of species in all sub-

areas, i.e.  $T = S_1 + S_2 + \dots + S_n$ .

## Results and Discussion

In 2009 and 2014, 37 detailed surveys were performed at 20 localities in the Kegen, Saryzhaz, and Tekes valleys and around Lake Tuzkol. Thus, the floristic composition of plant communities with the participation of *T. kok-saghyz* was described in detail (below).

List of co-occurring species of *T. kok-saghyz* is presented in supplementary material (Appendix).

Considering our previous studies (Ametov et al. 2015), the communities with the participation of *T. kok-saghyz* comprised 169 species from 110 genera and 35 families. The numbers were substantially higher than the numbers reported earlier: 73 species from 69 genera and 24 families (Ametov et al. 2015).

The first group, consisting of Asteraceae and Poaceae (23–22 species), were represented by the largest number of species, followed by second one of Fabaceae, Amaranthaceae, Brassicaceae and Cyperaceae (14–10 species). The third group of the most species-rich families included Ranunculaceae, Caryophyllaceae, Orobanchaceae and Rosaceae (6–5 species). In total, the top 10 most species-rich families accounted for 70 % of the total species richness (Table 1). Of the remaining 25 families, five were represented by two to four species and ten, by one species each.

The generic coefficient (number of species per genus) was 1.54. The largest genus with eight species was *Carex*, followed by *Juncus*, *Trifolium*, *Galium*, *Artemisia* and *Saussurea* with four species each; seven genera had three species, 23 genera had two, and the rest had one

species each.

As a result of the analysis, we found that 14 species represented the 'core' of the plant communities (Table 2), and

were found in 40 % or more revelés.

The group was followed by another 15 species, which were recorded in 25–39 % of the revelés (Table 3).

**Table 1. Ten most species-rich families of plant communities with the participation of *T. kok-saghyz*.**

| Family          | Number of species | Number of genera | Share of the total number of species, % |
|-----------------|-------------------|------------------|-----------------------------------------|
| Asteraceae      | 23                | 13               | 13.6                                    |
| Poaceae         | 22                | 15               | 13.0                                    |
| Fabaceae        | 16                | 10               | 9.5                                     |
| Amaranthaceae   | 14                | 11               | 8.3                                     |
| Brassicaceae    | 11                | 9                | 6.5                                     |
| Cyperaceae      | 10                | 2                | 5.3                                     |
| Ranunculaceae   | 6                 | 5                | 3.6                                     |
| Caryophyllaceae | 6                 | 4                | 3.6                                     |
| Orobanchaceae   | 6                 | 5                | 3.6                                     |
| Rosaceae        | 5                 | 2                | 3.0                                     |
| Total           | 118               | 76               | 70.0                                    |

**Table 2. Species of the floristic 'core' of plant communities with the participation of *T. kok-saghyz*.**

| Species                                                                 | Distribution area                             | Ecological group      |
|-------------------------------------------------------------------------|-----------------------------------------------|-----------------------|
| 1. <i>Neotrinia splendens</i> (Trin.)<br>M.Nobis, P.D.Gudkova & A.Nowak | Mountain-Siberian-Iranian                     | hemihalomesoxerophyte |
| 2. <i>Hordeum brevisubulatum</i> (Trin.)<br>Link                        | Turan-Mongolian                               | halomesophyte         |
| 3. <i>Leymus multicaulis</i> (Kar. et Kir.)<br>Tzvel.                   | Turanian                                      | haloxeromesophyte     |
| 4. <i>Puccinellia distans</i> (Jacq.) Parl.                             | Palaeartic (PA)                               | halomesoxerophyte     |
| 5. <i>Carex oederi</i> Retz. ( <i>Carex serotina</i><br>Merat)          | Palaeartic (PA)                               | hydromezophyte        |
| 6. <i>Iris halophila</i> var. <i>sogdiana</i> (Bunge)<br>Grubov         | Mountain-Central Asian-<br>Central Kazakhstan | mesophyte             |
| 7. <i>Potentilla multifida</i> L.                                       | Mountains of Central Asia                     | mesoxerophyte         |
| 8. <i>Oxytropis glabra</i> (Lam.) DC.                                   | Turan-Mongolian                               | mesophyte             |
| 9. <i>Thermopsis turkestanica</i> Gand.                                 | Tarbagatae- Tien Shan                         | mesophyte             |
| 10. <i>Plantago maritima</i> L.                                         | Holarctic (GA)                                | halomesophyte         |
| 11. <i>Artemisia sublessingiana</i> Krasch.<br>ex Poljakov              | Altai-Kazakhstan-Tien<br>Shan                 | xerophyte             |
| 12. <i>Cirsium esculentum</i> (Sievers) C.A.<br>Mey.                    | Gorno-Siberian-Tien Shan                      | hemigalomesophyte     |
| 13. <i>Galatella tianschanica</i> Novopokr.                             | Endemic (Ketmen)                              | halomesophyte         |
| 14. <i>Inula rhizocephala</i> Schrenk.                                  | Altai-Iranian                                 | mesophyte             |

**Table 3. The most frequent co-occurring species of *T. kok-saghyz*.**

| Species                                                | Distribution area                  | Ecological group  |
|--------------------------------------------------------|------------------------------------|-------------------|
| 1. <i>Leymus angustus</i> (Trin.) Pilg.                | Turan-Mongolian                    | haloxeromesophyte |
| 2. <i>Phragmites australis</i> (Cav.) Trin. ex Steud.  | Cosmopolitan                       | hydromezophyte    |
| 3. <i>Juncus triglumis</i> L.                          | Palaeartic (PA)                    | mesophyte         |
| 4. <i>Argentina anserina</i> (L.) Rydb.                | Holarctic (GA)                     | hygromesophyte    |
| 5. <i>Potentilla virgata</i> Lehm.                     | Gorno-Siberian-Gorno-Central Asian | mesoxerophyte     |
| 6. <i>Caragana auruntiaca</i> Koehne                   | Dzhungar-Tien Shan                 | mesoxerophyte     |
| 7. <i>Trifolium repens</i> L.                          | Palaeartic (PA)                    | mesophyte         |
| 8. <i>Geranium collinum</i> Stephan ex Willd.          | Palaeartic (PA)                    | mesophyte         |
| 9. <i>Lappula microcarpa</i> (Ledeb.) Gürke.           | Mountains of Central Asia          | mesoxerophyte     |
| 10. <i>Convolvulus lineatus</i> L.                     | Palaeartic (PA)                    | mesoxerophyte     |
| 11. <i>Plantago depressa</i> Willd.                    | Gorno-Siberian-Himalayan           | mesoxerophyte     |
| 12. <i>Achillea millefolium</i> L.                     | Palaeartic (PA)                    | xerophyte         |
| 13. <i>Leontopodium campestre</i> (Ledeb.) Hand.-Mazz. | Gorno-Siberian-Gorno-Central Asian | mesophyte         |
| 14. <i>Ligularia alpigena</i> Pojark.                  | Dzungarian-Pamir-Alai              | mesophyte         |
| 15. <i>Saussurea salsa</i> (Pall.) Spreng.             | Palearctic (PA) (South Palearctic) | haloxerophyte     |

In total, 29 (17.2 %) of 169 species were most common in the communities with the participation of *T. kok-saghyz*. They were the characteristic indicators of these communities. Of these, the largest group comprised mountain species (14), followed by Palaeartic (8); endemic and cosmopolitan groups had one species each. According to ecological preferences, the largest group comprised mesophytes (9 species), followed by the species growing on saline soils (7) and mesoxerophytes (7).

Typical halophytes were represented by *Hordeum brevisubulatum*, *Leymus multicaulis*, *L. angustus*, *Puccinellia distans*, *Plantago maritima*, *Galatella tianschanica*, and *Saussurea salsa*.

In addition to the most common species above, there were less common, but quite abundant species, the presence of which was a characteristic feature of some plant communities. This group comprised 'relatively abundant' (sp-cop1) ac-

cording to the Drude scale. There were 14 of those: *Agrostis gigantea*, *Poa bulbosa*, *P. pratensis*, *Carex stenophylla* subsp. *stenophylloides*, *Cerastium davuricum*, *Camphorosma monspeliaca*, *Atriplex verrucifera*, *Melilotus dentatus*, *Frankenia hirsuta*, *Astragalus tibetanus*, *Lomatocarpa albomarginata*, *Limonium gmelinii*, *Artemisia viridis*, *Artemisia schrenkiana*.

An analysis of the entire flora of communities studied revealed that the proportion of species preferring saline habitats was 31.4 %. Among those were typical halophytes (32 species), including representatives of the families Amaranthaceae (*Atriplex verrucifera*, *Bassia prostrata*, *Atriplex tatarica*, *Suaeda altissima*, *Salicornia europaea*, *Salsola rosacea*, *Climacoptera* spp.), Asteraceae (*Artemisia schrenkiana*, *Saussurea amara*, *S. robusta*, *S. prostrata*) and some other families (*Lysimachia maritima*, *Limonium gmelinii*, *L. myrianthum*, *Frankenia hirsuta*, *Nitraria*

*sibirica*, *Festuca arundinacea*, *Melilotus dentatus*).

Another 22 species were hemigalophytes and species that form, according to Bykov's (1962) terminology, galomophilic ecotypes (*Elymus repens*, *Phragmites australis*), representatives of the family Fabaceae (*Lotus krylovii*, *Trifolium fragiferum*, *Vicia cracca*), *Primula longis-carpa*, *Galium amblyophyllum*, *Artemisia austriaca*, *Aster altaicus*, *Scorzonera racemosa* and some others.

All these facts confirm the mesogalophytic nature of the co-occurring species of *T. kok-saghyz*. We were unable to find this species in the dry steppe communities. In Kyrgyzstan, by contrast, it is found in the steppes dominated by *Artemisia tianschanica* Krasch. ex Poljak., *Stipa capillata* L., and *Festuca valesiaca* Schleich. ex Gaudin (Golovkova 1959). Most likely, *T. kok-saghyz* was erroneously identified, because the author supplied the species name with the question mark.

Based on the analysis of the floristic composition according to the distribution area, we recorded a significant predominance of mountain species (about 50 %) and species with wide distribution range (mainly Palaearctic and Holarctic, with some cosmopolitans, about 40 %). The share of the lowland species was small. Apart from typical steppe species (*Festuca valesiaca*, *Cannabis sativa*), those were typical Turanian species (*Leymus multicaulis*, *Polygonum acetosum*, *Polygonum aviculare*, *Salsola rosacea*, *Limonium myrianthum*). The ranges of more than a dozen species (e.g. *Hordeum brevisubulatum*, *Poa bulbosa*, *Climacoptera lanata*, *Salsola orientalis*, *Ceratocarpus arenarius*, *Atriplex verrucifera*, *Oxytropis glabra*) were not typically Turanian, since they extend beyond the borders of the Turan plain itself to Mongolia, Iran, the

Mediterranean.

Of the mountain species, the narrowest endemics were of significant interest, due to their limited distribution and conservation importance. Their range was limited to one ridge of the Eastern Tien Shan (Ketmen, *Galatella tianschanica*) or partly extended to the Northern Tien Shan (Zailiysky Alatau), somewhat to the west (into the Central Tien Shan) or east (into Western China): *Ligularia knorringiana*, *Lonicera alberti*, *Euphrasia bajankolica*.

It turned out that the most similar (similarity coefficient 23.1 %) were communities at the western border of the surveyed area, in the vicinity of the village of Kegen. The value of the indicator gradually decreased towards the eastern border: from 22.7 % in the Saryzhaz River Valley, to 19.7 % in the vicinity of the village of Karasaz, and 18.7 % in the Tekes River Valley. Future surveys should attempt to verify this pattern in other parts of the species distribution range.

## Conclusions

In this article, we presented an extended list of species co-occurring with *T. kok-saghyz*, which was much longer than the lists produced by earlier studies (Lipschitz 1934, Pavlov 1948, Van Dijk et al. 2010, Ametov et al. 2015). We identified 14 species that make up the floristic 'core' and another 15 highly characteristic species were added. In our opinion, these 29 species are indicative of plant communities with the participation of *T. kok-saghyz*, i.e. their presence suggests a high probability of finding *T. kok-saghyz*. An analysis of the distribution range of these species indicates that most of them are mountainous or Palaearctic, which is not surprising, given that their habitat is in the inter-

mountain valleys at an altitude of about or slightly more than 2000 m. According to the results of the ecological analysis, most of the 29 species are mesogalophytic in nature. Of particular interest are four narrow mountain endemics that were found in communities with *T. kok-saghyz* and listed here. The results of the present study of the floristic composition of plant communities with the participation of *T. kok-saghyz* will help further study of this rare local endemic, which is also a very promising rubber-bearing plant. Specifically, our results will assist in searching for its potential habitats, as well as organizing population monitoring and assessing the stability of its state. This is because any changes in the diversity of typical plant community members will signal a change in the state of the species under study.

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## Appendix

List of co-occurring species of *T. kok-saghyz*

| No                              | Plant species name                                                                                                        |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| <b>Equisetaceae Rich. ex DC</b> |                                                                                                                           |
| 1.                              | <i>Equisetum arvense</i> L.                                                                                               |
| <b>Poaceae Barnhart</b>         |                                                                                                                           |
| 2.                              | <i>Agrostis gigantea</i> Roth                                                                                             |
| 3.                              | <i>Alopecurus pratensis</i> L.                                                                                            |
| 4.                              | <i>Brachypodium pinnatum</i> (L.) P.Beauv.                                                                                |
| 5.                              | <i>Bromus inermis</i> Leyss. ( <i>Bromopsis inermis</i> (Leyss.) Holub)                                                   |
| 6.                              | <i>Bromus oxyodon</i> Schrenk                                                                                             |
| 7.                              | <i>Deschampsia cespitosa</i> (L.) P.Beauv.                                                                                |
| 8.                              | <i>Elymus repens</i> (L.) Gould ( <i>Elytrigia repens</i> (L.) Nevski)                                                    |
| 9.                              | <i>Elymus sibiricus</i> L.                                                                                                |
| 10.                             | <i>Festuca rubra</i> L.                                                                                                   |
| 11.                             | <i>Festuca valesiaca</i> Schleich. ex Gaudin                                                                              |
| 12.                             | <i>Hordeum brevisubulatum</i> (Trin.) Link                                                                                |
| 13.                             | <i>Leymus angustus</i> (Trin.) Pilg.                                                                                      |
| 14.                             | <i>Leymus multicaulis</i> (Kar. & Kir.) Tzvelev                                                                           |
| 15.                             | <i>Lolium arundinaceum</i> (Schreb.) Darbysh. ( <i>Festuca regeliana</i> Pavl.)                                           |
| 16.                             | <i>Neotrinia splendens</i> (Trin.) M.Nobis, P.D.Gudkova & A.Nowak                                                         |
| 17.                             | <i>Phleum alpinum</i> L.                                                                                                  |
| 18.                             | <i>Phragmites australis</i> (Cav.) Trin. ex Steud.                                                                        |
| 19.                             | <i>Poa annua</i> L.                                                                                                       |
| 20.                             | <i>Poa bulbosa</i> L.                                                                                                     |
| 21.                             | <i>Poa pratensis</i> L.                                                                                                   |
| 22.                             | <i>Puccinellia distans</i> (Jacq.) Parl.                                                                                  |
| 23.                             | <i>Setaria viridis</i> (L.) P.Beauv.                                                                                      |
| <b>Cyperaceae Juss.</b>         |                                                                                                                           |
| 24.                             | <i>Carex capillaries</i> L.                                                                                               |
| 25.                             | <i>Carex oederi</i> Retz. ( <i>Carex serotina</i> Merat)                                                                  |
| 26.                             | <i>Carex orbicularis</i> Boott                                                                                            |
| 27.                             | <i>Carex panicea</i> L.                                                                                                   |
| 28.                             | <i>Carex pycnostachya</i> Kar. et Kir.                                                                                    |
| 29.                             | <i>Carex songorica</i> Kar. & Kir.                                                                                        |
| 30.                             | <i>Carex stenophylla</i> subsp. <i>stenophylloides</i> (V.I.Krecz.) T.V.Egorova ( <i>Carex stenophylloides</i> V. Krecz.) |
| 31.                             | <i>Carex turkestanica</i> Regel                                                                                           |
| 32.                             | <i>Schoenoplectus tabernaemontani</i> (C.C.Gmel.) Palla ( <i>Scirpus tabernaemontani</i> C. C. Gmel.)                     |
| <b>Juncaceae Juss.</b>          |                                                                                                                           |
| 33.                             | <i>Juncus compressus</i> Jacq.                                                                                            |
| 34.                             | <i>Juncus heptopotamicus</i> V.I.Krecz. & Gontsch.                                                                        |

35. *Juncus persicus* subsp. *libanoticus* (J.Thiébaud) Novikov & Snogerup (*Juncus vvedenskyi* V.Krecz.)

36. *Juncus triglumis* L.

#### **Alliaceae J. Agardh**

37. *Allium hymenorhizum* Ledeb.

38. *Allium korolkowii* Regel

#### **Iridaceae Juss.**

39. *Iris halophila* var. *sogdiana* (Bunge) Skeels (*Iris sogdiana* Bunge)

#### **Orchidaceae Juss.**

40. *Dactylorhiza umbrosa* (Kar. & Kir.) Nevski

#### **Cannabaceae Endl.**

41. *Cannabis sativa* L. (*Cannabis ruderalis* Janisch.)

#### **Urticaceae Juss.**

42. *Urtica cannabina* L.

43. *Urtica dioica* L.

#### **Polygonaceae Juss.**

44. *Polygonum aviculare* L. (*Polygonum heterophyllum* Lindm.)

45. *Polygonum acetosum* M.Bieb.

46. *Polygonum patulum* M.Bieb.

#### **Amaranthaceae Juss.**

47. *Anabasis salsa* (Ledeb.) Benth. ex Volkens

48. *Atriplex tatarica* L.

49. *Atriplex verrucifera* M.Bieb. (*Halimione verrucifera* (M. Bieb) Aellen)

50. *Bassia prostrata* (L.) Beck (*Kochia prostrata* (L.) Schrad.)

51. *Camphorosma monspeliaca* L.

52. *Ceratocarpus arenarius* L.

53. *Chenopodium karoï* (Murr) Aellen (*Chenopodium prostratum* Bunge)

54. *Climacoptera lanata* (Pall.) Botsch.

55. *Climacoptera obtusifolia* (Schrenk) Botsch.

56. *Krascheninnikovia ceratoides* (L.) Gueldenst.

57. *Salicornia europaea* L.

58. *Salsola rosacea* L.

59. *Salsola orientalis* S.G. Gmel.

60. *Suaeda altissima* (L.) Pall.

#### **Caryophyllaceae Juss.**

61. *Cerastium davuricum* Fisch. ex Spreng.

62. *Cerastium dichotomum* L.

63. *Cerastium falcatum* (Gren.) Bunge ex Fenzl. (*Cerastium bungeanum* Vved.)

64. *Herniaria glabra* L.

65. *Holosteum umbellatum* L.

66. *Silene viscosa* (L.) Pers.

#### **Ranunculaceae Juss.**

67. *Delphinium iliense* Huth

68. *Halerpestes sarmentosa* (Adams) Kom. (*Halerpestes salsuginosa* (Pall. ex Georgi) Greene)
69. *Ranunculus pulchellus* C.A.Mey.
70. *Ranunculus testiculatus* Crantz (*Ceratocephala testiculatus* (Crantz) Besser)
71. *Thalictrum foetidum* L.
72. *Thalictrum simplex* L.

#### **Brassicaceae Burnett**

73. *Alyssum desertorum* Stapf
74. *Berteroa incana* (L.) DC.
75. *Camelina microcarpa* Andr. ex DC.
76. *Capsella bursa-pastoris* (L.) Medik.
77. *Descurainia sophia* (L.) Webb ex Prantl
78. *Draba nemorosa* L.
79. *Lepidium cartilagineum* (J.Mayer) Thell. (*Lepidium crassifolium* Waldst. et Kit.)
80. *Lepidium draba* L. (*Cardaria draba* (L.) Desv.)
81. *Meniocus linifolius* (Stephan ex Willd.) DC.
82. *Sisymbrium polymorphum* (Murray) Roth
83. *Thlaspi arvense* L.

#### **Celastraceae R. Br. (Parnassiaceae S.F.Gray)**

84. *Parnassia laxmannii* Pall. ex Schult.

#### **Rosaceae Juss.**

85. *Argentina anserina* (L.) Rydb. (*Potentilla anserina* L.)
86. *Potentilla multifida* L.
87. *Potentilla virgata* Lehm.
88. *Sanguisorba alpina* Bunge
89. *Sanguisorba officinalis* L.

#### **Fabaceae Lindl.**

90. *Astragalus peterae* H.T.Tsai & T.T.Yu (*Astragalus abramovii* Gontsch.)
91. *Astragalus tibetanus* Benth. ex Bunge
92. *Caragana aurantiaca* Koehne
93. *Lathyrus pratensis* L.
94. *Lotus krylovii* Schischkin & Serg. (*Lotus sergievskiae* R. Kam. et Kovalevsk.)
95. *Medicago falcata* L.
96. *Medicago lupulina* L.
97. *Medicago medicaginoides* (Retz.) E.Small (*Trigonella arcuata* C. A. Mey.)
98. *Melilotus dentatus* (Waldst. & Kit.) Desf.
99. *Oxytropis glabra* DC.
100. *Thermopsis turkestanica* Gand.
101. *Trifolium fragiferum* L.
102. *Trifolium lupinaster* L.
103. *Trifolium pratense* L.
104. *Trifolium repens* L.
105. *Vicia cracca* L.

**Geraniaceae Juss**

- 106. *Geranium collinum* Stephan ex Willd.
- 107. *Geranium sibiricum* L.

**Nitrariaceae Lindl.**

- 108. *Nitraria sibirica* Pall.

**Zygophyllaceae R.BR.**

- 109. *Tribulus terrestris* L.

**Frankeniaceae Desv.**

- 110. *Frankenia hirsuta* L.

**Polygalaceae Hoffmanns. & Link**

- 111. *Polygala comosa* Schkuhr (*Polygala hybrida* DC.)

**Apiaceae Lindl.**

- 112. *Bupleurum krylovianum* Schischk.
- 113. *Lomatocarpa albomarginata* (Schrenk) Pimenov & Lavrova (*Alposelinum albomarginatum* (Schrenk) M. Pimen.)
- 114. *Seseli valentinae* Popov

**Primulaceae Batsch ex Borkh.**

- 115. *Androsace ovczinnikovii* Schischk. & Bobrov
- 116. *Lysimachia maritima* (L.) Galasso, Banfi & Soldano (*Glaux maritima* L.)
- 117. *Primula knorringiana* Fed.
- 118. *Primula longiscapa* Ledeb.

**Plumbaginaceae Juss.**

- 119. *Goniolimon orthocladum* Rupr.
- 120. *Limonium gmelinii* (Willd.) Kuntze
- 121. *Limonium myrianthum* (Schrenk) Kuntze

**Gentianaceae Juss.**

- 122. *Gentiana aquatica* L.
- 123. *Gentiana leucomelaena* Maxim.

**Convolvulaceae Juss.**

- 124. *Convolvulus arvensis* L.
- 125. *Convolvulus lineatus* L.

**Boraginaceae Juss.**

- 126. *Arnebia guttata* Bunge
- 127. *Cynoglossum viridiflorum* Pall. ex Lehm.
- 128. *Lappula microcarpa* (Ledeb.) Gürke.

**Lamiaceae Martinov**

- 129. *Marrubium anisodon* K.Koch
- 130. *Ziziphora tenuior* L.

**Orobanchaceae Vent. (Scrophulariaceae Juss.)**

- 131. *Euphrasia bajankolica* Juz.
- 132. *Leptorhabdos parviflora* (Benth.) Benth.
- 133. *Odontites vulgaris* Moench
- 134. *Pedicularis dolichorrhiza* Schrenk
- 135. *Pedicularis rhinanthoides* Schrenk.

- 
136. *Rhinanthus songaricus* (Sterneck) B. Fedtsch.

**Plantaginaceae Juss.**

137. *Plantago depressa* Willd.

138. *Plantago major* L.

139. *Plantago maritima* L.

**Rubiaceae Juss.**

140. *Galium amblyophyllum* Schrenk

141. *Galium saurense* Litv.

142. *Galium turkestanicum* Pobed.

143. *Galium verum* L.

**Caprifoliaceae Juss.**

144. *Lonicera alberti* Regel

**Campanulaceae Juss.**

145. *Adenophora liliifolia* (L.) A.DC.

146. *Codonopsis clematidea* (Schrenk) C.B.Clarke

**Asteraceae Bercht. & J.Presl**

147. *Achillea millefolium* L.

148. *Artemisia austriaca* Jacq.

149. *Artemisia heptapotamica* Poljak.

150. *Artemisia schrenkiana* Ledeb.

151. *Artemisia sublessingiana* Krasch. ex Poljakov

152. *Artemisia viridis* Willd.

153. *Aster altaicus* Willd.

154. *Cirsium esculentum* (Siev.) C.A.Mey.

155. *Cirsium sieversii* (Fisch. & C.A.Mey.) Petr. (*Cirsium polyacanthum* Kar. et Kir.)

156. *Galatella tianschanica* Novopokr.

157. *Inula rhizocephala* Schrenk

158. *Leontopodium campestre* (Ledeb.) Hand.-Mazz. (*Leontopodium fedtschenkoanum* Beauverd)

159. *Ligularia alpigena* Pojark.

160. *Ligularia knorringiana* Pojark.

161. *Saussurea amara* (L.) DC.

162. *Saussurea prostrata* C.Winkl.

163. *Saussurea robusta* Ledeb.

164. *Saussurea salsa* (Pall.) Spreng.

165. *Scorzonera parviflora* Jacq.

166. *Scorzonera racemosa* Franch.

167. *Taraxacum kok-saghyz* L.E.Rodin

168. *Taraxacum officinale* (L.) Weber ex F.H.Wigg.

169. *Tragopogon turkestanicus* S.A.Nikitin
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Note: synonyms accepted in Kazakhstan are given in brackets.



## FOSTERING THE SUSTAINABILITY OF COMMUNITY FORESTRY PROGRAM: CASE STUDY IN LAMPUNG-SUMATRA

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### Abstract

Community Forestry Program in Indonesia (called HKm: *Hutan Kemasyarakatan*) as the scheme for recovering forest degradation from encroachment has been operating for 13 years now, but until nowadays there is no available guideline for fostering its sustainability (SUST). HKm Authority, however, still have 22–24 years remain to foster the program before the scheme due. It is in needing both economic and tree biodiversity indicators of every HKm's member land as the guidance for sustaining the program. The income as the economic indicator itself is commonly affected by the endogenous and exogenous variables. This research aimed at determining the roles of: (i) endogenous and exogenous variables on income agroforestry yield (INCM), (ii) INCM on tree biodiversity performance (BIODV), and (iii) BIODV on the HKm's SUST. Data collected by interviewing 230 members of HKm Jaya Lestari located in Way Kanan Regency-Lampung, Indonesia in February-May 2018. These HKm members consisted of four ethnic groups which the two are as the native (Semendonese and Lampungese) that more adaptive to agroforestry cultivation, whereas the remains (Javanese and Sundanese) are the offspring of people moved from Java Island under colonization program by Dutch Administration since 1905. We employed Ordinary Least Square regression postulate model to investigate the first purpose and Loglinear Regression to examine the second and the third purposes. Minitab Version 16 software was applied for the models' goodness-fits test and parameter optimization at 90 and 95% confident level. The research suggests: (i) endogenous variables with positive effect on INCM were the family size, participation in extension activities, land holding acreage, the tribes whose Sundanese and Semendonese were higher than Javanese, and with negative effect was the land elevation; whereas the exogenous variable affected negatively the rural facility construction and nursery demonstration plot activities; (ii) the higher INCM the higher BIODV, but (iii) the better BIODV the lower SUST will be. For the sake of pursuing SUST, it recommends to continue fostering HKm members by managing the endogenous variables in order to rise up INCM, and then multiply BIODV as well as to broaden HKm members' awareness on voluntary planting some wooden trees that have been adaptive or endemic at local region such as iron wood (*Fagraea fragrans* Roxb), cinnamon (*Cinnamomum verum* J. Presl), and *Shorea javanica*.

**Key words:** agroforestry, biodiversity, forest recovery, income, sustainability.

## Introduction

Sustainability still remains a major theme in every development process since the Malthusian pessimism aroused in the early 19th century (Gleditsch 2021, Meiring 2020), including in the agrarian sectors (Pawlak and Kołodziejczak 2020, FAO 2017) that commonly susceptible to the socio-demographical dynamics, market pricing commodity shock, environmental disturbances, as well as macroeconomic or international policy changes as in Indonesia (Putra et al. 2021). The phenomena is also experiencing by almost all forest management programs in Indonesia including forest recovery from encroachment called HKm scheme (Wulandari and Inoue 2018). Forest encroachment itself was rampant during Indonesia underwent governmental reformation from authoritarian to democratization regime followed by forest decentralization to local government in the period of 1998 to 2001. According to Kelman (2013) during the period, especially in areas controlled by central government, such as protected forest areas, people perceive that they were free to act without any lawsuit of punishment. Besides, the poverty, meanwhile, accompanied by lacking of land holding as well as the limited government apparatus for controlling state own forest region were the major triggering on the encroachment phenomenon.

According to Sanudin et al. (2016) deforestation reached 54.56 % in Lampung Province, the province which most severely experienced deforestation in Indonesia during reformation and governmental decentralization period. So that this province was the first established HKm scheme. Under the scheme, forest encroachers recruited as HKm member for 35 years, permitted to manage their

claimed land by applying agroforestry gradually, forbidden cutting tree woods instead of non-wood products such as sap, latex, rattan, coffee fruit, vegetable, food crops, etc. This scheme can be considered as an incremental planning instead of radical planning due to limited resource or power. HKm schemes contribution on forest recovery can be indicated by the improved coverage forested area in Lampung Province.

According to Seno et al. (2018) in this province there has been forest cover improvement from 39,380 to 129,136 ha between 2001 and 2014. This improvement occurred particularly in the state own production forest and protected forest areas. Whereas the conservation forests or national parks were almost free from encroachment due to very tightly guarding activities. The improvement of forest coverage areas, further can contribute to the environmental services performance including microclimatic amenity, enhance ecological equilibrium, and at least to reduce infectious or zoonosis diseases incidence such dengue hemorrhagic fever (Seno et al. 2018, Mustika et al. 2016), malaria (Wigaty et al. 2016), pulmonary tuberculosis (Rosari et al. 2017), pneumonia (Adhyaksa et al. 2017), and avian influenza (Rohayati et al. 2018).

This significant progress of forest recovery that also contributed by HKm scheme, however, has never been examined for sustainability yet. It is important to note that the sustainability indicator is dynamic, always changes and even move down. The sustainability HKm program, therefore, must be nurtured, managed, and pursued by fostering some of determined variables. The important and relevant ones commonly used are both economic and tree biodiversity performance of every parcel of forest land as the indi-

cators of sustainability of HKm programs in Batutege and Liwa Forest Management Unit (Ruchyansyah et al. 2018, Wulandari et al. 2018). According to some researchers both indicators are trade off in a forest ecosystem. That condition was true for conventionally forest management in past, but not for agroforestry system currently.

Agroforestry system actually can afford both economic and biodiversity at once. The strata of vegetation are stake, pole, and seedling can be grown bellow the wood stumpages in it. This stratified tree trunk system means to compose tree biodiversity on one hand and can afford economic benefit for the farmers (Puspasari et al. 2017). Among them that can afford a highly economic benefit is for example cinnamon (*Cinnamomum verum* J. Presl), coffee (*Coffea canephora* Pierre ex A. Froehner) or cocoa (*Theobroma cacao* L.) for the stake and pole stratum respectively. There are so many vegetation species of seedling stratum that can afford highly economic benefit as well as to contribute the biodiversity enhancement, i.e. soybean, peanut, some vegetables, aromatic or medical herbs, etc. (Bakri et al. 2018).

Applying agroforestry system for HKm members, therefore, is a prominent way to meet their obligation for forest recovering besides providing for their family income. But, the farmers' ability certainly will be constrained by some endogenous and exogenous variables. Their stock of knowledge and skills, their physical capital, or productive asset available are the endogenous variables that are possibly controlled internally by HKm management. The skills and knowledge level, however, are commonly affected by their socio-demographic variables including age, sex, family size, education, culture or ethnicity, group involvement, participation in extension, access to information, and distance to mar-

ket place (Idayanti et al. 2019). Besides, the skills and knowledge land acreage, the ownership of hand phone, grocery, fishpond, and motorbike will become productive capital that determines their productivity and will shed out in the form of their income later on. Additionally, the exogenous variable including the availability of rural public investment as well as the social safety net maybe impact to their income.

Triggering by some incentive that possibly could be generated by the economic benefits from miscellaneous agroforestry yields, it is normal to expect that the farmers will add various tree wood species voluntarily on their land, particularly whenever their income can be promoted by fostering the HKm authority. In line with this background, it is needed to build model prediction of farmer income as the function of both the endogenous and exogenous variables and then the income needs to predict tree biodiversity performance as well as the control HKm program sustainability. This research, therefore, was conducted with the aims of: (i) Modeling HKm members' INCM based on their endogenous and exogenous variables, (ii) Modeling BIODV performance based on INCM, and (iii) Modeling HKm sustainability program as the function of BIODV. These three series model will become reliable tools in planning to foster HKm Schemes sustainability endeavor in Indonesia.

## Material and Methods

This study consists of field survey and data analyses, from February to May 2018. The field survey was conducted at Talang Mangga Village, Banjit District, Way Kanan Regency, Lampung Province, Indonesia (Fig. 1). Data were collected

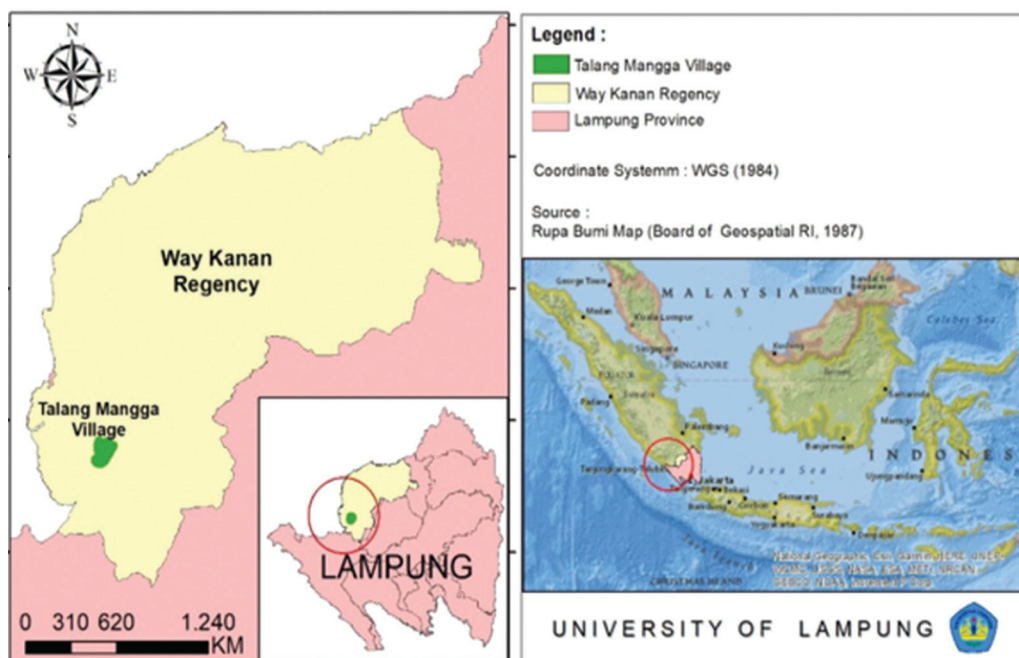


Fig. 1. Research location (GWKR 2016).

through interviews using questionnaires guidance to 230 HKm members. The cluster random sampling method on a population of HKm Mangga Jaya group members totaling 697 households and composed of 9 sub-groups. The sub-grouping was based on block area that may consist of one or more villages. The division followed the list that has been made since the beginning of HKm membership was formed. Each sub-group had about 73 to 76 households as members. Each one was treated as cluster.

We randomly drew samples of 25–26 households in each sub-group as potential respondents so total samples were 230 households, and we named this 230 respondents. As to the decision about 25–26 respondents as the minimum size of sample per sub-group is intended of having normal data distribution. According to the Central Limit Theorem (Johann Karl

Gauss 1777–1855 as cited by Lunsford et al. 2006, Dinov et al. 2008, Ghasemi and Zahediasl 2012, Sang and Hae 2017) if the sample data size is large enough, it will follow a normal distribution regardless population distribution form. Sang and Hae (2017) and also Ghasemi and Zahediasl (2012) have proven a sample size of  $>30$  is the golden rule to meet normal distribution, while according to Lunsford et al. (2006) and Dinov et al. (2008) the golden number of minimum size is 25 members.

### Model approach and testing hypotheses

In accordance with the aim of this research there are three measured response variables: 1) farmers' income of agroforestry yield (INCM), 2) tree biodiversity indices (BIODV), and 3) sustainability of HKm pro-

gram indices (SUST). As for the surrogate of three are explained in the following.

### Model I: Farmer income

Farmer INCM is intended to depict their welfare under HKm program. In this research, ECNM is measured by using the total income per family per annum, the income from cultivation on HKm land only, such as latex (rubber sap), coffee bean, areca nut, etc. Increased INCM is expected to become an important variable in determining the improvement of BIODV of every land parcel which belongs to HKm members. BIODV itself is a good indicator of the forest ecosystem recovery process particularly agroforestry system instead of monoculture cropping pattern.

According to Idayanti et al. (2019), INCM is significantly influenced by age, sex, and number of dependents. While as reported by Puspasari et al. (2017), there are no real differences between ethnicities in earning income. Setiawan et al. (2014), however, proved that in this study area Javanese ethnicity was more resilient in increasing their income than ethnic Lampung and others in making the living. Meanwhile, in the local forestry institution namely KPH Bukit Punggur (2014) Strategic Plan document, it is stated that the HKm members in this research area are composed of Javanese, Sundanese, Lampung, and Semendo ethnic groups. The first two are immigrants while the others are native who are very adaptive to agroforestry cultivation legacy from their ancestor. The ethnicity can be considered as the surrogate of a traditionally cultural bundle that have accumulated day by day along history. The different ethnicity can be utilized for contrasting skills and local knowledge in relation to their productivity in agroforestry cultivation. This variable,

therefore, should be counted on every community development plan included in the fostering to behave more efficiently in earning from agroforestry yields (INCM). The earning, in turn, will be the basic for stimulating HKm member to plant wooden tree crops other than rubber. INCM modeling functioning as the endogenous and exogenous variables of household in detailed is summarized in Table 1. Model I as the INCM prediction is expressed in formula (1):

$$\begin{aligned} \text{INCM}_i = & \alpha_0 + \alpha_1 \text{AGE}_i + \alpha_2 \text{SEX}_i + \alpha_3 \text{FMLSZ}_i \\ & + \alpha_4 \text{VDAM}_i + \alpha_5 \text{GADM}_i + \alpha_6 \text{AJOB}_i + \\ & \alpha_7 \text{CLVTN}_i + \alpha_8 \text{D1\_ELS}_i + \alpha_9 \text{D1\_JHS}_i + \\ & \alpha_{10} \text{D2\_SND}_i + \alpha_{11} \text{D2\_SMD}_i + \alpha_{12} \text{D2\_LPG}_i \\ & + \alpha_{13} \text{LHLD}_i + \alpha_{14} \text{UPLN}_i + \alpha_{15} \text{RICEF}_i + \\ & \alpha_{16} \text{GOAT}_i + \alpha_{17} \text{FPOND}_i + \alpha_{18} \text{MBIKE}_i + \\ & \alpha_{19} \text{GCERY}_i + \alpha_{20} \text{TVOW}_i + \alpha_{21} \text{HPOW}_i \\ & + \alpha_{22} \text{EXTN}_i + \alpha_{23} \text{ELVT}_i + \alpha_{24} \text{DLND}_i + \\ & \alpha_{25} \text{DVLN}_i + \alpha_{26} \text{DDST}_i + \alpha_{27} \text{RINVT}_i + \\ & \alpha_{28} \text{SCNET}_i + \alpha_{29} \text{NURSY}_i \\ & + \epsilon_i, \end{aligned} \quad (1)$$

where: INCM is income from agroforestry yield of respondents;  $\alpha_0$  is intercept;  $\alpha_{1-29}$  are parameter Model I;  $\epsilon$  is residual error Model I;  $i=1, 2, \dots, 230$  are respondent numbers; the other symbols correspond to the symbols in Table 1.

The working hypothesis Model I is expressed in the following:

-  $H_0: \alpha_1 = \alpha_2 = \alpha_3 = \dots = \alpha_{29} = 0$  (among the 29 variables enlisted in Table 1, there is no variable that affect the family's income significantly);

-  $H_1: \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \dots \neq \alpha_{29} \neq 0$  (among the 29 variables enlisted in Table 1, at least there would be one variable that affects the family's income significantly).

The testing hypothesis and optimization parameters process for Model I was conducted by applying Minitab 16. The Fisher statistic employed to examine the goodness fits test for the Model I at confi-

Table 1. The endogenous and exogenous variables of family head and their data scoring in model employed as well as the expected sign in regression result.

| Group of variable and the variables           | Symbol              | Unit or data scale measured | Scoring                               | Expected Sign in Regression: Brief explanation in relation to the income per family                                                  |
|-----------------------------------------------|---------------------|-----------------------------|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| <b>Social demographic*</b>                    |                     |                             |                                       |                                                                                                                                      |
| 1. Age                                        | AGE                 | year                        | integer number                        | - : the older the less their productivity will be                                                                                    |
| 2. Sex                                        | SEX                 | categorical                 | =1 if man; =0 if other                | + : man more powerful in cultivation than woman                                                                                      |
| 3. Family size number                         | FMLSZ               | person                      | integer number                        | + : the more person the more income                                                                                                  |
| 4. Role in village administration             | VADM                | -                           | =1 if village administrator           | + : will earn more access to information and power                                                                                   |
| 5. Role in HKm group                          | GADM                | -                           | =1 if administrator of HKm            | + : will earn more access to information and power                                                                                   |
| 6. Additional job                             | AJOB                | -                           | =1 if any                             | + : will bring other source of income                                                                                                |
| 7. Cultivation applied                        | CLTVN               | -                           | =1 if agroforestry; =0 if monoculture | + : who applied agroforestry have miscellaneous yield so that more secure from cropping failure as well as from pricing market shock |
| <b>Education level* (0 = never schooling)</b> |                     |                             |                                       |                                                                                                                                      |
| 8. Dummy elementary school                    | D <sub>1</sub> _ELS | dummy                       | =1 if elementary; =0 if others        | + : graduate ELS more innovative then who never schooling                                                                            |
| 9. Dummy junior high school                   | D <sub>1</sub> _JHS | dummy                       | =1 if junior high sch.; =0 if others  | + : graduate JHS more innovative then who ELS                                                                                        |
| <b>Ethnicity* (0 = Javanese tribe)</b>        |                     |                             |                                       |                                                                                                                                      |
| 10. Sundanese                                 | D <sub>2</sub> _SND | dummy                       | =1 if Sundanese; =0 if others         | - : Sundanese less adaptive in agroforest than Javanese                                                                              |
| 11. Semendones                                | D <sub>2</sub> _SMD | dummy                       | =1 if Semendones; =0 if others        | + : Semendones more adaptive than Javanese                                                                                           |
| 12. Lampungnese                               | D <sub>2</sub> _LPG | dummy                       | =1 if Lampungnese; =0 if others       | + : Lampungnese the most adaptive in agroforest                                                                                      |
| <b>Productive assets*</b>                     |                     |                             |                                       |                                                                                                                                      |
| 13. Total land holding acreage                | LHLD                | ha                          | rational number                       | + : the more total land holding the more income                                                                                      |
| 14. Up land acreage inside HKm area           | UPLN                | ha                          | rational number                       | + : the more up land in HKm area the more income                                                                                     |



| Group of variable and the variables          | Symbol | Unit or data scale measured | Scoring                  | Expected Sign in Regression: Brief explanation in relation to the income per family                                                           |
|----------------------------------------------|--------|-----------------------------|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 15. Rice field inside HKm area               | RICEF  | ha                          | rational number          | + : the more rice field in HKm area the more income                                                                                           |
| 16. Goat number ownership                    | GOAT   | ha                          | integer number           | + : the more number goat the more income                                                                                                      |
| 17. Fish pond ownership                      | FPOND  | categorical                 | =1 if own; =0 if other   | + : who owe fishpond will earn more income                                                                                                    |
| 18. Motorbike ownership                      | MBIKE  | categorical                 | =1 if own; =0 if other   | + : who owe motor bike will earn more income                                                                                                  |
| 19. Small grocery shop ownership             | GCERY  | categorical                 | =1 if own; =0 if other   | + : who owe small grocery will earn more income                                                                                               |
| Information and physical accessibility*      |        |                             |                          |                                                                                                                                               |
| 20. TV ownership                             | TVOW   | categorical                 | =1 if own; =0 if other   | + : who own TV will have more productive information                                                                                          |
| 21. HP ownership                             | HPOW   | categorical                 | =1 if own; =0 if other   | + : who own HP will have more productive information                                                                                          |
| 22. Extension participation                  | EXTN   | -                           | =1 if active =0 if other | + : who participate in extension have more productive                                                                                         |
| 23. Elevation of land area                   | ELVT   | m a.s.l.                    | rational number          | - : the higher the more effort and the less income                                                                                            |
| 24. Distance to land area                    | DLND   | minutes by bike             | rational number          | - : the farther distance the more time or transportation cost needed                                                                          |
| 25. Distance to village market               | DVLM   | minutes by bike             | rational number          | - : the farther distance the more time or transportation cost needed                                                                          |
| 26. Distance to subdistrict centre           | DDST   | minutes by bike             | rational number          | - : the farther distance the more time or transportation cost needed                                                                          |
| Beneficiary from rural facility investment** |        |                             |                          |                                                                                                                                               |
| 27. Rural facility investment                | RINVT  | -                           | =1 if any; =0 if other   | - : public investment activities project such as rural road improve will make trade off time and negatively impact to agroforestry activities |
| 28. Social safety net                        | SCNET  | -                           | =1 if any; =0 if other   | + : social safety net also will affect positively to income                                                                                   |
| 29. Nursery demonstration plot               | NURSY  | -                           | =1 if any; =0 if other   | + : the plot will affect positively to the farmers skill and their income                                                                     |

Note: \* endogenous variables, \*\* the exogenous variables.

dent level of 90 and 95 %. Then to depict every parameter of predictor variables we employed the T statistic at confident level of 90 and 95 % as well.

### Model II: Tree biodiversity prediction model

As mentioned before Model II is intended to predict the probability of tree biodiversity improvement of every land parcel belonging to HKm members. Model II is predicted by single variable of INCM. It is expected to express that HKm members will add more tree species voluntarily at their land whenever their INCM is risen up. In order to depict this objective, we employed the Loglinear Regression or Logistics Regression that expressed in the formula (2):

$$\begin{aligned} \ln \frac{p(\text{BIODV}_i) = 1}{1 - p(\text{BIODV}_i) = 1} = \\ = \beta_0 + \beta_1 \text{INCM}_i + \xi_i, \end{aligned} \quad (2)$$

where:  $\ln$  is logarithm operator using the natural number ( $e = 2,718...$ ) as the basis;  $p(\text{BIODV}_i) = 1$  are the probability of being succeeded in improving tree biodiversity of the respondent  $i^{\text{th}}$ ;  $1 - p(\text{BIODV}_i) = 1$  are the probability of being fail in improving tree biodiversity of respondent  $i^{\text{th}}$ ;  $\beta_0$  is intercept;  $\beta_1$  is parameter Model II;  $\xi_i$  is residual error Model II;  $i = 1, 2, \dots, 230$  are respondent numbers.

The working hypothesis of Model II is expressed in the following:

-  $H_0$ :  $\beta_1 = 0$  (family income does not affect tree biodiversity performance significantly);

-  $H_1$ :  $\beta_1 \neq 0$  (family income affects tree biodiversity performance significantly).

For  $H_1$  above, a positive number of parameter  $\beta_1$  was expected that would be produced later on through optimization process using statistical software of Minitab

16. Gald statistics was employed to test the goodness fits of model. Whereas the significance of parameter model was tested by employing Wald statistics. Both Gald test and Wald test were employed at confident levels of 90 and 95 %.

### Model III: HKm program sustainability prediction model

Model III is intended to predict SUST by using single predictor variable of BIODV. The model III is expressed in the formula (3):

$$\begin{aligned} \ln \frac{p(\text{SUST}_i) = 1}{1 - p(\text{SUST}_i) = 1} = \\ = \xi_0 + \xi_1 \text{BIODV}_i + \pi_i, \end{aligned} \quad (3)$$

where:  $\ln$  and  $i$  are as in formula (2);  $p(\text{SUST}_i) = 1$  is the probability of respondents -  $i^{\text{th}}$  succeeded to support HKm program sustainability;  $1 - p(\text{SUST}_i) = 1$  is the probability of respondents -  $i^{\text{th}}$  fail to support HKm program sustainability;  $\xi_0$  is intercept;  $\xi_1$  is a parameter Model III;  $\pi_i$  is residual error of Model III.

The working hypothesis Model III is expressed in the following:

-  $H_0$ :  $\xi_1 = 0$  (tree biodiversity performance does not affect the sustainability program significantly);

-  $H_1$ :  $\xi_1 \neq 0$  (tree biodiversity performance affects the sustainability program significantly).

Also in Model III, a positive number of parameter  $\xi_1$  was expected that would be produced by optimization process using statistical software of Minitab 16. Gald statistics was employed to test the Goodness fits of the model. Whereas the significance of parameter model was tested by employing Wald statistics. Both Gald test and Wald test were employed at confident levels of 90 and 95 %.

## Results and Discussion

### Result in descriptive statistics

Very firstly we need to describe three variables that were used as the respond variables in the three models regression, namely [INCM], [BIODV], and [SUST]. Having displayed the descriptive statistics of their respond, the three modeling results will be provided consecutively later on. It is important to note from data gathered of the field survey, that lowest [INCM] was USD 10 and the highest was USD 1,608 per year. Briefly distribution of [INCM] is provided in Table 2. Based on this term, the dominant class [ICNM] was less than USD 300 per year, with the frequency of 143 families (62.2 %). This fact can be treated as the bench mark in planning to enhance INCM from agroforestry earning that have to be fostered by HKM scheme.

**Table 2. Proportion of families based on their income (n=230).**

| No        | Income class, USD/year | Frequency      | Proportion, % |
|-----------|------------------------|----------------|---------------|
| 1         | <300                   | 143            | 62.2          |
| 2         | 301–600                | 38             | 16.5          |
| 3         | 601–900                | 31             | 13.5          |
| 4         | 901–1200               | 9              | 3.9           |
| 5         | 1201–1400              | 7              | 3.0           |
| 6         | >1400                  | 2              | 0.9           |
| Mean= 351 | Minimum =10            | Maximum =1,608 | Sd=340        |

As for [BIODV] is defined by addition the wooden tree crop that have planted and successful to grow, the number addition of wooden tree then are grouped in three classes BIODV namely: low, moderate, and high. The moderate class is defined in between 3 to 5 species added, while beyond both boundaries are low and high classes of BIODV respectively.

The distribution BIODV is described in Table 3. From this table we can appraise for forestry workers, who have been striving their effort to recovery forest degradation (Bakri et al. 2018, Chamberlain et al. 2019). It is the fact that for 11 years HKM's program operating only did 1.7 % or 4 parcels of land covered by the high BIODV. The dominant is still 54.4 % (125 parcels) – low in tree biodiversity performance (BIODV). This fact can be treated as the bench mark in planning to speed up the forest recovery program under HKM scheme as well.

**Table 3. Proportion of families based on tree biodiversity.**

| No | Tree biodiversity class | Frequency | Proportion, % |
|----|-------------------------|-----------|---------------|
| 1  | Low                     | 125       | 54.4          |
| 2  | Moderate                | 101       | 43.9          |
| 3  | High                    | 4         | 1.7           |

The third respond variable is classified as *yes* or *no* in supporting HKM's SUST. The distribution of this data is provided in Table 4. It is important to note that the criterion for separating into two classes (*yes versus not*) is the compliance of HKM's members to plant the additional wooden tree crops on their land even though without any financial assistant from HKM authority or from other sources. In case a member comply is '*yes*' – to support the probability of HKM's sustainability program. The revers is as '*no*'. This distribution is depicted in Table 4. The table displays more than half of the families do not support yet the probability of HKM's SUST. This fact should be taken into account in developing programs to foster it.

For the sake of pursuing the guidelines to foster SUST, we need to examine the relationship among the three variables consecutively in series models regression. Having known which ones among

both endogenous and exogenous variables (Table 1) that significantly affect INCM, we then can estimate or predict BIODV performance. We, furthermore, use the predicted BIODV to examine the SUST. The three regressions model is presented below.

**Table 4. Proportion of families who support the probability of HKm's sustainability program.**

| No | Family who support | Frequen-<br>cy | Proportion,<br>% |
|----|--------------------|----------------|------------------|
| 1  | Yes                | 87             | 37.8             |
| 2  | No                 | 143            | 62.2             |

### Result of the regression models

Model I is to explain the role of both the endogenous and exogenous variables in determining family income from agroforestry yield (INCM) in HKm land. The goodness of fits test result for Model I applied is provided in Table 5. Meanwhile the optimization parameter of variables affecting INCM can be seen in Table 6.

By referring to  $P = 0.000$  (Table 5), it means that we have had no enough facts

to reject  $H_1$  (that also means there is no enough facts to accept  $H_0$ ). In other words, Model I is valid or robust predictor model of INCM based on both endogenous and exogenous variables of every family at the study area. In addition,  $P = 0.000$  does not mean that this predictor model can predict 100% correctly or without any making miss prediction, but only below 1 % and maximum 0.04 % ( $=0.0004$ ) miss prediction. It is important to realize that there is no breaking any mathematical rules in case we write this  $P = 0.0004$  because this number is approximately the same with the original number namely  $P=0.000$  as the output of Minitab process. But  $P = 0.0004$  can help the interpretation about the robustness Model I obtained. It tells us that if we applied the model for predicting INCM based on the 29 predictor (Table 1, the endogenous and exogenous) variables to predict 10,000 families, we will get very high precision of predicted INCM, i.e. there will be maximum 4 families that miss predicted than the actual ones. Briefly, the confident level of Model I is more than 99 %.

**Table 5. Analysis of variance of role independent variables on family income.**

| Source         | Degree of freedom | Sum square | Mean square | F     | P     |
|----------------|-------------------|------------|-------------|-------|-------|
| Regression     | 33                | 18354608   | 632918      | 15.60 | 0.000 |
| Residual error | 195               | 8073640    | 40571       |       |       |
| Total          | 228               | 5404.31    |             |       |       |

Note:  $S = 201.423$ ;  $R^2 = 69.5\%$ ;  $R^2\text{-adj.} = 65.0\%$ .  $S$  = root square of total variances,  $R^2\text{-adj.}$  =  $R^2$  adjusted to sample size;  $F$  = Fisher statistic value;  $P$  = Probability to miss prediction.

**Table 6. Parameter optimization of socioeconomic variables that affected family income.**

| Predictor                         | Symbol | Coeff.   | SE Coeff. | T     | P            |
|-----------------------------------|--------|----------|-----------|-------|--------------|
| Constant                          | -      | 330      |           | 1.24  | 0.215        |
| <b>Social demography</b>          |        |          |           |       |              |
| 1. Age                            | AGE    | -0.413   | 1.203     | -0.34 | 0.731        |
| 2. Sex                            | SEX    | 27.350   | 55.049    | 0.50  | 0.620        |
| 3. Family size number             | FMLSZ  | 29.441   | 9.692     | 3.04  | <b>0.003</b> |
| 4. Role in village administration | VADM   | -0.503   | 60.294    | -0.01 | 0.993        |
| 5. Role in HKm group              | GADM   | -855.245 | 1283.217  | -0.67 | 0.506        |

| Predictor                                         | Symbol              | Coeff.   | SE Coeff. | T     | P            |
|---------------------------------------------------|---------------------|----------|-----------|-------|--------------|
| 6. Additional job                                 | ADJOB               | -4.385   | 46.455    | -0.09 | 0.925        |
| 7. Cultivation applied                            | CLTVN               | 841.259  | 1134.266  | 0.74  | 0.459        |
| <b>Education level (0 =never schooling)</b>       |                     |          |           |       |              |
| 8. Dummy elementary school                        | D <sub>1</sub> _ELS | 71.545   | 54.972    | 1.30  | 0.195        |
| 9. Dummy junior high school                       | D <sub>1</sub> _JHS | 7.965    | 57.951    | 0.14  | 0.891        |
| <b>Ethnicity (0 = Javanese tribe)</b>             |                     |          |           |       |              |
| 10. Sundanese                                     | D <sub>2</sub> _SND | 114.448  | 41.203    | 2.78  | <b>0.006</b> |
| 11. Semendonese                                   | D <sub>2</sub> _SMD | 130.476  | 48.189    | 2.71  | <b>0.007</b> |
| 12. Lampungese                                    | D <sub>2</sub> _LPG | 51.818   | 1108.392  | 0.47  | 0.640        |
| <b>Productive assets</b>                          |                     |          |           |       |              |
| 13. Total land holding acreage                    | LHLD                | 278.203  | 18.748    | 14.84 | <b>0.000</b> |
| 14. Up land acreage in Hkm area                   | UPLN                | 9.874    | 47.755    | 0.21  | 0.836        |
| 15. Rice field inside HKm area                    | RICEF               | -64.881  | 61.776    | -1.05 | 0.295        |
| 16. Goat number ownership                         | GOAT                | -4.154   | 33.112    | -0.13 | 0.900        |
| 17. Fish pond ownership                           | FPOND               | 18.559   | 33.580    | 0.55  | 0.581        |
| 18. Motorbike ownership                           | MBIKE               | -35.692  | 37.804    | -0.94 | 0.346        |
| 19. Small grocery shop ownership                  | GCERY               | -24.622  | 40.105    | -0.61 | 0.540        |
| <b>Information and physical accessibility</b>     |                     |          |           |       |              |
| 20. TV ownership                                  | TVOW                | -12.063  | 39.797    | -0.30 | 0.762        |
| 21. HP ownership                                  | HPOW                | -34.566  | 45.140    | -0.77 | 0.445        |
| 22. Participation in Extension                    | EXTN                | 166.790  | 35.622    | 4.68  | <b>0.000</b> |
| 23. Elevation of land area                        | ELVT                | -0.503   | 0.175     | -2.88 | <b>0.004</b> |
| 24. Distance to land area                         | DLND                | -1.601   | 5.175     | -0.31 | 0.758        |
| 25. Distance to village market                    | DVLM                | -1.601   | 5.175     | -0.31 | 0.758        |
| 26. Distance to district centre                   | DDIST               | -4.021   | 3.797     | -1.06 | 0.291        |
| <b>Beneficiary from rural facility investment</b> |                     |          |           |       |              |
| 27. Rural facility investment                     | FIVST               | -171.825 | 45.531    | -3.77 | <b>0.000</b> |
| 28. Social safety net                             | SCNET               | 68.657   | 63.245    | 1.09  | 0.279        |
| 29. Nursery demonstration plot                    | NURSY               | -199.587 | 40.685    | -4.91 | <b>0.000</b> |

Note: the bold numbers are significant at level <1.0 %; T=the critical value of T statistic.

As for which ones among the 29 variables that affect ICNM significantly, we must examine their probability to miss ( $P$ ) in Table 6. It connoted that there are eight variables affecting INCM significantly with  $P < 1\%$  (or confident level more than 99 %) namely the variables of the family number size (FMLSZ), the ethnicity where the Sundanese (D<sub>1</sub>\_SND) and Semendonese (D<sub>1</sub>\_SMD) compare to Javanese, land holding acreage (LHLD), participation in extension (EXTN), land elevation

position (ELV), rural investment facility (FISVT) and nursery development plot project (NURSY). In other words, against these eight variables, there is no enough facts to reject  $H_1$  (or all at once to accept  $H_0$ ). Additionally, that the last two variables mentioned happen to be the exogenous variables where the others six are the endogenous variables. Fortunately the effect of the six endogenous ones are in the same direction with the INCM, the better quality of each variable the better

INCM will be. On the contrary, in case the activities of both FISVT and NURSY exist, the INCM will reduce significantly.

As for the 21 variables remain on the contrary, there is no enough facts to reject  $H_0$  (or all at once to accept  $H_1$ ). All these variables have any significant effect to INCM. As mentioned before, Model II is intended to explain BIODV based on INCM. The goodness fits test of Model II as well as the significance effect of INCM on BIODV is provided in Table 7. This table depicts that there is no enough facts to reject  $H_1$  (and all at once to accept  $H_0$ ). In other words INCM affects significantly

BIODV. In case INCM at average rises up as much as one USD per year, BIODV will improve by 1.13 as indicated by its Odds Ratio and this improvement is very significant that indicated by its  $P$ -value = 0.000 or with confident level more than 99 %.

Developing Model III is motivated by seeking some clues to compose a guideline for fostering every HKm member in order to contribute the probability increase of HKm's SUST. The goodness fits test of Model III as well as the significance effect of BIODV as the predictor of SUST is provided in Table 8.

**Table 7. Wald test of Model II: effect of income to BIODV.**

| Predictor | Symbol | Coefficient | SE Coeff. | Z     | P     | Odds Ratio | 95% confident interval (CI) |       |
|-----------|--------|-------------|-----------|-------|-------|------------|-----------------------------|-------|
|           |        |             |           |       |       |            | Lower                       | Upper |
| Constant  | -      | -0.330442   | 0.200843  | -1.65 | 0.100 | -          | -                           | -     |
| Income    | INCM   | 0.122602    | 0.034123  | 3.59  | 0.000 | 1.13       | 1.06                        | 1.21  |

Note: Log-Likelihood = -149.873; Test that all slopes are zero:  $G = 15.685$ ,  $DF = 1$ ,  $P$ -value = 0.000.  $G$  = Gald statistic;  $Z$  = Coeff./SE coefficient;  $P$  = probability to miss of separately predicted  $\beta_0$  or  $\beta_1$  numbers;  $P$ -value = probability to miss of predicted BIODV using ECNM.

**Table 8. Wald test of Model III: effect of BIODV to HKm SUST.**

| Predictor         | Symbol | Coefficient | SE Coeff. | Z     | P     | Odds Ratio | 95% confident interval (CI) |       |
|-------------------|--------|-------------|-----------|-------|-------|------------|-----------------------------|-------|
|                   |        |             |           |       |       |            | Lower                       | Upper |
| Constant          | -      | -0.138836   | 0.199487  | -0.70 | 0.486 | -          | -                           | -     |
| Tree Biodiversity | BIODV  | -0.660920   | 0.275737  | -2.40 | 0.017 | 0.52       | 0.30                        | 0.89  |

Note: Log-Likelihood = -149.637; test that all slopes are zero result:  $G = 5.801$ ;  $DF = 1$ ;  $P$ -value = 0.016.  $G$  = Gald statistic;  $Z$  = Coeff./SE coeff.  $P$  = probability to miss of separately predicted  $\beta_0$  or  $\beta_1$  numbers;  $P$ -value = probability to miss of predicted SUST using BIODV.

Table 8 indicates that there is no enough facts to reject  $H_1$  (all at once to accept  $H_0$ ). It means that BIODV is a reliable variable to predict HKm's SUST. But unfortunately, in case the BIODV improve from low to

moderate or to high levels, the probability HKm program become sustain (SUST) would be reduced by 0.52 as indicates by its Odds Ratio with confident level is more than 98.3% as indicated by its  $P=0.017$ .



## Discussion

### Role of demographic variables on income

Among the demographic variables, only FMLSZ variable affects INCM, if the other variables are constant, a family who has more than one family member will have an increase in income around USD 29.441 per year. The effect of addition of labour supply (family members) to the region is very significant ( $P = 0.003$ ). This phenomenon means that the marginal labour productivity in the region is still positive in stimulating INCM. Because the core business of HKm authority is to release this protected forest from human occupation, it is a must to employ policy to enhance labour skills by extension or training program instead of mobilizing labour from outside area (Idayanti et al. 2019). Training in silviculture techniques cycle from seedling to post harvesting will make labour augmented by knowledge and technology, in turn will increase their work productivity and then lessen the excess demand of traditional labour (Supriadi et al. 2018). This finding is congruence with the effect of LHLD that will be elaborated below.

The other variables of demographics, namely: age, sex, role in village administration, role in a HKm group, additional job, and cultivation applied do not affect significantly INCM. As depicted in Table 5, there is no significant effect of SEX, as INCM is relatively the same. Similar to SEX is the variable of CLTVN, a family applying an agroforestry pattern indeed has a higher INCM than that using monoculture, but the difference is not significant ( $P = 0.459$ ).

Another AGE variable shows that INCM will decrease with increasing age of

the family heads each year, however, the effect is not significant ( $P = 0.731$ ). This reflects the agricultural work in the region is resilient enough to change in age of the farmers. So are the effects of the variables of VADM, GADM, and ADJOB. INCM of the family heads involved VADM are commonly lower than those free from that affair, but the difference is not significant ( $P = 0.993$ ). It is similar to GDAM, with  $P = 0.506$ . Both cases suggest that voluntary work does not significantly disturb families in making a living. An interesting fact there is the effect of ADJOB such as construction labour, pedicab drivers, etc. The families having ADJOB tend to lose their opportunity to intensify their agricultural work and have lower income than those not having ADJOB.

In short, FMLSZ is the only demographic variable that can enhance INCM. In development practice, allocating more manpower to this region can be the only opportunity available for forest planners to increase economic performance as a necessary condition for enabling sustainable development besides the biodiversity of any landholding plots. For the sake to find some opportunities in enhancing the economic performance, we need to examine other variables that give significant effects on INCM as also depicted in Table 3.

### Effect of education level on income

It is normal to expect an educational background influence on people's productivity in economic sectors, and so is it in the agroforestry sector in the study area. The higher people's education background the higher their innovativeness, that will be accompanied by their higher productivity reflected in their income. This expectation, unfortunately, cannot be achieved in this study. As referring to Table 5, the level

of education of family heads does not significantly affect ICNM. Family heads with an Elementary School education level ( $D_{1\_ELS}$ ) have an income of USD 71.545 compared to those who never schooling. The difference, however, is not significant ( $P = 0.195 = 19.5\%$  or  $> 5\%$ ). The similar effect occurs with family heads categorized as Junior High School ( $D_{1\_JHSC}$ ). Although the family heads of  $D_{1\_JHS}$  category have an extra of USD 7.965 per year also compared to those, the difference is not significant ( $P = 0.891$ ).

In brief, the 3 levels of education background of the family heads have no significant impact on ICNM. It can be concluded that the education has not yet significantly stimulated innovativeness so that there are no significant effects on ICNM either. The phenomenon, however, will be very useful for forest planners eager to look for an INCM elevating strategy, at least that the forest planners will not need to separate the family heads based on the education level in conducting extension activities, etc. The extension program itself gives a significant effect on INCM, as discussed below.

### Effect of ethnicity on income

Contrary to the educational level, the ethnicity affects INCM significantly. The family heads in the study area belong to 4 ethnic groups: Javanese, Sundanese, Semendonese, and Lampungese. In order to make a comparison of the magnitude effect among them, Javanese becomes the reference. The scoring applied for them equals to 0 in ICNM modeling (Table 1). The results, in Table 5 show that Lampungese ( $D_{2\_LGP}$ ) indeed have an average ICNM of USD 51.818 per year more than Javanese do. But the difference is not significant ( $P = 0.640 = 64\%$  or  $> 5\%$ ).

On the contrary, INCM of Sundanese reaches USD 130.475 per year more than of Javanese. The difference is significant ( $P = 0.006 = 0.6\%$  or  $< 1\%$ ). It seems that Semendonese people are the most productive in the study area. The family income of Semendonese ( $D_{2\_SMD}$ ) is USD 114.448 per year more than of Javanese. The difference is also significant ( $P = 0.007 = 0.7\%$  or  $< 1\%$ ).

It is interesting to discuss the differences in INCM based on the ethnicity analysis. Setiawan et al. (2014) revealed that Lampungese and Semenodenese in the study area could be regarded as the native ethnic groups whereas Javanese and Sundanese were the newcomers. The natives commonly cultivate cash crops, including coffee, cocoa, cinnamon, and rubber through the agroforestry system. Meanwhile, according to Nurhaida et al. (2007) both Javanese and Sundanese migrated from Java Island (or their offsprings) started in 1905 under Dutch Colonization and last recurrent in between 1961 and 1965 under the National Reconstruction Scheme. Newcomers do not do much cash crop cultivation through the agroforestry system. Instead, they do the perennial crops cultivation especially rice. Many of them, in fact, have no background in any agricultural livelihood at all. From this background it is easily understood why Javanese come last in INCM from rubber agroforestry cultivation. Reversing the argument, we have proven why Semendonese ( $D_{2\_SMD}$ ) is the most productive ethnic group in the study area, shown by their INCM.

We would be trapped in a wrong argument if we insist on using the origin of people to explain Sundanese or Lampungese productivities. Although Sundanese are the newcomers, they commonly live side by side with Semendonese. Like them,

the ancestors of Sundanese in West Java commonly lived in the upper area of a landscape, cultivated rice on terraced land combined with fish ponds and wood plants in their backyard. The agrocomplex system pattern in Sundanese community was found during the field research. Except for cultivating rice and managing fish ponds, both Sundanese and Semendoneses prefer to live in an area biophysically very similar so they commonly live side by side. Sundanese, however, are more intensive in adopting skills for the cultural technique of rubber agroforestry in daily work. This background can serve as an appropriate explanation why Sundanese are more productive than Javanese. A reverse argument perhaps could explain better why the productivity of Lampungese is not different from Javanese as expressed by their average INCM. The implication in developmental economic planning in relation to the four ethnic groups planners should take into consideration whenever they convey the technical assistant in extension activities.

This argument is in line with the findings of Nurhaida et al (2007) who proved the local language usage in extension activities was very effective in enhancing farmers' knowledge about the role agroforestry on soil and water conservation control. Nurhaida et al. (2011) also conducted a research at buffer zone of Way Kambas National Park-Lampung Province and reported the use of three tribal languages (Javanese, Sundanese, Balinese) in cartoon media of fable. They were much more effective in conveying messages of wildlife conservation than in Indonesian. Beside the language, the local knowledge about the matter (that had been inventoried before) also to was utilized in the extension media designed by Nurhaida et al. (2007, 2011). In Figure 2 is described that

agroforestry pattern demonstrated by Semendoneses or Sundanese should be introduced to Javanese or Lampungese by a subtle extension methods in order to be accepted without any cross culture barrier.

Additionally, the relevant custom including norm, habit, satire, allusion, folklore and other cultural acceptability or heritage from their ancestor were used exhaustively in Nurhaida et al. (2007, 2011). Because the participation in extension (EXT) is positively significant in enhancing INCM (Table 5), it is a rational way in using up the strategic program in order to become the strategy for fostering HKm's SUST through improving BIODV. All of the culture heritage of every tribe such as hospitality, local norm, habit, local wisdom, should be taken as consideration in developing extension programs.

### **Effect of productive asset**

Among the 8 variables of productive assets (Table 3) only landholdings under HKm scheme acreage have a significant effect on INCM. This claim is connoted by *P*-value of 0.000 which means this variable significantly influences the income because it has an error below 5 %. Its coefficient is 278.203 which means that the family income will increase by USD 278.203 per ha per year on landholding plots under HKm scheme. This implies that in the study area a landholding is still limited to achieve the community's welfare such as in Tanggamus Regency of Lampung Province (Ruchyansyah et al. 2018). This constraint can naturally encourage further encroachment if the authority cannot make an incentive policy to slow this tendency down. Thus, the challenge for forestry planners is to look for another productive asset that is possible to leverage INCM without presupposing any need to



increase land allocation. In relation to this challenge, fish pond management, goat and poultry development are prospective-

ly economic activities that are possible to improve the economic performance due to their better economic gains.



a



b



c



d

**Fig. 2. Cropping pattern in rubber silviculture: (a) Javanese, monoculture, seems diligent to clean weed as their ancestor who custom with annual crops in Java Island; (b) Semendonese almost an ideal agroforestry pattern; (c) Sundanese seems make adaptation to Semendonese; (d) Lampungese seems too little cultivation.**

### **The effect of information and physical accessibility**

Among the 4 variables, only the land elevation gives a significant effect on INCM. Farmers whose land elevation lies above 100 m a.s.l. will reduce their income by USD 0.503 per year. Perhaps the farmers must spend more effort or a bigger budget to cultivate rubber on land with higher

elevation such as found by Zhafira et al. (2019). The rubber sap productivity will also decrease significantly if cultivated on higher elevation due to the temperature suitability for rubber crop growth (Andrian et al. 2014).

As for both TVOW and HPOW variables, they do not significantly affect INCM. Farmer participation in extension programs, on the contrary, plays a significant

role in the enhancement of INCM. This kind of condition is based on the results of Idayanti et al. (2019) and Supriadi et al. (2018). Both research results have also proven that HPOW and TVOW have no effect on the income.

It is only the variable of farmer's participation in EXTN among the 6 ones of the information and physical accessibility having a positively significant effect on INCM. Farmers who are more active in EXTN can get an income of USD 166.790 per year, or more than those who are not. This proves that the extension program is an important source of information for the villagers such as found by Wulandari and Inoue (2018) in West Lampung. The knowledge contained in the extension can be very valuable in rubber cultivation activities. It is also possible that the social atmospheric interaction among the villagers has been improved by the extension activities so that the social capital can be developed as well.

### **Effect of rural facility investment activities**

These exogenous variables include FIVST, NURSY, and SCNET. The presence of FIVST has decreased INCM, farmers joining the temporary work have an average income of USD 171.85 less than those who do not. Perhaps the farmers spend too much time in the non farm work so they sacrificed the opportunity to work in the fields, including plant care, tapping sap, processing latex, etc. A similar situation also occurs in NURSY. These jobs are more attractive because the villagers can take cash than take money from selling rubber latex, coffee bean, cocoa and other agroforestry yields which the prices always decrease in the harvest season. This condition is also proven by Idayanti

et al. (2019) that the improvement of project facilities has a negative influence on the INCM.

As for SCNET program it has no significant effect on INCM. It seems that the money allocation in cash has reduced the work spirit of the farmers. But based on his research among pine (*Pinus merkusii* Jungh. & de Vriese) sap tappers community at forest plantation in Central Java-Indonesia, Cahyono (2010) reported that SCNET in cash assistance had been lessen the farmers' morale on working, reduced their productivity and increased consumption spending. On the contrary was the research conducted in the community of sap damar (*Shorea javanica* Koord. & Valetton) farmers at West Lampung Regency reported by Setiawan et al. (2014). SCNET in cash had stimulated their spirit in working and had induced their INCM enhancement. Both Cahyono (2010) and Setiawan et al. (2014) recommend that enhance extension program in order to foster the farmer's spirit to be able to empower themselves gradually escaping from poverty trap.

### **The role of income on tree biodiversity performance**

As seen in Table 7, *G* statistic is big enough ( $G = 15.685$ ) with  $P$ -value = 0.000. This can be equated with  $P$ -value = 0.0004 because the rounding of 3 digits will be the same as  $P$ -value = 0.000. So the meaning of  $P$ -value = 0.0004 (or  $P$ -value = 0.04 %) is that 99.06 % (100 % subtracted by 0.04 %) of BIODV variations among the 230 respondents' land parcels can be explained by the sole INCM variable, whereas the remaining 0.004 % can not, but should be explained by other variables that were not applied in this model. In brief, the precision of this model is very

high because the confident level is more than 99.04 %.

As for how much INCM variable can multiply BIODV, we need to refer to Odd Ratio obtained, namely 1.13 with  $P = 0.000$  that can also be equated to  $P = 0.0004$  (Table 7). It connotes that every farmer's income increases by an average of USD per year, accompanied by increasing of BIODV by 1.13 times. The increase is around 95 % CI (namely in between 1.01 and 1.26) with the missing probability being only around 0.06 %. This very small probability tells us that the model built is strong. This fact also justifies that the improvement of BIODV through farmers' income improvement in this research area is in line with the mission of HKm Scheme. In other words, HKm Authority has conducted an amendment program for rehabilitating the degradation of protected forests through farmers' income increasement effort. It indicate that the reforestation program under HKm scheme has been effective as proved by the responsiveness HKm members to the program of planting some annual and cash crops under rubber trees stumpage. It is logical that farmers depend on forest's biodiversity for their daily needs so they will manage their forest neatly and conserve the biodiversity (Wulandari et al. 2018).

### **The role of tree biodiversity performance on HKm's program sustainability**

The BIODV effect is strong enough to be the predictor variable of HKm Program sustainability. As seen in Table 8, this claim is proven by Gald statistic results at 5.801 with  $P$ -value = 0.016. It means that the sole predictor variable of BIODV is reliable as the indicator of sustainability of

HKm due to its small missing probability of only 0.016 (=1.6 % or less than 5 %). This number tells us that there will be 16 units missing if we use BIODV variable to predict 1,000 sustainability of HKm Program. Therefore we can rely on this model to predict the sustainability of HKm.

We, furthermore, are interested in knowing how big the change of sustainability of HKm is in case BIODV rises from low to medium or high. Unfortunately, the sustainability of HKm will drop to only 0.52 as BIODV rises from low to medium or high. This clue is indicated by Odd Ratio described in Table 5, namely 0.52 (CI = 0.30 to 0.89) with  $P = 0.017$ , indicating the model is strong enough.

The reduction in HKm program sustainability as a result of the increase in BIODV gives a signal of a critical phase. It implies that farmers, whose BIODV has been rising up, need more nurturing from HKm authority to support a critical breakthrough of a biodiversity development phase especially for newly wooden planted crops other than rubber. During that phase the farmers must pay much more attention in order to promote the growth of the newly planted wooden tree other than rubber. Those plants must survive from weed disruption, pests and borne diseases, poor soil fertility, and even from rubber plant shading. The farmers need to allocate their resources more than when planting rubber in a monocultural way, such as controlling weeds and pests, applying soil fertilizer, pruning rubber canopies and using them for green manure. This certainly will reduce the farmers' opportunity to earn income from the rubber sap production. This claim is also in line with FMLSZ roles to INCM as expressed in Table 6. HKm authority, therefore, strongly recommended to conduct activities, including technical assistance through intensifying



extension activities beside financial aids in the form of chemical material and cropping facilities for farmers whose BIODV has been rising up; otherwise, BIODV will possibly decrease.

For the sake of pursuing SUST, it recommends to continue fostering HKm members by managing the endogenous variables in order to rise up INCM, and then multiply BIODV as well as to broaden HKm members' awareness on voluntary planting some wooden trees that have been adaptive or endemic at local ecoregion such as *Fagraea fragrans* Roxb (Bramasto and Sudrajat 2018), *Cinnamomum* sp. (Menggala et al. 2019), and *Shorea javanica* (Wakhidah et al. 2020).

## Conclusion

The hypotheses have to be accepted at confident level more than 95% namely: (i) the endogenous variables with positive effect on the income from agroforestry yield (INCM) were the family number size, participation in extension activities, land holding acreage, tribes Sundanese and Semendonesse higher than Javanese, and with negative effect was the land elevation; whereas the exogenous variable affected negatively the rural facility construction and nursery demonstration plot activities; (ii) the INCM effect on tree biodiversity (BIODV) enhancement namely BIODV performance will rise up by 1.13 if ENCM rises up by USD one per year; and (iii) the BIODV on HKm's program sustainability (SUST) will reduce by 0.53. It is clue that the nurturing phase on HKm member at critical stage. It recommends that continue fostering HKm members by managing the endogenous variables in order to rise up INCM, and then multiply BIODV as well as to broaden HKm members' awareness

on voluntary planting some wooden trees is the prerequisite of pursuing SUST.

## Recommendations

Three consecutive models have been achieved by this research and are certainly very meaningful tool for developing next programs, particularly the strategies in fostering every HKm member in order to be able to contribute in pursuing HKm's program sustainability (SUST). Model III is the final point and flash back to use Model II and Model I. At the ultimate objective that the enhancement of tree biodiversity performance (BIODV) has to be able to stimulate the awareness of HKm's member to add wood tree at every vacant space of their lands. The extension activities, including silviculture techniques, are certainly a strategic way to broaden their knowledge if planting some wooden tree species will get some benefits of improvement in: shading coffee or cocoa crops, litter basalt and mulch of organic matter, soil fertility, and the opportunity to make earning from miscellaneous vegetable yields. Planting timber tree crops, therefore, can generate these economic incentive for the farmers. On the other side, planting many species of timber tree crops for HKm authority is the main indicator of succeeding duties in forest recovery program from the encroachment phenomenon.

As proved by Model II, this scenario in fostering SUST through corner stones of improving tree biodiversity (BIODV) will be possible as the prerequisite if and only if the farmer's income (INCM) can be risen up. The flash back, therefore, we have to exploit the Model I as the basis for enhancing INCM strategy. It is clear that we have to use the endogenous variables which have characteristic of enabling to

and being possible to induce INCM. From the six of endogenous variables (Table 4), only does the extension variable (EXTN) that meets the two characteristics, whereas the three variables remain do not, namely the family number size, land holding acreage, and land elevation.

Family size number is the endogenous variable that does not have meaning for fostering SUST. This variable is not possible to be added or reduced for the sake of enhancing INCM. And so does the elevation of land parcel position, there is no real act that can be conducted on changing the land elevation position across the landscape in whole HKm location. Additionally, although the land holding variable is possible to be expanded in order to enhance INCM, but adding the allocation of land tenure to HKm members is contrary to the main mission of the HKm Authority namely to free the protected forest from the occupation problem. So that the only strategic way in fostering SUST through INCM enhancement (that later on inducing BIODV) is the promoting extension.

In order to achieve SUST, therefore, the extension promotion is a very important strategy in fostering of every HKm member. Therefore, even though the extension materials are focused on silviculture techniques, as exemplified by Nurhaida et al. (2007, 2011), the implementation of the activities of each extension program must also consider the ethnicity variables, which in this HKm Sundanese and Semendonesse need to be distinguished from Javanese or Lampungese.

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## INFLUENCE OF WILDFIRE ON SOIL MICROBIAL COMMUNITY AND CHEMICAL PARAMETERS IN DOLNA BANIA REGION, BULGARIA

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### Abstract

Microbial indicators of forest soils affected by forest fire under conifers (*Pinus sylvestris* L., *Larix desidua* Mill.) and mixed (*Pinus sylvestris* L., *Quercus cerris* L.) forests from north slopes of Rila Mountain (Dolna Bania region) have been examined 7 days after a wildfire occurrence. An increased quantity of total microflora in the upper (0–5 cm) layer of fire-affected soil in comparison with that taken from a control (unburned) sampling site was established due to the rise of soil temperature and pH, accompanied with a simultaneous decrease in soil humidity. Results show the highest proportion of the analysed microflora represented by non-spore-forming bacteria, bacilli, bacteria assimilating mineral nitrogen. The quantity of *Actinomycetes* and *Micromycetes* decreased in soil affected by fire. The predominant groups of microorganisms (ammonifying and nitrifying bacteria) play an important role at different stages of mineralization processes of the organic matter in fire-affected soil.

**Key words:** microbial diversity, Rila Mountain, soils affected by fire.

### Introduction

Forest fires are becoming of increasing concern worldwide – both for the ecosystems they occur, and for the population. Some authors associate the increase in the frequency of fires in recent years with the climate change (Halofsky et al. 2020). The anthropogenic interference could also be accepted as a factor for their occurrence through human demography and activities, such as land use and fire management (Syphard et al. 2017, Wil-

liams et al. 2019).

Fires affect the soil organic matter, the amount of macro- and micro-nutrients, soil physical properties, soil acidity, and the amount and composition of flora, fauna and soil microbiota (Guerrero et al. 2005, Velizarova and Filcheva 2011). Fire can have many effects on soil organic carbon (SOC) through changing the quantity and quality of carbon inputs to soil, such as forest floor, and affecting conditions that control microbial activity and access to it (Berryman and al. 2020). Through



laboratory experiment was established that high-intensity and high-severity fires decreased SOC stored in macroaggregates in comparison with soils exposed to low temperatures (Araya et al. 2017). Additionally, Albalasmeh et al. (2013) found that in low- and moderate-severity burns, if long enough in duration, soil aggregates can degrade. The extremely high soil temperatures during fire events lead to chemical and microbial community transformations with potential feedbacks to SOC processing (Esquilín et al. 2007). Heat-induced changes also affect soil nitrate ( $-\text{NO}_3$ ), ortho-phosphate ( $-\text{PO}_4$ ), and sulfate ( $-\text{SO}_4$ ) status and facilitate their movement in surface overland flow (Miller et al. 2006). Microbial community responses to fire may correlate with soil physico-chemistry, such as pH or nutrient pool sizes, or availability, exemplifying microbe-environment feedbacks in response to extreme disturbances. Furthermore, selection for disturbance tolerant microbial communities and declines in microbial biomass presumably results in long-term effects on essential ecosystem functions, such as exoenzyme production and decomposition (Dooley and Treseder 2012; Holden et al. 2013).

One of the main factors for the restoration of soil fertility after fires is the state of soil microflora (quantity, quality composition and activity) which plays an important role in restoring ecosystems (Li et al. 2019). It serves as a biomarker in the monitoring of soil (Yakovlev 2000). Soil microorganisms can be affected by fire, either as a direct result of heating or as an indirect effect of changes in soil physico-chemical properties (Docherty et al. 2012).

Brown et al. (2019) and Yeager et al. (2005) found that in soils affected by fire, the amount of nitrogen-fixing and ammo-

nia-oxidizing bacteria is lower, while the number of species of *Clostridium* and *Bacillus* are higher than that in the soil from control sampling site. They established that these trends are kept during fourteen months after the fire. The growth of microorganisms is activated in the topsoil affected by fire. According to some authors their quantity at a 0–5 cm depth is 3 times higher than in the control soil (Bogdanov et al. 2003). Neary et al. (1999) report that the effect of heating on microbes is most significant in the surface soil layer, where microorganisms are most abundant. Other authors (Mabuhay et al. 2006) found that bacteria are more resistant to heat and recover faster after fire than *Micromycetes*. And in both groups of microorganisms they have proven fire resistant species – bacteria (*Massilia* sp., *Arthrobacter* sp.) and *Micromycetes* (*Penicillium* sp., *Fusicladium* sp.) (Whitman et al. 2019). The ratios of alpha-, beta- and gamma-proteobacteria, and *Cytophaga-Flavobacterium* group to total Eubacteria increased immediately after the wildfire, and the other eubacterial proportions decreased in the surface and middle layer soils (Kim et al. 2004). Richness of bacterial community composition tended to be lower in the high burn soils in mixed conifer forests relative to unburned soils, while it was similar across all soils in pine forests (Weber et al. 2014). Microbes differ in their sensitivity to heat caused by fire (Gema and Bååth 2009). Forest fires are one of the main factors that change the taxonomy and functional diversity of soil microbial communities. According to some authors, the microbial diversity decreases in soils after a fire (Smith et al. 2008, Bárcenas-Moreno et al. 2011, Xiang et al. 2014), while according to others – it increases. The heat-resistant species – mainly spore-forming appear after fire (Yeager et al. 2005, Brown et al. 2019)

which is an important indicator of soil state (Yakovlev 2000). Therefore, the study of microbial diversity in the dynamics after a fire is of great importance.

The aim of study was to assess the initial response – a week after wildfire occurrence of microbial and chemical indicators of forest soils (Chromic Luvisols) affected by crown and surface fire under conifers and mixed forests from north slopes of Rila Mountain (region of Dolna Bania).

## Materials and Methods

### Soil sampling

Soil sampling have been performed at five experimental sites as follows – two affected by crown fire and forest vegetation: Scots pine (*Pinus sylvestris* L.) – sampling site No1 (SS No1), European larch (*Larix decidua* Mill.) – SS No2; two experimental sites affected by surface fire and vegetation: Scots pine (*Pinus sylvestris* L.) – SS No3 and mixed forest – Scots pine (*Pinus sylvestris* L.) and Turkey oak (*Quercus cerris* L.) – SS No4. The control experimental site was established in an unaffected Scots pine (*P. sylvestris*) forest – SS No5. The studied sampling sites are situated at similar altitude, slope exposure and soil characteristics (Molla and Velizarova 2016). The soils are Chromic Luvisols (LV-cr) (WRBSR 2015).

The sampling was performed a week after forest fire. Soil samples were taken from 0–5 cm and 5–20 cm depth of soil profile mineral part. Those from surface mineral soil have been collected randomly at each sampling site. Sampling of the accumulated forest litter was carried out simultaneously. Within each plot for soil sampling, the litter was collected from the area with size 0.25 m × 0.25 m outlined by

wooden frame. Forest litter collected from fire-affected sampling sites was not possible to separate by fractions because of partly or fully carbonization. Litter samples from unaffected sampling site were separated into three fractions – litter layer (L), fermentation layer (F), and humus layer (H). They were dried and milled. All samples were transported and analysed within 48 h. Sampling and sample preparation processing have been performed following the standard methodological approach (Cools and De Vos 2020). The soil from observed sites belongs to Haplic Luvisols (WRBSR 2015). Identification and classification were performed according to the morphological peculiarities of the established soil profiles and based on the data received from the following laboratory analyses. The samples for microbial analysis were taken with a sterile instrument from 0–5 cm, 5–20 cm of soil mineral part, and from the forest litter affected by fire, in sterile paper bags.

### Microbiological analyses

Microbiological studies include the determination of non-spore-forming bacteria, bacilli, *Actinomycetes*, *Micromycetes* and bacteria assimilating mineral nitrogen. The analysed groups of microorganisms were determined on the respective nutrient media according to their morphological characteristics. The identification of species is subject to additional analyses. Appropriate dilutions of soil samples were inoculated on specific culture media plates: meat–peptone agar for non-spore-forming bacteria and bacilli, starch–ammonium agar for *Actinomycetes* and bacteria assimilating mineral nitrogen and Czapek's agar for *Micromycetes*. Agar plates were then incubated for 2 (non-spore-forming bacteria, bacilli, bacteria assimilating min-

eral nitrogen) and 10 (*Actinomycetes*, *Micromycetes*) days in thermostat and typical morphological colonies were counted with colony counter. The number of tested microorganisms was expressed as colony-forming units (cfu) per 1 g of dry soil (Zvyagintsev et al. 1980). The samples for microbiological analysis were taken with a sterile instrument, in sterile paper bags. They were transported and investigated the latest up to 48 h, as up to the moment of the culture they were stored in a refrigerator at 4–10 °C. The mineralization coefficient was calculated by dividing bacteria assimilating mineral nitrogen to non-spore-forming bacteria + bacilli, according Mishustin and Runov (1957), Nustorova and Malcheva (2020).

### Chemical analyses of soil

Soil samples were taken according to Bulgarian State Standard ISO 18400-104:2019 and ISO 18400-102:2019. The active reaction of soils (pH) was measured in water extract in compliance with Bulgarian State Standard ISO 10390:2011. The quantity of humus is determined as per method of Turin according to the methodology, represented in Donovan et al. (1974). The content of nitrogen is reported photometrically with Nitrospectral as per international standard ISO 14255:2002, in compliance with methods of 'Merck' company. The moisture of the soil is specified as per weight method through usage of thermostat and drying at temperature 105 °C up to a constant weight. Soil density was measured using metal ring pressed into the soil (intact core), and determining the weight after drying, detailed described in Donovan et al. (1974). The same methods were used for analyses of forest litter chemical parameters.

Statistical data processing includes

calculation of the average values and coefficient of variation ( $\pm CV$ ) by three replications for each group of microorganisms. Correlation analysis was applied to determine the relationships between soil chemical and microbiological indicators. Excel 2010 program for Windows was used for the statistical analysis.

## Results and Discussion

The results obtained show that the studied soils and forest litter differ in the total amount of microorganisms, their variability by groups and the degrees of soil organic matter mineralization (tables 1 and 2).

The active reaction of soil (pH) after forest fire is higher in all experimental variants compared to the control pH values (SS No5). More pronounced statistically significant differences were observed for the upper 5 cm of soil and for all sampling sites, affected by crown fire.

The soil bulk density values increased in the fire influenced soil in comparison with that of the control sampling site. This increase is higher for the surface 5 cm layer. The fire burns biomass and soil organic matter resulting in carbon decrease in crown fire affected sampling sites (SS No1 and SS No2), while surface fire SS No3 and SS No4 provoked an increase in soil organic carbon amount in comparison to that in control SS No5.

The data from Table 1 show that soils affected by fire contain a higher amount of total microflora compared with soil from the control SS – No5, except for the surface soil layer of SS No4. This trend is not typical for the amount of *Actinomycetes* in the upper soil layer and for the bacteria assimilating mineral nitrogen for both layers. The amount of these groups of micro-

Table 1. Soil indices, qualitative and quantitative composition of soil microflora.

| SS No | Depth, cm | C, % | N, %  | pH (H <sub>2</sub> O) | Moisture, % | Density, g/cm <sup>3</sup> | Colony-forming units per g of dry soil (x10 <sup>3</sup> cfu/g soil),<br>± Coefficient of variation (CV),<br>in brackets – as percentage of total microflora, % |                            |               |               |              | Coefficient of mineral-ization |                                         |
|-------|-----------|------|-------|-----------------------|-------------|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|---------------|---------------|--------------|--------------------------------|-----------------------------------------|
|       |           |      |       |                       |             |                            | Total microflora                                                                                                                                                | Non-spore-forming bacteria | Bacilli       | Actinomycetes | Micromycetes |                                | Bacteria, assimilating mineral nitrogen |
|       |           |      |       |                       |             |                            |                                                                                                                                                                 |                            |               |               |              |                                |                                         |
| 1     | 0÷5       | 1.66 | 0.042 | 6.06                  | 0.87        | 1.66                       | 5200                                                                                                                                                            | 4120±0.49 (79)             | 680±2.94 (13) | 100±9.172 (2) | 300±3.33 (6) | 1800±3.38                      | 0.38                                    |
|       | 5÷20      | 1.38 | 0.031 | 5.53                  | 1.07        | 2.04                       | 450                                                                                                                                                             | 380±9.49 (84)              | 44±7.87 (10)  | 8±12.50 (2)   | 18±5.56 (4)  | 784±0.51                       | 1.85                                    |
| 2     | 0÷5       | 1.93 | 0.085 | 6.42                  | 0.84        | 1.92                       | 20260                                                                                                                                                           | 19400±0.45 (96)            | 560±7.14 (3)  | 140±7.14 (1)  | 160±6.25 (1) | 3120±0.80                      | 0.16                                    |
|       | 5÷20      | 1.24 | 0.07  | 6.12                  | 1.85        | 1.97                       | 316                                                                                                                                                             | 202 ±4.32 (64)             | 80±7.50 (25)  | 14±7.14 (4)   | 20±10.00 (6) | 168±1.19                       | 0.60                                    |
| 3     | 0÷5       | 2.35 | 0.095 | 5.81                  | 1.36        | 2.15                       | 3300                                                                                                                                                            | 2260±2.34 (68)             | 760±5.26 (23) | 120±8.33 (4)  | 160±2.50 (5) | 3360±1.19                      | 1.11                                    |
|       | 5÷20      | 1.79 | 0.082 | 5.40                  | 1.77        | 1.43                       | 484                                                                                                                                                             | 368±1.09 (76)              | 90±8.01 (19)  | 0             | 26±7.69 (5)  | 1200±1.76                      | 2.62                                    |
| 4     | 0÷5       | 3.45 | 0.13  | 6.12                  | 1.93        | 1.40                       | 1760                                                                                                                                                            | 800±2.5 (46)               | 860±4.65 (49) | 60±8.82 (3)   | 40±5.00 (2)  | 3640±1.10                      | 2.19                                    |
|       | 5÷20      | 2.21 | 0.098 | 5.85                  | 5.93        | 1.40                       | 238                                                                                                                                                             | 90±8.01 (38)               | 84±4.76 (35)  | 26±7.69 (11)  | 38±5.26 (16) | 144±1.39                       | 0.83                                    |
| 5     | 0÷5       | 2.07 | 0.093 | 5.47                  | 1.61        | 1.34                       | 1860                                                                                                                                                            | 780±1.28 (42)              | 540±1.85 (29) | 380±3.16 (20) | 160±1.25 (9) | 3660±1.09                      | 2.77                                    |
|       | 5÷20      | 1.10 | 0.052 | 5.26                  | 13.1        | 1.78                       | 160                                                                                                                                                             | 32±6.25 (20)               | 94±4.26 (59)  | 10±10.00 (6)  | 24±4.17 (15) | 88±2.27                        | 0.70                                    |

Table 2. Forest litter chemical and microbiological indices.

| SS No | Sub-layer | C, %  | N, %  | pH (H <sub>2</sub> O) | Moisture, % | Stock, g/cm <sup>2</sup> | Total microflora | Non-spore-forming bacteria                                                                                                                                          |                   |                   |                   | Actinomycetes | Micromycetes | Bacteria, assimilating mineral nitrogen | Coefficient of mineralization |
|-------|-----------|-------|-------|-----------------------|-------------|--------------------------|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------|-------------------|---------------|--------------|-----------------------------------------|-------------------------------|
|       |           |       |       |                       |             |                          |                  | Colony-forming units per g of dry litter (x10 <sup>3</sup> cfu/g litter),<br>± Coefficient of variation (CV),<br>in brackets – as percentage of total microflora, % |                   |                   |                   |               |              |                                         |                               |
| 1     |           | 41.55 | 0.449 | 7.44                  | 0.48        | 3252                     | 6220             | 5960±0.67<br>(96)                                                                                                                                                   | 260±7.69<br>(4)   | 0                 | 0                 | 5160±1.16     | 0.83         |                                         |                               |
| 2     | BFL*      | 30.60 | 0.369 | 8.01                  | 1.41        | 6154                     | 8260             | 6400±3.13<br>(77)                                                                                                                                                   | 160±6.25<br>(2)   | 1620±1.23<br>(20) | 80±2.50 (1)       | 3200±3.13     | 0.49         |                                         |                               |
| 3     |           | 54.45 | 0.658 | 7.28                  | 0.38        | 6020                     | 6740             | 6400±1.56<br>(95)                                                                                                                                                   | 100±6.00<br>(1.5) | 20±10.00<br>(0.3) | 220±5.45<br>(3.3) | 3840±1.56     | 0.59         |                                         |                               |
| 4     |           | 40.65 | 0.292 | 6.80                  | 1.71        | 4910                     | 4940             | 3640±1.65<br>(74)                                                                                                                                                   | 1080±1.85<br>(22) | 0                 | 220±4.55 (4)      | 4000±3.50     | 0.85         |                                         |                               |
| 5     | L         | 59.70 | 1.565 | 5.06                  | 3.14        | 2505                     | 1680             | 1160±3.63<br>(71)                                                                                                                                                   | 160±5.00<br>(17)  | 20±5.00 (2)       | 340±1.56 (9)      | 2880±1.20     | 2.18         |                                         |                               |
|       | F         | 45.90 | 0.688 | 5.08                  | 7.67        | 2442                     | 15880            | 13760±0.58<br>(87)                                                                                                                                                  | 1540±2.25<br>(10) | 180±5.56<br>(1)   | 400±2.50 (3)      | 5720±1.40     | 0.37         |                                         |                               |
|       | H         | 22.20 | 0.150 | 5.37                  | 0.94        | 6041                     | 5060             | 3600±2.78<br>(69)                                                                                                                                                   | 860±4.65<br>(10)  | 120±3.33<br>(1)   | 480±1.67<br>(20)  | 9800±0.61     | 2.20         |                                         |                               |

Note: \*BFL – burned forest litter.

organisms is lower in the soils affected by fire in comparison to the control sample. It was found that both the total microflora and the quantity by groups is higher at a depth of 0–5 cm, as compared to the lower layer of soil, and the drop is statistically significant in SS No2 – 64 times. It should be noted that the amount of total microflora is higher in the top-soil layer from both sampling sites influenced with crown fire (SS No1 and 2) in comparison with that affected by surface fire (SS No3 and 4). At the deeper soil layer (5–20 cm), however, this quantity sharply decreased. According to some authors (Keeley 2009, Pérez-Izquierdo et al. 2021) the crown fire leads to accumulation of a bigger amount of biomass, respectively, organic compounds in soil surface layer, which in turns impacts fungal biomass and community.

The results for the number of microorganisms in the samples from forest floor show maxima in the fermentation layer (F layer), wherein the amount of non-spore-forming bacteria, bacilli and *Actinomycetes* is highest compared to L and H layers (Table 2). This is important for understanding the destruction of organic and inorganic compounds. According to research of Grishakina et al. (2006) the processes of organic nitrogen mineralization were the most intensive in the upper (L and F) sub-horizons of the litter. However, according to the results of our study the higher quantity of microorganisms does not always imply a higher activity, which is confirmed by values of mineralization coefficient – it is obstructed in the fermentation bed, as the ratio between the amonifying bacteria and bacteria assimilating mineral nitrogen is 3:1. This fact determines low rate of degradation of organic substance and, respectively – a low coefficient of mineralization in F layer, which is 6 times lower than that of L and H

layers from control sampling site.

Mineralization ratio expresses the degree and direction of the transformation processes in soil. It is a consequence of different roles of microorganisms in transformation of organic and inorganic substances. For all studied variants, non-spore-forming bacteria and bacilli dominate, which is a conformation or confirmation for slow mineralization processes of organic matter. The lowest mineralization coefficient of 0.16 and the highest amount of non-spore-forming bacteria was found for the surface soil horizon of SS No2. A similar trend of that coefficient was observed for other sampling sites under coniferous trees. Obviously, the leaves of broadleaf species in forest litter of SS No4 decompose faster than those of conifers, due to the lower content of compounds which are difficult to be decomposed. Similar results were presented by Prescott et al. (2000), studying decomposition rate of broadleaf and needle litter in forests of British Columbia.

At all sites tested the highest share of total microorganisms is composed of non-spore bacteria and bacilli and the trend is again a decrease in depth. The lowest quantity is the one of *Micromycetes* and *Actinomycetes* which were developed mainly in high humidity and low pH. These groups of microorganisms are present in higher amounts in the soil of SS No 2, 3 and 4 in burnt organic matter – presumably as an initial response where several soil parameters simultaneously changed – elevated temperatures, low humidity, and higher pH values, accumulation of burnt plant residues (forest litter) and soil organic carbon. For all studied cases, the bacilli quantitate in the surface layer of 0–5 cm of soil and in F layer of forest litter of the control sampling site is higher in comparison with the deeper layer of 5–20 cm.



The quantity of bacilli in the soil after fire is higher in comparison with the soil of the control trial plot, which is determined by the fact that they are spore-forming microorganisms. The number of bacteria, assimilating mineral nitrogen is highest in the topsoil and have the biggest decrease in depth (42 times) in the control soil, which correlates with the most pronounced reduction in depth of the nitrogen in it (2 times) in comparison to the soils affected by fire. Forest fires change the specific composition of microbial communities from soil. After them mushrooms are more reduced than bacteria (Bååth et al. 1995, Onet et al. 2019). In the burned soils, the relative number of spore-forming bacteria is higher as they are more heat resistant and consequently less affected by fire (Bárcenas-Moreno et al. 2011).

A lower quantity of microorganisms in the soil was found in cases of surface fire compared to the results, obtained in variants with crown fire (Table 1). Obviously, the difference in soil heating during different fire type of propagation patterns influences the metabolism and productivity of microorganisms. The higher soil moisture values, measured in 5–20 cm soil layer of SS No4, affected by surface fire could be in result of an increased hydrophobicity,

when the soil organic carbon transforms. This phenomenon occurs during the combustion process when distilled aliphatic hydrocarbons migrate along the soil profile and condense on soil particles forming a water-repellent layer. MacDonald and Huffman (2004) found that the soil surface in sites affected by fire at high and moderate severity was significantly more water repellent than soil surface in unburned sites.

The highest amount of burnt forest litter was found for sampling site No 2, for which a large amount of total microflora was found. For it, the lowest values of mineralization coefficient were established (Table 2). The mineralization of litter depends on temperature and humidity, as well as on chemical composition of plant material (Kuiters and Sarink 1986). Changes of water-holding capacity and physical properties of soil affected by fire are resulted in reduction in water resistance of the aggregate's stability, which in turn contributes to their degradation and soil compaction. Under these conditions, the multiplication of anaerobic microorganisms' groups increases in the areas affected by fire.

Correlation analysis is presented in tables 3 and 4, figures 1 and 2.

**Table 3. Correlation coefficient (R) for forest litter.**

| Forest litter                 | C       | N       | pH      | Moisture | Stock   | Total microflora | Coefficient of mineralization |
|-------------------------------|---------|---------|---------|----------|---------|------------------|-------------------------------|
| C                             | 1       |         |         |          |         |                  |                               |
| N                             | 0.8289  | 1       |         |          |         |                  |                               |
| pH                            | -0.1757 | -0.4443 | 1       |          |         |                  |                               |
| Moisture                      | 0.2539  | 0.3390  | -0.6322 | 1        |         |                  |                               |
| Stock                         | -0.5577 | -0.6345 | 0.5283  | -0.6565  | 1       |                  |                               |
| Total microflora              | -0.1034 | -0.2441 | -0.0737 | 0.7026   | -0.1960 | 1                |                               |
| Coefficient of mineralization | -0.0727 | 0.3236  | -0.5888 | -0.1958  | -0.0640 | -0.6877          | 1                             |

Table 4. Correlation coefficient (R) for soil.

| Soil                             | Soil depth | C       | N       | pH      | Mois-<br>ture | Soil<br>density | Total mi-<br>croflora | Coefficient of<br>mineralization |
|----------------------------------|------------|---------|---------|---------|---------------|-----------------|-----------------------|----------------------------------|
| Soil depth                       | 1          |         |         |         |               |                 |                       |                                  |
| C                                | -0.5810    | 1       |         |         |               |                 |                       |                                  |
| N                                | -0.3978    | 0.8606  | 1       |         |               |                 |                       |                                  |
| pH                               | -0.4784    | 0.3546  | 0.3005  | 1       |               |                 |                       |                                  |
| Moisture                         | 0.4707     | -0.3191 | -0.1483 | -0.4940 | 1             |                 |                       |                                  |
| Soil density                     | 0.0521     | -0.4270 | -0.4644 | 0.1906  | -0.0970       | 1               |                       |                                  |
| Total microflora                 | -0.5272    | 0.0727  | 0.0706  | 0.6428  | -0.3085       | 0.2550          | 1                     |                                  |
| Coefficient of<br>mineralization | -0.0010    | 0.3579  | 0.3188  | -0.5360 | -0.2298       | -0.5210         | -0.4622               | 1                                |

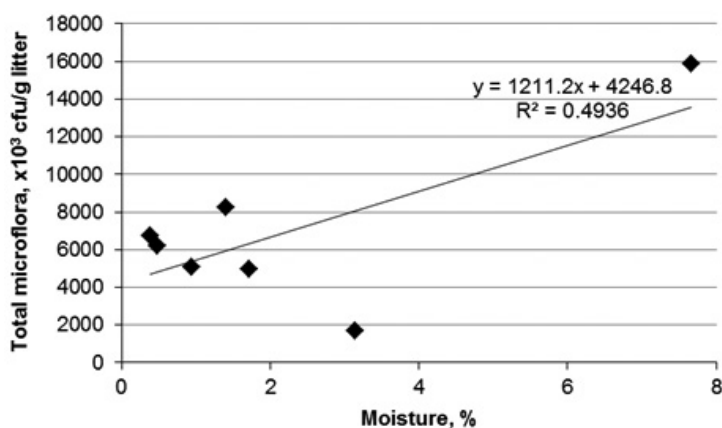


Fig. 1. Dependence between total microflora and humidity (forest litter samples).

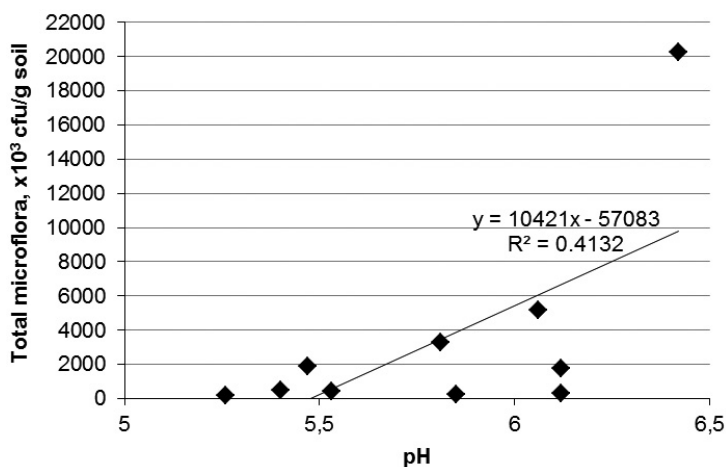


Fig. 2. Dependence between total microflora and pH (soil samples).

The applied correlation analysis showed the strongest correlation between total microflora and moisture content for forest litter samples and between pH and total microflora for soil samples.

## Conclusions

Changes in soil bulk density induce changes in soil carbon movement processes of transformed soil organic compounds and fine soil particles. Forest fires influence soil organic carbon content depending on type of fire – crown or surface.

The total amount of microorganisms is higher in fire-affected soil in comparison to that of control unaffected one. This specificity is influenced both by the type of forest and by the type of fire. A higher quantity of microbes was isolated from the soil under European larch and from sites affected by crown fire.

The composition of microbial coenosis is not affected by fires in relation to non-spore forming bacteria and bacilli – these groups of microorganisms dominate both the affected and unaffected by fire soils. There is change in the degree of dominance of *Actinomycetes* and *Micromycetes* – their percentage is higher in the composition of microbial coenosis in the control soil compared to burned soils.

A close correlation of certain indicators (total microflora, non-spore-forming bacteria, mineralization activity) has been established between soils affected by surface fires and the control soil, which is premised on their close values of organic carbon, nitrogen, pH and moisture. These indicators vary considerably in soils affected by crown fire and the control soil. Correlation analysis revealed the strongest dependence between total microflora and forest litter moisture and pH for soil samples.

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## LONG-TERM HEAVY METAL POLLUTION OF SOILS AND ITS IMPACT ON BACTERIAL CARBON METABOLISM

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### Abstract

Heavy metal pollution of soils may change their chemical and microbiological status. Changes in the function of decomposer communities may cause disruption in soil nutrient cycling and primary productivity of an ecosystem. In the present study, bacterial capacity to utilize different carbon substrates under heavy metal stress was evaluated by using community level physiological profiling technique and Biolog EcoPlate™ method. Soil samples were taken from the vicinity of mine Chelopech along Cu gradient and co-pollutants Zn and Pb. Soil texture was classified as loam, soil pH was defined as acidic, and soils were determined as well nutrient abundant. Soil concentrations of Cu, Zn and Pb varied in the range of 51–860 mg·kg<sup>-1</sup>, 44–180 mg·kg<sup>-1</sup> and 31–175 mg·kg<sup>-1</sup>, respectively. Both, the capacity of impacted bacterial communities to utilize organic carbon substances and bacterial functional diversity decreased under the heavy metal stress. Bacteria from un-polluted soils preferentially utilized carbohydrates and polymers, whereas the heavy metal stressed bacterial communities preferentially used proteinogenic and non-proteinogenic carboxylic acids. The highest levels of adverse impacts were recorded both at seriously polluted soil, and on the utilization of amines and carbohydrates. Local variability of soil properties might modify the effects of heavy metals. It can be concluded that the EcoPlate™ method can be used to evaluate community functional variability in relation to different levels of heavy metal stress, as statistically significant results have been obtained.

**Key words:** CLPP, EcoPlate™, heavy metal, mining activities, soil pollution.

### Introduction

Soil microorganisms are crucial agents of terrestrial ecosystems promoting the nutritional cycling, soil fertility and energy flow through the decomposer food web (Mas-

sensini et al. 2015, Klimek et al. 2016). Thus, soil microorganisms are strongly susceptible to soil properties, including the effects of various soil pollutants.

Heavy metals (HMs) are the most widespread pollutants, which may signif-



icantly accumulate in soils of industrial and mining areas. Large accumulation may decrease microbial biomass, activity and community structure (Juwarkar et al. 2007, Wang et al. 2007, Chodak et al. 2013, Lenart-Boroń and Boroń 2014, Xie et al. 2016). In this context, microorganisms can play the role of soil quality indicators of the adverse effects of HMs on soil biota. Heterotrophic bacteria are an important part of soil microbial communities closely involved into the organic matter turnover (Massensini et al. 2015). Generally, heterotrophic bacteria can be described as metabolically heterogeneous (Haferburg and Kothe 2012), and from ecological perspective, determining the changes in their metabolic profiles under HM stress can give valuable information about the capacity of impacted soils to maintain high fertility and primary productivity.

One of the tools appropriate for analysis of bacterial functional diversity is the community level physiological profiling (CLPP) technique (Garland and Millis 1991). Its application is an indirect technique for profiling the changes in carbon metabolism of bacterial communities under pollution stress. CLPP technique uses different microplate systems for bacteria evaluation, but Biolog EcoPlate™ system was created especially for ecological studies, containing 31 naturally disperse carbon substrates (Insam 1997). The advantages of CLPP over other microbial techniques are the simplicity of the protocol and the largely reduced cost. However, some limitations based on its biases as a culturing method were reported – the potential preference of fast growing copiotrophic bacteria (*r*-strategists of ecological point of view), incubation regime, etc. (Preston-Mafham et al. 2002, Lladó and Baldrian 2017).

The aim of the study was to assess the differences in bacterial functional profiles from HM (Cu, Zn and Pb) polluted soils, using Biolog EcoPlate™ system. Even considering the biases mentioned above, the method should be able to identify shifts in bacterial catabolism under HM stress. Although the method preliminarily identifies the activity of copiotrophic bacteria, the results should be indicative for potential impact of HMs on dead organic matter decomposition because the copiotrophs are the key players in the soil carbon cycling.

## Materials and Methods

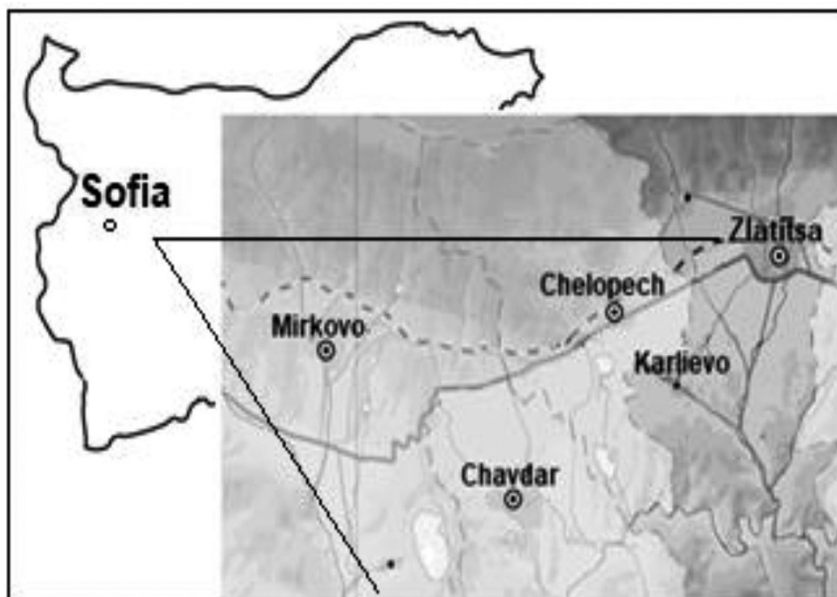
### Study area and soil sampling

The study area is in the region of Chelopech mine located in the central-western part of Bulgaria (Fig. 1). The mine has begun operations since 1954 and its exploitation caused soil HM pollution over time (Dinev et al. 2008).

Sampling was done in May 2018 along a gradient of soil Cu concentrations (co-pollutants Zn and Pb) in the vicinity of Chelopech (42.6995° N, 24.0847° E; Chel\_1.1, Chel\_1.2, Chel\_4.1, Chel\_6.1, Chel\_1.2, Chel\_7.1 and Chel\_7.2), Chavdar (42.6599° N, 24.0561° E; Chav\_3.1 and Chav\_3.2) and Karlievo (42.6852° N, 24.1059° E; Karl\_5.1 and Karl\_5.2) villages. Five subsamples both per site and soil depth [0 – 20 cm (Chel\_1.1, Chel\_4.1, Chel\_6.1, Chel\_7.1 and Karl\_5.1) and 20 – 40 cm (Chel\_1.2, Chel\_6.2, Chel\_7.2 and Karl\_5.2)] were pooled randomly and used for further analyses.

### Soil abiotic variables

Soil pH was measured in 0.01 mol L<sup>-1</sup> CaCl<sub>2</sub> (ISO 10390:2005). Soil texture was



**Fig. 1. Sampling locations (Chelopech, Chavdar and Karlievo villages) in the region of Chelopech mine.**

determined by Kachinsky method (1958), and the total organic carbon (TOC) – according to Chen et al. (2014). Soil nitrate ( $\text{NO}_3\text{-N}$ ) and ammonium ( $\text{NH}_4\text{-N}$ ) nitrogen, and inorganic phosphates ( $\text{P}_2\text{O}_5$ ) were determined according to the methods of Keeney and Nelson (1982) and Olsen (1982), respectively. Soil moisture (SM) was calculated after oven drying ( $105^\circ\text{C}$ ). The total concentrations of HMs were analysed by ELAN 5000 Inductively Coupled Plasma Mass Spectrometer (Perkin-Elmer, Shelton, CT, USA) according to ISO 11047:1998 after soil decomposition by *aqua regia* (total HMs) and soil extraction with 0.01 M  $\text{CaCl}_2$  (bioavailable forms of HMs). Nemerow's pollution index (NPI; Cheng et al. 2007) was calculated, using the total HM soil concentrations, in order to express by single value the level of pollution. The soils were classified as un-polluted at  $\text{NPI} < 0.7$ , and precaution ( $0.7 \leq \text{NPI} < 1.0$ ), slightly ( $1.0 \leq \text{NPI} < 2.0$ ),

moderately ( $2.0 \leq \text{NPI} < 3.0$ ) and seriously ( $3.0 \leq \text{NPI}$ ) polluted, after which were grouped for analysis as follows: un-polluted (Chel\_1.1 and Chel\_1.2), precaution (Chav\_3.1 and Chav\_3.2), slightly (Chel\_6.1, Chel\_6.2, Chel\_7.1 and Chel\_7.2), moderately (Chel\_4.1 and Karl\_5.2) and seriously (Karl\_5.1) polluted. Different levels of soil pollution were noted as un-polluted (UnP), precaution (PrP), slightly (SIP), moderately (MoP) and seriously (SeP) polluted. The results are given as means and standard errors for the respective pollution level, except SeP, where the means and standard errors were for sampling repeats ( $n=5$ ) of Karl\_5.1.

### **Bacterial functional profiling**

Biolog Ecoplates™ system, containing 31 carbon substrates (CSs) in three replicates (Biolog Inc., Hayward CA, USA)

were applied to evaluate the changes occurred in CLPPs under HM stress. The microplates' wells were inoculated with 120  $\mu\text{L}$  bacterial cell suspensions - 1 g soil in 50 mL sterile 0.9 percent NaCl, suspended for 30 min at 240 rpm followed by filtration through 8.0  $\mu\text{m}$  and 3.0  $\mu\text{m}$  pore size membranes. The microplates were incubated at 25  $^{\circ}\text{C}$  in dark. Substrate utilization was monitored every 12 h by measuring absorbance at 590 nm using Microplate Reader LKB 5060-006 and software package DV990 'Win 6'. The measurements of CSs were corrected for background absorbance by subtracting the absorbance of control (water) sample. CSs with corrected optical density (OD) less than 0.25 were considered as non-oxidized and their values were set to zero (Garland 1996). Biolog CSs were grouped according to Weber and Legge (2009) into five carbon guilds (CGs) depending on their chemical moieties: carbohydrates (CH), polymers (Polym), carboxylic acids (CA), amino acids (AA), and amines/amides (Amin). The changes in CLPPs were evaluated calculating the average well colour development (AWCD) according to Garland and Mills (1991) and the maximum utilization rate (MUR) of CG. AWCD and MUR were expressed as CSs' utilization curves (AWCD) and point data at 92 h (MUR). AWCD manifested the total potential of copiotrophic bacteria to metabolize Biolog CSs, whereas MUR indicated bacterial ability to metabolize different guilds of organic substances (CH, Polym, CA, AA and Amin) as both carbon and energy sources.

### Data analysis

One-way ANOVA followed by Tukey's test were performed to examine the differences in values of soil properties and bacte-

rial variables. Pearson correlation analysis was passed to identify environmental – bacterial relationships. Above statistics were performed with the package PAST (Hammer et al. 2001) at a level of significance  $p < 0.05$ .

## Results and Discussion

### Soil environments

Soil textures were classified as loam (UnP, PrP, SIP and MoP) to silt loam (SeP) with pH varying according to SSDS (2017) classification from very strong acidic (MoP) through strong acidic (PrP and SeP) to moderate acidic (UnP and SIP) (Table 1). Soils were well abundant of nutrients with TOC varying from 13.95  $\text{mg}\cdot\text{kg}^{-1}$  to 26.86  $\text{mg}\cdot\text{kg}^{-1}$ , and the variability of  $\text{P}_2\text{O}_5$  and inorganic nitrogen ( $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$ ) ranged from 7.48  $\text{mg}\cdot\text{kg}^{-1}$  to 11.46  $\text{mg}\cdot\text{kg}^{-1}$  and from 8.58  $\text{mg}\cdot\text{kg}^{-1}$  to 49.04  $\text{mg}\cdot\text{kg}^{-1}$ , respectively. The outliers of the general trend of soil nutrient variability were  $\text{NO}_3\text{-N}$  concentrations in UnP and PrP soils.

Cu exceeded Bulgarian maximum permissible concentrations (MPC, 80  $\text{mg}\cdot\text{kg}^{-1}$ ) in all soils except UnP, whereas Zn concentrations were under MPC (200  $\text{mg}\cdot\text{kg}^{-1}$ ), and Pb was above (60  $\text{mg}\cdot\text{kg}^{-1}$ ) in MoP and SeP (Table 2). According to Bulgarian legislation, MPC is the soil HM content ( $\text{mg}\cdot\text{kg}^{-1}$ ), the exceeding of which under certain conditions leads to soil function disturbance and a risk for environment and human health.

Cu in polluted soils exceeded the background values (UnP) by 1.71 (PrP) – 16.86 (SeP) times. Zn and Pb concentrations were by 0.5–0.8 (PrP – SIP) to 2.0 (SeP) and by 1.0–1.5 (PrP – SIP) to 5.0 (SeP) times higher than the background values, respectively.

**Table 1. Soil physico-chemical properties given as means and standard errors (in brackets).**

| Soil | pH     | Sand   | Silt   | Clay   | SM     | TOC    | P <sub>2</sub> O <sub>5</sub> | NO <sub>3</sub> -N | NH <sub>4</sub> -N |
|------|--------|--------|--------|--------|--------|--------|-------------------------------|--------------------|--------------------|
|      |        |        | %      |        |        |        |                               |                    |                    |
| UnP  | 5.70   | 45.60  | 37.40  | 17.00  | 5.15   | 13.95  | 8.92                          | 40.82              | 2.19               |
|      | (1.10) | (0.00) | (0.00) | (0.00) | (0.15) | (0.91) | (6.57)                        | (2.13)             | (0.27)             |
| PrP  | 5.10   | 45.00  | 35.80  | 19.20  | 7.65   | 17.44  | 6.75                          | 45.39              | 3.66               |
|      | (0.20) | (0.00) | (0.00) | (0.00) | (0.92) | (7.91) | (2.17)                        | (17.08)            | (1.11)             |
| SIP  | 5.76   | 44.90  | 38.14  | 16.96  | 5.43   | 20.73  | 7.48                          | 6.60               | 3.29               |
|      | (0.27) | (0.46) | (0.03) | (0.54) | (0.80) | (2.08) | (1.16)                        | (2.35)             | (0.57)             |
| MoP  | 4.80   | 41.00  | 40.40  | 18.60  | 5.80   | 26.86  | 11.46                         | 3.71               | 4.87               |
|      | (0.00) | (6.92) | (6.72) | (0.21) | (1.06) | (1.72) | (1.59)                        | (0.95)             | (0.89)             |
| SeP  | 5.20   | 31.30  | 49.80  | 18.90  | 7.30   | 16.86  | 10.90                         | 8.32               | 2.60               |
|      | (0.06) | (0.00) | (0.00) | (0.00) | (0.93) | (0.71) | (0.64)                        | (1.51)             | (0.11)             |

**Table 2. Soil concentrations of total (Cu, Zn and Pb) and bioavailable (Cu<sup>a</sup>, Zn<sup>a</sup> and Pb<sup>a</sup>) forms of heavy metals, and respective NPI.**

| Soil | Cu                  | Zn      | Pb            | Cu <sup>a</sup> | Zn <sup>a</sup> | Pb <sup>a</sup> | NPI    |
|------|---------------------|---------|---------------|-----------------|-----------------|-----------------|--------|
|      | mg·kg <sup>-1</sup> |         |               |                 |                 |                 |        |
| UnP  | 51.00               | 88.25   | 31.25         | 0.19            | 0.13            | 0.08            | 0.59   |
|      | (2.00)              | (1.76)  | (3.76)        | (0.01)          | (0.10)          | (0.02)          | (0.02) |
| PrP  | <b>89.00</b>        | 44.50   | 33.30         | 0.23            | 0.22            | 0.09            | 0.91   |
|      | (2.50)              | (2.50)  | (1.70)        | (0.02)          | (0.04)          | (0.04)          | (0.02) |
| SIP  | <b>134.16</b>       | 72.80   | 48.48         | 0.55            | 2.48            | 0.16            | 1.36   |
|      | (9.56)              | (8.39)  | (6.31)        | (0.03)          | (0.21)          | (0.04)          | (0.10) |
| MoP  | <b>251.75</b>       | 102.50  | <b>91.25</b>  | 0.38            | 1.61            | 0.18            | 2.48   |
|      | (12.90)             | (15.91) | (16.78)       | (0.09)          | (0.67)          | (0.05)          | (0.09) |
| SeP  | <b>860.00</b>       | 180.00  | <b>175.50</b> | 0.65            | 3.30            | 0.08            | 8.24   |
|      | (9.06)              | (1.37)  | (3.15)        | (0.04)          | (0.12)          | (0.03)          | (0.07) |

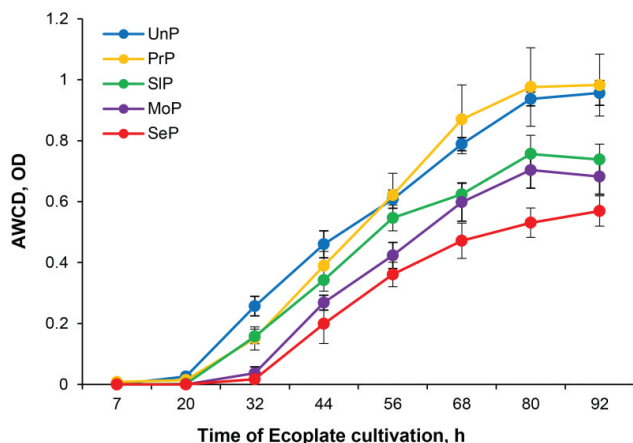
Note: HM concentrations that exceeded Bulgarian MPC (Regulation 3, 2008) are given in bold.

Many reports, dedicated to HM soil pollution, evidenced that not the total but the mobile (bioavailable) forms of HMs were toxic for soil organisms (Krishnamurti and Naidu 2002, Rensing and Maier 2003, Gobran and Huang 2005, Brandt et al. 2006, Krishnamurti and Naidu 2008, Xiao et al. 2017). The study found that the bioavailable forms of HMs increased by increasing the levels of soil pollution, being under 0.5 % of total concentrations, except Zn<sup>a</sup>

which concentrations were 3.4 % (SIP), 4.27 % (MoP), and 1.83 % (SeP) of total. The relation between total and bioavailable forms of HMs was not significant ( $p > 0.05$ ), suggesting that not only the level of pollution but also some other local soil peculiarities, such as pH, clay and organic matter content (Krishnamurti and Naidu 2002, Gobran and Huang 2005, Magrisso et al. 2009), might control the concentrations of bioavailable HMs in soils.

## Total bacterial catabolic potential

AWCD was used to evaluate bacterial catabolic potential to utilize Biolog carbon sources under increasing levels of soil HM pollution (Fig. 2).



**Fig. 2. AWCD of increasing levels of heavy metal polluted and un-polluted soils.**

AWCD curves show a general sigmoidal shape, varying in the values of lag-phase (time for adaptation) and slope (maximum utilization rate) in a context of soil HM pollution. HMs affected negatively bacterial catabolic activity, except that of PrP, where the effects were positive. The stimulation effects were manifested by increase of curve slope from 0.121 (UnP) to 0.123 (PrP). For other soils, the curve slopes decreased compared to UnP by 21 % (SIP), 30 % (MoP) and 44 % (SeP). The trend of decrease in maximum utilization rates of Biolog carbon sources was accompanied by the trend of lag-phase increase following the order: 7 h (PrP) < 20 h (UnP and SIP) < 32 h (MoP and SeP). We assumed that the increased bacterial activity in PrP might reflect that Cu and Zn are essential metals for bacterial functioning and in low concentra-

tions act as stimulants for the microbial communities as it was reported by Bruins et al. (2000) and Gadd (2010). At higher HM levels, both essential (Cu and Zn) and nonessential (Pb) metals can damage bacterial cell membranes, alter enzyme specificity, disrupt cellular functions, and damage the structure of DNA. Our results are consistent with the studies of Gryta et al. (2014), Kenarova et al. (2014) and Kuźniar et al. (2018) who all reported decrease of bacterial potential to catabolize carbon sources under metal stress.

Additionally, an interesting phenomenon is clearly manifested on Figure 2 – AWCD curves are very close to each other early on (0–68 h) but diverged later (68–92 h) over the course of time. We suggested that at the beginning of EcoPlates' cultivation, AWCD was dominated by few metal tolerant copiotrophic species, which were positively selected by the high nutrient levels in the wells – phenomenon demonstrated by other authors (Preston-Mafham et al. 2002). After 68 h, the increased curves' divergence might reflect the growth of other species, low abundant, which number/activity inversely correlated with the levels of HM stress. The manner of delayed curve divergence on Figure 2 confirmed the above mentioned suggestion, indicating the highest bacterial functional (metabolic) diversity in UnP and PrP and the lowest one in SeP. Similar phenomenon of late curve divergence was evidenced by Muñiz et al. (2014) and Yuangen et al. (2006) in their experiments, studying the HM effects on bacterial functional diversity.

## Kinetics of carbon guilds' utilization

To further compare the catabolic diversity among different levels of soil HM pollution, Biolog carbon sources were grouped into carbon guilds. The ratio of CGs' utilization rates in AWCD and their kinetic curves are shown on figures 3a and 3b-f, respectively.

UnP's bacterial metabolism was well balanced (Fig. 3a), and the share of CGs'

utilization in AWCD value (point data at 92 h) slightly decreased in the order: Amin > Polym ≥ CH > CA ≥ AA. CGs' utilization over time formed sigmoidal curves, which differed each other by the longevity of lag-phase and the value of curve slope (Fig. 3b-f). In general, HM stress caused extinction of lag-phase (except at CH for PrP – MoP) and decrease into the curve slopes (except AA and CA for PrP).

CGs' utilization under stress delayed

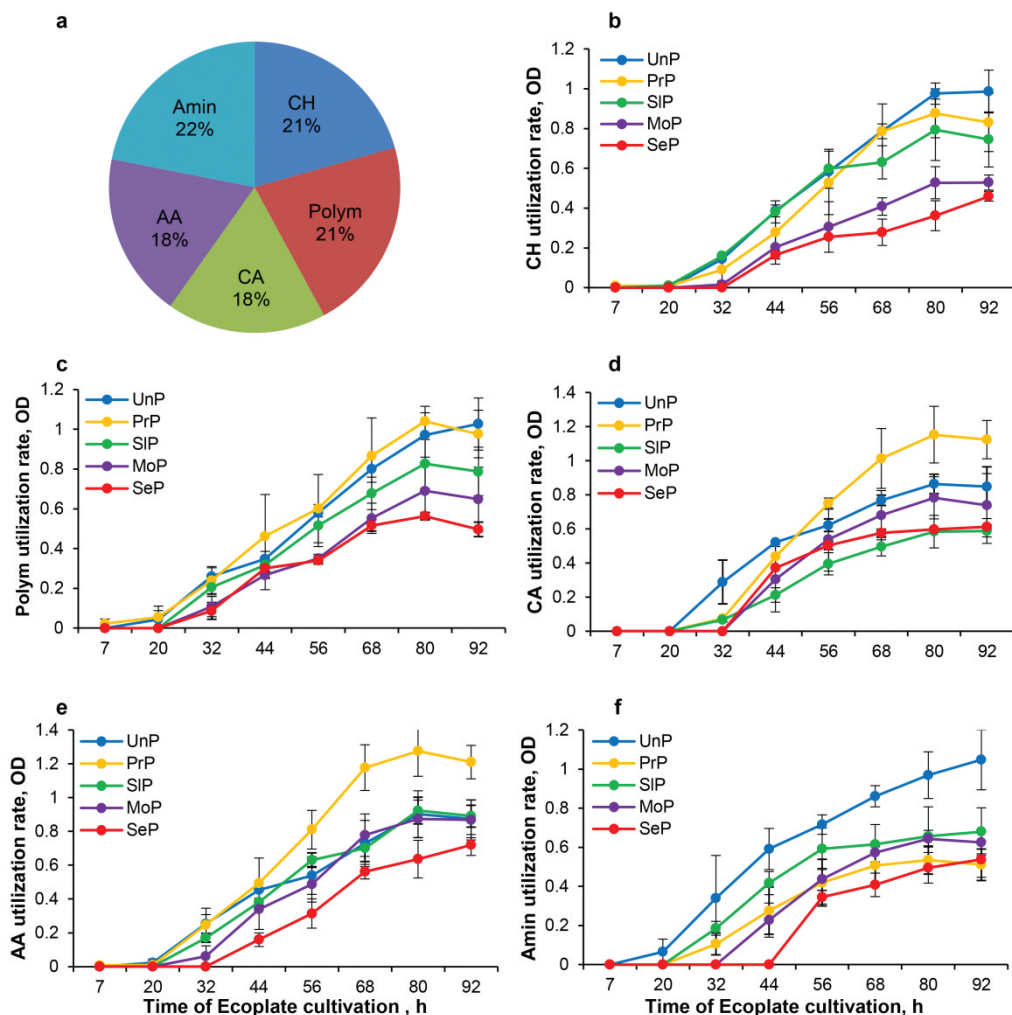


Fig. 3. Ratio of CGs' utilization rates in AWCD (a), and kinetic curves.



commonly by 12 and more hours. For example, the utilization of AA and Amin at SeP soil delayed by 24 h and 36 h, respectively, compared to UnP. A twenty-four-hour delay was recorded also for Amin utilization at MoP soils. On the other hand, HM stress shortened the lag-phase of CH sigmoidal curves of PrP, SIP and MoP soils. This fact indicated that the enzymes involved into carbohydrate catabolism in HM impacted cells were already synthesized, probably to gain more energy for stress overcoming. The highest level of soil pollution (SeP) inhibited this process.

It was recorded that bacterial catabolism misbalanced under HM stress. The curve slopes (MUR) under soil pollution decreased and the ratio between the utilization rates of CGs within AWCD changed. The curve slopes of HM impacted CGs' utilization decreased in the order: PrP: AA > CA > Polym > CH > Amin; SIP: AA > Polym > CH  $\geq$  Amin > CA; MoP: AA > CA > Polym > Amin > CH; SeP: CA > AA > Polym > Amin > CH. Under HM impact, the most preferable CGs were AA and CA and the less preferable - Amin and CH. Some exception was evidenced for SIP soils, probably due to the modulating effects of some local soil peculiarities.

Similar shifts in metabolic profiles were evidenced in earlier experiments (Yuangen et al. 2006, Kenarova et al. 2014, Muñiz et al. 2014, Kuźniar et al. 2018), where it was found that AA was the most intensively metabolized CG by HM stressed soil bacteria, whereas CH and Polym were preferred carbon sources by un-impacted ones. What was the reason of bacterial catabolic shift under stress was not clear. We suggested that HM stress induced detoxification mechanisms in microbial and plant cells involving AA synthesis – macromolecules that

could later be metabolized by the soil microbiota, which was demonstrated in the reports of Hall (2002) and Sharma and Dietz (2006).

The highest decrease of MUR was detected for SeP. Compared to UnP, MUR of CA and AA decreased by 30 % each; Polym, Amin and CH decreased by 43 %, 56 % and 60 %, respectively.

However, some stimulation effects compared to UnP were observed – for example, MUR of AA, CA and Polym at PrP increased by 42 %, 23 % and 4 %, respectively.

The late kinetic curve divergence was observed almost for all CGs (Fig. 3b-f), and the mode of divergence corresponded to the respective CG. ANOVA analysis of kinetic curves (covered only the period of curve divergence: 68–92 h) confirmed the significance of divergence pattern. Because we assumed that the late kinetic curve divergence reflected the functional diversity of soil bacterial communities growing on the respective CG, we could notice that: 1) functional diversity of Amin utilizing bacteria was the highest at UnP and it was reduced even by the lowest HM pollution level ( $p < 0.001$ ); 2) HM pollution stimulated the functional diversity of bacteria on AA (PrP;  $p = 0.000$ ) and CA (PrP and SIP;  $p < 0.001$ ), and inhibited that at SeP (AA:  $p = 0.023$  and CA:  $p = 0.002$ ); 3) CH and Polym compared to UnP supported less functionally diverse communities at SIP (CH;  $p = 0.045$ ), MoP (CH and Polym;  $p < 0.007$ ) and SeP (CH and Polym;  $p < 0.001$ ).

## Conclusion

Chelopech mining activities caused HM (Cu, Zn and Pb) accumulation in soils, being classified according to NPI, as precau-

tion to seriously polluted ones. HM pollution affected negatively the catabolic activity of impacted bacterial communities, decreasing their potential to metabolize soil organic carbon matter. HM pollution decreased the functional diversity of bacterial communities capable to utilize Amin (PrP – SeP), and CH and Polym (SIP – SeP). Low (PrP – SIP) and high (MoP – SeP) levels of HM pollution increased and decreased, respectively, the functional diversity of bacteria capable to utilize CA and AA. The above results conclude the suitability of Biolog EcoPlate™ method for studies on soil bacterial carbon metabolism under HM pollution.

## Acknowledgement

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# STATE OF COENOPOPULATIONS OF *QUERCUS ROBUR* L. GROWING IN RAVINES LOCATED IN THE DNIEPER RIVER'S RAPIDS SECTION (RECREATION ZONE OF THE CITY OF ZAPORIZHZHYA), UKRAINE

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## Abstract

The research was conducted in three typical ravine forests of the southern variant of the Ukrainian Steppe. The age and vitality structure were studied, demographic characteristics of *Quercus robur* L. coenopopulations in 1999 and 2019 were calculated and changes that occurred over a 20-year period were analyzed. These forests are subject to a high anthropogenic pressure, being a part of the recreational area of residents of the large industrial city of Zaporizhzhya as well as tourists visiting the island of Khortytsia. There is a gradual change of the structure of the elementary demographic unit of the coenopopulation of *Q. robur* with an increase in anthropogenic impact starting from spotted and then through diffuse to eventually becoming pointlike. Coenopopulations of this edificator species sampled from the ravines under study are many-component and have a bimodal real spectrum. During the study period, significant changes occurred in the left, pregenerative parts of the spectrum and are associated with the changes in the quantitative ratios of juvenile, adult and virginile individuals. As a result of recreational exposure, the range of variants of ontogenetic development of *Q. robur* decreases, and the variants themselves include a smaller number of age states. Estimation of the state of *Q. robur* coenopopulations using eight demographic indices showed some decrease in the regenerative potential and increase in the share of generative and postgenerative individuals in the coenopopulations of Heneralka and Khortyts'ka gullies. Due to the decrease of the anthropogenic impact, the changes in Shyroka gully are less apparent. All coenopopulations of *Q. robur* are young and have significant adaptive potential. Therefore, they are capable of sustainable generational turnover even in case of low amount of specimens.

**Key words:** adaptive potential, age and vitality structure, edificator, polyvariance of ontogenesis.

## Introduction

Common oak (*Quercus robur* L.) is one of the main forest-forming and most valuable deciduous trees of Ukraine from an

economical standpoint (Slyepkyh and Korshykov 2016, Kopyi et al. 2017). During the process of its growth and development, it is capable to form mixed in composition and complex in structure

relatively high-yielding and biologically relatively stable tree groups under favourable conditions (Dyatlov 2007). *Q. robur* is highly valued for its high-quality wood, which is strong, flexible, durable and with a beautiful structure. On the one hand, *Q. robur* is a source of natural raw material, the stands of which perform various environmental functions, and on the other hand, it is a tree species that is constantly negatively affected, which results in a significant reduction of oak stands (Puryaev et al. 2019). Weakening of the resilience of natural oak forests is caused by different reasons, including the impact of two powerful environmental factors – anthropogenic pressure and global climate change, leading to their degradation and en masse dessication (Kharchenko and Kharchenko 2012). The decline of oaks in Europe is a matter of serious concern. The causes of the challenging natural regeneration of *Q. robur* and phytopathological aspects of its growth have attracted the attention of many researchers (Marçais and Desprez-Loustau 2014, Jensen and Löf 2017, Bobiec et al. 2018).

*Q. robur* is the main species of ravine forests in the southern part of the Ukrainian Steppe, which display an intrazonal character under the aforementioned conditions. Ravine forests play a role in the protection of soil, nature, erosion control, regulating water regime as wells as a recreational resource. They alone contain a valuable gene pool consisting of forest (Yakovlieva-Nosar et al. 2005, Yakovlieva-Nosar 2007, Bessonova and Zaitseva 2016, Yakovlieva-Nosar and Bessonova 2018), steppe (Bessonova et al. 2014), meadow, swamp, psammophytic and petrophytic vegetation with a number of rare and endemic species.

The ravines of the Zaporizhzhya region belong to a special geographic va-

riant – the ravines of the Dnieper Rapids area (Bel'gard 1950). Coenoses of ravine forests in the vicinity of such industrial giant as the city of Zaporizhzhya are not only affected by industrial emissions, but also suffer from large-scale recreational activities of city residents. To substantiate comprehensive measures for their conservation, it is necessary to monitor the state of natural populations of *Q. robur*.

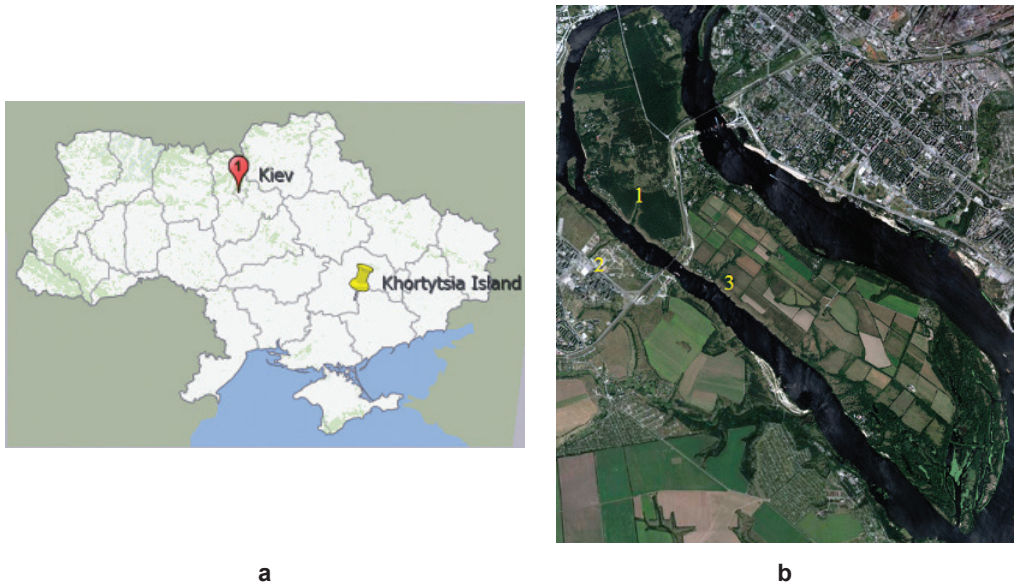
In this regard, the aim of this study was to monitor changes in age and vitality structure of populations of *Quercus robur* L. in three typical ravine forests of southeastern Ukraine, differing in the level of anthropogenic load, over the 20 year period.

## Material and Method

The analysis of the state of *Q. robur* populations was carried out in the ravine forests on the island of Khortytsya (Heneralka and Shyroka gullies) and on the right bank of the Dnieper River (Khortyts'ka gully) (Fig.1). The island of Khortytsia is located in the subzone of grass-fescue-feathergrass steppe and is part of the recreational zone of Zaporizhzhya. Khortyts'ka gully is located opposite the Heneralka gully across the Dnieper River and is an object of mass recreation for citizens. The Shyroka gully is also subject to a strong anthropogenic pressure, as the sanatorium-dispensary of the Zaporizhzhya Titanium and Magnesium Plant adjoins its north-western side. Its territory is connected to the ravine by the stairway. In addition to the transit type of recreational activities, ravine plantings are exposed to bivouac and mining forms of recreation.

According to the forest site typology characteristics determined by Bel'gard





**Fig. 1. Location of the island of Khortytsia on the map of Ukraine (a) and map of the island of Khortytsia (b) (SAS.Planet 2020).**

Note: Coordinates of the extreme points (tops and mouths) of the gullies under study: 1 – Heneralka (47°83′06.1″ N 35°06′73.5″ E; 47°82′67.9″ N 35°06′57.8″ E); 2 – Khortyts'ka (47°49′15.99″ N 35°03′18.66″ E; 47°49′27.69″ N 35°03′44.35″ E); 3 – Shyroka (47°49′23.1″ N 35°05′29.2″ E; 47°49′04.16″ N 35°05′00.24″ E).

(1971), the ravine forest of the Heneralka gully can be considered to be of type E<sub>1</sub> (birch/black maple oak forest), Shyroka gully to type Dn<sub>1-2</sub> (derived from birch-hazel type of forest with no *Fraxinus excelsior* L. and *Acer campestre* L.); Khortyts'ka gully is a degraded specimen of E trophotope with a simplified structure (mainly curtains of *Acer campestre* L. and *A. tataricum* L. with a slight admixture of other species). According to EUNIS forest type T1-99 Steppe *Quercus* forests (G1.7A1Euro-Siberian steppe *Quercus* woods) (Didukh 2020, EEA2020) (Fig. 2).

While studying the coenopopulations of *Quercus robur* L., the elementary demographic unit (EDU) was taken to be a set of individuals of the species, which

grew in each of the gullies under study and was able to self-sustain due to the cycle of generations. Ontogenetic spectra and the spatial type of EDU were established by Smirnova et al. (1993).

The localization of individuals of the generative fraction and undergrowth clusters were mapped for each of the coenopopulations under study.

The age states of *Q. robur* were determined based on the recommendations of Chistyakova (1989) and Rabotnov (1964). The generally accepted classification ( $p \rightarrow s$ ) was used for their description (Zlobin 1989, Evstigneev and Korotkov 2016). Characteristics of periods of ontogenesis and age (ontogenetic) states are given in Table 1.



Fig. 2. Phytocenosis of ravine forests (a – Heneralka, b – Shyroka).

Table 1. Ontogenetic periods and ontogenetic stages of trees.

| Ontogene-<br>tic period | Ontogenetic<br>stage | Symbol | Duration<br>(Chistyakova<br>1994) | Description (Chistyakova 1994,<br>Sklyar 2014)                                                                                                |
|-------------------------|----------------------|--------|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Latent               | (1) Seed             | se     |                                   |                                                                                                                                               |
|                         | (2) Seedling         | p      |                                   | the youngest plants that have a primary root and scaly leaves                                                                                 |
|                         | (3) Juvenile         | j      |                                   | young individuals with a trunk without branching and 3–5 green leaves of the juvenile type, which differ in size and shape from adults        |
| 2. Pregene-<br>rative   | (4) Immature         | im     | 20                                | side shoots of the II–V order appear, and the diameter of a trunk no more than 2 times exceeds diameter of lateral branches                   |
|                         | (5) Virginile        | v      | 40                                | have a characteristic morphological structure for adult plants, but such individuals have not yet entered the phase of flowering and fruiting |
|                         | (6) Young            | g1     | 60                                | crown pointed, fruiting                                                                                                                       |
| 3. Genera-<br>tive      | (7) Mature           | g2     | 120                               | capable of sparse and irregular generative crown obtuse, fruiting reproduction abundant                                                       |
|                         | (8) Old              | g3     | 140                               | crown broadly rounded                                                                                                                         |
| 4. Postgene-<br>rative  | (9) Subsenile        | ss     | 20                                | lose the ability to generative reproduction, begin to collapse                                                                                |
|                         | (10) Senile          | s      | 20                                | have a secondary crown with juvenile leaves, no fruiting                                                                                      |

The recovery index ( $I_{\text{recov.}} = \Sigma j \rightarrow v / \Sigma g_1 \rightarrow g_3$ ) was determined by the formula recommended by Zhukova (1987), which characterizes the ratio of all individuals of the pregenerative period to these of the generative period of development. We calculated the indices developed by Kovalenko, which characterize the participation of individual ontogenetic groups of individuals in the population: renewal index ( $I_{\text{renew.}} = \Sigma p \rightarrow v / \Sigma p \rightarrow s$ , characterizes the participation of all specimens of the pregenerative period), generative index ( $I_{\text{gener.}} = \Sigma g_1 \rightarrow g_3 / \Sigma p \rightarrow s$ , characterizes the participation of all specimens of the generative period of development), the aging index ( $I_{\text{aging}} = \Sigma g_3 \rightarrow s / \Sigma p \rightarrow s$ , characterizes the participation of the plants from old generative to senile), the general age index ( $I_{\text{age}}$ , represents the ratio of  $I_{\text{aging}} / I_{\text{renew.}}$ ) (Zlobin et al. 2013).

To characterize the ontogenetic structure of coenopopulations, the index  $\delta$  (Zhukova 1967), the age coefficient ( $\Delta$ ) (Uranov 1975, Zlobin 1989) and the average energy efficiency ( $\omega$ ) were calculated (Zhivotovskiy 2001).

Index  $\delta$  is the ratio of the difference between the number of old ( $P$ ) and young ( $p$ ) specimens to the total number of specimens in the population calculated by formula (1).

$$\delta = \frac{P - p}{P + p}, \quad (1)$$

The age coefficient of the coenopopulation was determined by the formula (2).

$$\Delta = \frac{\Sigma k_i m_i}{\Sigma k_i}, \quad (2)$$

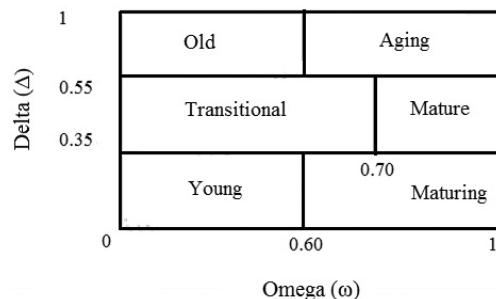
where:  $k_i$  – number of the  $i$ -th age state,  $m_i$  – age of individuals.

The energy efficiency index was calculated using the formula (3).

$$\omega = \frac{\Sigma n_i e_i}{\Sigma n_i}, \quad (3)$$

where:  $n_i$  – number of plants that belong to an  $i$ -th age state,  $e_i$  – energy efficiency of plants.

The type of coenopopulation was determined by Rabotnov (1964) taking into account the coefficient  $\Delta$  and the 'delta-omega' classification by Zhivotovskiy (2001) (Fig. 3).



**Fig. 3. Types of normal plant populations according to the 'delta-omega' classification.**

The vitality of specimens and coenopopulations was determined using classical methods (Vorontsova 1967, Zlobin 1989). The following parameters were calculated:

1) the average score of vitality of specimens as per a given period;

2) the average score of vitality of specimens in the coenopopulation calculated by formula (4):

$$F = \frac{\Sigma p}{Ns}, \quad (4)$$

where:  $p$  – points,  $Ns$  – number of specimens.

3) vitality criterion of the coenopopulation calculated by formula (5):

$$P = P_{\text{PrG}} + P_{\text{G}} + P_{\text{PsG}}, \quad (5)$$

where:  $P_{\text{PrG}}$  – vitality criterion of specimens of the pregenerative period;  $P_{\text{G}}$  – indicator of vitality of specimens of the generative period;  $P_{\text{PsG}}$  – vitality criterion of specimens of the postgenerative period.

4) criterion of relative vitality of coenopopulations calculated by formula (6):

$$P_{rel.} = \frac{P}{P_{max}}, \quad (6)$$

where:  $P_{max}$  – the largest possible vitality estimate (the sum of the products of the maximum points of vitality of individuals of each period divided by the average number of individuals of a given period).

Models of ontogenetic development were determined using the methods developed by Chistyakova (1989) and Sklyar (2014).

## Results

*Q. robur* is an edificator of the ravine forests under study with its specimens forming the first layer. In the past, this species was dominant in the ravine forests, as in the first half of the XIX century oak groves used to cover the territory of the island of Khortytsia, but uncontrolled logging led to their significant decline in the second half of the same century (Novyts'kyi 2005).

The population size of *Q. robur* in the Heneralka gully is small – only 74 individuals were found in 1999; however, this number is sufficient for self-sustaining of the population under study. 37 individuals of *Q. robur* were registered in the ravine forest of the Khortyts'ka gully, subjected to the highest recreational pressure. The population of *Q. robur* in Shyroka gully reached 318 individuals, of which 260 were full-fledged plants, and 58 became the so-called 'sticks'. This can be explained by the lack of sunlight for the young specimens to develop properly under the shadow of maternal trees. This feature of the development of the younger generation of *Q. robur* is pointed out by other authors (Kharchenko and

Kharchenko 2012, Annighöfer et al. 2015). In 2019, the number of *Q. robur* individuals was 71, 28 and 286, respectively. The total number of individuals in 1999 in the Heneralka gully was 14.0 % compared to the tree stand of the ravine forest, in the Shyroka gully – 31.3 %, in the Khortyts'ka gully – 10.8 %. Over the 20 year period of controlled observation, their share in the stands did not change substantially and in the year of 2019 it reached 12.2 %, 30.5 % and 8.1 %, respectively.

*Q. robur*, as a strong edificator, is characterized by a continuous spotted type of EDU, which is realized under optimal and suboptimal conditions (Smirnova et al. 1993). The signs of the spotted structure still remained in the area of the ravine forest of the Heneralka gully in 1999, but there was a tendency of gradual transition to EDU of the diffuse type. In the coenopopulations of *Q. robur* of Khortyts'ka and Shyroka gullies the type of EDU approached the pointlike stage, which may indicate a long-term significant impact of anthropogenic load. Only in some undisturbed areas of these gullies with the highest concentration of individuals, *Q. robur* retained its edificatory effect. No changes in the type of EDU were registered for *Q. robur* in the ravine forests under study in 2019 in comparison with 1999. Generally, there is an adaptive response of the population to prevent it from reaching a critical stage: the ability to form small-sized EDU and ensure the turnover of generations at low population size. The existence of these mechanisms is reported by Zaugol'nova et al. (1992), but also Chadayeva and Shkhagapsoyev (2016).

The age spectra of *Q. robur* coenopopulations in the studied ravine forests are presented in Figure 4. These spectra are bimodal, which is typical for species with

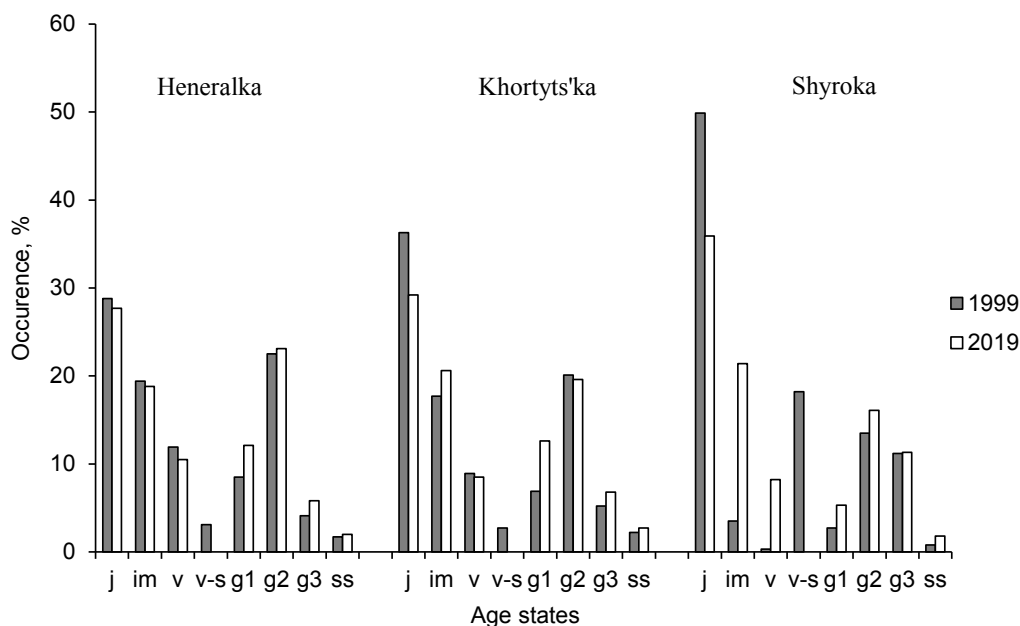


Fig. 4. Age spectra of *Q. robur* coenopopulations in ravine forests.

significant lifespan, with a well-defined period of aging and periodicity of natural regeneration, with maximum juvenile (*j*) and in most cases – middle-aged generative (*g*<sub>2</sub>) individuals. The participation of virginile (*v*) individuals was insignificant.

In 1999, the juvenile and middle-aged generative ontogenetic fractions accounted for the majority of population of the Heneralka gully. A similar pattern was observed in the ravine forest of the Khortyts'ka gully. In the Shyroka gully, the first maximum value corresponds to the specimens that belong to the juvenile age state, and the second one – to quasi-senile individuals (Fig. 2). Smirnova et al. (1984) characterizes the aforementioned 'sticks' as being compact individuals of a quasi-senile ontogenetic state.

Quasi-senility, as a phenomenon of morphological imitation of senility under adverse conditions, is viewed from the standpoint of phytocoenotic tolerance.

The share of this group among immature and virginile *Q. robur* plants, in particular in deciduous oak/hornbeam forests, can reach 20–25 %. The relative participation of quasi-senile specimens in the coenopopulations of *Q. robur* increases from south to north within its natural range. They constitute a reserve for the formation of adult plants under the low-light conditions (Smirnova et al. 1984).

Studies conducted in 2019 also showed the presence of a bimodal ontogenetic spectrum for all studied coenopopulations of *Q. robur*, with peaks observed in the areas of juvenile and middle-aged generative age states. At the end of the 20 year study period, senile individuals of *Q. robur* were absent in all of the populations under study.

It is believed that in the steppe forests the coenopopulation of *Q. robur* is characterized by an ontogenetic spectrum with the absence or suppression of imma-



ture/virginal and adolescent generative groups (Smirnova et al. 1990). Because *Q. robur* is a strong edificator, adult plants prevent the emergence and development of the younger generation in the understorey space when forming a solid tree canopy. Its natural regeneration occurs in canopy breaks, so-called 'regeneration windows' (Smirnova et al. 1993). In small forests, and in particular, ravine forests, some areas of the phytocoenosis are affected by the 'marginal effect'. That is, edificatory species have the opportunity to regenerate in the marginal zone of the forest, where seedlings are not hindered by the canopy of generative trees. In such situations, the ontogenetic spectrum of the coenopopulation becomes bimodal or even left-handed (Travlyeyev et al. 1996).

According to the 'Gap mosaic concept' (Korotkov 1991, Remmert 1991, Yamamoto 2000, Burke 2006, Smirnova and Toropova 2016), forests are formed by a large number of elements of the mosaic-tier structure, which develop asynchronously and are the so-called 'regeneration windows' at different stages of development. As we have already mentioned, clusters of young trees are tied to breakouts in the forest canopy. In the gullies under study there are areas with marginal deviation, as the ravine forests of the Dnieper rapids are near the ecological limit of their distribution and are characterized by curtain-meadow complexes.

Young plants of the population – juvenile and immature – are located mainly on the periphery of the projections of the crowns of maternal trees, as well as in micro-depressions with a small layer of plant litter (up to 4 cm thick) and are confined to canopy breaks. It should be noted that undergrowth in the ravine forest of the Shyroka gully is in the least fa-

vourable light conditions. Up to 80 % of *Q. robur* plants that belong to the pregenerative age states are affected by powdery mildew in all of the ravine forests under study.

Age structure is one of the most important features of the population. It reflects such important processes as the intensity of reproduction, mortality, the rate of the cycle of generations. The ability of the population system to self-sustain and its stability depend on this aspect of the structural organization. The age structure of the population depends on the genetic characteristics of the species, which can be realized in different ways depending on the specific conditions of existence of individual populations (Krychfalushiy and Mezev-Krychfalushiy 1994).

To characterize the age of *Q. robur* populations, we first used the index  $\delta$  (Zhukova 1967), which can differentiate the age level only of those populations with the presence of both young and old individuals, which is observed in the ravine forests under study. As noted by Uranov (1975), in the absence of one of these categories,  $\delta$  is equal to +1 or -1, regardless of the differences in the age of the population. In 1999, the highest value of this index was in the coenopopulation of *Q. robur* growing in the Heneralka gully (-0.89) (Table 2), while a slightly lower value was registered in the Khortyts'ka gully (-0.84) with the lowest attributed to the ones growing in the Shyroka gully (-0.78), which is explained by the small share of mature and virginal plants in the coenopopulation of this ravine forest. Minus when calculating the index  $\delta$  shows that the young specimens prevail over the old in the coenopopulation (formula 1). The numerical expression (in modulo) is used for a general idea of the age of the coenopopulation.



Table 2. Dynamics of demographic indicators of *Q. robur* coenopopulations.

| Gully       | Years | Indices                 |                         |                        |                         |                  |          |          |          | Type of coenopopulations |
|-------------|-------|-------------------------|-------------------------|------------------------|-------------------------|------------------|----------|----------|----------|--------------------------|
|             |       | $I_{\text{renew., \%}}$ | $I_{\text{gener., \%}}$ | $I_{\text{aging, \%}}$ | $I_{\text{recov., \%}}$ | $I_{\text{age}}$ | $\Delta$ | $\omega$ | $\delta$ |                          |
| Heneralka   | 1999  | 62.2                    | 36.5                    | 5.4                    | 1.63                    | 0.09             | 0.23     | 0.46     | -0.89    | Young                    |
|             | 2019  | 52.1                    | 45.1                    | 8.5                    | 1.16                    | 0.16             | 0.26     | 0.52     | -0.83    | Young                    |
| Khortyts'ka | 1999  | 62.2                    | 35.1                    | 8.1                    | 1.69                    | 0.13             | 0.22     | 0.43     | -0.84    | Young                    |
|             | 2019  | 53.6                    | 42.9                    | 14.3                   | 1.25                    | 0.27             | 0.26     | 0.47     | -0.71    | Young                    |
| Shyroka     | 1999  | 71.1                    | 28.3                    | 11.0                   | 1.87                    | 0.15             | 0.34     | 0.39     | -0.78    | Young                    |
|             | 2019  | 66.4                    | 32.5                    | 12.2                   | 2.04                    | 0.18             | 0.31     | 0.40     | -0.76    | Young                    |

Shyroka gully was a place of active recreation at the time not only for citizens and tourists, but also for the guests to the sanatorium, which is located on its north-western side. Active recreational activities led to the fact that the natural renewal of *Q. robur* was recorded in the ravines situated the furthest from the main thalweg. Clusters of quasi-senile individuals were seen growing in the soil loosened previously by human hands, under a forest canopy in the main thalweg.

After 20 years, in the areas of ravine forests of the Heneralka and Shyroka gullies, the index  $\delta$  did not change, and in the Khortyts'ka gully it decreased by 15.5 %, indicating a reduction in the total number of young individuals at the expense of juveniles.

As it turned out, the age estimate according to the previous index appears to be very rough. According to Uranov (1975), each age state of an individual tree has its own corresponding numerical value and the greater the value is, the closer the specimen is to the completion of its ontogenesis. In this regard, we calculated the  $\Delta$  index, which showed the highest age values of the coenopopulation of *Q. robur* in the Shyroka gully in the year of 1999, which is consistent with the previous statement about the difficulty of recovery under the conditions of active recreation (Table 1). Analyzing the chan-

ges that have taken place over the 20-year period, we have concluded that the current trend of aging of *Q. robur* coenopopulations in Heneralka and Khortyts'ka gullies is weak, which can become stable and significant provided that the existing level of recreational load is maintained. At the same time, a relative increase in the value of the index  $\Delta$  by 13.0 % and 18.2 %, respectively, was registered. In the Shyroka gully against the background of a decrease in recreational pressure and the associated increase in the number of individuals on the left side of the spectrum, no such negative changes were observed.

Uranov (1975), while calculating the age of coenopopulation  $\Delta$ , introduced the concept of the share of the energy available to the plant, utilized the moment of registering its age state. This aspect was extended by Zhivotovskiy (2001) in the form of the efficiency index ( $\omega$ ) – the value of the 'load' on the energy resources of the environment, which is expressed in shares of their use by individuals of the middle-aged generative state of the population. The values of the index  $\omega$  calculated by us indicate an increase in the magnitude of the load for the time span from 1999 to 2019, being most apparent in the coenopopulation of *Q. robur* growing in the Heneralka gully (by 13.0 %), and slightly less – in the Khortyts'ka gully (by

9.4 %). This indicator practically did not change in the case of the Shyroka gully.

Relying on the combined use of both indices ( $\Delta$  and  $\omega$ ) by Zhivotovskiy (2001) we identified the types of investigated populations of *Q. robur* as 'young' both at the beginning of observations – in 1999; as well as 20 years later – in the year of 2019. The calculated values of the index  $\Delta$ , which varied from 0.22 to 0.34, and the index  $\omega$ , the values of which ranged from 0.39 to 0.52, were used to determine the position of each coenopopulation in the 'delta-omega' space.

The next block of indices that has been used by us characterizes the contribution of each ontogenetic cohort relative to the total number of specimens in the population.

Thus, the recovery index ( $I_{\text{recov.}}$ ) in young normal populations should exceed the value of 1. In 1999, the value of this index varied from 1.63 to 1.87, and in 2019 – from 1.16 to 2.04. This determines the state of the coenopopulation as stable and the ability of the pregenerative fraction to completely replace its generative fraction. It should be noted that for the past 20 years the value of this index in the ravine forests of the Heneralka and Khortyts'ka gullies decreased by 28.8 % and 26.0 %, respectively, while there was no change in the case of Shyroka gully.

Analysis of the set of indices proposed by Kovalenko shows the presence of a fairly high regenerative potential of the coenopopulation of *Q. robur* in all of the gullies studied both in the year of 1999 as well as in 2019. Although over a 20 year period there is some decrease in the value of  $I_{\text{renew.}}$ , especially in the Heneralka and Khortyts'ka gullies (by 16.2 % and 13.8 %, respectively). At the same time, in the coenopopulations of these gullies, the values of the indices of generative-

ness ( $I_{\text{gener.}}$ ) and aging ( $I_{\text{aging}}$ ) actually increased. The values of the age index ( $I_{\text{age}}$ ) were quite low both at the beginning of the study (1999) (in a 0.09 to 0.15 range) and in 2019 (from 0.16 to 0.27), which also adds to the evidence of relative youthfulness of the populations under study.

Such changes in the values of age indices over the period of 20 years in ravine forests are due not so much to endogenous causes (individuality of environmental and coenotic conditions, peculiarities of formation etc.), as to the influence of such a powerful exogenous factor as anthropogenic load (in this case recreation). Active recreational activities also affect the implementation of models of ontogenetic development of woody plants (Table 3) through the creation of difficult conditions for the existence of seedlings and juvenile specimens (trampling, soil compaction, mechanical damage) and the deterioration of sanitary conditions of generative part of coenopopulation due to mechanical damage, which significantly compromises their immune system.

Increasing anthropogenic pressure leads to a decrease in the variety of variants of *Q. robur* ontogenesis in ravine forests, and the variants of ontogenetic development themselves include a smaller number of age states (Table 2).

According to Sklyar (2014), model No 1 describes a variant of development of *Q. robur*, in which plants undergo a complete ontogenetic cycle and die in a senile state. In models No 2–7, the ontogenetic cycle is incomplete: individuals die in the generative or in any of the pregenerative states. The shortest cycle of development is according to the model No 7, when the plant dies in the seedling state. In models No 1–5, the letter 'a' indicates a variant of ontogenetic development, when a fraction of immature *Q. robur* plants is being attri-

buted to the 'sticks' category. Such plants, for the most part, stop their development at this stage and die, that is, the incomplete ontogenesis has been realized in such a case, or, even though it happens less often, pass to the next ontogenetic state.

In 1999, the 'sticks' (v-s) were registered in all of the ravine forests under study (Fig. 1). In 2019, some of them were eliminated, and the rest were able to transition to the next age state.

The distribution of individuals by levels of vitality is one of the manifestations of morphological heterogeneity of coenopopulations. Plant morphogenesis integrates the level of metabolic processes and through the morphological status of vegetative and generative organs informatively characterizes the vitality of individuals (Osmanova 2009). In this regard, we determined the vital signs of ontogenetic groups and coenopopulations with an interval of 20 years (Table 4).

**Table 3. Polyvariance of ontogenetic development of *Q. robur* in ravine forests.**

| Name of the gully | Model of ontogenetic development |                      |                 |                      |                                |                                     |                                |                 |                |
|-------------------|----------------------------------|----------------------|-----------------|----------------------|--------------------------------|-------------------------------------|--------------------------------|-----------------|----------------|
|                   | No 1<br>(p...s)                  | No 1a<br>(p...t...s) | No 3<br>(p...v) | No 3a<br>(p...t...v) | No 4<br>(p...im <sub>2</sub> ) | No 4a<br>(p...t...im <sub>2</sub> ) | No 5<br>(p...im <sub>1</sub> ) | No 6<br>(p...j) | No 7<br>(p...) |
| Heneralka         | +                                | +                    | +               | +                    | +                              |                                     |                                | +               | +              |
| Khortyts'ka       | +                                |                      |                 |                      |                                |                                     | +                              | +               | +              |
| Shyroka           | +                                | +                    |                 | +                    |                                | +                                   |                                | +               | +              |

Note: + is symbol designating the model realized in the ravine forest.

**Table 4. Vitality structure of *Q. robur* coenopopulations in ravine forests.**

| Gully       | Age  | Vitality indicators of ontogenetic groups clustered according to a given period |     |     | Vitality indicators of a coenopopulation |      |                  |
|-------------|------|---------------------------------------------------------------------------------|-----|-----|------------------------------------------|------|------------------|
|             |      | PrG                                                                             | G   | PsG | F                                        | P    | P <sub>rel</sub> |
| Heneralka   | 1999 | 5.7                                                                             | 6.5 | 2.0 | 19.2                                     | 14.2 | 0.74             |
|             | 2019 | 5.4                                                                             | 6.4 | 1.5 | 18.8                                     | 13.3 | 0.71             |
| Khortyts'ka | 1999 | 4.6                                                                             | 5.9 | 2.0 | 33.7                                     | 12.5 | 0.63             |
|             | 2019 | 4.2                                                                             | 5.7 | 1.0 | 39.0                                     | 10.9 | 0.62             |
| Shyroka     | 1999 | 3.8                                                                             | 6.6 | 3.5 | 4.4                                      | 13.9 | 0.57             |
|             | 2019 | 4.1                                                                             | 6.6 | 2.7 | 4.9                                      | 14.0 | 0.61             |

Note: Age periods: PrG – pregenerative, G – generative, PsG – postgenerative; the parameter F – the average score of vitality of specimens.

As is the case with all the variants of observation, the highest vital signs were attributed to generative individuals, and the lowest – to the individuals of the post-generative period (Table 3). Lower values of this indicator in young pregenerative plants of *Q. robur* compared to the generative ones are associated with the affection of powdery mildew and the transition of some of them to a quasi-senile state.

Over a 20 year period, the vitality of pregenerative and generative ontogenetic groups of *Q. robur* coenopopulations of Heneralka and Shyroka gullies practically did not change, but saw a significant decrease in the case of postgenerative ones, especially in the case of the Khortyts'ka gully (by 50.0 %). The regularity and direction of changes in the vitality of the *Q. robur* coenopopulation as a whole

is clearly demonstrated by the indicator  $P$ : in the Heneralka and Shyroka gullies it changed insignificantly, while in the Khortyts'ka gully's case it has decreased by 12.8 %.

Indicator  $P_{rel.}$  shows what proportion of vitality score from the maximum possible value a coenopopulation has at the time of the study. In the case of Heneralka gully this indicator is the highest of all the coenopopulations under study during the entire period of observation (0.74 and 0.71), and it was the lowest in the case of the Shyroka gully (0.57 and 0.61), but for the past 20 years this parameter has not changed in any meaningful way in all of the gullies under study.

Thus, over the 20 year observation period, practically the same type of EDU and the bimodal nature of the ontogenetic spectra of *Q. robur* coenopopulations have been carefully preserved. Analysis of age using eight indices demonstrates the adaptive capacity of the studied coenopopulations and the ability to function given a low quantity of the population. As is the case with all of the coenopopulations that consist of young individuals, plants belonging to the pregenerative fraction are capable of replacing the generative specimens in the future. With the decrease in anthropogenic pressure in the Shyroka gully, the condition of the left side of the ontogenetic spectrum has improved.

## Conclusions

In the ravine forest of the Heneralka gully there are signs of a spotted structure of EDU. There is a tendency to transform the spatial structure of EDU: a gradual change to the diffuse type in the case of Heneralka gully, and to the pointlike type

in the case of Khortyts'ka and Shyroka gullies, which indicates a chronic, significantly pronounced anthropogenic stress.

Coenopopulations of *Q. robur* in the gullies under study are many-component with a bimodal real spectrum. During the 20 year observation period, the share of mature and virginal plants decreased slightly in the case of Heneralka gully and increased in the case of Khortyts'ka and Shyroka gullies. The number of juveniles decreased in all the gullies.

As a result of recreational exposure, the range of variants of ontogenetic development of *Q. robur* decreases, and the variants themselves include a smaller number of age states.

Comprehensive analysis using eight demographic indices shows a slight decrease in the intensity of natural regeneration in the Heneralka and Khortyts'ka gullies, increase in the share of generative and postgenerative individuals (increase in the load on energy resources of the environment), but the changes did not lead to a critical stage of coenopopulations of *Q. robur* in these gullies. The Shyroka gully shows some improvement concerning the demographic situation due to the decrease in anthropogenic pressure.

All coenopopulations of *Q. robur* in the 'delta-omega' space are defined as young, which due to their adaptive potential are able to self-sustain the cycle of generations.

The studied ravine forests are located on the territory of the Khortytsia National Reserve. Regulation of recreational activities is taking place to reduce the anthropogenic impact on the phytocenoses of the ravine forest. To maintain the *Q. robur* population, it is recommended to plant acorns collected from mother trees within each small ravine in blanks.

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## EVALUATION OF THE ECOLOGICAL PROPERTIES OF GENUS *VIBURNUM* L. SPECIES UNDER RIGHT-BANK FOREST-STEPPE OF UKRAINE

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### Abstract

Under Right-Bank Forest-Steppe of Ukraine, 11 *Viburnum* species and 5 cultivars of different geographical origin are cultivated. The vast majority of species is property of a limited number of botanical gardens. There is no information about the ecological properties of most of the introduced taxa of genus *Viburnum* L. in condition of the Right-Bank Forest-Steppe of Ukraine. Therefore, the study of the ecological properties of various species of this genus under these conditions is relevant. The purpose of the study is a comparative analysis of the ecological properties of species belonging to the genus *Viburnum* L. in relation to the formation of their taxonomic composition in collections and rational use in greening and gardening. The following ecological indicators of the species were investigated: the duration of the dormant period, winter hardiness, drought resistance and water retention capacity. It was established that the winter hardiness of the species is satisfactory and does not depend on the duration of the period of deep dormancy. Monitoring the winter hardiness of uneven-aged plants of the same species made it possible to trace the change in resistance in ontogenesis. An increase in winter hardiness in all species is observed during the transition from juvenile to mature state, which is reflected by the value of the winter hardiness coefficient. Drought resistance of most species is high, exceptions are *Viburnum lantana* 'Aureum' and *Viburnum burejaeticum* Rgl. et Herd. Water retention is higher in evergreen species and resistance to dehydration is higher in *V. opulus* L. and *V. rufidulum* Raf. The studied species are promising and quite suitable for further implementation under Right-bank Forest-Steppe of Ukraine.

**Key words:** dormant period, drought resistance, water retention, winter hardiness.

### Introduction

Two aboriginal species – *Viburnum opulus* L. and *Viburnum lantana* L. grow in Ukraine. Over the years 24 species and 11 cultivars of *Viburnum* of different geographical origin (Kokhno and Kurdyuk 1994) were introduced to the territory of Ukraine. On the territory of the Right-Bank

Forest-Steppe of Ukraine, 11 species and 5 cultivars of the genus are cultivated (Demchenko 2000, 2016).

The morphophysiological features of the annual development cycle in connection with the introduction of plants are of great importance.

The state of dormancy and its depth in winter is an important adaptive reaction of

woody plants to the climatic conditions of the temperate zone on which their winter hardiness depends.

The Right-Bank Forest-Steppe of Ukraine is characterized by winters with unstable snow cover. Frequent and prolonged temperature changes are especially dangerous in winter, when plants are in a state of forced dormancy. From the moment plants enter a state of deep and forced dormancy, its duration will depend on their winter hardiness and hence the success of the introduction. Due to climate change, limiting factors in the introduction of plants include their resistance to drought.

High plant productivity under conditions of insufficient water supply and high temperatures is the best feature of drought tolerance.

Lishchuk and Pilkevich (1999) consider that when evaluating plant resistance to drought, it is more methodically appropriate to determine the water-holding capacity for the time during which the leaves give up a certain amount of water while wilting. Recover of turgor with the same dehydration allows to objectively compare leaves of species of different resistance.

Some fragmentary data about winter hardiness of species of the genus *Viburnum* L. in various soil and climatic conditions are found in the works of Rehder 1949, Lypa et al. 1952, Rubtsov et al. 1974, Kolesnikov 1974, Grigoriev 1980, Bozhkova 1989, Plotnikova 1988, Kuznetsov et al. 1994, Aksenov and Aksenova 2001, Robinson and Hamilton 1980a, 1980b. The majority of authors argue that in different botanical and geographical regions of introduction, species such as *V. opulus*, *V. lantana*, *V. lentago* L., *V. burejaeticum* Rgl. et Herd., turned out to be quite resistant to winter conditions, data on other *Viburnum* species almost not given.

There are contradictory statements about the winter hardiness of certain species. According to data of Rubtsov et al. (1974), *V. rhytidophyllum* Hemsl. in Kiev freezes to the level of snow cover without shelter. Solodukhin (1985) claims that it does not withstand long-term frosts down to -20 °C. According to Lypa et al. (1952), this species has a winter hardiness score I (quite winter hardy).

Some fragmentary data about the drought resistance of species of the genus *Viburnum* in different regions of introduction can be found in the works of Lypa et al. (1952), Kormilitsyn and Marchenko (1960), Kolesnikov (1974), Rubtsov et al. (1974), Grigoriev (1980), Panova (1982), Aksenov and Aksenova (2001), Bussmann et al. (2020). Most of the authors consider that *Viburnum* in various soil and climatic conditions turned out to be quite drought-resistant. Some authors believe that some species are quite drought-resistant, but development is better on sufficiently moist soil conditions.

It became necessary to conduct such research due to the lack of data about the ecological features of most species of the genus *Viburnum* in the conditions of the Right-Bank Forest-Steppe of Ukraine.

A study of the ecological properties of species of the genus *Viburnum* in sheltered ground conditions is presented in some works (Chen et al. 2020, Sun et al. 2020). Some issues of the ecological features of species of the genus are highlighted (Zimmerman et al. 2005, Gómez-Bellot et al. 2015, Sifola et al. 2017, Cirillo et al. 2019).

The purpose of the study is a comparative analysis of the ecological properties of species of the genus *Viburnum* in connection with the formation of their taxonomic composition in collections and rational use in landscaping and gardening

of such ecological indicators of species of the genus as winter hardiness, duration of dormancy, drought resistance and water-holding capacity in the conditions of the Right-Bank Forest-Steppe of Ukraine.

## Materials and Methods

The studies were carried out with the following taxa of the genus *Viburnum*: *V. opulus* L., *V. opulus* 'Roseum', *V. opulus* 'Nanum', *V. lantana* L., *V. lantana* 'Aureum', *V. lantana* 'Variegatum', *V. carlesii* Hemsl., *V. prunifolium* L., *V. rhytidophyllum* Hemsl., *V. buddleifolium* C.H. Wright, *V. burejaeticum*, *V. lentago*, *V. rufidulum* Raf., *V. sargentii* Koehne, *V. sargentii* 'Flavum', *V. veitchii* C.H. Wright. The objects of study grow in open ground in the collection plantations of the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine (Kyiv), O.V. Fomin Botanical Garden of T. Shevchenko National University of Kyiv, The National University of Life and Environmental Sciences of Ukraine, arboretums 'Syrets' (Kyiv), 'Oleksandriia' (Bila Tserkva), 'Sofiivka' (Uman). Also, city parks and gardens of Kyiv, Bila Tserkva, Uman, Vinnitsa, and Cherkasy were examined.

The duration of the period of deep and forced dormancy of *Viburnum* species was determined according to the method of Nesterov (1957). The duration of the period of deep dormancy was studied on cut 1-2-year-old shoots of the objects of study. From mid-November to mid-February, 2 to 3 shoots of each species were cut 1–2 times a month and placed in water at room temperature; the winter hardiness of the studied species was determined according to a seven-point scale of icing adopted by the MBG Academy of Sciences of the USSR (Plotnikova 1988). The

coefficient of winter hardiness of *Viburnum*, depending on the age of plants, was determined by the formula (1) proposed by Kosenko (2002).

$$W = \frac{ADV}{DSG}, \quad (1)$$

where:  $W$  is winter hardiness coefficient;  $ADV$  is average duration of vegetation, days;  $DSG$  is duration of shoots growth, days.

Drought resistance was evaluated using the scale of Pyatnitsky (1961). Measurement of water retention capacity and resistance of leaves to dehydration was carried out according to the method of Lishchuk and Pilkevich (1999). During the vegetation season, monthly studied samples of leaves were taken and weighed, then subjected to wilting. At regular intervals (2, 4, 8 hours) they were weighed again.

After the leaves had lost 40 % of the water, their ability to restore turgor was determined. For this purpose they were laid between layers of filter paper, previously moistened with water. After keeping the leaves in humid conditions, wilting results were reported. Leaves, resistant to dry conditions and withstood wilting, after absorbing water, acquire a green colour and normal turgidity. The leaves tissues of drought-resistant species after transfer in the same conditions and during the same period of wilting, turgor is not restored and in most cases in the process of restoring turgor turn brown. Sometimes the leaves partially restore turgor, ie partially damaged.

## Results and Discussion

A characteristic feature of the end dormant period is a rapid and simultaneous budding of the objects of study (Table 1).

**Table 1. Determination the duration of the release of *Viburnum* spp. buds from a state of deep dormancy.**

| Species, cultivars             | Cutting shoots dates |      |       |       |       |
|--------------------------------|----------------------|------|-------|-------|-------|
|                                | 15.11                | 3.12 | 20.12 | 29.01 | 15.02 |
| <i>V. opulus</i>               | 46                   | 20   | 14    | 5     | 4     |
| <i>V. opulus</i> 'Roseum'      | 30                   | 13   | 5     | 5     | 4     |
| <i>V. opulus</i> 'Nanum'       | 41                   | 26   | 11    | 10    | 5     |
| <i>V. lantana</i>              | —                    | 19   | 10    | 9     | 4     |
| <i>V. lantana</i> 'Aureum'     | —                    | 18   | 9     | 9     | 4     |
| <i>V. lantana</i> 'Variegatum' | —                    | —    | 12    | 10    | 5     |
| <i>V. carlesii</i>             | —                    | —    | 17    | 7     | 3     |
| <i>V. rhytidophyllum</i>       | 51                   | 24   | 8     | 10    | 6     |
| <i>V. lentago</i>              | —                    | 56   | 39    | 8     | 4     |
| <i>V. rufidulum</i>            | —                    | 33   | 15    | 8     | 4     |
| <i>V. prunifolium</i>          | —                    | 39   | 21    | 8     | 4     |
| <i>V. buddleifolium</i>        | —                    | —    | 25    | 10    | 7     |
| <i>V. burejaeticum</i>         | —                    | 38   | 21    | 8     | 4     |
| <i>V. veitchii</i>             | —                    | —    | 19    | 8     | 4     |
| <i>V. sargentii</i>            | 28                   | 13   | 14    | 4     | 4     |
| <i>V. sargentii</i> 'Flavum'   | 30                   | 9    | 12    | 4     | 4     |

It was found that most of the studied species leave the state of deep dormancy in the second half of December – early January, the only exception being *V. lentago*, which leaves the state of deep dormancy on 28.01. There is a delay in the exit from the state of deep dormancy in *V. opulus* 'Nanum' in comparison with the main species *V. opulus* and *V. opulus* 'Roseum'.

Most of the introduced *Viburnum* species in the conditions of the Right-Bank Forest-Steppe of Ukraine finish their growing season at the end of October – beginning of November and pass into a state of dormancy, which lasts until the end of March – beginning of April. The duration of the dormant period and its depth in the studied species are different, 140–185 days. The shortest dormant period is in *V. burejaeticum* (140) and *V. lantana* 'Aureum' (148), the longest – in the native *V. opulus* (185) and its cultivar *V. opulus* 'Nanum' (181). The period of deep dor-

mancy in *Viburnum* species lasts 60–70 days, then all these species enter a period of forced dormancy, which lasts 80–110 days depending on temperature conditions. Direct relationship between winter hardiness of species of the genus *Viburnum* and the duration of deep dormancy period has not been established.

During the years of our monitoring, the winter hardiness of the species of the genus *Viburnum* was quite satisfactory and was estimated at point I. Damage to parts of one-year shoots of *V. veitchii* and *V. buddleifolium* is occasionally observed (winter hardiness score II). Evergreen species tolerate a drop in temperature to -23–25 °C. At lower temperatures, leaves freeze over, we observed it in winter of 2012–2013.

Rubtsov et al. (1974) claim that in Kyiv conditions one-year shoots of *V. prunifolium* freeze, but this species is quite winter-hardy according to Lypa et al. (1952). Some authors (Kolesnikov 1974, Rubtsov

et al. 1974) consider that *V. carlesii* can withstand frosts down to  $-18$ – $-20$  °C, but damage to one-year shoots is observed. Over the years of monitoring, we have not recorded damage to *V. rhytidophyllum*, *V. prunifolium* and *V. carlesii* by low temperatures (up to  $-32$  °C).

Monitoring of the winter hardiness of uneven-aged plants of the same species made it possible to track the changes in resistance in ontogenesis (Table 2). The dynamics of the values of the coefficient of winter hardiness of perennial species is

presented in Figure 1. An increase in winter hardiness in all species is observed during the transition from juvenile to mature state, which is reflected by the value of the winter hardiness coefficient. According to Table 2, we can conclude that one-year seedlings have the lowest winter hardiness. Winter hardiness increases with age, the values of the coefficients of winter hardiness of three-year summer plants approach those of adult species. For young plants, the first two years of life are critical in terms of winter hardiness.

**Table 2. Coefficient of winter hardiness of introduced *Viburnum* spp.**

| Species               | Age, years | Duration of shoots growth, days | Average duration of growing period, days | Winter hardiness coefficient |
|-----------------------|------------|---------------------------------|------------------------------------------|------------------------------|
| <i>V.lentago</i>      | 46         | 69                              | 204                                      | 2.95                         |
|                       | 1          | 95                              | 204                                      | 2.14                         |
|                       | 2          | 75                              | 204                                      | 2.72                         |
|                       | 3          | 70                              | 204                                      | 2.91                         |
| <i>V.carlesii</i>     | 28         | 96                              | 210                                      | 2.18                         |
|                       | 1          | 121                             | 210                                      | 1.73                         |
|                       | 2          | 102                             | 210                                      | 2.05                         |
|                       | 3          | 98                              | 210                                      | 2.14                         |
| <i>V.prunifolium</i>  | 20         | 71                              | 202                                      | 2.84                         |
|                       | 1          | 99                              | 202                                      | 2.04                         |
|                       | 2          | 79                              | 202                                      | 2.55                         |
|                       | 3          | 74                              | 202                                      | 2.72                         |
| <i>V.veitchii</i>     | 20         | 116                             | 212                                      | 1.82                         |
|                       | 1          | 141                             | 212                                      | 1.50                         |
|                       | 2          | 124                             | 212                                      | 1.70                         |
|                       | 3          | 117                             | 212                                      | 1.81                         |
| <i>V.burejaeticum</i> | 7          | 109                             | 225                                      | 2.06                         |
|                       | 1          | 135                             | 225                                      | 1.66                         |
|                       | 2          | 115                             | 225                                      | 1.95                         |
|                       | 3          | 110                             | 225                                      | 2.04                         |
| <i>V.sargentii</i>    | 30         | 68                              | 214                                      | 3.14                         |
|                       | 1          | 96                              | 214                                      | 2.22                         |
|                       | 2          | 75                              | 214                                      | 2.85                         |
|                       | 3          | 70                              | 214                                      | 3.05                         |

Monitoring the results of overwintering of the studied species allowed us to make adjustments to the idea of winter hardiness. 7 species, in accordance with the zoning proposed by Rehder (1949), were

considered for zones IV and V (*V. carlesii* – IV, *V. veitchii* – V, *V. buddleifolium* – V, *V. burejaeticum* – V or IV, *V. rhytidophyllum* – V, *V. sargentii* – V or IV, *V. rufidulum* – V), turned out to be quite winter hardy in



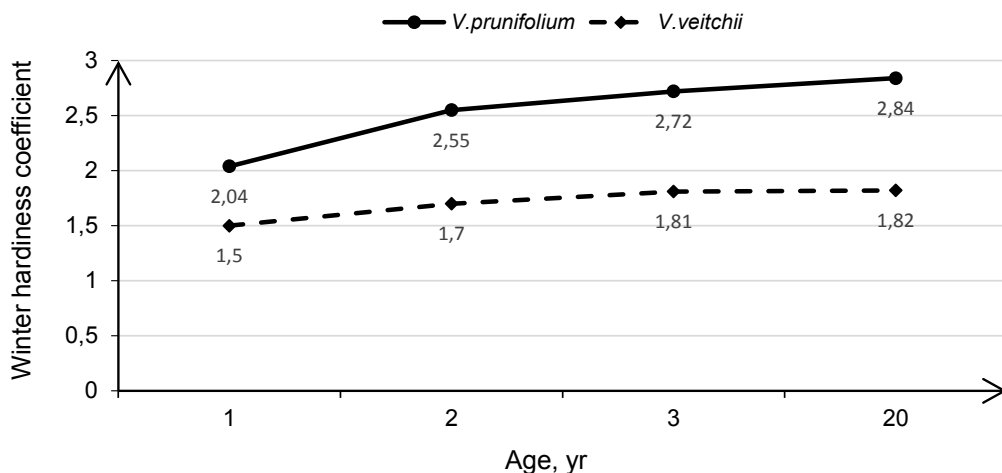


Fig. 1. Coefficient of winter hardiness of introduced *Viburnum* spp.

Kyiv, which is located in zone III. This is especially true of species occurring from the East Asian floristic region (according to Takhtajan 1978), the complexity of the formation and development caused a wide range of adaptive properties of the species in the historical aspect.

Rubtsov et al. (1974) believe that *V. prunifolium* can't stand summer drought in Kyiv conditions. According to our monitoring, this species is quite drought-resistant. Solodukhin (1985) considers that the drought resistance of *Viburnum* increases with the ability of the leaf to protect itself from sunlight. He thinks that *Viburnum lantana* with outgrowths on leaves, as well as *Viburnum lentago* with glossy leaves, are less damaged by high temperatures than *Viburnum* with thin and delicate leaves. Burning of the leaves edges and their dropping is a damage, which can be noticed. According to our data, all studied species are quite drought-resistant in Kyiv conditions. All of them can withstand short dry periods without noticeable damages. However, burning of the edges of *V. lan-*

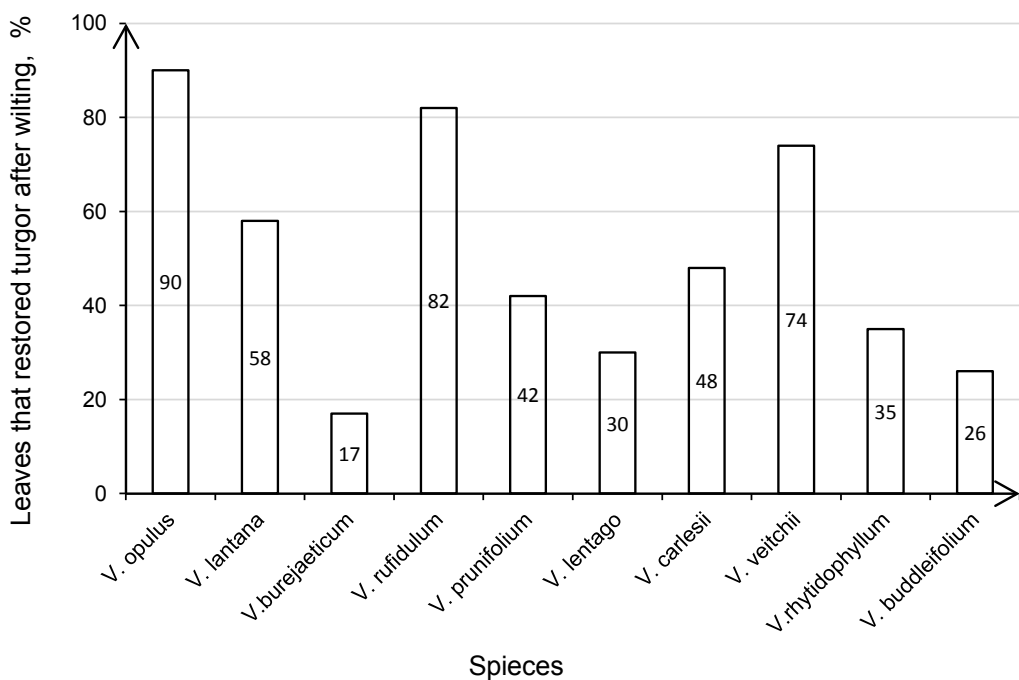
*tana* 'Aureum' leaves and a temporary loss of turgor by the leaves of *V. burejaeticum* were observed during long summer droughts. So the damage was observed for those species whose leaves were covered with outgrowths.

The percentage of leaves that regained turgor and green color after suffering the same conditions and wilting time is one of the main indicators of the resistance of species to drought conditions (Table 3).

Since no signs of wilting were observed in adults and young seedlings of the studied species, we estimate the drought resistance of these species and cultivars at 5 points. The only exceptions are *V. burejaeticum* and *V. lantana* 'Aureum'. Leaves and shoots do not suffer from drought in *V. burejaeticum*, there is only a temporary loss of turgor – 4 points. In most of the leaves of *V. lantana* 'Aureum', which is partially damaged, such as leaves change colour at the edges – 3 points. The distribution of species that restored turgor after wilting is presented in Figure 2.

**Table 3. Water holding capacity and resistance to dehydration of leaves of species of the genus *Viburnum* spp.**

| Species                  | The water content in the leaves before withering, % | The time during which the leaves emit 40% water | Leaves that restored turgor after wilting, % |
|--------------------------|-----------------------------------------------------|-------------------------------------------------|----------------------------------------------|
| <i>V. opulus</i>         | 56.2 ±2.0                                           | 16 h                                            | 90                                           |
| <i>V. lantana</i>        | 55.8 ±1.3                                           | 9 h 30 min                                      | 58                                           |
| <i>V. burejaeticum</i>   | 51.4 ±1.7                                           | 10 h 10 min                                     | 17                                           |
| <i>V. rufidulum</i>      | 58.6 ±1.0                                           | 18 h                                            | 82                                           |
| <i>V. prunifolium</i>    | 58.4 ±1.2                                           | 32 h 30 min                                     | 42                                           |
| <i>V. lentago</i>        | 56.9 ±1.5                                           | 10 h                                            | 30                                           |
| <i>V. carlesii</i>       | 61.7 ±2.1                                           | 16 h 15 min                                     | 48                                           |
| <i>V. veitchii</i>       | 60.4 ±1.8                                           | 9 h 40 min                                      | 74                                           |
| <i>V. rhytidophyllum</i> | 64.3 ±1.6                                           | 18 h 30 min                                     | 35                                           |
| <i>V. buddleifolium</i>  | 63.8 ±2.2                                           | 52 h                                            | 26                                           |

**Fig. 2. Water holding capacity and resistance to dehydration of leaves of species of the genus *Viburnum* spp.**

According to the data in the Table 3, it can be concluded that the evergreen species of *Viburnum* (*V. rhytidophyllum* and *V. buddleifolium*) have the highest wa-

ter-holding capacity, and the resistance to dehydration is the highest in *V. opulus* and *V. rufidulum*.

## Conclusions

The investigated species of the genus *Viburnum* turned out to be quite winter-hardy in the conditions of the Right-Bank Forest-Steppe of Ukraine due to the timely termination of vegetation and the short growth period of shoots, which have time to lignify and enter a state of dormancy even before the cold starts. Most species and cultivars of *Viburnum* are quite drought-resistant in the conditions of the Right-Bank Forest-Steppe of Ukraine.

As a result of research about the resistance of *Viburnum* species, it can be concluded that they have high ecological plasticity, winter hardiness and drought resistance, which ensures their successful cultivation in the Forest-Steppe of Ukraine.

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