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**Acknowledgement to reviewers of the manuscripts  
submitted to Forestry Ideas in 2019 (January to November):**

Reza **Akhavan** – Research Institute of Forests and Rangelands, Tehran, Iran  
Olena **Andreieva** – Zhytomyr National Agroecological University, Ukraine  
Hafiz Syed Hamid **Arshad** – University of Management & Technology, Lahore, Pakistan  
Dimitrios N. **Avtzis** – Forest Research Institute, Thessaloniki, Greece  
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Chelestino **Balama** – Sokoine University of Agriculture, Morogoro, Tanzania  
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Vienna (BOKU), Austria

Nadka **Ignatova** – University of Forestry, Sofia, Bulgaria

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Nasko **Iliev** – University of Forestry, Sofia, Bulgaria

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Pakistan

Masoom Khan **Khanhasan** – Kermanshah Agricultural and Natural Resources Research  
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Pavel **Klyushin** – State University of Land Management, Moscow, Russia

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Panagiotis **Michopoulos** – Forest Research Institute of Athens, Greece

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Dmitry **Schepaschenko** – International Institute for Applied Systems Analysis, Laxenburg, Austria

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Bojan **Simovski** – Ss. Cyril Methodius University in Skopje, North Macedonia

Hortensia **Sixto** – National Research Institute and Agrarian and Food Technology, Madrid, Spain

Stanislav Ihorovych **Slusar** – National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

Uliana **Sokolenko** – Petro Vasylenko National Technical University of Agriculture, Kharkiv, Ukraine

Leila **Soleimannejad** – University of Tehran, Iran

Ihor **Soloviy** – Ukrainian National Forestry University, Lviv, Ukraine

Andrew **Speak** – Free University of Bozen-Bolzano, Bolzano, Italy

Raffaele **Spinelli** – Institute of Tree and Timber IVALS, Rome, Italy

Athanasios **Stampoulidis** – Demokritus University of Thrace, Orestiada, Greece

Hubert **Sterba** – University of Natural Resources and Life Sciences Vienna (BOKU), Austria

Marion Le **Texier** – University Rouen Normandie, Mont-Saint-Aignan, France

Sara **Thornton** – University of Leicester, United Kingdom

Viktor **Tkach** – Ukrainian Research Institute of Forestry and Forest Melioration named after G. M. Vysotsky, Kharkiv, Ukraine

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Javier **Vinueta** – Research Institute for Hunting Resources (IREC), Ciudad Real, Spain

Olga **Yakimenko** – Moscow State University, Russia

Yordanka **Yovkova** – University of National and World Economy, Sofia, Bulgaria

Nikolay **Zafirov** – University of Forestry, Sofia, Bulgaria

Peter **Zhelev** – University of Forestry, Sofia, Bulgaria

# EVALUATION OF ALTITUDE EFFECTS ON THE SPATIAL STRUCTURE OF CAUCASIAN OAK (*QUERCUS MACRANTHERA*) STANDS IN ARASBARAN PROTECTED FORESTS, NORTHWEST OF IRAN

Milad Safari<sup>1\*</sup>, Kiomars Sefidi<sup>2</sup>, Ahmad Alijanpour<sup>3</sup>,  
and Mohammad Razi Elahian<sup>4</sup>

<sup>1</sup>Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Iran.

\*E-mail: safarimilad72@gmail.com

<sup>2</sup>Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Iran.

<sup>3</sup>Faculty of Natural Resources, University of Urmia, Iran.

<sup>4</sup>Department of Natural Resources, East Azarbaijan Province, Iran.

Received: 14 February 2019

Accepted: 01 July 2019

## Abstract

This study investigated the relationships between physiographical factors and trees structural characteristics in Arasbaran forest, northwest of Iran. Systematic randomized sampling method was used to collect data and in sample plot used the distance method for determination of spatial distribution pattern. Results of spatial distribution pattern indices showed the clumped spatial distribution for Caucasian oak trees (*Quercus macranthera* Fisch. & C.A.Mey. ex Hohen). In addition, the altitude affected the tree's characteristics significantly. The greatest tree's diameter at breast height was found in  $R_3$  and density of trees was decreased by increasing of altitude. Distance to neighbour index showed four to six meter distances between trees. DBH and height differentiation indices demonstrated uniformity in trees. Landform indices had the greatest average on  $R_3$  and had a significant correlation with trees density and crown area. It could be concluded that the difference in physiographical condition is one of the main factors of the tree's spatial distribution and forest structure variation at physiographical units in this study area.

**Key words:** altitude range, distance method, physiography, structure indices.

## Introduction

Physiographic factors modification including altitude, slope, and aspect could change forest characteristics such as forest type, structure, and spatial patterns. Therefore, forest ecosystems parameters modify within local physiography through a complex interaction of topography, vegetation composition, and structure (Gerhardt and Foster 2002, Kovacs et al. 2017).

The identification of structural attrib-

utes in forest stands (e.g. vertical complexity and spatial pattern) could help to maintain forest ecosystem function, improve conservation and management practices, preserving biodiversity and mitigation strategies against the effect of local and global changes (Kovacs et al. 2017).

Trees create the basic structure of forests ecosystems by the canopy and its variation stratification and horizontal spatial pattern (Redmond et al. 2017). Also, forest spatial patterns cover a wide range

of factors, including environmental factors, land physiography, trees interaction, etc. spatial pattern study was known as recording the position of each individual tree on forest stand. Study on forest structure being used to assess the knowledge of natural distribution in the forest stand and heterogeneity in different topography condition can affect trees spatial distribution (Carrer et al. 2018). The spatial distribution pattern refers to the status of horizontal allocation or distribution of individual trees in a stand and reflects processes on stands (Gangying et al. 2007; Friedman et al. 2001).

Forest structure has been characterized by several ways but nowadays sampling methods, such as distance method, are used to analyse forest structure. In this method, the position of trees is considered (Ghalandarayeshi et al. 2017).

Numerous studies, worldwide, have described the interaction of forest structure and physiographic factors in forest stands. These studies focus on forest structure composition and spatial pattern. Gerhardt and Foster (2002) researched on physiographical effects on forest composition and structure as a major challenge of ecologists, conservationists and land managers in New England in the eastern United States and suggested that altitudes are one of the main factors controlling structure and composition of forests. To understand the effects of direction on forest composition and community structure, Sharma et al. (2010) studied seven natural forests types in Garhwal Himalaya and concluded that the value of the basal area and diversity indices were modified in different aspects. Askari et al. (2013) studied the spatial patterns of trees in a reserved area in the Zagros forest in the southwest of Iran. They used some indices and showed the clumped pattern

in the studied area. Mirzaei et al. (2016) investigated the effects of physiographic factors (altitude, slope, and aspect) on the spatial distribution of *Quercus brantii* var. *persica* tree species in west oak forests of Iran and they concluded that physiographic condition had a key role in the variation of the spatial distribution pattern of trees.

Also, various oak forests are studied in Iran by Hoseini (2016), Pourbabaei et al. (2012), Valipour et al. (2013) and Safari et al. (2011).

Caucasian oak or Persian oak (botanic name: *Quercus macranthera*, Family Fagaceae) is a deciduous tree with up to 30 m height from southwest Asia (Iran and Turkey) (Anonymous 2018). In this study, we carried out to determine some structural characteristics of Caucasian oak (*Quercus macranthera*) stands and assessed physiographic factors such as slope, aspect, and altitude effects on forest structure indices. Analyses were conducted on Caucasian oak stands in Arasbaran protected forest in the east Azarbaijan province in the northwest of Iran.

We tested the following hypotheses: Is there any relationship between physiography aspects and Caucasian oak distribution pattern?, and Are forest structural indices influenced by the interaction of altitudes and species structure and special pattern in Caucasian oak stands? Therefore, the main aim was to study on the most suitable physiographic factor in the Caucasian oak habitat in the northwest forest of Iran.

## Materials and Methods

### Study area

Arasbaran is located in the northwest of Iran at the border with Armenia and Azer-

baijan. The area is 9478.690 ha and located at 38°43'41" N – 39°8'11" N latitude and 46°39'50" E – 47°1'48" E longitude (Fig. 1). Arasbaran is a high mountainous region with an altitude ranging from 256 m

to 2896 m a.s.l. The Arasbaran vegetation has particular importance because of the uniqueness in Iran. In this vegetation area there are more than 1000 plant species (Talebi et al. 2014).



Fig. 1. The location of the study area.

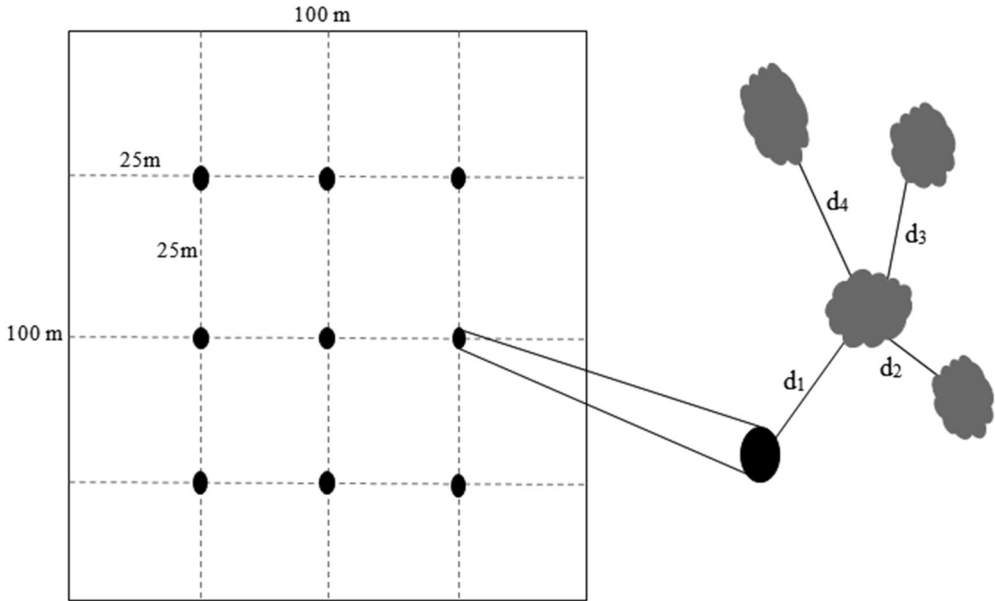
### Sampling design

For characterizing the physiographic effect on stand structure, three *Quercus macranthera* dominated stands were selected in three ranges of altitude: 1200–1400 m ( $R_1$ ), 1400–1600 m a.s.l. ( $R_2$ ) and 1600–1850 m a.s.l. ( $R_3$ ), in the Arasbaran forest. In each stand, three hectares sampling plot was established. To characterize structural characteristics within stands, 25 × 25 m grid of sampling points stabilized as a systematic random method (Fig. 2). In each point, the distance method was used to identify a single nearest oak tree as a reference tree and its DBH ≥ 7.5 cm and total height was measured and the distance between the reference tree and

the three neighbouring trees was measured (Moridi et al. 2015, Sefidi et al. 2015). Also, the DBH and the total height of all neighbouring trees were measured. And, physiographic characteristics including slop (%), aspect and altitude (m a.s.l.) in eight geographic directions in the centre of sampling plot for each reference and neighbour trees was measured and recorded (Sefidi et al. 2015). Totally, 81 sampling points (27 points in each altitude range) were determined for this study.

### Data analysis

Distance indices were used to analyze the spatial distribution and stand structure including uniform angle index, species



**Fig. 2. Sampling and plot design used in the study.**

Note: Centre of sampling plot, d1: plot centre distance to reference tree,  $d_2$ ,  $d_3$  and  $d_4$ : distance of the reference tree to the first, second and third neighbour trees, respectively.

combination, DBH differentiation, height differentiation and distance to neighbour (Pommerening 2006). Afterward, the spatial structure indices including Hopkins, Eberhart, and Johnson – Zimmer in each range of altitude were measured (Askari et al. 2013). For physiography's effect, the analysis in following indices was measured: Landform Index (LI), is the mean of slope gradients plot to the skyline, divided by 100 to convert percent to a decimal value. Terrain Shape Index (TSI), the mean of slope gradients from plot centre to boundary in eight directions separated by horizontal angles of 45 and aspect slope index (AS)= $\cos(45-\text{Aspect})+1$  was calculated for land physiographic condition study (Beers et al. 1966; McNab 1989, 1993; Sefidi et al. 2016) (Table 1).

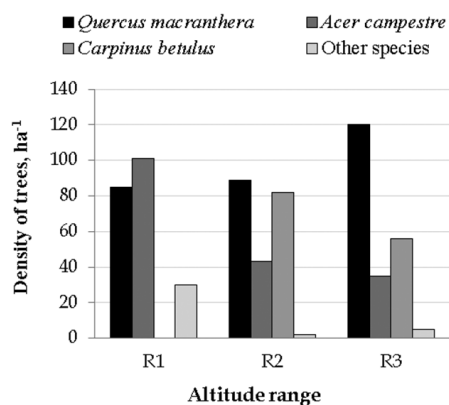
**Table 1. Determination of spatial distribution pattern using distance indices (Mirzaei et al. 2016).**

| Spatial pattern | Hopkins | Johnson-Zimmer | Eberhart |
|-----------------|---------|----------------|----------|
| Clumped         | $>0.5$  | $>2$           | $>1.27$  |
| Random          | $=0.5$  | $=2$           | $=1.27$  |
| Uniform         | $<0.5$  | $<2$           | $<1.27$  |

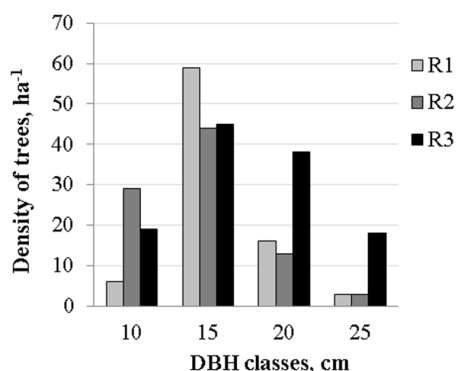
## Results

The number of trees per hectare showed that the largest number of Caucasian oak is in the  $R_3$  as the highest altitude plots (1600–1850 m a.s.l.) (Fig. 3).

Oak trees diameter distribution showed that the most number of large trees are at high altitude range (Fig. 4).



**Fig. 3.** Density of trees in three altitude ranges.

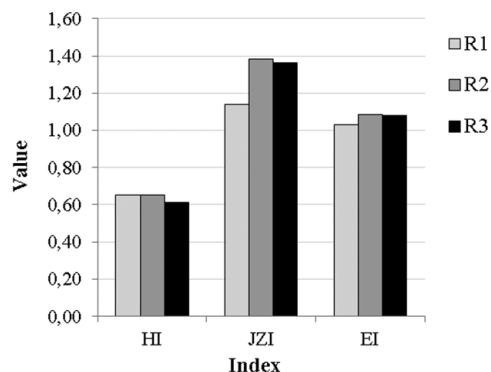


**Fig. 4.** DBH distribution of trees in three altitude ranges.

According to findings of the stand spatial structure distribution indices, the Hopkins index showed the clumped pattern in all three altitudes; Johnson-Zimmer and Eberhart indices showed a uniform spatial distribution pattern in all altitude ranges (Fig. 5).

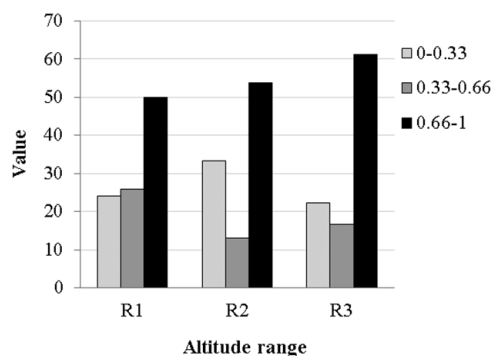
Uniform angle index showed the most amount in 0.6–1 class in all altitude ranges and the amount of this class was the highest in  $R_3$  (Fig. 6).

Species interspecific index showed the most species interspecific composition in the lowest altitude (1200–1400 m a.s.l.) and in class 100 % (Fig. 7).

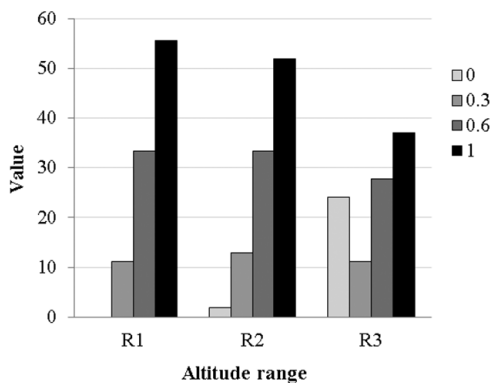


**Fig. 5.** Spatial distribution pattern indices in the study area.

Note: HI – Hopkins index, JZ – Johnson-Zimmer index, EI – Eberhart index.

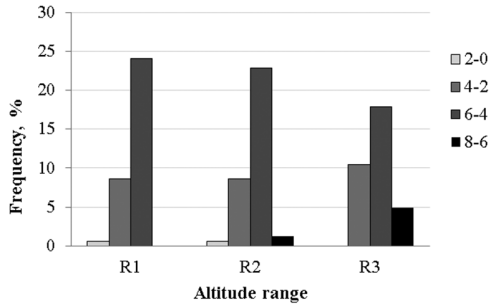


**Fig. 6.** Uniform angle index in three altitude ranges.



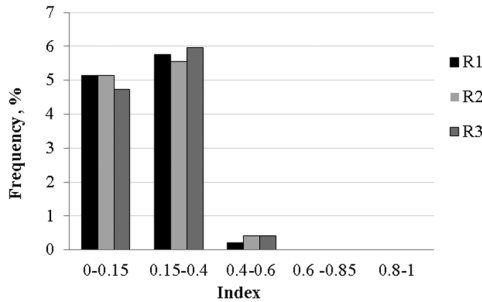
**Fig. 7.** Species interspecific index in three altitude ranges.

Distance to neighbour index showed that the lowest altitude had the most distance in 4–6 m distance category and this distance decreased to neighbour trees with increasing altitude (Fig. 8).



**Fig. 8. Distance to neighbour index in three altitude ranges.**

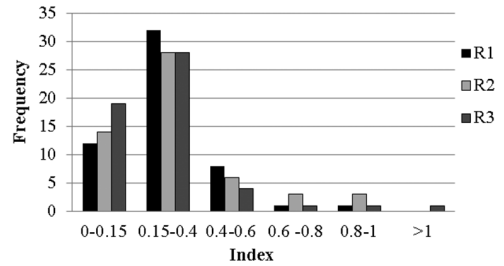
Diameter differentiation index showed that the most number of diameter differentiation was accrued in the lowest altitude and in the smallest classes (Fig. 9).



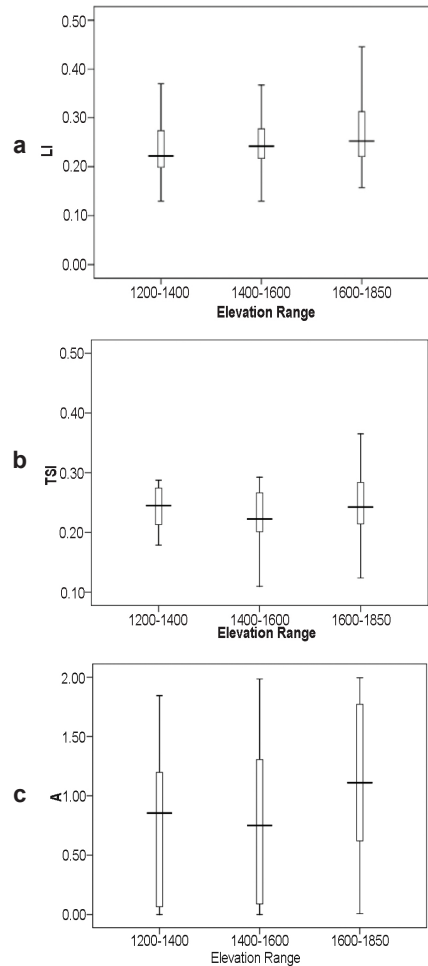
**Fig. 9. DBH differentiation index in three altitude ranges.**

Height differentiation index showed that the most number of height differentiation was accrued in the lowest altitude and in the smallest classes of height (Fig. 10).

Box plot of the relation between altitudes ranges (horizontal axis) and landform indices (Landform Fig. 11-a, TSI Fig. 11-b, A' Fig. 11-c respectively in the vertical axis and Table 2) showed that all landform indices had the greatest average in the highest altitudes ( $R_3$ ).



**Fig. 10. Height differentiation index in three altitude ranges.**



**Fig. 11. Box plots of the comparison of landform indices in altitude ranges.**  
Note: a – LI index; b – TSI index; c – A' index.



**Table 2. Pearson correlation and correlation test between structural quantitative characteristics and physiographic characteristics.**

| Structural quantitative characteristics | Altitude Range | LI     |        | TSL    |       | A'     |        |
|-----------------------------------------|----------------|--------|--------|--------|-------|--------|--------|
|                                         |                | r      | Sig.   | r      | Sig.  | r      | Sig.   |
| Density, N/ha                           | R <sub>1</sub> | 0.114  | 0.570  | 0.014  | 0.944 | 0.111  | 0.584  |
|                                         | R <sub>2</sub> | -0.095 | 0.637  | -0.070 | 0.730 | 0.074  | 0.713  |
|                                         | R <sub>3</sub> | -1.28  | 0.524  | 0.520  | 0.005 | 0.007  | 0.970  |
| Crown area, cm <sup>2</sup>             | R <sub>1</sub> | -0.249 | 0.211  | 0.027  | 0.894 | -0.578 | 0.002* |
|                                         | R <sub>2</sub> | 0.259  | 0.192  | -0.380 | 0.851 | -0.575 | 0.002* |
|                                         | R <sub>3</sub> | 0.248  | 0.212  | -0.235 | 0.237 | -0.147 | 465/0  |
| Basal Area, cm <sup>2</sup> /ha         | R <sub>1</sub> | -0.340 | 0.082  | -0.920 | 0.647 | 0.103  | 0.608  |
|                                         | R <sub>2</sub> | 0.019  | 0.926  | 0.024  | 0.906 | -0.161 | 0.422  |
|                                         | R <sub>3</sub> | -0.446 | 0.002* | -0.317 | 0.107 | -0.156 | 0.437  |

Note: \* – correlation is significant at 5 %.

## Discussion

Description of the composition, structure and special patterns of forests and determining environment important roles on biological communities can be used to design conservation or management strategies for similar forest types (Chokalingam and White 2001, Gerhardt and Foster 2002).

The preliminary results of our quantitative studies suggest that the most density and the biggest DBH classes were present in R<sub>3</sub>. This can be related to anthropogenic disturbance and close to rural areas and human-made degradation of oak stands in the lower altitudes in the study area.

Erfanifard et al. (2012) stated that clumped spatial distribution was due to the heavy seed of some tree species, the anthropogenic disturbance, and grazing livestock. Wei-dong et al. (2001) suggested that the spatial distribution pattern of a species population is affected by many ecological (e.g. forest biodiversity, species seed distribution habit, etc.) and growing condition (interference human activities, conservation status, etc.). In addition,

they emphasized that tree species with heavy fruits and seeds cannot easily distribute by means of natural factors, such as wind and water.

Mirzaei et al. (2016) showed the clumped distribution pattern for *Quercus brantii* var. *persica* stands in the Zagros forests in the west of Iran. They argued that spatial distribution pattern is depended on physiographic factors including altitude, slope (%) and aspect because the stands are available to livestock and local people. Also with increasing altitude and slope, the density of trees reduced and temperature and rainfall changed, therefore these reasons may change the spatial distribution pattern of oak trees in different physiographic conditions.

Pourbabaei et al. (2012) reported that HI and JZI indices showed a random pattern for three oak species (*Quercus libani* G. Olivier, *Q. brantii* Lindl. and *Q. infectoria* Oliv.) stands in the west forest of Iran. Distribution of seeds, reaching the stage of maturity of the seedlings and competition was identified as the effective factors in that spatial distribution pattern.

According to the uniform angle index, it showed a clumped distribution in our

study area. Gangying et al. (2007) performed in the analysis of the tree spatial distribution pattern and concluded that the uniform angle index is a suitable alternative for practical field assessment and it is more effective and feasible than other indices. They stated that if the frequency was larger on the left side in the diagram of uniform angle index than on the right side, then the distribution is random; if on the contrary, the distribution is a clump. Therefore, this index was introduced as accurate in determining the spatial distribution pattern of forest stands (Gangying et al. 2007).

Diameter and height differentiation indices indicated that the average size of neighbour trees was 0–40 % larger or smaller than oak trees. Values of these indices closer to 0 indicated uniformity in size and values closer to one indicated greater heterogeneity in size (Sefidi et al. 2015). This study showed a moderate level of diameter and height differentiation. Also, three altitude ranges had almost the same values of diameter and height differentiation and showed uniformity in trees size.

In this study, the most distance to the neighbour tree (four to six meter) was in R3. We concluded that increasing the altitude could increase the species distance to the neighbour. This result is corresponding to Mirzaei et al. (2016) who stated that reduction of temperature and rainfall could affect the trees density reduction in low altitude ranges.

There was a significant correlation among the physiographic indices, different altitude ranges and trees structural characteristics (density, crown area, and basal area). The effects of altitude factor on oak stands were shown in this study. Therefore, we observed the variability of forest characteristics depending on differ-

ent altitudes. Many factors have played an important role in shaping the regional forest structure consisting of natural (physiography, climatic condition, etc.) and anthropogenic factors (livestock, forestry activities, etc.) (Mirzaei et al. 2016, Fortuny et al. 2017).

## Conclusions

Our finding suggested that the sensitivity of oak stands to the difference in local physiography and forest structural characteristics varied with site conditions. These must be considered as an important part of the ecological basis to develop sustainable management guidelines, especially if increasing human uses are expected on these ecosystems. Our study emphasized the importance of introducing environmental variables and their effects on forest ecosystems characteristics, such as spatial distribution pattern. It seems that human destruction and access to the forests are the most important reasons for changing the spatial pattern in this study. The forest structure has improved due to reduced access to forest stands in high altitude. Other factors, such as climatic conditions, can also be considered in subsequent studies. Finally, based on our results, the forest structure can directly be affected by the physiographic condition.

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## SATELLITE MAPPING OF BULGARIAN LAND COVER – CORINE 2018 PROJECT

Ventzeslav Dimitrov<sup>1</sup>, Radka Koleva<sup>2\*</sup>, Youlin Tepeliev<sup>2</sup>, Yulia Kroumova<sup>3</sup>,  
Todor Lubenov<sup>1</sup>, and Nadezhda Ilieva<sup>3</sup>

<sup>1</sup>Space Research and Technology Institute – BAS, Acad. G. Bonchev Str. Block 3, 1113 Sofia, Bulgaria.

<sup>2</sup>University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria.

\*E-mails: rad\_koleva@abv.bg, rad.koleva@gmail.com

<sup>3</sup>National Institute of Geophysics, Geodesy and Geography – BAS, Acad. G. Bonchev Str. Block 3, 1113 Sofia, Bulgaria.

Received: 05 June 2019

Accepted: 08 July 2019

### Abstract

The main aim of the CORINE Land cover 2018 project is to identify and map the changes of land cover/land use for the period 2012–2018 using multitemporal/multispectral satellite imagery. Harmonized methodology with a 44 class nomenclature and a computer assisted photo-interpretation are applied for creating a geospatial database of Bulgarian territory for the year 2018. A brief description of the applied methodology and the main results achieved are presented. The whole Bulgarian territory is mapped in details adequate for the 1:100 000 scale with a minimum mapping unit of 25 ha and a minimum change area of 5 ha. A statistical analysis of the created databases is made. For the investigated period (2012–2018) the largest in number (2720), the largest as area (53,558 ha) and with the highest percentage (53.54 %) of the total area of the changes are the changes occurring in class 3 'Forests and semi-natural areas'. Six types of changes prevail, forming over 3/4 of the area of all changes – loss of coniferous forests (23,392 ha – 23 %), loss of broad-leaved forests (18,389 ha – 18 %), pastures into non-irrigated arable land (14,534 ha – 14 %), vineyards into non-irrigated arable land (9451 ha – 9 %), fruit trees and berry plantations into non-irrigated arable land (6051 ha – 6 %) and restored broad-leaved forests (4865 ha – 5 %). The area of recovered broad-leaved forests (change 324-311) is 4865 ha, which is almost 4 times less than the lost (18,389 ha). Two negative change processes were identified – conversion of vineyards (221) and orchards (222) into non-irrigated arable land (211), i.e. extensification of agriculture, but also was an intensification one – change of pastures (231) to non-irrigated arable land (211).

**Key words:** change detection, Copernicus, CORINE Land Cover 2018, land cover/land use, remote sensing, satellite images.

### Introduction

The European Commission initiated the CORINE Land Cover (CLC) project in 1985 as a part of the CORINE programme

(Heymann et al. 1994). The primary mapping in Europe was performed between 1986 and 1995 in the project CLC 1990. Further, the CLC database was maintained and updated regularly, as a part of

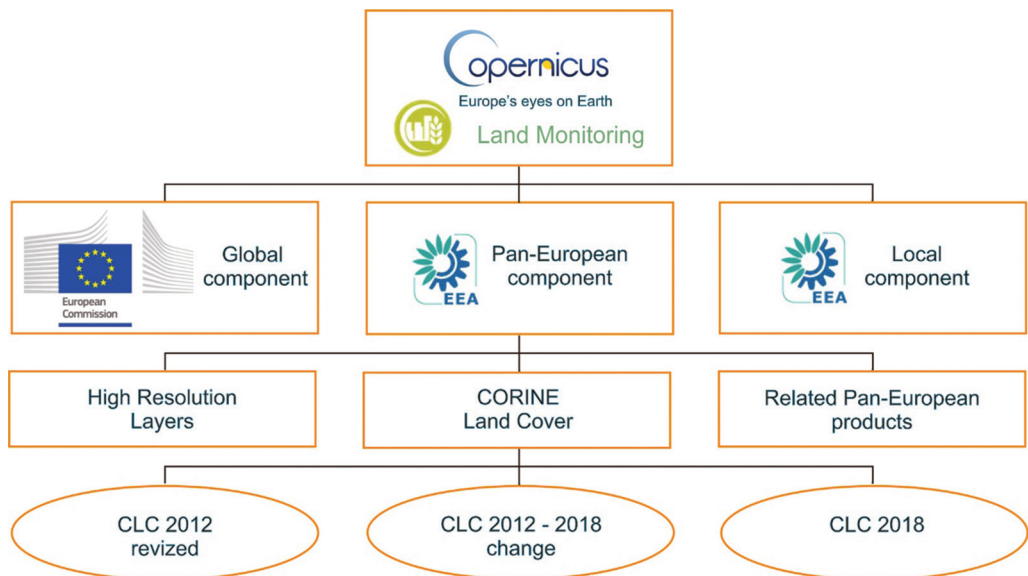
the commitments the European Environment Agency (EEA): CLC2000 (Bossard et al. 2000), CLC2006 (Anonymous 2007), CLC2012 (Büttner et al. 2014), and CLC2018 (Kosztra et al. 2017). An in-depth analysis of four of the aforementioned CLC phases in Europe for the period 1990–2012 on the methodology, data, case studies and prospects of CLC can be found in (Feranec et al. 2016).

Currently, the CLC-related activities are part of the Copernicus programme. Copernicus is the European flagship programme and system for Earth observation and monitoring (Anonymous 2017a). Copernicus Land Monitoring Service (CLMS) provides geographical information on land cover to a broad range of users in the field of environmental terrestrial applications (Fig. 1). The European Commission's Joint Research Centre manages technically the Global Land service. The pan-European component of the CLMS is coordinated by the EEA and produces

land cover/land use data in the CORINE Land Cover, the High Resolution Layers, and related products (e.g. European Settlement Map).

In ellipses at the bottom end of the Figure 1 products delivered by the CORINE Land Cover 2018 (CLC2018) mapping campaign are shown: the revised land cover map of year 2012 (CLC2012revised), land cover changes between the years 2012–2018 (CLC-Change 2012–2018) and the CORINE Land Cover database for the year 2018 (CLC2018).

The CLC nomenclature includes 44 land cover and land use classes at its third level (Heymann et al. 1994, Bossard et al. 2000). CLC uses a Minimum Mapping Unit (MMU) of 25 ha for areal phenomena and a minimum width of 100 m for linear ones, while the MMU for changes is 5 ha. Different MMUs mean that the change layer has higher resolution than the status layer. Due to differences in MMUs the difference between two status layers



**Fig. 1. Copernicus Land Monitoring Service and CORINE Land Cover 2018.**

from different years will not equal to the corresponding CLC-Changes layer. One interested in CLC-Changes between two

neighbour surveys should use the CLC-Change layer. The evolution of CORINE Land Cover can be seen in Table 1.

**Table 1. Evolution of CORINE Land Cover (Anonymous 2017b).**

| CLC Feature                        | CLC1990                          | CLC2000                                                                                                 | CLC2006                                                              | CLC2012                                                              | CLC2018                                                              |
|------------------------------------|----------------------------------|---------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------|
| Satellite data                     | Landsat-5 MSS/TM single date     | Landsat-7 ETM single date                                                                               | SPOT-4/5 and IRS P6 LISS III dual date                               | IRS P6 LISS III and Rapid-Eye dual date                              | Sentinel-2 and Landsat-8 for gap filling                             |
| Time consistency                   | 1986–1998                        | 2000 +/- 1 year                                                                                         | 2006 +/- 1 year                                                      | 2011–2012                                                            | 2017–2018                                                            |
| Geometric accuracy, satellite data | ≤ 50 m                           | ≤ 25 m                                                                                                  | ≤ 25 m                                                               | ≤ 25 m                                                               | ≤ 10 m (Sentinel-2)                                                  |
| Min. mapping unit/width            | 25 ha/100m                       | 25 ha/100m                                                                                              | 25 ha/100m                                                           | 25 ha/100m                                                           | 25 ha/100 m                                                          |
| Geometric accuracy, CLC            | 100 m                            | better than 100 m                                                                                       | better than 100 m                                                    | better than 100 m                                                    | better than 100 m                                                    |
| Thematic accuracy, CLC             | ≥ 85 % (probably not achieved)   | ≥ 85 % (achieved)                                                                                       | ≥ 85 %                                                               | ≥ 85 % (probably achieved)                                           | ≥ 85 %                                                               |
| Change mapping (CHA)               | not implemented                  | boundary displacement min 100 m; change area for existing polygons ≥ 5 ha; for isolated changes ≥ 25 ha | boundary displacement min 100 m; all changes ≥ 5 ha are to be mapped | boundary displacement min 100 m; all changes ≥ 5 ha are to be mapped | boundary displacement min 100 m; all changes ≥ 5 ha are to be mapped |
| Thematic accuracy, CHA             | -                                | not checked                                                                                             | ≥ 85 % (achieved)                                                    | ≥ 85 %                                                               | ≥ 85 %                                                               |
| Production time                    | 10 years                         | 4 years                                                                                                 | 3 years                                                              | 2 years                                                              | 1.5 years                                                            |
| Documentation                      | Incomplete metadata              | standard metadata                                                                                       | standard metadata                                                    | standard metadata                                                    | standard metadata                                                    |
| Access to the data (CLC, CHA)      | unclear dissemination policy     | dissemination policy agreed from the start                                                              | free access for all users                                            | free access for all users                                            | free access for all users                                            |
| Number of countries involved       | 26 (27 with late implementation) | 30 (35 with late implementation)                                                                        | 38                                                                   | 39                                                                   | 38 (Turkey to be added in 2019)                                      |

The number of countries participating in CLC2018 project is 39 with a total mapped area of 5.8 million km<sup>2</sup> (Fig. 2), including 33 member countries and 6 co-

operating countries. The list of EEA member countries (coloured in green) includes the 28 European Union Member States together with Iceland, Liechtenstein, Nor-





**Fig. 2. Countries participating in CORINE Land Cover 2018 project (Anonymous 2019).**

way, Switzerland and Turkey. The six West Balkan countries (coloured in blue) are cooperating countries: Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia as well as Kosovo (Anonymous 2019).

Bulgaria has participated in the Copernicus programme, in particular CLC, since the early 1990s, so this time is our country's fifth participation in the CLC successive projects within the framework of the EEA's Earth observation activities (Stoimenov et al. 2014). This time the production of CLC for the 2018 reference year

was one of the tasks of a larger project for Copernicus supporting activities by countries for the period 2017–2021. In addition to the work on CLC update, three other tasks were included: verification of 2012 reference year local component products and enrichment of Urban Atlas; Post-production verification of the High Resolution Layers for the 2015 reference year; and Dissemination. The essence of CLC land cover update is to identify and map the changes of land cover/land use for the period 2012–2018 using multitemporal/multispectral satellite imagery.



## Methodology

CLC is produced by the majority of countries by visual interpretation of high resolution satellite imagery. In a few countries semi-automatic solutions are applied. The methodology for interpretation of satellite images by basic working units (BWU) practically does not differ from that used in the previous projects. It is unified and harmonized for all 39 countries involved in the implementation of the project. Its full description is given in the respective EAA document (Büttner and Kosztra 2017). This guideline is based on the previously known 'CLC2006 Technical Guidelines' (Anonymous 2007) and 'CLC2012 Addendum to the CLC2006 Technical Guidelines' (Büttner et al. 2014). A CLC nomenclature with 44 classes is used (36 for Bulgaria – see Table 3).

The methodology is based on the use of multi-spectral satellite imagery from

two time horizons, in this case – 2012 and 2018 ( $\pm 1$  year) and a wide range of *insitu* digital databases:

- digital colour orthophotos;
- LUCAS 2012 (Land Use and Coverage Area frame Survey of EUROSTAT);
- Google Earth with Street View and Google Maps;
- topographic maps M 1:25 000 and M 1:50 000;
- physical blocks from the Land Parcel Identification System.

## Satellite Image Data

In Table 2 below the dates are shown of the two sets of Sentinel-2 input satellite images datasets (Coverage 1 and 2) used in the project. Figures 3 and 4 show the spatial distribution of the satellite scenes from the two image databases (IMAGE2012 and IMAGE2018) over the territory of the country.

**Table 2. Satellite imagery (IMAGE2018) from Sentinel-2 satellites, acquired in the summer and early autumn of 2017 for the territory of Bulgaria.**

| Coverage 1 |                  |             | Coverage 2 |                  |             |
|------------|------------------|-------------|------------|------------------|-------------|
| Satellite  | Acquisition date | Tile number | Satellite  | Acquisition date | Tile number |
| S2B        | 2017/06/30       | t35tlg      | S2A        | 2017/08/24       | t35tlg      |
| S2B        | 2017/06/30       | t35tlh      | S2A        | 2017/08/24       | t35tlh      |
| S2B        | 2017/06/30       | t35tlj      | S2A        | 2017/08/24       | t35tlj      |
| S2B        | 2017/06/30       | t35tmg      | S2A        | 2017/08/24       | t35tmg      |
| S2B        | 2017/06/30       | t35tmh      | S2A        | 2017/08/24       | t35tmh      |
| S2B        | 2017/06/30       | t35tmj      | S2B        | 2017/08/19       | t35tmj      |
| S2B        | 2017/07/23       | t34tfp      | S2B        | 2017/09/11       | t34tfp      |
| S2B        | 2017/07/23       | t34tgn      | S2B        | 2017/09/11       | t34tfm      |
| S2B        | 2017/07/23       | t34tgp      | S2B        | 2017/09/11       | t34tfn      |
| S2B        | 2017/08/02       | t34tfl      | S2B        | 2017/09/11       | t34tfl      |
| S2B        | 2017/08/02       | t34tfm      | S2B        | 2017/09/11       | t34tgl      |
| S2B        | 2017/08/02       | t34tfn      | S2B        | 2017/09/11       | t34tgm      |
| S2B        | 2017/08/02       | t34tgl      | S2A        | 2017/09/11       | t34tgn      |
| S2B        | 2017/08/02       | t34tgm      | S2A        | 2017/09/11       | t34tgp      |

| Coverage 1 |                  |             | Coverage 2 |                  |             |
|------------|------------------|-------------|------------|------------------|-------------|
| Satellite  | Acquisition date | Tile number | Satellite  | Acquisition date | Tile number |
| S2A        | 2017/07/02       | t35tng      | S2B        | 2017/09/03       | t35tlf      |
| S2A        | 2017/07/22       | t35tnh      | S2B        | 2017/09/10       | t35tng      |
| S2A        | 2017/07/22       | t35tnj      | S2B        | 2017/08/26       | t35tnh      |
| S2A        | 2017/07/02       | t35tpj      | S2B        | 2017/08/24       | t35tnj      |
| S2B        | 2017/06/30       | t35tlf      | S2B        | 2017/08/24       | t35tpj      |
| S2B        | 2017/06/30       | t35tmf      | S2B        | 2017/09/08       | t35tmf      |

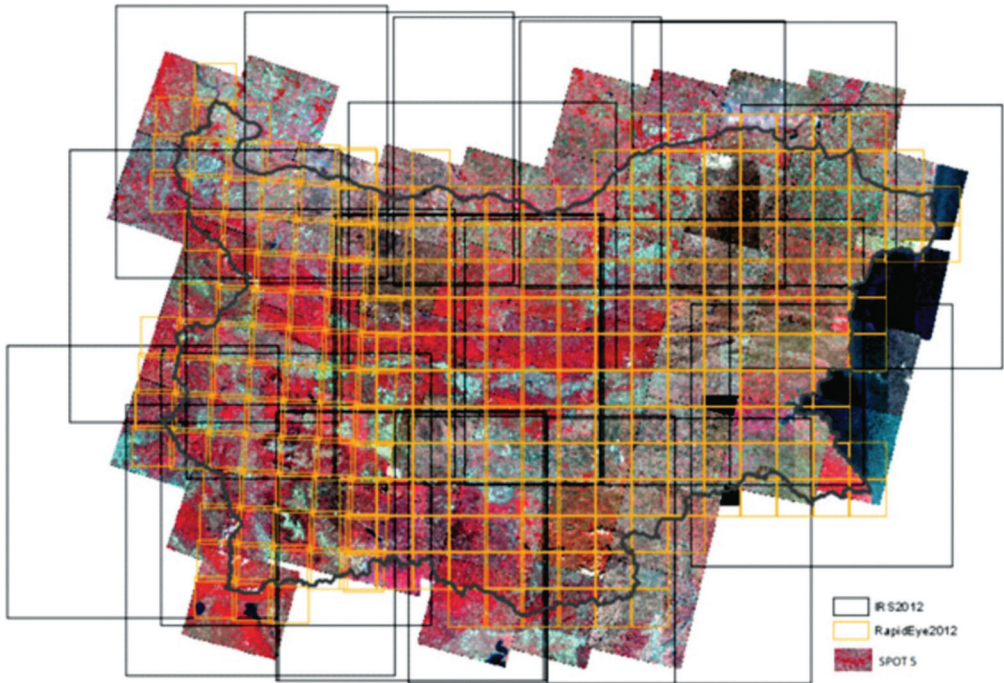


Fig. 3. Spatial distribution of satellite scenes of IMAGE2012.

### Preparation of InterChange Projects for BWUs

The process of computer assisted visual interpretation is preceded by the preparation of InterChange projects by Basic Working Units (BWUs). In Figure 6 the selected division is shown of the territory of the country into BWUs. The territory is

divided into 68 BWUs (Fig. 5) with outlines in which a compromise has been reached between the complete coincidence with the map sheet division of the standard topographical maps of the Military Geographic Service in 1:100 000 scale and the convenience of the interpreters' work in the border regions of Bulgaria and in the edge matching of the neighboring BWUs.

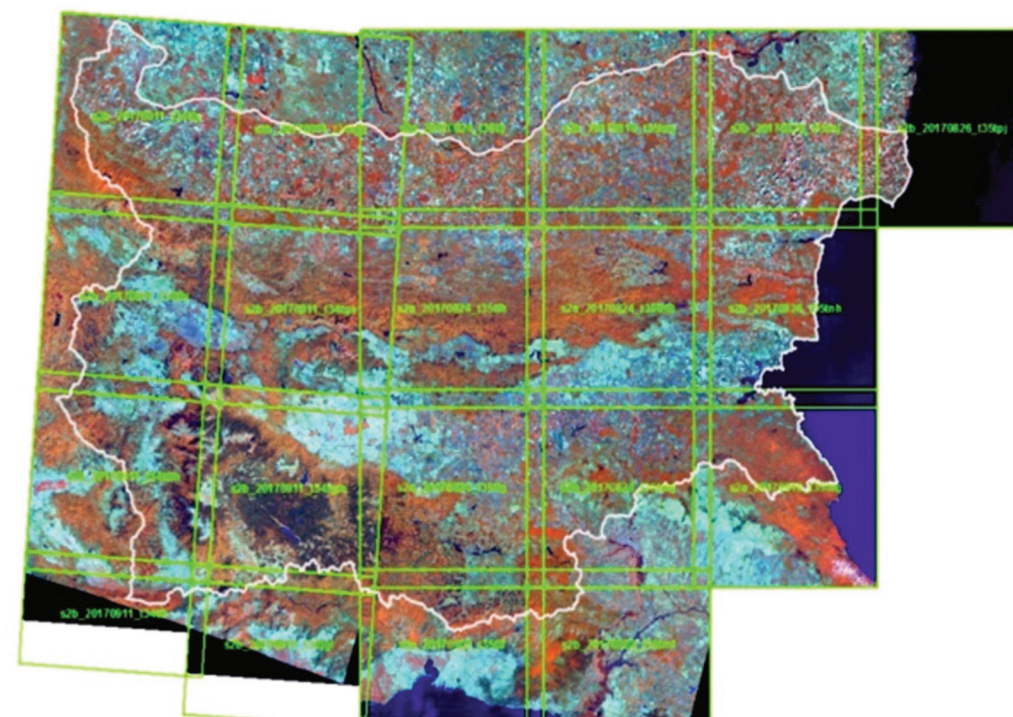


Fig. 4. Spatial distribution of satellite images of IMAGE2018.

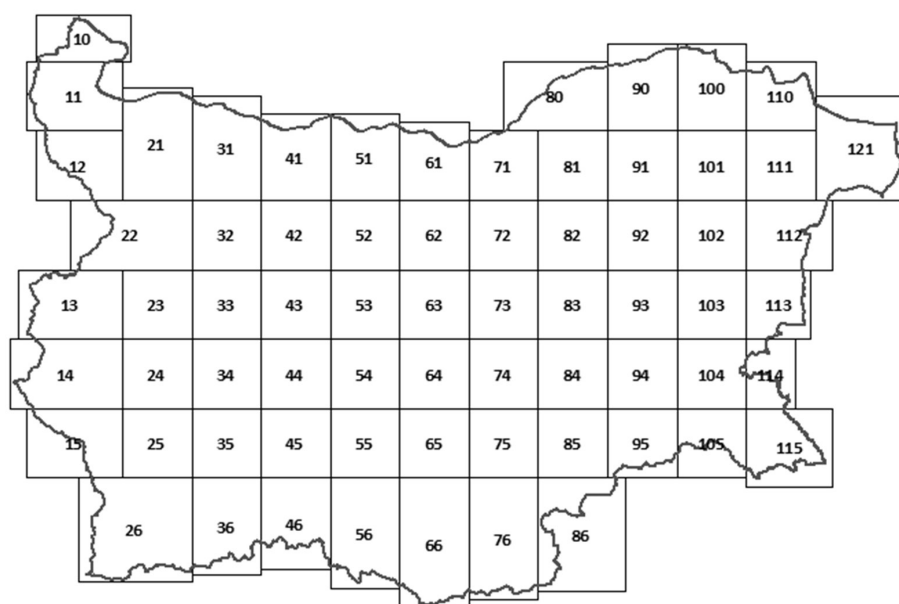


Fig. 5. Division of the Bulgarian territory into BWUs.

This ensures continuity with the work with-in the previous CLC projects.

Each BWU prepared for the interpreters, in addition to the above-described sub-images and entire satellite scenes from the IMAGE2012 database, also contains: vector data from the CLC2012 database, WMS links to the additional data: topographic and thematic maps in digital format and orthophoto maps from 2011 to 2017.

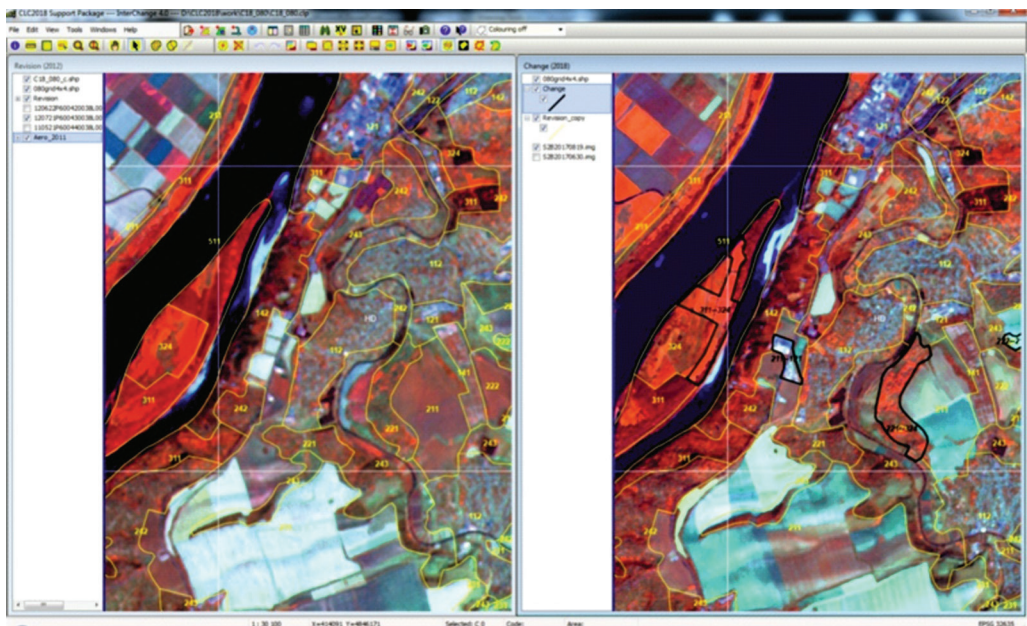
### Detection and Mapping of Land Cover Changes in the Period 2012–2018

The preferred approach of most countries in the project is first to make corrections / improvement in the CLC2012 database obtaining the so-called revised CLC2012<sub>revised</sub> database. Then, changes in the land cover are detected by visual comparison of all input and ancillary data and imag-

es from the IMAGE2012 and IMAGE2018 datasets.

For the computer-assisted photointerpretation (CAPI), the Hungarian software product InterChange (Anonymous 2012) has been used working in two synchronized windows for detecting the changes (see Fig. 6). False color satellite image compositions are compared – IMAGE2012, loaded in the left window (revision) and IMAGE2018 – in the right (change) window, the CLC2012 vector database being overlayed on both of them. The rich set of in-situ data and digital maps allow reliable and accurate delineation of the corrected CLC2012 polygons in the left window and the changes found in the right one.

In the process of identifying and mapping land cover and land use changes, the following principles are respected: outline real changes to reflect the natural and



**Fig. 6.** InterChange screen with two synchronized windows and a set of basic GIS tools. Left window (Revision 2012) – data for 2012 and right window (Change) – CLC data for 2012, satellite and in-situ – for 2018.



socio-economic processes, take into account the logic in the landscape development as a natural-anthropogenic system. Other principles are to comply with the opportunities and the likelihood the detected changes to occur during the 6-year study period and to ignore short-term annual changes (days, seasons) that are characteristic for the agricultural crops, the water bodies and the wetlands.

The basic parameters of the created databases are:

- minimum mapping unit (MMU) of 25 ha;
- minimum width of linear elements (MMW)  $\geq 100$  m;
- minimum area of change polygons  $\geq 5$  ha (total for the so-called technical polygons);
- CLC nomenclature for the land cover – 44 classes (36 for Bulgaria);
- mapping only real changes.

### Creating CORINE Land Cover Database for the Reference 2018 year

The Technical team of the Space Research and Technology institute (SRTI) at the Bulgarian Academy of Sciences implemented the technical part of the task. The overall project management, liaison with the EEA and the results dissemination was fulfilled by the Executive Environmental Agency (ExEA) of Bulgaria. The workflow of SRTI activities included a lot of procedures like image and vector datasets download and preliminary processing, InterChange projects preparation for BWUs, computer assisted image interpretation. We have to add here also activities on the quality assurance and control (QA and QC) – internal and external, creation of CLC2012revision database and CLC Change 2012–

2018 databases with metadata.

For the automated creation of the CLC2018 database we used common GIS software and a specialized module provided by the EEA. The CLC2018 database is obtained by means of a complex overlay GIS operation presented by the (+) symbol:

$$\text{CLC2018} = \text{CLC2012}_{\text{revised}} (+) \text{CLC}_{\text{Change2012-2018}}$$

### Internal and External Quality Control

The internal verification of the results obtained by the interpreters was carried out on a regular basis – after completion of the BWU, before and after the external checks. The overall process of BWU-level checks is noted in the metadata.

In accordance with the terms of the agreement with the EEA, two external verifications were carried out remotely (via the Internet) by the EEA TT on BWU selections. The final check of the photointerpretation work found that the thematic accuracy of the databases created according to the EEA TT criteria was better than 85 %.

### Results and Discussion

Three databases were created as a result of the project implementation: the revised CLC2012, CLC-Change2012–2018 and CLC2018, all complemented with INSPIRE compliant metadata. These databases are the main deliveries of the project.

Furthermore, the following analysis shows inherent features of the land cover and reveals some processes on the base of registered changes.

**Statistical figures of CLC2018**

In Table 3 the areas of the different types of land cover/land use are given, as well

as their percentage of the total area and the number of polygons from the CLC2018 database.

**Table 3. CLC2018 level 3 land cover polygons.**

| CLC class | CLC class name                                                                        | Area       |        | Count  |
|-----------|---------------------------------------------------------------------------------------|------------|--------|--------|
|           |                                                                                       | ha         | %      |        |
| 111       | Continuous urban fabric                                                               | 814        | 0.01   | 4      |
| 112       | Discontinuous urban fabric                                                            | 388,046    | 3.50   | 3,949  |
| 121       | Industrial or commercial units                                                        | 77,388     | 0.70   | 1,161  |
| 122       | Road and rail networks and associated land                                            | 4,486      | 0.04   | 69     |
| 123       | Sea ports                                                                             | 739        | 0.01   | 13     |
| 124       | Airports                                                                              | 6,255      | 0.06   | 33     |
| 131       | Mineral extraction sites                                                              | 32,109     | 0.29   | 316    |
| 132       | Dump                                                                                  | 4,077      | 0.04   | 41     |
| 133       | Construction sites                                                                    | 540        | 0.00   | 9      |
| 141       | Green urban areas                                                                     | 4,348      | 0.04   | 64     |
| 142       | Sport and leisure facilities                                                          | 13,372     | 0.12   | 189    |
| 211       | Non-irrigated arable land                                                             | 3,821,699  | 34.43  | 5,150  |
| 213       | Rice fields                                                                           | 36,855     | 0.33   | 24     |
| 221       | Vineyards                                                                             | 115,846    | 1.04   | 1,336  |
| 222       | Fruit trees and berries plantations                                                   | 45,152     | 0.41   | 711    |
| 231       | Pastures                                                                              | 391,297    | 3.53   | 5,048  |
| 242       | Complex cultivation patterns                                                          | 262,278    | 2.36   | 3,088  |
| 243       | Land principally occupied by agriculture with significant areas of natural vegetation | 1,061,572  | 9.56   | 8,348  |
| 311       | Broad leafed forest                                                                   | 2,297,548  | 20.70  | 5,538  |
| 312       | Coniferous forests                                                                    | 533,561    | 4.81   | 1,857  |
| 313       | Mixed forest                                                                          | 644,870    | 5.81   | 4,110  |
| 321       | Natural grassland                                                                     | 408,566    | 3.68   | 2,905  |
| 322       | Moors and heathlands                                                                  | 23,020     | 0.21   | 73     |
| 324       | Transitional woodland-scrub                                                           | 762,285    | 6.87   | 8,434  |
| 331       | Beaches, dunes, sand                                                                  | 1,898      | 0.02   | 43     |
| 332       | Bare rocks                                                                            | 12,633     | 0.11   | 121    |
| 333       | Sparsely vegetated areas                                                              | 38,405     | 0.35   | 395    |
| 334       | Burnt areas                                                                           | 69         | 0.00   | 2      |
| 411       | Inland marshes                                                                        | 8,395      | 0.08   | 67     |
| 412       | Peatbogs                                                                              | 1,318      | 0.01   | 2      |
| 421       | Salt marshes                                                                          | 408        | 0.00   | 2      |
| 422       | Salines                                                                               | 1,210      | 0.01   | 5      |
| 511       | Water courses                                                                         | 32,537     | 0.29   | 33     |
| 512       | Water bodies                                                                          | 64,848     | 0.58   | 425    |
| 521       | Coastal lagoons                                                                       | 734        | 0.01   | 7      |
| Total:    |                                                                                       | 11,099,180 | 100.00 | 53,572 |

From the data provided, it can be seen that two types of land cover: Non-irrigated arable land (3,821,699 ha) and Forests (3,475,979 ha) cover almost 2/3 (65.75 %) of the territory of Bulgaria.

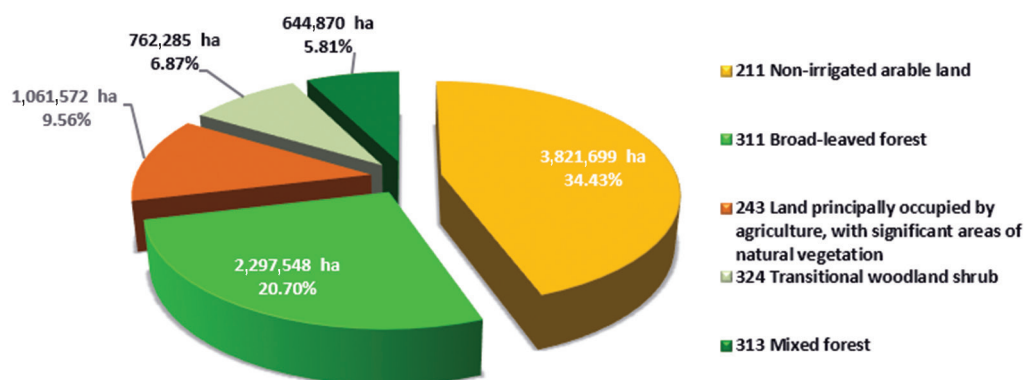
The distribution of major land cover classes at level 1 of the CLC nomenclature is shown in Table 4.

**Table 4. Area of main classes (level 1) for CLC2018.**

| Code class | CLC level 1 classes            | Area       |        | Count  |
|------------|--------------------------------|------------|--------|--------|
|            |                                | ha         | %      |        |
| 1xx        | Artificial surfaces            | 532,460    | 4.80   | 5,843  |
| 2xx        | Agricultural areas             | 5,734,700  | 51.67  | 23,598 |
| 3xx        | Forests and semi-natural areas | 4,722,855  | 42.55  | 23,217 |
| 4xx        | Wetlands                       | 11,331     | 0.10   | 46     |
| 5xx        | Water bodies                   | 98,119     | 0.88   | 452    |
| Total:     |                                | 11,099,180 | 100.00 | 53,572 |

In Figure 7 a diagram can be seen, showing the areas and their percentage of the total area of the 5 classes of land

cover (level 3 of the CLC nomenclature) covering more than 3/4 of the territory of Bulgaria in 2018 reference year.



**Fig. 7. The five land cover classes, forming more than 3/4 of the territory of the country in 2018.**

### Land cover changes in the period 2012–2018

For the period 2012–2018 4,751 change polygons have been found and mapped with a total area of 100,235 ha. In terms of number and area this is more than twice compared to the previous three periods of CLC mapping. In Table 5 the areas (ha) are given of the detected land cover changes at level 1 of the CLC nomenclature for the survey period, as well as their percentage of the area of changes and their number.

Traditionally, the largest in number (2720), the largest as area (53,558 ha) and with the highest percentage (53.54 %) of the total area of the changes are the changes occurring in class 3 'Forests and semi-natural areas'. Six types of changes prevail, forming over 3/4 of the area of all changes (see Table 6 and Fig. 8).

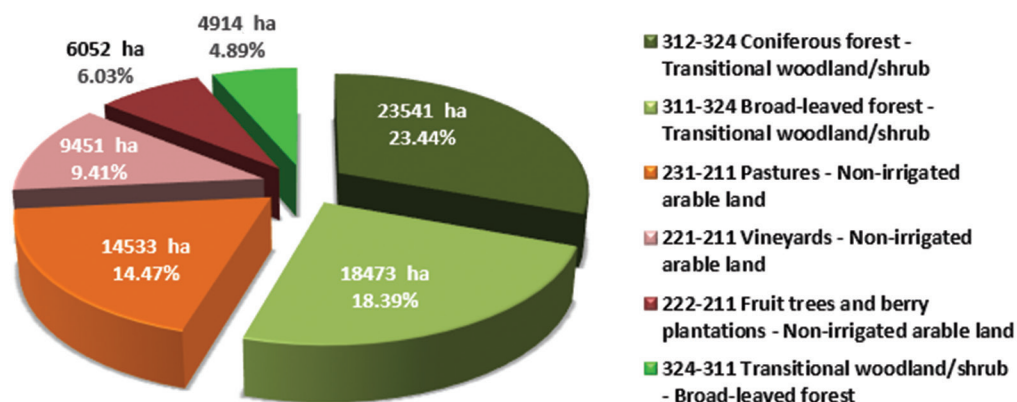


**Table 5. Land cover changes at level 1 of the CLC nomenclature for the survey period.**

| Code class | Changes in level 1 classes     | Area    |         | Count |
|------------|--------------------------------|---------|---------|-------|
|            |                                | ha      | %       |       |
| 1xx        | Artificial surfaces            | 940     | 0.94%   | 48    |
| 2xx        | Agricultural areas             | 45,429  | 45.41%  | 1,978 |
| 3xx        | Forests and semi-natural areas | 53,558  | 53.54%  | 2,720 |
| 4xx        | Wetlands                       | 87      | 0.09%   | 2     |
| 5xx        | Water bodies                   | 21      | 0.02%   | 3     |
| Total:     |                                | 100,035 | 100.00% | 4,751 |

**Table 6. The largest in terms of area and number changes for the period 2012–2018.**

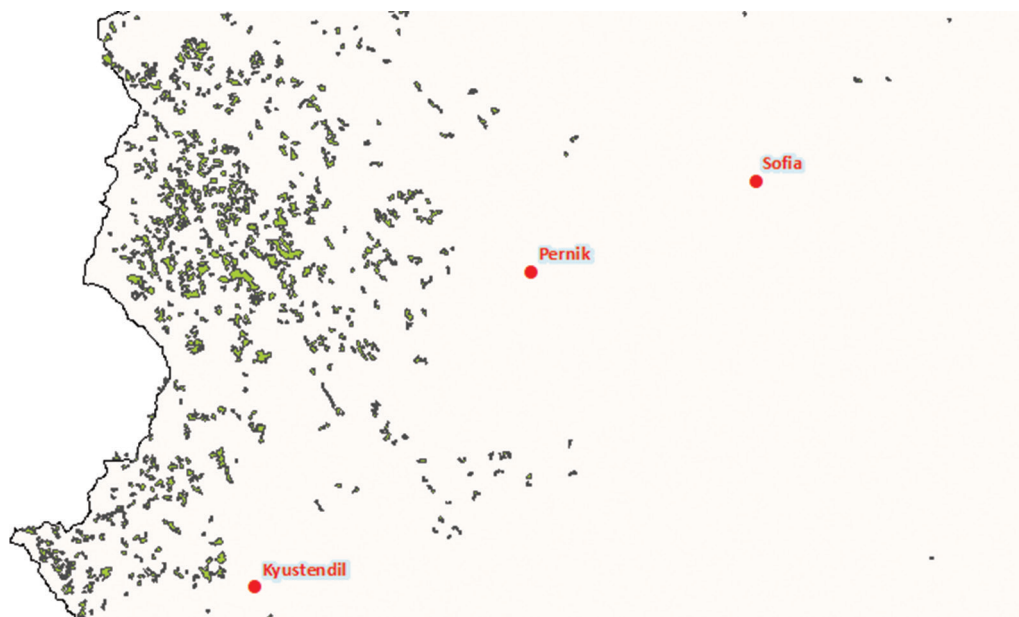
| Type of change | Description of the change                                        | Area   |    | Count |
|----------------|------------------------------------------------------------------|--------|----|-------|
|                |                                                                  | ha     | %  |       |
| 312-324        | Loss of coniferous forests                                       | 23,392 | 23 | 867   |
| 311-324        | Loss of broad-leaved forests                                     | 18,389 | 18 | 1242  |
| 231-211        | Pastures into non-irrigated arable land                          | 14,534 | 14 | 765   |
| 221-211        | Vineyards into non-irrigated arable land                         | 9451   | 9  | 341   |
| 222-211        | Fruit trees and berry plantations into non-irrigated arable land | 6051   | 6  | 220   |
| 324-311        | Restored broad-leaved forests                                    | 4865   | 5  | 275   |
| Total:         |                                                                  | 76,682 | 77 | 3710  |

**Fig. 8. The types of changes with the highest number and percentage of the total area.**

The forest loss of both types (coniferous and broad-leaved) is much more considerable against the restored one. The area of recovered broad-leaved forests (change 324-311) is 4865 ha, which is almost 4 times less than the broad-leaved forest loss (18,389 ha).

It can be seen from Figure 9 that the

largest in terms of area and number are losses of coniferous (312-324) and broad-leaved (311-324) forests. The main reason for this is the intensive invasion of bark beetle in the coniferous forests on both the western border with Serbia and the Republic of Northern Macedonia (Fig. 9) and on a smaller scale on the border with



**Fig. 9. Large number of changes 312-324 on our western border – North of Kyustendil.**

Greece. This explains the above marked increase in the number of changes in Bulgaria for the period. The phenomenon is of a transient nature and the expected adequate measures by the competent authorities should limit it and liquidate it. This allows diverse and in-depth statistics to be produced for a quarter of a century and comparisons with the other 38 countries.

As is well known, land cover changes can be considered the relevant information source about processes (flows) in the landscape (Feranec et al. 2010). and various types of land cover transformation to different categories of land use change. In relation to agriculture, from Fig. 9 the some specific processes can be marked. Along with an intensification course (change of pastures (231) to non-irrigated arable land (211), extensification processes are available – conversion of vineyards (221) and orchards (222) to non-irrigated arable land (211).

## Conclusions

The article presents the methodology and main results of the CORINE Land Cover 2018 Bulgaria. The status of the CLC as a part of Land Monitoring Service of the Copernicus programme is indicated. The most important deliveries of the project are described, namely geospatial databases CLC2012revised, CLC-Change2012–2018 and CLC2018. The applied methodology ensured consistency between these three databases. As a result of a statistical analysis facts and figures, derived from CLC databases, are presented. Major land cover transformations, like deforestation, forestation, extensification and intensification are exposed.

All the project results are freely available from the ExEA website for further and more detailed analyses and applications.

## Acknowledgements

The CORINE Land Cover 2018 Bulgaria task is financed by EEA through ExEA within the Specific Contract No 3436/R0-COPERNICUS/EEA. 56955 and a contract No 3497/30.11.2017 between ExEA and SRTI. We would like to thank the European Environment Agency and the Executive Environmental Agency for project's funding and supervision! Special thanks to Dr. Anton Stoimenov for his leadership, contribution and support for the realization of this study!

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## BIOGEOCHEMICAL CHANGES IN FOREST ECOSYSTEMS POLLUTED BY INDUSTRIAL EMISSIONS, EAST SIBERIA, RUSSIA

Tatiana A. Mikhailova, Olga V. Shergina\*, and Olga V. Kalugina

Siberian Institute of Plant Physiology and Biochemistry, Siberian Branch of the Russian Academy of Sciences, 664033 Irkutsk, 132 Lermontova Str., Russia.

\*E-mail: sherolga80@mail.ru

Received: 27 March 2019

Accepted: 15 July 2019

### Abstract

The biogeochemical data of pine (*Pinus sylvestris* L.) forests have been studied in the impact and buffer zones of the influence of technogenic emissions from the large industrial center Ussol'no-Sibirskoe (East Siberia, Russia). Changes in the acid-base balance, accumulation and migration of elements-pollutants, the content of nutrient elements in the components of forest ecosystem – tree-stands, forest litter, soil horizons – on contaminated areas compared to the background sample plot have been revealed. A significant shift in the acid-base balance to the alkaline range and an active migration of elements-pollutants in soil horizons and forest litter have been shown to be key processes causing a disturbance of exchange reactions of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$  cations in the soil absorbing complex (SAC) and a decrease in nutrient elements migration into root systems of trees. Pronounced changes in the acid-base balance, high accumulation of elements-pollutants, binding of nutrient elements by pollutants in the soil horizons and in plant tissues lead to the disruption of nutrition and to the inhibition of pine trees growth processes. The biogeochemical parameters observed are characterized by interconnected changes in the main components of the forest ecosystem (soil and tree-stand) and can serve as adequate criteria for assessing its state under technogenic pollution.

**Key words:** acid-base balance, elements migration, pine forests, soil profile, technogenic pollution.

### Introduction

Nowadays, increasing technogenic pollution is one of the significant factors in the destabilization of forest ecosystems. The negative impact of industrial pollution appears in the disfunction of biogeochemical processes due to unregulated flux of elements-pollutants (Mikhailova and Shergina 2010). Technogenic fluxes of many hazardous pollutants, such as, for example, sulphur compounds and

heavy metals, become commensurate with the quantities of substances naturally involved in the biogenic circulation (Aleksenko 2000). The resulting ecosystem disbalance of elements can cause a significant deterioration in the nutritional status of forests, which can later lead to their structural and functional transformation continuing until the break-up of biogeocenosis (Paoletti et al. 2010, Dmuchowski et al. 2011, Mikhailova et al. 2016). The results of many studies show that in forest

ecosystems, natural soils and tree-stands are the most sensitive to atmospheric pollution (Kaigorodova 1996, Motuzova 2013, Mikhailova et al. 2017b). To assess the negative anthropogenic impact on forest ecosystems, a complex of various data is used. Biogeochemical data which characterize the functioning of the soil and woody plants are quite informative. At the same time, monitoring methods in most cases are based on the state analysis of a single component of the forest ecosystem (Lindenmayer et al. 2000, Moffat 2003, De Vries and Groenenberg 2009, Burrascano et al. 2011). For example, soil pollution is often assessed by disturbing the acid-base balance of the soil solution, and there is no unequivocal judgment about its effect on the migration of nutrient elements in the soil profile. Some authors believe that the acidic conditions in the soil medium impede the redistribution of nutrients in the soil (Kaigorodova and Vorobeichik 1996, Schroth et al. 2007). Others point out that the mobility of nutrient elements directly depends on an increase in soil alkalinity (Makarov et al. 1995, Maslova 2008). In such studies, experimental soils are usually used (Fokin et al. 1982, Alewell and Matzner 1993, Alewell 2002, Selim et al. 2004), which is not quite acceptable, since these soils differ significantly from natural ones according to many characteristics. In a number of works on the deterioration of forest ecosystem, the authors judge by the content of pollutants in the polluted air and their quantity adsorbed by the soil, as well as by the change in some parameters of this component (Zhang and Sparks 1990, Piirainen et al. 2002, Malinova 2009, Vařát et al. 2015, Medvedev and Derevyagin 2017). However, in our opinion, for a more adequate judgment of the state of technogenic polluted for-

est ecosystem, data that characterize the disturbance degree of the biogeochemical correlation of its main components – soil and tree-stand – are needed. On the basis of such data, it is possible to estimate how disturbed this correlation is due to technogenic fluxes of pollutants and what the future vector of the ecosystem transformation is. Such studies are especially significant for areas that have been subjected to the prolonged exposure to technogenic emissions, since in such areas it is possible to clearly establish the direction of pathological biogeochemical disturbances and adequately assess the state of the ecosystems. In the Russian Federation, such studies are relevant for the Siberian region, where a large number of industrial centers are concentrated; therefore, their emissions have a large negative impact on the natural migration of biogenic elements in forest ecosystems. The purpose of this work is to identify changes in the complex of biogeochemical data: acid-base balance, accumulation and migration of elements-pollutants, content of biogenic elements in the forest ecosystem' components – soil, forest litter, and tree-stands – under technogenic pollution.

## Material and Methods

Studies were conducted in 2015–2017 in forest ecosystems polluted by technogenic emissions from a large industrial center located near town Usolie-Sibirskoe, Eastern Siberia, Russia (52°45'N, 103°38'E) (Fig. 1). Most of the industrial enterprises of the center are concentrated in the northwestern direction from the town. The main transfer of technogenic emissions, in which are dominated by sulphur oxides and aerosols of heavy metals occurs in the



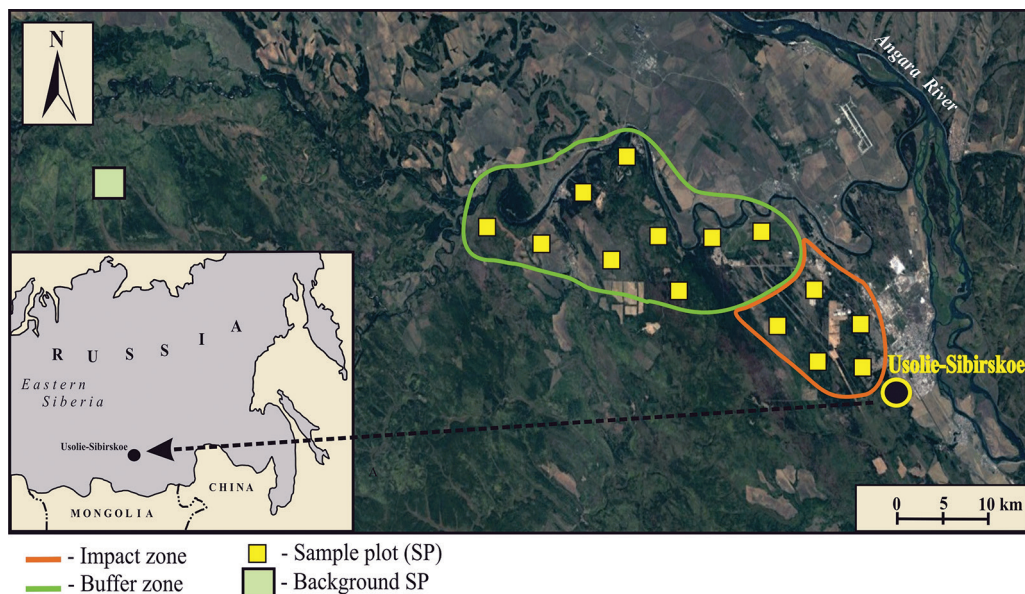


Fig. 1. Location of sample plots in impact and buffer zones.

same direction (Review ... 2016–2017). The technogenic load on the polluted territory is characterized as heavy (State ... 2017).

Field studies in forests were carried out on 14 sample plots (SP) with a size of 0.1 ha each. They were created using the ICP Forest international method (Manual ... 2010). In the studied area, the impact and buffer zones of technogenic influence were established according to the method of the Roshydromet of the Russian Federation (Guidelines ... 1991, Ecological ... 1999, Atlas ... 2004). The impact zone was located at a distance of up to 10 km from the industrial center, and its area was about 45 km<sup>2</sup>. The buffer zone is up to 35 km far from the industrial center, and its area is about 180 km<sup>2</sup> (Fig. 1). Five SP were created within the impact zone, and nine – in the buffer zone. Background SP was laid at a distance of 80 km from the industrial center (52°55'N, 102°07'E, 604 m a.s.l.) in a healthy forest, not subjected to

the influence of technogenic emissions.

Scots pine (*Pinus sylvestris* L.) forests dominate in the study area. They are located within the boundaries of one soil okrug with the predominance of gray forest soils (WRB, 2006. Greyic Phaeozems Albic) occurring on Jurassic sandstones and mudstones (Regional ... 1998). In the study area, herbaceous pine forests of III class of bonitet are common; fullness of tree-stands (Stand density index) varies from 0.4 to 0.5. The description of the soil type was carried out in accordance with the generally accepted in the Russian Federation classification (Classification ... 1977); the designation of horizon indices was given in accordance with the soil classification of Vorobieva (1999). We have shown that soil profiles in all the SPs are represented by the following set of horizons: O – Ad – A – AB – B – BE – Bt,f – BC – C (Unified State Register of Soil Resources (EGRPR), 2006. A0 – A1 – A1A2 – Bt – BC – C), in which zones of humus



accumulation and eluvio-illuvial redistribution of elements and their compounds are distinguished. Forest litter was studied by use the square pocket method for taking averaged samples in a fivefold replication. A survey of pine stands was carried out according to the methods adopted in forestry, as well as using the recommendations of the international manual of ICP Forests (Methodical ... 1981, Manual ... 2010). To determine the content of nutrient elements and elements-pollutants, samples of needles were taken from shoots of the second year of life from 5–6 pine trees of 40–45 years of age. The samples of pine needles, forest litter and soil horizons from all the SPs collected during the field studies were delivered to the laboratory for analytical studies. Determination of Ca, Mg, K, and Na in pine needles was carried out after the preliminary ashing of the samples at temperature of 450°C in a muffle furnace, followed by the dissolution the ash in concentrated hydrochloric acid. Their mobile forms, which are part of the soil adsorption complex (SAC), were extracted with ammonium acetate buffer (1 M  $\text{CH}_3\text{COONH}_4$ ) with pH 4.8 (Hue and Evans 1983, Burt 2004). Mobile forms of sulphur and heavy metals were replaced with a normal solution of hydrochloric acid. The content of chemical elements in soil and plant samples was determined by atomic absorption spectrophotometry, flame photometry, photocolourimetry (Ermakov 1987, Carter and Gregorich 2008). Certified techniques and analytical equipment of the Center 'Bioanalitica' (SIFIBR SB RAS) were used. The measurements were performed with flame photometer Flavo (Carl Zeiss, Germany), AAS vario 6 FL (Germany), FT-IR Spectrum One spectrophotometer (Perkin Elmer, AAA, Czech Republic).

For statistical processing of the data obtained, computer programs 'R statistical computing medium', version 3.1.1., were used (Shipunov et al. 2014). The following factors were calculated: the Pearson linear correlation coefficient ( $r_{xy}$ ), the coefficient of determination ( $R^2$ ) of the functional dependence between the data (Schabenberger and Pierce 2002). Data processing and their graphical representation were performed in Microsoft Excel, Mathcad 12. The schematic map was made using Corel DRAW (version 13) and Google Earth Pro (version 7.1.8.3036).

## Results and Discussion

### Changes in the pH of forest ecosystem components

Acid-base balance largely determines the chemical activity of the elements both in the soil and in the plant (Pierzynski et al. 2005, Shamrikova et al. 2006, Molla and Velizarova 2015). Therefore, in our studies, it was prior to determine the level of acid-base balance in the horizons of soil profile, forest litter, and pine assimilative organs on the technogenic polluted territory. A pronounced change in this indicator towards alkaline values has been revealed, especially in the impact zone (Fig. 2). The actual acidity ( $\text{pH}_{\text{H}_2\text{O}}$ ) in the forest litter is recorded from 6.40 (buffer zone) to 7.80 (impact zone); in the upper soil horizons (Ad, A), where organic matter and humus accumulate – to 7.60; in the mineral part of the soil it is from 5.80 to 6.90. This indicates a technogenic influx of alkaline components of industrial emissions to the soil surface on the territory adjacent to the industrial complex. In the soil on the background SP, pH shift

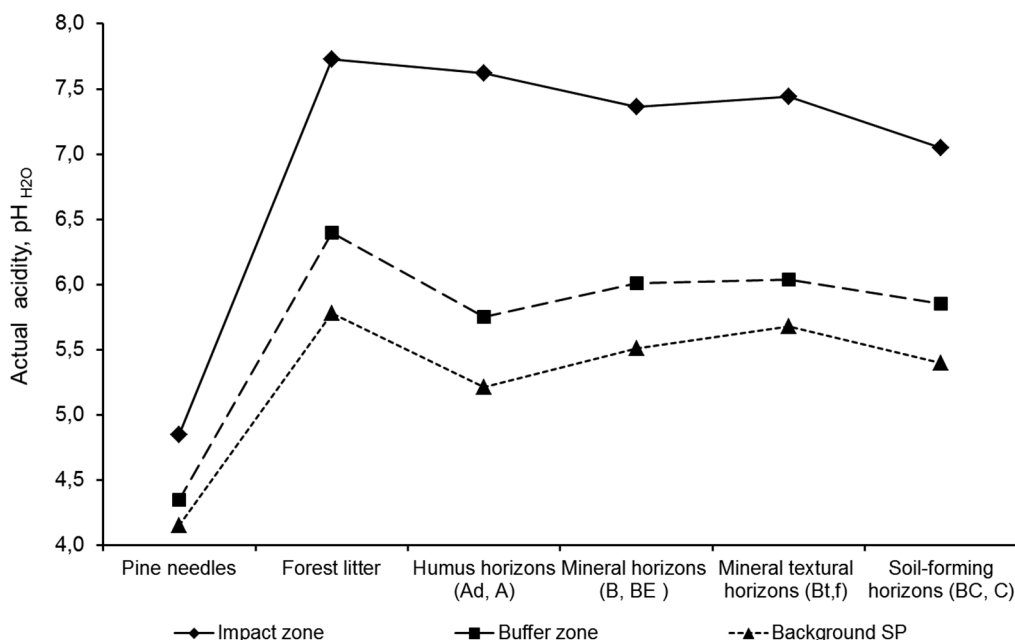


Fig. 2. Changes in the actual acidity in comparison with the background SP.

in the forest litter and the upper horizons is not recorded. This soil is characterized by a gradual decrease in  $\text{pH}_{\text{H}_2\text{O}}$  down the profile from 5.70 to 5.40.

In pine needles in the polluted areas,  $\text{pH}_{\text{H}_2\text{O}}$  varies less than in the soil horizons – from 4.35 (buffer zone) to 4.85 (impact zone). At the same time, the correlations between actual acidity indicators of soil horizons and the forest litter on the one hand, and acidity values of needles on the other hand, are high ( $r = 0.85\text{--}0.98$ ,  $P = 0.05$ ,  $n = 78$ ). This suggests that changes in  $\text{pH}_{\text{H}_2\text{O}}$  in the needles are closely related to changes in  $\text{pH}_{\text{H}_2\text{O}}$  in the forest litter and soil. In general, the revealed substantial alkalization of forest ecosystem components during technogenic pollution can significantly change the migration ability of elements-pollutants (sulphur, lead, cadmium) and their chemical affinity to biogenic elements.

### Migration of pollutants (lead, cadmium and sulphur) in polluted soils

The change in the acid-base balance is a very significant factor contributing to the increased migration of heavy metals in the soil horizons (Latypova 2000, Motuzova 2000). Moreover, in most cases this happens when the balance shifts to the acid direction (Bezuglova and Orlov 2000). However, we have previously found an increase in the migration of mobile forms of heavy metals along the soil profile with increasing alkalinity (Shergina and Mikhailova 2011). In these studies, when determining the content of mobile forms of lead and cadmium in gray forest soils in the polluted zones, we have found an active illuvial redistribution with depth, as well as a high accumulation of these ions in the humus horizon (Fig. 3). As it can be seen from this Figure, the content of lead and

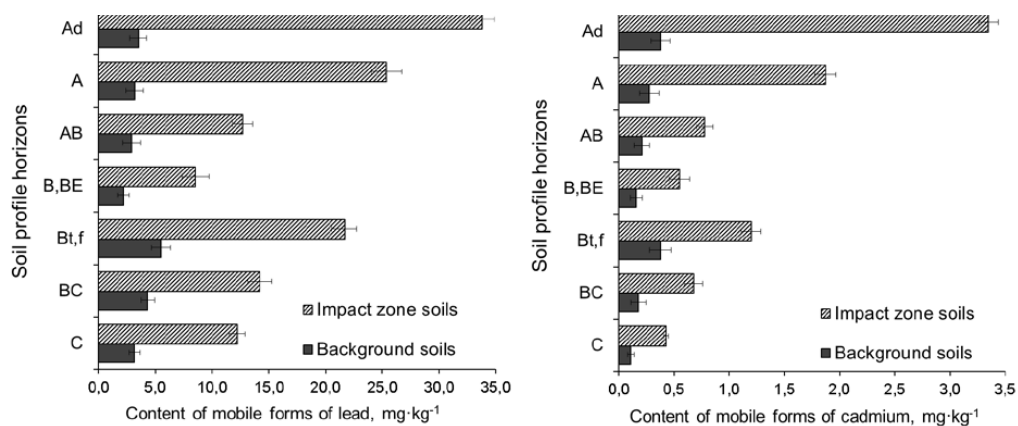


Fig. 3. Content of lead (left) and cadmium (right).

cadmium exceeds the background level by 7–10 times in the impact zone in the upper humus-accumulative horizons.

In the underlying illuvial horizon BE of the soil profile, the concentration of these elements decreases by 4–6 times relative to the accumulation in the humus horizons, and in the textural horizon Bt,f it increases again up to 3–4 times compared to the background. In the soil-forming horizons BC and C of the polluted soils, the accumulation of lead, cadmium is also significant – up to 14.25 and 0.68 mg·kg<sup>-1</sup>, respectively. The data obtained indicate the active migration of heavy metals along the profile of polluted soils. Whereas other researchers report the accumulation of pollutant elements mainly in the upper soil horizons (Stroganova et al.

2003, Fedorets and Bahmet 2003).

Our studies on the accumulation and migration of sulphates in the polluted soils showed their high concentrations in all soil horizons. However, it should be noted that the limits of fluctuations between their minimum and maximum values are significant (Table 1). In the upper part of the soil profile, sulphur share in the form of sulphates is concentrated in the humus-accumulative horizons (Ad, A), that is, it is part of the organic matter. In the underlying soil horizons B and BE, a decrease in the level of sulphur is noted. However, in Bt,f, and BC horizons, its content slightly increases again. Such a vertical change in the concentration of mobile sulphates along the soil profile

Table 1. Minimum and maximum values of mobile sulphates content (mg·kg<sup>-1</sup>).

| Soil horizon index | Impact zone<br>( $P=0.05$ , $n=15$ ) | Buffer zone<br>( $P=0.05$ , $n=27$ ) | Background SP<br>( $P=0.05$ , $n=9$ ) |
|--------------------|--------------------------------------|--------------------------------------|---------------------------------------|
| Ad                 | 22.2–32.6                            | 10.5–24.5                            | 5.8±0.4                               |
| A                  | 19.3–21.8                            | 6.3–17.7                             | 1.9±0.2                               |
| AB                 | 10.2–15.3                            | 4.8–10.2                             | 1.2±0.1                               |
| B                  | 9.3–13.6                             | 3.9–9.6                              | 0.7±0.1                               |
| BE                 | 7.7–10.9                             | 3.1–7.5                              | 0.5±0.1                               |
| Bt,f               | 14.3–19.5                            | 7.2–14.1                             | 1.7±0.3                               |
| BC                 | 7.6–11.2                             | 5.1–8.8                              | 0.8±0.2                               |
| C                  | 5.7–8.4                              | 2.1–6.7                              | 0.3±0.1                               |

can lead to the transformation of sulphur compounds and enhance the process of deep gleying under the anaerobic conditions in the soil profile.

An additional source of technogenic sulphur in the soil can be an increase in its content in fallen leaves and needles, correspondingly, in the forest litter (Hovland 1981). When determining the content of mobile sulphates in the forest litter in the impact zone, we have found an increase in their concentration from 2.5 to 5.4 times and from 2 to 2.6 times in the buffer zone, compared with the background level. The maximum values of mobile sulphur in the forest litter in the SPs of the impact zone reach 36–50 mg·kg<sup>-1</sup>. Those values for the SPs in buffer zone reach 25–35 mg·kg<sup>-1</sup>. A correlation relationship of a high confidence level ( $r=0.91$ ,  $P=0.05$ ,  $n=32$ ) has been found between the sulphur content in the forest litter and its content in the upper humus horizons Ad and A. That confirms the presence of technogenic deposition of sulphur to the soil surface and the further fixation of sulphur containing

compounds by organic matter, most often by humic acids.

### Binding of exchange cations ( $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{K}^{+}$ , $\text{Na}^{+}$ ) by pollutants in polluted soils

Revealed soil alkalinization in SPs of the impact and buffer zones is a consequence of influence emissions from the Usolie-Sibirskoe industrial center, specifically, from the thermal power plants that use coal with a high content of alkaline-earth compounds (State ... 2017). Calcium compounds dominate among the alkaline components of the emissions. On this basis, the relationship between the content of polluting ions  $\text{SO}_4^{2-}$  and  $\text{Pb}^{2+}$  and a mobile form of  $\text{Ca}^{2+}$  in the soil horizons of the impact and buffer zones have been observed (Fig. 4). As it can be seen from the graphs, the relationship between these parameters is directly proportional. The areas of maximum conjugate accumulation of polluting ions and  $\text{Ca}^{2+}$  have been found in the humus horizons Ad and A, as well as in the textural horizon Bt,f (Fig. 4).

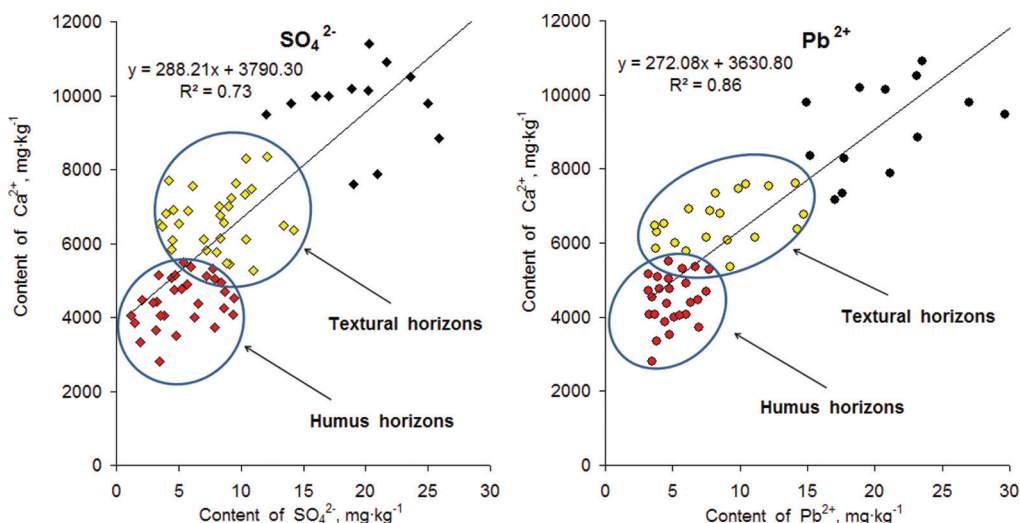


Fig. 4. Relationship between exchange cation  $\text{Ca}^{2+}$  and polluting ions  $\text{SO}_4^{2-}$  and  $\text{Pb}^{2+}$  in the polluted soils in the impact and buffer zones.

That is due to the presence of humic compounds and a thin silt fraction with high adsorption capacity. In the background soils, there is no accumulation of pollutants, and there is no correlation between the content of mobile forms of sulphur and calcium, as well as of lead and calcium.

In addition to calcium, a direct relationship has been found between the content of other SAC cations ( $Mg^{2+}$ ,  $K^+$ ,  $Na^+$ ) and sulphur ions (and lead ions) in the polluted soils. Moreover, for all the soil horizons in the impact and buffer zones, these relationships are reliable ( $r=0.58-0.78$ ,  $P=0.05$ ,  $n=52$ ). Based on the data obtained for polluted soils, the following sequence of the SAC cations correlation (in order of weakening) with sulphate ion ( $SO_4^{2-}$ ) and lead ion ( $Pb^{2+}$ ) within the soil profile can be represented:  $Ca^{2+}(r=0.85) > Na^+(r=0.78) > Mg^{2+}(r=0.67) > K^+(r=0.58)$ . This means that the closest correlation of the polluting ions is observed with the divalent calcium cation ( $Ca^{2+}$ ), and the smallest – with the monovalent  $K^+$  cation. Thus, the binding of SAC ions with polluting ions is one of the main reasons for the disturbance of biogeochemical migration of nutrient elements in the soil profile and for the decrease in their flux into plant root systems.

### Accumulation of elements-pollutants in the needles of pine trees

The results of the analysis of pine needles samples showed a significant accumulation of pollutants (sulphur, lead, cadmium) in the assimilative organs of trees. The highest level is recorded in the impact zone. For instance, the sulphur concentration rises by 2–6 times ( $400-1200 \text{ mg} \cdot \text{kg}^{-1}$ ), lead – by 5–17 times ( $0.45-1.53 \text{ mg} \cdot \text{kg}^{-1}$ ), cadmium – by 4–10 times ( $0.15-0.38 \text{ mg} \cdot \text{kg}^{-1}$ ) compared to background values. The calculation of correlations between the content of elements-pollutants in the needles and in soil horizons showed that these are correlations of a high level of significance (Table 2). They indicate the presence of an active influx of pollutants (sulphur, lead, cadmium) from the soil horizons through the root system with xylem transport into the assimilative organs of plants.

In turn, the high accumulation of elements-pollutants causes a disturbance of the ratio of nutrients in the needles of trees. It is shown that an increase in the proportion of sulphur, cadmium, and especially lead in the needles causes a significant decrease in the degree of biogenic elements in it (Table 3). It has been found

**Table 2. Correlation coefficients between pollutant content in the soils and pine needles in the impact zone of pollution ( $P=0.05$ ,  $n=45$ ).**

| Soil horizon index | Sulphur Needles | Lead Needles | Cadmium Needles |
|--------------------|-----------------|--------------|-----------------|
| O                  | 0.85            | 0.79         | 0.65            |
| Ad                 | 0.76            | 0.74         | 0.63            |
| A                  | 0.66            | 0.60         | 0.59            |
| AB                 | 0.61            | 0.52         | 0.54            |
| B                  | 0.58            | 0.51         | 0.49            |
| BE                 | 0.54            | 0.49         | 0.48            |
| Bt,f               | 0.78            | 0.71         | 0.67            |
| BC                 | 0.69            | 0.65         | 0.61            |
| C                  | 0.62            | 0.59         | 0.52            |

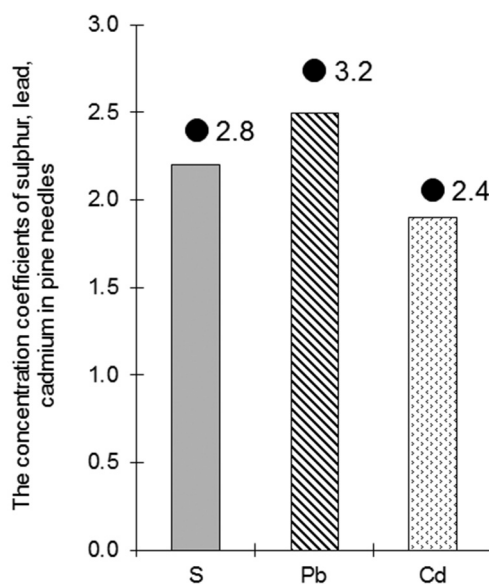
**Table 3. Changes in concentration ratios (in %) of elements in pine needles.**

| Elements ratios | Impact zone | Buffer zone | Background SP |
|-----------------|-------------|-------------|---------------|
| Ca:S            | 85:15       | 90:10       | 96:4          |
| Mg:S            | 80:20       | 87:13       | 93:7          |
| K:S             | 76:24       | 81:19       | 92:8          |
| Na:S            | 72:28       | 77:23       | 91:9          |
| Ca:Pb           | 90:10       | 95:5        | 97:3          |
| Mg:Pb           | 80:20       | 88:12       | 94:6          |
| K:Pb            | 70:30       | 79:21       | 92:8          |
| Na:Pb           | 68:32       | 75:25       | 91:9          |
| Ca:Cd           | 95:5        | 98:2        | 99:1          |
| Mg:Cd           | 87:13       | 92:8        | 97:3          |
| K:Cd            | 79:21       | 86:14       | 94:6          |
| Na:Cd           | 76:24       | 82:18       | 92:8          |

that in the assimilative organs of trees in the impact zone of the Usolie-Sibirskoe industrial center, the strongest decrease in the level of nutrient elements is observed against the increasing concentrations of elements-pollutants. In the buffer zone, the imbalance of elements in the needles is smaller, but nevertheless, it is clearly expressed in comparison with the background SP.

Consequently, in the polluted soils (impact and buffer zones), there is a pronounced disturbance of the nutrition pine trees due to a lack of basic nutrient elements. It should also be noted that needles aerially absorb elements-pollutants from the polluted air. This fact plays an important role in the imbalance of the ratio of nutrient elements and the disturbance of pine mineral nutrition. The activity of this way of entry of pollutants can be judged by comparing the concentration coefficients of elements-pollutants in needles with the exceeding frequency of their maximum permissible concentrations (MPC) in the atmospheric air polluted with emissions from the Usolie-Sibirskoe industrial center (Fig. 5). This figure shows the correspondence between the excess of MPC of sulphur, lead, cadmium and the excess of

their concentration coefficients in needles. In addition, during the aerial absorption of pollutants in the process of gas exchange, both the mineral nutrition and the process of photosynthesis are disturbed at the same time (Mikhailova et al. 2017a). Consequently, the negative change in the nu-



**Fig. 5. Concentration coefficients of elements-pollutants in pine needles and MPC (black circles) in the atmospheric air of Usolie-Sibirskoe industrial center.**



tritional status of pine trees in the polluted area is due to the influence of pollutants both through the soil on the root food, and through the direct aerial absorption by the assimilative organs. The disturbance of pine mineral nutrition appears primarily in the inhibition of the growth processes of assimilative organs. Thus, in the impact zone, the weight of one needle is reduced twice compared with the background value, the needles weight on the shoot – by 4.5–5 times, the number of needles on the shoot – by 2–3 times, the lifetime of the needles is reduced to 2–3 years, the level of crown defoliation increases to 50–60 %. In the buffer zone, growth data are reduced to a lesser degree – the weight of one needle is reduced by 1.3 times, the needle weight on the shoot – by 2.5–3.5 times, the number of needles on the shoot – by 1.5–2 times, the lifetime of the needles is reduced to 3 years, the level of crown defoliation is 30–45 %. Thus, the morphostructural data of trees indicate a pronounced damaging effect of industrial emissions on the vital state of pine trees, especially in the impact zone of pollution by emissions from Usolie-Sibirskoe industrial center.

## Conclusion

The complex of biogeochemical parameters of pine (*P. sylvestris*) forests in the impact and buffer zones of the influence of technogenic emissions of the large industrial center Usolie-Sibirskoe (Eastern Siberia, Russia) has been studied. It has been revealed that the technogenic impact has led to a significant shift in the acid-base balance towards alkaline values in the forest litter and upper soil horizons. The impaired acid-base balance

caused a change in the migration fluxes of elements-pollutants in the soil. The active movement and accumulation of sulphate ion and mobile forms of lead and cadmium in all the horizons of gray forest soils, up to the soil-forming one, has been detected. The content of these pollutants in the soil horizons exceeded the background values from 14 to 28 times. Mobile forms of heavy metals and sulphur have been shown to alter the migration ability and the quantity of the exchange cations  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$  in the SAC of humus and mineral horizons. The binding of SAC ions with pollutant ions can be considered as one of the main causes of the disturbance of biogeochemical migration of nutrient elements in the soil profile, and changes in their nutritional regime, that bring about a decrease in the migration flux of nutrients to the root systems of plants. It is shown that the active coming of elements-pollutants from the soil and polluted air into the assimilative organs leads to the imbalance of nutrient elements in the needles and, as a result, to the suppression of their growth processes. This is evidenced by a significant reduction in many morphostructural parameters of trees. The studied biogeochemical parameters are characterized by interconnected changes in the main components of the forest ecosystem (soil and tree-stands), so they can serve as adequate criteria for assessing its condition under technogenic pollution.

## Acknowledgment

The authors thank Russian government program No 52.1.10 for financial support and Russian Foundation of the Basic Research, the research project No 12-04-31036.

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## CONTENT AND STOCK OF ORGANIC CARBON IN SOILS ON THE TERRITORY OF VITOSHA NATURE PARK

Ludmila Malinova<sup>1\*</sup>, Pavel Pavlov<sup>1</sup>, and Biser Hristov<sup>2</sup>

<sup>1</sup>University of Forestry, 10 Kl. Ohridski Blvd., Sofia 1797, Bulgaria.

\*E-mail: ludmila\_malinova@yahoo.com

<sup>2</sup>N. Poushkarov Institute of Soil Science, Agrotechnologies and Plant Protection, Sofia 1331,  
7 Shosse Bankya Str.

Received: 28 May 2019

Accepted: 02 August 2019

### Abstract

A complex of humus parameters was studied and a database was created about the content of soil organic matter and org. C stock in the surface 20 cm layer of Umbrisols in order to monitor the relationship 'climate changes – organic C stock' over time. Geo-coordinated stations located near the Cherni Vrah meteorological station were used, where the temperatures and precipitation have been observed since 1935. Higher acidity ( $\text{pH}_{\text{H}_2\text{O}}$ ), higher amount of total carbon and free low-molecular humic acids were determined in the surface 10 cm soil layer in comparison with the 10–20 cm layer. The share of humic and fulvic acids in the total carbon of the two layers did not differ and was characterized by stable values. The org. C stock in the surface 10 cm layer was  $7.00 \pm 1.31 \text{ t.ha}^{-1}$  and  $15.55 \pm 2.72 \text{ t.ha}^{-1}$  in the 10–20 cm layer. The total org. C stock in the surface 20 cm layer of Umbrisols was 18594.15 t. The obtained results allow future statistical evaluations of information about monitoring the relationship 'climate changes – org. C stock' over time.

**Key words:** Ca complexed humic acids, fulvic acids, humic acids, optical characteristics, org. C stock, Umbrisols.

### Introduction

One of the most topical issues, related to conservation of soil fertility, is the loss of soil organic matter (SOM). There are many reasons for these losses – tillage, land use changes, erosion, climate changes, etc. Modern challenges for SOM protection are largely related to climate changes. It is assumed that the SOM decomposition rate will increase with rising temperatures (Tate et al. 1993, Orlova and Vasilievskoi 1994, Simmons et al. 1996). Climate changes and their effect on soil depend on different biotic, abiotic and an-

thropogenic factors. The variation of org. C stock has been accepted as an indicator of their impact on SOM (IPCC GPG 2003, IPCC 2006). It is expected that the rising temperatures will have an impact on the content of org. C in soil in long term, but it is more likely that short-term changes, caused by the applied management practices and land use changes, will occur (EEA 2017). Examples of such changes include increased soil compaction rates, erosion, pollution, etc. The contemporary evaluation reveals that the information about the org. C stock in the arable land may be greatly increased – by about 25 %

(EEA 2017). In most studies this stock is estimated for the organic and surface soil layers which occupy the upper 30 cm soil. Worldwide, soils contain about 1500 Pg org. C (Batjes 1996), which is about three times the amount of carbon in plants and twice as much in the atmosphere (IPCC 2000, GFOI 2016). According to Jansen (2003) soils contain approximately 2344 Pg C in the first 3 m layer, 1502 Pg C of which are in the first meter.

The soils in the forest territories of Bulgaria, which are not affected by degradation processes, are comparatively rich in organic matter (Rousseva and Marinov 2014). According to Boyadgiev et al. (1994) the org. C stock in soils in the country is about 1.3 Gt, and according to Filcheva and Rousseva (2004) – 1.5 Gt. Different studies were carried out – estimates for different soil depths of 25 cm, 50 cm and 100 cm, by soil groups (Filcheva et al. 2002, Filcheva and Rousseva 2004), by climate zones (Hristov and Filcheva 2016), etc. The creation of databases can contribute to the monitoring of changes in org. C stock, caused by climate changes, but in the IPCC methodological guidelines for evaluation of org. C stock (Guidance 2003, 2006) it is recommended to create permanent monitoring sites in order to collect regular information over time. In the forest area of the country there is only one such site, located in the field station for intensive monitoring of forest ecosystems in Yundola. The collected database refers to *Dystric Cambisols* (Malinova et al. 2011). Disadvantage of this site is the short-term monitoring of temperature and precipitation – since 1998 (Kolarov et al. 2002).

The aim is analysis and evaluation of the soil organic matter content and org. C stock in a specially designed experimental plot on the territory of Vitosha Nature Park, located near a meteorological sta-

tion. A database on the content of soil organic matter and org. C stock in the top 20 cm soil layer of Umbrisols was created in order to monitor their relationships to climate changes over time.

## Subject and method of the research

The Cherni Vrah area was selected for the purpose of the present study, where measurements of the temperature and precipitation have been carried out since 1935. It is the highest peak of Vitosha Mountain. Apart from the presence of the meteorological station, the fact that soils of the high mountain areas are considered the most sensitive to temperature increase due to the combination of this process with the acidification of atmospheric depositions (Kulhavý et al. 2009), is also significant for selecting the location for creation of the experimental site.

Cherni Vrah is located at an altitude of 2290 m. The terrain of Vitosha is layered due to the multiple mountain elevations during the Neogene and Quaternary. The Vitosha pluton is composed of Upper Cretaceous intrusive rocks – gabbro, monzonite and leucosyenite (Management Plan ... 2014). The vegetation is meadow.

The experimental site is located on the territory of the Sofia State Forest Enterprise in section 1178, subsection 10, in the immediate vicinity of Cherni Vrah (Pic. 1), at an altitude of 2260 m. The soil is Umbrisols, formed under the impact of meadow vegetation including *Nardus stricta*, *Vaccinium* sp., *Juniperus* sp. The soil-forming rock is leucomonzonite. No soil erosion is observed. An area with flat terrain is selected in order to prevent the occurrence of erosion processes. No





**Pic. 1. Soil sampling area near Cherni Vrah.**

signs of human impact are determined.

The experimental plot consists of 10 geo-coordinated sampling points, located at a distance of 1 m in the north-south direction. Soil samples from depths 0–10 cm and 10–20 cm were collected from each sampling point.

The following soil parameters were analysed: total carbon; total content of org. C extracted with a double solution of sodium pyrophosphate and sodium hydroxide; extractable carbon with 0.1M NaOH; 'aggressive' fraction of fulvic acids

(0.1 N  $\text{H}_2\text{SO}_4$ ); content of org. C in humic acids and fulvic acids; 'free' and  $\text{R}_2\text{O}_3$  complexed humic acids; optical characteristics of humic acids. The  $E_{465}/E_{665}$  ratio was calculated as the ratio of absorbance at 465 nm and 665 nm wavelength. The content and composition of soil organic matter was determined by the modified Tyurin method (i.e. 120 °C, 45 min. and  $\text{Ag}_2\text{SO}_4$  as a catalyst) and by the Kononova-Belchikova method (Kononova 1966, Filcheva and Tsadilas 2002), and bulk density according to ISO 11272.

## Results

The soil at the experimental plot is Umbrisols with a profile *Asod* – A – C. *Asod* is with a soil depth of about 5 cm. The lower limit of the *umbric* horizon is at 38 cm depth, with a clear transition to a C horizon. In a fresh state the soil is characterized by from 10 YR 2/4 colour in *Ah* to 10 YR 2/1 in the A horizon. Soil texture is loam, aggregates – barely observable and soil does not react under the influence of a 10 % HCl solution.

The soil has a highly acidic reaction (see Table 1). It is the most acidic in the surface 10 cm layer ( $\text{pH}=4.53 \pm 0.06$ ), where active decomposition processes of grass vegetation residues occur. The pH values show strong acidification of this soil layer. The difference in pH between layers 0–10 cm and 10–20 cm is statistically significant (Fig. 1). The median splits the data sets for the two layers in intervals that completely deviate (Fig. 1).

The higher acidity of the surface soil layer is due to the higher presence of free low-molecular humic acids in it (see Table 1). The significance of the difference with the 10–20 cm layer is demonstrated by  $p=0.02$  (calculated of free low-molec-

ular humic acids as a % of the soil sample) and by  $p=0.03$  (calculated as a % of the total carbon). It can be assumed that the values are above the critical limit of  $\text{pH}=4.0$ , after which the carbon mobilization is enhanced (Funakawa et al. 2006).

The total carbon amount is very high. It is differentiated in depth as in the surface 10 cm layer it is the highest ( $17.29 \pm 1.51$  %) and sharply decreases in depth – 10–20 cm layer. The difference between the two layers is also statistically significant  $p=0.00$  (Fig. 2).

Taking into consideration the humic and fulvic acid amounts (extracted with  $0.1\text{M Na}_4\text{P}_2\text{O}_7 + 0.1\text{M NaOH}$ ) as a percentage of the soil sample, it is determined that they accumulate more actively in the surface 10 cm soil layer and in depth their content decreases (figs 3 and 4). However, their share in the total carbon does not differ in the two layers, which indicated their stability (figs 5 and 6).

The humus type, determined by the ratio between the org. C in humic (Cha) and fulvic (Cfa) acids is estimated as fulvic-humic.

The ratio varies from 0.77 to 1.61. The results do not clearly outline the reason for the presence of the reversed hu-

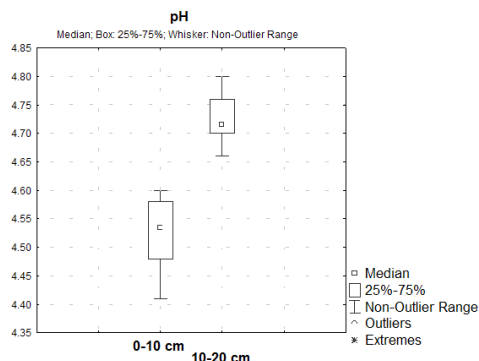


Fig. 1. Reaction of soil solution in layers 0–10 cm and 10–20 cm in Umbrisols.

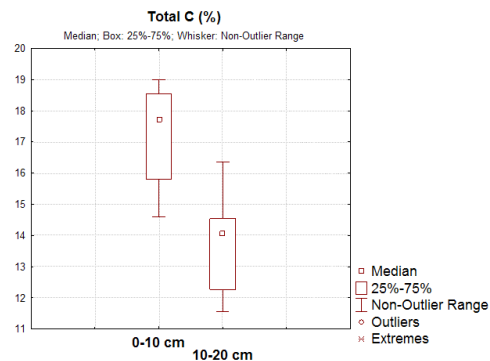


Fig. 2. Total carbon content in layers 0–10 cm and 10–20 cm in Umbrisols.

Table 1. Soil organic matter content and composition.

| Sam-<br>pling<br>point<br>No | Soil<br>depth,<br>cm | pH<br>H <sub>2</sub> O | Total<br>C,<br>% | Organic carbon<br>extracted with<br>0.1M Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub> +0.1M<br>NaOH |                       |                       | Ra-<br>tio<br>C <sub>h</sub> /C <sub>f</sub> | Organic carbon hu-<br>mic acid fractions, %              |                   | Nonex-<br>tracted<br>org. C,<br>% | Extracted<br>org. C<br>0.1N H <sub>2</sub> SO <sub>4</sub><br>% | Optical properties, %                                      |                                                           |                      |
|------------------------------|----------------------|------------------------|------------------|------------------------------------------------------------------------------------------------------|-----------------------|-----------------------|----------------------------------------------|----------------------------------------------------------|-------------------|-----------------------------------|-----------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------|----------------------|
|                              |                      |                        |                  | Org. C,<br>%                                                                                         | C <sub>h</sub> ,<br>% | C <sub>f</sub> ,<br>% |                                              | Free and<br>R <sub>2</sub> O <sub>3</sub> com-<br>plexed | Ca com-<br>plexed |                                   |                                                                 | Total humic<br>acids<br>E <sub>465</sub> /E <sub>665</sub> | Free humic<br>acids<br>E <sub>465</sub> /E <sub>665</sub> | Org. C<br>NaOH,<br>% |
|                              |                      |                        |                  |                                                                                                      |                       |                       |                                              |                                                          |                   |                                   |                                                                 |                                                            |                                                           |                      |
| 1                            | 0–10                 | 4.4                    | 18.54            | 8.89<br>47.95                                                                                        | 4.14<br>22.33         | 4.75<br>25.62         | 0.87                                         | 100.00                                                   | 0.00              | 9.65<br>52.05                     | 0.74<br>3.99                                                    | 4.95                                                       | 4.78                                                      | 8.34<br>44.98        |
|                              | 10–20                | 4.7                    | 14.54            | 6.82<br>46.91                                                                                        | 3.82<br>26.27         | 3.00<br>20.64         | 1.27                                         | 100.00                                                   | 0.00              | 7.72<br>53.09                     | 0.80<br>5.50                                                    | 4.84                                                       | 4.75                                                      | 5.95<br>40.92        |
| 2                            | 0–10                 | 4.5                    | 18.99            | 7.25<br>38.18                                                                                        | 3.27<br>17.22         | 3.98<br>20.96         | 0.82                                         | 100.00                                                   | 0.00              | 11.74<br>61.82                    | 0.72<br>3.79                                                    | 4.89                                                       | 4.40                                                      | 6.93<br>36.49        |
|                              | 10–20                | 4.7                    | 16.36            | 5.84<br>35.70                                                                                        | 3.05<br>18.64         | 2.79<br>17.05         | 1.09                                         | 100.00                                                   | 0.00              | 10.52<br>64.30                    | 0.67<br>4.09                                                    | 4.86                                                       | 4.72                                                      | 5.78<br>35.33        |
| 3                            | 0–10                 | 4.6                    | 15.45            | 6.27<br>40.58                                                                                        | 3.27<br>21.17         | 3.00<br>19.41         | 1.09                                         | 100.00                                                   | 0.00              | 9.18<br>54.42                     | 0.78<br>5.05                                                    | 4.83                                                       | 4.86                                                      | 5.89<br>38.12        |
|                              | 10–20                | 4.8                    | 12.27            | 3.65<br>29.75                                                                                        | 1.96<br>15.97         | 1.69<br>17.77         | 1.16                                         | 100.00                                                   | 0.00              | 8.62<br>70.25                     | 0.70<br>5.70                                                    | 5.19                                                       | 4.63                                                      | 3.44<br>28.04        |
| 4                            | 0–10                 | 4.5                    | 17.27            | 6.53<br>37.81                                                                                        | 2.84<br>16.44         | 3.69<br>21.37         | 0.77                                         | 100.00                                                   | 0.00              | 10.74<br>62.19                    | 0.70<br>4.05                                                    | 4.77                                                       | 4.67                                                      | 6.16<br>35.67        |
|                              | 10–20                | 4.7                    | 14.27            | 3.87<br>27.12                                                                                        | 2.07<br>14.51         | 1.80<br>12.61         | 1.15                                         | 100.00                                                   | 0.00              | 10.40<br>72.88                    | 0.68<br>4.76                                                    | 5.17                                                       | 4.47                                                      | 3.55<br>24.89        |
| 5                            | 0–10                 | 4.5                    | 18.18            | 6.60<br>36.30                                                                                        | 3.60<br>19.80         | 3.00<br>16.50         | 1.20                                         | 100.00                                                   | 0.00              | 11.58<br>63.70                    | 0.63<br>3.46                                                    | 4.74                                                       | 4.91                                                      | 6.60<br>36.30        |
|                              | 10–20                | 4.8                    | 13.95            | 4.25<br>30.47                                                                                        | 2.62<br>18.78         | 1.63<br>11.69         | 1.61                                         | 100.00                                                   | 0.00              | 9.70<br>69.53                     | 0.74<br>5.30                                                    | 4.86                                                       | 4.77                                                      | 3.87<br>27.74        |
| 6                            | 0–10                 | 4.5                    | 18.74            | 6.21<br>33.14                                                                                        | 3.83<br>20.40         | 2.38<br>12.70         | 1.61                                         | 2.48<br>64.75                                            | 1.35<br>35.25     | 12.53<br>66.86                    | 0.53<br>2.83                                                    | 5.27                                                       | 5.22                                                      | 6.16<br>32.87        |
|                              | 10–20                | 4.7                    | 13.62            | 6.76<br>49.63                                                                                        | 2.76<br>20.26         | 4.00<br>29.37         | 0.69                                         | 1.45<br>52.54                                            | 1.31<br>47.46     | 6.86<br>50.37                     | 0.43<br>3.16                                                    | 4.95                                                       | 4.93                                                      | 3.12<br>22.71        |
| 7                            | 0–10                 | 4.5                    | 17.66            | 6.43<br>36.41                                                                                        | 3.83<br>21.69         | 2.60<br>14.72         | 1.47                                         | 2.79<br>72.85                                            | 1.04<br>27.15     | 11.23<br>63.59                    | 0.49<br>2.77                                                    | 5.31                                                       | 5.28                                                      | 5.24<br>29.67        |
|                              | 10–20                | 4.7                    | 14.17            | 5.23<br>36.91                                                                                        | 2.79<br>19.69         | 2.44<br>17.22         | 1.14                                         | 2.28<br>81.72                                            | 0.51<br>18.28     | 8.94<br>63.09                     | 0.49<br>3.46                                                    | 4.60                                                       | 5.02                                                      | 4.30<br>30.35        |

|    |       |     |       |             |             |             |             |             |             |              |             |              |             |             |
|----|-------|-----|-------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|--------------|-------------|-------------|
| 8  | 0-10  | 4.6 | 14.60 | <u>5.56</u> | <u>3.00</u> | <u>2.56</u> | <u>1.17</u> | <u>2.69</u> | <u>0.31</u> | <u>9.04</u>  | <u>0.49</u> | <u>4.084</u> | <u>5.06</u> | <u>3.98</u> |
|    |       |     |       | 38.08       | 20.55       | 17.53       |             | 89.67       | 10.33       | 61.92        | 3.36        |              |             | 27.26       |
|    | 10-20 | 4.7 | 14.60 | <u>4.15</u> | <u>1.96</u> | <u>2.19</u> | <u>0.89</u> | <u>1.76</u> | <u>0.20</u> | <u>10.45</u> | <u>0.49</u> | <u>5.13</u>  | <u>4.97</u> | <u>3.44</u> |
|    |       |     |       | 28.42       | 13.42       | 15.00       |             | 89.80       | 10.20       | 71.58        | 3.36        |              |             | 23.56       |
| 9  | 0-10  | 4.6 | 17.76 | <u>6.00</u> | <u>3.31</u> | <u>2.69</u> | <u>1.23</u> | <u>2.48</u> | <u>0.83</u> | <u>11.76</u> | <u>0.71</u> | <u>4.61</u>  | <u>5.25</u> | <u>5.56</u> |
|    |       |     |       | 33.78       | 18.64       | 15.15       |             | 74.92       | 25.08       | 66.22        | 3.99        |              |             | 31.31       |
|    | 10-20 | 4.7 | 11.55 | <u>4.58</u> | <u>2.28</u> | <u>2.30</u> | <u>1.00</u> | <u>1.76</u> | <u>0.52</u> | <u>6.97</u>  | <u>0.54</u> | <u>5.38</u>  | <u>4.85</u> | <u>3.65</u> |
|    |       |     |       | 39.65       | 19.74       | 19.91       |             | 77.19       | 22.81       | 60.35        | 4.67        |              |             | 31.60       |
| 10 | 0-10  | 4.6 | 15.80 | <u>5.89</u> | <u>2.90</u> | <u>2.99</u> | <u>0.97</u> | <u>2.07</u> | <u>0.83</u> | <u>9.91</u>  | <u>0.43</u> | <u>5.06</u>  | <u>5.30</u> | <u>5.02</u> |
|    |       |     |       | 37.28       | 18.36       | 18.92       |             | 71.38       | 28.62       | 62.72        | 2.72        |              |             | 31.77       |
|    | 10-20 | 4.8 | 11.66 | <u>3.49</u> | <u>1.96</u> | <u>1.53</u> | <u>1.28</u> | <u>0.93</u> | <u>1.03</u> | <u>8.17</u>  | <u>0.39</u> | <u>5.22</u>  | <u>4.86</u> | <u>2.73</u> |
|    |       |     |       | 29.93       | 16.81       | 13.12       |             | 47.45       | 52.55       | 70.07        | 3.34        |              |             | 23.41       |

Notes: In columns of organic carbon extracted with 0.1M Na4P2O7+0.1M NaOH: underlined number shows the share of org. C of soil sample mass, in % and not underlined number shows the share of org. C of total carbon, in %. In columns of org. C in humic and fulvic acid fractions: underlined number shows the share of org. C of soil sample mass, in % and not underlined number shows the share of org. C of total carbon, in %. C<sub>h</sub> is humic acids; C<sub>f</sub> is fulvic acids; E<sub>465</sub>/E<sub>665</sub> ratio of absorbance at wavelength of 465 nm and 665 nm.

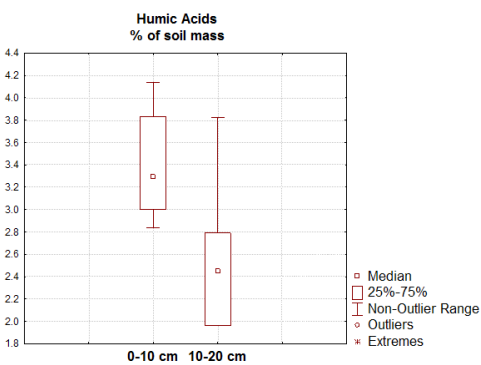


Fig. 3. Humic acid content (% of soil mass) in layers 0-10 cm and 10-20 cm.

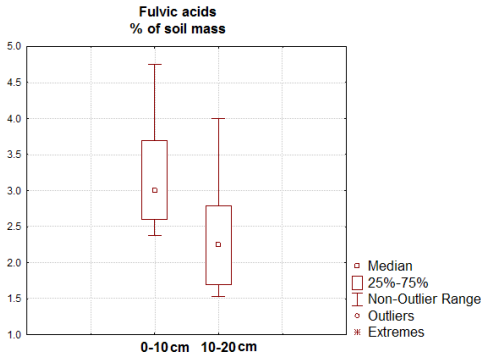


Fig. 4. Fulvic acid content (% of soil mass) in layers 0-10 cm and 10-20 cm.

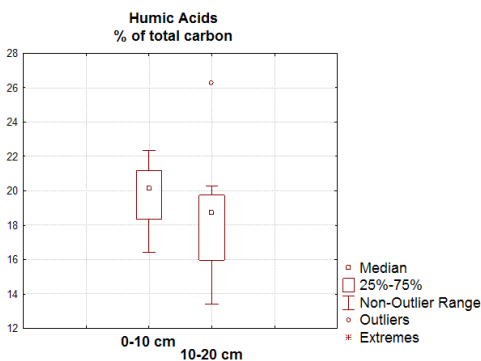
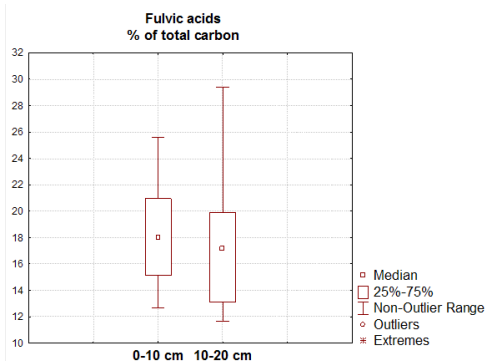


Fig. 5. Humic acid content (% of total carbon) in layers 0-10 cm and 10-20 cm.





**Fig. 6.** Fulvic acid content (% of total carbon) in layers 0–10 cm and 10–20 cm.

mic-fulvic humus (see Table 1). According to Bonifacio et al. (2011), humus forms in soil are the first tool characterizing the circulation of soil organic matter and should be related to the stability of org. C stock. The humification degree of soil organic matter is very high (on the scale of Artinova 2014a). It is expressed by the values of percentage of humic acids in the total organic carbon, which are over 20 %. These are found in profiles 1, 2, 3, 6, 7 and 8. In the other cases the humification is high.

The mobile, 'free' and  $R_2O_3$  complex humic acids, expressed as a percentage of the total humic acid content is high and varies within the range 47–100 %. Very low to average content of Ca complex humic acids is determined in the course of the analysis, which is the result of losses of this element in the intensive leaching process. It is demonstrated by the aggressive fulvic acids in soil, extracted with 0.1N  $H_2SO_4$ , the amounts of which vary from 2.72 % to 5.70 % of the total org. C. The Ca complex humic acids determine the humus resistance to oxidation processes and stabilize SOM (Bogacz 2011)

which is of great importance for Umbrisols due to their soil texture.

The content of non-extracted org. C is high. In the humic acid sum it reaches 50.37 % – 72.88 %, occupying a significant part of them which can be attributed to a number of factors. It is well known that the decrease of temperatures and increase of average annual precipitation quantities slow down the mineralization processes (Bot and Benites 2005). At the same time, the low clay content of these soils (Andreeva 2013) creates a limited adsorbent for establishing the connection between clay particles and organic matter, which is a prerequisite for delayed decomposition.

The results of the humic acid optical density ( $E4_{465nm}/E6_{665nm}$ ) are estimated from medium to high with the prevalence of high values, which indicates an accelerated condensation processes of humic acids. This process was confirmed in Umbrisols by Artinova (2014b). Humus state of the surface soil layer, immediately exposed to atmospheric impact, is estimated as stable. Regardless of its high acidity, the percentage of humic acids, fulvic acids and non-extracted carbon in the total carbon content is stable and does not differ from the underlying soil layer.

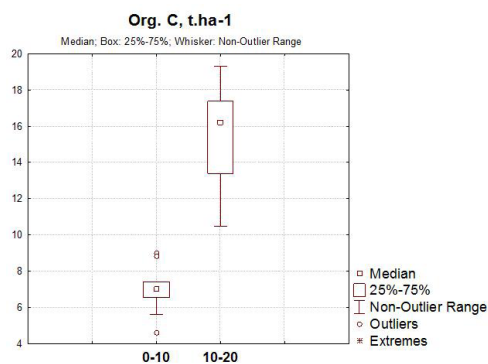
The org. C stock (Table 2) in the surface 10 cm layer is  $7.00 \pm 1.31 \text{ t.ha}^{-1}$  and  $15.55 \pm 2.72 \text{ t.ha}^{-1}$  in the 10–20 cm layer. Much higher values can be found in the relevant literature. In Latvia, for example, the org. C stock in 20 cm soil layer of Umbrisols is  $72 \pm 8.3 \text{ t.ha}^{-1}$ . According to Turrióna et al. (2009), at equal other conditions the soil-forming rocks have a great importance – soils formed on granite contain less organic matter quantities in comparison with soils developed on shale.

**Table 2. Location of sampling points, bulk density, content and stock of org. C.**

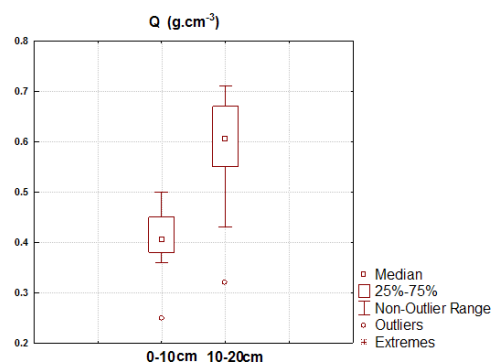
| Point No | WGS 84 coordinates | Depth, cm | Bulk density, kg.m <sup>-3</sup> | Org. C, g.kg <sup>-1</sup> | Org. C, t.ha <sup>-1</sup> |
|----------|--------------------|-----------|----------------------------------|----------------------------|----------------------------|
| 1        | 42.564767200       | 0–10      | 249                              | 18.54                      | 4.62                       |
|          | 23.280099200       | 10–20     | 557                              | 14.54                      | 16.20                      |
| 2        | 42.564788300       | 0–10      | 378                              | 18.99                      | 7.18                       |
|          | 23.280092900       | 10–20     | 321                              | 16.36                      | 10.50                      |
| 3        | 42.564812100       | 0–10      | 365                              | 15.45                      | 5.64                       |
|          | 23.280084500       | 10–20     | 546                              | 12.27                      | 13.40                      |
| 4        | 42.564823900       | 0–10      | 399                              | 17.27                      | 6.89                       |
|          | 23.280086900       | 10–20     | 619                              | 14.27                      | 17.67                      |
| 5        | 42.564824400       | 0–10      | 408                              | 18.18                      | 7.42                       |
|          | 23.280047200       | 10–20     | 612                              | 13.95                      | 17.07                      |
| 6        | 42.564825000       | 0–10      | 480                              | 18.74                      | 9.00                       |
|          | 23.280040200       | 10–20     | 708                              | 13.62                      | 19.29                      |
| 7        | 42.564831600       | 0–10      | 407                              | 17.66                      | 7.19                       |
|          | 23.280031400       | 10–20     | 429                              | 14.17                      | 12.16                      |
| 8        | 42.564839000       | 0–10      | 454                              | 14.60                      | 6.63                       |
|          | 23.280021600       | 10–20     | 595                              | 14.60                      | 17.37                      |
| 9        | 42.564846700       | 0–10      | 498                              | 17.76                      | 8.84                       |
|          | 23.280023300       | 10–20     | 701                              | 11.55                      | 16.19                      |
| 10       | 42.564851300       | 0–10      | 414                              | 15.80                      | 6.54                       |
|          | 23.280020700       | 10–20     | 669                              | 11.66                      | 15.60                      |

The difference between org. C stock in the two layers is statistically significant (Fig. 7). It is more than two times and comes mainly from the bulk density val-

ues. Under the influence of the grass species root system it is significantly lower in the layer 0–10 cm, compared to the layer 10–20 cm (Fig. 8).



**Fig. 7. Org. C stock in layers 0–10 cm and 10–20 cm in Umbrisols.**



**Fig. 8. Bulk density in layers 0–10 cm and 10–20 cm in Umbrisols.**



The org. C stock in the surface 20 cm layer is  $11.27 \pm 1.65 \text{ t.ha}^{-1}$ . Taking into consideration the area of Umbrisols on the territory of the Vitosha Nature Park – 1645.5 ha, the total org. C stock in the surface 20 cm layer of these soils is 18594.15 t.

The current state of the parameters examined in the present study has been formed for a long period of time. No relevant data for soils in the area can be found in the scientific literature, so no comparisons or estimates for the impact of climate changes on the org. C stock can be made.

The first available data about weather conditions (temperatures and precipitation), dates back to 1901, but regular information has been collected since 1935 by the Cherni Vrah meteorological station. Analysing the existing information (Management Plan ... 2014, Preparation of water ... 2014) it was determined that the variation of the mean annual air temperature  $T_y$  (°C) with the increase of the altitude  $H$  (m) is linear and can be analytically described by a straight line equation. According to data for the period 1961–1990, this variation can be expressed by the equation  $T_y = -0.0055 \cdot H + 12.709$  at very high correlation coefficient  $R = 99.8 \%$ . Regarding the period 1961–2010, the analytical expression is  $T_y = -0.0055 \cdot H + 12.91$  at  $R = 99.7 \%$ .

The minimum and maximum temperature values calculated for the period 1961–2010 are as follows:  $-10.3^\circ\text{C}$  (January),  $-10.2^\circ\text{C}$  (February) and  $5.7^\circ\text{C}$  (August). Regarding the period 1961–1990 the values are:  $-10.3^\circ\text{C}$  (February),  $-10.0^\circ\text{C}$  (January),  $6.0^\circ\text{C}$  (July) and  $6.2^\circ\text{C}$  (August).

When comparing the absolute maximum and minimum temperatures for the periods 1961–2010 and 1961–1990, it was determined that the absolute min-

imums are practically the same, but the absolute maximums are higher in the last 20 years. Temperature is a key factor controlling the rate of decomposition of plant residues. According to some authors, the reaction rates doubled for each increase of  $8\text{--}9^\circ\text{C}$  in the mean annual air temperature (Bot and Benites 2005), but others consider that the relationship between decomposition intensity and temperature variation is not linear (Wetterstedt 2010).

Regarding precipitation, results show that for the last 115 years the annual sum of annual precipitation has decreased remarkably mainly in the areas with an altitude of up to 1800–1900 m a.s.l. The decrease of annual precipitation for the higher parts of the Park, where the present study was carried out, is less pronounced.

## Conclusions

A complex of humus parameters was studied and a database on the content of soil organic matter and org. C stock was created for the surface 20 cm layer of Umbrisols at geo-coordinated points, located near the Cherni Vrah meteorological station. Higher acidity ( $\text{pH}_{\text{H}_2\text{O}}$ ), higher total carbon content, free low-molecular humic acids, as well as humic and fulvic acids, calculated as a percentage in the soil sample, were determined in the surface 10 cm layer. The share of humic acids in the total carbon did not differ and was characterised by stable values. At that stage the calcium complex humic acids are little or absent and their behaviour over time should be monitored. The obtained results allow future statistical evaluations of information about monitoring the relationship 'climate changes – org. C stock' over time.

## Acknowledgments

This report was realized with the support of project No 22/2018 of SRS – University of Forestry and BG05M2OP001-2.009-0034 Support for the development of scientific capacity at the University of Forestry.

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## EFFECT OF INTENSIVE REARING ON FUNCTIONAL MORPHOLOGY: A CASE STUDY WITH THE ROCK PARTRIDGE (*ALECTORIS GRAECA GRAECA*)

Paolo Viola<sup>1</sup>, Riccardo Primi<sup>1</sup>, Federica Gabbianelli<sup>2</sup>, Pier Paolo Danieli<sup>1</sup>,  
Livia Lucentini<sup>3</sup>, and Andrea Amici<sup>1\*</sup>

<sup>1</sup>Department of Agriculture and Forest Science, DAFNE. University of Tuscia, Viterbo, Italy.  
\*E-mail: amici@unitus.it

<sup>2</sup>Department for Innovation in Biological, Agro-food and Forest systems, DIBAF, University of Tuscia, Viterbo, Italy.

<sup>3</sup>Department of Biotechnology, University of Perugia, Italy.

Received: 07 February 2019

Accepted: 20 August 2019

### Abstract

Rock partridge (*Alectoris graeca*) is included in Annex I of the EU Birds Directive as Species of Conservation Concern (SPEC 1), because of the continuing decline in the area of occupancy. In this context, *ex situ* conservation programs and production systems of captive Rock partridges suited to the wild are necessary to ensure that insurance, reintroduction or restocking goals are met. Anyway, morphological changes occurring in captive-reared animals indicate the loss of animal's ability to survive in natural environment. In this study, we used the offspring of wild Apennine rock partridges (*Alectoris graeca graeca*). The young birds were divided into two groups, the first (G1) was housed in enriched and wild-like environment, the second (G2) was subjected to intensive-rearing conditions. Starting at 14 days post-hatching (DPH) and continuing up to 98 DPH, body mass (BM), tarsus length (TL), tarsus depth (TD), tarsus width (TW), head width (HW), head length (HL), wing length (WL) and beak length (BL), were measured fortnightly. Birds in G1 showed shorter heads ( $F = 10.50$ ,  $p = 0.000$ ) and thinner tarsi ( $F = 9.80$ ,  $p = 0.000$ ) at 84 DPH. At 98 DPH also the TD measurement ( $F = 8.71$ ,  $p = 0.001$ ) became significantly lower in G1 than in G2. Birds in G1 showed morphological disadvantages (shorter heads and less developed limbs) as a possible result of limited physical and cognitive exercise in simple artificial environment. Our results suggest that intensive rearing does not contribute to relevant morphological disadvantages within 70 DPH. Accordingly, birds for restocking or reintroduction should be translocated within this time limit into enriched and wild-like environment where they can exercise before the release into the wild. A first figure of morphological measurements for Apennine Rock partridge is reported.

**Key words:** captive morphological changes, environmental enrichment, morphometry, rearing systems, sexual dimorphism in size.

### Introduction

Rock partridge (*Alectoris graeca* Meisner, 1804) has been recently declared

as a near-threatened species in Europe (Birdlife International 2018) and vulnerable at national scale, in Italy, by Peronace et al. (2012) and Rondinini et al. (2013). The

species is included in Annex I of the EU Birds Directive and has been recently classified into Species of Conservation Concern (SPEC 1), because of the continuing decline in the area of occupancy (Amici et al. 2009, Staneva and Burfield 2017).

Captures of wild birds for translocations, which are needed to reinforce wild populations and restore metapopulation functionality, are ill-timed (Ellis et al. 1978), because the small isolated populations are at a critical state (Cattadori et al. 2003, Amici et al. 2013, Trocchi et al. 2016). Therefore, *ex situ* conservation programs and production systems of captive Rock partridges suited to the wild are necessary to ensure that insurance, reintroduction or restocking goals are met (Armstrong and Seddon 2008).

In *ex situ* conservation programs, efforts commonly concentrate on preserving the genetic variability of the captive populations (Frankham et al. 1986). Although the preservation of genetic variability is clearly a principal objective, the behavioural, physiological and morphological changes require attention because potential alterations caused by captive breeding could affect the animal's ability to survive in natural environment (Liukkonen-Anttila et al. 1999, 2000; Millán et al. 2003; Price 2002; Alonso et al. 2005; O'Regan and Kitchener 2005). Such changes have commonly been detected in multigenerational captive animals and have often been attributed to the 'passive selection for animals that are behaviourally more suited to captivity' (O'Regan and Kitchener 2005). Morphology and behaviour have also been reported to respond and exhibit plasticity in adaptability to early environmental stimuli (Whiteside et al. 2016, Santilli and Bagliacca 2017).

Natural or semi-natural rearing systems can mitigate the negative effects of intensive rearing, allowing for better survival rate after release (Buner and Aebischer 2008, Pérez et al. 2015, Mihajlov et al. 2018). However, breeders rarely exploit this type of complex and expensive rearing strategy.

The effect of hand-rearing systems on the behaviour, physiology, soft tissues (gut, heart, liver, and gizzard) and muscles development have been studied in wild galliform species (Paganin and Meneguz 1992, Bergero et al. 1995, Putaala et al. 1997, Liukkonen-Anttila et al. 2000, Tobalske and Dial 2000, Millán et al. 2003, Hess et al. 2005, Gaudioso et al. 2011a). Environmental enrichment protocols (Whiteside et al. 2016), antipredator training (Gaudioso et al. 2011b, Sánchez-García et al. 2016), complex diets (Whiteside et al. 2015) and pre-release acclimatization of young birds in protected wild-like environment (Cocchi et al. 1998, Buner and Aebischer 2008), have been proposed to mitigate the negative effects of intensive hand-rearing systems.

However, captive morphological changes and associated potential disadvantages affecting viability of captive-bred Rock partridges when released into the wild need more attention and insights to understand if, how early and how strongly the effect of strict captivity could affect the functional morphology of the bird.

The aims of this study were to assess at which stage of growth and to what extent intensive rearing affects the external morphology of Rock partridge providing a first morphological description of the Apennine Rock partridge (*Alectoris graeca graeca*) and evaluating the magnitude of sexual dimorphism in size.

## Material and Methods

### Assumptions

According to available knowledge, we developed our study on the premise that studying multigenerational captive birds, which are available in large quantities, would generate biased results because long periods of captivity can alter animal morphology (Price 2002, O'Regan and Kitchener 2005). Therefore, we decided that working with small samples representative of an uncorrupted wild phenotype was better than a large sample of multigenerational captive birds. We based our study on four basic assumptions:

1. the wild phenotype, including the morphology, is the most functional in the wild;
2. offspring of wild parents have a genotype not corrupted by conscious or inadvertent artificial selection;
3. when subjected to stimuli like those in the wild, offspring of wild parents can adequately represent the wild morphology;
4. morphological changes recorded in offspring produced by wild parents and reared under intensive conditions are the result of plasticity in adaptability to contingent non-natural stimuli, and these changes could be interpreted as a loss of functionality in the wild (disadvantages).

### Animals

For our experiment, because the critical conservation status of this species prevents the capture of large number of wild birds, and with the aim to exclude the genetic effect on the exterior morphology, we used two experimental groups of related chicks hatched from the eggs laid by the

female of the same wild breeding pair.

Wounded wild birds captured in Sirente-Velino Mountains were assigned to an authorized fosterage and released into a dedicated rehabilitation aviary (50 m<sup>2</sup> wide, 3 m high), where scattered rocks and composite vegetative cover were available. Seeds and feed specifically intended for breeders (21 % CP, 2750 Kcal/kg ME) were provided *ad libitum* with a feeder hopper protected by a hut; water was also provided *ad libitum*.

The birds were maintained, for two successive reproductive seasons (April–June), in standard conditions. These wild birds mated freely in the aviary, with the female laying 39 eggs overall. Eggs were collected daily, weighted, stored as described in González-Redondo (2010) and artificially incubated in the third decade of June. Overall, thirty-three (33) eggs hatched after 23 days of artificial incubation.

Chicks were assigned to two groups, G1 and G2, consisting respectively of sixteen and seventeen individuals. Three chicks in G2 died during the first week post hatching. At sexual maturity, a 1:1 sex ratio (8 males and 8 females) was verified in the G1 whereas in the G2 there were more males than females (8 males and 6 females).

### Experimental design

The birds in G1, that was the treatment group, were reared under intensive conditions. After hatching, the chicks were placed in a heated room in a cage at density of 16 chicks/m<sup>2</sup> for up to 14 days post-hatching (DPH). Heating was conducted as described in Günlü et al. (2007). From 15 to 35 DPH, the available indoor area was enlarged to allow density of 2 chicks/m<sup>2</sup>. From hatching to 35 DPH,



they were kept indoors on a concrete floor covered with straw. Starting at 36 DPH, the indoor-outdoor phase began in an adjacent aviary of 25 m<sup>2</sup>. Henceforth, 2 m<sup>2</sup> per bird were available until the end of the trial. The group was fed *ad libitum* with a starter diet (28 % CP and 2850 Kcal/kg ME) during the first three weeks, and subsequently with a second diet (22 % CP and 2850 Kcal/kg ME). Water was available *ad libitum* throughout the trial, and during the first day after hatching, it was fortified with sugar (5 % w/v) and minerals (0.05 % w/v).

The birds in G2, that was the control group, were reared in a semi-natural complex environment under the guidance of their natural parents. After hatching, the chicks were immediately placed under the hen that continued to incubate surrogate eggs. The parental couple accepted the chicks without incident, and the family group remained in a 50 m<sup>2</sup> aviary in a complex semi-natural environment (alternation of composite vegetative cover, draining ground, stones, rocks and ramps) until the end of the trial. The presence of ants, which were attracted by some up-turned plant pots positioned as suggested by Buner and Aebischer (2008), was verified in the aviary. Edible seeds (*Triticum aestivum* L., *Hordeum vulgare* L., *Sorghum vulgare* Pers., *Pisum sativum* L. and *Vicia faba* var. *minor* Beck) and green foods (*Medicago sativa* L. and *Trifolium incarnatum* L.) were available *ad libitum*, but during the first three weeks, chicks ate almost exclusively the arthropods (pupae and eggs) naturally present in the aviary and the moths that were artificially provided as recorded by direct observations. No mixed feed was given to the animals. Water was available *ad libitum* throughout the trial.

## Data recording

Chicks were individually identified with non-toxic colour markers on the *patagium* of the right wing. Starting at 14 DPH and continuing up to 98 DPH, the birds were weighed and measured fortnightly by the same researcher for eight external body traits (BTs). BTs recorded were body mass (BM), tarsus length (TL), tarsus depth (TD), tarsus width (TW), head width (HW), head length (HL), wing length (WL) and beak length (BL). TL was the distance between the proximal and the distal ends of the tarsus-metatarsus (Pis 2012). TD and TW were, respectively, the depth and the width of the tarsus-metatarsus at the distal end of the spur scale. HW was the distance between the two orbital faces of the frontal bone, and HL, between the midpoint of the occipital and the nasal face of the frontal bone (Çağlayan et al. 2011). WL was the distances between the wrist joint (radio-carpal) and the longest primary (Bernard-Laurent et al. 2003), and BL, the length of the straight line along the upper margin of the beak (Pis 2012). Partridges were weighed with an electronic balance ( $\pm 0.01$  g accuracy). All linear measures were taken to the nearest 0.01 mm with a digital calliper except for WL, which was measured by a ruler ( $\pm 1$  mm accuracy). All bilateral measurements were taken on the left side of the bird.

## Statistical analyses

Data analysis was performed with R (R Development Core Team 2011). The normality of the data distribution was tested in each group using Q-Q plot and the Shapiro-Wilk test.

With the aim to assess the morphological changes and the occurrence of SSD at

different stage of growth, an unbalanced  $2 \times 2$  (group and sex) full factorial ANOVA was performed. The GLM procedure (F-test) with type III sums of squares was used because it is independent of sample sizes. The effects of the group and of the sex were investigated by age in all the BTs separately as well as in their interaction (group  $\times$  sex). Once verified the occurrence of not significant interactions between the main factors, the analysis was

repeated with the type II sums of squares that, for non-significant interaction, gives a more powerful test. When the effects of the group were significant, the Tukey HSD post hoc test, Tukey-Kramer for unbalanced cases, were used in pairwise comparisons.

The Sexual Size Dimorphism Index (SSDI) (Calabuig et al. 2011) was used to assess the magnitude of the sexual dimorphism in size:

$$\text{SSDI} = \frac{\text{mean size of the males} - \text{mean size of the females}}{\text{mean size of the females}} \times 100.$$

For all the statistics, 1 % significance level ( $p = 0.01$ ) was accepted.

WL and BL were then excluded from the protocol because of inaccurate measures not reliable for group comparisons.

## Results

At 14 DPH, in G1, difficulties were found in measuring WL and BL in a standardized and replicable way, because the tip of the longest primary and of the beak were often irregularly worn with indented edges.

### Morphological comparisons between groups

The group and sex interactions were never significant. Instead, the separate effects of the sex and of the group were significant in some cases (Table 1).

**Table 1. Effects of the group and sex (GLM, F-test at  $p = 0.01$ ) on BTs at 14, 28, 42, 56, 70, 84 and 98 DPH.**

| Body traits: |         | BM    |              | TL    |              | TD    |              | TW    |              | HW    |              | HL     |              |
|--------------|---------|-------|--------------|-------|--------------|-------|--------------|-------|--------------|-------|--------------|--------|--------------|
| DPH          | Effects | F     | p            | F     | p            | F     | p            | F     | p            | F     | p            | F      | p            |
| 14           | Group   | 11.71 | <b>0.002</b> | 4.39  | 0.061        | 4.13  | 0.069        | 0.04  | 0.922        | 23.78 | <b>0.000</b> | 2.80   | 0.098        |
|              | Sex     | 4.66  | 0.040        | 5.60  | 0.025        | 2.77  | 0.111        | 0.95  | 0.337        | 1.13  | 0.298        | 0.99   | 0.328        |
| 28           | Group   | 1.72  | 0.200        | 2.45  | 0.129        | 0.15  | 0.129        | 1.56  | 0.222        | 27.60 | <b>0.000</b> | 2.350  | 0.137        |
|              | Sex     | 32.24 | <b>0.000</b> | 49.42 | <b>0.000</b> | 10.38 | <b>0.003</b> | 10.72 | <b>0.002</b> | 5.10  | 0.032        | 6.82   | 0.014        |
| 42           | Group   | 4.24  | 0.054        | 0.30  | 0.514        | 3.44  | 0.055        | 0.03  | 0.693        | 97.39 | <b>0.000</b> | 0.01   | 0.903        |
|              | Sex     | 11.72 | <b>0.002</b> | 91.12 | <b>0.000</b> | 13.17 | <b>0.001</b> | 19.25 | <b>0.000</b> | 9.46  | 0.050        | 33.33  | <b>0.000</b> |
| 56           | Group   | 9.06  | 0.015        | 2.06  | 0.333        | 1.680 | 0.109        | 0.50  | 0.337        | 61.14 | <b>0.000</b> | 0.04   | 0.845        |
|              | Sex     | 40.49 | <b>0.000</b> | 56.19 | <b>0.000</b> | 24.35 | <b>0.000</b> | 8.78  | <b>0.006</b> | 6.09  | 0.020        | 31.30  | <b>0.000</b> |
| 70           | Group   | 6.06  | 0.047        | 1.08  | 0.564        | 2.73  | 0.051        | 5.79  | 0.011        | 10.48 | <b>0.004</b> | 0.03   | 0.970        |
|              | Sex     | 27.51 | <b>0.000</b> | 59.33 | <b>0.000</b> | 31.39 | <b>0.000</b> | 14.26 | <b>0.000</b> | 5.13  | 0.032        | 14.36  | <b>0.000</b> |
| 84           | Group   | 1.10  | 0.530        | 0.04  | 0.724        | 9.80  | <b>0.000</b> | 0.80  | 0.161        | 5.22  | 0.046        | 10.50  | <b>0.000</b> |
|              | Sex     | 15.00 | <b>0.000</b> | 34.09 | <b>0.000</b> | 39.16 | <b>0.000</b> | 23.25 | <b>0.000</b> | 5.23  | 0.030        | 18.89  | <b>0.000</b> |
| 98           | Group   | 0.86  | 0.617        | 0.00  | 0.540        | 6.29  | <b>0.004</b> | 8.71  | <b>0.001</b> | 3.29  | 0.143        | 121.39 | <b>0.000</b> |
|              | Sex     | 16.88 | <b>0.000</b> | 37.21 | <b>0.000</b> | 35.54 | <b>0.000</b> | 28.19 | <b>0.000</b> | 10.33 | <b>0.003</b> | 28.22  | <b>0.000</b> |

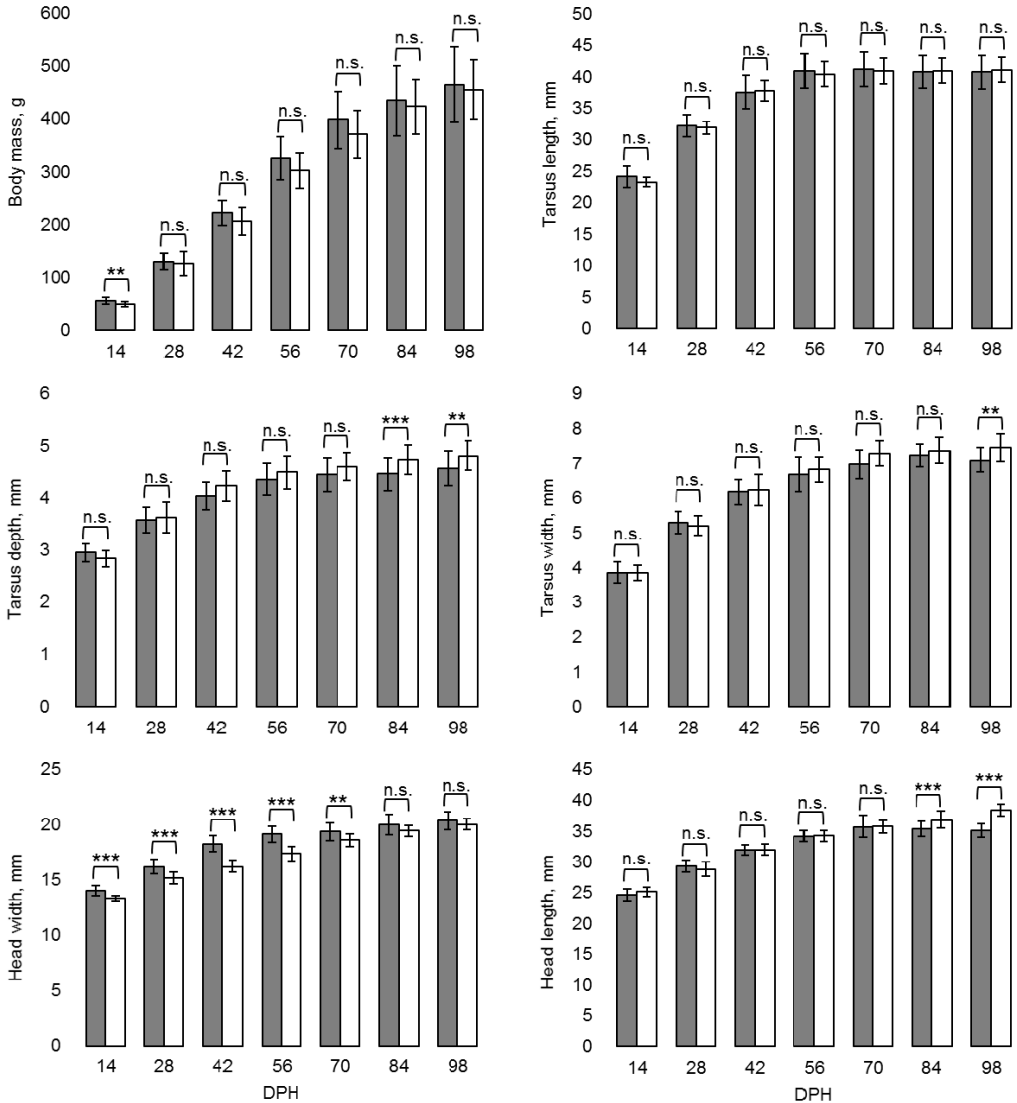
Note: significant differences are bolded.

The group's effect was graphically represented (Fig. 1) aiming to provide a complete figure of this effect.

Birds in G1 were constantly heavier than birds in G2 although not always at the chosen statistical significance level.

BM was significantly different between groups at 14 DPH.

TL was not sensitive to the intensive rearing; in fact, the average values of both groups overlapped somewhat consistently during the entire observation



**Fig. 1. Comparisons (GLM F-test at  $p = 0.01$ ) between G1 (grey bars) and G2 (white bars).**

Note: vertical bars denote standard deviations (SD); \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

period. TD and TW showed the first significant difference between groups at 84 DPH and 98 DPH respectively. These measures were higher in G1 at an early stage of growth but at 28 and 42 DPH, respectively, the average values of G2 exceeded those of G1. Birds in G1 had wider heads (HW) than birds in G2, but this difference, which was greatest at 42 DPH, narrowed progressively and maintained significance until 70 DPH but not after. HL was not sensitive to the intensive rearing until 84 DPH; in fact, in the period between 14 DPH and 70 DPH, the average values of the groups constantly

overlapped. After 70 DPH, HL reached a plateau in G1 and continued to grow in G2. Differences in HL between groups became significant at 84 DPH.

### Sexual dimorphism in size

A significant effect of sex was detected starting from 28 DPH (Table 1) and a descriptive statistic of each BT, is also provided by sex and group in tables 2 and 3. For sex comparisons  $p = 0.05$  significance level would allow to highlight differences between sexes 14 days earlier than 0.01 level.

**Table 2. Descriptive statistics (mean  $\pm$  SD) of males ( $n = 8$ ) and females ( $n = 8$ ) of G1.**

| Body traits | Sex | Days post hatching |                   |                   |                   |                   |                   |
|-------------|-----|--------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|             |     | 28                 | 42                | 56                | 70                | 84                | 98                |
| BM          | ♂   | 141.91 $\pm$ 8.4   | 237.57 $\pm$ 21.2 | 355.12 $\pm$ 20.3 | 430.30 $\pm$ 37.5 | 469.11 $\pm$ 64.4 | 507.11 $\pm$ 64.4 |
|             | ♀   | 118.32 $\pm$ 11.2  | 206.83 $\pm$ 12.4 | 295.65 $\pm$ 29.8 | 365.15 $\pm$ 46.8 | 403.61 $\pm$ 54.1 | 427.42 $\pm$ 57.1 |
| TL          | ♂   | 33.70 $\pm$ 0.7    | 39.72 $\pm$ 1.0   | 43.14 $\pm$ 1.6   | 43.52 $\pm$ 1.2   | 42.98 $\pm$ 1.9   | 43.03 $\pm$ 1.7   |
|             | ♀   | 30.83 $\pm$ 1.3    | 35.12 $\pm$ 1.4   | 38.83 $\pm$ 1.6   | 39.06 $\pm$ 1.7   | 38.94 $\pm$ 1.5   | 38.80 $\pm$ 1.6   |
| TD          | ♂   | 3.75 $\pm$ 0.1     | 4.20 $\pm$ 0.2    | 4.56 $\pm$ 0.3    | 4.66 $\pm$ 0.3    | 4.71 $\pm$ 0.3    | 4.81 $\pm$ 0.3    |
|             | ♀   | 3.39 $\pm$ 0.2     | 3.87 $\pm$ 0.1    | 4.14 $\pm$ 0.1    | 4.22 $\pm$ 0.1    | 4.23 $\pm$ 0.1    | 4.35 $\pm$ 0.1    |
| TW          | ♂   | 5.49 $\pm$ 0.2     | 6.40 $\pm$ 0.3    | 6.85 $\pm$ 0.5    | 7.18 $\pm$ 0.4    | 7.45 $\pm$ 0.3    | 7.36 $\pm$ 0.2    |
|             | ♀   | 5.13 $\pm$ 0.3     | 5.94 $\pm$ 0.3    | 6.51 $\pm$ 0.4    | 6.76 $\pm$ 0.4    | 7.04 $\pm$ 0.2    | 6.88 $\pm$ 0.3    |
| HW          | ♂   | 16.57 $\pm$ 0.6    | 18.62 $\pm$ 0.4   | 19.42 $\pm$ 0.6   | 19.65 $\pm$ 0.8   | 20.40 $\pm$ 1.0   | 20.81 $\pm$ 0.9   |
|             | ♀   | 15.82 $\pm$ 0.4    | 17.90 $\pm$ 0.8   | 18.82 $\pm$ 0.7   | 19.08 $\pm$ 0.8   | 19.60 $\pm$ 0.7   | 19.96 $\pm$ 0.5   |
| HL          | ♂   | 29.87 $\pm$ 0.6    | 32.56 $\pm$ 0.5   | 34.86 $\pm$ 0.5   | 36.74 $\pm$ 1.2   | 36.14 $\pm$ 0.5   | 36.08 $\pm$ 0.7   |
|             | ♀   | 28.69 $\pm$ 0.9    | 31.36 $\pm$ 0.5   | 33.58 $\pm$ 0.7   | 34.78 $\pm$ 1.6   | 34.82 $\pm$ 1.4   | 34.33 $\pm$ 0.7   |

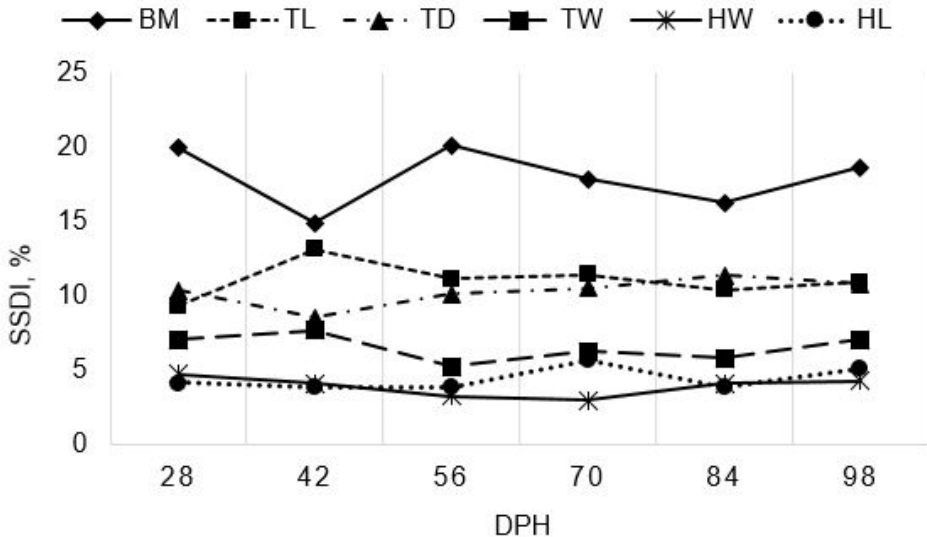
**Table 3. Descriptive statistics (mean  $\pm$  SD) of males ( $n = 8$ ) and females ( $n = 6$ ) of G2.**

| Body traits | Sex | Days post hatching |                   |                   |                   |                   |                   |
|-------------|-----|--------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|             |     | 28                 | 42                | 56                | 70                | 84                | 98                |
| BM          | ♂   | 139.43 $\pm$ 15.1  | 215.58 $\pm$ 17.1 | 324.41 $\pm$ 16.4 | 401.68 $\pm$ 17.7 | 455.41 $\pm$ 32.2 | 489.02 $\pm$ 45.1 |
|             | ♀   | 107.43 $\pm$ 16.5  | 194.62 $\pm$ 31.6 | 273.82 $\pm$ 26.1 | 329.25 $\pm$ 33.5 | 378.86 $\pm$ 37.9 | 409.31 $\pm$ 31.1 |
| TL          | ♂   | 32.63 $\pm$ 0.7    | 39.01 $\pm$ 0.6   | 41.88 $\pm$ 1.2   | 42.39 $\pm$ 1.4   | 42.19 $\pm$ 1.6   | 42.32 $\pm$ 1.7   |
|             | ♀   | 30.96 $\pm$ 0.4    | 36.26 $\pm$ 0.9   | 38.61 $\pm$ 0.7   | 39.14 $\pm$ 0.9   | 39.50 $\pm$ 1.1   | 39.54 $\pm$ 1.1   |
| TD          | ♂   | 3.70 $\pm$ 0.3     | 4.36 $\pm$ 0.2    | 4.67 $\pm$ 0.2    | 4.77 $\pm$ 0.2    | 4.92 $\pm$ 0.2    | 5.00 $\pm$ 0.2    |
|             | ♀   | 3.52 $\pm$ 0.2     | 4.05 $\pm$ 0.3    | 4.25 $\pm$ 0.3    | 4.37 $\pm$ 0.1    | 4.48 $\pm$ 0.1    | 4.55 $\pm$ 0.1    |
| TW          | ♂   | 5.32 $\pm$ 0.2     | 6.48 $\pm$ 0.2    | 7.06 $\pm$ 0.2    | 7.51 $\pm$ 0.3    | 7.61 $\pm$ 0.3    | 7.70 $\pm$ 0.2    |
|             | ♀   | 5.06 $\pm$ 0.3     | 5.90 $\pm$ 0.4    | 6.51 $\pm$ 0.3    | 7.01 $\pm$ 0.2    | 7.05 $\pm$ 0.2    | 7.12 $\pm$ 0.3    |
| HW          | ♂   | 15.24 $\pm$ 0.6    | 16.46 $\pm$ 0.5   | 17.57 $\pm$ 0.3   | 18.83 $\pm$ 0.6   | 19.60 $\pm$ 0.5   | 20.27 $\pm$ 0.4   |
|             | ♀   | 15.17 $\pm$ 0.5    | 15.96 $\pm$ 0.3   | 17.02 $\pm$ 0.8   | 18.27 $\pm$ 0.2   | 19.21 $\pm$ 0.4   | 19.68 $\pm$ 0.5   |
| HL          | ♂   | 29.07 $\pm$ 1.2    | 32.51 $\pm$ 0.5   | 34.83 $\pm$ 0.6   | 36.34 $\pm$ 0.7   | 37.69 $\pm$ 0.7   | 38.86 $\pm$ 0.7   |
|             | ♀   | 28.44 $\pm$ 1.10   | 31.31 $\pm$ 0.79  | 33.51 $\pm$ 0.80  | 35.03 $\pm$ 0.9   | 35.71 $\pm$ 1.2   | 37.68 $\pm$ 0.1   |

In both G1 and G2, SSDI showed larger features in males than in females (figs 2 and 3).

In both G1 and G2, the SSDIs in BM showed a peak at 28 DPH (SS-

DIG1 = 19.94, SSDIG2 = 19.80) and then decreased before reaching the maximum values at 56 DPH in G1 (SSDI = 20.12) and at 70 DPH in G2 (SSDI = 22.00). The SSDI in TL reached its maximum in G1



**Fig. 2. Trends of Sexual Size Dimorphism Index in G1.**

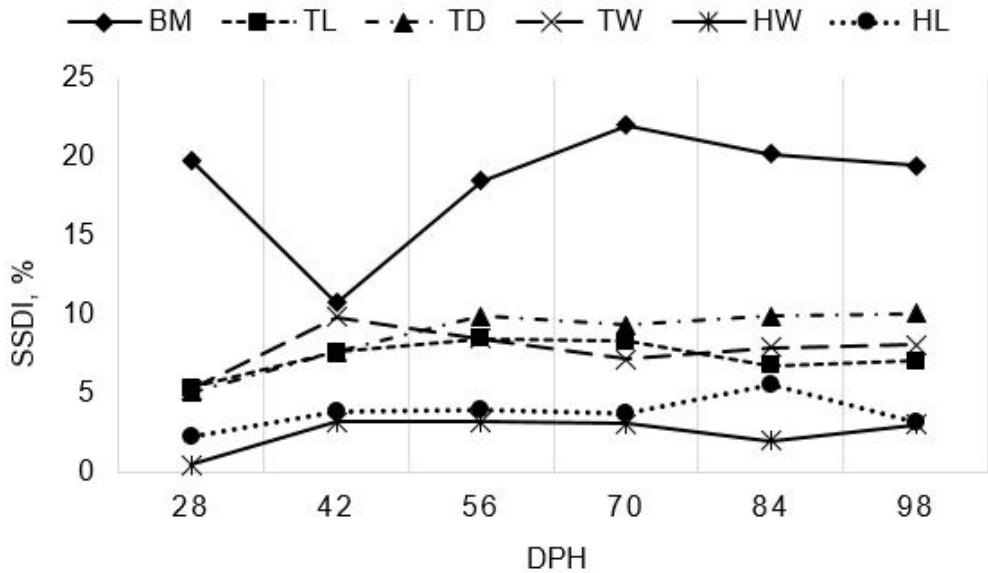


Fig. 3. Trends of the Sexual Size Dimorphism Index in G2.

and G2, respectively, at 42 DPH ( $SSDI_{G1} = 13.10$ ) and 56 DPH ( $SSDI_{G2} = 8.46$ ). For TD, the maximum SSDI occurred in G1 and G2, respectively, at 84 DPH ( $SSDI_{G1} = 11.38$ ) and 98 DPH ( $SSDI_{G2} = 10.05$ ). The third measure of TW reached its maximum dimorphism in size at 42 DPH in both groups ( $SSDI_{G1} = 7.68$ ,  $SSDI_{G2} = 9.83$ ). The maximum difference between sexes in HL occurred in G1 and G2, respectively, at 70 DPH ( $SSDI_{G1} = 5.62$ ) and 84 DPH ( $SSDI_{G2} = 5.54$ ). Overall, the maximum SSD did not exhibit a very different magnitude (SSDI) in the groups but was always observed at least two weeks earlier in the treatment group than in the control one.

## Discussion

The slight wounds and cuts on the beaks' tips and primary feathers recorded in G1 during the indoor phase are probably con-

sequences of aggressiveness and agonistic interactions between captive chicks housed at high densities without shelters or shields. In these conditions, aggressive behaviour is well known (Duncan and Hawkins 2009). These injuries impair the use of BL and WL as reliable morphological indicators. Unfortunately, our data do not allow the assessment of the resilience times of these injuries that, in the case of permanence until the time of release, could represent a limiting factor for the birds' survival in the wild.

At least up to 28 DPH, the birds in G1 showed larger size than those in G2, although not always significantly. However, according to the BTs considered, the birds in G2 compensated, and in some cases surpassed the measurements of the birds in G1 (Fig. 1). This evidence suggests that the intensive rearing system minimizes energy costs and provides more resources for growth at an early stage, but also suggests that life in an enriched semi-nat-



ural habitat allows for progressive and greater development of the muscles (Whiteside et al. 2016, Santilli and Bagliacca 2017) which mitigate the overall differences in BM.

In contrast with Whiteside et al. (2016) and Santilli and Bagliacca (2017) who reported, respectively, that 7- and 5-week-old pheasants grown in an environment enriched with perches were heavier than those subjected to standard commercial rearing conditions, we found differences in BM between groups only at 14 DPH with birds in G1 heavier than birds in G2. These authors explained their results highlighting that when natural or artificial perches are available, young pheasants are incentivized to fly to perches for roosting or to escape chases and that a frequent take-off allows for the marked development of pectoral muscles; differently, in Rock partridges, the tendency to use perches is unknown in both nature and captivity. In G2 we found that the use of wings was limited to occasional short flights and Wing Assisted Incline Running (Dial 2003). Our result is in accordance with that of Akşit et al. (2017) who recorded significant differences between broiler chickens provided with perches and conspecifics without perches only at 14 DPH. These authors hypothesized that the lower body weight of chickens with perches could be associated with their higher activity and that this is a transitory condition because activity tended to decrease as birds aged according to Bailie et al. (2013).

In our study, birds in G2 moved inside the semi-natural aviary principally on foot, walking or running on the rough and uneven ground, enriched with rocks and ramps.

The exercise in this complex environment allowed for a greater development of the muscles of the limbs according to

Whiteside et al. (2016) and Santilli and Bagliacca (2017). In fact, birds in G2, showed wider and deeper tarsi than those observed in G1 at 84 and 98 DPH respectively.

In our study, TL consistently overlapped between the groups. Likewise, Bernard-Laurent et al. (2003) did not observe significant differences in TL between hand-reared and wild *A. g. saxatilis* (Bechstein, 1805) males. Most likely, this result is due to the heritability of this trait (Kondra and Shoffner 1955, Lerner 1989).

The higher values of HL observed in G1 at 70 DPH are quite difficult to explain because we have not specifically focused on brain mass and cranial volume. However, other authors found these parameters positively correlated with the cognitive abilities of the examined animal and that the complexity of the environmental stimuli is a crucial factor in this regard (Sol et al. 2005, 2007; Møller 2010; Whiteside et al. 2016).

Concerning the wider head (HW) recorded in G1 until 70 DPH, we suppose, according to Mani (2008), it may depend on a slight irritation of the respiratory mucosa, due to ammonia in the air during the indoor phase, with consequent swelling of the eyelids or eyebrows.

As expected, our results reveal sexual dimorphism in size (SSD) in both G1 and G2 with males larger than females and without notable differences between groups. However, SSD occurred earlier in G1 than in G2 as well as the maximum distance between males and females that occurred first in G1 and at least 2 weeks later in G2. Anderson et al. (1993) proved that in sexually dimorphic bird species, the larger sex grows faster than the smaller one and requires more energy during growth. Evidently, intensive rearing, artificially heating, low exercise and *ad libitum*

availability of industrial feed amplify the differences between sexes in growth rate at least at an early stage of growth.

## Conclusions

In this paper, we present evidences that intensive rearing determines significant morphological changes in Rock partridges, particularly at the tarsus level, that are recordable, with high statistical significance ( $p \leq 0.01$ ), starting from 84 DPH. Furthermore, we cannot exclude that feathers and beaks usury, recorded on intensive reared birds, could persist and limit their survival probability when released in the wild.

Therefore, the semi-natural rearing approach should be encouraged because it can mitigate the negative effects of the intensive rearing, allowing for a better survival rate after release.

However, breeders rarely exploit this type of complex and expensive rearing strategy, then, where intensive reared birds are the only possible choice, we recommend their translocation from strict captivity to wild-like pre-release acclimatization site, where they can exercise before the final release into the wild, within 70 DPH. Within this time limit, birds seem not significantly corrupted by the intensive rearing, at least morphologically, and the chance of fostering by barren wild pairs could be preserved where Rock partridges are still present, as suggested by Buner and Aebischer (2008) in the guidelines for re-establishing Grey partridge (*Perdix perdix* Linnaeus, 1758) through releasing.

In addition, although molecular sex determination methods are already available (Vucicevic et al. 2013), the magnitude of SSD suggests the possibility of a cheap, expeditious and early accurate sex de-

termination facilitating the translocation of sex-balanced groups. In this view, further researches should be oriented on the development of early sex determination methods based on SSD.

## Acknowledgements

The authors are grateful to Fabrizio and Emanuela Marricchi (Breeding La Starniana, Onano, Viterbo, Italy), who made this study possible by providing facilities, carefully managing the parents and the experimental groups of chicks, and the Rehabilitation Centre of the Riserva Naturale Regionale Lago di Vico. Authors thank the reviewers for the help in improving the text.

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## IMPACT OF DIFFERENT PARAMETERS ON THE PRODUCTIVITY OF CHIPPING WOOD FROM THINNINGS

Dimitar Georgiev and Dimitar Peev\*

Department Technologies and mechanization in forestry, University of Forestry, Sofia 1797, 10  
Kliment Ochridski Blvd., Bulgaria. E-mails: dimitarg@hotmail.com, dimitar\_peev@ltu.bg\*

Received: 09 July 2019

Accepted: 29 August 2019

### Abstract

In this article a study is described for determining the impact of the chipper power and the size of materials on the productivity of different chippers. Machines with various engine powers have been used in the range of 21 to 70 kW, being equipped with disc or drum chipping mechanism propelled by either self-engine or PTO. The experiments have been carried out with fresh, scots pine small-size wood, grouped into nine groups of materials. The results indicate that the greatest impact on the productivity of the chipping machines has their power, then is the diameter of the materials and least is the influence is the length of the materials.

**Key words:** chippers, chipper power, scots pine wood, small sized wood.

### Introduction

Over the last few years there has been a growing interest in wood biomass (Georgiev 2013, Marinov et al. 2013, Stoilov et al. 2008). From thinnings in young stands large quantity of primarily small-size wood is obtained, which can be used as a bio-fuel for heat production. As technological chips this wood is used in electrical power stations and cogeneration plants, in bio-gas stations, for producing densified bio-fuels such as pellets and briquettes (Alakangas 2005, Abdallah et al. 2011).

Logging technologies used for thinnings envisage harvesting of round materials. They include many operations like removing of branches and cross cutting the stems into small sections. The costs are very high, making the final product too expensive. It is known that no valua-

ble materials are obtained from thinnings because the harvested wood is mainly for firewood, for pulp and plate production. This once again confirms that the currently applied technologies for thinnings are not efficient enough (Jylhä 2011, Georgiev 2013, Peev 2017).

In many countries, including in Bulgaria this wood has to be chipped into technological chips, which can be done in the forest, on the roadside or on the place where it would be processed. For this purpose, different chippers are used – mainly mobile, disc or drum driven by a tractor or by self-engine. In case when the raw material is near the processing site, stationary chipping machines with electric drive are also used.

The variety of machines that are used concerning their type, their construction and operating parameters is great, which



affects their productivity and the quality of the chips.

Studies have shown that chipping machines with too great power for this kind of wood – very often over 80 kW (Spinelli et al. 2005) have high prices which means high chipping costs.

The size of the materials affects the productivity of the chipping machines and its increasing leads to growth of productivity. Increasing the length of the chips also increases the productivity of the chippers due to the reduction of the number of cuts, respectively reducing the cutting work of wood materials into longer chips (Georgiev 1986, Spinelli and Magagnotti 2012, Di Fulvio 2015).

The number of rotations of the cutting mechanism, the number of knives, the cutting angle etc. also impact the productivity of the chippers (Valshchikov 1970, Fetyaev 2016). According to Kováč et al. (2011), the greatest impact on energy consumption have the size of the materials, the wood species and the sharpening angle of the knives.

According to other authors (Nati and Spinelli 2010, Glushkov et al. 2015) increasing of knife's wear significantly increases fuel consumption.

In conclusion, it can be said that the comminution of wood has been subject of many studies in different countries. The experiments have been carried out at different time under different conditions and with different wood materials – coniferous and deciduous small-sized materials (Brik and Vasilyev 1975, Hellström 2010, Abdallah et al. 2011, Spinelli and Magagnotti 2012, Di Fulvio et al. 2015) and logging waste (Nati and Spinelli 2010, Yoshida et al. 2016), which does not allow good analysis and comparability of the results.

The purpose of this study is to determine the impact of the dimensions of

materials and the power of the cutting machine on the productivity during the chipping of wood from thinnings. At the same time, the particle size of the chips obtained by means of different chipping machines is determined, and according to the requirements of the standards their application has been determined.

Due to the limit of volume this article presents the results from investigations only on the chipping productivity of wood from thinnings by chippers with different power. The goal is ultimately to optimize the chipping process and to determine the most suitable chipping machine according to the size of the chipped materials. The optimization of the chipping process is an object of another study, the results of which will be published later.

## Material and Methods

The research that is the aim of this study has been carried out with mobile chippers Schliesing 200 MX, Vermeer BC 1000 XL, Heizohack HM 6-300 EM, Bruks 850 M и Wallenstein BX 62 R.

The object of the study can be represented schematically with the 'black box' model (Fig. 1).

According to the diagram, the values  $Y_p$  ( $i = 1, 2...p$ ) represent the baseline of

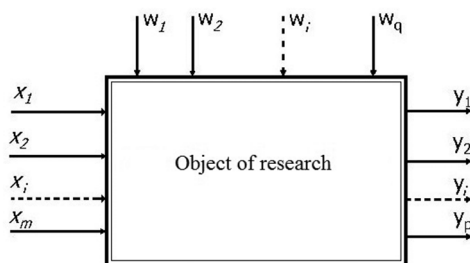


Fig. 1. Cybernetic model of the researched object.

the study. The necessary condition for realizing of an active experiment is to have a real opportunity to impact the technological process and to maintain the level of factors. All possible ways of action are called input factors and are marked with  $X_i$  ( $i = 1, 2 \dots m$ ). The dimensions  $W_i$  ( $i = 1, 2, \dots, q$ ) are disturbing factors that are unmanageable during the process.

The mobile chippers are adjusted to produce 0.02 m long chips. There are possibilities to control the factors by the dimensions of the chipped materials and the power of the chippers. The following manageable factors are selected for the study:

$X_1$  – diameter of materials, cm;

$X_2$  – length of materials, m;

$X_3$  – power of chipper, kW.

Other controllable factors influencing the process are:

$X_4$  – length of the chips, m;

$X_5$  – moisture content, %.

To reduce the number of attempts, the factors  $X_4$  and  $X_5$  are maintained at a single level. The moisture content of wood  $X_5$  is maintained at about 50–55 %. The length of the chips  $X_4$  as mentioned above is maintained at 0.02 m. Wood materials from scots pine are used, because it has the largest participation among coniferous species in our country.

A multifactor experiment of type  $3^m$  is carried out, where  $m$  is the number of factors that are maintained at three levels as follows:  $X_1$  – 6, 10, 14 cm;  $X_2$  – 1, 3, 5 m;  $X_3$  – 21, 45.5, 70 kW.

The target function is in accordance with the subject of the study and is presented with the main indicators of the research process:  $Y$  – productivity,  $\text{m}^3/\text{h}$ .

To determine the productivity, the cutting time of the different groups of materials is determined. The time is measured with a stopwatch accurate to 0.1 s. The

productivity of chippers is determined by the following formula (1):

$$P_h = 3600 \frac{V_c}{t_c} \text{ m}^3/\text{h}, \quad (1)$$

where:  $P_h$  is the productivity in  $\text{m}^3/\text{h}$ ;  $V_c$  – the volume of the chipped group of materials,  $\text{m}^3$ ;  $t_c$  – time for chipping of the materials, s.

The volume of chipped groups of materials is determined by the Smalian formula (2):

$$V_c = \left( \frac{G_1 + G_2}{2} \right) l \text{ m}^3, \quad (2)$$

where:  $V_c$  is the volume of chipped materials in  $\text{m}^3$ ;  $G_1$  – the circular area of the thick end of the materials,  $\text{m}^2$ ;  $G_2$  – the circular area of the thin end of the materials,  $\text{m}^2$ ;  $l$  – the length of the chipped materials, m.

The circular area of the thick or thin end of the materials is determined by the formula (3):

$$G_i = \frac{\pi d^2}{4} \text{ m}^2, \quad (3)$$

where  $d$  is the diameter of the thick or thin end of the materials, m.

Formula (2) is used to determine the volume of round wood materials up to 5 m in length.

Achieving the set goal is realized through a planned multifactor experiment.

The complete square equation for determine the influence of the three factors  $X_1$ ,  $X_2$  and  $X_3$  on the productivity is as follows (formula 4):

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 \quad (4)$$

The stepwise regression analysis is used to find out which model is the most suitable one.

Based on the advanced matrix of the

model, different models in CranR and STATISTICA programs and the most suitable is defined. This is based on the Akaike's Information Criterion (AIC), according to which the smaller AIC criterion is more appropriate and simplified in terms of stepwise regression analysis (Crawley 2007).

## Results and Discussion

According to methodology of the study in Table 1 are shown the levels and the intervals of variation of the studied factors.

**Table 1. Basic level and factor variation intervals for determining the productivity of the chipping machine.**

| Indicator                   | D,<br>cm | L,<br>m | N,<br>kW |
|-----------------------------|----------|---------|----------|
| Coded factor                | $X_1$    | $X_2$   | $X_3$    |
| Basic level ( $X_i = 0$ )   | 10       | 3       | 45,5     |
| Interval of variation       | 4        | 2       | 24,5     |
| Top level ( $X_i = 1$ )     | 14       | 5       | 70       |
| Bottom level ( $X_i = -1$ ) | 6        | 1       | 21       |

Due to the difficulty to find and test a chipping machine with a power equal to the mid-range (45.5 kW), a machine with a near power (55 kW) are used and that has been taken into account in the coding of factor values.

To describe the target function or the function of the productivity response, a stepwise regression analysis is performed using a second degree polynomial of type (4). Experimental data are processed with STATISTICA program. The results obtained for the estimation of regression coefficients in the model are shown in Table 2.

The results show that the coefficient of determination  $R^2 = 0.766$  which indicate that 77 % of the change of  $Y$  is described by the second degree model. The Fisher's criterion  $F_T(9, 80) = 29.161$  and the corresponding probability  $p < 2.2e-16 < 0.05$  show that the equation is adequate. At level of significance  $\alpha = 0.05$  the coefficients  $b_{23} = -0.011$  and  $b_{22} = -0.707$  are non-significant and should be excluded.

**Table 2. Results of regression analysis to determine the productivity of the chipping machine.**

| N = 90    | $b_i$    | Std. Err. of $b_i$ | $t(80)$  | p-level  |
|-----------|----------|--------------------|----------|----------|
| Intercept | 5.99472  | 0.568035           | 10.55342 | 0.000000 |
| $X_1$     | 2.15038  | 0.280409           | 7.66873  | 0.000000 |
| $X_2$     | -0.74410 | 0.280409           | -2.65364 | 0.009602 |
| $X_3$     | 3.21944  | 0.341235           | 9.43467  | 0.000000 |
| $X_{12}$  | -0.89500 | 0.323724           | -2.76470 | 0.007070 |
| $X_{13}$  | 2.34169  | 0.400070           | 5.85320  | 0.000000 |
| $X_{23}$  | -0.01095 | 0.400070           | -0.02737 | 0.978231 |
| $X_{11}$  | -1.23167 | 0.457815           | -2.69031 | 0.008687 |
| $X_{12}$  | -0.70667 | 0.457815           | -1.54356 | 0.126641 |
| $X_{13}$  | 3.10028  | 0.542748           | 5.71220  | 0.000000 |

Note:  $R = 0.87543613$ ;  $R^2 = 0.76638842$ ; Adjusted  $R^2 = 0.74010712$ ;  $F_T(9, 80) = 29.161$ ;  $p < 2.2e-16$ ; Std. Error of estimate: 2.0474.

The full regression model that describes the best target function and has the best predictive values is the following (formula 5):

$$Y = 5.99 + 2.15x_1 - 0.74x_2 + 3.22x_3 - 0.90x_1x_2 + 2.34x_1x_3 - 0.01x_2x_3 - 1.23x_1^2 - 0.71x_2^2 + 3.10x_3^2 \quad (5)$$

According to the CranR program, the model that is most suitable excludes only the coefficient  $b_{23}$ . This is based on the

Akaike's Information Criterion (AIC), according to which the model with the lower AIC criterion is more suitable and sufficiently simplified in terms of stepwise regression analysis.

The equal after the stepwise regression analysis is as follow (formula 6):

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (6)$$

The results from stepwise regression analysis are shown in Table 3.

**Table 3. Results of regression analysis for determine the productivity after exclusion of factor  $X_2X_3$ .**

| $N = 90$  | $b_i$    | Std. Err. of $b_i$ | $t(80)$  | $p$ -level |
|-----------|----------|--------------------|----------|------------|
| Intercept | 5.99472  | 0.564521           | 10.61912 | 0.000000   |
| $X_1$     | 2.15038  | 0.278674           | 7.71648  | 0.000000   |
| $X_2$     | -0.74667 | 0.262684           | -2.84245 | 0.005663   |
| $X_3$     | 3.21944  | 0.339124           | 9.49341  | 0.000000   |
| $X_{12}$  | -0.89500 | 0.321721           | -2.78191 | 0.006721   |
| $X_{13}$  | 2.34169  | 0.397594           | 5.88965  | 0.000000   |
| $X_{11}$  | -1.23167 | 0.454983           | -2.70706 | 0.008277   |
| $X_{12}$  | -0.70667 | 0.454983           | -1.55317 | 0.124281   |
| $X_{13}$  | 3.10028  | 0.539389           | 5.74777  | 0.000000   |

Note:  $R = 0.87543488$ ;  $R^2 = 0.76638623$ ; Adjusted  $R^2 = 0.74331327$ ;  $F_T(8,81) = 33.216$ ;  $p < 2.2e-16$ ; Std. Error of estimate: 2.0347.

After removing of non-essential factor and substitution with the regression coefficients, the equation is as follow (formula 7):

$$Y = 5.99 + 2.15x_1 - 0.75x_2 + 3.22x_3 - 0.90x_1x_2 + 2.34x_1x_3 - 1.23x_1^2 - 0.71x_2^2 + 3.10x_3^2 \quad (7)$$

The coefficient of determination  $R^2 = 0.766$ , the Fisher's criterion  $F_T(8, 81) = 33.216$  and the corresponding probability  $p < 2.2e-16$  show that the equation is adequate.

The results from the regression analysis indicate that the biggest impact on the productivity during the chipping of

small sized wood affect the power of the chipping machine, then the diameter of the materials and at the end – the length of materials. A basis for this conclusion gives the comparison between the values of regression coefficient. The coefficient before the factor power of the chipper has the biggest absolute value.

In figures 2, 3 and 4 the surface of equal response of the target function is shown, respectively for  $Y = f(x_1x_2)$ ,  $Y = f(x_1x_3)$ , and  $Y = f(x_2x_3)$ . In figures 5, 6 and 7 are represented the lines of equal response respectively for  $f(x_1x_2) = Y = \text{const}$ ,  $f(x_1x_3) = Y = \text{const}$ , and  $f(x_2x_3) = Y = \text{const}$ , according to the sizes of materials and the power of chipping machine.

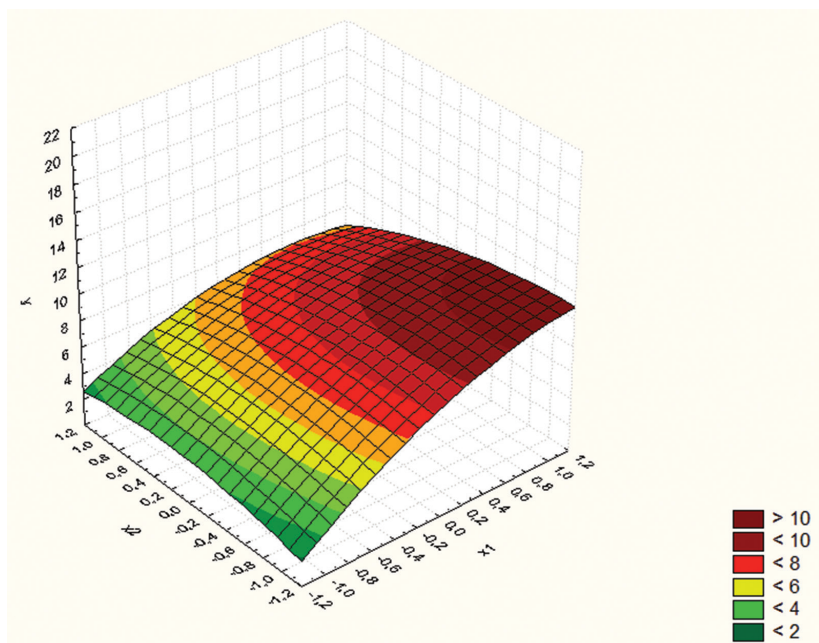


Fig. 2. Surface of response  $Y = f(x_1, x_2)$  for the productivity of chipping machine according to the diameter of materials ( $x_1$ ) and their length ( $x_2$ ).

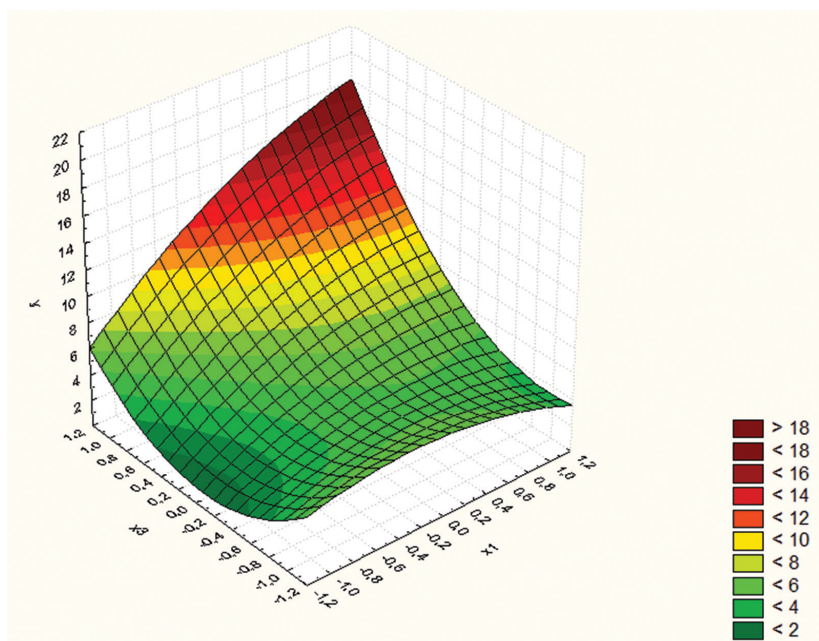


Fig. 3. Surface of response  $Y = f(x_1, x_3)$  for the productivity of chipping machine according to the diameter of materials ( $x_1$ ) and the power ( $x_3$ ).

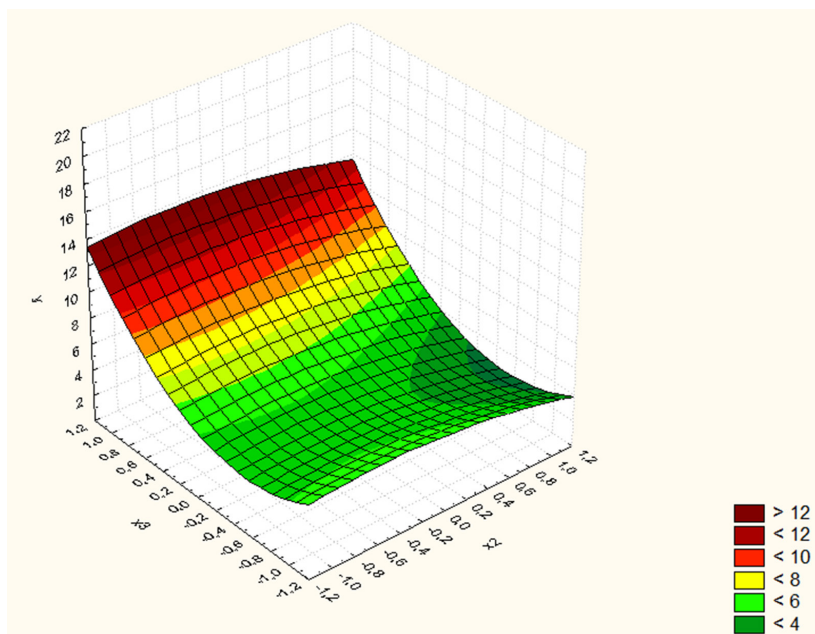


Fig. 4. Surface of response  $Y = f(x_2, x_3)$  for the productivity of chipping machine according to the length of materials ( $x_2$ ) and the power ( $x_3$ ).

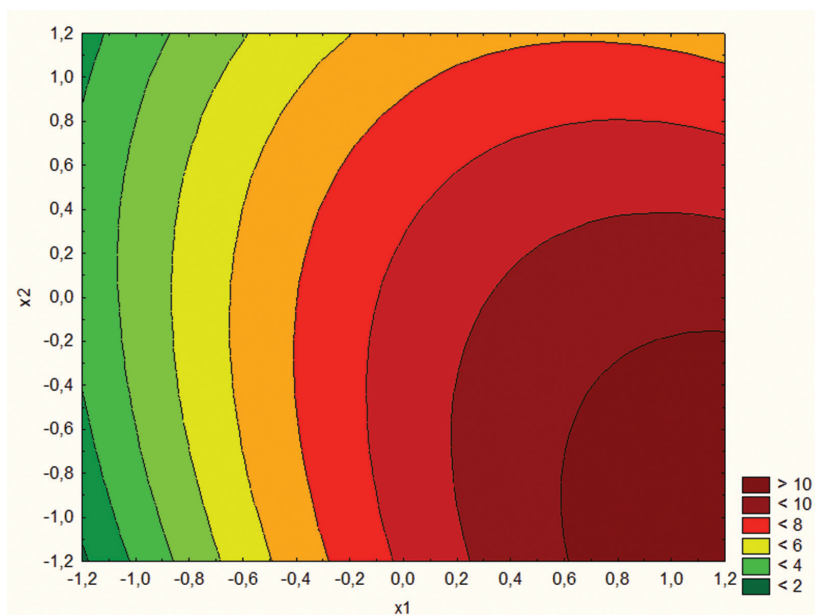


Fig. 5. Lines of equal response  $f(x_1, x_2) = Y = \text{const}$  for the productivity of chipping machines according to the diameter ( $x_1$ ) and the length ( $x_2$ ).



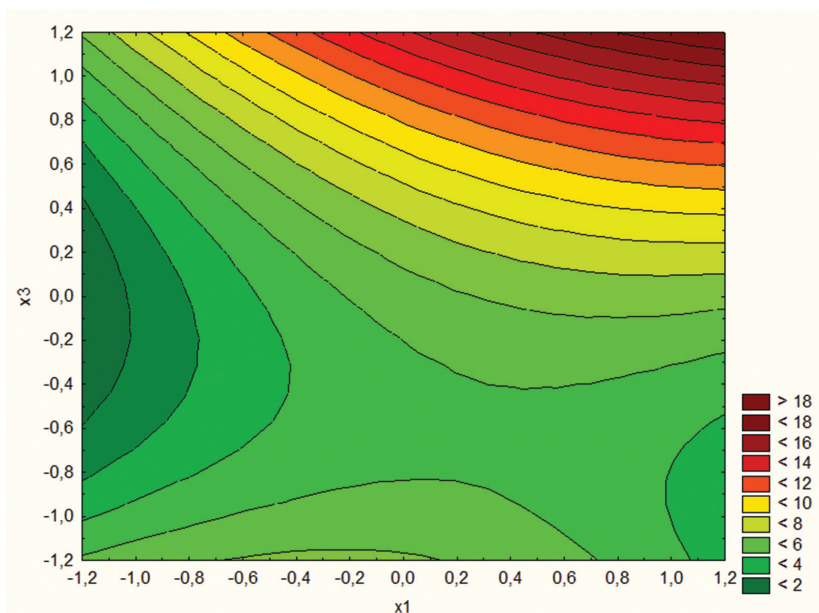


Fig. 6. Lines of equal response  $f(x_1, x_3) = Y = \text{const}$  for the productivity of chipping machines according to the diameter of the materials ( $x_1$ ) and the power ( $x_3$ ).

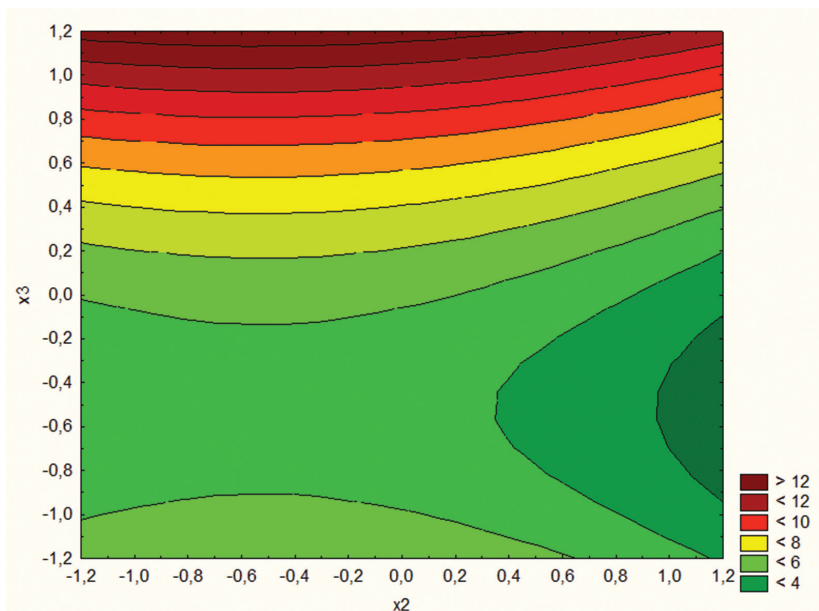


Fig. 7. Lines of equal response  $f(x_2, x_3) = Y = \text{const}$  for the productivity of chipping machines according to the length of the materials ( $x_2$ ) and the power ( $x_3$ ).

In figures 2 and 5 it can be seen that surface of response and the lines of equal response have maximum when the diameter of materials is 12–14 cm ( $x_1$  from 0.6 to 1.0) and the length is from 1 m to 2.8 m ( $x_2$  from -1 to -0.1). For the chippers with power around 50 kW the productivity is 10–11 m<sup>3</sup>/h when the materials that are chipped have diameter 13 cm and length 3 m. If the length of the materials is more than 3 m, the productivity starts to go down.

Figures 3 and 6 show that when the length of materials is 3 m, the surface of response and the lines of equal response for the productivity, have maximum when the diameter is between 12 and 14 cm ( $x_1$  from 0.5 to 1.0) and the power of the machine is 70 kW ( $x_3 = 1.0$ ). The biggest productivity at these parameters is 16–17 m<sup>3</sup>/h.

The analysis of the data referring to the

impact of the length of materials and the power of chipping machine (figures 4 and 7) indicates that the surface of response has a maximum at power 70 kW and 3 m length. In Figure 4 it can also be seen, that if the length of chipped materials is more than 3 m the productivity is lower.

It's interesting to see the influence of the length of materials when the power of the chipping machine is lowest – 21 kW. In Figure 7 it becomes clear that at diameter 10 cm (the middle of the interval), the productivity is the highest at the length around 2 m, after that because of the overloading of the engine it goes down.

As a whole the impact of the length when 1 m long materials are chipped is weaker. This is due that the small in diameter and length materials have been fed in the chipping machine almost without any pauses.

In figures 8, 9 and 10 the impact of the

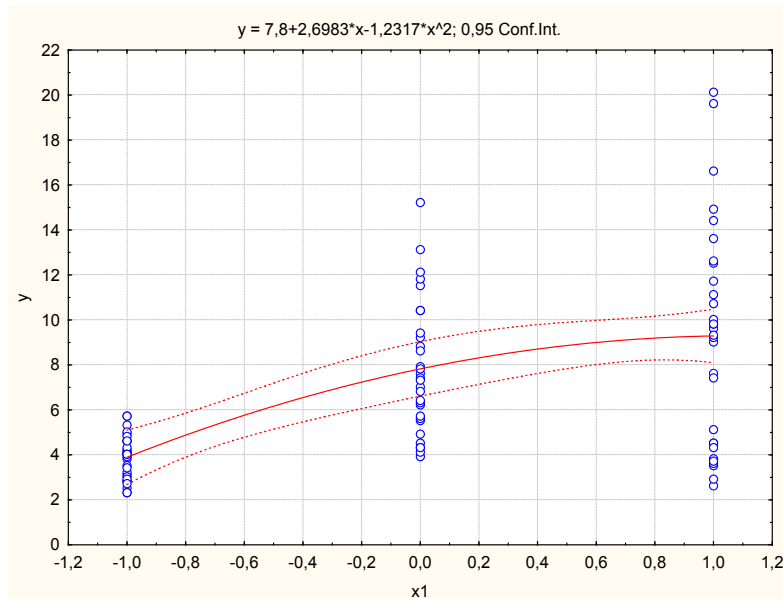
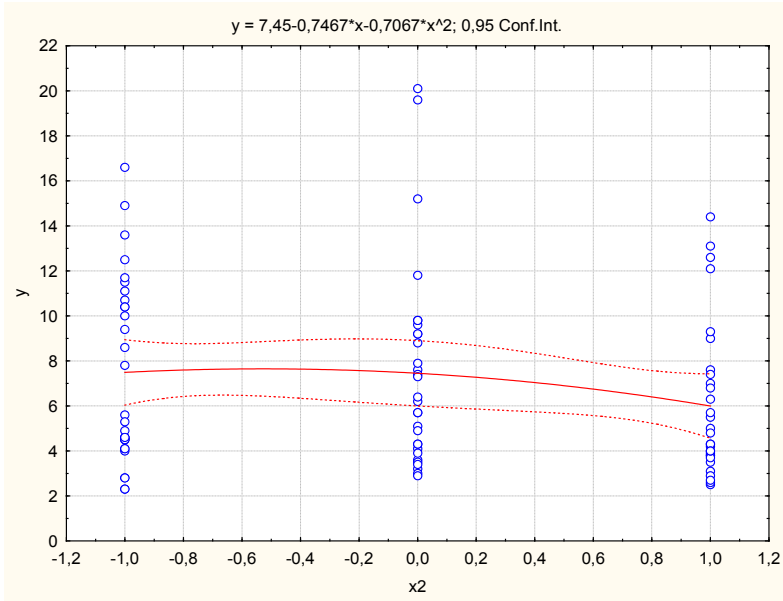
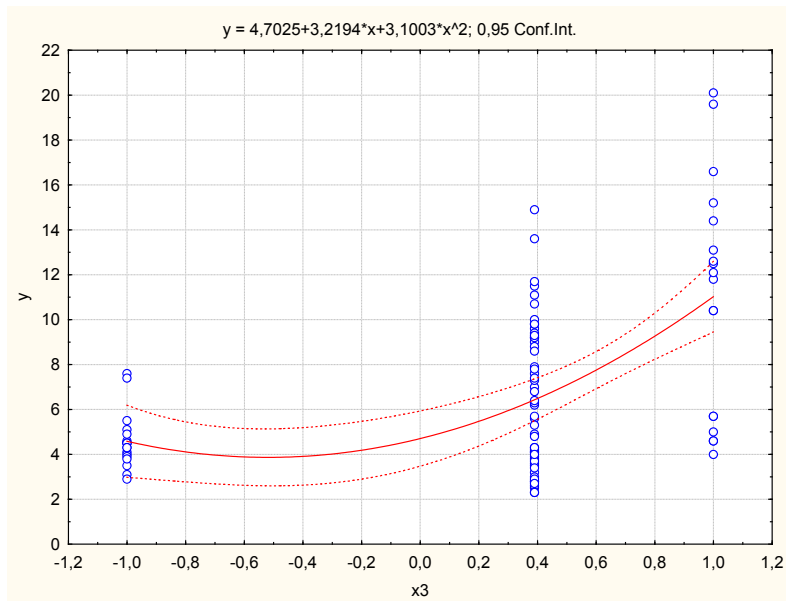


Fig. 8. Productivity of chipping machine according to the diameter of materials ( $x_2=0$ ;  $x_3=0$ ).



**Fig. 9. Productivity of chipping machine according to the length of materials ( $x_1=0$ ;  $x_3=0$ ).**



**Fig. 10. Dependence between the productivity of chipping machine and its power ( $x_1=0$ ;  $x_2=0$ ).**

separate factors on the productivity of the chipping machine is shown, confirming the conclusions made above.

In Figure 8 it can be seen that the degree of growth of the productivity is different. When the diameter grows from 6 cm to 10 cm ( $x_1$  from -1.0 to 0.0) the productivity increases almost double – with 95 %. When the diameter of materials grows from 10 cm to 14 cm ( $x_1$  from 0.0 to 1.0) the degree of increase is smaller – 18 %, because the loading of the engine grows. These results correspond to a power of the chipper in the middle of the interval – 45.5 kW. In the same figure it can be seen that for higher or lower machine power the level of curve line is higher or lower than the main curve, but the tendency is the same.

## Conclusions

An investigation has carried out to establish how the diameter and the length of materials and the power of the chipper itself influence on the productivity during the chipping.

A multiple mathematical model has been created the influence of diameter and the length of wood materials and the power of the chipping machine on its productivity has been determined. The scots pine materials from thinning have been chipped. The impact of the power of the chipper on the productivity is most considerable, next is the impact of the diameter of the materials and lowest is the impact of length.

The maximum productivity has been achieved when the power of the chipping machine is highest and the diameter of the materials is largest at the length 3 m, which could be expected.

The impact of the length of wood ma-

terials on the output of chipper is quite interesting, because it is stronger when chipping is done by machines with lower power.

For instance when the power of the chipper is 21 kW, the best productivity during chipping of materials with diameter of 10 cm is achieved at the length 2 m. Over that length the productivity gets lower.

The result of the investigation shows, that the impact of the length of materials on the output of chipping machine, at power 50–70 kW, is better visible when the length is more than 3 m, because then it starts to go down. It is due to overloading of the engine.

It should be taken into consideration, that more power of the chippers means higher machine's price and high chipping costs. The result of this investigation put the question is it suitable to use chippers with high power engines for chipping of small sized wood from thinnings. The obvious answer is that the parameters of chipping machines and most of all their power, must correspond to the type and dimensions of chipped materials.

## Acknowledgements

The present study has initiated and implemented with the support of the National Science Program 'Young Scientists and Postdoctoral Students'. We express our gratitude for the concern to the young researchers, scientists and professors of Bulgaria.

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## RETROSPECTIVE ASSESSMENT ON SCOTS PINE STANDS SITUATED FAR AND NEAR CHERNOBYL FALLOUT AREAS

Anton Potapenko<sup>1</sup>, Nikolay Bulko<sup>1</sup>, Alexander Kozlov<sup>1</sup>, Pavel Mohnachev<sup>2</sup>,  
Nadezda Kuzmina<sup>2</sup>, Konstantin Zavyalov<sup>2</sup>, and Sezgin Ayan<sup>3\*</sup>

<sup>1</sup>Institute of Forest of the National Academy of Sciences of Belarus 246001, Gomel, Republic of Belarus.

<sup>2</sup>Institute of the Russian Academy of Sciences Botanical Garden, Ural Branch of Russian Academy of Sciences 620134, Yekaterinburg, Russia.

<sup>3</sup>Kastamonu University, Faculty of Forestry, Department of Silviculture, Kastamonu, Turkey.  
\*E-mail: sezginayan@gmail.com

Received: 08 July 2019

Accepted: 09 September 2019

### Abstract

The high radiosensitivity of woody plants and the large forest areas polluted by Chernobyl fallout demand assessment of radiation effect on the forest ecosystems components. This research aims to study the state of Scots pine (*Pinus sylvestris* L.) stands located in the far and near areas contaminated by Chernobyl fallout, and to assess the current dose loads on the structural elements of the trees 30 years after the Chernobyl Nuclear Power Plant (CNPP) accident. The study was conducted in radioactively contaminated Scots pine stands, which are the near and far areas, in the Chernobyl fallout areas. The experimental plots were established during the period from 1991 to 2006 inside Scots pine stands from the II–IV age classes. The retrospective assessment of dose loads of the Scots pine was conducted according to the data obtained on 13 experimental plots located in the far area of the Chernobyl fallout through the software RESRAD-BIOTA 1.5 (11/18/2009). The condition of pine stands in the near areas has significantly worsened since the accident, compared to their condition before the accident. The changes in the state of the pine stands after the accident were characterized by their strong weakening. Ambiguous trends were also observed in the stability of stands depending on the type of forest and land relief. In 1986, the radionuclide <sup>134</sup>Cs accounted for 25 % of the total amount of soil pollution by mixture (<sup>134</sup>Cs + <sup>137</sup>Cs) in pine stands. However, in 1995, this amount decreased to 2.5 %. The state of the Scots pine stands after the accident were characterized by their strong weakening.

**Key words:** anthropogenic factor, dose loading, pine stands, radiation dose, stability, state of stands.

### Introduction

Forest ecosystems are dynamic and natural formations, which cover a considerable portion of the land surface on our planet, and among others significantly affect the distribution and migration of radioactive

materials in the biosphere at a global scale. In this framework, forests act as accumulators of radionuclides, preventing the migration of radioactive materials on the surface of the earth. During the Chernobyl accident, 60–90 % of radioactive fallout was accumulated in the tree layer



due to the high retention capacity of the forest ecosystems (Sokolov et al. 1994).

Radiation effects in contaminated natural ecological systems depend on the radiosensitivity of the dominant species. Scots pine (*Pinus sylvestris* L.) and spruce (*Picea abies* L. Karst.) forests are sensitive to radiation, and their destruction can even occur under the influence of small doses of radiation, which although do not cause noticeable violations in phytocoenoses of other types, such as herbaceous vegetation (Tikhomirov and Aleksakhin 1971).

Depending on the size of the absorbed dose, woody plants can have various radiobiological effects. The primary reactions of a forest to radioactive effects generally depends on the radiation dose of its separated components. Decrease in radiation intensity mostly affects the radiation dose distribution of separate organs of woody plants or organisms. At the same time, the soil shielding from radiation reduces the radiation dose at a great extent. This condition can have a decisive impact on the survival of populations of irradiated organisms (Aleksakhin et al. 1970, Menshikov et al. 2019).

In terms of the importance of issues addressed by forest radioecology, issues relating to radioecological effects on humans are generally considered first. Nevertheless, the high radiosensitivity of woody plants and the large forest area polluted by Chernobyl fallout demand assessment of radiation effect on the forest ecosystems components.

Arkhipov et al. (1994) reported that by 1991 Scots pine trees had returned to 'normal' with no obvious morphological damage in stands in the low and medium (up to 10 Gy) dose regions, and a new plant community was developing in the severely damaged regions. However, in

1995 there was still evidence of cytogenetic damage in seedling roots of pines in two sites at Chernobyl of dose rates (approximately 0.25 and 27 mGy·h<sup>-1</sup>) (Geraskin et al. 2003). It is not clear whether this was a result of the initial acute dose (10–20 Gy at the high dose site) or the ongoing chronic exposure, or a combination of the two. A reduction in mutation load with time and adaptation was observed in other studies (Abramov et al. 1995, Kovalchuk et al. 2004, Beresford et al. 2016). Abramov et al. (1995), Kovalchuk et al. (2004) and Beresford et al. (2016) found that mutation load was increased in the first two years after the accident but that 'in areas with contamination up to 10 mR h<sup>-1</sup> (approx. 100 mGy·h<sup>-1</sup>) the mutation load decreased to control levels by 1990. In the areas with contamination up to 130 mR·h<sup>-1</sup> (approx. 1300 mG·h<sup>-1</sup>) the mutation load (still) exceeded the control by 4–8 times'.

This research aims to study the state of Scots pine stands, located in far and near sites contaminated by Chernobyl fallout 30 years after Chernobyl Nuclear Power Plant (CNPP) accident and to assess the current dose loads on the structural elements of the Scots pine trees.

## Material and Methods

The study was conducted in Scots pine stands in radioactively contaminated the near (plots 'Nt- Chernobyl near field fallout' with the numbers from 1 to 6, up to 30 km from the CNPP) and far areas (plots 'Ft-Chernobyl far field fallout' with the numbers from 1 to 13, more than 30 km from the CNPP) located in the Chernobyl fallout areas (Fig. 1). The study was carried out in 2016–2017 (about 30 years after the CNPP accident).

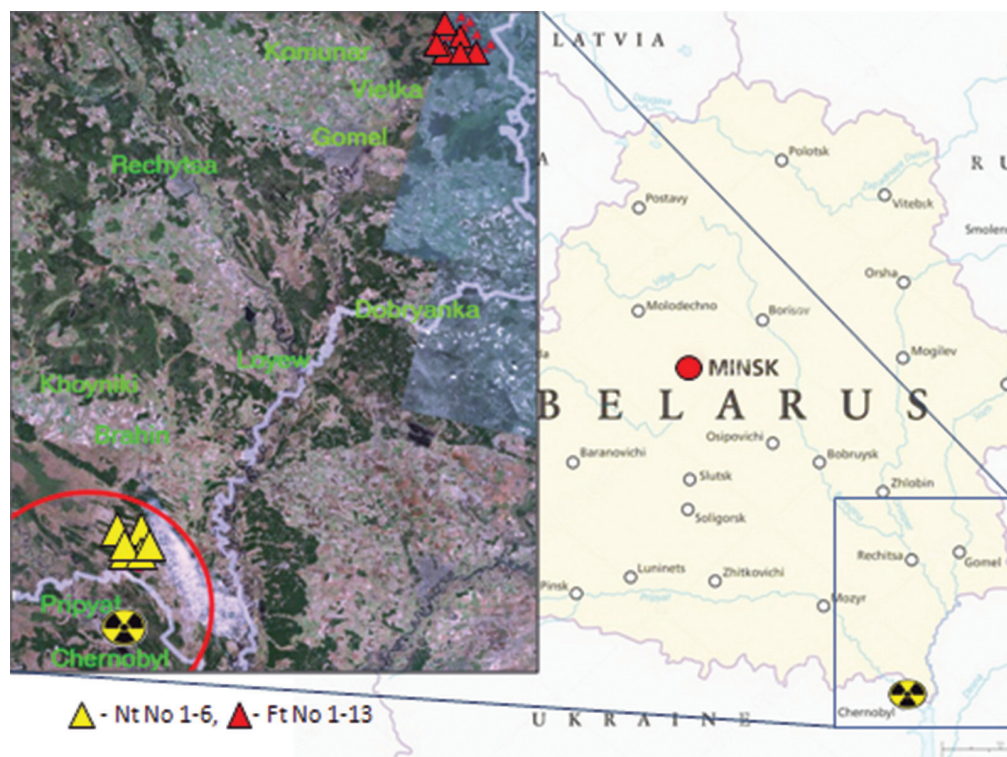


Fig. 1. Location of experimental.

Determination of soil contamination density and dose rate was carried out at all sites in the year when these samples were laid as well as studies conducted again in 2016 (Table 1).

The retrospective assessment of dose loads of the Scots pine was conducted according to the data obtained on 13 experimental plots (21 test areas) located in the far area of the Chernobyl fallout through the software RESRAD-BIOTA 1.5 (11/18/2009), developed at Argonne National Laboratory (USA) (ISCRS 2004).

The dynamics of the pollution density of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  of the soil-litter complex, as well as their contribution to the formation of dose loads on trees in long-range pine stands were determined in the study area 1Ft located in the far area of the Chernobyl fallout, by modeling the data

from 1991, which were obtained at the initial stage of laying the study area.

The dose rate ( $\mu\text{Sv h}^{-1}$ ) was determined at a height 1 m above ground and at ground level. The average daily and annual doses absorbed by the Scots pine stands in the far area of the Chernobyl fallout for the study period were  $0.35 \pm 0.02$  mGy per day and  $0.13 \pm 0.01$  Gy per year, respectively.

Forest inventory parameters (diameter at breast height, height, basal area, stand volume, stand density and site class) were determined for each experimental plot using standard techniques (Baginsky 1984, Zagreev et al. 1992, TKP 026-2006 (02080) 2006). The data obtained were compared with the data of these stands from the time of establishment of experimental plots (Ipatyev 2000, 2005).

**Table 1. Characteristics of Scots pine stands in the experimental plots in the near and far areas located in the Chernobyl fallout.**

| Object number                     | Year of object book-mark | Age of a stand, years | Dose rate, $\mu\text{Sv}\cdot\text{h}^{-1}$ |                  | Contamination density by $^{137}\text{Cs}$ , $\text{Ci}\cdot\text{km}^{-2*}$ |
|-----------------------------------|--------------------------|-----------------------|---------------------------------------------|------------------|------------------------------------------------------------------------------|
|                                   |                          |                       | at a height of 1 m*                         | at ground level* |                                                                              |
| Chernobyl far field fallout (Ft)  |                          |                       |                                             |                  |                                                                              |
| 1Ft                               | 1991                     | 80                    | 2.58 / 0.84                                 | 3.18 / 1.05      | 41.50 / 27.3                                                                 |
| 2Ft                               | 1993                     | 91                    | 1.30 / 0.89                                 | 1.67 / 1.12      | 23.14 / 20.3                                                                 |
| 3Ft                               | 1994                     | 91                    | 1.47 / 0.96                                 | 1.85 / 1.26      | 34.76 / 29.4                                                                 |
| 4Ft                               | 1994                     | 72                    | 1.47 / 0.92                                 | 1.82 / 1.07      | 27.67 / 20.6                                                                 |
| 5Ft                               | 1996                     | 50                    | 1.04 / 0.83                                 | 1.22 / 0.91      | 17.66 / 13.4                                                                 |
| 6Ft                               | 1996                     | 65                    | 1.50 / 1.24                                 | 1.74 / 1.39      | 34.73 / 27.4                                                                 |
| 7Ft                               | 2002                     | 54                    | 0.67 / 0.68                                 | 1.12 / 0.75      | 10.59 / 15.4                                                                 |
| 8Ft                               | 2006                     | 70                    | 0.89 / 1.02                                 | 1.13 / 1.12      | 23.23 / 16.7                                                                 |
| 9Ft                               | 2006                     | 60                    | 0.91 / 1.15                                 | 1.26 / 1.23      | 28.44 / 23.0                                                                 |
| 10Ft                              | 2006                     | 45                    | 0.81 / 0.70                                 | 1.08 / 0.88      | 20.00 / 16.8                                                                 |
| 11Ft                              | 2008                     | 33                    | 0.98 / 0.75                                 | 1.18 / 0.88      | 18.51 / 16.9                                                                 |
| 12Ft                              | 2008                     | 88                    | 1.11 / 0.94                                 | 1.39 / 1.14      | 21.19 / 23.5                                                                 |
| 13Ft                              | 2008                     | 33                    | 1.45 / 1.15                                 | 1.70 / 1.44      | 26.53 / 36.7                                                                 |
| Chernobyl near field fallout (Nt) |                          |                       |                                             |                  |                                                                              |
| 1Nt                               | 1993                     | 79                    | 12.35 / 4.1                                 | 16.94 / 4.9      | 206.80 / 131.6                                                               |
| 2Nt                               | 1993                     | 79                    | 11.73 / 4.7                                 | 14.89 / 5.6      | 254.20 / 169.4                                                               |
| 3Nt                               | 1997                     | 63                    | 11.80 / 5.6                                 | 16.20 / 7.9      | 241.40 / 237.4                                                               |
| 4Nt                               | 1997                     | 63                    | 9.00 / 4.8                                  | 11.20 / 5.9      | 150.00 / 143.7                                                               |
| 5Nt                               | 1997                     | 63                    | 6.50 / 3.7                                  | 7.00 / 4.3       | 129.60 / 123.6                                                               |
| 6Nt                               | 1997                     | 63                    | 6.90 / 3.5                                  | 8.40 / 4.2       | 178.20 / 79.2                                                                |

Note: \*numerator – data as of the year of the object bookmark; denominator – data as of 2016.

To assess the state of trees the 'Scale of Categories of State of Coniferous Trees' in standard TKP 026-2006 'Sustainable Forest Management. Sanitary Regulations in Forests of the Republic of Belarus' was used, which was defined as follows:

- I – Without signs of decline;
- II – Weakened trees;
- III – Strongly weakened ones;
- IV – Tree dieback;
- V – Dead wood of the current year;
- VI – Dead wood of the last year (old).

The average category of the state of trees in stands was determined according to their average size by indices of state categories and percentage of trees in ac-

cordance with their referred categories.

The state of forest stands was evaluated according to the index of a sanitary state (Karpenko 1981, Alekseev 1990), which was calculated for each experimental plot according to the following equation (1):

$$I_n = \frac{\sum I_k \cdot n}{N}, \quad (1)$$

where:

$I_n$  – the index of a sanitary state of forest stands;

$I_k$  – category of sanitary state (I–VI);

$n$  – quantity of trees of this category of state;

$N$  – quantity of trees on the experimental area.

Statistical analysis was performed using Statistica (version 9.0).

## Results and Discussion

The sustainability indicators of the Scots pine in the approaching maturity stands of the IV age class on the experimental plots in the near and far field areas (Nt 1–6 and Ft 1–13) demonstrated that, in the specific zone, the sanitary state of pine stands considerably differed depending on the forest type. It was found that in the radiation zone the density of soil contamination with  $^{137}\text{Cs}$  in pine forests varied from 15 to 35  $\text{Ci}\cdot\text{km}^{-2}$  (Ft 1–13). The bulk of the pine trees be-

longed to III and IV categories, while they were strongly weakened and were on die-back status (Table 2, Fig. 2).



Fig. 2. Pine stands in the far site of Chernobyl fallout with soil contamination density of  $^{137}\text{Cs}$  27.3  $\text{Ci}\cdot\text{km}^{-2}$ .

Table 2. The sanitary state of Scots pine stands in Ft and Nt areas of the Chernobyl fallout.

| Object number                     | Type of forest | Age of a forest stand, years (2016) | Total trees, pieces / % | Category of a sanitary state of a forest stand |      |      |      |     |      | In  |
|-----------------------------------|----------------|-------------------------------------|-------------------------|------------------------------------------------|------|------|------|-----|------|-----|
|                                   |                |                                     |                         | I                                              | II   | III  | IV   | V   | VI   |     |
| Chernobyl far field fallout (Ft)  |                |                                     |                         |                                                |      |      |      |     |      |     |
| 1Ft                               | Pine mossy     | 92                                  | 75 / 100.0              | 1.1                                            | 51.4 | 18.6 | 6.1  | 5.6 | 17.2 | 3.2 |
| 2Ft                               | Pine mossy     | 80                                  | 184 / 100.0             | 0.0                                            | 11.6 | 38.1 | 22.6 | 0.5 | 27.3 | 3.9 |
| 3Ft                               | Pine mossy     | 92                                  | 73 / 100.0              | 0.0                                            | 6.3  | 69.1 | 7.4  | 1.1 | 16.2 | 3.5 |
| 4Ft                               | Pine mossy     | 50                                  | 45.25 / 100.0           | 0.0                                            | 0.0  | 42.1 | 22.1 | 3.4 | 32.4 | 4.3 |
| 5Ft                               | Pine mossy     | 65                                  | 18.50 / 100.0           | 0.0                                            | 0.0  | 25.8 | 28.8 | 3.4 | 42.0 | 4.6 |
| 6Ft                               | Pine mossy     | 72                                  | 84.33 / 100.0           | 0.0                                            | 1.9  | 58.3 | 7.0  | 1.2 | 31.7 | 4.0 |
| 7Ft                               | Pine mossy     | 33                                  | 88 / 100.0              | 0.0                                            | 0.0  | 76.1 | 11.4 | 4.5 | 8.0  | 3.4 |
| 8Ft                               | Pine mossy     | 88                                  | 102 / 100.0             | 0.0                                            | 0.0  | 76.5 | 8.8  | 0.0 | 14.7 | 3.5 |
| 9Ft                               | Pine mossy     | 33                                  | 52 / 100.0              | 0.0                                            | 0.0  | 73.1 | 7.7  | 5.8 | 13.5 | 3.6 |
| 10Ft                              | Pine mossy     | 70                                  | 161 / 100.0             | 0.0                                            | 0.0  | 65.8 | 14.3 | -   | 19.9 | 3.7 |
| 11Ft                              | Pine mossy     | 54                                  | 101 / 100.0             | 0.0                                            | 1.0  | 60.4 | 11.9 | 5.0 | 21.8 | 3.9 |
| 12Ft                              | Pine bracken   | 72                                  | 234 / 100.0             | 0.0                                            | 4.7  | 56.9 | 13.7 | 1.7 | 23.1 | 3.8 |
| 13Ft                              | Pine mossy     | 45                                  | 248 / 100.0             | 0.0                                            | 0.0  | 44.0 | 25.8 | 2.8 | 27.4 | 4.1 |
| Chernobyl near field fallout (Nt) |                |                                     |                         |                                                |      |      |      |     |      |     |
| 1Nt                               | Pine lichen    | 63                                  | 150 / 100.0             | 22.0                                           | 44.7 | 14.0 | 10.7 | 2.0 | 6.7  | 2.5 |
| 2Nt                               | Pine mossy     | 63                                  | 78 / 100.0              | 39.7                                           | 35.9 | 9.0  | 6.4  | 2.6 | 6.4  | 2.2 |
| 3Nt                               | Pine bilberry  | 63                                  | 90 /100.0               | 26.7                                           | 34.4 | 15.6 | 8.9  | -   | 14.4 | 2.6 |
| 4Nt                               | Pine sedge     | 63                                  | 41 / 100.0              | 14.6                                           | 24.4 | 19.5 | 9.8  | -   | 31.7 | 3.5 |
| 5Nt                               | Pine mossy     | 79                                  | 132 / 100.0             | -                                              | 18.9 | 32.6 | 15.9 | 1.5 | 31.1 | 3.9 |
| 6Nt                               | Pine mossy     | 79                                  | 112 / 100.0             | 0.9                                            | 28.6 | 38.4 | 11.6 | 1.8 | 18.8 | 3.4 |

Before the Chernobyl accident, Belarusian forests were characterized by a high level of forest management. Thinning was carried out regularly, according to the established periods. As a result, trees of the lower structural levels were periodically withdrawn from the plantations. Consequently, most, especially the pine stands had elevated status indices (from 1.2 to 1.7) including those in the CNPP zone (Stepanchik 1996).

At present, the state of highly polluted  $^{137}\text{Cs}$  pine stands has significantly deteriorated compared to the state of stands at the time of the accident. In specific, the average index of the sanitary state of stands from 3.2 raised to 4.6, which is 43.7 percentage higher. Forest stands in the far areas of the Chernobyl radioactive fallout were strongly weakened, especially stand of II–III classes of age that was not caused by a radiation factor, but it was due to the lack of economic activity. As a result of the long term absence of forest management activities in radionuclide-contaminated pine stands of all age groups, the proportion of healthy pine trees was lower, and the proportion of dying and dry pine trees is higher than in stands, 5 years after the accident at the CNPP. Most of this trend is expressed in young II class and middle-aged stands, which is fixed by high index of sanitary condition, which are, on average, 4.1, in pine stands; 61–80 years it is 3.3 (Potapenko et al. 2017).

To date, the state of pine stands polluted by  $^{137}\text{Cs}$  in the first decades after the CNPP accident has been worsened significantly compared to the results of assessment of the state of pine stands at the first stages of their development after the accident. Moreover, the stands were strongly weakened, especially those in II–III age classes. During the absence of forestry management practices for 8–24

years, the pine stands of all age groups, polluted by radionuclides, were characterized by the predominance of strongly weakened stands. Most of these tendencies were observed in young growth II class and middle-aged forest stands, fixed by high indices of sanitary state, producing an average of 4.1. In 61–80-year-old stands, index of sanitary state decreased by 1.2 times and produced an average of 3.3 (Potapenko et al. 2017).

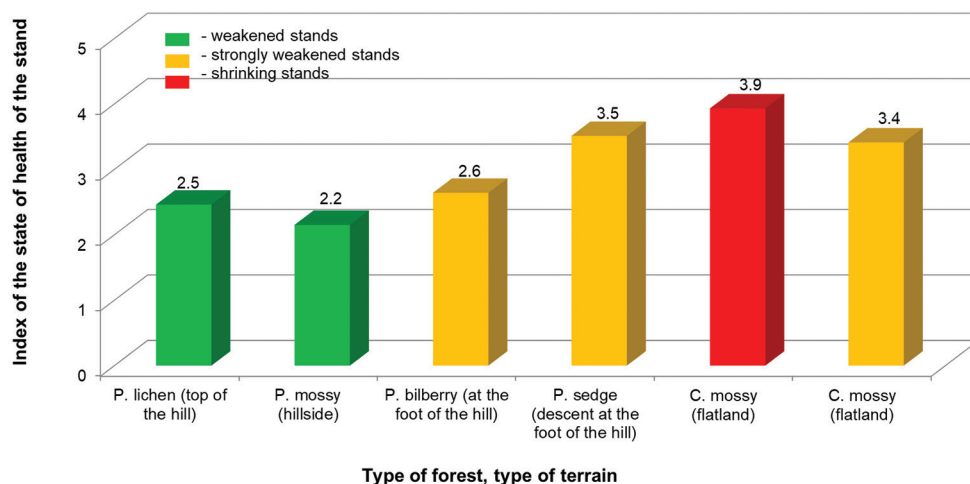
In pine stands growing in the areas with the density of soil pollution with  $^{137}\text{Cs}$  ranged from 79 to 237  $\text{Ci}\cdot\text{km}^{-2}$ , the percentage of healthy pine trees of the I category of a sanitary state changed from 14.6 % to 39.7 %. At the same time, the greatest indicators of trees in this category were noted in mossy pine forests, which grew on a hill slope, whereas the smallest were observed in sedge pine forests at the foot of the hill (Table 2, Fig. 3).

Note that, in pine stands growing on the plain with soil pollution density contaminated with  $^{137}\text{Cs}$  ranging from 133 to 169  $\text{Ci}\cdot\text{km}^{-2}$ , this category of trees was practically absent.

The distribution of weakened trees of the category II in the stand was quite similar. The greatest percentage of trees in this category with  $^{137}\text{Cs}$  soil pollution density ranging from 79 to 237  $\text{Ci}\cdot\text{km}^{-2}$  was noted in lichen pine forests at the top of hill, accounting for 44.7 %, while that in the mossy ones on a hill slope was 35.9 %.

In mossy pine forests growing on the flat area, the individual share of weakened trees of the Scots pine decreased by 1.3–1.9 times in comparison to mossy pine forests on the slope of the hill. In addition, the share of trees in categories III and IV of a sanitary state increased twice (Fig. 2). The smallest share of trees of these categories (9.0 % and 6.4 % respectively), were found in the mossy pine forest grow-





**Fig. 3. Sanitary state of pine stands depending on the type of forest and the relief of the land in near field of the Chernobyl radioactive fallout.**

ing in the middle part of the hill slope. At the same time, the greatest share of trees in categories V and VI was observed in the sedge pine forest at the foot of the hill and the mossy pine forest on the plain.

Our analysis of the sanitary state of Scots pine stands in the near field of the Chernobyl fallout showed ambiguous trends of their stability in various forests and relief.

In the initial period after the Chernobyl accident, the radionuclide composition of the radioactive fallout was characterized by the predominance of  $^{137}\text{Cs}$  in the far trace, the half-life ( $T_{1/2}$ ) of which was 30 years, as well as the presence of such radionuclides as:  $^{131}\text{I}$  ( $T_{1/2} = 8$  days),  $^{144}\text{Ce}$  ( $T_{1/2} = 286$  days) and  $^{134}\text{Cs}$  ( $T_{1/2} = 2.06$  years). Of the above radionuclides in 1991, there were quite noticeable amounts of  $^{137}\text{Cs}$  and  $^{134}\text{Cs}$ , which was confirmed by studies Ipatiev (2000) (Fig. 4).

According to the established data, the content of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  in the litter-soil complex was determined for the period 1987 to 1996, in which their relative dy-

namics in the territory of the far area was noted. Figure 4 shows that by 1996 the  $^{134}\text{Cs}$  content in the  $^{134}\text{Cs} + ^{137}\text{Cs}$  mixture had decreased to 1.5%. At the same time,  $^{137}\text{Cs}$  prevailed in the soil-litter complex, the share of which was 98.5%. Similar results were obtained by other authors (Bulavik and Perevolotsky 1997).

It is well known that, in the year of the Chernobyl accident, the dose load on the biota was mainly determined by radioactive fallout. Subsequently, at the concentration of radionuclides in the upper soil layers, the dose loads on the vegetation components were caused both by internal irradiation (due to root consumption) and external (shielded by surface soil). Therefore, the main source of absorbed doses is the specific activity of radionuclides in the soil, which allows using RESRAD-BIOTA to assess the dose load on vegetation.

Based on the activity of radionuclides in the soil at the 1Ft site during screening in 1991, absorbed doses from  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  for the period 1987–1996 in pine plantations were estimated (Fig. 5).



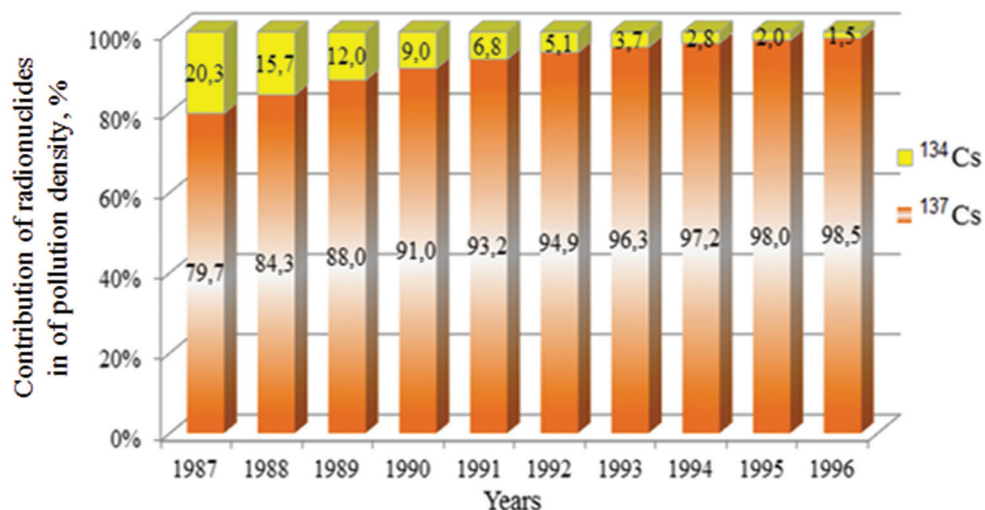


Fig. 4. Dynamics of pollution density of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  of soil-litter complex in the long-range area of Chernobyl fallout over a 10-year period.

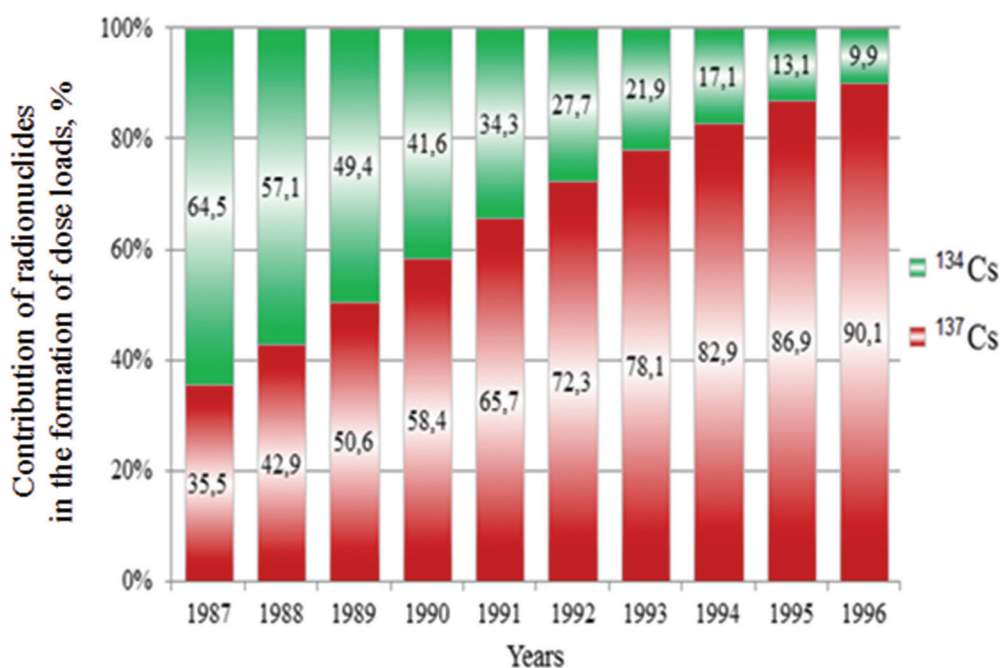


Fig. 5. Dynamics of contribution of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  in the formation of dose loads of pine trees in pine stands in the long-range area of Chernobyl fallout over a 10-year period.

It was found that in 1987, despite the content of  $^{134}\text{Cs}$  in the soil was 20.3 % of the mixture of  $^{134}\text{Cs}$  +  $^{137}\text{Cs}$ , the dose load on pine stands from  $^{134}\text{Cs}$  was 1.8 times (64.5 %) higher compared to  $^{137}\text{Cs}$  (35.5 %). This is due to the higher total photon energy at  $^{134}\text{Cs}$  (1.55 MeV/decay), than  $^{137}\text{Cs}$  (0.565) (Gusev and Belyaev 1991). Subsequently, by 1996, due to the radioactive decay of  $^{134}\text{Cs}$ , the dose from this nuclide decreased by 6.5 times (to 9.9 %). Thus, after 1996, the main source of  $\gamma$ -radiation on pine trees was  $^{137}\text{Cs}$ . The highest levels of radiation doses for tree layer from the mix  $^{134}\text{Cs}$ + $^{137}\text{Cs}$  identified during our evaluation fell on 1987. However, their size even at that time did not exceed 4.7 mGy per day (1.7 Gy per year) (Gusev and Belyaev 1991).

Using the results of periodic studies in pine phytocenoses (for 25 years), where the density of radionuclide contamination components of soil absorbing complex (moss, litter, soil layers) was determined, a retrospective assessment of radiation doses of structural elements of pine trees in the period from 1991 to 2016 was performed.

The calculation of dose load in the applied model was performed on the basis of data of the radionuclide content in the layers of the soil and covering complex. At the same time, the change in radiation doses can depend not only on the radionuclide disintegration process but also on the joint action of some other factors, which cannot be considered when sampling for identification of its impurity. These factors include the discrete nature of the Chernobyl radioactive fallout, the digging activity of wild animals and rodents that disturb the existing natural distribution of  $^{137}\text{Cs}$  in the layers of the soil and covering complex, and the features and speed of migration of radionuclide in it.

These factors modify distribution of  $^{137}\text{Cs}$  on the layers of the soil and covering complex, as well as both features and speed of radionuclide migration.

The assessment of dose loads on the tree layer, generative organs, and seedlings of the Scots pine at the experimental plots are given in Table 3. As seen from the table, in the studied pine stands, generally, the maximum and minimum dose loads in their structural elements showed the following: maximum: on the tree layer – 0.206 Gy per year, generative organs – 0.052 Gy per year, and seedlings – 0.065 Gy per year; minimum: on the tree layer – 0.068 Gy per year, generative organs – 0.017 Gy per year, and seedlings – 0.022 Gy per year.

The obtained results showed that dose loads of structural elements of pine stands on sites with the largest levels of pollution (32.7 and 36.1 Ci·km<sup>-2</sup>) on the far in the Chernobyl areas did not exceed the amount for the tree layer of 0.21 Gy per year, which were 17.4 times lower than the dose of 3.7 Gy per year offered by the Publication 91 on behalf of the International Commission on Radiological Protection (ICRP 2004) as a dose of radiation that is safe for land plants.

On the basis of the carried out assessment of the radiation doses of pine plants in pine stands in the area of the Chernobyl far field fallout with a  $^{137}\text{Cs}$  soil pollution density ranging from 15 to 36 Ci·km<sup>-2</sup>, we can possibly conclude that morphological signs of radioactive pollution impact on pine trees cannot be revealed considering that the threshold level of pollution of the studied stands was significantly lower than the level at which they arise (3.7 Gy per year), since according to the Publication 91 ISCRS threshold level, safe for terrestrial plants in the studied plantings is significantly lower.

**Table 3. Doses of radiation in structural elements of pine trees in the stands of the Chernobyl far areas at present.**

| Object number | The average dose, Gy per year* |       |       |                   |       |       |           |       |       |
|---------------|--------------------------------|-------|-------|-------------------|-------|-------|-----------|-------|-------|
|               | Tree layer                     |       |       | Generative organs |       |       | Seedlings |       |       |
|               | M                              | min   | max   | M                 | min   | max   | M         | min   | max   |
| 1 (1Ft)       | 0.135                          | 0.061 | 0.201 | 0.254             | 0.253 | 0.254 | 0.317     | 0.316 | 0.317 |
| 2 (1Ft)       | 0.136                          | 0.125 | 0.146 | 0.253             | 0.253 | 0.254 | 0.316     | 0.315 | 0.318 |
| 3 (1Ft)       | 0.128                          | 0.052 | 0.183 | 0.253             | 0.253 | 0.254 | 0.316     | 0.315 | 0.317 |
| 4 (1Ft)       | 0.106                          | 0.070 | 0.150 | 0.254             | 0.254 | 0.254 | 0.317     | 0.317 | 0.317 |
| 5 (2Ft)       | 0.129                          | 0.092 | 0.188 | 0.254             | 0.253 | 0.254 | 0.316     | 0.316 | 0.317 |
| 6 (2Ft)       | 0.188                          | 0.118 | 0.284 | 0.253             | 0.253 | 0.254 | 0.317     | 0.315 | 0.318 |
| 7 (2Ft)       | 0.130                          | 0.071 | 0.167 | 0.253             | 0.253 | 0.254 | 0.316     | 0.316 | 0.317 |
| 8 (3Ft)       | 0.171                          | 0.092 | 0.291 | 0.254             | 0.253 | 0.254 | 0.316     | 0.315 | 0.317 |
| 9 (3Ft)       | 0.152                          | 0.122 | 0.206 | 0.253             | 0.253 | 0.254 | 0.316     | 0.315 | 0.317 |
| 10 (4Ft)      | 0.068                          | 0.038 | 0.092 | 0.196             | 0.025 | 0.254 | 0.316     | 0.316 | 0.317 |
| 11 (5Ft)      | 0.150                          | 0.093 | 0.183 | 0.253             | 0.253 | 0.254 | 0.316     | 0.315 | 0.317 |
| 12 (6Ft)      | 0.128                          | 0.103 | 0.155 | 0.254             | 0.253 | 0.254 | 0.316     | 0.315 | 0.318 |
| 13 (6Ft)      | 0.111                          | 0.104 | 0.116 | 0.254             | 0.253 | 0.254 | 0.317     | 0.316 | 0.318 |
| 14 (6Ft)      | 0.107                          | 0.087 | 0.127 | 0.254             | 0.253 | 0.254 | 0.317     | 0.316 | 0.317 |
| 15 (7Ft)      | 0.102                          | 0.079 | 0.120 | 0.253             | 0.253 | 0.254 | 0.317     | 0.316 | 0.318 |
| 16 (8Ft)      | 0.139                          | 0.127 | 0.158 | 0.253             | 0.253 | 0.253 | 0.316     | 0.315 | 0.316 |
| 17 (9Ft)      | 0.206                          | 0.160 | 0.296 | 0.254             | 0.253 | 0.254 | 0.316     | 0.316 | 0.317 |
| 18 (10Ft)     | 0.094                          | 0.080 | 0.103 | 0.254             | 0.253 | 0.254 | 0.317     | 0.316 | 0.317 |
| 19 (11Ft)     | 0.079                          | 0.064 | 0.094 | 0.254             | 0.253 | 0.254 | 0.317     | 0.316 | 0.317 |
| 20 (12Ft)     | 0.129                          | 0.112 | 0.154 | 0.253             | 0.253 | 0.254 | 0.317     | 0.317 | 0.318 |
| 21 (13Ft)     | 0.105                          | 0.094 | 0.116 | 0.253             | 0.253 | 0.253 | 0.316     | 0.315 | 0.316 |

Note: \* numerator – average.

Krivolutsky (2000) stated that forest and fruit trees in the 30-km CNPP zone were seriously damaged by pests. Within this zone accelerated development of new phytopathogenic forms, races with enhanced virulence, thus accelerated horizontal transfer of genes among different species of microorganisms became possible (Dmitriev et al. 2007). Those pathogens could be easily exported out of the contaminated areas. Therefore, the zone of 30-km CNPP may be an environmental hazard and the ecological processes within the zone need to be monitored attentively. To date, some living populations inhabiting the 30-km CNPP zone

demonstrating high levels of mutagenesis (Golubev et al. 2005) and morphologic anomalies (Soroichinsky 2003), which can lead to a decline in adaptation and reproductive potential in organisms comprising the populations (Moller and Mousseau 2003). At the same time, an analysis of the patterns of the formation of biological effects in the zone exposed to radioactive contamination as a result of the Chernobyl accident, suggests that dose rates in the order of 0.1 mGy/day are able to cause significant increase in genetic effects in the most sensitive representatives of flora and fauna (Geras'kin et al. 2006, 2008). From this point of view, conifer trees are a

unique object due to their high radio sensitivity. Indeed, experimental studies have shown that the frequency of cytogenetic disorders in the root meristem of seedlings of pine seeds from the most polluted areas exceeds the control level by two times (Geras'kin et al. 2007).

## Conclusions

The sanitary condition of pine stands in near and far field sites of the Chernobyl fallout has significantly worsened 30 years after the accident when compared to initial estimations. These stands are characterized by their strong weakening. Ambiguous trends are also observed in the sustainability of stands depending on the forest type and land relief. The stands growing on the territory with the expressed difference of the moesorelief (from 5 to 15 m) in lichen, mossy, and bilberry types of forests were the most resistant among the studied pine stands of various forests in the near field sites of Chernobyl fallout. Among them, most resistant were the stands growing in the middle part of the hill slope.

In pine stands on the territory of the Chernobyl far field fallout for the 9-year period after the CNPP accident, the  $^{134}\text{Cs}$  contribution in soil pollution density and the total radiation dose of pine trees in the  $^{134}\text{Cs} + ^{137}\text{Cs}$  mixture decreased considerably due to disintegration of  $^{134}\text{Cs}$ . The greatest dose load of the tree layer of the Scots pine from radionuclide was noted in 1991, i.e.,  $^{137}\text{Cs}$  of 1.0–1.7 mGy per day, and from a  $^{134}\text{Cs} + ^{137}\text{Cs}$  mixture of 1.6–2.4 mGy per day.

The radiation doses of structural elements of the pine trees were influenced by the following factors: radionuclide disintegration, changes in its contents caused by

the discrete nature of radioactive losses, digging activity of animals, and features of vertical migration of radionuclide. In this regard, the size of daily radiation doses at the tree layer of the pine for the 30-year period after the CNPP accident changed from 0.19 to 0.57 mGy per day. To date, in pine stands on the far field sites with  $^{137}\text{Cs}$  soil pollution contamination ranging from 15 to 36 Ci·km<sup>-2</sup>, dose loads at the tree layer of the pine show a value of 0.07–0.21 Gy per year. This value was 17.4–52.1 times lower than the safe doses of radiation. At the same time, an analysis of the patterns of formation of biological effects in the zone exposed to radioactive contamination as a result of CNPP accident suggests that dose rates of the order of 0.1 mGy per day can induce a significant increase in genetic effects in the most sensitive representatives of flora and fauna (Geras'kin et al. 2007). From this point of view coniferous trees are a unique object due to their high radio sensitivity.

## Acknowledgement

The work was carried out on the instructions of the state research program 'Nature Use and Ecology' subprogram 'Radiation and Natural Ecosystems' and within the state task of the Botanical Garden of the Russian Academy of Sciences, Ural Branch: Institute Botanic Garden.

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# **ECONOMIC VALUE ANALYSIS OF COMMUNITY FOREST FOOD PRODUCTS IN NGARIP VILLAGE, ULU BELU SUBDISTRICT, TANGGAMUS REGENCY (A CASE FROM INDONESIA)**

Susni Herwanti<sup>1\*</sup>, Indra Gumay Febryano<sup>1</sup>, and Dini Zulfiani<sup>2</sup>

<sup>1</sup>Department of Forestry, Faculty of Agriculture, University of Lampung. Jl Soemantri Brodjonegoro, Gedung Meneng, Bandar Lampung, 35145, Lampung, Indonesia.

\*E-mail: sh4nt@yahoo.com

<sup>2</sup>Department of Public Administration, Faculty of Social and Political Science, University of Mulawarman. Jl. Muara Muntai, Kampus Gunung Kelua, Samarinda 75114, East Kalimantan, Indonesia.

Received: 08 August 2018

Accepted: 12 September 2019

## **Abstract**

The cultivation of community forestry (Hutan Kemasyarakatan/HKm) land by planting some crops had increased its economic value. Therefore, this study aims to identify the types of food crop products and analyze the economic value of HKm food products. The data was obtained through in-depth interviews and field observations. Data analysis was done by qualitative and quantitative methods. The results showed that the products utilized in HKm consist of 28 species dominated by coffee products. These products are mixed from agricultural crops, plantations, and forestry planted in agroforestry on HKm land with coffee plants as the main crop. Other food products that are also found in HKm are chili, pepper, spring onions, cocoa, cloves, avocado and so on. Crops products other than coffee are planted spread among coffee plants with an average number of coffee plants of 2000 to 2500 stems per ha. The economic value of HKm food products reached 5 billion Rp. with the highest economic value being the coffee product as the main plant (60 %). The highest economic benefit of HKm land occurs in August while the economic benefits are low enough in December, January, February, March, and April. Farmers need to diversify food products and take into account the harvest period in order to obtain the optimum benefits from HKm land at all times. Therefore, farmers are advised to plant commercial crops such as bananas, papaya, eggplant, chayote, tomatoes, spring onions, avocados, jackfruit, sugar palm, pepper, ginger and chili with an agroforestry system because these species have high economic value and are able to provide sustainable economic and ecological benefits, while for coffee, cacao and cloves, although the economic value is high, it is not recommended to develop on HKm land because it is related to the policy which only allows maintaining coffee and cocoa plants in the forest. In this regard, the Government's support is very much needed related to HKm's policy based on the economic value in order to reconcile the interests of the community and forest sustainability.

**Key words:** agroforestry, HKm food product, HKm land.

## **Introduction**

Community forestry (Hutan Kemasyarakatan/HKm) is one of the community forestry

schemes that aims to bring together the two conflicting interests of community and forest's sustainability. The community around the forest is very dependent on it,

and the forest with all its functions has a strategic existence for life. Many research results in various countries, especially developing ones have proved people's dependence on forests existence, especially those from the poor category such as Koshi Tappu Wildlife Reserve, Nepal (Chaudhary et al. 2016), Kenya (Langat et al. 2016), Indonesia (Qurniati et al. 2017, Widianingsih et al. 2016), etc. Furthermore, according to the research results of Herwanti (2012), the income from the HKm land contributes 53 % annually of total income in Pekon Ngarip community. It is also proved that the Ngarip Village community had a high dependence on forest land. High forest dependency if left without a win-win solution from the government will cause higher forest damage, especially in Lampung Province, Indonesia.

The HKm scheme provided solutions to sustainable forest management based on sustainable economic, ecological and social principles by applying agroforestry practices that are seen as contributing to food security (Kiptot et al. 2013, Mbow et al. 2014, Salampessy 2019, Susanto and Triyono 2016, Coulibaly et al. 2017), nutrition (Vira et al. 2015, Jamnadass et al. 2013, Noordwijk et al. 2014), soil quality improvements, sustainable production systems (Alao and Shuaibu 2013) food, medicine, animal feed and microclimate modification (Oino and Mugure 2013, El-Tantawi et al. 2017). Agroforestry in Ngarip Village is a land use system that integrates agricultural crops and forestry simultaneously in a single land so that through agroforestry practices in the HKm area expected food needs for Ngarip villagers can be fulfilled through long-term food sources, medium, and short term. According to Herwanti (2016), Ngarip Village community had a level of food security with sufficient category. The more plant

species present and already in production, the more diverse types of food are available. These types of crops are not all food for farmers because some species are commercial crops which yields could be profitable so that only the abundant or non-commercial species become food for farmers.

Many economic assessment studies have been carried out by researchers including studies of the economic value of non-timber forest products in the Kapuas-Kahayan protected forest (Hastari and Yulianti 2018), the economic value of fruit, fuel-wood, and water in protected forests. Other examples are Wosi Rendani West Papua (Nurapriyanto et al. 2018), economic assessment for the Tembawang ecosystem in Sanggau District, West Kalimantan Province, Indonesia (Roslinda et al. 2017), economic value of ecosystem services in the Mazandaran Forest Reserve (Jahanifar et al. 2017), the total economic value of agroforestry in the Krueng Aceh watershed area (Kadir 2014) and so on. Naidoo (2008) states that economic assessment studies can be used to show that conservation can produce tangible economic benefits for the community. Furthermore, Jilkova et al. (2010) state that the economic assessment of environmental resources is considered an important theoretical tool for making decisions about the allocation of scarce natural resources. If natural resources and the environment have no economic value then these resources can be economically undervalued even considered worthless and therefore it can be exploited by the community (Tegenie 2015). The need to identify the economic value of food products in this HKm area is important in addressing economic and conservation issues. In an economic perspective, the contribution of food products HKm become benchmark in

improving the welfare of community and in an ecological perspective, agroforestry crops become benchmarks in the improvement of forest land conditions. According to Mayrowani and Ashari (2011), poor consumption patterns are closely related to community access to food sources due to poverty. In this case, HKm as part of the forestry sector can contribute to providing non-rice food through food diversification so that public access to food can be increased, and indirectly increases the welfare of the community. Economic assessment of food products on HKm land is an important thing to do because it involves the availability of data that can be used for policymakers in planning HKm programs to bring together economic (food) and ecological needs, especially in Ngarip Village. Therefore, this study was conducted with the aim to identify the

types of food products from HKm land and estimate their economic value. The economic value of food products was calculated based on the prevailing market price at the study site.

## Materials and Methods

### Study area

This research was conducted in Ngarip Village, Ulu Belu Subdistrict, Tanggamus Regency, Lampung Province, Indonesia for 2 months (April and May 2017). Site selection was done purposively based on consideration of efficiency and obtaining HKm permit. It is one of the villages in the district which borders protected forest area and has the most population. The majority of the villagers are farmers (Ngar-

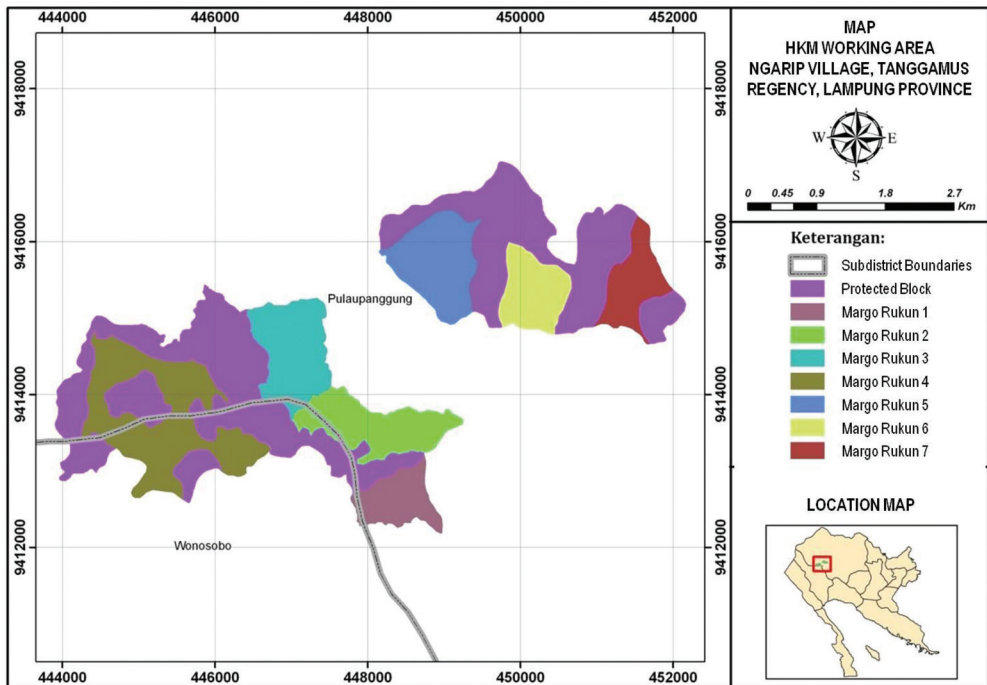


Fig. 1. Research location in HKm land, Ngarip Village, Tanggamus Regency.

ip HKm 79 %) who use the land of protected forest area for agroforestry, while the rest work as farm labourers, construction workers, traders, civil servants, and so on. The total area of HKm land is 1446.85 ha consisting of protected blocks of 39 and 32. The area of HKm land managed by the community is 1 ha in average. Ngarip Village has been granted HKm license since 1999 but this permit was renewed in 2004 and never extended after. Ngarip Village has only been granted a definitive permit for 35 years in 2007. Figure 1 presents research location.

### Data type

The type of data in this research was primary and secondary. Primary data were: HKm products already in production, the selling price of the product, the frequency of product utilization and the number of products utilized. Secondary data in the form of data supporting research derived from literature studies, sub-districts and various other supporting data. Data collection was conducted through the method of depth interview to HKm farmers by using a questionnaire and observation in the field. Several variables used in this study are presented in Table 1.

**Table 1. Research variable.**

| No | Question                                                               |
|----|------------------------------------------------------------------------|
| 1  | Area of HKm                                                            |
| 2  | Types of HKm food products                                             |
| 3  | Frequency of utilization per year                                      |
| 4  | Perfection time per year                                               |
| 5  | Amount in one utilization (kilogram / bundle / nut / trailer / liter)  |
| 6  | Total utilization per year (kilogram / bundle / nut / trailer / liter) |
| 7  | Price per unit of product (Rp.)                                        |
| 8  | Total economic value per year (Rp./year)                               |

Note: 1000 Rp. = 0.06014 euro.

### Selected respondents

Respondents were members of the HKm group randomly selected. Samples were taken randomly because respondents had homogeneous characteristics as HKm farmers. The number of respondents chosen based on the Slovin formula (Arikunto 2010) is 73 people with a total population of 282 farmers. The calculation was done by the formula (1):

$$n = \frac{N}{N(e)^2 + 1} = \frac{282}{282(0.1)^2 + 1} = 73, \quad (1)$$

where:  $n$  is number of respondents,  $N$  is population number of HKm farmer,  $e$  is Error limit (10 %).

### Data analysis

The analysis of economic value was done by using the prevailing market price at the research location. The market price method was used to analyze the economic value of HKm food products is done on all commercial and subsistence HKm food products. Stages of economic assessment are carried out as follows:

1. Assessment of products for commercial use and subsistence (self-consumption) on HKm land is done directly based on market price applicable in the research location.

2. Calculation of economic value per product type is done by the formula (2):

$$NE \text{ HKm} = TU \cdot P, \quad (2)$$

where:  $NE \text{ HKm}$  – the economic value of HKm products;  $TU$  – total utilization (unit·year<sup>-1</sup>);  $P$  – price per type (Rp.).

3. Calculation of the total economic value of HKm products by summing up all economic values per product type (formula 3):

$$NT \text{ HKm} = NE \text{ HKm}_1 + NE \text{ HKm}_2 + \dots + NE \text{ HKm}_p, \quad (3)$$

where:  $NT$  HKm – total value of the product;  $NE$  HKm<sub>*i*</sub> – economic value of product type *i*.

## Results and Discussion

### HKm in Ngarip Village

HKm licensing has changed land management practices in Ngarip Village from monoculture coffee plantations to coffee agroforestry management. In the 1970s, people utilized forest areas with monoculture coffee gardening. This system had devastating impact on the environment especially the community's forest utilization at that time and did not meet the conservation rules. The results of Ramos-Scharrón and Figueroa-Sánchez (2017) research found that coffee farming systems were estimated to produce sediments of  $-11 \text{ mg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ , decreasing soil fertility, increasing biodiversity and soil loss compared to traditional agroforestry systems (Kassa et al. 2016). Furthermore, according to Deng et al. (2016), the impacts of forest cover change may lead to decrease in soil carbon stocks, increase surface temperatures (Younesazadeh et al. 2015), decline in soil quality (Bonilla-Bedoya et al. 2017), increase soil erosion (Sharma et al. 2011), etc.

The HKm program is launched in order to improve and maintain functioning forests that have undergone functional changes such as those occurring in protected forest areas in Regions 39 and 32 in Ngarip Village. HKm program seeks to improve the condition of forests through their use in accordance with the status of forest areas and local wisdom owned by Ngarip Village community.

As in a protected forest area, Ngarip villagers are prohibited from taking tim-

ber or logging trees on HKm land. The permissible utilization is the utilization of non-timber forest products such as fruits, seeds, yams, leaves and so forth that are believed to have greater economic value than the one of a monoculture plantation system. Agroforestry practice undertaken was expected to provide economic services such as sustainable food sources and other economic benefits meanwhile improving forest conditions. The 12th North American agroforestry conference highlights that agroforestry is a profitable land use from biophysical and socioeconomic aspects (Moorhead and Dickens 2012). According to Vaast et al. (2016), coffee and cocoa agroforestry systems are more stable over time, resistant to climate change and price fluctuations by combining ecological services with diversified production. Trees as one component of agroforestry crops in an appropriate natural resource management strategy have the potential to nurture and in some cases increase yield compared to monoculture management. Furthermore, tree and agricultural integration provide livelihood benefits, provide additional income sources, and provide greater survival strategies to adapt to the markets and climate change (Reed et al. 2017).

The granting of HKm permit for 35 years gives peace and security to the community because it has gained the right to manage the forest. According to Legesse et al. (2018), property rights are one of the major factors affecting Ethiopian farmers' decisions to invest in land management. Farmers in Ethiopia feel secure so they have the courage to make a decision to reforest. According to Krishna et al. (2017), the protection of property rights under customary law provides security for rural communities. The sense of external ownership security is low when

the land cannot be given an official title. The agroforestry system applied to HKm land with various ecological and economic benefits is a form of farmer's decision to manage the forest because it is based on security and trust. For 35 years, agroforestry practices implemented are expected to improve soil conditions while providing food for farmers.

### The kinds of food products in HKm land

Ngarip Village has various types of food products from HKm agroforestry land utilized by villagers both for subsistence since 1970s and commercially. Food products that are used regularly for commercial needs are coffee, cocoa, cloves, pepper and banana while the rest are used for their own needs. The production of 28 species consists of agroforestry tree products, grains, and products such as intercropping vegetables and tubers. This is similar to research outcome of Teketay and Tegineh (1991) who showed that coffee (*Coffea arabica* L.) is found to grow under the shade of 16 tree species and 15 types of inter-cropping plants such as

grains, fruits, vegetables, stimulants, oil-seeds and spices. According to Abebe (2013), species richness is an important indicator of diversity, however in terms of usefulness, not only species richness is considered important, but having an appropriate mix of various functional groups of plants is also considered very important (Abebe et al. 2010 ) to meet balanced nutrition and household nutritional needs. The coffee agroforestry system that produces food products in Ngarip Village is an appropriate mixture of various functional groups of plants. The diversity of food products serves to meet the needs of family food while improving and maintaining the environment. Among the various food products, there is one product that provides 2 benefits at once, namely chayote product. This product is used by fruit and leaves as a vegetable and both have market prices. However, the use of leaves isn't as much as the use of its fruit. This is because harvesting leaves takes longer than fruit harvesting while selling price is the same. In addition, people are more familiar with the fruit than the leaves. Table 2 presents the types of food products in HKm land.

**Table 2. Food products of HKm Ngarip Village.**

| Number | Type of HKm product | Scientific name                           | Number of respondent | Share of respondents, % |
|--------|---------------------|-------------------------------------------|----------------------|-------------------------|
| 1      | Coffee              | <i>Coffea robusta</i> L.Linden            | 73                   | 100                     |
| 2      | Cacao               | <i>Theobroma cacao</i> L.                 | 13                   | 17.8                    |
| 3      | Clove               | <i>Eugenia aromatica</i> (L.) Baill.      | 7                    | 9.6                     |
| 4      | Pepper              | <i>Piper nigrum</i> L.                    | 33                   | 45.2                    |
| 5      | Sugar palm          | <i>Sugar palmga pinnata</i> (Wurmb) Merr. | 10                   | 13.7                    |
| 6      | Chili               | <i>Capsicum frutescens</i> L.             | 46                   | 63.0                    |
| 7      | Spring onion        | <i>Allium fistulosum</i> L.               | 14                   | 19.2                    |
| 8      | Leaves of chayote   | <i>Sechium edule</i> *                    | 1                    | 1.4                     |



| Number | Type of HKm product | Scientific name                           | Number of respondent | Share of respondents, % |
|--------|---------------------|-------------------------------------------|----------------------|-------------------------|
| 9      | Chayote             | <i>Sechium edule</i> **                   | 8                    | 11.0                    |
| 10     | Cassava leaves      | <i>Manihot esculenta</i> Crantz           | 2                    | 2.7                     |
| 11     | Long beans          | <i>Vigna sinensis</i> L.                  | 3                    | 4.1                     |
| 12     | Rampai              | <i>Solanum lycopersicum</i> L. syn.       | 7                    | 9.6                     |
| 13     | Eggplant            | <i>Solanum melongena</i> L.               | 11                   | 15.1                    |
| 14     | Tomato              | <i>Lycopersicon esculentum</i> Mill.      | 5                    | 6.8                     |
| 15     | Avocado             | <i>Persea americana</i> Mill.             | 22                   | 30.1                    |
| 16     | Mango               | <i>Mangifera indica</i> L.                | 1                    | 1.4                     |
| 17     | Jackfruit           | <i>Artocarpus heterophyllus</i> Lam.      | 25                   | 34.2                    |
| 18     | Papaya              | <i>Carica papaya</i> L.                   | 7                    | 9.6                     |
| 19     | Banana              | <i>Musa</i> L. sp.                        | 27                   | 37.0                    |
| 20     | Water apple         | <i>Psidium guajava</i> L.                 | 1                    | 1.4                     |
| 21     | Areca Nut           | <i>Areca catechu</i> L.                   | 1                    | 1.4                     |
| 22     | Breadfruit          | <i>Artocarpus altilis</i> (Park.) Fosberg | 3                    | 4.1                     |
| 23     | Durian              | <i>Durio zibethinus</i> L.                | 1                    | 1.4                     |
| 24     | Ginger              | <i>Zingiber officinale</i> Rosc.          | 16                   | 21.9                    |
| 25     | Turmeric            | <i>Curcuma domestica</i> Valet            | 5                    | 6.8                     |
| 26     | Sweet potato        | <i>Ipomoea batatas</i> (L.) Lam.          | 1                    | 1.4                     |
| 27     | Cassava             | <i>Manihot</i> Mill. Sp                   | 11                   | 15.1                    |
| 28     | Taro                | <i>Colocasia esculenta</i> (L.) Schott    | 12                   | 16.4                    |

Note: \* – leaves, \*\* – fruit.

### Economic value of HKm food product

The result of research showed that all food products in Ngarip Village have high economic value. The economic value is derived from the market price of commercial products or the market price approach of subsistence products. The total economic value of the product reaches Rp. 5,000,000,000 or Rp. 72,900,000 per household per year. The largest economic value was obtained from coffee products (60 %) which is the main product while the remaining 40 % in agroforestry products other than coffee the greatest value comes from pepper products. According

to the results of the study, the number of coffee plants on HKm ranged from 2000 to 2500 stems per ha while other types of plants were planted scattered between and under coffee plants. These results indicated that other agroforestry products have substantial economic value. It is in accordance to El Tahir and Vishwanath's (2015) research outcome who found that the agroforestry economic value contributed significantly to the lives of local communities in Eastern Sudan, which is about 7,346,000 SDG (1,335,636.36 USD) per household per year. Table 3 presents the economic value of agroforestry food products on HKm land.

**Table 3. The economic value of each type of HKm product.**

| No                                                                                     | Type of product | Average product utilization, unit·year <sup>-1</sup> | Price, Rp·unit <sup>-1</sup> | Average product economic value, Rp·year <sup>-1</sup> | Total value of economy product, Rp·year <sup>-1</sup> |
|----------------------------------------------------------------------------------------|-----------------|------------------------------------------------------|------------------------------|-------------------------------------------------------|-------------------------------------------------------|
| 1                                                                                      | Coffee          | 2197.00                                              | Rp. 20.000 kg <sup>-1</sup>  | 43,946,236.56                                         | 3,208,075,269                                         |
| 2                                                                                      | Chili           | 476.38                                               | Rp. 20.000 kg <sup>-1</sup>  | 9,527,671.23                                          | 695,520,000                                           |
| 3                                                                                      | Pepper          | 145.56                                               | Rp. 90.000 kg <sup>-1</sup>  | 13,100,547.95                                         | 956,340,000                                           |
| 4                                                                                      | Banana          | 710.14                                               | Rp. 1.300 kg <sup>-1</sup>   | 923,178.08                                            | 67,392,000                                            |
| 5                                                                                      | Avocado         | 42.19                                                | Rp. 5000 kg <sup>-1</sup>    | 210,958.90                                            | 15,400,000                                            |
| 6                                                                                      | Ginger          | 38.36                                                | Rp. 13.750 kg <sup>-1</sup>  | 527,397.26                                            | 38,500,000                                            |
| 7                                                                                      | Spring onion    | 43.73                                                | Rp. 15.000 kg <sup>-1</sup>  | 655,890.41                                            | 47,880,000                                            |
| 8                                                                                      | Chayote leave   | 157.81                                               | Rp 2.000 bndl <sup>-1</sup>  | 315,616.44                                            | 23,040,000                                            |
| 9                                                                                      | Chayote         | 105.21                                               | Rp. 2.000 kg <sup>-1</sup>   | 210,410.96                                            | 15,360,000                                            |
| 10                                                                                     | Cassava leave   | 13.15                                                | Rp. 2.000 bndl <sup>-1</sup> | 26,301.37                                             | 1,920,000                                             |
| 11                                                                                     | Long beans      | 11.10                                                | Rp. 2.000 bndl <sup>-1</sup> | 22,191.78                                             | 1,620,000                                             |
| 12                                                                                     | Cacao           | 70.18                                                | Rp. 25.000 kg <sup>-1</sup>  | 1,754,480.53                                          | 128,077,079                                           |
| 13                                                                                     | Mango           | 0.79                                                 | Rp. 3.500 kg <sup>-1</sup>   | 2,756.85                                              | 201,250                                               |
| 14                                                                                     | Jackfruit       | 30.82                                                | Rp. 3.500 kg <sup>-1</sup>   | 107,876.71                                            | 7,875,000                                             |
| 15                                                                                     | Rampai          | 8.28                                                 | Rp. 7.000 kg <sup>-1</sup>   | 57,994.52                                             | 4,233,600                                             |
| 16                                                                                     | Eggplant        | 18.71                                                | Rp. 5.000 kg <sup>-1</sup>   | 93,561.64                                             | 6,830,000                                             |
| 17                                                                                     | Tomato          | 54.11                                                | Rp. 7.700 kg <sup>-1</sup>   | 416,661.99                                            | 30,416,325                                            |
| 18                                                                                     | Papaya          | 109.08                                               | Rp. 2.000 kg <sup>-1</sup>   | 218,150.68                                            | 15,925,000                                            |
| 19                                                                                     | Clove           | 6.52                                                 | Rp 85.000 kg <sup>-1</sup>   | 554,246.58                                            | 40,460,000                                            |
| 20                                                                                     | Durian          | 0.82                                                 | Rp. 15.000 nut <sup>-1</sup> | 12,328.77                                             | 900,000                                               |
| 21                                                                                     | Turmeric        | 3.63                                                 | Rp. 10.000 kg <sup>-1</sup>  | 36,301.37                                             | 2,650,000                                             |
| 22                                                                                     | Cassava         | 27.03                                                | Rp. 515 kg <sup>-1</sup>     | 13,919.22                                             | 1,016,103                                             |
| 23                                                                                     | Sweet potato    | 4.11                                                 | Rp. 4.000 kg <sup>-1</sup>   | 16,438.36                                             | 1,200,000                                             |
| 24                                                                                     | Taro            | 40.44                                                | Rp. 2.000 kg <sup>-1</sup>   | 80,876.71                                             | 5,904,000                                             |
| 25                                                                                     | Breadfruit      | 11.67                                                | Rp. 3.100 kg <sup>-1</sup>   | 36,180.82                                             | 2,641,200                                             |
| 26                                                                                     | Sugar palm      | 6.16                                                 | Rp. 15.000 kg <sup>-1</sup>  | 92,465.75                                             | 6,750,000                                             |
| 27                                                                                     | Areca nut       | 0.18                                                 | Rp. 15.000 kg <sup>-1</sup>  | 2,671.23                                              | 195,000                                               |
| 28                                                                                     | Water apple     | 0.21                                                 | Rp. 2.000 kg <sup>-1</sup>   | 410.96                                                | 30,000                                                |
| Total economic value of HKm product, Rp·year <sup>-1</sup>                             |                 |                                                      |                              |                                                       | 5,326,351,826                                         |
| Average economic value of HKm products, Rp·household <sup>-1</sup> ·year <sup>-1</sup> |                 |                                                      |                              |                                                       | 72,963,724                                            |

Note: bndl – bundle; 1000 Rp. = 0.06014 euro.

Agroforestry products in the study area have different harvest periods so farmers get results and income in each period. Based on the results of the research, farmers benefit from HKm land

throughout the year and the amount is fluctuating. The highest economic benefits were obtained by farmers in August when coffee was harvested, while the low economic benefits occurred in December,

January, February, March, and April when commercial crops had not yet produced or commercial crops had been produced but not much. In December, the economic value derived mainly from avocado, cocoa, and tomatoes. In January and February, high economic values were obtained from banana, jackfruit, durian, areca nut, and tomato. In March and April, the economic value comes from rampai (a type of small tomato), spring onions, eggplant, sugar palm, breadfruit, and water apple which at that time began to produce. In May to August, there was an increase in economic value strongly influenced by the production of cocoa and coffee which were undergoing a harvest period. In September, the economic value declined slightly because coffee products were at the end of the harvest period but this month the clove began production. In October and November, the economic value experienced an increase again because pepper entered the harvest period. Based on the results of the study, the fluctuations in the economic value of food products were caused by several factors, namely: i) the product is a commercial type, such as coffee, pepper, cocoa, ginger, avocado, sugar palm, jackfruit, chili, and cloves, ii) the product has a high level of harvest frequencies in the year such as cacao, durian, avocado, tomatoes, jackfruit, spring onion, pepper, clove which produce more than a year and bananas, papaya, cassava leaves, chayote leaves and chayote which produce every month, and iii) total production of commercial crops. If commercial products often produce in the year with an abundant amount, then the economic value of the product is high. And vice versa, if commercial products rarely produce and the amount of production is low, the economic value of these food products is low. This occurs in several types of plants on HKm

lands such as avocados, jackfruit, and sugar palm. This type has the potential to be developed on HKm land, but because there are not many plants and crops found on HKm land, the economic value of the product decreases. Harvest frequencies of each type of product and the economic benefits resulting from each product are presented in Table 4 and Figure 2.

The HKm permit granted to the Ngarip Village community has created an agroforestry management model that is able to provide more economic value than monoculture management at that time. This economic value is obtained from commercial and subsistence product usage. Many people have benefited from agroforestry products for their own consumption such as fruits and vegetables that are quite expensive to buy in the market. In addition to the high and varied nutritional content, consumption of agroforestry products also reduces household expenses so that people can allocate their income to buy other necessities. Unfortunately, the community is not fully aware of the condition because there are still many people who rely only on coffee sales, while agroforestry products besides coffee also provide a fairly high economic contribution.

Therefore, the research on the economic value of food products attempts to show the people of Ngarip Village that the agroforestry food products grown on HKm land can provide economic benefits very significant in value. Farmers need to diversify the types of crops for the community to get more food and income variations so that during peak season farmers do not rely solely on income from one product. In addition, diversification of plant species should consider the harvest period so that farmers do not suffer from food shortages, especially in December, January, February, March and April by multiplying

the types of commercial crops that allow harvest in those months such as bananas, chayote, tomatoes, spring onions and so forth. According to Fouladbash and Currie (2015), agroforestry households in Liberia are more food resistant than monoculture

households. Households that practice agroforestry consume more food per day through diversified sources of income, improve crop yields and additional food products than households that practice monoculture farming.

**Table 4. Harvesting frequencies.**

| Kind of plant           | Month |     |       |       |     |      |      |        |      |     |     |     |
|-------------------------|-------|-----|-------|-------|-----|------|------|--------|------|-----|-----|-----|
|                         | Jan   | Feb | March | April | May | June | July | August | Sept | Oct | Nov | Dec |
| Coffee                  |       |     |       |       |     | V    | V    | V      | V    |     |     |     |
| Chili                   |       |     |       |       | V   | V    |      |        |      |     |     |     |
| Pepper                  |       |     |       |       |     |      |      |        |      | V   | V   |     |
| Banana                  | V     | V   | V     | V     | V   | V    | V    | V      | V    | V   | V   | V   |
| Avocado                 |       |     |       |       |     |      |      |        |      |     | V   | V   |
| Ginger                  |       |     |       |       |     |      |      | V      |      |     |     |     |
| Spring onion            |       |     |       | V     |     |      |      | V      |      |     |     | V   |
| Chayote leave           | V     | V   | V     | V     | V   | V    | V    | V      | V    | V   | V   | V   |
| Chayote                 | V     | V   | V     | V     | V   | V    | V    | V      | V    | V   | V   | V   |
| Cassava leave           | V     | V   | V     | V     | V   | V    | V    | V      | V    | V   | V   | V   |
| Long beans              |       |     |       |       |     | V    | V    | V      | V    | V   |     |     |
| Cacao                   | V     | V   | V     | V     | V   | V    | V    |        |      |     | V   | V   |
| Mango                   |       |     | V     | V     |     |      |      |        |      |     |     |     |
| Jack fruit              |       | V   | V     |       |     |      |      |        |      |     |     |     |
| Rampai                  |       |     | V     | V     | V   |      |      |        |      |     |     |     |
| Eggplant                |       |     | V     | V     | V   |      |      |        |      |     |     |     |
| Tomato                  | V     | V   |       |       |     |      |      |        |      |     |     | V   |
| Papaya                  | V     | V   | V     | V     | V   | V    | V    | V      | V    | V   | V   | V   |
| Clove                   |       |     |       |       |     |      |      |        | V    | V   |     |     |
| Durian                  | V     | V   |       |       |     |      |      |        |      |     |     |     |
| Turmeric                |       |     |       |       |     |      |      |        |      |     | V   |     |
| Cassava                 |       |     |       |       |     |      |      |        | V    |     |     |     |
| Sweet potato            |       |     |       |       |     |      |      |        |      | V   |     |     |
| Taro                    |       |     |       |       |     |      |      |        |      |     | V   |     |
| Bread fruit             |       |     | V     | V     |     |      |      |        |      |     |     |     |
| Sugar palm              |       |     | V     | V     | V   | V    |      |        |      |     |     |     |
| Areca nut               |       | V   |       |       |     |      |      |        |      |     |     |     |
| Water apple             |       |     | V     |       |     |      |      |        |      |     |     |     |
| Number of type of crops | 8     | 10  | 13    | 12    | 10  | 10   | 8    | 9      | 9    | 9   | 10  | 9   |

The estimation of the economic value of HKm food products obtained in this study indicates that the management model of agroforestry in Ngarip Village has contributed to improving the economy through increasing non-rice food availability, in-

creasing income, increasing employment opportunities, increasing market access and so on. According to Menurut El Tahir and Vishwanath (2015), economic value can be an indication of how the capability of agroforestry management model in

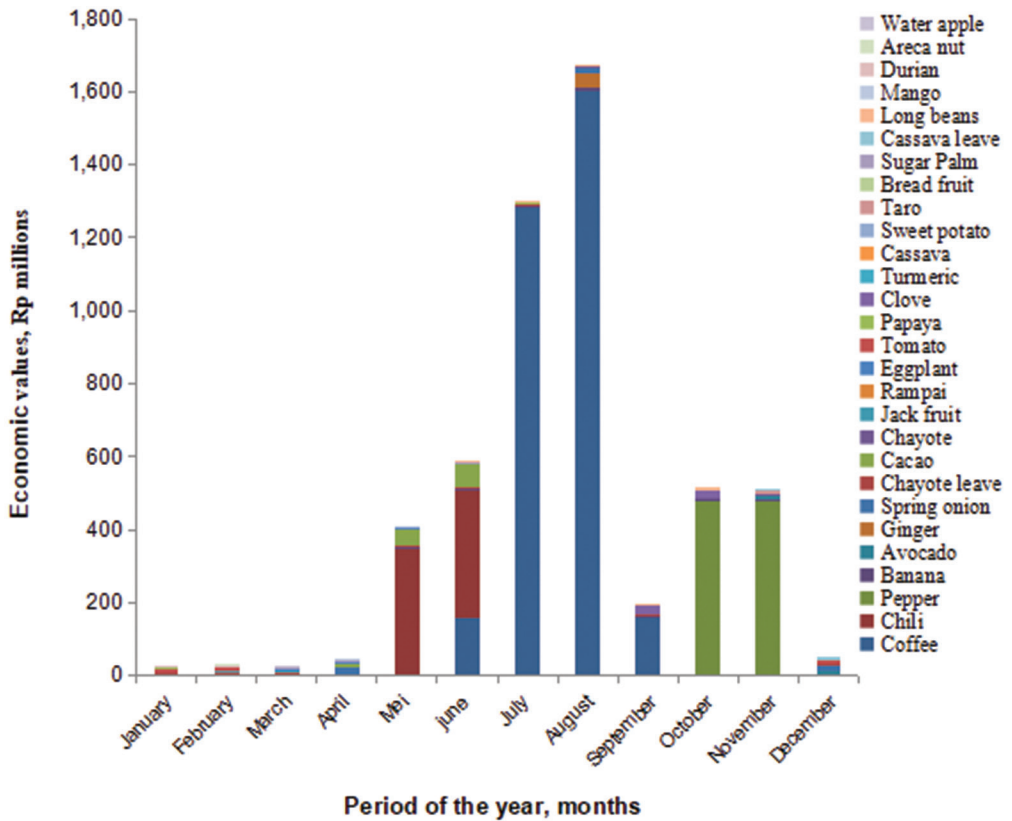


Fig. 2. Economic value of each product type.

HKm land applied by community has a role in improving the economy. In addition, the results of this economic assessment can play a role in providing input regarding HKm land management policies (Ndebele and Forgie 2017). Protection Forest Management Unit (KPHL) North Kotaagung as policy holder at local level need to apply win-win solution related to land management of HKm by community in Ngarip Village, such as policy on seed, selection of superior seeds and selection of crop type in accordance with the knowledge of local communities for successful forestry development. According to Salampessy et al.

(2017), communities in the management of traditional agroforestry have their own decisions in choosing tree species based on community's ecological knowledge and they need the government to support. Meinzen-Dick (2014) states that interventions in land management require well-defined policy and property ownership support. Therefore, HKm's 35 year license should be supported by a flexible HKm policy by taking into account the economic value of food products so that the management of the land can be more efficient and optimal according to the needs of both the forest and the community.

## Conclusion

Food products on the land of HKm Ngari Village consists of 28 species and 60 % is dominated by coffee products while the rest were chili, pepper, spring onions, cocoa, cloves, avocado, etc. Farmers benefit from HKm land in every month since the land is capable of producing various types of food products every month. The economic value of food products in HKm land reach Rp. 3,000,000,000 or Rp. 72,900,000 per household per year from 28 types of food crops. The highest economic value came from coffee, which amounted to Rp. 3,208,075,269 per year and the lowest economic value came from water apple about Rp. 30,000 per year. The highest economic benefits occurred in August when coffee was harvested. While the low economic benefits occurred in December, January, February, March, and April when coffee and other commercial crops have not produced. However, In October and November, the economic value increased again due to pepper and other crops experienced a harvest period. Most types of crops are harvested more than once a year and some even produce every month such as bananas, chayote, chayote leaves, papaya and cassava leaves but the economic value is very low compared to the five main commercial products, such as coffee, chili, pepper, cocoa, and cloves. This fluctuation in economic value was due to several cases, such as the type of commercial crops, harvest frequency and quantity of crop production per month.

## Acknowledgment

The authors thank to protection forest management unit (KPHL) of Kotaagung

Utara and Lampung University for facilitating the field research works.

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## ANALYSIS OF PARK ZAIMOV WOODY VEGETATION IN SOFIA, BULGARIA

Vladimir Tomov

Department of Landscape Architecture, Faculty of Ecology and Landscape Architecture,  
University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria.  
E-mail: Vladimirtomov@ltu.bg

Received: 13 August 2019

Accepted: 13 September 2019

### Abstract

The aim of the research was assessment of the vegetation in park Zaimov, situated in the central part of Sofia. The used methods represent a new approach for more profound assessment of urban green spaces vegetation in Bulgaria, in more than one aspect. Therefore, those methods could be a subject of improvement and development in future studies. All woody vegetation of the park was taxonomically identified and mapped. Forty-four tree species from 27 genera were registered in the park. The individuals count 1156 trees with calculated relative effective volume (REV) of 79,511.45 m<sup>3</sup>. This volume decreases 10 times during winter, which makes the park vegetation inefficient during this period. The vegetation is in good condition except trees at the south border of the park. Models of the tree crowns of four common species, well presented in the park, were made. The aesthetic values of the presented species give well-balanced and enough in quantity ornamental accents to the park environment in the different times of the year. The valuable old vegetation should be preserved in future reconstructions and better care should be provided to the new planted one. A strong suggestion for building a denser hedge barrier of evergreen vegetation across the south border of the park was made.

**Key words:** alley trees, species diversity, tree crown parameters, urban green spaces, vegetation condition.

### Introduction

Providing healthy and aesthetic environment in big cities is one of the biggest challenges of the modern society. Urban nature fulfils important immaterial and non-consumptive human needs (Chiesura 2004). Failure to provide the restorative and psychological benefits of access to nature in the city could have substantial health costs in the long run (Thompson 2002). Sofia is the biggest city and capital of Bulgaria, hosting more than one

fourth of the country's population. It has dramatic issues with air quality, especially during winter. There are several main factors which contributed to the air pollution, and the measures are mostly late and insufficient. According to the European Environment Agency (EEA) report Bulgaria is amongst the countries with worst air quality. It is also on top of the list for most years of life lost (YLL) attributable to particulate matter 2.5 µm or less (PM2.5) (EEA 2018).

Sofia is still one of the European cap-

itals with most square metres of urban greenery, as a result of the partly preserved Adolf Muesmann's master plan for the green system (Kovachev et al. 2012). The attention in analysing and regulating the urban greenery was focused on quantity parameters of the green system than quality ones (Kovachev 2005). Furthermore, Sofia is losing more and more green areas due to urbanization and the quality of the existing ones has been dropping due to bad maintenance. Most of the public park reconstructions are implemented unprofessionally and without the needed preceding analysis. As a result, valuable vegetation is removed from places where it is absolutely essential, trees are planted where they can't develop and fulfil their ecological function, or the lack of maintenance limited their chance to survive.

Park Zaimov is one of the most visited parks in Sofia's central part. It covers around 10 hectares and was constructed between 1950 and 1960 on the place of old military barracks, situated in the mar-

gins of the city by that time. As Diko Dikov commented: There was built the residential complex Zaimov, now Oborishte, and the park in front of it. From the beautiful gardens in front of the barracks, only few huge poplars were kept (Dikov 2010) (Fig. 1).

The plan composition of the park is geometric with parterres, water effects and sculptures along the main axis. The park hosts various cultural, entertainment and sport events and was the first public space in Sofia with free Wi-Fi. In spite of the undoubtedly high value of the park, there isn't full description of the park vegetation, its ecological and aesthetic value, (health) status, functional capacity and biodiversity. Furthermore, Sofia Municipality aims to reconstruct and renovate the park in 2020 (Official statement of Sofia municipality – Anonymous 2019a).

The aim of the study is to make objective assessment of the woody vegetation of the park and to give recommendations for future reconstructions, so to maximize the benefits of this urban green area.



**Fig. 1. Park Zaimov when built (Anonymous 2019b).**

## Materials and Methods

All woody plants in the park were taxonomically identified. They have been categorized as broadleaves or conifers and mapped. The diameters at breast height (DBH) of the old individual trees were measured. Diameter of new planted trees and trees with trunk diameter distinctly less than 10 cm was not measured. They were considered less than 7.62 cm for calculations after the Nowak et al. (2007) formula. The height of the trees and the crown height were measured with altimeter Blume-Leiss Model BL6. The crown diameter was measured as projection of the crown on the ground. The density of the crown was estimated by sight for every individual tree and they were divided into 3 groups: with dense (70–100 %), medium (40–70 %) or sparse (10–40 %) crown. A complete map of the vegetation was made, showing the foliage volumes in the park during active growing season (July) and during winter (January). For the purpose of the study, vegetative objects (trees and shrubs) were categorized in different height categories – 0–2 m, 2–5 m, 5–10 m, 10–15 m, 15–20 m, over 20 m. The relative effective volume (REV) of the vegetation in the park was calculated as function of the absolute volume of the crown (AVC) (calculated mathematically), the density of the crown defined in percentage, and coefficient take into consideration the months with leaves (1 for evergreen vegetation and 0.5 for broadleaves). Although very relative, calculating the effective volume will give possibility to compare different urban green spaces by REV per m<sup>2</sup>, which can give us a clue about the ecological benefits and air qual-

ity relations, as well. Using the collected data about individual tree crowns, model of the crowns of four common species of alley trees in the park, at age of around 60 years, were made. Trees and shrubs aesthetic value was estimated and they were categorized as 'species with ornamental flowers or fruits' (ff), 'species with autumn leaf colour effect' (ace), 'species/cultivars with permanent leaf colour effect' (pce), 'evergreen species' (e), 'species with ornamental bark' (ob), 'cultivars with ornamental crown form' (ocf). The health status of the trees was estimated according to the 5-grade scale with: 0 – fully healthy tree, 1 – satisfactory health status, 2 – unsatisfactory, 3 – poor, 4 – dying or fully dead tree (Pencheva 2017).

The tree crown parameters were analysed by Analysis of Variance (ANOVA) and Post Hoc LSD test using SPSS 19.0 (SPSS for Windows 7).

## Results and Discussion

### Diversity and aesthetic value of the species in the park

All 1156 individual trees in the park were representatives of 44 species (27 genera). From them 13 species with 283 individuals were conifers and 31 species with 873 individuals – broadleaves (Table 1, Fig. 2A). From all trees 155 are young, planted less than 5 years ago. The new planted species are mostly ornamental trees with big aesthetic value like *Acer platanoides* L. 'Faassen's Black', *Albizia julibrissin* Durazz., *Styphnolobium japonicum* (L.) Schott, *Prunus serrulata* Lindl. 'Kanzan', *Picea pungens* Engelm., etc.



Table 1. Tree species in park Zaimov.

| Species                                           | Number of individuals | Percentage of participation | New planted trees | Aesthetic value of the species |
|---------------------------------------------------|-----------------------|-----------------------------|-------------------|--------------------------------|
| <b>Conifers</b>                                   | <b>283 (3)</b>        | <b>24.4</b>                 | <b>24</b>         |                                |
| <i>Abies concolor</i> (Gordon) Lindley            | 19 (2)                | 1.6                         | 6                 | pce, e                         |
| <i>Cedrus atlantica</i> (Endl.) Manetti           | 2                     | 0.2                         | -                 | e                              |
| <i>Cedrus atlantica</i> 'Glaucous'                | 2                     | 0.2                         | -                 | pce, e                         |
| <i>Cedrus deodara</i> (Roxb.) G.Don               | 13                    | 1.1                         | 3                 | e                              |
| <i>Chamaecyparis lawsoniana</i> (A. Murray) Parl. | 3                     | 0.3                         | -                 | e                              |
| <i>Picea abies</i> (L.) H. Karst                  | 60                    | 5.2                         | -                 | e                              |
| <i>Picea omorika</i> (Pančić) Purk.               | 5                     | 0.4                         | -                 | e                              |
| <i>Picea pungens</i> Engelm.                      | 95 (1)                | 8.2                         | 11                | e                              |
| <i>Picea pungens</i> Engelm. 'Glaucous'           | 8                     | 0.7                         | -                 | pce, e                         |
| <i>Pinus nigra</i> J.F.Arnold                     | 15                    | 1.3                         | 1                 | e                              |
| <i>Pinus strobus</i> L.                           | 11                    | 1.0                         | 3                 | e                              |
| <i>Taxus baccata</i> L.                           | 4                     | 0.3                         | -                 | e, ob                          |
| <i>Platycladus orientalis</i> L.                  | 47                    | 4.1                         | -                 | e                              |
| <b>Broadleaves</b>                                | <b>874 (29)</b>       | <b>75.6</b>                 | <b>135 (16)</b>   |                                |
| <i>Acer campestre</i> L.                          | 1                     | 0.1                         | -                 | ace                            |
| <i>Acer platanoides</i> L.                        | 162 (3)               | 14.0                        | 6 (1)             | ace                            |
| <i>Acer platanoides</i> 'Faasens.Black'           | 12 (5)                | 1.0                         | 12 (5)            | pce                            |
| <i>Acer pseudoplatanus</i> L.                     | 10                    | 0.9                         | 5                 | ace                            |
| <i>Acer pseudoplatanus</i> L. 'purpurea'          | 1                     | 0.1                         | -                 | pce, ace                       |
| <i>Acer saccharinum</i> L.                        | 3                     | 0.3                         | -                 | ace                            |
| <i>Aesculus hippocastanum</i> L.                  | 66 (2)                | 5.7                         | 3                 | ff                             |
| <i>Ailanthus altissima</i> Mill.                  | 11 (2)                | 1.0                         | -                 | ff, ace                        |
| <i>Albizia julibrissin</i> Durazz.                | 11                    | 1.0                         | 11                | ff                             |
| <i>Betula pendula</i> Roth                        | 52 (3)                | 4.5                         | -                 | ace, ob                        |
| <i>Catalpa bignonioides</i> Walter                | 12                    | 1.0                         | 2                 | ff                             |
| <i>Catalpa bignonioides</i> Walter 'Nana'         | 1                     | 0.1                         | 1                 | ocf                            |
| <i>Cotoneaster</i> × <i>watereri</i> Exell        | 1                     | 0.1                         | -                 | ff, ocf, e                     |
| <i>Fraxinus excelsior</i> L.                      | 18                    | 1.6                         | 14                | ace                            |
| <i>Fraxinus ornus</i> L.                          | 2                     | 0.2                         | -                 | ff, ace                        |
| <i>Fraxinus angustifolia</i> Vahl                 | 145 (3)               | 12.5                        | 3                 | ace                            |
| <i>Fraxinus pensilvanica</i> Marshall             | 82 (2)                | 7.1                         | -                 | ace                            |
| <i>Juglans regia</i> L.                           | 3                     | 0.3                         | -                 | -                              |
| <i>Liriodendron tulipifera</i> L.                 | 1                     | 0.1                         | -                 | ace                            |
| <i>Morus alba</i> L.                              | 6                     | 0.5                         | -                 | -                              |
| <i>Morus alba</i> L. 'Pendula'                    | 2                     | 0.2                         | -                 | ocf                            |
| <i>Platanus x acerifolia</i> (Aiton) Willd.       | 20                    | 1.7                         | 3                 | ace, ob                        |
| <i>Populus alba</i> L.                            | 11 (1)                | 1.0                         | -                 | ace, pce, ob                   |
| <i>Populus nigra</i> L.                           | 7                     | 0.6                         | -                 | ace                            |
| <i>Prunus avium</i> L.                            | 1                     | 0.1                         | -                 | ff                             |
| <i>Prunus cerasifera</i> Ehrh.                    | 16                    | 1.4                         | -                 | ff                             |
| <i>Prunus cerasifera</i> Ehrh. 'Atropurpurea'     | 4                     | 0.3                         | -                 | ff, pce                        |

| Species                                        | Number of individuals | Percentage of participation | New planted trees | Aesthetic value of the species |
|------------------------------------------------|-----------------------|-----------------------------|-------------------|--------------------------------|
| <i>Prunus serrulata</i> Lindl. 'Kanzan'        | 12 (2)                | 1.0                         | 12 (2)            | ff                             |
| <i>Quercus petraea</i> (Matt.) Liebl.          | 5 (2)                 | 0.4                         | 5 (2)             |                                |
| <i>Quercus robur</i> L.                        | 1                     | 0.1                         |                   |                                |
| <i>Quercus robur</i> L. 'Fastigiata'           | 5                     | 0.4                         |                   | ocf                            |
| <i>Quercus rubra</i> L.                        | 20 (6)                | 1.7                         | 18 (6)            | ace                            |
| <i>Robinia pseudoacacia</i> L.                 | 21 (1)                | 1.8                         | -                 | ff                             |
| <i>Robinia pseudoacacia</i> L. 'Umbraculifera' | 6                     | 0.5                         | -                 | ocf                            |
| <i>Styphnolobium japonicum</i> (L.) Schott     | 10                    | 0.9                         | 10                | ff, ace                        |
| <i>Sorbus torminalis</i> (L.) Crantz           | 1                     | 0.1                         | -                 | ace                            |
| <i>Tilia cordata</i> Mill.                     | 120                   | 10.4                        | 15                | ace                            |
| <i>Tilia platyphyllos</i> Scop.                | 8                     | 0.7                         | 6                 | ace                            |
| <i>Tilia tomentosa</i> Moench                  | 1                     | 0.1                         | 1                 | ff, pce, ace                   |
| <i>Ulmus laevis</i> Pall.                      | 3                     | 0.3                         | -                 | ace                            |

Note: in brackets the amount of dying or fully dead trees are shown; the aesthetic value of the species/cultivars with the suggested categories described in material and methods.

Shrub vegetation was not identified and mapped by single individuals, but on groups (vegetative volumes) (Fig. 2A). The following species were found in the park, with ornamental value in brackets: *Pinus mugo* Turra (e), *Juniperus* × *media* (e), *Berberis julianae* Schneid. (ff, ace), *Berberis thunbergii* DC. 'Atropurpurea' (ff, pce), *Cornus sanguinea* L. (ff, ob), *Deutzia scabra* Thunb. (ff), *Forsythia* × *intermedia* (ff), *Hybiscus syriacus* L. (ff), *Spiraea* × *vanhouttei* (ff), *Syringa vulgaris* L. (ff), *Ligustrum ovalifolium* Hassk., *Mahonia aquifolium* (Pursh) Nutt. (ff, ace, e), *Symphoricarpos albus* (L.) S.F.Blake (ff), *Prunus laurocerasus* L. (e), *Pyracantha coccinea* M.Roem. (ff, ace), *Rosa canina* L. (ff), *Rosa hybrida* (ff), *Ruscus aculeatus* L. (ff, e), *Sambucus nigra* L. (ff, ace).

The common species, used as alley trees when the park was built, were *Fraxinus angustifolia*, *Fraxinus pensilvanica*, *Acer platanoides*, *Tilia cordata*, *Aesculus hippocastanum* and *Betula pendula*. Silver birch trees had been planted in the central main axis, but only few of them are still

standing and they are not in a very good condition. Big number of *Fraxinus pensilvanica* trees has been heavily pruned at some stage and their crowns are atypical. Knowing that the alley trees are the same age (approximately 60-years-old) and having big number of individuals from the other four species are prerequisites for calculation of the mean tree crowns parameters (Table 2).

There is no significant difference between the crown's parameters of Norway maple, Horse chestnut and Small-leaved lime mature trees in park conditions (Table 2, Fig. 3). *Fraxinus angustifolia* mean crown is around a meter taller and wider than the crown of the other three species (Table 2). Norway maple trees are smaller in height in park conditions (12.67 m) (Table 2) than in the forest (from 18.5 to 27 m in different stands) (Tomov et al. 2014). However, the mean trunk diameter of the park trees is 35.75 ± 1.25 cm, which is a lot more than any of 50+ year-old forest stands (ranging from 18 to 30 cm) and is only 22 % less than the 120-year-old



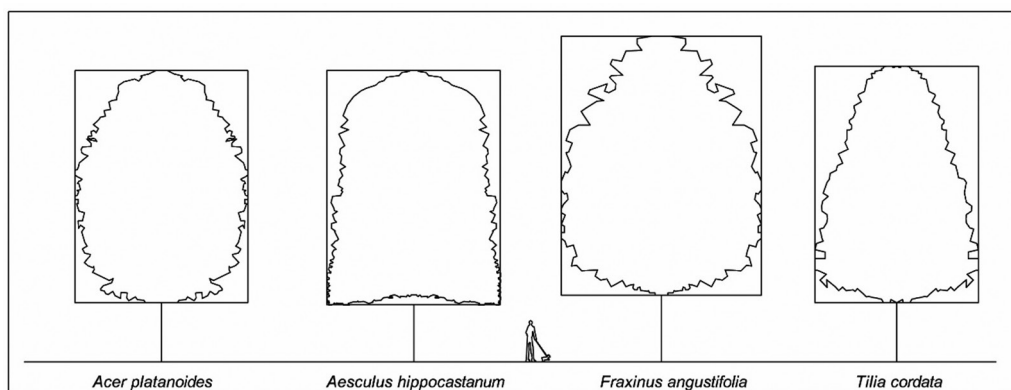
forest stand. That shows that the difference in the crown is not a result of worse conditions in the urban territory, but it is due to the low competition for light in less denser groups in the park. The same tendency was revealed for the *Tilia cordata*

mean parameters. The trees are higher ( $22 \pm 4$  m) in forest stands with smaller diameter ( $22 \pm 9$  cm) (Hagemeier and Leuscher 2019) compared to those in the park:  $12.85 \pm 0.22$  m height and  $40.42 \pm 1.67$  cm DBH (Table 2).

**Table 2. Parameters of four common species in park Zaimov.**

| Species<br>(number of trees)       | Trunk diameter<br>(DBH), cm | Tree height,<br>m  | Crown diameter,<br>m | Crown height,<br>m |
|------------------------------------|-----------------------------|--------------------|----------------------|--------------------|
| <i>Acer platanoides</i> (136)      | $35.75 \pm 1.25$ a          | $12.67 \pm 0.15$ a | $7.51 \pm 0.14$ a    | $10.01 \pm 0.17$ a |
| <i>Aesculus hippocastanum</i> (57) | $46.44 \pm 2.79$ b          | $12.65 \pm 0.18$ a | $7.56 \pm 0.24$ a    | $10.19 \pm 0.21$ a |
| <i>Fraxinus angustifolia</i> (92)  | $47.45 \pm 4.08$ b          | $14.16 \pm 0.23$ b | $8.70 \pm 0.23$ b    | $11.26 \pm 0.26$ b |
| <i>Tilia cordata</i> (63)          | $40.42 \pm 1.67$ ab         | $12.85 \pm 0.22$ a | $7.12 \pm 0.23$ a    | $10.28 \pm 0.21$ a |

Note: mean values  $\pm$  standard error of mean, followed by the same letter are not significantly different with level of significance ( $p \leq 0.05$ ).



**Fig. 3. Model of tree crowns of four common species at 60 years, M 1:200.**

Furthermore, these trees presented a genetic reservoir of mature well-adapted to urban environment genotypes of the species. They could be investigated thoroughly as a breeding material.

In general, the ornamental diversity within the park is high enough, with different effects nearly all the year round. Reasonably there aren't any long perspective views in park of that size, but still some close and middle range perspectives, with nice colour and texture contrasts, are revealed. Adding the seasonal flowers

which are planted regularly in the central parterres, there is plenty of eye-catching vegetation. Each recreational environment requires a correct accent saturation rate for optimal aesthetic effect (Galev 2016), so planting more and more ornamentals without consulting a professional is controversial. However, more shrubs are needed to separate the spaces a little bit, adding fluence to the vertical transition from the lawns to the tree canopy, but above all to provide the needed border isolation from main boulevards.

### **Vegetation health status**

Most of the vegetation (82.8 %) is in good health status (scoring 0 or 1). Some old alley trees (mostly from *Betula pendula*) inside the park are in bad condition (2 to 4) due to the species' relatively short life span. That shouldn't be big concern and they will be flowingly replaced if the right park maintenance applied. There are two bad tendencies though. The vegetation in the south part of the park adjacent to Yanko Sakuzov Blvd. suffers from the negative influence of the intense car traffic. Furthermore, big part of the old alley trees in that border part is missing (probably removed because of poor condition and potential threat) as it can be seen on the map (Fig. 2A). All this means that the border vegetation doesn't fulfil its main function, to provide isolation to the inside park areas. The hedge, mainly from *Ligustrum ovalifolium*, has been kept very short and barely does any good in that direction. The other bad tendency is that big percentage of the new planted trees is either already dead or suffering (mostly from droughts in the summer and lack of watering). That is something common to the whole city and is very big problem concerning a whole bunch of institutions and reflects negatively to the citizens' both health and financial status.

### **Crown parameters and ecological aspect**

Conifers are usually with high density crowns but due to self-pruning or bad condition 37 individuals were defined with sparse crown, 139 were considered with medium crown density and 104 – with dense crown. The broadleaves were spread as follows: 116 – sparse, 691 – medium, 38 – dense. The whole REV

of the tree vegetation was 79,511.45 m<sup>3</sup>. With park area of 102,000 m<sup>2</sup> it indicates 0.8 m<sup>3</sup> mean REV of vegetation per square meter. That number could allow comparisons with other green areas, if the method is applied in future researches. Tree oxygen production varies by tree size and many more different factors, but according to the algorithm of Nowak et al. (2007), it can be presented as a function of the tree trunk diameter (DBH). Based on data from Minneapolis, Minnesota (Nowak et al. 2006) it had been calculated that trees 2.54 to 7.62 DBH produced  $\approx 2.9$  kg O<sub>2</sub>/year, trees 22.86 – 30.48 DBH: 22.6 kg O<sub>2</sub>/year, 45.72 – 53.34 DBH: 45.6 kg O<sub>2</sub>/year; 68.58 – 76.2 DBH: 91.1 kg O<sub>2</sub>/year, and greater than 76.2 DBH: 110.3 kg O<sub>2</sub>/year (Nowak et al. 2007). Calculating with those ratios, park Zaimov is producing 29,282.04 kg of net oxygen (produced O<sub>2</sub> – consumed O<sub>2</sub>) annually. In other terms 1 m<sup>3</sup> REV produces 0.37 kg of oxygen on a yearly basis. In that way REV can be used instead of DBH for future researches where vegetation is denser and the individual trees can't be measured. Just for better understanding the ecological value of the vegetation, it needs to be said that, according to Perry and LeVan (2003) an average adult human oxygen consumption rate is 0.84 kg/day.

Only around 10 % (7520.55 m<sup>3</sup>) of the REV was made by conifers (Fig. 2B), which roughly means that during winter, when the air pollution problem is worst, the capacity of the park vegetation to absorb dirt and CO<sub>2</sub> and produce oxygen is reduced 10 times. It is fair to say that the percentage of conifer individual trees (24.4 %) is adequate, but more than 2/3 of them are planted in the past 20 years (24 young new planted trees and 169 – younger than 20 years) (Fig. 4).





**Fig. 4.** Park Zaimov nowadays, seen from the residential buildings.

The most planted conifer species has been *Picea pungens* (Fig. 4), which has good tolerance to dry and polluted air and must be preferred to *Picea abies*. The Norway spruce needs moist fresh air, which automatically means that those 60 individuals in the park are already suffering or will suffer at some stage. The placement of the evergreen vegetation is also an issue, because in the borderline adjacent to the most intense traffic there isn't any evergreen vegetation, except one big patch of *Mahonia aquifolium*, which for some unknown reason has been kept as low as half a meter tall. The other exception is a group of *Platycladus orientalis* trees planted under the canopy and had never been pruned. As a result, they don't fulfil their aesthetic targets, neither the ecological ones. More evergreen shrubs and trees planting needs to be considered

in future reconstructions of the park, as a barrier against air and noise pollution mainly from south. These will raise the REV during winter and in general, and will make the inside of the park more suitable for visitors.

The highest tree in the park is 22 m tall *Quercus robur* 'Fastigiata' individual, followed by a pack of ash trees around 20 m. In long terms a higher multilevel canopy in some areas of the park could be targeted by planting suitable tree species.

## Conclusions

Vegetation in park Zaimov is generally well planned and contains a lot of valuable trees from common park species in good condition, at age of around 60 years. It needs to be well preserved in the future.



More vegetation needs to be added, in places where the old one has been removed or impend to be, due to conditional reasons. These needs to be done fluently and according to the vision of landscape architects. It is highly recommended to build higher and denser hedge barrier of evergreen vegetation across the south border of the park.

More intensive post planting maintenance is needed for the new planted vegetation to survive and develop.

## Acknowledgments

The present study was initiated and implemented with the support of the National Science Program 'Young Scientists and Postdoctoral Students'. We express our gratitude for the concern for the young researchers, scientists and professors of Bulgaria.

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## ASSESSMENT OF THE EFFICIENCY OF SUSTAINABLE FOREST MANAGEMENT IN UKRAINE

Orest Furdychko<sup>1</sup>, Mykola Shershun<sup>1</sup>, Oleksii Shkuratov<sup>1\*</sup>,  
Oksana Drebot<sup>1</sup> and Oleh Yaremko<sup>2</sup>

<sup>1</sup>Institute of Agroecology and Environmental Management of the National Academy  
of Agrarian Sciences of Ukraine, 12 Metrological Str., Kyiv, 03143, Ukraine.

E-mails: agroecologynaan@gmail.com; shershun\_mh@ukr.net; shkuratov\_ai@ukr.net\*;  
drebot\_oksana@ukr.net

<sup>2</sup>Ternopil Oblast Department of Forestry and Hunting, 5a Bagataya Str., Ternopil, 46008,  
Ukraine. E-mail: terlists@ukrpost.ua

Received: 03 May 2019

Accepted: 17 September 2019

### Abstract

Determined that in connection with decentralization in the sphere of forest in Ukraine, the state forest management authority needs to assess the effectiveness of the implementation of the powers delegated to the regions. The results of the study of regulatory framework and practice of assessing the effectiveness of forest resources use in the context of various management entities led to the conclusion that there is no single approach to both assessing and determining criteria and indicators of forestry management effectiveness. In this regard, the article presents a methodological approach to assessing the effectiveness of sustainable forest management, which involves the application of a set of evaluation criteria and indicators, unlike existing ones, characterizing the combination of forest, forest exploitation, forest protection and reforestation processes in the forest management system. The choice of the system of assessment indicators for sustainable forest management in Ukraine was carried out taking into account the accumulated national experience and pan-European criteria and indicators of sustainable forest management. The key principle of the proposed approach is elimination of the difference in the dimensions of reduced parameters by normalization, that is, their translation into a dimensionless form. Application of this approach allows to determine the level of use of productive, ecosystem, protective and socio-economic functions of forest ecosystems, and to identify problem aspects of forest management, depending on the elements of forestry activities.

**Key words:** criteria, evaluation, indicators, forest management, sustainable.

### Introduction

The management system that has been developed in Ukraine's forestry in recent years can be characterized by a number of problems, including environmental and economic barriers to improving the efficiency of forestry production and the

transition to sustainable development of the industry. This requires development of new mechanisms for sustainable forest management aimed at improving the efficiency of use and reproduction of natural resources of forest ecosystems.

Today the domestic forestry is faced with the task of gradually abandoning the

extensive use of forest resources, taking into account the growing crisis of the provision of forestry with necessary raw materials. Extensive forest management is contrary to current trends in the development of international markets towards greening economic activity and biodiversity conservation. Therefore, to replace the extensive model, an intensive forest management model is being increasingly introduced, which is based on the principles of sustainable management and provides for ensuring a sufficient level of reforestation, enhancing the care of the young, planning commercial thinning, thinning of mature plantations, etc. In this case, one of the main problems is to increase the efficiency of economic indicators without compromising the integrity of the forest and its ecological functions (MacDicken et al. 2015).

Theoretical approaches to forest management with regard to sustainable development are characterized by a number of forest management elements, in particular, 'environmentally oriented forest management' (Zheldak 2010), 'sustainable forest management' (Wijewardana 2008), 'environmentally sustainable forest management' (Dubas 2011), 'ecosystem management of forestry' (Yarova 2010), 'sustainable forest management' (Drebot et al. 2014), etc. These approaches meet with the postulates and principles of sustainable forest management, giving priority to certain aspects (economic, environmental, social).

The concept of sustainable forest management has been mentioned during the Ministerial Conference on the Protection of Forests in Europe and later adopted by the Food and Agriculture Organization (FAO) as the basis for forestry development. By their definition, sustainable forest management is the management of

forests and forest lands, allowing them to maintain their biodiversity, productivity, resilience, viability and potential to perform, now and in the future, relevant environmental, economic and social functions without compromising other ecosystems at local, national and global levels (FAO 2014).

In general, management from an economic point of view interests the society, first of all, as a type of effective activity on the management of forest resources for the achievement of goals. It should be noted that the main task of management is the formation of a unified system of interaction of its elements to achieve the planned result at minimum cost.

According to the concept of sustainable development, forest management should be aimed at preserving the ecological, economic and social value of forests, providing favorable conditions for rational and, most importantly, sustainable forest management, planning activities for the protection and reproduction of forest ecosystems. Accordingly, the essential-substantial bases of the concept of 'sustainable forest management' takes on a refined value of systematic purposeful influence of subjects of management of forestry process together with mechanisms, institutions, forms and techniques aimed at balancing the economic interests of forestry and forest ecosystems capacity to conserve their productivity and environmental functions. In this circumstance, it is necessary to conduct a detailed scientifically based analysis of the system of sustainable forest management and reporting on the implementation of management decisions.

Forestry, as an economic sector, includes forestry, logging, production and primary processing of industrial or fuel wood, the collection of non-timber forest

resources, recreational forest use, ecological entrepreneurship, forest management, etc. Forestry is a sphere of economic activity that deals with the cultivation, protection and use of forest resources. In general, forest management can be defined as an activity aimed at using forest resources and other beneficial properties of a forest to satisfy the material and spiritual needs of society, depending on the socio-economic level of its development, environmental conditions and the actual state of forest resources in a certain area (Furdychko 2014).

The project developed by scientists from the Institute of Agroecology and Environmental Management of NAAS (Furdychko et al. 2012), provides for the creation of a system of national criteria and indicators for sustainable forest management, the development of the situation on the improvement of reporting forms that are used in the context of individual forest enterprises. However, the proposed indicators do not clearly define the norms and criteria for the improvement of economic processes in order to adapt them to the system of sustainable forest management. Further development requires methodological and methodical approaches to systematization of the main indicators of forest management into a unified system for evaluating management decisions.

In Ukrainian forest legislation, the concept of forest management has traditionally been shared, limiting public administration only to the definition of the competence of the relevant state authorities. The new edition of the Forest Code of Ukraine (in 2006) for first time gave a broad definition of the tasks of state regulation and management in the field of forest relations to ensure the effective protection, rational use and reproduction of forests. Today, the forest management system in Ukraine

is characterized by authoritarian methods, which provides for the accumulation of the economic, managerial, control and other functions of forest management almost one forest relations entity – the State Forest Resources Agency of Ukraine. However, in order to improve the efficiency of forest management, separate administration powers in the field of forest relations have been transferred to the regional level – to the regional forestry and hunting departments.

In modern economic conditions, optimization of management decisions in the use of forest resources is one of the most important questions about the growth of economic efficiency in this area (Kolesnik and Sinyatullina 2017, Lim and Innes 2017, Trishkin et al. 2017). At the same time, the technology of functioning of organizational and economic tools and methodological support for sustainable forest management reflects the set of stages of preparation, adoption and implementation of management decisions on the rational use of forest resources in order to harmonize environmental and economic goals towards achieving sustainable forest management.

As mentioned earlier, the methods currently used by the authorities to assess the effectiveness of forest management are based mainly on comparing the actual value of a given statistical indicator with the corresponding value for the previous year (or plan for a year), which does not allow conducting an objective assessment of the quality of performance of functions by forestry entities. Evaluating the effectiveness is carried out according to criteria that assess the quality of execution of powers delegated to the entity for the reporting fiscal year, and not the level of forest management. As a result, evaluating the effectiveness is based on compar-

ing the actual level of target indicators for the reporting period with similar indicators of the previous year. That is, the assessment is carried out in relation to what has been achieved, and not on the basis of comparison with individual criteria, since such criteria are not taken into account today, which does not allow us to assess the objectivity of the functions performed by forest management.

That is why, in the context of decentralized forest management, in order to form an objective view of the regions and inter-regional comparisons, a big problem is to assess the effectiveness of the execution of powers transferred to the regions in the field of forest relations (Shmatkov and Grigoriev 2011).

The results of the researching of regulatory framework and practice of assessing the efficiency of forest resource use in the context of various management subjects (state, region, forestry enterprise) allow to conclude that there is no uniform approach to assessing and determining criteria and indicators for forest management effectiveness. For example, representatives of the School of the National Forestry University suggest to determine the effectiveness of forest management in three main areas: goal setting efficiency, adaptability and reorganization efficiency (Lytsur and Holovko 2011). From their point of view, management system adaptability can be characterized by such qualitative parameters as the existence of mechanisms for maintaining feedback with the public and interested people, the existence of mechanisms for introducing the achievements of science into management practice. Reorganization efficiency can be estimated by the costs of converting the current management system and the level of risk associated with the failure of this transformation.

Storozhuk (2016) for the purpose of operational assessment of the state and effectiveness of forest management in the reserch uses a comprehensive set of criteria suggested by the Department of Agriculture and Rural Development of the World Bank. A group of international experts suggests a methodology for assessing the effectiveness of forest management, where the indicators, characterizing it, are formed according to the cost principle. Many indicators are determined by the sum of the costs of carrying out certain activities or in relative terms (Rametsteiner and Mayer 2004, Gough et al. 2008, Baycheva et al. 2013, Lim and Innes 2017).

Researches conducted by Shmatkov and Grigoriev (2011) adhere to the approach to assessing the quality and effectiveness of state forest management in the form of a rating. In particular, the rating offered by them widely presents a number of environmental, social and economic indicators that are absent in the set of assessment criteria of the Russian assessment system. However, the structure of the rating objectives according to this methodology does not include an assessment of the effectiveness of forest management, including forest reproduction, which combined forestry and logging into a single process (Mironov 2013).

Taking into account all the varieties of existing approaches to assessing forest management, it is determined that some of them do not take into account national peculiarities of forest management, others are informational, others are not entirely objective, since they are based on unconfirmed benchmark efficiency values. The current approach to assessing the effectiveness of forest management based on an analysis of target forecast indicators, which is used today by the authorities,

also cannot be considered satisfactory, because its use does not illustrate the quality of forest management and the effectiveness of the transferred powers to regional authorities. The results of the assessment according to the current approach are based on a comparison of the actual value of target indicator for the year with the forecast, that is, the assessment was carried out in relation to the achieved, and not on the basis of comparison with the optimal value of the indicator. Given this, the purpose of the article is to analyze the problems of assessing the effectiveness of forest management and the theoretical and methodological justification for its improvement, taking into account the specifics of the forest sector of economy of Ukraine.

## Material and Methods

Classically, to determine the effectiveness of the management system, regardless of its level, is to evaluate the results of work compared to the nested resources, while taking into account their qualitative characteristics. In this regard, it is advisable to establish the effectiveness of the public administration system through a comparison of relevant indicators, criteria and established standards, requirements at the initial stage and at the final stage, that is, after the implementation of specific measures to improve and transform management forms and methods (McDonalda and Lane 2004). As noted above, a numerical demonstration of a certain criterion is an indicator or their system, reflecting the estimated property of a certain phenomenon. Of course, any criterion can be expressed by a set of indicators that will reveal it, that is, reflect the characteristics of a particular criterion (both in quantitative

terms and descriptive attributes) of forest management system (Kimmins 2004, Spilsbury 2005). Such indicators allow us to estimate the vector of transformations in this system, which, taking into account the time intervals, reflects the corresponding trends in forest management.

As international experience shows, since 1998, that is, from the base of the first indicator system in Europe in a sustainable forest management system and further in the course of its development and improvement of appropriate criteria and indicators are the indispensable tool for integrated national forest policy in all European countries. The Ministerial Conference on the Protection of European Forests is organized as a regional political process based on interstate agreements (MCPFE 1998). This process is on a regular basis attended by the ministers of forestry in Europe, and equivalent people responsible for forest management. Based on the improvement of data collection systems, and given the need for constant updating of information characterizing the indicators of sustainable forest management, in 2015 at the 7th Ministerial on the Protection of Forests in Europe conference in Madrid was updated existing set of European Indicators (MCPFE 2015). According to the developed project, quantitative (34) and qualitative (11) indicators were presented. In particular, quantitative indicators are designed to characterize the status and change of the main aspects considered from the point of view of sustainable forest management. This information helps to facilitate the assessment of the achievement of the objectives of each criterion and provides for the consistent promotion of sustainable forest management. In general, criteria and indicators of sustainable forest management can serve as a basis for definition and as-



assessment of sustainable development of the domestic forest industry.

Thus, at the moment, the European criteria are recognized means of stimulating and supporting sustainable forest management, and the implementation of policies at national level. Nevertheless, there is a large difference in the methods and quality of adaptation of the European criteria to national characteristics.

Therefore, a prerequisite of effective forest management within the existing national forest policy is to create a system of national criteria and indicators for sustainable forest management in Ukraine. At the same time, national criteria should consider international commitments as well as national strategic priorities. Here, it will be important to take into account the experience of the Russian model for assessing the effectiveness of forest management, whereby the Resolution of the Government of Russian Federation approved the 'Criteria for evaluating the effectiveness of the activities of state authorities of the constituent entities of the Russian Federation on the exercise of delegated powers of the Russian Federation in the field of forest relations' characterizing the organization of the use of forests located on land forest fund; organizing and ensuring the protection of forests from forest fires; organizing and ensuring the reproduction of forests located on the lands of the forest fund; organizing and ensuring the protection of forests located on forest land; implementation on the lands of the forest fund of the federal state forest supervision (forest protection); organization of activities for the implementation by state authorities of the constituent entities of the Russian Federation of the transferred powers in the field of forest relations; preservation of forests located on forest land.

The modern forest management sys-

tem is based on the organization of control over the observance of norms 'bottom-up' – from a separate section to the state level, and the main object of control is solely the process of compliance, not the final result. Therefore, the generalized data on the state of forestry on the territory of Ukraine does not include indicators of the effectiveness of forest management according to general indicative indicators, which does not allow the formation of reliable scientifically based forecasts of forest development. In addition, the forecast and resource models for the calculation of indicative indicators of forest management have not been implemented.

In our opinion, apart from economic factors, the system for evaluating the effectiveness of sustainable forest management, designed to establish sustainable development, should take into account environmental factors. This, in turn, makes it necessary to take into account in the system of forest management such elements of forest management as: guarantees the biological productivity of forest biodiversity, ensuring proper implementation of the protective functions of forests, increasing income levels of forest management entities and workers in the forest sector. In general, the criteria for evaluating the effectiveness of sustainable forest management should be characterized by: organization of the use of forests located on forest land; organizing and ensuring the protection of forests from forest fires and pests; organization and maintenance of forest reproduction; organization and protection of forests; implementation of state forest supervision (forest protection) on forest lands; financial and economic organization of activities in the field of forest relations.

At the first stage, it is necessary to select appropriate indicators that will reveal

the effectiveness of the forest management system on the basis of sufficiently developed information support for the implementation of appropriate calculations. The choice of these indicators should be based on the absolute identity of the elements of selected indicative parameters in the design of all forest management systems and include three key canons: existence and ability to access the source data on state reporting (State Statistics Service of Ukraine, Ministry of Ecology and Natural Resources of Ukraine, State Forest Agency) resources of Ukraine, etc.; the ability to use a certain indicator at least at one of the stages of forest management; the ability of the selected indicator to a certain distribution in the calculation of common criteria and analysis of the effectiveness of forest management at all stages of implementation of economic relations. The latter can include both the relations of transitional phase of economic development, and the relations of market economy, and those that are formed during the primary research, the implementation of planning and forecasting functions in the area under researching.

The next stage includes collecting the necessary information materials and, on their basis, analyzing the data obtained regarding the criteria and indicators, in terms of determining the effectiveness of forest management. Through the implementation of such an analysis, it is possible to detect dynamic transformations regarding criteria and indicators during certain periods, and to identify the most important factors influencing these transformations.

The final stage is a retrospective analysis and implementation of conformity assessment of actual data and targets in a given plane. The degree of their achieve-

ment allows us to identify the level of efficiency of the forest management system in general, and the level of efficiency of the executive in the industry in particular.

According to our estimates, the analysis of the effectiveness of forest management requires consideration of the direction, regularity of management influences on the dynamic process of increasing forest, quality, economic and social characteristics of forests (forest cover, marketability, safety, etc.) when performing forest and logging functions by economic entities. Ensuring effective sustainable forest management should include the use of a set of criteria and indicators characterizing the assessment of the effectiveness of forest, forest exploitation, forest protection, forest protection and reforestation processes in forest management. Therefore, the choice of the system of indicators for sustainable forest management (Table 1) was carried out in the light of national experience, and the Pan-European criteria for sustainable forest management indicators.

Priority in the selection of criteria or efficiency indicators depends on the conditions of forest management, including from the spatial distribution of the productive forces. Also, the values of target indicators allow to evaluate the effectiveness of management activities in the field of organization of the use of forest resources, their protection and reproduction. In addition, the proposed system of criteria and indicators takes into account both current problems of forest management, related to supporting the value of wood and non-timber forest resources and services, and the direction of forestry development, environmental-economic and social features.

**Table 1. Criteria and indicators for sustainable forest management.**

| Criteria and indicators                                                                                                                                          | Unit           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|
| Criterion 1. Conservation and increase of forest resources (C1)                                                                                                  |                |
| 1.1. Forest cover dynamics                                                                                                                                       | %              |
| 1.2. Dynamics of wood stock in forests                                                                                                                           | %              |
| 1.3. Reforestation index (area of forest reproduction relative to the total area of forest land)                                                                 | %              |
| 1.4. The share of sowing and planting forests in the total area of reforestation                                                                                 | %              |
| Criterion 2. Preservation and maintenance of productive functions of forest ecosystems (C2)                                                                      |                |
| 2.1. Using average wood increment                                                                                                                                | %              |
| 2.2. The share of the area of operational forests in relation to the total area of forest land                                                                   | %              |
| 2.3. Dynamics of stock of mature and overmature stands (per 1 ha of forest land)                                                                                 | %              |
| 2.4. Volume of harvested wood (per 1 ha of forest land)                                                                                                          | m <sup>3</sup> |
| 2.5. Volume of harvested secondary forest products (per 1 ha of forest land)                                                                                     | t              |
| Criterion 3. Maintaining viability and supporting ecosystem functions of forests (C3)                                                                            |                |
| 3.1. Index of logging for the formation and improvement of forests (to the total area of forest land)                                                            | %              |
| 3.2. Share of the area of forests for conservation and recreational purposes in relation to the total area of forest land                                        | %              |
| 3.3. Dynamics of the share of forest conservation area and recreational purposes in relation to the total area of forest land                                    | %              |
| 3.4. The share of the area of natural reserve fund in relation to the total area of forest land                                                                  | %              |
| 3.5. Dynamics of the share of the natural reserve fund in relation to the total forest area                                                                      | %              |
| 3.6. The area of dead forest plantations per 1000 ha of forest land                                                                                              | ha             |
| 3.7. Dynamics of the area of forest plantations destroyed under the influence of adverse factors (fires, pests, diseases, etc.)                                  | %              |
| 3.8. Indicator of the phytosanitary condition of forests (the ratio of the area of damaged forest stands (diseases, pests, fires, etc.) to forest covered lands) | %              |
| Criterion 4. Support and enhance the protective functions of forests (C4)                                                                                        |                |
| 4.1. The share of the area of protective forests relative to the total area of forest land                                                                       | %              |
| 4.2. Dynamics of the share of protective forests in relation to the total forest area                                                                            | %              |
| Criterion 5. Support for the socio-economic functions of forestry (C5)                                                                                           |                |
| 5.1. Amount of products, works and services of forestry (per 1 ha of forest land)                                                                                | eur            |
| 5.2. Price of impersonal cubic meters of sold wood                                                                                                               | eur            |
| 5.3. Profitability of forestry activities                                                                                                                        | %              |
| 5.4. Average monthly wage of full-time employees                                                                                                                 | eur            |
| 5.5. Amount of payments to the consolidated budget of Ukraine (per 1 ha of forest land)                                                                          | eur            |

For the formation of the main indicators necessary for the implementation of

our proposed methodological approach, information is used over a five-year period

in order to minimize the influence of natural factors and market conditions.

Proposed methodological approaches to evaluating management efficiency include eliminating differences of dimensions given by normalizing parameters, i.e. transform them into dimensionless form at intervals from 0 to 1 (where 1 corresponds to the best (optimum) values of this index and the 0 – to its worst (unacceptable) values) (Shkuratov 2017). For this, the absolute values of the indicators are compared with the best (in terms of optimization conditions, the maximum or minimum) value of the corresponding indicator among the estimated objects:

$$I_i = X_i/Y_0, \text{ if } I_i \rightarrow \max, \quad (1)$$

$$I_i = Y_0/X_i, \text{ if } I_i \rightarrow \min, \quad (2),$$

where:  $I_i$  – normalized value of the  $i$ -th indicator;  $X_i$ ,  $Y_0$  – accordingly, the current value of this indicator and the target value for this type.

Normalized indicator shows the extent to which the development of forestry, which comprehensively reflects the current level of reserves and possible extensions. To calculate the value of a criterion, it is necessary to determine the arithmetic average of all indicators within the framework of this criterion. The aggregate indicator of the level of efficiency of sustainable forest management, in turn, is defined as the arithmetic average of the five criteria.

The application of the proposed methodological approach allows to determine the level of use of the productive, ecosystem, protective and socio-economic functions of forest ecosystems and to identify problematic aspects of management depending on elements of forest management activities.

## Results

For the purpose of testing the proposed approach, we calculated the integral indicator of the effectiveness of sustainable forest management in the regional dimension of the forestry sector in Ukraine. Table 2 shows the results of evaluating the effectiveness of sustainable forest management in the regions of the country by criteria and aggregate indicators ( $E_{fm}$ ).

For example, if we take the best cumulative indicator of the effectiveness of sustainable forest management in the context of the regions of Ukraine, it is equal to 0.71 (Rivne region). This indicates that some indicators are lower compared with the best in Ukraine, in particular, as can be seen from Table 2 are indicators illustrating Criterion 4. Support and enhancement of the protective functions of forests (0.58) and Criterion 5. Support for the socio-economic functions of forestry (0.61). At the same time, according to Criterion 1. Conservation and increase in the volume of forest resources, the Rivne region is at the highest level in Ukraine, and according to Criterion 2. Preservation and support of the productive functions of forest ecosystems has one of the highest values.

This method involves relative comparability of calculated indicators, because the benchmark is an indicator illustrating not the best indicator for Ukraine among forest enterprises, but the average value of the indicator for the region. However, the advantage of the proposed approach is that it allows you to determine how effectively or ineffectively forest management is conducted at the regional level in relation to the best indicators for the country.

**Table 2. The results of the effectiveness evaluation of sustainable forest management (2012–2017).**

| Region          | Criteria |       |       |       |       |          |
|-----------------|----------|-------|-------|-------|-------|----------|
|                 | $C_1$    | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $E_{fm}$ |
| Cherkasy        | 0.42     | 0.72  | 0.76  | 0.78  | 0.67  | 0.67     |
| Chernihiv       | 0.67     | 0.64  | 0.74  | 0.52  | 0.63  | 0.64     |
| Chernivtsi      | 0.58     | 0.81  | 0.62  | 0.71  | 0.69  | 0.68     |
| Dnipropetrovsk  | 0.28     | 0.22  | 0.36  | 0.52  | 0.26  | 0.33     |
| Donetsk         | 0.16     | 0.18  | 0.33  | 0.61  | 0.24  | 0.30     |
| Ivano-Frankivsk | 0.75     | 0.67  | 0.66  | 0.65  | 0.52  | 0.65     |
| Kharkiv         | 0.34     | 0.46  | 0.71  | 0.61  | 0.28  | 0.48     |
| Kherson         | 0.12     | 0.28  | 0.44  | 0.72  | 0.17  | 0.35     |
| Khmelnitsky     | 0.41     | 0.67  | 0.72  | 0.61  | 0.56  | 0.59     |
| Kirovograd      | 0.16     | 0.52  | 0.43  | 0.61  | 0.50  | 0.44     |
| Kyiv            | 0.46     | 0.78  | 0.59  | 0.56  | 0.60  | 0.60     |
| Luhansk         | 0.51     | 0.21  | 0.67  | 0.52  | 0.31  | 0.44     |
| Lviv            | 0.68     | 0.65  | 0.66  | 0.72  | 0.51  | 0.64     |
| Mikolaiv        | 0.18     | 0.14  | 0.63  | 0.48  | 0.24  | 0.33     |
| Odesa           | 0.47     | 0.19  | 0.54  | 0.67  | 0.22  | 0.42     |
| Poltava         | 0.26     | 0.55  | 0.64  | 0.66  | 0.35  | 0.49     |
| Rivne           | 0.87     | 0.83  | 0.68  | 0.58  | 0.61  | 0.71     |
| Sumy            | 0.47     | 0.72  | 0.72  | 0.52  | 0.69  | 0.62     |
| Ternopil        | 0.45     | 0.57  | 0.75  | 0.71  | 0.42  | 0.58     |
| Vinnitsa        | 0.38     | 0.61  | 0.73  | 0.68  | 0.55  | 0.59     |
| Volyn           | 0.47     | 0.72  | 0.77  | 0.59  | 0.60  | 0.63     |
| Zakarpattia     | 0.88     | 0.43  | 0.65  | 0.63  | 0.46  | 0.61     |
| Zaporizhia      | 0.11     | 0.12  | 0.62  | 0.59  | 0.26  | 0.34     |
| Zhytomyr        | 0.65     | 0.87  | 0.78  | 0.46  | 0.67  | 0.69     |

Conventionally, all the regions can be divided into 3 groups (or clusters). For clustering, a cumulative indicator of the effectiveness of sustainable forest management is used (Table 3). This grouping

of regions can be carried out separately for each criterion in order to understand exactly which area in particular region needs to be improved in forest management.

**Table 3. Grouping of Regions on the level of effectiveness of sustainable forest management.**

| The value of the total efficiency index | Level of efficiency | Region                                                                                                                                                               |
|-----------------------------------------|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.67–1.00                               | High (A)            | Cherkasy, Chernivtsi, Rivne, Zhytomyr                                                                                                                                |
| 0.34–0.66                               | Medium (B)          | Chernihiv, Ivano-Frankivsk, Kharkiv, Kherson, Khmelnytsky, Kirovograd, Kyiv, Luhansk, Lviv, Odesa, Poltava, Sumy, Ternopil, Vinnitsa, Volyn, Zakarpattia, Zaporizhia |
| 0.01–0.33                               | Low (C)             | Dnipropetrovsk, Donetsk, Mikolaiv                                                                                                                                    |

## Conclusions

Analyzing the changes over time of forest management indicators, it is possible to determine the conditions of any type of reproduction performed within a given territory, and as a result, to grasp the intensity and significance of the impact of sustainable forest management mechanism on forest management in the region. The results of such an assessment will make it possible to evaluate the effectiveness of the entire forest management system in a particular region, determining the degree of compliance with the real goals of activities in the field of increasing forest productivity and improving their quality. And also to identify promising approaches to the management of economic entities of forestry, to create proposals for improving forest legislation in the field of regulatory legal acts regulating forestry management. The practical significance of the results obtained on a comparative assessment of the management system is the ability to determine the direction of activating the administrative influence of forest management authorities and improving the organizational structure of forestry.

Tested our proposed methodical approach to assessing sustainable forest management, it is possible to speak about the relevance of its use in practice, since it enables the public authorities, and business entities and investors to make appropriate management decisions and improve the efficiency of use and reproduction of forest resources.

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## IMPACT OF SPACING, CLONE AND COPPICING ON BIOMASS PRODUCTION OF TWO BLACK POPLAR HYBRIDS

Tatiana Stankova<sup>1\*</sup>, Veselka Gyuleva<sup>1</sup>, Emil Popov<sup>1</sup>, Krasimira Petkova<sup>2</sup>,  
Dimitar N. Dimitrov<sup>1</sup>, Vasil Biserkov<sup>2</sup>, Ekaterina Andonova<sup>1</sup>,  
and Penka Stefanova<sup>1</sup>

<sup>1</sup>Forest Research Institute of the Bulgarian Academy of Sciences, 132 Kliment Ochridski Blvd.,  
1756 Sofia, Bulgaria. \*E-mail: tatianastankova@yahoo.com

<sup>2</sup>University of Forestry, 10 Kliment Ochridski Blvd., 1797 Sofia, Bulgaria.

Received: 25 March 2019

Accepted: 22 September 2019

### Abstract

The main objective of this study was to investigate the influence of genotype, spacing, age and harvesting cycle on the woody biomass production from coppiced plants of the black poplar hybrids (*Populus × euramericana* (Dode) Guinier) 'Agathe F' and 'Guardi'. The experiment was carried out in a Nelder wheel trial plantation with 11 nearly-square spacings, ranging from 1.0 to 11.5 m<sup>2</sup> and data collection took place at the end of the 2nd, 4th and 5th year from plantation establishment. Spacing significantly affected dendromass production in both clones and all harvesting cycles considered. The individual plant biomass generally increased with spacing, but growth approached saturation at the lowest densities for the plants of clone 'Agathe F'. Comparable dendromass amounts were recorded for both clones after 1 and after 3 years of shoot growth, and marginally significant genotype effect was found for the 4-year-period of dendromass production, when the plants of 'Guardi' attained higher biomass yields. No significant effect of the harvesting cycle was distinguished within 3-year production period, the accumulated amounts of 1- and 2-year-old shoots yielding similar quantities to those of 3-year-old sprouts for both clones. The black poplar hybrids did not differ significantly in the number of sprouts produced at any of the investigated ages. The shoot number increased with growing space and with stump age, the influence of age being obscured only at the highest planting densities. The plants of clone 'Agathe F' showed substantial growth decline in the 5th year from plantation establishment due to worsen environmental conditions and biotic pests, while clone 'Guardi' proved higher suitability for cultivation as a short rotation crop under Mediterranean climate, because of its steady growth even at worsen site conditions. Under unfavourable alterations in the water availability and without additional irrigation, coppiced plantations of 'Guardi' would produce above 4 Mg/ha/year dry dendromass, if cultivated on light arable Fluvisols.

**Key words:** dendromass production, Nelder wheel design, plantation density, *Populus × euramericana* 'Agathe F', *P. × euramericana* 'Guardi', short-rotation crops.

### Introduction

Poplars (*Populus* spp.) are recognized as the fastest-growing forest tree species at

temperate continental climate. They possess many other valuable characteristics, such as ease of propagation, aptitude to hybridize, pleasing appearance and

many uses (Isebrands and Richardson 2014) and, together with eucalypts (*Eucalyptus* spp.) and black locust (*Robinia pseudoacacia* L.), are among the most widely planted hardwood trees in the world (DeGomez and Wagner 2001). The 'eucalypts of the temperate geographic belt', have attracted the attention of Bulgarian foresters, primarily in pursue of intensified timber production and numerous studies have been conducted to fulfill the needs for modern poplar silviculture in Bulgaria (Kolarov 1974; Marinov et al. 1982; Krastanov et al. 1984, 1986, 1987a, 1987b).

Poplars are among the most appropriate species for use in short-rotation (energy) crops for biomass production due to their fast growth and ability to sprout. Traditional poplar clones selected for productivity and stress resistance have been used in preliminary experiments in Italy to evaluate their potential in short-rotation forestry; however, according to Paris et al. (2011) the results were not encouraging, mainly because these genotypes were not specifically selected for short-rotation plantations. On the other hand, Sixto et al. (2013) tested different interspecific poplar hybrids for their performance in short-rotation crops and concluded that clones showing intermediate reactivity to the test environments may be of interest for use in a large target population of environments, or in areas where environmental conditions are very heterogeneous, provided the mean performance is above average. The study findings showed that such intermediate clones were the black poplar hybrids 'I-214' and 'Guardi': the first is widely used in industrial plantations and the second is becoming more popular. Although traditional poplar clones have not been specifically selected for use in short-rotation crops, the advantages of

their application in such plantings are that they have already been tested in various environments and their mass propagation is inexpensive. The black poplar hybrids *Populus* × *euramericana* (Dode) Guinier were first introduced to Bulgaria in the 1950s (Naydenov and Stoyanov 2017) and at the end of the last century a dozen clones of this group have already been successfully approbated for broad use in the afforestation practice (Tsanov and Mikov 1997). 'Agathe F' is a female clone imported from the Netherlands in 1974, characterized by a straight stem and better growth than 'I-214' and in 1997 accounted for around 6 % of the poplar plantations (Tsanov and Mikov 1997; Naydenov and Stoyanov 2017). The female clone 'Guardi' was selected in Italy, but imported from Romania in 1979. It was characterized by ecological plasticity in terms of drought, salted or excessively moist soils, and by multipurpose timber (Naydenov and Stoyanov 2017).

It has been suggested that research on Short Rotation Forestry should focus on genetic improvement, plantation design, rotation length and tending operations (Cañellas et al. 2012). Ceulemans and Deraedt (1999) reported that optimum rotation time and plantation density for poplar energy plantations are generally 4 years and 2500 to 10,000 plants per hectare, respectively. An experimental plantation was established in the spring of 2013 in South-Western Bulgaria using the Nelder wheel design with the *Populus* × *euramericana* clones 'Agathe F' and 'Guardi' and 11 nearly-square spacings (initial densities from 870 to 10,000 plants per hectare). The experiment was designed to study the effect of genotype, spacing and rotation length on the biomass production. The main objectives of this study were: 1) to investigate the in-

fluence of genotype and spacing on the woody biomass yielded per plant (at the end of the 2nd, 4th and 5th year from plantation establishment, respectively); 2) to examine the effect of root age on the amount of dendromass yield from 1-year-old shoots at 2- and 5-year-stump age; 3) to compare the woody biomass yields, obtained by 1- and 2-cut harvesting cycles; 4) to study the effect of spacing, genotype and age on the number of shoots per stump.

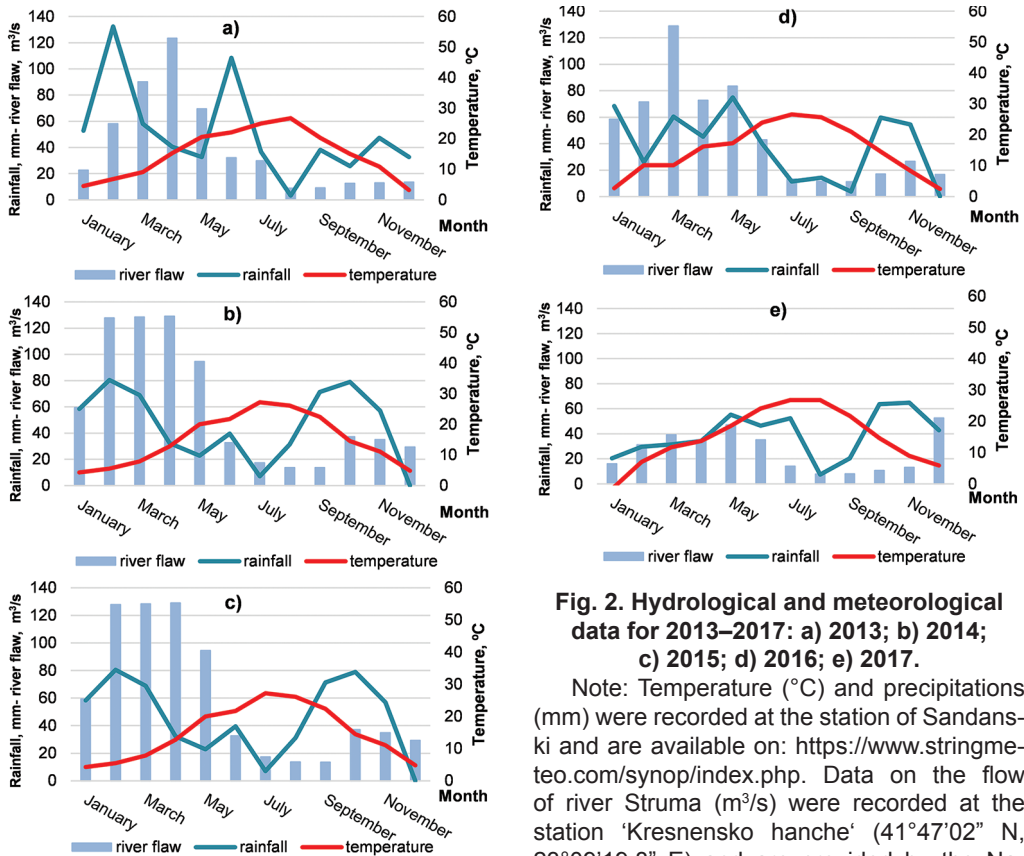
## Materials and Methods

*Populus × euramericana* 'Agathe F' is characterized with high ecological plasticity and long growth period, while fast initial growth and tolerance to adverse environments is specific to *P. × euramericana* 'Guardi' (Tsanov and Mikov 1997). Therefore, we chose to examine the potential of these clones for short-term biomass production under Mediterranean climate in South-western Bulgaria. Experimental plantation with the two *Populus × euramericana* (Dode) Guinier clones 'Agathe F' and 'Guardi' was established in March 2013 on the territory of Mikrevo nursery of Strumyani Forestry Estate in South-western Bulgaria (Fig. 1). The nursery is situated at altitude 138 m a.s.l in the valley of river Struma. The climate is transitional Mediterranean, with hot summer of maximum average monthly temperatures exceeding 25°C and mild, warm winter of minimum average monthly temperatures usually above 0 °C (Fig. 2). The annual amount of precipitations, registered in the last 5 years, ranged from 460 mm (in 2016) to above 700 mm (in 2014). The soil is arable Fluvisol, of low bulk density and slight alkalinity, characterized by good water permeability. The Nelder wheel experimental design (Nelder

1962, Namkoong 1965) was adopted for the trial plantation, with 11 nearly-square spacings, ranging from 1.0 to 11.5 m<sup>2</sup>, and corresponding to initial densities of 10,000 to 870 plants/ha. The two clones were arranged in alternating spokes and the planting densities varied along the spokes (Fig. 1, Table 1). Plantation was established on prepared nursery land using standard lignified cuttings (18–20 cm). Irrigations (10 L per plant) were carried out weekly 8 times during the first growth period and nitrogen fertilizer (20 g NH<sub>4</sub>NO<sub>3</sub> per plant) was applied once. More than 95 % rooting was achieved and the empty spots were replanted in the autumn of 2013 with standard 1-year-old ramets from the same clones. Infestation of the wood-boring insect *Paranthrene tabaniformis* Rot. was detected during the first (2013) and the second (2014) growth periods, causing harms to around 1/3 of the plants each time. This was one of the reasons to coppice the entire plantation in the winter of 2013–2014 and again in the winter of 2014–2015. Severe root damage of the poplar plants, caused by the beetle *Capnodis tenebrionis* L., was found in the summer of 2017 and the test plantation was cut and uprooted at the beginning of 2018.

Data collection took place in the winters of 2014–2015 and 2016–2017, and in the autumn of 2017. The trees of six spokes (3 spokes per clone) were harvested after the second growth period (2014) and provided dendromass data from coppiced plants of 2-year-old roots and 1-year-old shoots (Fig. 1). The same spokes were sampled again after the 4th (2016) and after the 5th (2017) growth periods, which assured leafless biomass data from coppiced plants of 4-year-old roots, 2-year-old shoots and from plants of 5-year-old roots, 1-year-old shoots (Fig. 1).





**Fig. 2. Hydrological and meteorological data for 2013–2017: a) 2013; b) 2014; c) 2015; d) 2016; e) 2017.**

Note: Temperature (°C) and precipitations (mm) were recorded at the station of Sandanski and are available on: <https://www.stringmeteo.com/synop/index.php>. Data on the flow of river Struma (m³/s) were recorded at the station 'Kresnensko hance' (41°47'02" N, 23°09'19.8" E) and are provided by the National Institute of Meteorology and Hydrology of Bulgaria.

The dendromass, harvested from each plant in the initially selected in 2014 spokes (Fig. 1), was additionally summed to estimate the total yield of woody biomass per plant as a result of one-, two- or three-coppicing cycles, referred hereafter as 'harvesting cycles'. These harvesting cycles were carried out within periods of variable duration (1-, 3- and 4-years), referred hereafter as 'production periods' (Table 1). To achieve the first research objective, we investigated the effect of clone and spacing on the accumulated per plant woody biomass production at the end of the 2nd, 4th and 5th year (harvesting cy-

cles R2S1; R2S1, R4S2 and R2S1, R4S2, R5S1, respectively, as denoted in Table 1). The influence of root age along with spacing (second research objective) was studied by clone for the dendromass yield from 1-year-old shoots (harvesting cycles R2S1 and R5S1 in Table 1). The effect of harvesting cycle, expressed by the number of cuts within certain production period, together with the impact of spacing on the woody biomass production of the examined poplar clones, was explored for 1- and 2-cut cycles (harvesting cycles R5S3 and R4S2, R5S1, respectively, as denoted in Table 1) (third research objective).



The number of shoots, as affected by spacing and clone, was examined at each root age – shoot age combination (R2S1, R5S1, R5S3 and R4S2 in Table 1) and the shoot counts of the different root age – shoot age combinations (R2S1, R5S1 and R4S2 in Table 1) were compared by clone (fourth research objective). To assist the interpretations and the comparisons with other studies, the total dendromass yield per hectare (Mg/ha) was calculated for each level of spacing by multiply-

ing the dendromass, harvested per plant, with the product  $\frac{10000}{Spacing} \frac{1}{1000}$ , where 1/1000 converts kg into Mg and 10,000/Spacing estimates the number of plants per hectare (10,000 m<sup>2</sup>), assuming square growing space of 'Spacing' m<sup>2</sup> per plant (Table 1). Thereafter, the annual biomass increment (Mg/ha/year) was determined by division of the total dendromass yield per hectare to the years of shoot growth.

**Table 1. Description of the analyzed data.**

| Clone      | Production period, years | Harvesting cycle* | Number of trees | ***Spacing, m <sup>2</sup>                                        | Dry woody biomass per plant, kg mean (min–max) | Shoot number mean (min–max) |
|------------|--------------------------|-------------------|-----------------|-------------------------------------------------------------------|------------------------------------------------|-----------------------------|
| 'Agathe F' | 1 year                   | R2S1              | 33              | 1.00, 1.28, 1.63, 2.08, 2.66, 3.40, 4.34, 5.54, 7.07, 9.03, 11.53 | 0.705 (0.119–1.561)                            | 5 (2–6)                     |
|            |                          | R5S1              | 33              |                                                                   | 0.330 (0.008–0.877)                            | 21 (2–43)                   |
|            | 3 years                  | R2S1, R4S2**      | 33              |                                                                   | 4.110 (0.579–10.045)                           | 14 (1–30)                   |
|            |                          | R4S2, R5S1        | 33              |                                                                   | 4.736 (0.159–9.386)                            |                             |
|            |                          | R5S3              | 44              |                                                                   | 4.623 (0.808–11.267)                           | 17 (5–46)                   |
|            | 4 years                  | R2S1, R4S2, R5S1  | 33              |                                                                   | 4.441 (0.593–10.756)                           |                             |
| 'Guardi'   | 1 year                   | R2S1              | 33              | 1.00, 1.28, 1.63, 2.08, 2.66, 3.40, 4.34, 5.54, 7.07, 9.03, 11.53 | 0.727 (0.021–1.951)                            | 5 (3–8)                     |
|            |                          | R5S1              | 33              |                                                                   | 0.824 (0.061–7.968)                            | 26 (8–57)                   |
|            | 3 years                  | R2S1, R4S2**      | 33              |                                                                   | 5.124 (1.272–14.439)                           | 14 (4–31)                   |
|            |                          | R4S2, R5S1        | 33              |                                                                   | 5.221 (1.357–22.179)                           |                             |
|            |                          | R5S3              | 44              |                                                                   | 5.674 (0.205–25.993)                           | 17 (2–30)                   |
|            | 4 years                  | R2S1, R4S2, R5S1  | 33              |                                                                   | 5.947 (1.607–22.407)                           |                             |

Note: \* – the harvesting cycle is coded as a sequence of Root age (Rx) Shoot age (Sy) – (RxSy) combinations, with the total shoot age equal to the duration of the production period; \*\* – the stem number corresponds to R4S2 Root age – Shoot age combination; \*\*\* – the spacing variants are presented in all Clone-Harvesting cycle combinations (column 1 × column 3).

Growing space that varied from 1.0 to 11.5 m<sup>2</sup> was regarded as a continuous variable and was treated as a covariate to each of the factors 'clone', 'root age', 'harvesting cycle' and 'root age – shoot age combination', analysed separately by study objective. The graphical examination of the data (see figs 3–6) showed that

the data points were not evenly distributed on both sides of the visualized main relationships, but their variance increased with the increase in spacing. Since this observation diagnoses heteroscedasticity of errors (Picard et al. 2012), rank transformed non-parametric Analysis of covariance method (Olejnik and Algina 1983)

was applied to fulfil the study objectives while assuring unbiased and efficient statistical inferences. Following the standard ANCOVA procedure, we first examined the full model, including the factor, the covariate and their interaction. Significant factor  $\times$  covariate interaction indicates that the factor effect is dependent upon the value of the covariate and it is impossible to claim significance or non-significance of the factor throughout the range of the covariate under consideration. When there was no statistically significant factor  $\times$  covariate interaction, the significance of the factor effect throughout the range of the covariate was tested.

## Results

Tracking the monthly amounts of rainfall in the area during the growth period from April to October showed irregular distribution of precipitations, with well-expressed summer minimum, which correlates with

the annual minimum of Struma river flow, while coinciding with the maximum of the average monthly temperatures (Fig. 2). This observation suggests limited water availability to plants during the period of active development, which acts as a growth-impeding factor. Therefore, our results present the growth and productivity of the studied poplar hybrids under moderate drought (Fig. 2).

The results on the influence of clone and growing space on the woody biomass yield from the selected poplar genotypes at 1-, 3- and 4-year-production periods did not reveal clone  $\times$  spacing interaction. Growing space influenced significantly the amount of harvested biomass per plant, which increased with the decrease of density (Table 2, Fig. 3). Comparable dendromass amounts were recorded for the two clones at 1 and 3 years duration of growth, and marginally significant genotype effect was found at the 4-year-production period, when the plants of 'Guardi' attained higher biomass yields (Table 2, Fig. 3).

**Table 2. Results of ANCOVA, testing the effect of clone and growing space on the total harvested dendromass by harvesting cycle.**

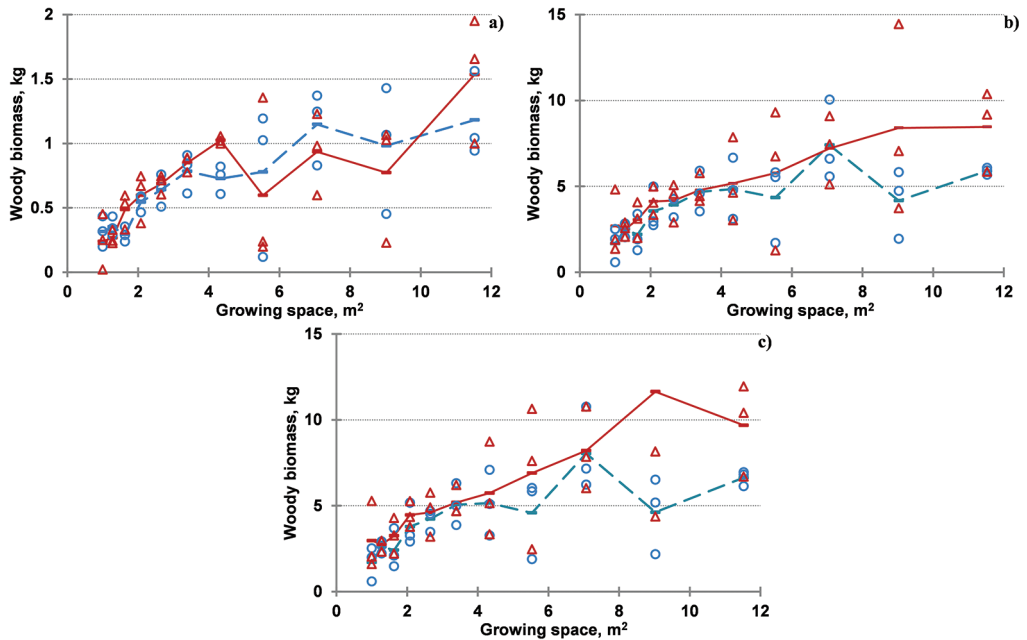
| Harvesting Cycle* | Factors and co-variables     | DF | SS       | MS       | F-value | P-value                 |
|-------------------|------------------------------|----|----------|----------|---------|-------------------------|
| 'R2S1'            | Clone                        | 1  | 40.1455  | 40.1455  | 0.210   | 0.649                   |
|                   | Clone $\times$ Growing space | 1  | 48.5470  | 48.5470  | 0.254   | 0.616                   |
|                   | Growing space                | 1  | 12,040.5 | 12,040.5 | 62.93   | $5.180 \times 10^{-11}$ |
|                   | Residuals                    | 62 | 11,863.3 | 191.343  |         |                         |
| 'R2S1, R4S2'      | Clone                        | 1  | 0.13636  | 0.13636  | 0.001   | 0.979                   |
|                   | Growing space                | 1  | 12,040.5 | 12,040.5 | 63.68   | $3.867 \times 10^{-11}$ |
|                   | Residuals                    | 63 | 11,911.8 | 189.076  |         |                         |
|                   | Clone                        | 1  | 40.4369  | 40.4369  | 0.214   | 0.645                   |
| 'R2S1, R4S2'      | Clone $\times$ Growing space | 1  | 20.7409  | 20.7409  | 0.110   | 0.741                   |
|                   | Growing space                | 1  | 11,735.0 | 11,735.0 | 62.18   | $6.250 \times 10^{-11}$ |
|                   | Residuals                    | 62 | 11,700.4 | 188.716  |         |                         |
|                   | Clone                        | 1  | 496.379  | 496.379  | 2.668   | 0.107                   |
| 'R2S1, R4S2'      | Growing space                | 1  | 11,735.0 | 11,735.0 | 63.07   | $4.508 \times 10^{-11}$ |
|                   | Residuals                    | 63 | 11,721.1 | 186.050  |         |                         |

| Harvesting Cycle*  | Factors and co-variates | DF | SS       | MS       | F-value | P-value                 |
|--------------------|-------------------------|----|----------|----------|---------|-------------------------|
| 'R2S1, R4S2, R5S1' | Clone                   | 1  | 66.0427  | 66.0427  | 0.381   | 0.539                   |
|                    | Clone×Growing space     | 1  | 21.4561  | 21.4561  | 0.124   | 0.726                   |
|                    | Growing space           | 1  | 12,488.9 | 12,488.9 | 72.00   | $5.721 \times 10^{-12}$ |
|                    | Residuals               | 62 | 10,754.8 | 173.464  |         |                         |
|                    | Clone                   | 1  | 687.409  | 687.409  | 4.019   | 0.049                   |
|                    | Growing space           | 1  | 12,488.9 | 12,488.9 | 73.01   | $3.995 \times 10^{-12}$ |
|                    | Residuals               | 63 | 10,776.2 | 171.051  |         |                         |

Note: *DF* – degrees of freedom, *SS* – sum of squares, *MS* – mean square, \* – the harvesting cycle is coded as a sequence of Root age (Rx) Shoot age (Sy) – (RxSy) combinations, with the total shoot age equal to the duration of the production period

Growing space affected substantially the dendromass, yielded from 1-year-old shoots of both clones, but root age (2

vs. 5 years) exerted significant influence only on the growth of 'Agathe F' plants (Table 3, figs 4a and 4b). While the mean



**Fig. 3. Trends of cumulated woody biomass with growing space for different production periods. a) 1-year production period, harvesting cycle R2S1; b) 3- year production period, harvesting cycle R2S1, R4S2; c) 4-year production period, harvesting cycle R2S1, R4S2, R5S1.**

Note: Circles and dashed line indicate the biomass values and their average, respectively, for clone 'Agathe F', while triangles and solid line – for clone 'Guardi'. The harvesting cycle is coded as a sequence of Root age (Rx) Shoot age (Sy) – (RxSy) combinations, with the total shoot age equal to the duration of the production period.

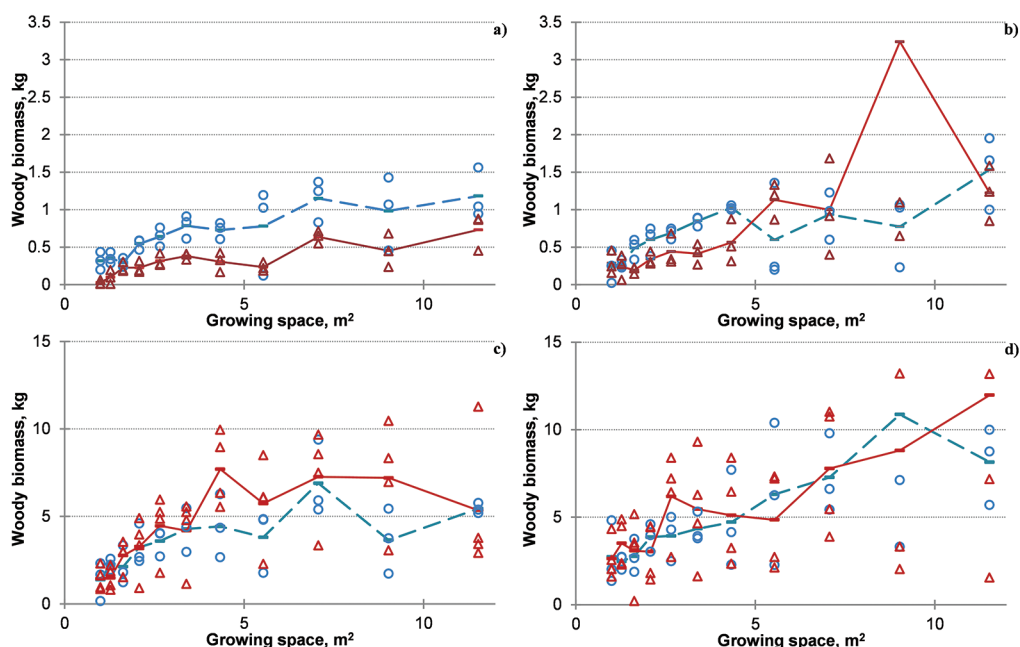
shoot weight amounted to around 2 kg dry mass for 'Guardi' at both root ages and 'Agathe F' at root age 2 years, the mean

plant mass across the densities did not exceed 1 kg for 'Agathe F' at root age 5 years.

**Table 3. Results of ANCOVA, testing the effect of harvesting cycle and growing space on the total harvested dendromass by clones.**

| Clone                                              | Factors and covariates | DF | SS        | MS       | F-value | P-value                 |
|----------------------------------------------------|------------------------|----|-----------|----------|---------|-------------------------|
| 1-year production period ('R2S1' vs. 'R5S1')       |                        |    |           |          |         |                         |
| 'Agathe F'                                         | HC                     | 1  | 1686.70   | 1686.70  | 14.21   | $3.675 \times 10^{-4}$  |
|                                                    | HC×Growing space       | 1  | 7.63788   | 7.63788  | 0.064   | 0.801                   |
|                                                    | Growing space          | 1  | 9721.35   | 9721.35  | 81.88   | $6.129 \times 10^{-13}$ |
|                                                    | Residuals              | 62 | 7360.95   | 118.725  |         |                         |
|                                                    | HC                     | 1  | 6862.56   | 6862.56  | 58.67   | $1.405 \times 10^{-10}$ |
|                                                    | Growing space          | 1  | 9721.35   | 9721.35  | 83.12   | $4.068 \times 10^{-13}$ |
| 'Guardi'                                           | Residuals              | 63 | 7368.59   | 116.962  |         |                         |
|                                                    | HC                     | 1  | 690.922   | 690.922  | 3.796   | 0.056                   |
|                                                    | HC×Growing space       | 1  | 371.250   | 371.250  | 2.040   | 0.158                   |
|                                                    | Growing space          | 1  | 11,904.3  | 11,904.3 | 65.41   | $2.79 \times 10^{-11}$  |
|                                                    | Residuals              | 62 | 11,284.3  | 182.004  |         |                         |
|                                                    | HC                     | 1  | 392.742   | 392.742  | 2.123   | 0.150                   |
| 'Agathe F'                                         | Growing space          | 1  | 11,904.3  | 11,904.3 | 64.34   | $3.272 \times 10^{-11}$ |
|                                                    | Residuals              | 63 | 11,655.5  | 185.008  |         |                         |
| 3-year production period ('R2S1, R4S2' vs. 'R5S3') |                        |    |           |          |         |                         |
| 'Agathe F'                                         | HC                     | 1  | 5.85847   | 5.85847  | 0.020   | 0.888                   |
|                                                    | HC×Growing space       | 1  | 228.486   | 228.486  | 0.779   | 0.380                   |
|                                                    | Growing space          | 1  | 14,980.0  | 14,980.0 | 51.05   | $5.608 \times 10^{-10}$ |
|                                                    | Residuals              | 73 | 21,421.34 | 293.443  |         |                         |
|                                                    | HC                     | 1  | 551.727   | 551.727  | 1.886   | 0.174                   |
|                                                    | Growing space          | 1  | 15,836.4  | 15,836.4 | 54.13   | $2.109 \times 10^{-10}$ |
| 'Guardi'                                           | Residuals              | 74 | 21,649.8  | 292.565  |         |                         |
|                                                    | HC                     | 1  | 297.554   | 297.554  | 0.810   | 0.371                   |
|                                                    | HC×Growing space       | 1  | 329.926   | 329.926  | 0.899   | 0.346                   |
|                                                    | Growing space          | 1  | 11,220.0  | 11,220.0 | 30.56   | $4.762 \times 10^{-7}$  |
|                                                    | Residuals              | 73 | 26,802.17 | 367.153  |         |                         |
|                                                    | HC                     | 1  | 6.41667   | 6.41667  | 0.018   | 0.895                   |
| 'Guardi'                                           | Growing space          | 1  | 10,899.5  | 10,899.5 | 29.73   | $6.274 \times 10^{-7}$  |
|                                                    | Residuals              | 74 | 27,132.1  | 366.650  |         |                         |

Note: *DF* – degrees of freedom, *SS* – sum of squares, *MS* – mean square, *HC* – harvesting cycle; \* – the harvesting cycle is coded as a sequence of Root age (Rx) Shoot age (Sy) – (RxSy) combinations, with the total shoot age equal to the duration of the production period.



**Fig. 4. Trends of cumulated woody biomass with growing space compared for different root ages or harvesting cycles.**

Note: a) Harvesting cycle R2S1 (circles and dashed line) vs. R5S1 (triangles and solid line) for clone 'Agathe F'; b) Harvesting cycle R2S1 (circles and dashed line) vs. R5S1 (triangles and solid line) for clone 'Guardi'; c) Harvesting cycle R4S2, R5S1 (circles and dashed line) vs. R5S3 (triangles and solid line) for clone 'Agathe F'; d) Harvesting cycle R4S2, R5S1 (circles and dashed line) vs. R5S3 (triangles and solid line) for clone 'Guardi'. The markers indicate the individual plant values, while the line – their average. The harvesting cycle is coded as a sequence of Root age (Rx) Shoot age (Sy) – (RxSy) combinations, with the total shoot age equal to the duration of the production period.

Significant spacing effect was also proven when 1- and 2-cut harvesting cycles were compared at 3-year production period (Table 3), showing dendromass increase with growing space (figs 4c and 4d). However, no significant effect of the harvesting cycle was distinguished, the accumulated amounts of 1- and 2-year-old shoots yielding similar quantities to those from 3-year-old poplar sprouts for both clones.

Increasing with growing space number of shoots was found at all investigated root age – shoot age combinations, but

the compared poplar hybrids did not differ significantly in the number of sprouts produced (Table 4, Fig. 5). Shoot number increased with stump age, leading to manifestation of substantial differences regarding this parameter for both clones (Table 1, Fig. 6).

The statistically significant age x growing space interaction (Table 5) was related to the highest planting densities where no significantly different shoot number according to stump age was distinguished (at 1 m<sup>2</sup> for 'Agathe F') or only the youngest (R2S1) and the oldest (R5S1) plants

had significantly different number of sprouts (at 1.28 m<sup>2</sup> for 'Agathe F' and at 1 m<sup>2</sup> for 'Guardi'). The number of shoots differed significantly according to stump

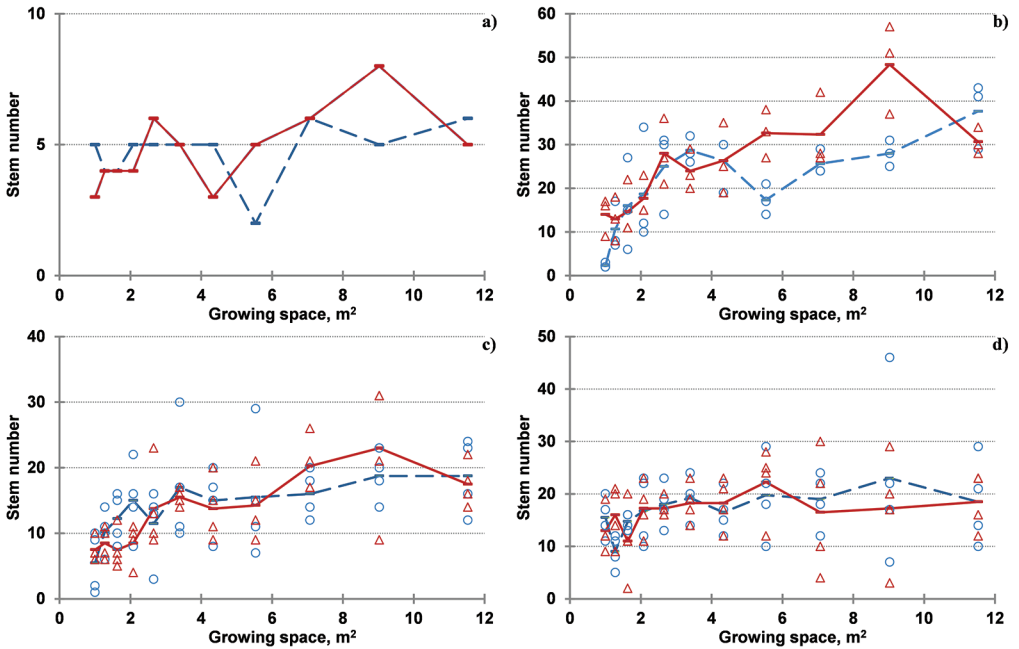
age at the wider spacings for both clones (Fig. 6). No decrease in the sprouting ability was distinguished for both clones after 3 successive coppicings.

**Table 4. Results of ANCOVA, testing the effect of clone and growing space on the number of shoots by root age – shoot age combinations.**

| Root age + shoot age | Factors and co-variables | DF | SS       | MS       | F-value | P-value                 |
|----------------------|--------------------------|----|----------|----------|---------|-------------------------|
| 'R2S1'               | Clone                    | 1  | 3.64269  | 3.64269  | 0.144   | 0.709                   |
|                      | Clone×Growing space      | 1  | 20.4045  | 20.4045  | 0.808   | 0.381                   |
|                      | Growing space            | 1  | 390.223  | 390.223  | 15.44   | 0.001                   |
|                      | Residuals                | 18 | 454.827  | 25.2682  |         |                         |
|                      | Clone                    | 1  | 20.0455  | 20.0455  | 0.801   | 0.382                   |
|                      | Growing space            | 1  | 390.223  | 390.223  | 15.60   | 0.001                   |
|                      | Residuals                | 19 | 475.232  | 25.0122  |         |                         |
| 'R4S2'               | Clone                    | 1  | 598.470  | 598.470  | 1.599   | 0.210                   |
|                      | Clone×Growing space      | 1  | 520.828  | 520.828  | 1.391   | 0.242                   |
|                      | Growing space            | 1  | 24,729.8 | 24,729.8 | 66.06   | 3.369×10 <sup>-12</sup> |
|                      | Residuals                | 84 | 31,447.3 | 374.373  |         |                         |
|                      | Clone                    | 1  | 84.0455  | 84.0455  | 0.223   | 0.638                   |
|                      | Growing space            | 1  | 24,729.8 | 24,729.8 | 65.75   | 3.418×10 <sup>-12</sup> |
|                      | Residuals                | 85 | 31,968.2 | 376.096  |         |                         |
| 'R5S1'               | Clone                    | 1  | 12.4175  | 12.4175  | 0.074   | 0.786                   |
|                      | Clone×Growing space      | 1  | 64.2970  | 64.2970  | 0.385   | 0.537                   |
|                      | Growing space            | 1  | 13,007.4 | 13,007.4 | 77.83   | 1.502×10 <sup>-12</sup> |
|                      | Residuals                | 62 | 10,362.2 | 167.133  |         |                         |
|                      | Clone                    | 1  | 518.561  | 518.561  | 3.133   | 0.082                   |
|                      | Growing space            | 1  | 13,007.4 | 13,007.4 | 78.59   | 1.108×10 <sup>-12</sup> |
|                      | Residuals                | 63 | 10,426.5 | 165.500  |         |                         |
| 'R5S3'               | Clone                    | 1  | 79.1527  | 79.1527  | 0.133   | 0.716                   |
|                      | Clone×Growing space      | 1  | 8.21023  | 8.21023  | 0.014   | 0.907                   |
|                      | Growing space            | 1  | 6616.56  | 6616.56  | 11.12   | 0.001                   |
|                      | Residuals                | 84 | 49971.1  | 594.893  |         |                         |
|                      | Clone                    | 1  | 186.182  | 186.182  | 0.317   | 0.575                   |
|                      | Growing space            | 1  | 6616.56  | 6616.56  | 11.25   | 0.001                   |
|                      | Residuals                | 85 | 49,979.3 | 587.991  |         |                         |

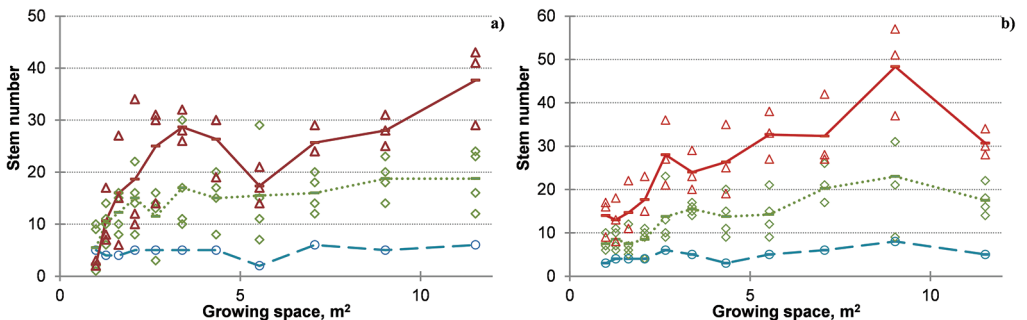
Note: *DF* – degrees of freedom, *SS* – sum of squares, *MS* – mean square; \* – plant age is abbreviated as the sequence of Root age (Rx) Shoot age (Sy) – (RxSy).





**Fig. 5. Trends in number of stems with growing space by root age-shoot age combinations.**

Note: a) R2S1; b) R5S1; c) R4S2; d) R5S3. Circles and dashed line indicate number of shoots and their average, respectively, for clone 'Agathe F', while triangles and solid line – for clone 'Guardi'. Plant age is abbreviated as the sequence of Root age (Rx) Shoot age (Sy) – (RxSy).



**Fig. 6. Trends in number of stems with growing space by clones.**

Note: a) clone 'Agathe F'; b) clone 'Guardi'. Circles and dashed line indicate stem number and their average, respectively, for plant age (R2S1). Diamonds and dotted line indicate number of shoots and their average, respectively, for plant age (R4S2), while triangles and solid line – for plant age (R5S1). Plant age is abbreviated as the sequence of Root age (Rx) Shoot age (Sy) – (RxSy).

**Table 5. Results of ANCOVA, testing the effect of root age - shoot age and growing space on the number of shoots by clones.**

| Clone      | Factors and co-<br>variates | DF | SS       | MS      | F-value | P-value                 |
|------------|-----------------------------|----|----------|---------|---------|-------------------------|
| 'Agathe F' | Age                         | 2  | 446.148  | 223.074 | 0.866   | 0.424                   |
|            | Age×Growing<br>space        | 2  | 2673.93  | 1336.96 | 5.192   | 0.008                   |
|            | Growing space               | 1  | 6874.93  | 6874.93 | 26.70   | $1.642 \times 10^{-6}$  |
|            | Residuals                   | 82 | 21,116.8 | 257.522 |         |                         |
| 'Guardi'   | Age                         | 2  | 3543.97  | 1771.98 | 12.77   | $1.489 \times 10^{-5}$  |
|            | Age×Growing<br>space        | 2  | 1042.02  | 521.010 | 3.754   | 0.028                   |
|            | Growing space               | 1  | 7082.76  | 7082.76 | 51.03   | $3.374 \times 10^{-10}$ |
|            | Residuals                   | 82 | 11,381.1 | 138.794 |         |                         |

Note: *DF* – degrees of freedom, *SS* – sum of squares, *MS* – mean square, Age – Root age – Shoot age combination, abbreviated as the sequence of Root age (Rx) Shoot age (Sy) – (RxSy) with the levels R2S1, R5S1 and R4S2.

## Discussion

*Populus × euramericana* 'Agathe F' is a black poplar hybrid, which has been described as a very perspective cultivar for wood production, having high ecological plasticity and long growth period (Tsanov and Mikov 1997). The potential of *Populus × euramericana* 'Guardi' for cultivation in short-rotation plantations has been recognized due to its fast initial growth. It has been described as a cultivar of the future, because of its ability to succeed in relatively adverse growth conditions (Tsanov and Mikov 1997). Although the ecological and biological characteristics of both clones suggest that they would fit well the transitional Mediterranean climate of the South-western Bulgaria plains, the plants of clone 'Guardi' appeared more suitable for the particular growth environment. While the trees of 'Agathe F' showed well distinguished growth decline in 2017, steady growth and increased dendromass yield was recorded for the plants of 'Guardi' (figs 3c, 4a, and 4b).

Brief examination of the meteorological and hydrological data for the period 2013–2017 (Fig. 2) showed worsening of the water availability to plants in 2017 that could have caused growth diminishing in 'Agathe F' plants resulting in significantly different biomass production between the clones at the end of the 4-year production period (Table 2, Fig. 3c). This outcome confirmed also that clone 'Guardi' resisted better the worsen growth conditions and its coppiced plants produced average annual yield of 4.0 Mg/ha/year dry mass in the last 4 years. Paris et al. (2018), who studied the biomass production of poplar short rotation crops with clone 'Monviso', established under Mediterranean climate and irrigated during the summer season, admitted that it was lower than the production from the same clone, but grown under non-irrigated, fertile alluvial soils of northern, continental Italy. The authors reported that the biomass yield varied according to the applied water amount from 4.1 to 5.3 Mg/ha/year for the poplar plants of 5-year-old roots and 2-year-old shoots,

while it ranged from 3.8 to 6.8 Mg/ha/year for poplars of 6-year-old roots and 3-year-old shoots. They also derived the conclusion that solutions to improve the yield such as, choosing alternative species or clone and scheduling irrigation more efficiently, must be searched since biomass yield of 10 Mg/ha/year represents the break-even point to get financial profitability of poplar Short Rotation Crops in Italy. This advice should be considered also by the prospective biomass producers at the transitional Mediterranean conditions of South-western Bulgaria, since our estimated yields are comparable with the data of Paris et al. (2018), obtained for the control treatment of clone 'Monviso', irrigated with average amount of 115 mm during the summer. In addition, care should be taken to minimize the infestation by wood-boring insects, such as *Paranthrene tabaniformis* Rot. and *Saperda populnea* L., which destroy the invaded shoots, diminishing the usable amount of the biomass harvest and weakening the plants, making them susceptible to other pests. Furthermore, protection from *Capnodis tenebrionis* L., which is known to attack even healthy plants, must be ensured to avoid yield decrease and losing the entire plantation.

To explore the influence of root age on the biomass productivity of the selected poplar clones, we examined the dendromass yield from 1-year-old shoots at 2 and 5 years of stump age. Decreased with stump age dendromass production was found for the plants of 'Agathe F' in our study, but the growth of 'Guardi' remained stable after three successive coppicings (Table 3, figs 4a and 4b). From analysis of the environmental data, we found that in the 5th year from the establishment of the plantation (2017), the flow of river Struma, which is tightly connected with the under-

ground water level, dropped nearly twice below the values measured in the preceding years (average annual flow 25 m<sup>3</sup>/s vs 40–60 m<sup>3</sup>/s). At the same time, the annual rainfall amount was below 500 mm and the average monthly temperature in January dropped below zero, which is unusual for the transitional Mediterranean climate (Fig. 2). These observations indicate that in 2017 in our trial plantation the highly water-demanding poplar plants were exposed to abiotic stress, leading to declined vigor and weakened resistance to pests. Our conclusion agrees with the inference by Bergante and Facciotto (2011) that water, obtained from irrigation and from rainfall seems to be of crucial importance for biomass production from short-rotation crops, established with Salicaceae species. The outcome of the analysis suggested also higher vulnerability of clone 'Agathe F' in comparison with 'Guardi' at the particular site conditions as well as its susceptibility to the root destroying insect *C. tenebrionis*.

As it has been found in studies by other investigators (Laureysens et al. 2003, Paris et al. 2015), the number of shoots per plant increased significantly with stump age for both clones. In agreement with Laureysens et al. (2003), the increased number of shoots observed can be attributed to the bigger stump diameter at more advanced age. Unlike the study by Štochlová et al. (2019), our results did not reveal statistically significant difference in the number of shoots, produced by the two poplar clones. Parallel comparison of the findings on the shoot number and the biomass amounts for the 1-year-old shoots (figs 4a, 4b, 6a, and 6b, tables 3 and 5) suggested that the significantly increased number of the one-year-old sprouts at 5 years stump age, although positively related to plant biomass production (Stankova

et al. 2017), does not directly derive its increase. This result is in concordance with the observation by Oliveira et al. (2017) that there is greater uncertainty in the biomass estimation in the year following coppicing, because this growth stage is related to the shoot, rather than to the root age. In addition, the study by Paris et al. (2015) showed that coppicing significantly decreased shoot dimensions. Finally, the aforementioned plant weakening due to the worsened environmental conditions suggested and the experimental data provided in Stankova et al. (2017) confirmed that the increased number of 1-year-old shoots, recorded in 2017, was related to a decreased shoot size of the poplar plants, as compared to 2014.

Our results showed that the one cut of 3-year-old shoots and the two successive cuts of 2- and 1-year-old shoots yielded similar amounts of woody biomass for both clones (Table 3). This finding is particularly important, if we consider that for the same final yield, a greater number of cuts implies higher cost and more energy consumption. The average amount of dendromass cumulated per plant of 5-year-old roots within the last 3 years of growth was around 4.2 kg for the ramets of 'Agathe F' and 5.4 kg for the ramets of 'Guardi' (figs 4c and 4d). The outcome of the comparison between the harvesting cycles in our study agrees with the finding about different clones of poplar, willow and black locust in Central Germany, where the rotation period did not significantly affect tree biomass accumulation and two 3-year cycles produced the same amounts of dendromass as one 6-year harvesting cycle (Gruenewald et al. 2007). By contrast, Blake (1983) found that in *Populus trichocarpa*, a single harvest after 8 years was one third more productive than two rotations of 4 years. Similarly, Armstrong

et al. (1999) reported that a single harvest in a 4-year cutting cycle yielded more biomass than two harvests on a 2-year cycle in a study of biomass production in 3 poplar clones grown at 2 densities on 3 sites in the UK. Furthermore, the study by Nassi o di Nasso et al. (2010) with the clone 'Lux' of *Populus deltoides* Bartr. at temperate climate conditions derived the conclusion that the biomass production at 3-year cutting cycle is significantly higher than the dendromass harvested at 1- and 2-year periods of coppicing. The results from the present study disagree also with the finding by Stankova et al. (2019) about the open-pollinated families of two black locust clones, which showed that one-coppicing cycle resulted in a significantly higher yield than the combination of two or three coppicings within 2- or within 4-year production periods for both black locust families.

Studies investigating plant biomass or volume in relation to growing space have generally reported positive correlations between biomass/volume of individual plants and spacing (Jink and Mason 1998, Bernardo et al. 1998, Erkan and Aydin 2016). We found that spacing significantly affected tree dendromass in both clones and all harvesting cycles considered (tables 2 and 3). The individual plant biomass generally increased with spacing, but growth approached saturation at the lowest densities for the plants of clone 'Agathe F', showing that no advantage of wider growing area has been taken by trees at spacing above 7 m<sup>2</sup> (figs 3 and 4).

## Conclusions

The plants of clone 'Agathe F' revealed substantial growth decline in the 5th year of plantation establishment due to wors-

ened environmental conditions and biotic pests. Clone 'Guardi' proved its higher suitability for cultivation as a short rotation crop under Mediterranean climate, because of its steady growth even at worsen site conditions. Under unfavourable alterations in the water availability and without additional irrigation, coppiced plantations of 'Guardi' would produce above 4 Mg/ha/year dry dendromass, if cultivated on light arable Fluvisols. Growing space proved to be a major determinant of dendromass yield from juvenile coppiced plants of the investigated black poplar hybrids. The biomass yield of 'Guardi' increased steadily across the spacings from 1.0 to 11.5 m<sup>2</sup>, while that of 'Agathe F' showed tendency to saturation at spacing above 7 m<sup>2</sup>.

## Acknowledgements

This work was financially supported by the National Science Fund of Bulgaria (DN06/3, 2016, DFNI-E01/6, 2012). The data on the water flow of river Struma was provided by the National Institute of Meteorology and Hydrology of Bulgaria. We thank the forestry officers from Strumyani Forestry Estate for their cooperation and logistic support in carrying out the experimental work and data collection.

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## BIOMASS ESTIMATION AND ALLOMETRIC EQUATION FOR TREE SPECIES IN DRY FOREST OF EAST NUSA TENGGARA, INDONESIA

Aah Ahmad Almulqu<sup>1,2\*</sup>, Noulkamol Arpornpong<sup>3</sup>,  
and Jaruntorn Boonyanuphap<sup>3</sup>

<sup>1</sup>Graduate School of Naresuan University, University of Naresuan, Phitsanulok 65000, Thailand.

\*Email: ahmadalmulqu@yahoo.com

<sup>2</sup>Department of Forest Management, Kupang State Polytechnic for Agricultural, East Nusa Tenggara, Indonesia.

<sup>3</sup>Faculty of Agriculture, Natural Resources and Environment, Naresuan University, Phitsanulok, Thailand.

Received: 19 June 2019

Accepted: 26 September 2019

### Abstract

In this study, we developed allometric equations for approximating tree biomass components in dry forests in Kupang regency, Indonesia. Biomass allocation was examined and allometric equations were developed using tree height and DBH as variable for individual tree species with DBH<20 cm and DBH>20 cm, respectively. Allometric equations were elaborated for leaf, branch, stem, root biomass and overall tree biomass. Based on the results, leaf, branch, stem and root accounted for 7 %, 16 %, 66 % and 11 % of overall tree biomass. The values of leaf, branch, stem, root and total tree biomass (t) with DBH>20 cm was  $0.033\pm0.016$ ,  $0.067\pm0.034$ ,  $0.289\pm0.082$ ,  $0.049\pm0.023$  and  $0.441\pm0.156$ , respectively. It was also found that the tree biomass (t) with DBH<20 cm was  $0.039\pm0.014$ . All allometric equation models of tree biomass have a high quality-of-fit as shown by high constancy value ( $R^2$ ), which indicated significant linear relationships between biomass and the predictors (DBH and tree height).

**Key words:** constancy value, DBH, Kupang, predictor, tree height.

### Introduction

The importance of forests in carbon (C) cycling has gained increasing attention in recent years. With the current interest in greenhouse gas emissions, and their impact on global climate change, accurate, precise, and verifiable estimation of carbon stocks in forests have become insistently requirement (Lewis et al. 2013). Accurate estimation of tropical tree biomass is essential to determine geographic patterns in carbon stocks, the magnitudes

of fluxes due to land-use change, to quantify avoided carbon emissions (Basuki et al. 2009), and for appraising productivity and carbon sequestration (Ounban et al. 2016). Henry et al. (2010) informed that measurements to elaborate allometric equations could be done by both direct and indirect methods. An allometric equation is a statistical model linking tree biomass to a set of predictors such as tree diameter and/or height, forest type, or wood specific gravity (Chave et al. 2005) and morphological characters, i.e. bas-

al diameter (or area), canopy diameter, or canopy volume (Kuyah et al. 2016). These standards can be applied individually, or merged in one allometric model (Brown 2002). Forest inventory data can be converted into biomass estimates at tree-level by applying allometric equation, and the sum of all data for the trees allows a biomass estimate to be attained at plot level (Chave et al. 2004).

The use of indirect methods gives fast results, however negatively impact on the accuracy in estimating tree carbon (Gbemavo et al. 2014). It is a non-destructive method, based on indirect and randomized branch sampling of the plant parts for overall biomass determination (Gregoire et al. 1995). There are a lot of techniques used to approximate forest biomass at different spatial scales, but they all eventually depend on ground and destructive measurements of individual tree biomass to adjust to allometric equations (Gibbs et al. 2007). Through new allometric models, we are able to improve the preciseness of biomass assessment protocols (Chave et al. 2004). Species-specific allometric equations developed on site provides better biomass approximation than generalized equations (Pilli et al. 2006), because the use of generalized equations can lead to a bias in estimating biomass for a particular species (Cairns et al. 2003, Litton et al. 2006). Furthermore, the locations within a specific continent have been found to explain almost 50 % of variations in tree allometry (Banin et al. 2012). Moreover, recent approaches incorporating data on wood density hold more promise (Chave et al. 2005).

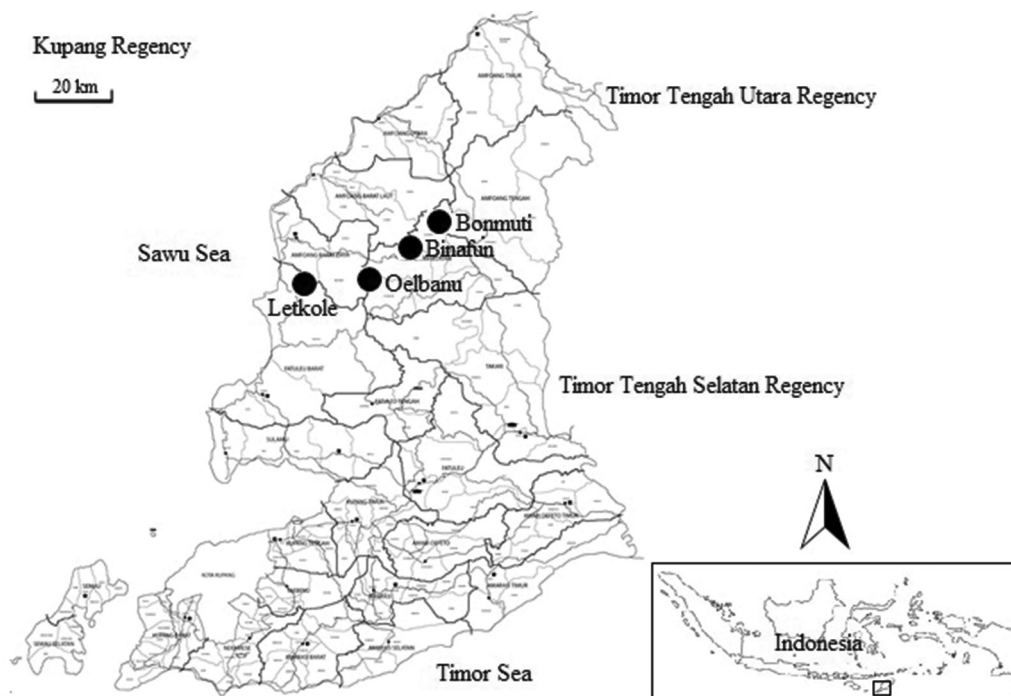
Allometric equations should be able to represent the diversity of biomass from various tree species (Henry et al. 2011). Destructive harvesting for developing allometric models has rarely been conduct-

ed in the tropics, while few studies which have developed the allometric models, have opted smaller size of sample plots than the scale of species variety patterns; therefore, the results may not be representative (Mc William et al. 1993). The species are grouped all together and use generalised allometric relationships for broad forest types or ecological zones (Brown 2002). Although Brown (1997) and Chave et al. (2005) have reported general allometric equations for tropical dry, moist- and rainforests, there is still scarcity of allometric equations, especially for tree species of tropical dry forest (but see: Chaturvedi et al. 2010, Chaturvedi et al. 2012, Chaturvedi and Raghubanshi 2013, Chaturvedi and Raghubanshi 2015), where habitat conditions are highly heterogeneous (Chaturvedi 2010). Moreover, according to Anitha et al. (2015), we did not find any biomass equations from Nusa Tenggara regions, particularly in East Nusa Tenggara, Indonesia. The objectives of this study were to: 1) develop allometric equations for approximating the biomass carbon stock of tree species in Kupang regency, East Nusa Tenggara, Indonesia; and 2) validate the newly developed equations for 20 sampled tree species.

## Materials and Methods

### Study area

This study covered the Mutis Timau Protected Forest Management Unit (Mutis Timau PFMU), which consists of three regencies: Kupang, Timor Tengah Selatan and Timor Tengah Utara (latitude 90°20'00" – 90°45'10" South and longitude 123°42'30" – 124°20'00" E) in Eastern Indonesia (Fig. 1). Data for this study



**Fig. 1.** Location of research sites at Mutis Timau PFMU, East Nusa Tenggara province, Indonesia.

were collected from 4 dry forest study sites named Binafun, Bonmuti, Letkole and Oelbanu, each study site contained two 10,000 m<sup>2</sup> sampling plots.

The research sites represent the dry forests of East Nusa Tenggara, Indonesia, and surrounding areas are the wettest areas on the island of Timor. Although the rain falls almost every month, the highest frequency of rainfall occurs during November to July. According to Fisher et al. (1999) the high-intensity rainfall (2000–3000 mm/year) at our study sites occurs during the rainy season with average temperatures ranging from 14 °C to 29 °C, and in extreme conditions can even decrease up to 9 °C. The high-speed winds occur in November until March. Around 71 % area are hilly (15–30 % slope) to mountainous (>30 % slope).

### Data analysis

The breast height diameter (DBH) of all trees in the sample plots was quantified. We divided sample trees into two groups: tree species with DBH < 20 cm and DBH > 20 cm, each group of 20 species. The height and DBH of trees was quantified after felling. The harvested trees were dissected to categorize them into their component parts (leaf, branch, stem, root). Subsamples of approximately 200–300 g were taken for dry-weight determination in the laboratory for every component. The samples were dried at 80 °C until constant weight was achieved to obtain dry weights to the nearest 0.1 g. For calculating water content (WC) from the field weighed disc weight (FW) and oven dried disc weight (DW), the equation

(1) was used:

$$WC = \frac{FW - DW}{FW} \quad (1)$$

For estimating total wood dry mass, the wet mass of leaf, branch, stem, root was multiplied by  $(1 - WC)$ . Because of the large variations in  $WC$  of branches for large trees,  $WC$  was estimated separately after the branches were partitioned in different size classes (Chaturvedi and Raghubanshi 2015).

All sample trees were measured and recorded for species, the activity was carried out on the height variable for tree sample with  $DBH < 20$  cm and  $DBH$  variable for tree sample with  $DBH > 20$  cm. Linear regressions were used to determine the allometric equation model of each tree components such as leaf biomass, branch biomass, stem biomass, root biomass, total biomass, leaf carbon, branch carbon, stem carbon, root carbon, total carbon. In the present study, we transformed the observed data using logarithmic transformation which is commonly used in dimension analysis studies to fit appropriate allometric equations (Sprugel 1983, Istrefi et al. 2019).

All allometric equations in this study were validated in term of  $RMSE$  (%), Akaike Information Criteria ( $AIC$ ) and determination value ( $R^2$ ) (Mayer and Butler 1993). All statistical analyses were done using Xlstat version 2014 (equation 2):

$$RMSE(\%) = 100 \sqrt{\frac{1}{n} \sum_{i=1}^n \left( \frac{y_i - \hat{y}_i}{y_i} \right)^2}, \quad (2)$$

where:  $n$  is trees number applied for model development, and  $y_i$  and  $\hat{y}_i$  are observed and predicted biomass.

Akaike Information Criteria ( $AIC$ ) (equation 3):

$$AIC = n \ln \left( \frac{SSE}{n} \right) + 2.p, \quad (3)$$

where:  $SSE$  is the sum of squares of the errors,  $n$  – sample size, and  $p$  – number of regression coefficients in the model being evaluated (including the intercept). The  $AIC$  value was minimized by the best validated model.

## Results and Discussion

The ranges of *diameter at breast height* ( $DBH$ ) and tree height ( $H$ ) for each tree sample species are shown in Table 1. The values of measured mean  $DBH$  reported in this study for *Terminalia mollis* M.A. Lawson at  $DBH > 20$  cm are lower compared to other tree samples and were higher for individuals with greater mean  $H$  ( $144.500 \text{ cm} \pm 55.905 \text{ cm}$ ) at  $DBH < 20$  cm. In the present study, *Pipturus argenteus* Wedd. was found *larger in size* with  $22.225 \text{ cm} \pm 7.539 \text{ cm}$  mean  $DBH$ , and was representing  $11.5\text{--}31.5 \text{ cm}$   $DBH$  ranges, while the highest  $H$  was represented as  $152.813 \pm 57.849 \text{ cm}$  across all tree samples.

In Table 2, specific results of tree component biomass are shown. The results showed that the mean biomass per components for trees with  $DBH < 20$  cm for leaf, branch, stem, root, total biomass was  $0.033 \text{ t}$ ,  $0.067 \text{ t}$ ,  $0.289 \text{ t}$ ,  $0.049 \text{ t}$ ,  $0.441 \text{ t}$  and  $0.039 \text{ t}$ , respectively. The mean biomass per tree species was highest for *Vitex parviflora* accounting  $0.082 \text{ t}$  and  $0.162 \text{ t}$  for both leaf and branch components. The highest biomass of stem and root was  $0.403 \text{ t}$  and  $0.089 \text{ t}$  for *Terminalia mollis* and *Garuga floribunda*, respectively. The mean total biomass of tree sample at  $DBH > 20$  cm ( $0.441 \text{ t}$ ) represented more than a ten time of tree sample at  $DBH < 20$  cm ( $0.039 \text{ t}$ ).

**Table 1. Character of biomass values in each sample tree species.**

| No | Species                                         | DBH > 20 cm |             |              |        | DBH < 20 cm |           |            |        |
|----|-------------------------------------------------|-------------|-------------|--------------|--------|-------------|-----------|------------|--------|
|    |                                                 | min DBH, cm | max DBH, cm | mean DBH, cm | SD DBH | min H, cm   | max H, cm | mean H, cm | SD H   |
| 1  | <i>Alstonia scholaris</i> (L.) R. Br.           | 10.21       | 29.55       | 19.714       | 6.669  | 95          | 195       | 150.625    | 34.15  |
| 2  | <i>Broussonetia papyrifera</i> (L.) Vent.       | 10.21       | 35          | 21.678       | 8.805  | 90          | 200       | 147.813    | 41.189 |
| 3  | <i>Euodia macrophylla</i> Blume                 | 10.21       | 30          | 20.926       | 6.536  | 90          | 200       | 145.625    | 35.538 |
| 4  | <i>Ficus glomerata</i> Roxb.                    | 10.21       | 32.5        | 22.064       | 7.599  | 75          | 200       | 141.5      | 44.706 |
| 5  | <i>Pipturus argenteus</i> G.Forst.              | 10.55       | 32.5        | 22.225       | 7.539  | 75          | 250       | 152.813    | 57.849 |
| 6  | <i>Oroxylum indicum</i> (L.) Kurz               | 10.22       | 30          | 21.201       | 7.038  | 70          | 210       | 136.563    | 56.737 |
| 7  | <i>Hibiscus tiliaceus</i> L.                    | 11.5        | 31.5        | 22.188       | 7.038  | 75          | 215       | 140.625    | 54.768 |
| 8  | <i>Macaranga tanarius</i> (L.) Mull. Arg, Di DC | 10.5        | 25          | 17.75        | 5.604  | 60          | 200       | 135        | 56.774 |
| 9  | <i>Eucalyptus urophylla</i> S.T. Blake          | 10.25       | 30          | 18.625       | 6.933  | 75          | 250       | 144.688    | 57.979 |
| 10 | <i>Nauclea orientalis</i> (L.) L.               | 11.5        | 30          | 19.313       | 6.511  | 70          | 220       | 139.75     | 60.263 |
| 11 | <i>Litsea diversifolia</i> Blume                | 12.5        | 30          | 20.844       | 6.853  | 75          | 215       | 139.75     | 56.824 |
| 12 | <i>Mangifera indica</i> L.                      | 10.5        | 30          | 20.844       | 7.786  | 78          | 240       | 144.25     | 55.979 |
| 13 | <i>Peltophorum inerma</i> Roxb.                 | 12.5        | 30          | 19.781       | 5.933  | 80          | 210       | 145.313    | 48.252 |
| 14 | <i>Homalium tomentosum</i> (Vent.) Benth        | 12          | 30          | 19.563       | 7.341  | 75          | 210       | 142.5      | 49.933 |
| 15 | <i>Bauhinia malabarica</i> Roxb.                | 10.5        | 30          | 18.644       | 7.349  | 90          | 210       | 146.875    | 46.039 |
| 16 | <i>Alstonia villosa</i> Blume.                  | 11          | 32          | 20.75        | 8.048  | 75          | 225       | 143.438    | 56.501 |
| 17 | <i>Tamarindus indica</i> L.                     | 11          | 30          | 19.844       | 7.002  | 80          | 250       | 146.25     | 56.994 |
| 18 | <i>Terminalia mollis</i> M.A. Lawson.           | 10          | 30          | 16.875       | 7.27   | 70          | 220       | 144.5      | 55.905 |
| 19 | <i>Garuga floribunda</i> Decne.                 | 10          | 34          | 20.438       | 8.647  | 70          | 210       | 145.625    | 55.644 |
| 20 | <i>Vitex parviflora</i> Juss.                   | 10.5        | 30          | 19.25        | 6.387  | 90          | 215       | 146.563    | 49.79  |

**Table 2. Biomass values for each sample tree species.**

| No | Species                                         | DBH > 20 cm |             |             |             | DBH < 20 cm, t |
|----|-------------------------------------------------|-------------|-------------|-------------|-------------|----------------|
|    |                                                 | Leaf, t     | Branch, t   | Stem, t     | Root, t     |                |
| 1  | <i>Alstonia scholaris</i> (L.) R. Br.           | 0.027±0.008 | 0.071±0.013 | 0.399±0.077 | 0.035±0.005 | 0.071±0.024    |
| 2  | <i>Broussonetia papyrifera</i> (L.) Vent.       | 0.024±0.008 | 0.064±0.015 | 0.364±0.074 | 0.031±0.006 | 0.061±0.002    |
| 3  | <i>Euodia macrophylla</i> Blume                 | 0.020±0.004 | 0.050±0.018 | 0.339±0.063 | 0.027±0.005 | 0.052±0.022    |
| 4  | <i>Ficus glomerata</i> Roxb.                    | 0.014±0.003 | 0.036±0.009 | 0.283±0.045 | 0.023±0.005 | 0.037±0.020    |
| 5  | <i>Pipturus argenteus</i> G.Forst.              | 0.010±0.002 | 0.024±0.007 | 0.229±0.064 | 0.018±0.005 | 0.021±0.014    |
| 6  | <i>Oroxylum indicum</i> (L.) Kurz               | 0.008±0.001 | 0.022±0.017 | 0.225±0.072 | 0.016±0.004 | 0.015±0.008    |
| 7  | <i>Hibiscus tiliaceus</i> L.                    | 0.008±0.003 | 0.020±0.011 | 0.186±0.068 | 0.014±0.004 | 0.013±0.010    |
| 8  | <i>Macaranga tanarius</i> (L.) Mull. Arg, Di DC | 0.008±0.003 | 0.023±0.021 | 0.159±0.083 | 0.015±0.006 | 0.012±0.013    |
| 9  | <i>Eucalyptus urophylla</i> S.T. Blake          | 0.011±0.004 | 0.032±0.027 | 0.192±0.060 | 0.030±0.010 | 0.019±0.013    |
| 10 | <i>Nauclea orientalis</i> (L.) L.               | 0.019±0.008 | 0.039±0.018 | 0.230±0.060 | 0.063±0.032 | 0.030±0.009    |
| 11 | <i>Litsea diversifolia</i> Blume                | 0.025±0.012 | 0.054±0.022 | 0.287±0.090 | 0.073±0.043 | 0.037±0.010    |
| 12 | <i>Mangifera indica</i> L.                      | 0.027±0.012 | 0.060±0.032 | 0.244±0.086 | 0.073±0.041 | 0.036±0.009    |



|    |                                          |             |             |             |             |             |
|----|------------------------------------------|-------------|-------------|-------------|-------------|-------------|
| 13 | <i>Peltophorum inerma</i> Roxb.          | 0.041±0.021 | 0.076±0.041 | 0.309±0.111 | 0.081±0.053 | 0.041±0.012 |
| 14 | <i>Homalium tomentosum</i> (Vent.) Benth | 0.046±0.022 | 0.069±0.037 | 0.274±0.091 | 0.057±0.024 | 0.041±0.014 |
| 15 | <i>Bauhinia malabarica</i> Roxb.         | 0.053±0.025 | 0.096±0.050 | 0.339±0.090 | 0.061±0.020 | 0.052±0.026 |
| 16 | <i>Alstonia villosa</i> Blume.           | 0.047±0.024 | 0.095±0.068 | 0.288±0.120 | 0.053±0.020 | 0.044±0.010 |
| 17 | <i>Tamarindus indica</i> L.              | 0.063±0.041 | 0.107±0.057 | 0.319±0.098 | 0.066±0.033 | 0.047±0.021 |
| 18 | <i>Terminalia mollis</i> M.A. Lawson.    | 0.069±0.049 | 0.145±0.105 | 0.403±0.136 | 0.079±0.046 | 0.044±0.012 |
| 19 | <i>Garuga floribunda</i> Decne.          | 0.073±0.054 | 0.143±0.096 | 0.340±0.119 | 0.089±0.075 | 0.055±0.018 |
| 20 | <i>Vitex parviflora</i> Juss.            | 0.082±0.043 | 0.162±0.085 | 0.360±0.084 | 0.077±0.040 | 0.047±0.014 |
| 21 | All species                              | 0.033±0.016 | 0.067±0.034 | 0.289±0.082 | 0.049±0.023 | 0.039±0.014 |

For tree sample at DBH<20 cm, the mean tree biomass was 0.124 t, 0.095 t, 0.267 t and 0.133 t for tree height class at 50–100 cm, 100–150 cm, 150–200 cm and 200–250 cm, respectively. The biomass proportion also varied between the tree components and between species. Between tree components the proportion of tree biomass was 20.0 % for tree height class at 50–100 cm; 15.4 % for tree height class at 100–150 cm; 43.2 % for tree height class at 150–200 cm and 21.5 % for tree height class at 200–250 cm. Compared to other tree species, *Alstonia*

*scholaris* had the highest mean tree biomass at 100–150 cm (0.255 t) and 150–200 cm (0.750 t) tree height class. Same pattern was observed for *Alstonia villosa* (0.247 t) and *Garuga floribunda* (0.331 t) at 50–100 cm and 200–250 cm tree height class (Fig. 2).

We found that biomass among DBH classes (i.e., 10–15 cm, 15–20 cm, 20–25 cm, 25–30 cm and 30–35 cm) differed among the sample tree species. DBH class of 10–15 cm (24.9 %), 25–30 cm (23.9 %) and 30–35 cm (20.4 %) contributed predominantly to tree biomass

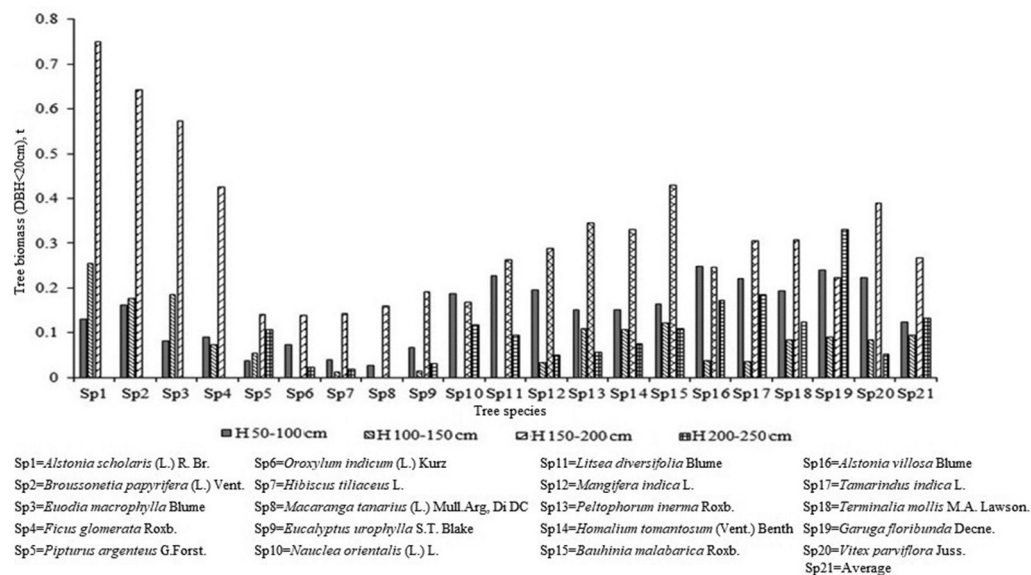


Fig. 2. The values of tree biomass by class tree height (DBH<20 cm).

accumulation, whereas DBH class of 15–20 cm (11.3 %), 20–25 cm (19.7 %) were responsible for a small proportion of the overall tree biomass. *Terminalia mollis* (4.979 t), *Vitex parviflora* (2.662 t), *Vitex parviflora* (3.470 t), *Tamarindus indica* (4.090 t) and *Alstonia villosa* (2.539 t) had the highest biomass in each DBH class (Fig. 3).

Table 3 shows the regression models developed for estimating tree biomass

components of all tree species. The RMSE, AIC and  $R^2$  values indicated that the developed models were good and useful for the estimation of biomass of all components for all species. However, the lowest values of  $R^2$  are found in several tree species, such as *Ficus glomerata*, *Oroxylum indicum*, *Hibiscus tiliaceus*, *Macaranga tanarius*, *Eucalyptus urophylla*, *Bauhinia malabarica*, and *Vitex parviflora*.

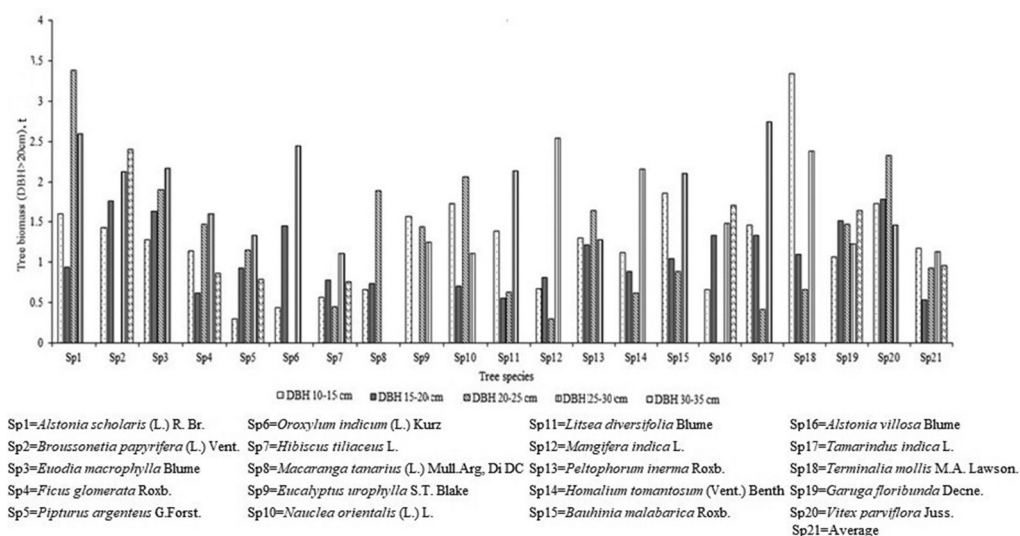


Fig. 3. The values of tree biomass by class DBH (DBH>20 cm).

Table 3. Biomass equation for all sample species.

| No | Tree species and DBH class     | Tree component | Allometric equation            | RMSE  | AIC      | $R^2$ |
|----|--------------------------------|----------------|--------------------------------|-------|----------|-------|
| 1  | <i>Alstonia scholaris</i>      | DBH<20 cm      | $B = -0.027 + 0.001 \cdot H$   | 0.01  | -145.532 | 0.84  |
|    |                                | DBH>20 cm      |                                |       |          |       |
|    |                                | Leaf           | $LB = 0.007 + 0.001 \cdot DBH$ | 0.003 | -179.573 | 0.805 |
|    |                                | Branch         | $BB = 0.035 + 0.002 \cdot DBH$ | 2.857 | -192.101 | 0.968 |
|    |                                | Stem           | $SB = 0.177 + 0.011 \cdot DBH$ | 0.017 | -128.961 | 0.956 |
|    |                                | Root           | $RB = 0.022 + 0.001 \cdot DBH$ | 0.003 | -182.852 | 0.681 |
|    |                                | Total          | $TB = 0.240 + 0.015 \cdot DBH$ | 0.02  | -122.921 | 0.962 |
| 2  | <i>Broussonetia papyrifera</i> | DBH<20 cm      | $B = -0.008 + 0.0004 \cdot H$  | 0.011 | -141.508 | 0.757 |
|    |                                | DBH>20 cm      |                                |       |          |       |
|    |                                | Leaf           | $LB = 0.007 + 0.001 \cdot DBH$ | 0.004 | -173.852 | 0.76  |
|    |                                | Branch         | $BB = 0.031 + 0.002 \cdot DBH$ | 0.008 | -153.648 | 0.764 |
|    |                                | Stem           | $SB = 0.190 + 0.008 \cdot DBH$ | 0.023 | -118.499 | 0.908 |

| No | Tree species and DBH class                          | Tree component | Allometric equation   | RMSE  | AIC      | R <sup>2</sup> |
|----|-----------------------------------------------------|----------------|-----------------------|-------|----------|----------------|
| 3  | <i>Euodia macrophylla</i><br>DBH<20 cm<br>DBH>20 cm | Root           | RB=0.017+0.001·DBH    | 0.003 | -182.559 | 0.772          |
|    |                                                     | Total          | TB=0.244+0.011·DBH    | 0.033 | -107.718 | 0.904          |
|    |                                                     |                | B=-0.033+0.001·H      | 0.008 | -152.898 | 0.88           |
|    |                                                     | Leaf           | LB=0.007+0.001·DBH    | 0.002 | -197.357 | 0.81           |
|    |                                                     | Branch         | BB=-0.006+0.003·DBH   | 0.004 | -177.571 | 0.961          |
|    |                                                     | Stem           | SB=0.143+0.009·DBH    | 0.017 | -129.114 | 0.935          |
|    |                                                     | Root           | RB=0.011+0.001·DBH    | 0.002 | -201.722 | 0.905          |
|    |                                                     | Total          | TB=0.155+0.013·DBH    | 0.02  | -123.39  | 0.954          |
| 4  | <i>Ficus glomerata</i><br>DBH<20 cm<br>DBH>20 cm    |                | B=-0.018+0.0004·H     | 0.01  | -145.746 | 0.764          |
|    |                                                     | Leaf           | LB=0.005+0.0003·DBH   | 0.001 | -212.073 | 0.864          |
|    |                                                     | Branch         | BB=0.025+0.001·DBH    | 0.008 | -151.051 | 0.187          |
|    |                                                     | Stem           | SB=0.155+0.006·DBH    | 0.009 | -148.785 | 0.962          |
|    |                                                     | Root           | RB=0.01+0.001·DBH     | 0.002 | -202.712 | 0.885          |
|    |                                                     | Total          | TB=0.195+0.007·DBH    | 0.014 | -134.158 | 0.942          |
| 5  | <i>Pipturus argenteus</i><br>DBH<20 cm<br>DBH>20 cm |                | B=-0.013+0.0002·H     | 0.006 | -159.886 | 0.818          |
|    |                                                     | Leaf           | LB=0.005+0.0002·DBH   | 0.000 | -250.056 | 0.948          |
|    |                                                     | Branch         | BB=0.004+0.001·DBH    | 0.003 | -189.35  | 0.875          |
|    |                                                     | Stem           | SB=0.051+0.008·DBH    | 0.021 | -122.511 | 0.903          |
|    |                                                     | Root           | RB=0.004+0.001·DBH    | 0.001 | -217.396 | 0.959          |
|    |                                                     | Total          | TB=0.065+0.01·DBH     | 0.022 | -119.794 | 0.92           |
| 6  | <i>Oroxylum indicum</i><br>DBH<20 cm<br>DBH>20 cm   |                | B=-0.0004+0.0001·H    | 0.005 | -165.646 | 0.597          |
|    |                                                     | Leaf           | LB=0.004+0.0001·DBH   | 0.000 | -253.57  | 0.94           |
|    |                                                     | Branch         | BB=-0.007+0.001·DBH   | 0.015 | -132.125 | 0.295          |
|    |                                                     | Stem           | SB=0.019+0.01·DBH     | 0.024 | -117.374 | 0.897          |
|    |                                                     | Root           | RB=0.004+0.001·DBH    | 0.001 | -215.885 | 0.932          |
|    |                                                     | Total          | TB=0.02+0.012·DBH     | 0.036 | -104.863 | 0.854          |
| 7  | <i>Hibiscus tiliaceus</i><br>DBH<20 cm<br>DBH>20 cm |                | B=-0.007+0.0001·H     | 0.006 | -161.943 | 0.651          |
|    |                                                     | Leaf           | LB=0.001+0.0003·DBH   | 0.001 | -211.825 | 0.767          |
|    |                                                     | Branch         | BB=-0.002+0.001·DBH   | 0.008 | -152.152 | 0.456          |
|    |                                                     | Stem           | SB=-0.01+0.009·DBH    | 0.028 | -112.241 | 0.838          |
|    |                                                     | Root           | RB=0.001+0.001·DBH    | 0.001 | -211.757 | 0.92           |
|    |                                                     | Total          | TB=-0.011+0.011·DBH   | 0.038 | -103.204 | 0.814          |
| 8  | <i>Macaranga tanarius</i><br>DBH<20 cm<br>DBH>20 cm |                | B=-0.01+0.0001·H      | 0.01  | -146.934 | 0.493          |
|    |                                                     | Leaf           | LB=-0.0003+0.0004·DBH | 0.001 | -210.523 | 0.806          |
|    |                                                     | Branch         | BB=-0.013+0.002·DBH   | 0.018 | -125.82  | 0.284          |
|    |                                                     | Stem           | SB=-0.082+0.014·DBH   | 0.033 | -107.548 | 0.853          |
|    |                                                     | Root           | RB=-0.003+0.001·DBH   | 0.002 | -205.563 | 0.939          |
|    |                                                     | Total          | TB=-0.098+0.017·DBH   | 0.05  | -94.07   | 0.798          |

| No | Tree species and DBH class  | Tree component | Allometric equation | RMSE  | AIC      | R <sup>2</sup> |
|----|-----------------------------|----------------|---------------------|-------|----------|----------------|
| 9  | <i>Eucalyptus urophylla</i> |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0001·H   | 0.008 | -151.698 | 0.6            |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=0.0002+0.001·DBH | 0.002 | -201.743 | 0.854          |
|    |                             | Branch         | BB=-0.016+0.003·DBH | 0.021 | -121.834 | 0.444          |
|    |                             | Stem           | SB=0.035+0.008·DBH  | 0.014 | -135.267 | 0.951          |
| 10 | <i>Nauclea orientalis</i>   |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.013+0.0001·H    | 0.005 | -167.275 | 0.681          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.003+0.001·DBH | 0.003 | -186     | 0.875          |
|    |                             | Branch         | BB=-0.011+0.003·DBH | 0.007 | -156.357 | 0.858          |
|    |                             | Stem           | SB=0.062+0.009·DBH  | 0.02  | -123.199 | 0.895          |
| 11 | <i>Litsea diversifolia</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.015+0.0001·H    | 0.005 | -168.358 | 0.781          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.008+0.002·DBH | 0.005 | -168.047 | 0.834          |
|    |                             | Branch         | BB=-0.002+0.003·DBH | 0.012 | -140.745 | 0.733          |
|    |                             | Stem           | SB=0.025+0.013·DBH  | 0.026 | -114.982 | 0.922          |
| 12 | <i>Mangifera indica</i>     |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.015+0.0001·H    | 0.004 | -174.074 | 0.797          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.002+0.001·DBH | 0.006 | -163.292 | 0.796          |
|    |                             | Branch         | BB=-0.011+0.003·DBH | 0.018 | -127.094 | 0.705          |
|    |                             | Stem           | SB=0.059+0.009·DBH  | 0.053 | -92.363  | 0.649          |
| 13 | <i>Peltophorum inerma</i>   |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 14 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.01+0.0002·H     | 0.009 | -148.366 | 0.611          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.009+0.003·DBH | 0.009 | -150.529 | 0.859          |
|    |                             | Branch         | BB=-0.022+0.005·DBH | 0.013 | -136.822 | 0.88           |
|    |                             | Stem           | SB=0.058+0.011·DBH  | 0.043 | -98.929  | 0.794          |
| 15 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 16 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 17 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 18 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 19 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 20 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 21 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 22 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 23 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 24 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 25 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 26 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 27 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 28 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 29 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 30 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 31 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 32 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 33 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 34 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 35 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 36 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 37 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 38 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 39 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 40 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 41 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 42 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 43 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=-0.005+0.0003·H   | 0.019 | -124.841 | 0.478          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.004+0.003·DBH | 0.011 | -141.728 | 0.812          |
|    |                             | Branch         | BB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
|    |                             | Stem           | SB=-0.076+0.008·DBH | 0.025 | -116.196 | 0.792          |
| 44 | <i>Homalium tomentosum</i>  |                |                     |       |          |                |
|    |                             | DBH<20 cm      | B=0.011+0.0002·H    | 0.008 | -154.355 | 0.651          |
|    |                             | DBH>20 cm      |                     |       |          |                |
|    |                             | Leaf           | LB=-0.025+0.003·DBH | 0.008 | -153.781 | 0.873          |
|    |                             | Branch         | BB=-0.048+0.006·DBH | 0.018 | -126.243 | 0.817          |
|    |                             | Stem           | SB=-0.023+0.017·DBH | 0.052 | -93.011  | 0.799          |
| 45 | <i>Bauhinia malabarica</i>  |                |                     |       |          |                |
|    |                             | DBH            |                     |       |          |                |

| No | Tree species and DBH class                         | Tree component | Allometric equation | RMSE  | AIC      | R <sup>2</sup> |
|----|----------------------------------------------------|----------------|---------------------|-------|----------|----------------|
| 16 | <i>Alstonia villosa</i><br>DBH<20 cm<br>DBH>20 cm  | Branch         | BB=-0.026+0.007·DBH | 0.015 | -132.357 | 0.916          |
|    |                                                    | Stem           | SB=0.131+0.011·DBH  | 0.038 | -102.772 | 0.834          |
|    |                                                    | Root           | RB=0.015+0.002·DBH  | 0.008 | -151.102 | 0.83           |
|    |                                                    | Total          | TB=0.116+0.023·DBH  | 0.059 | -88.448  | 0.898          |
|    |                                                    |                | B=0.02+0.0001·H     | 0.004 | -178.761 | 0.88           |
|    |                                                    | Leaf           | LB=-0.01+0.003·DBH  | 0.010 | -145.295 | 0.836          |
|    |                                                    | Branch         | BB=-0.061+0.008·DBH | 0.031 | -108.803 | 0.798          |
|    |                                                    | Stem           | SB=0.025+0.013·DBH  | 0.065 | -85.802  | 0.728          |
|    |                                                    | Root           | RB=0.006+0.002·DBH  | 0.008 | -153.085 | 0.853          |
|    |                                                    | Total          | TB=-0.04+0.025·DBH  | 0.103 | -70.909  | 0.806          |
| 17 | <i>Tamarindus indica</i><br>DBH<20 cm<br>DBH>20 cm |                | B=0.001+0.0003·H    | 0.012 | -139.548 | 0.704          |
|    |                                                    | Leaf           | LB=-0.035+0.005·DBH | 0.023 | -118.618 | 0.707          |
|    |                                                    | Branch         | BB=-0.042+0.007·DBH | 0.022 | -119.726 | 0.855          |
|    |                                                    | Stem           | SB=0.061+0.013·DBH  | 0.039 | -102.179 | 0.856          |
|    |                                                    | Root           | RB=-0.019+0.004·DBH | 0.014 | -135.104 | 0.836          |
|    |                                                    | Total          | TB=-0.035+0.03·DBH  | 0.090 | -75.135  | 0.851          |
| 18 | <i>Terminalia mollis</i><br>DBH<20 cm<br>DBH>20 cm |                | B=0.015+0.0002·H    | 0.004 | -175.286 | 0.899          |
|    |                                                    | Leaf           | LB=-0.032+0.006·DBH | 0.024 | -118.151 | 0.786          |
|    |                                                    | Branch         | BB=-0.081+0.013·DBH | 0.041 | -100.187 | 0.856          |
|    |                                                    | Stem           | SB=0.132+0.016·DBH  | 0.072 | -82.531  | 0.74           |
|    |                                                    | Root           | RB=-0.021+0.006·DBH | 0.017 | -128.96  | 0.876          |
|    |                                                    | Total          | TB=-0.001+0.041·DBH | 0.120 | -66.081  | 0.871          |
| 19 | <i>Garuga floribunda</i><br>DBH<20 cm<br>DBH>20 cm |                | B=0.013+0.0002·H    | 0.009 | -148.647 | 0.775          |
|    |                                                    | Leaf           | LB=-0.037+0.005·DBH | 0.027 | -113.479 | 0.761          |
|    |                                                    | Branch         | BB=-0.065+0.01·DBH  | 0.040 | -100.928 | 0.837          |
|    |                                                    | Stem           | SB=0.091+0.012·DBH  | 0.059 | -88.931  | 0.775          |
|    |                                                    | Root           | RB=-0.051+0.007·DBH | 0.048 | -95.211  | 0.62           |
|    |                                                    | Total          | TB=-0.062+0.035·DBH | 0.117 | -66.693  | 0.875          |
| 20 | <i>Vitex parviflora</i><br>DBH<20 cm<br>DBH>20 cm  |                | B=0.019+0.0001·H    | 0.010 | -144.453 | 0.464          |
|    |                                                    | Leaf           | LB=-0.042+0.006·DBH | 0.013 | -136.956 | 0.914          |
|    |                                                    | Branch         | BB=-0.082+0.013·DBH | 0.029 | -111.385 | 0.892          |
|    |                                                    | Stem           | SB=0.129+0.012·DBH  | 0.035 | -105.213 | 0.835          |
|    |                                                    | Root           | RB=-0.039+0.006·DBH | 0.012 | -140.359 | 0.921          |
|    |                                                    | Total          | TB=-0.034+0.037·DBH | 0.078 | -79.789  | 0.908          |
| 21 | All species<br>DBH<20 cm<br>DBH>20 cm              |                | B=0.001+0.0002·H    | 0.006 | -160.848 | 0.828          |
|    |                                                    | Leaf           | LB=-0.012+0.002·DBH | 0.006 | -162.155 | 0.877          |
|    |                                                    | Branch         | BB=-0.026+0.005·DBH | 0.012 | -138.478 | 0.878          |
|    |                                                    | Stem           | SB=0.058+0.011·DBH  | 0.020 | -122.878 | 0.943          |
|    |                                                    | Root           | RB=-0.014+0.003·DBH | 0.008 | -154.064 | 0.897          |
|    |                                                    | Total          | TB=0.005+0.022·DBH  | 0.040 | -101.058 | 0.938          |

Among the tree components the mean leaf biomass (tree/ha) was  $0.032 \pm 0.015$  (range 0.009–0.071) (Fig. 4), branch biomass  $0.067 \pm 0.033$  (range 0.026–0.149), stem biomass  $0.288 \pm 0.079$  (range 0.142–0.444), root biomass  $0.048 \pm 0.022$  (range 0.02–0.104) and total biomass  $0.441 \pm 0.151$  (range 0.201–0.775). The values of tree biomass for each component also varied along the diameter at breast height (DBH). Generally, tree components biomass increased with DBH for whole species. Among the tree components, tree species biomass had high coefficient of determination ( $R^2$  for different components are: leaf = 0.877, branch = 0.877, stem = 0.943, root = 0.897, total = 0.938).

We compared the aboveground biomass for all species generated in our study using a generic equation (Fig. 5). The results indicated an average total biomass

of 0.387 t (this study), 0.967 t (Chaturvedi et al. 2012), 0.213 t (Chakraborty et al. 2016) and 1.670 t (Sato et al. 2015). The total above-ground biomass model compared with previously published equations indicated that the current equation diverged considerably from them. The total above-ground biomass was overestimated when they were applied to a data set taken from the present study.

In our study, stems (66 %) of all tree species have more biomass than the leaf, branch and root components, while the value of tree biomass with  $DBH < 20$  cm ( $0.039 \pm 0.014$ ) was almost similar to leaf biomass ( $0.033 \pm 0.016$ ) (Table 2). Henry et al. (2011) reported similar pattern, and they discovered percentage stem biomass (69 %) to be higher than for branch (27 %) and leaf (4 %). However, Geldenhuys and Golding (2008) reported that more than

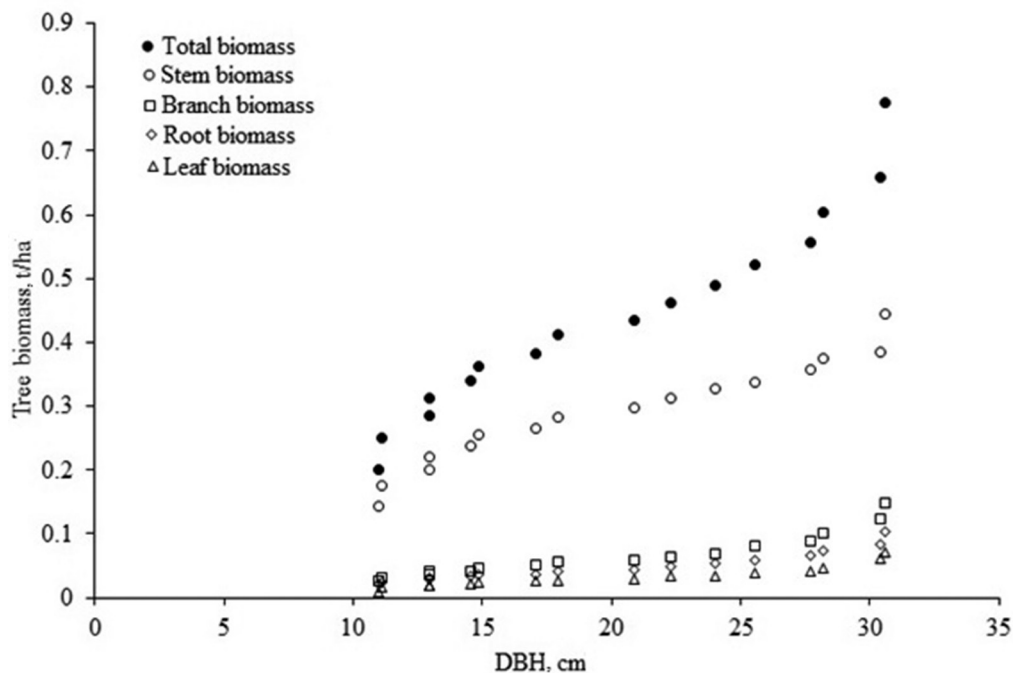


Fig. 4. The mean values of tree biomass in each tree components.



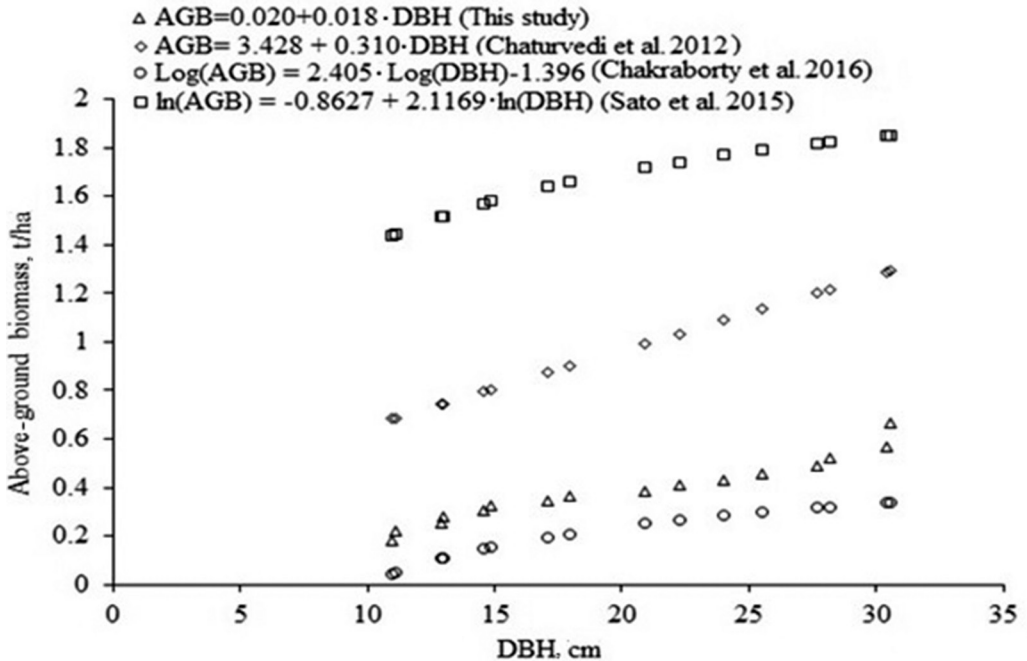


Fig. 5. Comparative values of aboveground biomass by different equation.

50 % of the timber in woodlands is branch biomass. In another study in the Miombo woodland stands, Chamshama et al. (2004) discovered a very high percentage biomass for branches than stems among species. The biomass distribution among different tree components might be relevant to the site conditions where the trees are growing. In dense forests with strong competition for light and space, the trees tend to develop smaller branches and foliage biomass than in open forest types (Segura and Kanninen 2005).

Almost all of the allometric equations presented in this study satisfied the recent criterion of proposed selection for biomass estimation models ( $R^2 > 80\%$  and low values of RMSE and AIC). It was indicated that the inclusion of DBH variable only in this study was the *good* predictor for estimation of tree biomass. Basuki et al. (2009) reported that adding height into

allometric equations did not elevate the accuracy of the estimation, whereas the model with single variable (DBH only) has higher reliability than generic models with up to three variables (Huy et al. 2016). In addition, it is difficult to measure height of trees accurately in tropical dense forest. According to Ishihara et al. (2015), the key to evaluating forest ecosystem functions and the global carbon cycle depends on how accurate the estimated tree and forest biomass are. Most allometric equations are site specific, usually developed from a small number of trees harvested in a small area and are either species specific or ignore interspecific differences in allometry. Due to less site-specific allometries, general equations are often used to sites for which they were not originally developed (foreign sites), sometimes causing large errors in biomass estimates.

The mean total above-ground bio-

mass estimated by four of the previous equations differed significantly ( $P < 0.001$ ) from that of the recent study. Amazingly, the allometric equation developed from a data set of European beech growing on dry sites (Chakraborty et al. 2016) provided the lowest overestimation. Among the previous equations, there was developed from data sets of three varied sites from three countries, therefore, this equation was considered more common equation which could be applied better in other forest ecosystems in the tropics. This indicates that allometric equations of the same region may be more similar in their approximation of tree biomass. The need for site specific models to be encouraged for accurate determination of tree components biomass in dry forests has been revealed by the comparison of the previous equations to the current one. However, where site specific allometric equations are not available, care must be taken in choosing allometric equations for forests. In that case, the exploration of equations within the same region or continent should be carried out (Addo-Fordjour and Rahmad 2013).

## Conclusions

This information source is essential for the development of conventional and sustainable management plans of tropical dry forest ecosystems. In addition, it is crucial for many applications to have the accurate approximation of tree components biomass in dry forests, from the commercial management of timber to the global carbon cycle. Some relationships of allometric were developed for liana stem and total above-ground biomass using liana diameter, length, diameter squared, and a combination of them as predictors. One

type of allometric equations was developed by models fitted to untransformed data. The diameter was a good estimator of all tree components biomass. Therefore, the models that used only diameter as the parameter estimate are recommended for use. A comparison of the total above-ground allometric equation elaborated in this study with previously published models indicated that the previous equations overestimated total above-ground biomass of tree by at least 44 %. According to the application of the proposed model to the previously published data and the application of the published equation to the recent data, conclusion could be drawn that it is a must to consider the application of site specific equation (Basuki et al. 2009).

## Acknowledgments

The authors wish to express their sincere thanks to the SEARCA (Southeast Asian Regional Centre for Graduate Study and Research in Agriculture) for funding this research. The authors are also grateful to the Mutis Timau PFMU East Nusa Tenggara, Indonesia, for all facilities and all convenience.

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## DO HAND REARED GREY PARTRIDGES (*PERDIX PERDIX* L., 1758) SURVIVE AFTER RELEASING IN UPLAND HABITATS OF WESTERN BULGARIA?

Evlogi Angelov, Gradimir Gruychev, and Stoyan Stoyanov\*

Wildlife Management Dept., University of Forestry, 10 St. Kl. Ohridski Blvd., 1797 Sofia, Bulgaria, E-mails: evoangelov@gmail.com, stoyans@abv.bg\*

Received: 08 July 2019

Accepted: 08 October 2019

### Abstract

Releasing of hand-reared game birds is a powerful tool to increase the population size of wild birds and to lower hunting pressure on their natural populations. Survival and adaptation in the wild of farm game birds is crucial for assessing game farming efficiency. Survival rate of 36 Grey partridges released in the autumn from cages in the harsh environment of Mala Mountain uplands (850 m a.s.l.) (Central Western Bulgaria) was estimated by applying radio-telemetry. The study area was covered mainly by hay fields and pastures, while arable land was below 10 % of the territory. The birds stayed within an area of 70 ha (100 % maximum convex polygon) with dispersion below 770 m from releasing points. Very few birds dispersed in such long distances, while most of them stayed close to the cages. After releasing partridges showed preferences to scrub near hay fields. The highest mortality rates occurred in the first week when almost 80 % of birds died, and only one bird probably survived more than two weeks. The main factor for mortality was predation by Red fox (66.7 %). Synthesis and application: Grey partridge population size in harsh environments could not be increased by releasing of farm birds using traditional methods. Still the use of farm produced birds is reliable way for wild bird populations recovery, but the correct methods and high-quality farm birds have to be used. Habitat quality also plays an important role in the survival of released birds and their interactions with wild populations.

**Key words:** farm birds, Grey partridge, home range, radio telemetry, survival rates.

### Introduction

Grey partridge (*Perdix perdix* L., 1758) occurs throughout much of the Western Palearctic, with a native range encompassing Portugal, Spain, France, the Netherlands, Germany, Ireland, the United Kingdom, Norway, Sweden, Finland, Belgium, Luxembourg, Denmark, Poland, Estonia, Latvia, Lithuania, Russia, Belarus, Ukraine, the Czech Republic, Slovakia, Switzerland, Liechtenstein, Austria, Italy, Hungary, Slovenia, Croatia,

Bosnia and Herzegovina, Serbia, Romania, Moldova, North Macedonia, Bulgaria, Greece, Turkey, Armenia, Georgia, Azerbaijan, Iran, Kazakhstan and China. It was introduced and reintroduced to many parts of Europe, including Finland, Britain, Russia and France; also successfully introduced to USA and Canada. (del Hoyo et al. 1994, BirdLife International 2016). In Bulgaria the species occupies almost all the lowland and foothill regions (Simeonov et al. 1990) but can climb up at considerably high altitudes up to 1800 m in



the mountains (Patev 1950). During the winter Grey partridge performs vertical migrations from higher parts of the mountains to foothills or lowlands. Throughout dry summer months it moves towards mountains where it finds more accessible food (Simeonov et al. 1990). The species is listed as 'Least concern' in the IUCN Red List with decreasing population trend (BirdLife International 2016). In Bulgaria Grey partridge is under regime of protection and regulated use (Biodiversity Act, Annex 4). During 1980–1984 Grey partridge population size has increased from 561,100 to 600,240 individuals (Simeonov et al. 1990). Independent ornithological studies report 20,000–30,000 breeding pairs (Nankinov 2004) and 10,000–25,000 breeding pairs (Gerassimov and Mitev 2007). According to official hunting statistics in the period 2004–2012 Grey partridge population varies from 226,000 to 303,000. There is significant difference among the numbers reported by the ornithological researches and the national game census. The breeding density in foothill habitats is considered low, but more research is needed. The aim of this study is to estimate the effectiveness of releasing hand-reared Grey partridges in harsh habitats by using adaptation cages.

## Material and Methods

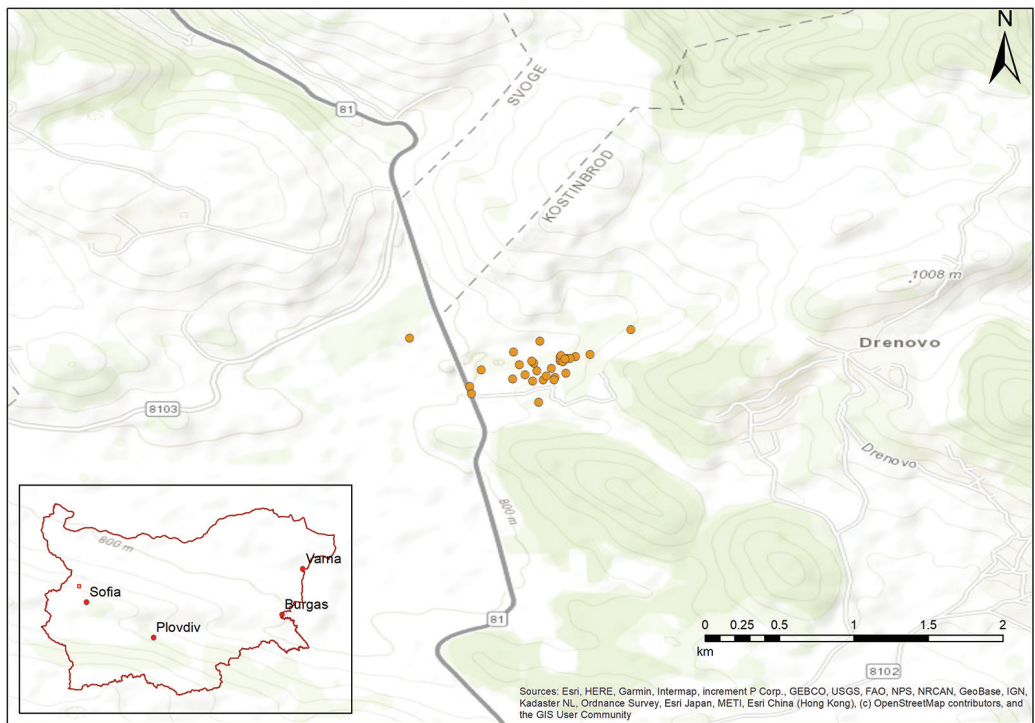
### Study area

The study area is part of Mala Mountain in Central Western Bulgaria (Fig. 1). It includes the following types of habitats: thinned deciduous forests – 12.9 %, shrubs – 13.5 % and meadows – 73.4 %. Actions for improvement of habitat quality were not taken before the release of birds. The density of natural Grey partridge pop-

ulation was low. It was not estimated precisely, but the presence of at least two flocks was detected. The main mammalian predators that occur in the area are Red fox (*Vulpes vulpes* (Linnaeus, 1758)), Stone marten (*Martes foina* (Erxleben, 1777)) and Western polecat (*Mustela putorius* Linnaeus, 1758). The data about their population size and hunting bag statistics is missing or are not reliable. From avian raptors Northern goshawk (*Accipiter gentilis* (Linnaeus, 1758)) and Common buzzard (*Buteo buteo* (Linnaeus, 1758)) were spotted in the area.

The average altitude is 850 m a.s.l. The climate is moderate continental. The soils are represented by cambisols and rendzinas, covered with oak forests. The average annual temperatures are 8–10 °C (Koprarev 2002). According to Bondev (1991), most of the study area is covered by xerothermal grass communities with a prevalence of *Dichantietia ischaemi*, *Poaeta bulbosae*, *Poaeta concinnae*, *Chrysopogoneta grylli* and *Ephemereta*, shrub (*Amygdaleta nannae*) and grass (*Artemisieta albae*, *Agropyreta pectiniformae*, *Agropyreta brandsae*, *Brometa riparii*, etc.). The farmlands replace mixed Turkey oak (*Quercus cerris* L.) and Hungarian oak (*Quercus frainetto* Ten.) forests as well. Agricultural areas have been uncultivated over the last 10 years and are covered with patches of shrubs presented by Jerusalem thorn (*Paliurus spina-christi* Mill.), Blackthorn (*Prunus* sp.), Rose-Hip (*Rosa*), Hawthorn (*Crataegus* sp.).

Meadows are predominantly presented by mesophytous grass communities (*Festuceta pratensis*, *Poaeta sylvicolae*, *Alopecureta pratensis*, *Lolieta perennis*, *Agrostideta stoloniferae*, etc.) replacing forests of Elm (*Ulmus*), Raywood ash (*Faraxinus oxycarpa* M. Bieb. ex. Willd.), Pedunculate oak (*Quercus robur* L.), etc.



**Fig. 1. Study area in Mala Mountain, Central Western Bulgaria.**

Note: Points represent dispersion of partridges after release. Most of detections were post-mortal and almost every bird was detected only once.

(Bondev 1991). They are used as pastures and for hay. Agricultural crops occupy less than 10 % of the study area, and the habitats provide low quality of food resources. A part of the study area is covered by thinned oak forests presented by Turkey oak (*Quercus cerris* L.) and Hungarian oak (*Quercus frainetto* Ten.).

### Field methods

In 2014 forty-one hand-reared Grey partridges were released – five birds in the spring, and 36 in the autumn (Table 1). Before release the birds were held for four days in pens with dimensions 1.2/1/2.4 m (width/height/length).

**Table 1. Number of released Grey partridges (*Perdix perdix*).**

| Season of release | Date/group         | Number of marked birds |        |       |
|-------------------|--------------------|------------------------|--------|-------|
|                   |                    | Male                   | Female | Total |
| Spring            | 21.3.2014          | 5                      |        | 5     |
|                   | 28.9.2014/Group 1  | 6                      | 6      | 12    |
| Autumn            | 5.10.2014/Group 2  | 6                      | 7      | 13    |
|                   | 12.10.2014/Group 3 | 5                      | 6      | 11    |
| Total             |                    | 22                     | 19     | 41    |

Each bird was tagged by 10 g radio transmitter RI-2B (Holohil System Ltd). Partridges were monitored every 3–4 days after release. The location of each bird with exact geographical coordinates was determined after observation by using application Androzic, v. 1.7.9 for Android on a mobile device. For each found dead bird reasons for mortality were identified by using traces left on the birds and radio transmitters and were separated in three categories: mammalian predator, avian raptor and unknown.

### Data analysis

Dispersion of the released birds is estimated with Map Source 6.15.11 (Garmin Ltd.).

The home range was defined by minimum convex polygon (MCP) (Mohr 1947) applying CALHOME Software (Kie et al. 1996). Habitat-use of the released birds was estimated by Jacobs index (Jacobs 1974) within the area of the 100 % MCP divided into several habitat types.

Differences in dispersion of the three groups of hand-reared partridges, released in the autumn, were estimated by applying one-way ANOVA. The survival of the birds is estimated by using Kaplan-Meier index (Kaplan and Meier 1958, Pollock et al. 1989) and parametric analysis with Weibull distribution (Pinder et al. 1978, Crawley 2013). Differences between survival rates of the three groups were tested with log-rank test (Krebs 1999) and by parametric model with Weibull distribution (Pinder et al. 1978). Parametrical analysis of the survival curve is less sensitive to small size of samples and accident variance observed at non-parametric analysis (Skalski et al. 2005). The analyses were performed by using *R* software (*R* Core Team 2019), and package survival, v. 2.37-7 (Therneau and Grabsch 2000,

Therneau 2014).

### Results

All birds released in the spring were found dead in 20 days' period and their dispersion, home range and habitat use were not analyzed due to insufficient data collected. The birds released in the autumn stayed near the adaptation cage during the whole study. The average distance of dispersal was 203.02 m  $\pm$  168.22 m (mean, st. dev., min–max: 17.4–770.2 m). We did not find any significant differences between the dispersion of the three groups ( $F = 0.377$ ,  $df = 1, 31$ ,  $p = 0.544$ ). Some individuals moved further from the releasing point due to chasing by predators. The home range, estimated with MCP size, was no more than 100 ha (Table 2).

**Table 2. Home range of the released Grey partridges.**

| Group   | MCP<br>100 %, ha | MCP<br>95 %, ha | MCP<br>75 %, ha | MCP<br>50 %, ha |
|---------|------------------|-----------------|-----------------|-----------------|
| Group 1 | 61.9             | 61.9            | 24.4            | 11.1            |
| Group 2 | 73.9             | 73.9            | 13.7            | 5.7             |
| Group 3 | 75.9             | 35.4            | 18.2            | 8.7             |

Hand-reared birds occupied considerably small area near the release pens. The birds preferred shrubs ( $J = 0.56$ ) than meadows ( $J = -0.26$ ) and deciduous forests ( $J = -0.13$ ).

The main part of mortality after releasing occurred in the first two weeks (Fig. 2) and was caused mainly by mammalian predators (Table 3).

Although there were differences in survival rates between groups, almost all birds died in two weeks (Fig. 3). Only one bird with lost signal had unknown fate and probably survived after the two weeks' period.

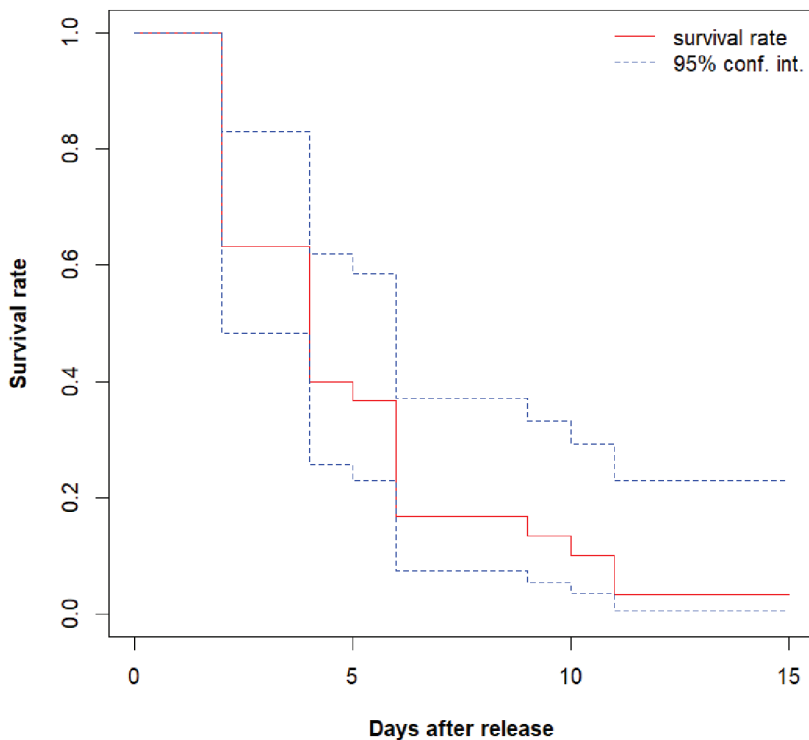


Fig. 2. Grey partridges' survival rates after releasing in the autumn.

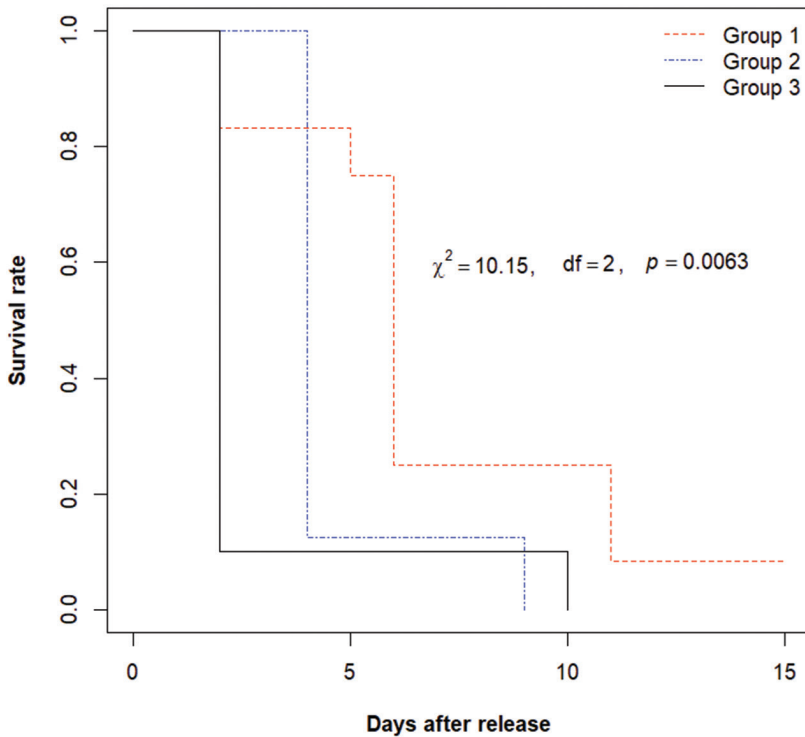
Table 3. Reasons for mortality.

| Reasons for mortality            | Mortality of birds |      |
|----------------------------------|--------------------|------|
|                                  | number             | %    |
| Adaptation period                | 3                  | 8.3  |
| After releasing period:          |                    |      |
| Red fox ( <i>Vulpes vulpes</i> ) | 24                 | 66.7 |
| Other mammalian predators        | 4                  | 11.1 |
| Stray dogs                       | 1                  | 2.8  |
| Lost signal                      | 4                  | 11.1 |
| Total                            | 36                 | 100  |

## Discussion

Our results showed that hand-reared partridges stayed near the point of release

even chased by predators. Similar behaviour of Galliform birds released from farms was reported in other studies as well (Šálek et al. 2002; Gruychev 2012, 2014). Estimated mean dispersion was smaller compared to studies on radio-tracked partridges in other parts of their range (Potts 1986, Birkan and Serre 1988, Putaala and Hisa 1998). We suppose that dispersal range depends on environmental conditions of the habitats, and quality and health status of farm birds. The results provide a clue of how the release points should be chosen in order to reduce birds' movements. Single individuals moved farther away due to chasing by predators, as it was suggested by other studies on hand reared Galliform birds (Homan et al. 2000, Gruychev 2014).



**Fig. 3. Differences in survival rates between groups.**

Note: See Table 1 for the date of release and the number of birds in each group.

Released farm birds had a very small home range close to the points of release. The home range of Grey partridge varies significantly in different habitats (O'Gorman et al. 1999, Rantanen et al. 2010). In the most suitable habitats with higher densities the birds occupy smaller areas compared to habitats with low quality and densities (Šálek et al. 2002). It was confirmed by our results as well. The hand-reared partridges preferred shrubs and avoided other parts of the area, as reported also for Upper Thracian lowland (Milanov 1991) and around the town of Sevlievo (Botev 1962). The Jacobs index was negative for meadows and thinned deciduous forests. The avoidance of habitats with high moisture was found also in lowland regions in Bulgaria (Milanov 1991). The

shrub vegetation is crucial for Grey partridge and should be considered as one of important factors when the release points of farm birds are being decided.

The high mortality in short time after release confirms that it is impossible to rapidly increase Grey partridge's population by using conventional release methods in the harsh habitats. Some studies reported poor survival of older birds compared to young ones (Buner and Schaub 2008), but our results showed that mortality was high in both groups and did not depend on the age. Other researchers also reported the predation as a main reason for the high mortality (Potts 1986, Rantanen et al. 2010). Survival of the farm birds should depend on the survival skills due to the level of experience regarding anti-pred-

ator behaviour (Dowell 1990). When the birds are released in places where a wild population is present then the farm birds take advantage of the anti-predator skills of wild individuals. According to other researchers, the survival of hatched chicks of released farm birds is close to that of chicks hatched in the wild population (Panek 1992, 1997; Potts and Aebischer 1994; Putaala 1997), but despite the presence of wild birds near the release pens the farm birds' mortality was almost 100 %. Game birds reared in farms experience lasting physiological and ethological modifications which subsequently lead to problems during the adaptation (Lucio 1992). Their behaviour differs from that of the wild birds (Gaudioso et al. 2002). These are probably the reasons for the failure of our experiment. However, the releasing of farm birds can be a reliable tool for re-establishing wild populations (Nadal 1992, Carvalho and Borralho 1997). Some very important factors before releasing should be considered: birds' vitality, predation and habitats. Habitats' quality and predator control are crucial for farm birds' survival after release. Spring release, when farm birds are joined by an old pair is more successful. Appropriate release methods and working with high quality birds should be considered for future recovery programs in upland habitats of Western Bulgaria.

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## ROLE OF CORS RTK (NETWORK RTK) MODE MEASUREMENTS IN DETERMINATION OF THE FOREST BOUNDARY: A CASE STUDY OF ISKI-CORS

Atınç Pirtir\* and Ramazan Gürsel Hosbas

Department of Surveying Engineering, Yildiz Technical University, Davutpasa Campus,  
34210 Esenler Istanbul, Turkey. \*E-mail: atinc@yildiz.edu.tr

Received: 25 July 2019

Accepted: 22 October 2019

### Abstract

Network Real-time kinematic mode survey technology shows really an efficient and fast improvement within today's technological developments. Permanent reference stations for Global Navigation Satellite System (GNSS) have for a long time been used for positioning of rovers in RTK (Real-Time Kinematic) mode. In this article, we examine the performance and use of Continuously Operating Reference Station (CORS-Network RTK) as an extension of RTK technology-based data acquisition systems near/under tree canopy. As a general rule, a clear view of the sky is preferred when using RTK for determining location. Eight permanent reference stations belonging to the İSKİ (Istanbul Water and Sewerage Administration) in Istanbul, Turkey were used for the test measurements. This paper presents the results of İSKİ (Istanbul Water and Sewerage Administration) CORS satellite measurements made using Networked Transport of Radio Technical Commission for Maritime Services via Internet Protocol (NTRIP) data transmission. As a result of measurements taken at 17 measurement points in the obstructed and unobstructed environments, the accuracies obtained at the points with numerous covers in the form of tree branches and leaves ranged from several centimetres which is characteristic for GPS/GLONASS measurements taken under conditions of limited availability of satellites.

**Key words:** accuracy, Global Navigation Satellite System (GNSS), location, measurement point, reference station, satellite measurements.

### Introduction

When defining forest, one must also define where forest ends; forest edge or forest boundary is the imagined line that separates forest and non-forest. The question of a clear definition of the forest boundary is particularly difficult in transition areas between forest and non-forest where a dense forest is gradually opening up to tree-free land, as for example at the timber line or at the boundary of deserts RTK stands for Real Time Kinemat-

ic, which is a GPS positioning technology better than *Differential Global Positioning System* (DGPS) in term of accuracy and its capability to keep the accuracy when moving. RTK provides cm grade accuracy while DGPS can provide sub-meter accuracy. To enjoy RTK, the GPS receiver shall support dual frequency L1 and L2. DGPS requires single frequency only. In addition, you need a reference station with known position and a Radio Technical Commission for Maritime Services (RTCM) antenna to broadcast correction

to rover. What we know is that phase of carrier and other correction information (such as orbital correction, ionospheric correction and geometric correction) would be transferred from the base station to the rover. At rover, it will compare its phase received with the phase sent by base station to attain a relative position at millimetre level, and this is accurate baseline to provide good measurement. Of course, accuracy of the rover cannot exceed that of base station (Lachapelle et al. 2001, Pirti 2008, Parti et al. 2009). Network RTK is not a latest technology in fact. It was developed in 90s and it has been established in many countries in Europe and States, even China and Hong Kong have established reference station network, which is termed Continuously Operating Reference Station (CORS). CORS is an extension of RTK technology; it is composed of a network of reference stations and a central data processing centre that is a service running 7×24 non-stops. Corrections would be transferred to rover using GSM or wireless network with a standard protocol called Networked Transport of Radio Technical Commission for Maritime Services via Internet Protocol (NTRIP), i.e. RTCM over IP Network Transport of RTCM via Internet Protocol. There are three Network RTK technologies being available in the market including VRS, FKP and IMAX (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003, Kaartinen et al. 2015, Wright et al. 2017).

Virtual Reference Station (VRS) is developed by Trimble; it requires a bi-directional communication between a data processing centre and rover. To start measurement, rover needs to provide an approximate position to the centre and it will select relevant reference station within the

proximity to calculate corrections (satellite orbit and clock errors, reference station receiver clock errors, multipath and particularly ionospheric and tropospheric effects) for the rover. A virtual reference station would be created a few meters near the rover for on-going measurements (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003).

The SAPOS (Satellite Positioning) community in Germany introduced a method for broadcasting network correction streams called 'FKP'. FKP stands for the German word 'Flächenkorrekturparameter' which means area correction parameter. Within SAPOS, the providers standardize RTCM 2.3 with a proprietary extension (a type 59 message). This additional message describes the linear ionospheric and geometric correction around a physical reference station. The linear corrections are derived from a data processing centre using multiple reference stations. This is running in a data broadcasting model different from VRS. However, initial position could be sent from rover to centre for selection of reference station to yield a better FKP (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003).

The last one is IMAX from Leica. IMAX is a variant of Max. Max stands for master-Auxiliary corrections while iMax stands for individualized Master-Auxiliary corrections. The difference between Max and iMax is that Max supports RTCM 3.0 that would be broadcasted to rover, while iMax supports RTCM 2.3 and 3.0 that require bi-directional communication. However, the mechanism is that same those servers at the centre will select closest master reference station and auxiliary reference stations to the rover, estimation to correct ambiguity would be provided. The differ-

ence from VRS is that Max uses real reference station but not a virtual reference station. There is Auto-Max in which server would provide optimum master and auxiliary configuration (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003, Kaartinen et al. 2015, Wright et al. 2017).

### **Continuously operating reference stations (CORS)**

Within the past year, a new technological development has emerged that dramatically enhances the utility of RTK GPS positioning. For a number of years, various agencies of the federal government have cooperated in developing a network of continuously operating reference stations (CORS) for GPS. These facilities 1) continuously receive and archive signals from all GPS satellites that are visible to them and 2) broadcast corrections to coarse acquisition (C/A) pseudo ranges to be used for differential positioning by any receiver that can receive them. This form of differential positioning produces accuracies of  $\pm 2\text{--}5$  m and is suitable for applications such as automatic vehicle location, personal navigation, and mapping of natural resources. The more recent development in CORS applies to more accurate RTK surveys that employ carrier phase measurements instead of the coarse acquisition code. Achievable accuracies are at the centimetre level. CORS data can be used for Real-Time Kinematic (RTK) applications, meaning that the station provides continuous correction data to roving GPS receivers with internet accessible capabilities. The GPS correction data is typically transmitted at 1-Hz through the internet. Therefore, a GPS system utilizing a cellular modem can obtain the

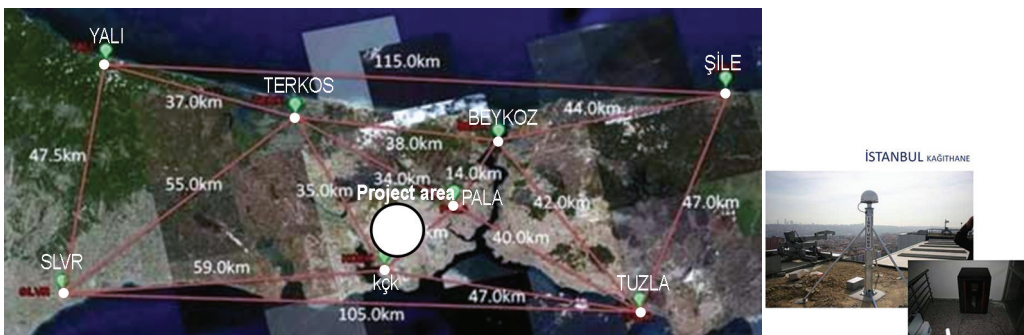
correction data which in return provides centimetre level position accuracy within a short range of the CORS station (1 to 30 miles depending on terrain and other operating conditions). The raw correction data is also archived and made available via the internet for post-processing of GPS data for static surveying, mapping and remote sensing projects. GPS positions are based on a series of calculations and averages. Applying statistical principles, the more data that is used and the more calculations that are made, the more confidence we can have in the results. Continuously Operating Reference Stations (CORS) are permanently located GPS receivers that operate on a continual basis. They are continuously collecting satellite data and using it to recalculate their positions. CORS generally use higher quality GPS antennas, which allow for even more precise calculations. CORS can be implemented in both post processed and RTK surveying. Many CORS are equipped with one or more communication links. CORS that broadcast over UHF radio are making the corrections available to the general public. Anyone with the right UHF radio link on their receiver and within signal range should be able to use the corrections for RTK surveys. CORS stations that are using other methods for broadcasting the corrections may or may not be available to the general public. In order to access the corrections a user might need to be added to a user list or subscribe to a pay service. The advantage of being able to access a CORS for RTK surveys is that this eliminates the need to set up a reference receiver for each survey. The benefit of a CORS site or network is the ability to provide accurate, repeatable position data free of charge permitting users to return to the exact same locations over time. Data collected from CORS sites has

a wide array of uses. For example, CORS data can be used for monitoring coastal subsidence, surveying, determining the amount of perceptible water vapour in the atmosphere, recording and locating utility lines, and machine guidance for construction and precision agriculture. The CORS files have data grouped in both one-hour and one-day intervals. During the day of collection, the data is posted in one-hour intervals starting at midnight, Coordinated Universal Time (UTC). Each file is identified by the station identifier, day of the year, a letter designator indicating the hour, the year, and the type of data contained in the file. There are three types of files available for each hour. These are the navigation file (data on satellite positions), the observation file (observed pseudo range data) and the station file (receiver station data) which are designated by n, o and s, respectively. As mentioned earlier, the data is also stored in one-day intervals. This avoids needing to merge CORS files to process data that spans two or more one-hour intervals. However, these one-day files involve considerable amounts of data to download and process. Thus to avoid file conversions, handling unnecessary data, and to simplify the downloading process, the website also provides a User

Friendly Option (UF CORS) (Bock et al. 2002, Rizos 2007, Snay 2008).

## Materials and Methods

The work was performed in the Campus of Yıldız Technical University Davutpaşa/ Esenler, Istanbul Turkey, and see figures 1 and 2. The 17 points were selected in the project area. Two of them were marked in the unobstructed environment; the others were marked near/in the forest environment (see Fig. 3). Two tests were carried out in order to evaluate the performance and the accuracy of the CORS RTK (VRS) method for the survey projects. Throughout the first test, we measured all 17 points by using static GPS measurements. The static GPS survey was conducted on 25 May 2009 in order to determine the coordinates of these 17 test points. The measurements on these test points were performed with at least 2 hours of observation time. The minimum elevation cut-off angle and the sample rate were 10 degrees and 10 seconds, respectively. All static GPS measurements were carried out using six Ashtech Z Max GPS receivers and data processing and network adjustments were conducted us-



**Fig. 1. Istanbul water and sewerage administration (ISKI) CORS GPS network and the project area in Istanbul, Turkey.**





Fig. 2. The project area in Davutpaşa, Istanbul, Turkey.

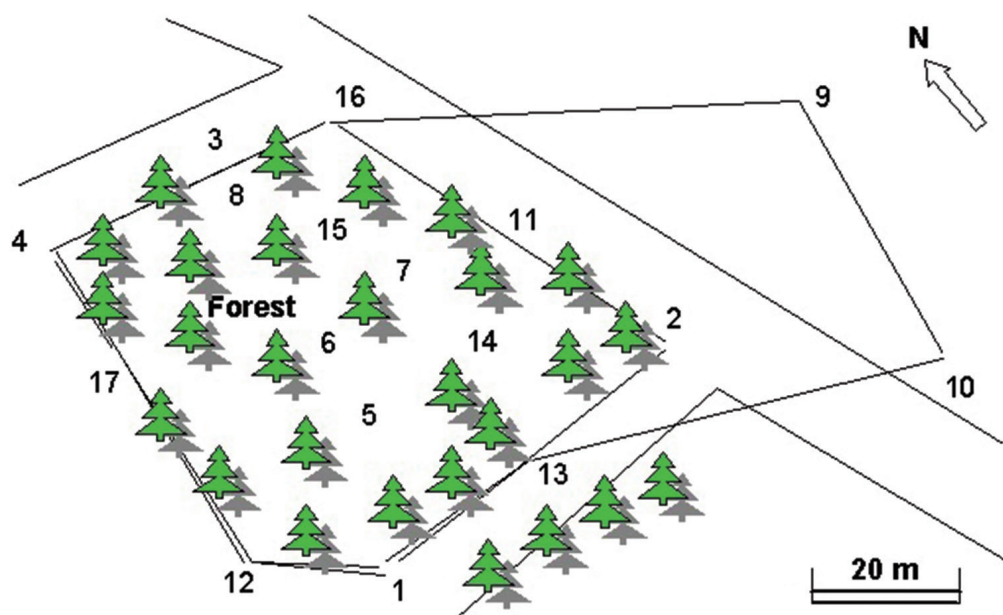


Fig. 3. Distribution of test points in the project area.

ing the Ashtech Solution 2.60 Software. In the adjustment procedure, the ED50 (European Datum 1950) coordinates of N102 (triangulation point in Yıldız Technical University Davutpaşa Campus in Istanbul, Turkey, see Fig. 2) were held fixed (Table 1). Throughout the second test, we performed CORS RTK measure-

ments for 17 test points in the project area by using a Topcon HiperPro RTK (GPS/GLONASS) field unit. For this CORS RTK survey, (Istanbul Water and Sewerage Administration) İSKİ CORS reference points were used in the İstanbul region of Turkey (see Fig. 1). İSKİ CORS system consists of eight stations and one central process-

**Table 1. Coordinates and their standard deviations of the test points.**

| Point No | X, m        | Std., mm | Y, m          | Std., mm | H, m   | Std, mm |
|----------|-------------|----------|---------------|----------|--------|---------|
| 102      | 406,739.361 | fixed    | 4,543,871.860 | fixed    | 71.020 | fixed   |
| 1        | 406,725.971 | 11       | 4,543,807.512 | 13       | 70.791 | 24      |
| 2        | 406,758.683 | 19       | 4,543,840.925 | 16       | 69.686 | 26      |
| 3        | 406,706.434 | 12       | 4,543,867.141 | 18       | 72.400 | 20      |
| 4        | 406,686.43  | 17       | 4,543,854.375 | 19       | 73.349 | 21      |
| 5        | 406,726.575 | 29       | 4,543,833.006 | 33       | 71.163 | 43      |
| 6        | 406,717.805 | 25       | 4,543,843.890 | 27       | 71.429 | 34      |
| 7        | 406,725.556 | 44       | 4,543,853.778 | 44       | 71.605 | 46      |
| 8        | 406,707.998 | 30       | 4,543,859.063 | 44       | 72.063 | 78      |
| 9        | 406,774.905 | 11       | 4,543,877.576 | 16       | 70.051 | 21      |
| 10       | 406,791.782 | 11       | 4,543,839.573 | 13       | 69.320 | 19      |
| 11       | 406,741.477 | 15       | 4,543,855.711 | 19       | 71.000 | 28      |
| 12       | 406,709.896 | 11       | 4,543,808.910 | 11       | 71.309 | 21      |
| 13       | 406,743.074 | 15       | 4,543,823.778 | 16       | 70.531 | 34      |
| 14       | 406,734.294 | 24       | 4,543,841.464 | 22       | 71.141 | 30      |
| 15       | 406,716.893 | 29       | 4,543,860.761 | 73       | 71.605 | 92      |
| 16       | 406,719.405 | 4        | 4,543,874.624 | 6        | 71.887 | 8       |
| 17       | 406,694.361 | 4        | 4,543,838.558 | 6        | 71.213 | 9       |

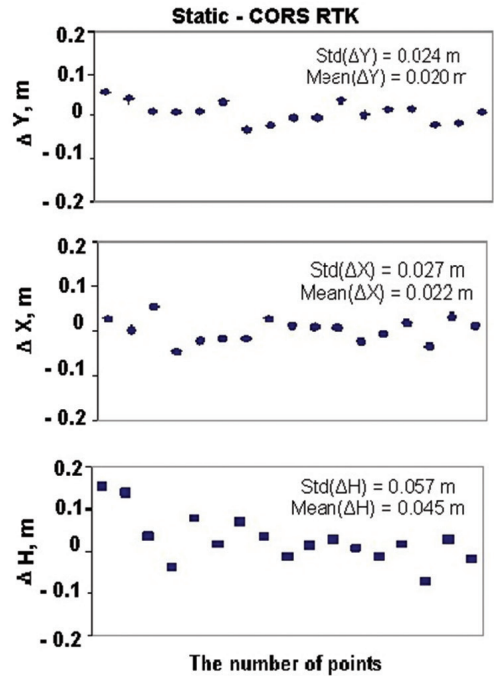
ing centre for the processing and distribution of Global Navigation Satellite System (GNSS) data (Fig. 1). These stations are designed to form a precise geodetic network of permanent stations which continuously track the visible GNSS satellites and where satellite receivers are to be installed. The GNSS receivers will telemetry the data to the Central Processing Centre via internet or a GSM media at a measurement interval of 1 second. The objectives of establishing İSKİ CORS network are to increase and to improve the real-time and post processing capabilities of GNSS and their geomatics and engineering applications, monitoring of recent crustal movements and atmospheric and geodynamic studies. In the last test for this study, we performed total station measurements for 17 test points in the project area. The objective of the tests was to assess the CORS RTK (VRS) achievable accuracy by using İSKİ CORS reference points.

So, the CORS RTK survey performance (VRS) was evaluated in the unobstructed environment and near/in the obstructed (forest) environment, under varying site conditions and where problems due to signal blockage were expected (see Fig. 3). As explained above, three different survey methods were used to coordinate a group of 17 points, marked on the ground. Figure 3 illustrates the distribution of the test points. The maximum distance between the points in the North-South direction was about 50 m. In the East-West direction the maximum distance was about 50 m.

## Results

To evaluate the CORS RTK accuracy, CORS RTK surveys using İSKİ CORS reference points were performed, each time occupying all of the test points. The CORS RTK surveys were performed on 30 May

2009 (9:00 – 19:45 h local time (LT)). The İSKİ CORS reference station PALA was about 10 km away from the CORS RTK measurement site, KÇK about 12 km (see Fig. 2). The satellite visibility was 8–11 (GPS+GLONASS) satellites in open areas (points 9 and 10) and the recorded PDOP average values were between 1.2 and 2.5. A total of 17 point observations for the 17 test points were obtained on 30 May 2009. CORS RTK survey was performed according to no of points. In the analysis step, the accuracy assessment of the CORS RTK survey was conducted by comparing the coordinates of a group of points (17 points) obtained from İSKİ CORS reference points with the coordinates determined by the static GPS measurements from Point No 102. Figure 4 shows the differences and their means and standard deviations for the 17 points. The analysis of the test between the CORS RTK results and static GPS results shows that the discrepancies of the horizontal coordinates are a few mm to 1 cm in the unobstructed environment (points 9 and 10, see Fig. 4, the marked part). The discrepancies of the height coordinates were a few centimetres to about 2 cm in the unobstructed environment (Fig. 4, the marked part). Except for the unobstructed area (Points 9 and 10), the other fifteen points have poor lines of sight to the satellites because of the forested area (see figs 2 and 3). The trees and bushes caused severe obstruction of almost 50–90 % of the sky for these fifteen points in the project area (Fig. 2). Even though several satellites were shaded by the trees and bushes, they can be still tracked by the receiver. Five-six (4 GPS+1–2 GLONASS) satellites were visible in this period. The PDOP value was between 3.4 and 4.2 for this period (Pirti 2005, 2008). Due to the above mentioned reasons, the CORS



**Fig. 4. Comparison of the coordinates of the 17 points in the project area between static GPS and CORS RTK surveys.**

RTK measurements on fifteen points took a very long time. The ambiguity resolution time was approximately 10 hours 30 minutes for these fifteen points. The differences for the horizontal coordinates of these fifteen points between CORS RTK and static measurements were greater than 2 cm (see Fig. 4).

Elevation or height differences are necessary measurements for many forest operation activities. Some of the potential and useful GPS applications in forestry include tree location mapping, forest compartment boundary survey, forest road survey, ground truth activities (remote sensing) and resources inventory (Pirti 2005, 2008). An analysis of the measurements at the project area clearly demonstrates that the differences are greater (~5 cm) for the vertical coordinates for the

fifteen points (see Fig. 4). For the other two points, the height differences were at the level of a few centimetres (see Fig. 4, the marked part).

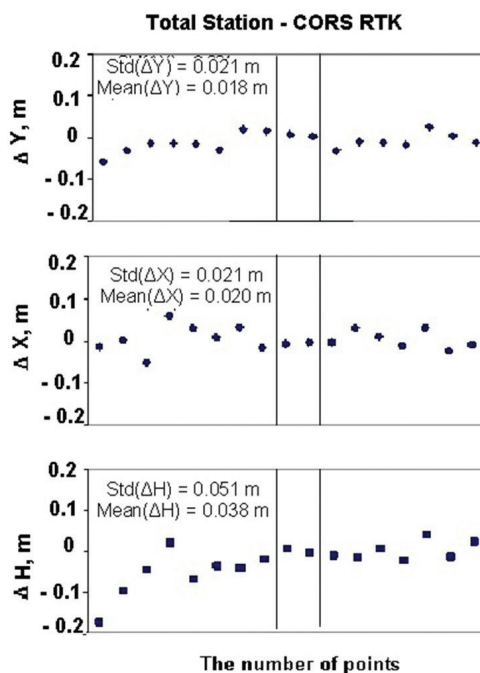
The total station survey was carried out to check the performance of the CORS RTK. The 17 point coordinates were established by a total station (Topcon GTS-701 (angle accuracy:  $\pm 2''$ , distance measurement accuracy: 2 mm + 2 ppm)). The Point No 101 and Point No 102 triangulation points were fixed for the total station surveys (Fig. 2). The ITRF coordinates of Point No 101 and Point No 102 were determined in static GNSS technique (survey time 60 min) by fixing the IGS reference point ISTA. The sequence of terrestrial measurements was the same with the CORS RTK survey. In order to compute the coordinates of the 17 points, horizontal direction, zenith angle and slope distance were recorded with Topcon GTS-701.

In this test, the accuracy assessment of the CORS RTK survey was performed by comparing the coordinates of a group of points (17 points) gained from ISKI CORS reference points with the coordinates determined by the total station from Point No 102. The term 'geodetic' is used to loosely refer to bearings and coordinates related to the European Datum 1950 (ED50). Figure 5 gives the coordinate differences between the CORS RTK and the traditional survey.

The comparison of the results of the CORS RTK and total station surveys shows that standard deviation of the horizontal coordinate differences was about 1 cm in the unobstructed area. The standard deviation of the height differences was 2 cm in the unobstructed area (see Fig. 5, the marked part). As shown in Figure 5, the mean differences between the RTK survey and the total station survey were

less than 1 cm for the horizontal coordinates and less than 2 cm for the vertical coordinates (points 9 and 10). Again, the largest variations in horizontal and vertical components were recorded for the fifteen points (the obstructed area) (see Fig. 5). The variations were about 6 cm in the X-Y coordinates and about 20 cm in the H coordinates in the obstructed environment.

The mean differences between the RTK and traditional survey were less than 1 cm for the horizontal components and less than 2 cm along the vertical components under good conditions. The mean differences between the CORS RTK and traditional surveys were less than 6 cm for the horizontal components, and less than 20 cm along the vertical components in the obstructed areas. Apart from the points which are near/in the forest area,



**Fig. 5. Comparison of the coordinates of the 17 points in the project area between total station and CORS RTK surveys.**

when comparing the CORS RTK, static GPS, total station results of the tests, the horizontal components of the test points as separately determined by these tests seems very consistent, with changes ranging between a few millimetres up to 1 cm. The height value was less consistent, and sometimes differed up to 2 cm at the same point among the CORS RTK, static GPS, and total station sessions. However, the maximum differences of the horizontal and vertical components are about 10–20 cm in the experiment because these fifteen points are near/in the forest area.

The comparison of the results of the static GPS and total station surveys is shown in Figure 6. The standard deviation of the horizontal coordinate differences was about 1 cm for the unobstructed and obstructed areas. The standard deviation

of the height differences was about 2 cm for the unobstructed and obstructed areas (see Fig. 6). As shown in Figure 6, the mean differences between the static GPS survey and the total station survey were less than 1 cm for the horizontal components and less than 2 cm for the vertical components.

## Conclusions

In this paper, we have shown that CORS RTK can be used for forest boundary surveying, although a common obstacle, the sky blockage, will hinder its full effectiveness. Despite the accuracy problems in forested areas, the CORS RTK method is a very efficient replacement for difficult total station survey situations. Particularly where the centimetre level horizontal accuracy is required, the CORS RTK method is problem free. This study shows that the CORS RTK method can replace other survey methods in the forest applications which require the above mentioned accuracy. But this problem can be overcome supplemented by conventional survey techniques. In this study, CORS RTK method by using only ISKI CORS reference points took approximately 10 hours 30 minutes to complete 17 points survey in the project area. Total station method took approximately 1 h to survey 17 points in the field. The CORS RTK took about 15 min in the office (Data transfer and processing). Total station took about 10 min in the office (Data transfer and processing).

## Acknowledgement

We would like to thank the staff of Topcon Company and ISKI (Istanbul Water and

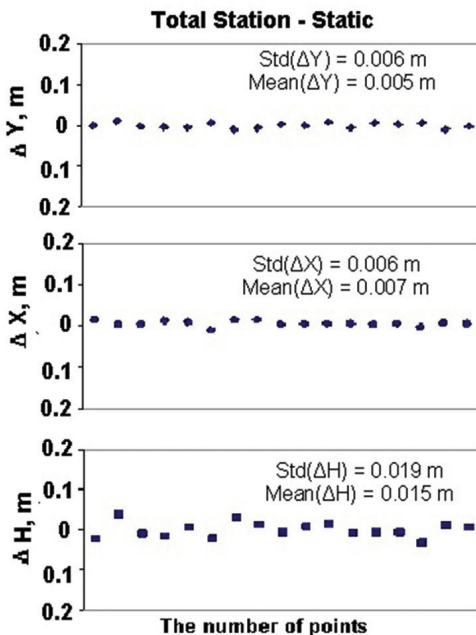


Fig. 6. Comparison of the coordinates of the 17 points in the project area between total station and static GPS surveys.



Sewerage Administration) in Istanbul, Turkey for their helps.

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## ASSESSMENT OF ACRISOLS SOIL FERTILITY ON THE TERRITORY OF PETROHAN TRAINING AND EXPERIMENTAL FOREST RANGE, BULGARIA

Kameliya Petrova, Pavel Pavlov\*, and Yordan Ivanov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria.

\*E-mail: pavelppj@googlemail.com

Received: 15 July 2019

Accepted: 27 October 2019

### Abstract

The soil fertility of Acrisols on the territory of 'Petrohan' Training and Experimental Forest Range was assessed by applying the National Classification System developed for soils in forest territories, according to which the following 4 indicators were used – soil depth, org. C stock, total N stock and available soil moisture. In accordance with it Acrisols were characterized from low to moderately fertile. The growth of tree species was also assessed and it was determined as very good for *Fagus sylvatica* L., *Quercus petraea* (Matt.) Liebl. and *Betula pendula* L. For *Pinus sylvestris* L. and *Carpinus betulus* L. was established low growth. The good growth of tree stands did not correspond to the soil fertility assessments. They were different regarding the different indicators. It is assumed that the static examination of nutrient stock should be replaced by studies on the balance of their use and recovery in soils through the biological nutrient cycling.

**Key words:** available soil moisture, forest soil, org. C stock, total N stock, tree growth.

### Introduction

Different indicators for assessment of soil fertility are mentioned in scientific literature. They can be divided into chemical (nutrients), physical (soil depth) and biological (soil organisms). The most frequently used indicators are  $\text{pH}_{\text{H}_2\text{O}}$ , humus quantity, total amounts of nitrogen, phosphorus and potassium, as well as available forms of nitrogen, phosphorus, potassium, copper, zinc, boron, iron, etc. (Deng et al. 2016). The ratio of nutrients in soil is also significant (Ingestad 1987). Particular attention is given to the ratio org. C/N (Lukina et al. 2011), which is an indicator of nitrogen nutrition. According to Deng et al. (2016) the high soil ferti-

ty in forest territories is characterized by the high nitrogen content, low phosphorus and moderate potassium content. According to Legout et al. (2014) soil fertility is high if the  $\text{pH}_{\text{H}_2\text{O}}$ , exchange basic cations and available phosphorus are in high quantities or the ratio C/N in soil is low. Fungal communities are also an important indicator. Their interrelation with soil fertility is very strong at the levels of species, genera/orders and functional groups (Sterkenburg et al. 2015).

Ponette et al. (2014) studied indicators such as climate, water balance, availability of nutrients, etc., taking into account that at certain moment the fertility indicators could have an opposite effect – disturbance of water balance, delayed

organic matter decomposition, changes in the duration of vegetation period, etc.

The deficiency of plant nutrients in soil is important in agricultural lands. Such an approach is often applied to naturally growing species but this creates a number of difficulties, especially regarding the plant communities (Chapin et al. 1986). For example, significant differences in nutrient content were determined in tree layer and forest floor. The ratio between org. C and nutrient amount is higher in the forest floor (Vesterdal and Raulund-Rasmussen 1998). For practical purposes the soil 'chemical fertility' in a given forest is usually determined by a group of nutrients which content is compared to the requirements of the different tree species. This approach is inherited from agronomy and is often unreliable when applied in forest ecosystems. Sometimes these soils are poor in main macroelements such as Ca, Mg, K and are still characterized by high fertility (Legout et al. 2014). Practice showed that the highest species richness often occurred in poor growing conditions (Huston 1980). However, in some cases gradients of changes in plant communities, depending on soil  $pH_{H_2O}$  and amount of available nitrogen, were determined (Sterkenburg et al. 2015).

Contemporary approaches for assessment of soil fertility include a number of complex relations in forest ecosystems, connected with the nutrient cycling. The recovery of elements in soil is assessed. The main method is associated with decomposition of organic matter deposited on the surface of forest litterfall (Ponette et al. 2014). Significant relations between the adsorption processes occurring on the fine roots of tree species and leaf biomass were determined (Shun 2018, Meng et al. 2018).

Finding the sensitive indicators in for-

est ecosystems, which could evolve under the influence of the carried out silvicultural practices and global environmental changes, is a challenge to contemporary science (Ponette et al. 2014).

The aim of the present study was to assess the soil fertility of Acrisols on the territory of 'Petrohan' Training and Experimental Forest Range.

## Material and Methods

The studied soils occupy an altitude from 692 m to 754 m on the northern slope of the Balkan Mountains, on the territory of 'Petrohan' Training and Experimental Forest Range. They are formed on acidic magma and metamorphic rocks, mainly granite, gneiss granite, diorite, gabbro, etc., which are the result of basic magma fractionation and its mixing with acidic one (Tacheva et al. 2006, 2007). The relief is typically mountainous, with steep slopes, deep-cut river valleys, and steep secondary ridges (Ninov 2002). The continental nature of the climate in this area is highly pronounced. The absolute air temperature minimums reach  $-28.0^{\circ}\text{C}$ . Temperatures in July are from  $19.6^{\circ}\text{C}$  to  $20.2^{\circ}\text{C}$ , reaching  $26.0$ – $27.0^{\circ}\text{C}$ . The amount of precipitations is within the range of 450–500 mm (Koleva-Lizama 2006). The main tree specimen, taking part in the soil-forming process, is the Common beech (*Fagus sylvatica* L.). Other deciduous tree species also occur – Common hornbeam (*Carpinus betulus* L.), Turkey oak (*Quercus cerris* L.), Sessile oak (*Quercus petraea* (Matt.) Liebl.), etc. The distribution of coniferous tree species is limited, mainly stands of Scots pine (*Pinus sylvestris* L.), Austrian pine (*Pinus nigra* Arn.), etc.

Acrisols is a new soil unit for Bulgaria, described for first time in 2019 on the

territory of 'Petrohan' Training and Experimental Forest Range (Malinova and Petrova 2019). In accordance with the WRB requirements (2006–2007) they were determined as Vetic Acrisols.

The National Classification System, developed for soils in forest territories, was applied to assess the fertility of this soil type (Donov 1976, Donovan and Yordanov 1988, Raikov et al. 2011). Four indicators – soil depth, org. C stock, total N stock and available soil moisture, determined for the soil profile depth, were used. Soils, having the following characteristics, are assessed as fertile: deep soils (>150 cm), with a high humus stock (>150 t·ha<sup>-1</sup>) and high nitrogen stock (>10 t·ha<sup>-1</sup>), and high values of available soil moisture (>400 mm). Low fertile soils are shallow ones (<100 cm), with low humus (<100 t·ha<sup>-1</sup>) and low nitrogen stock (<5 t·ha<sup>-1</sup>), as well as with low values of available soil moisture (<200 mm). Moderately fertile soils are characterized by intermediate indicators.

The content of soil organic matter was determined by the modified Turin method – 120 °C, 45 min and Ag<sub>2</sub>SO<sub>4</sub> as a catalyst (Kononova 1963, Filcheva and Tsadilas 2002); total nitrogen – using Kjeldal's method with Kjeltex Auto 1030 Analyzer; total water capacity, field capacity, wilting point and available soil moisture – Kachinskii method (Kachinskii 1963) and bulk density – ISO 11272.

The forest mensuration methods were determined according the stands' age. A tabular method was used for the young stands (up to 20 years); older stands were assessed by applying a mathematical and statistical method. Sample plots with dimensions from 30×50 m to 40×70 m were used. The height and DBH (diameter at breast height) of all trees on the plots were measured. The following indicators

were determined: stand composition and origin; average age, average height, average DBH and growing stock by tree species; site index by tree species and relative stocking. The age of stands was determined using increment borer.

## Results

In the National Scale for Assessment of Soil Fertility in forest territories it is assumed that the increase of soil depth will also increase root soil layer and also the area from which the tree roots take nutrients and water (Donov 1976, Donovan and Yordanov 1988). Previous studies demonstrated that org. C stock, total N stock and available soil moisture can be limiting factors to the tree growth, but the increase of their values resulted in improved growth. The assessment is actual over time although in the recent past nitrogen depositions were too high for the territory of the continent. In some regions they affected the soils in forest ecosystems which resulted in changes of the org. C/N ratio, eutrophication, etc. Their reduction began shortly – after 2015 (EEA 2015). According to some authors, soils in forest ecosystems are not easily saturated with nitrogen (Robert et al. 2012), even when the amounts of nitrogen depositions exceed the needs of vegetation on a given territory. No changes of the ratio org. C/N, caused by increased nitrogen depositions, was determined for the soils on forest territories of Bulgaria for the period 1998–2015 (Tsvetkova et al. 2016), which allowed the use of the assessment scale developed by Donovan and Yordanov (1988) in the respective part for total N stock.

The results, necessary for assessment of soil fertility, are presented in Table 1. Acrisols refer to the shallow soils.

Table 1. Acrisols location, composition parameters and available soil moisture (ASM).

| Soil profile, No | Coordinates                     | Elevation, m | Soil horizons | Soil depth, cm | Humus, t·ha <sup>-1</sup> | Total N, t·ha <sup>-1</sup> | Bulk density, g·cm <sup>-3</sup> | ASM, mm |
|------------------|---------------------------------|--------------|---------------|----------------|---------------------------|-----------------------------|----------------------------------|---------|
| 1                | 43°11'08.5" N<br>23°07'52.3" E  | 754          | A             | 0-27           | 159                       | 105                         | 1.4                              | 77      |
|                  |                                 | 754          | Bt1           | 27-52          | 46                        | 51                          | 1.5                              | 77      |
|                  |                                 | 754          | Bt2           | 52-82          | 36                        | 59                          | 1.6                              | 74      |
| 2                | 43°11'21.5" N<br>23°07'58.2" E  | 717          | A             | 0-5            | 29                        | 8                           | 1.2                              | 22      |
|                  |                                 | 717          | Bt            | 5-47           | 126                       | 51                          | 1.1                              | 189     |
| 3                | 43°11'21.04" N<br>23°07'59.9" E | 694          | A             | 0-13           | 72                        | 34                          | 1.2                              | 53      |
|                  |                                 | 694          | Bt            | 13-42          | 148                       | 91                          | 1.6                              | 74      |
| 4                | 43°11'35.2" N<br>23°08'13.3" E  | 649          | A             | 0-15           | 45                        | 29                          | 1.2                              | 52      |
|                  |                                 | 649          | B             | 15-55          | 52                        | 65                          | 1.5                              | 115     |
|                  |                                 | 649          | Bt            | 55-102         | 8                         | 50                          | 1.7                              | 113     |
| 5                | 43°10'29.9" N<br>23°09'12.1" E  | 692          | A             | 0-7            | 32                        | 12                          | 1.3                              | 27      |
|                  |                                 | 692          | B             | 7-23           | 39                        | 15                          | 1.4                              | 40      |
|                  |                                 | 692          | Bt            | 23-105         | 111                       | 57                          | 1.6                              | 288     |

Their profile was less than 100 cm. The boundary between shallow and medium deep soils (100 cm) was slightly exceeded from 2 to 5 cm in only two of the profiles – No 4 and 5. The results showed a different degree of erosion processes occurring in the past. In the predominant case A horizon had a depth from 5 to 15 cm. An exception was determined in profile No 1 where the humus horizon reached 27 cm. According to a study, carried out by Ilieva and Petrova (2019), the terrain and climatic conditions on the territory of the Forest Range are a prerequisite for the high erosion potential. The absence of modern intensive processes of sheet and gully water soil erosion is due to the high soil-protecting efficiency of the stands on 92.6 % of the territory.

Humus stocks in the studied soil profiles were different (Table 1). Profiles No 1, 3 and 5 were referred to the high stock category (over 150 t·ha<sup>-1</sup>). Profile No 2 can be referred to the same category, although the excess over 150 t·ha<sup>-1</sup> was only 5 t·ha<sup>-1</sup>. The high stock is due to their higher soil depth.

The high humus content, illustrated for profile No 1 on Figure 1, is also important. Profile No 3 was characterized by the high humus content also in the *argic* diagnostic horizon (Fig. 2). The *argic* horizon itself is enriched with clay that contributes for the active use of humic substances with it. It can be assumed that in this case the soil texture shows a greater influence on the ASM than on the soil depth. Profile No 4 was different – the stock was medium.

The assessment of the total nitrogen stock did not fully coincide with that of the humus. It was high in profiles No 1, 3 and 4, and medium in profiles No 2 and 5.

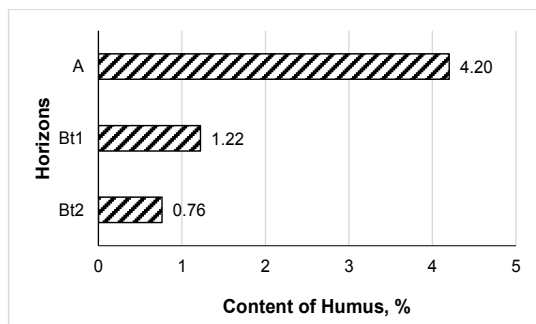


Fig. 1. Humus in soil profile No 1.

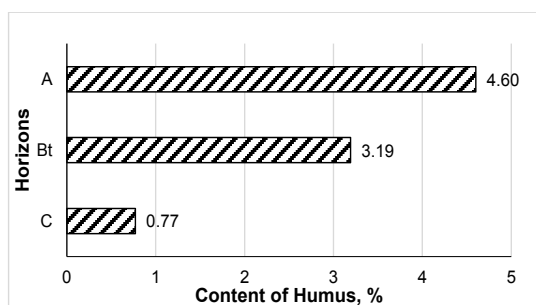


Fig. 2. Humus in soil profile No 2.

The values of the available soil moisture were assessed as low in only one of the profiles – No 3. It was shallow and the values of the available soil moisture in the surface and *argic* horizons were 126 mm. In the other profiles the values ranged from 210 mm to 355 mm and can be assessed as medium.

The assessments regarding the 4 criteria applied to the studied soil profiles are presented in Table 2.

The assessments differed regarding the individual indicators in the same profile. Similar results were also obtained from other authors (Legout et al. 2014), which confirmed the complexity of the overall assessment of soil fertility. In summary, according to the applied assessment scale (Donov and Yordanov 1988) the fertility of Acrisols was low in the shallow soils (profiles No 1, 2 and 3). In these soils the root layer was a limiting factor. The other two profiles (No 4 and 5) were characterized by moderate fertility.

In studies, carried out by Malinova and Petrova (2019), the 'chemical' fertility was assessed as very low. Acrisols were characterized by an oxide composition in the fine earth. It contained mainly quartz (45–49 %), microcline (17–25 %) and albite (10–19 %). Clay minerals were absent or difficult to determine due to their low content. This explains the very low cation exchange capacity – lower than 6 cmol (+)·kg<sup>-1</sup>, which is enough to assess the soil as very poor.

The growth of tree species, however, was very good. They are of natural origin. The predominant tree species on the Forest Range territory is *Fagus sylvatica*. On the territory, where Acrisols were determined, it was presented in 2 stands – pure Beech (profile No 2) and mixed with other deciduous species (profile No 4) of

Table 2. Results from the assessment of soil profiles.

| Soil profile, No | Soil depth      | Humus stock     | Total N stock   | Available soil moisture |
|------------------|-----------------|-----------------|-----------------|-------------------------|
| 1                | shallow         | high            | high            | high                    |
| 2                | shallow         | high            | moderately high | high                    |
| 3                | shallow         | high            | high            | low                     |
| 4                | moderately deep | moderately high | high            | high                    |
| 5                | moderately deep | high            | moderately high | high                    |

similar age. The site index was high – I for the mixed stand and II for the pure stand. The high site index of the Sessile oak – I class, should be noted. Unlike the Common beech and Sessile oak, the Common hornbeam was characterized by much worse growth. In the studied pure Common hornbeam stand (profile No 5), the site index fell to IV class.

Good growth on Acrisols demonstrated the young stands of Silver birch and Scots pine, which are less demanding. They are also of natural origin. Their dendrometric indicators (Table 3) allowed to refer both tree species to I yield class. Scots pine had the highest yield class – I<sup>A</sup>.

The spring-summer aspect of grass species showed great variety. The largest number of species was determined in the Silver birch stand. Its crown was not dense and allowed the passage of enough light and heat to the soil surface for development of grass and shrub species. The presence of the following species was determined in the stand: *Pteridium aquilinum* (L.) Kuhn, *Aethusa cynapium* L., *Rubus Idaeus* L., *Rubus fruticosus* L., *Campanula persicifolia* L., *Fragaria vesca* L., *Galium* sp., *Euphorbia cyparissias* L., *Ajuga reptans* L., *Potentilla recta* L., *Leucanthemum vulgare* Lam., *Filipendula vulgaris* Moench, *Clinopodium vulgare* L., *Crataegus monogyna* Jacq., *Festuca* sp., *Melica uniflora* Retz., *Anthriscus cerefolium* L. Participation of grass species in the other sites was limited. In addition to the aforementioned species there were also single or small groups of *Rumex acetosella* L., *Taraxacum officinale* (L.) Weber, *Viola odorata* L., *Viola sylvatica* Fr., *Galium* sp., *Athyrium filix-femina* (L.) Roth, *Polygonatum multiflorum* (L.) All., etc.

The good growth of tree stands did not correspond to the soil fertility assessments. They were different regarding the

different indicators.

The assessments themselves are different for each indicator and this should also be taken into account in practice, for example when determining forest sites. In this case, the studied sites fall into the same site (Raikov et al. 2011). In it, they should be homogeneous in terms of both abiotic factors and growth of tree species.

Other authors also had similar difficulties when performing a complex assessment of soil fertility in forest ecosystems (Chapin et al. 1986, Ponette et al. 2014, Legout et al. 2014, Vesterdal and Raulund-Rasmussen 1998). According to Legout et al. (2014) enough nutrients for the good growth of stands are present in soils when the geochemical component of circulation of substances in the system 'soil – plant' prevails over the biological one. The main source of nutrients in this case is the weathering process occurring in the mineral part of soil. Atmospheric depositions and rise of water in a capillary way from the deeper soil layers also contribute to them. In contrast, small amount of nutrients in soil is observed in the cases of dominating biological or chemical circulation. The importance of biological circulation for plant nutrition is well described in the literature based on the example fast-growing eucalyptus forests. It was determined that the nutrient content in the aboveground biomass is directly dependent on the presence of slash – aboveground organic residues such as leaves, branches, bark, etc. The slope contains immobilized nutrients which in the process of mineralization pass into available for plants form (Nzila et al. 2002, Laclau et al. 2003).

The circulation of nutrients in the examined forest ecosystems with presence of Acrisols has not been studied yet. The results of the analysis of their cation ex-



Table 3. Stands' characteristics.

| Soil profile No | Tree species                                                                                                                                               | Tree participation | Origin              | Average age, years | Relative stocking | Average height, m | Average DBH, cm | Site index     | Growing stock, m <sup>3</sup> .ha <sup>-1</sup> |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|---------------------|--------------------|-------------------|-------------------|-----------------|----------------|-------------------------------------------------|
| 1               | <i>Pinus sylvestris</i> L.                                                                                                                                 |                    | Seed natural origin | 15                 | 1.0               | 7.5               | 10              | I <sup>a</sup> | 84                                              |
|                 | Single trees: <i>Betula pendula</i> L., <i>Acer pseudo-platanus</i> L., <i>Pyrus pyraeaster</i> L., <i>Prunus avium</i> L., <i>Prunus cerasifera</i> Ehrh. | 10                 |                     |                    |                   |                   |                 |                |                                                 |
| 2               | <i>Fagus sylvatica</i> L.                                                                                                                                  |                    | Seed natural origin | 86                 | 0.97              | 23.6              | 29.6            | II             | 403                                             |
|                 | Single trees: <i>Prunus avium</i> L., <i>Quercus petraea</i> (Matt.) Liebl.                                                                                | 10                 |                     |                    |                   |                   |                 |                |                                                 |
| 3               | <i>Betula pendula</i> L.                                                                                                                                   | 9                  | Seed natural origin | 20                 | 1.02              | 10.7              | 11.9            | I              | 86                                              |
|                 | <i>Pinus sylvestris</i> L.                                                                                                                                 |                    | Seed natural origin | 20                 |                   | 11.3              | 11.0            | I <sup>a</sup> | 11                                              |
|                 | Single trees: <i>Carpinus betulus</i> L., <i>Acer pseudo-platanus</i> L., <i>Populus tremula</i> L., <i>Fagus sylvatica</i> L.                             | 1                  |                     |                    |                   |                   |                 |                |                                                 |
| 4               | <i>Fagus sylvatica</i> L.                                                                                                                                  | 7                  | Seed natural origin | 84                 | 0.72              | 27.4              | 30.9            | I              | 227                                             |
|                 | <i>Quercus petraea</i> (Matt.) Liebl.                                                                                                                      | 2                  | Seed natural origin | 78                 |                   | 27.2              | 31.8            | I              | 58                                              |
|                 | <i>Carpinus betulus</i> L.                                                                                                                                 | 1                  | Seed natural origin | 80                 |                   | 21.8              | 19.7            | III            | 31                                              |
| 5               | <i>Carpinus betulus</i> L.                                                                                                                                 | 10                 | Seed natural origin | 105                | 0.79              | 22.3              | 28.0            | IV             | 230                                             |
|                 | Single trees: <i>Fagus sylvatica</i> L.                                                                                                                    |                    |                     |                    |                   |                   |                 |                |                                                 |

change properties showed that in the conditions of very high to high soil acidity ( $\text{pH}_{\text{H}_2\text{O}}$  in the A horizon from 4.7 to 5.4), forest litter was saturated with bases (96–97 %) (Malinova and Petrova 2019). This means that litter is an important nutrient depot in the circulation of substances. Good growth of stands revealed that its decomposition released enough amounts of nutrients which were easily-absorbable by the roots of tree species. The ratios org. C/N in the litter (from 18 to 27) and in the surface soil horizon (from 9 to 20) were low and showed a relatively fast release of mineral nitrogen, i.e. the factors which determine the good growth of stands were available.

## Conclusions

The assessment of soil fertility of Acrisols through chemical and physical indicators is insufficient to interpret the good growth of stands on very poor soils on the territory of the 'Petrohan' Training and Experimental Forest Range. The static examination of nutrient stock should be substituted with studies on the dynamics of their depletion and recovery. The nutrient stock in the forest litter was low and concentrated. For now, it can be assumed that the biological circulation of substances is the main source of mineral nutrition of plants and its balance should be studied and maintained in the long term.

## Acknowledgements

The current study was performed in the framework of the National Programme of the Bulgarian Ministry of Education and Science 'Young scientists and postdoctoral students'.

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## RESULTS OF GRAFTING OF *MORUS ALBA* L. ORNAMENTAL FORMS

Volodymyr Vitenko\*, Volodymyr Shlapak, Iryna Kozachenko, Volodymyr Kulbitskyi, Svitlana Maslovata, Sergiy Koval, and Oleh Lazariev

Department of Forestry, Uman National University of Horticulture, 1 Instytutska Str., 20305  
Uman, Ukraine. \*E-mail: uman.vitenko@ukr.net

Received: 05 October 2018

Accepted: 25 November 2019

### Abstract

Based on the processing of literary sources and our own research, we studied the features of grafting ornamental forms of *Morus alba*: 'Pendula', 'Globosa', 'Pyramidalis', 'Contorta', 'Macrophylla' and 'Tatarica'. It is proposed to distribute these ornamental forms according to the grafting and budding dates: winter – the second or the third decade of February – the first decade of March; spring: early spring (the second or the third decade of March); spring the average (the first – the second decade of April); late spring (the third decade of April – the first to the second decade of May); summer – the end of the first decade of July is the first decade of August. It is investigated that the best period for its holding is the first and the second decade of April. It is determined that the most effective method of winter grafting is improved copulation, which was carried out in early March – the highest average splicing of various components after grafting of these plants was observed in forms 'Tatarica' (70 %) and 'Macrophylla' (60 %). When grafting plants by splitting in these forms, the highest average splicing is also noted – compared 61 % and 54 %. The highest splicing results of grafted plants during their spring grafting were also obtained by applying the improved copulation method in forms 'Tatarica' – (88–92 %), 'Pendula' – (78–84 %) and 'Macrophylla' – compared 65–75 %. The largest number of splices of grafted plants during grafting by applying the method for behind the bark is noted in form 'Tatarica' (87–91 %, a little lower – in 'Pendula' (73–77 %) and 'Macrophylla' – compared 64–72 %. It was investigated that the wild plant (*M. alba*) and its studied ornamental forms resemble their internal structure and the grafting sites are quickly spliced and are completely covered with a protective fabric before the onset of the rest period.

**Key words:** bark, improved copulation, splitting, white mulberry, winter and spring grafting.

### Introduction

With the development of ornamental horticulture, the demand for introduced ornamental fruit plants, including ornamental belonging to Moraceae family, greatly increases. White mulberry (*Morus alba* L.) varieties can be grown with the use of grafting (in winter and spring) or chip bud-

ding (in spring and summer).

Grafting refers to artificial methods of vegetative propagation, which is a combination of shoots or buds of one plant with another, which has a root system (Vitenko 2014, Vitenko and Shlapak 2016).

Krenke (1966) notes that the descriptions of different grafting techniques have been known since the times of Aristotle

and Theophrastus, etc. The most common among them is improved copulation, from behind the bark splitting.

Sobchenko (2005, 2008) points out that currently there are about 400 different methods of grafting various plants. Commercial grafting methods include two large groups: 1) ablactation – when different parts of different plants are joined by convergence they are not separated from the parental forms until they are completely merged; 2) grafting of one plant into a separate part of another. This compound allows the implanted parts to grow together due to the activity of living cells in the cambial zone, as a result of division the contact area between two plants is filled with calus tissue with a large number of parenchymal cells.

Kosenko et al. (2008) define grafting as a form of botanic transplantation (transplanting and joining of tissue organs of different plants), this value is widely used in gardening and consists of splicing parts of one plant with another.

Matvienko et al. (2006) recommend using the middle parts of grafted plants, because the buds in the lower ones usually develop more slowly and upper part doesn't matured.

According to Glukhov et al. (2003), during reproduction *M. alba* is used for bank grafting and in the butt of fire arms (April), bud graftin in T-like incision (August), the butt bud (August).

So far, the problem of a low degree of splicing of various parts of these ornamental plants has not been solved, and the optimal time for grafting in Ukraine has not been determined.

The aim of our work is to study the effective ways of the reproduction of forms of *M. alba* by grafting. For this, it is necessary to establish the best methods and time of grafting.

## Materials and Methods

During the studing years 2006–2018 grafting of forms of *M. alba* the following materials were used: cleft-graft scion – 3–5 summer saplings (*M. alba*), which were grown on the experimental site of the dendropark 'Sofiyivka' of the National Academy of Sciences of Ukraine and training and experimental section of the green house complex of the faculty of Forestry and Landskape Gardening of Uman National University of Horticulture.

But the cleft-graft scions shoots of the ornamental varieties of *M. alba*: '*Pendula*', '*Globosa*', '*Pyramidalis*', '*Contorta*', '*Macrophylla*', and '*Tatarica*'. The leaf cutting was cut from the medial part of one-year shoots of mother plants grown on experimental plots of the Sofiyivka arboretum and Uman National University of Horticulture of the National Academy of Sciences of Ukraine.

While grafting of forms of *M. alba*, the most effective methods were chosen: improved copulation behind the cortex and in splitting.

This is done as follows: ground, depending on the desired height of the root-stock (150–180 cm) cut away, cutting parallel to the surface of the earth. On the center of cross section (throughout the diameter of the cut), using a garden knife, make a cut with a depth of 0.5 to 1.5 cm. The graft is taken with two kidneys from the middle part of the annual shoot growth. The average graft length is 15–20 cm. At the lower end of the graft, two incisions were made with a length of 1.5 cm and then inserted into the splitting of the root-stocks. The splicing area is treated with garden oil and it is bounded with a special film (tape). When the graft and the wild plant fused together (after 1.5–2 months), the special film was removed.

The improved copulation method was used for grafting of thin shoots if the scion and rootstock diameters were the same. For a tight connection of grafting components and their better growth in sections adnation longitudinal splitting ('tongues') is made connecting them with a tab one after the other. Using this method, smooth and straight diagonal cuts were made on the root plant and the graft. The length of the incision is 3–4 times greater than the thickness of the graft by 3–5 cm. The splicing area is also treated with garden ointment and it is bounded with a special film (tape). A special film (tape) is removed when splicing components rootstocks and graft were made.

Grafting for behind the bark is carried out in the period of active movement of juice. Transplants should be prepared shortly before grafting the graft is prepared with ordinary copulation. On the side of the stump (wild plant) in a smooth place make a longitudinal section of the bark length by 3–5 cm. The edges of this incision are slightly separated from the wood by the heel of the coping knife. The graft is placed in the incision of the bark of a wild plant. The place of attachment of the graft and the wild plant is well tied with a special tape. It was removed the tape when they are spliced.

The features of anatomical structure of the annual shoots of *M. alba* were investigated using their cross-section using the Gritsaienko's method (2003). According to this technique the typical shoots were selected at three-time repetition. Blurring and clarification of selected shoots were carried out in Javel water for two–three days. After clarification the cuts were washed with distilled water for two three days. Coloring of the shoots was done with the help of a crystal paint (a mixture of 1 ml of 5 % sulfuric acid and 1 ml of

1 % aqueous dye solution) and followed by fixing in a solution of the next composition: 30 ml of glycerol; 80 ml of water; 2 g of zinc chloride and 0.2 g of potassium iodine.

## Results and Analysis

We studied the peculiarities of grafting forms of *M. alba* ('Pendula', 'Globosa', 'Pyramidalis', 'Contorta', 'Macrophylla', and 'Tatarica'). Taking into account of its long growing period the grafting terms were suggested to be divided into winter, spring and summer periods.

Winter grafting was held in February (the 2nd–3rd decades) and in early March (the 1st decade). Spring grafting of *M. alba* and its ornamental varieties was divided into 3 periods: I – early spring (the 2nd–3rd decades of March); II – mid spring (the 1st–2nd decades of April); III – late spring (the 3rd decade of April – the 1st–2nd decades of May); summer grafting took place from late July till early August.

Preparations for winter grafting of *M. alba* forms began with autumn planting of rootstocks into containers and placing them in special premises till the beginning of the process. The scions forms of *M. alba* were cut in late January–early February and preserved in a basement. A few days before the scions were moved to the premises and prepared for vaccination. Then they were carried to the open area. After 1–2 years of cultivation the plants were sold (Vitenko 2014).

The final data on the application of grafting components of various ornamental forms of *M. alba* during the winter terms of its carrying out (February – early March) is given in diagram one and two (figs 1 and 2).

The best grafting technique for win-



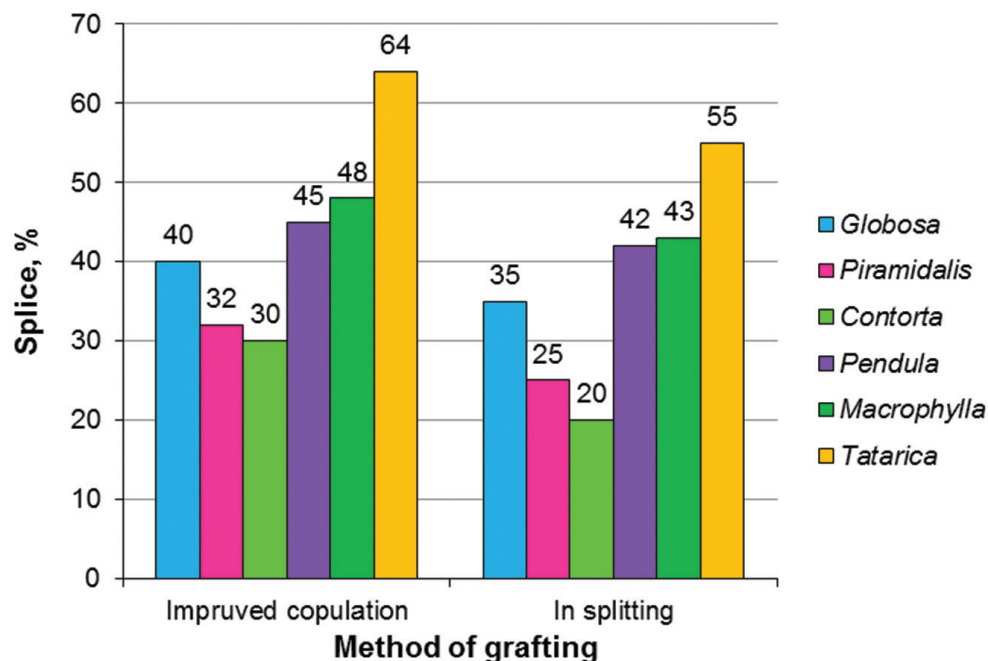


Fig. 1. Results of winter grafting forms of *M. alba* (February).

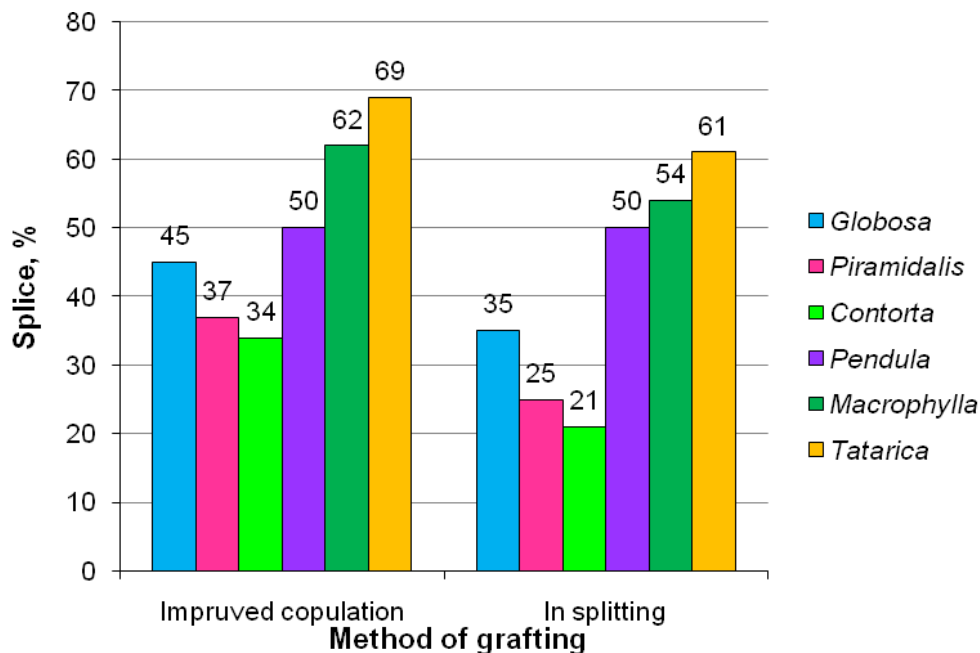


Fig. 2. Results of winter grafting forms of *M. alba* (March).

ter conditions proved to be the improved copulation, which was carried out in early March. The highest percentage of spliced components of the grafting is noted in '*Tatarica*' (70 %) and '*Macrophylla*' (60 %). The February grafting of these forms gave lower rates – 64 and 55 % accordingly. Method of the improved copulation gave the lowest rates at '*Pyramidalis*' – 37 % in early March and 32 % in February and '*Contorta*' – 35 % and 30 % accordingly.

The cleft graft technique proved less positive though the tendency stayed similar to the improved copulation. The highest average cleft grafting in success was also noted with the above mentioned forms – 61 % and 54 % accordingly. In our opinion, this rather low indicators plicing components rootstocks and graft were made. *M. alba* success on winter period can be explained by low physiological activity, when the process of growing together of scion and rootstock is still quite slow. It is also difficult to select the most viable cuttings in winter as they do not have enough time to grow in the stiff climatic conditions of Ukraine.

Spring grafting of *M. alba* forms was divided into 3 periods: early spring (the 2nd–3rd decades of March); mid spring (the 1nd–2nd decades of April); late spring (the 3rd decade of April – the 1st–2nd decades of May). Such division was grounded by a large discrepancy in the quantitative indicator of positive results.

The first period had the vastest day temperature changes and it has least favorable for grafting as the scions had been cut in winter, when all grafted material looked viable. *M. alba* and its forms ('*Pendula*', '*Globosa*', '*Pyramidalis*', '*Contorta*', '*Macrophylla*' and '*Tatarica*') have one important distinction from the native flora – anelongated period of linear shoot growth (the 1<sup>st</sup>decade of autumn). It is the

reason why their apical and partially medial parts do not have time to grow stiff before the resting period. It should also be noted that it's difficult to recognize the improper scions from the one-year shoots.

The second period is characterized by the intense sap flow in studied plants. During this (especially in the 2nd decade of April) all annual shoots start budding, which allows the quality scion for further grafting. We think this is the best spring period for the effective growing of good planting material (ornamental forms of *M. alba*).

The last 3 periods where characterized by the high activity of all physiological processes in plants. The optimal grafting is the socalled from plant to plant by blanks of grafting elements and their maintenance in a humid environment before the onset of grafting. In this period, there is a process of rapid growing together of scion and rootstock, but there is a number of obstacles for grafting itself as high air temperature, rapid growth of socalled sleeping buds on the rootstock, etc.

The initial preparation for the spring graft was begun with the sap flow start indicated by the active bark detachment. The above mentioned condition of the scion plant gave a signal to the start of plants grafting. In case of insufficient soil moisture a few days before the grafting, the rootstocks were well watered. Preparation of ornamental varieties cuttings began just before the graft procedure. The scions had to have three buds.

Taking into account of many years experience of spring tree grafting in the 1st–2nd decades of April, we chose two techniques that gave the most positive results – the improved copulation and grafting for behind the bark.

Grafting for behind the bark was implemented during a period of active sap

movement. This propagation technique of the forms differs greatly from the improved copulation. Cuttings (scions) were cut just before the grafting of the basal and medial parts of the shoots. Grown seedlings of *M. alba* were used as stocks.

Further studies proved the effectiveness of 3-bud scion used for the graft. We left 2–3 cm of 'stump', above plant top bud which prevented its drying. The shoot was cut across at the desired stem height.

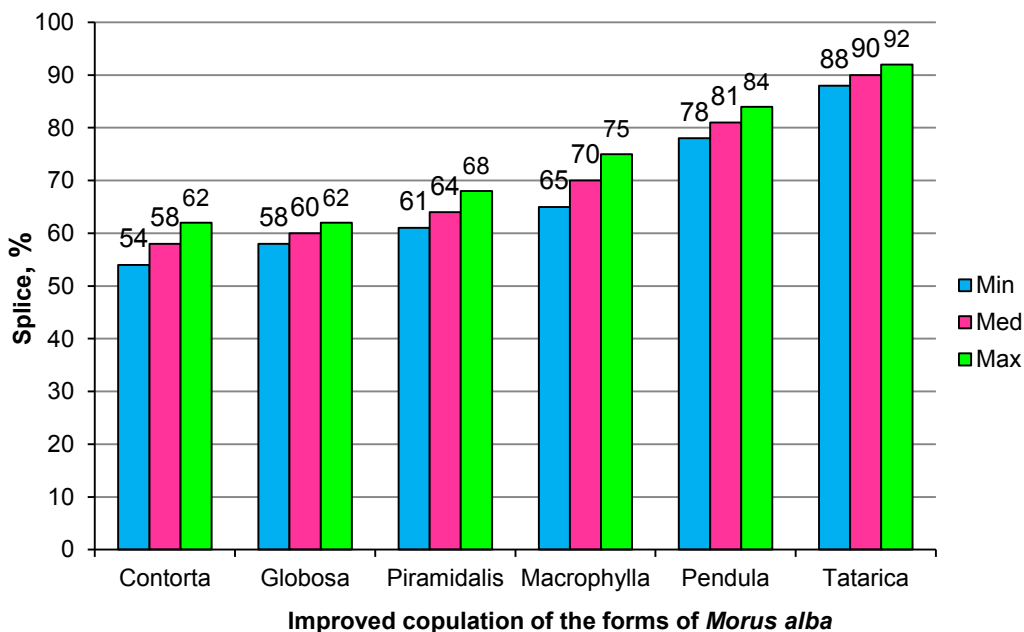
The cut was made smoothly which contributed to a better occluding of the wound and good wound healing. The cuttings were prepared as the ordinary grafting. On the side of the stump (wild plant) on a place grafting we made a longitudinal bark section of 3–5 cm to the wood. The edges of this section were slightly separated from the wood by the end of the knife.

The cutting was placed behind the bark. The obtained data during the graft-

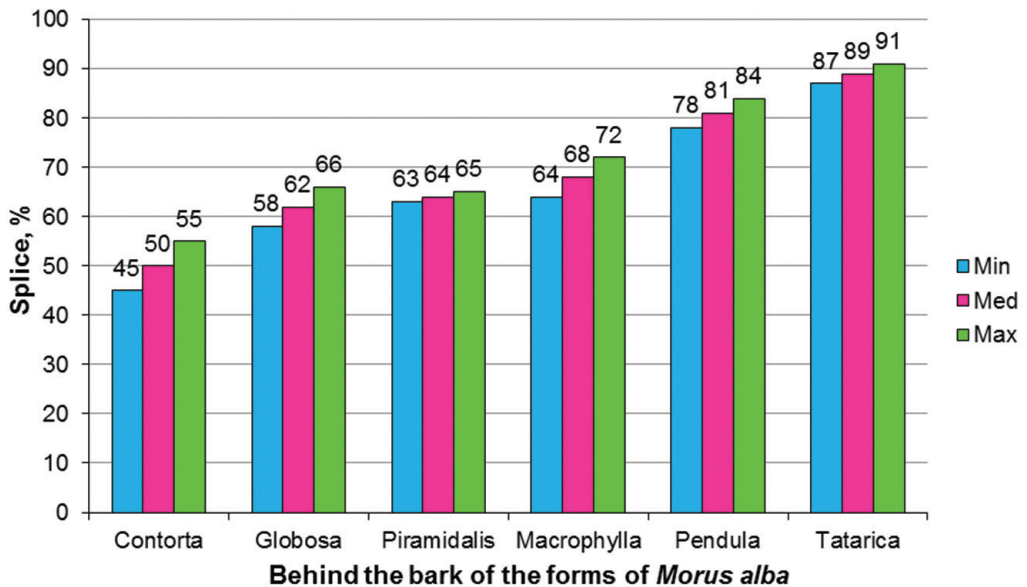
ing (by the two above-mentioned techniques) of the *M. alba* forms data can be seen on the diagrams (figs 3 and 4).

The data in Figure 3 show that the best results of the scion and rootstock growing together during spring graft technique was observed of using the improved copulation method '*Tatarica*' – 88–92 %. High rate of graft was also noted '*Pendula*' (78–84 %) and '*Macrophylla*' (65–75 %). The lowest percentage of joining was observed with '*Contorta*' – from 54 to 62 %, and at engraftment of '*Globosa*' – 58–62 %. The '*Pyramidalis*' had some higher level plicing components wild and grafting plant taking rate than that of '*Globosa*': minimum – 61 %, average – 64 %, and maximum – 68 %.

Data analysis shows (Fig. 4) that the best taking of rootstocks with scions using the bark inlay method was obtained with '*Tatarica*' (87–91 %). A high percentage of



**Fig. 3. Results of plicing indices graft forms of *M. alba* for the average spring grafting (the 1st–2nd decades April) by the way of improved copulation (average 2005–2017).**



**Fig. 4. Results of splicing indices graft forms of *M. alba* for the spring grafting of behind the bark (average 2005–2017).**

growing together was noted with '*Pendula*' (73–77 %) and '*Macrophylla*' (64–72 %). Higher rate of success in lay method for bark of the improved copulation method was recorded at '*Globosa*' (58–66 %). The form '*Pyramidalis*' showed even slightly higher indices results of the scion and rootstock growing (63–67 %).

The lowest percentage of successful grafting growing scence was observed with '*Contorta*' (45–55 %). Behind the bark of forms *M. alba*.

Splicing graft components of rootstocks and forms are shown in Figure 5 where there is an increase in the percentage of splices of grafting forms during the medium spring grafting compared to early spring.

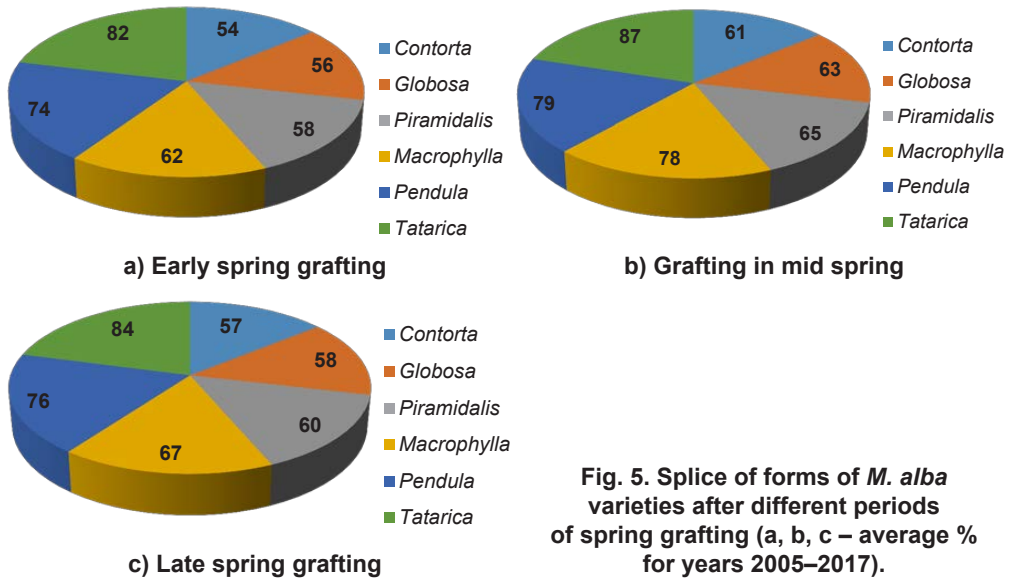
Among the *M. alba* varieties the best results were obtained in '*Tatarica*' (87 %), '*Pendula*' and '*Macrophylla*' (73–79 %). The lowest result was obtained with '*Contorta*' – 61 % of all grafts of '*Pyramidalis*'

and '*Globosa*' proved 65 % and 63 % respectively.

While grafting the aforementioned ornamental *M. alba* varieties in the late spring period, we obtained lower taking rates than those of the mid spring, but some what higher results than in the early spring. Among various methods of spring grafting the most effective proved to be the improved copulation (see Table 1).

Table 1 shows that the best result (92 %) was obtained an the grafting method of improved copulation forms '*Tatarica*' and then '*Pendula*' – 84 %; '*Macrophylla*' – 75 %; '*Pyramidalis*' – 68 %; '*Globosa*' – 65 %; and '*Contorta*' – 62 %.

Grafting the above-mentioned forms using the bark method also showed the best result in '*Tatarica*' – 91 %. The rest are arranged in this order: '*Pendula*' – 75 %; '*Macrophylla*' – 72 %; '*Pyramidalis*' – 65 %; '*Globosa*' – 66 %; '*Contorta*' – 55 %.



**Fig. 5. Splice of forms of *M. alba* varieties after different periods of spring grafting (a, b, c – average % for years 2005–2017).**

**Table 1. Spring grafting results of *M. alba* ornamental forms (average for years 2005–2017).**

| No | Ornamental forms   | Method technique    |      |      |              |      |      |
|----|--------------------|---------------------|------|------|--------------|------|------|
|    |                    | Improved copulation |      |      | Graft method |      |      |
|    |                    | Splice, %           |      |      |              |      |      |
|    |                    | min                 | med  | max  | min          | med  | max  |
| 1  | <i>Contorta</i>    | 54.0                | 58.0 | 62.0 | 45.0         | 50.0 | 55.0 |
| 2  | <i>Globosa</i>     | 58.0                | 61.5 | 65.0 | 58.0         | 62.0 | 66.0 |
| 3  | <i>Pyramidalis</i> | 61.0                | 64.0 | 68.0 | 63.0         | 64.0 | 65.0 |
| 4  | <i>Macrophylla</i> | 65.0                | 70.0 | 75.0 | 64.0         | 68.0 | 72.0 |
| 5  | <i>Pendula</i>     | 78.0                | 81.0 | 84.0 | 73.0         | 75.0 | 77.0 |
| 6  | <i>Tatarica</i>    | 87.0                | 89.0 | 92.0 | 87.0         | 89.0 | 91.0 |

Was grafting forms of *M. alba*, it is very important to study the characteristics of the further growth of the grafting components in the place of their connection.

It is very important to study the characteristics of the further growth grafting forms of *M. alba* of the inoculative components in the place of their connection. Despite the scientifically established facts of higher compatibility of grafting components within one species, these studies

are highly required for the forms of *M. alba*, which have phenological growth and development differences from the native plants of Ukraine.

As a rootstock for forms of *M. alba*, plants of seed and vegetative origin, which are most identical in biochemical composition, were used. The years of researches have shown that the best grafting method of forms is the improved method of copulation (Fig. 6).



**Fig. 6.** Splice of form '*Macrophylla*', where: 1 – rootstock; 2 – scion; 3 – places of splice after the first year of growth.

It can be seen from Figure 6 that before the start of the rest period, the grafting sites of forms with wild plants are completely covered with protective cloth. This is due to the activity of physiological processes inside the plants.

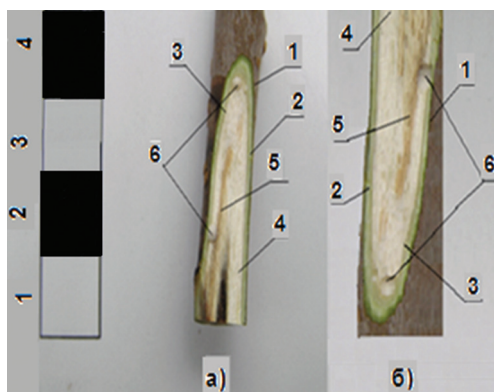
The dynamics of the process of splice grafted plants over a two-year period can be studied using the example of '*Globosa*' form (Fig. 7), where it is evident that during two years of growth, by means of the rapid division of the cells of the productive tissue the forms undergo a period of complete splicing with a wild plant at the place of their connection using the improved copulation method.

By conducting a longitudinal section of the rootstock and the scions, we studied the structure of the tissue inside the plants to compare. The results are shown in Figure 8.

On the basis of the cross sectional cutting (Fig. 8) of the scion form '*Tatarica*' and the rootstock of *M. alba*, it can be



**Fig. 7.** Grafting of one-year (a) and two-year (b) *M. alba* '*Globosa*', where: 1 – rootstock, 2 – graft, 3 – place of graft.



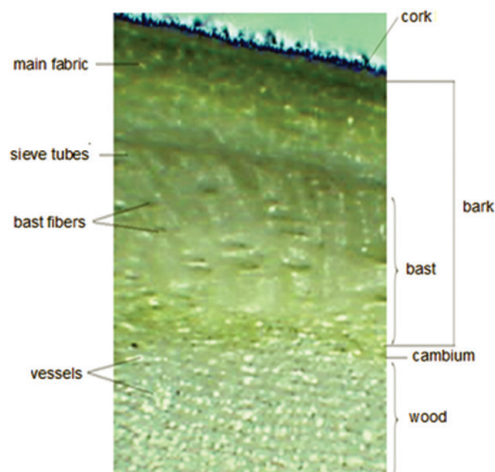
**Fig. 8.** Longitudinal section of shoots of *M. alba* '*Tatarica*' (a) and *M. alba* (b), where: 1 – bark, 2 – bast, 3 – cambium, 4 – wood, 5 – protective tissue, 6 – cellular sap.

concluded that their internal tissue structure is similar. Taking this into account we can state their compatibility, which is other beneficial key factor to the rapid splice of grafted components.

By carrying out a cross-section of the



grafting site, the internal structure was examined (for comparison). The results of the research induced in Figure 9.



**Fig. 9. A cross-section of a one-year *M. alba* shoot (photo by Sergiy Koval and Oleh Lazariev).**

On the basis of the cross-section in the fusion zone of 'Tatarica' form from *M. alba*, one can conclude that their internal structure of tissues is similar. Given this aspect, it can be argued that there is compatibility between them, which, combined with other favorable factors is the key to a quick splice grafted components.

The peculiarity of the anatomical structure of annual shoots of *M. alba* was investigated with the help of their cross-section by the method of Gritsayenko (2003). According to this technique, 20 typical shoots were selected at three-time repetition blurring and clarification of the selected shoots was carried out in Javel water for two–three days. After clarification, the sections were washed (three–fourtimes change) in distilled water for two three days.

Further coloring of *M. alba* shoots was done with the help of a crystal violet dye solution (a mixture of 1 ml of 5 % sulfuric

acid and 1 ml of 1 % aqueous dye solution) and followed by fixing in a solution of this composition: 30 ml of glycerol; 80 ml of water; 2 g zinc chloride and 0.2 g potassium iodine. Due to this factor the light gray parts of the tree shoots were well colored violet-blue (Fig. 9).

It was clearly seen that the exterior of the escape is covered with a layer of cork tissue – a tissue consisting of dead and dying cells. They perform a protective function. The bark, in turn, consists of conductive, mechanical and main tissue. Tubes are part of the conductive tissue and the mechanical one is represented by bast fibers, which give the stem of this plant strength and flexibility. The main fabric performs the function of accumulation of nutrients and fills the gaps between two above-mentioned tissues. The next tissue is the cambium which function is to create new layers of wood and bast. Between the bark and the core is a solid fabric – wood, which makes up the bulk of the shoot. The main structural unit of wood is fiber, which at its initial stage of development has a rather elastic and pervious for aqueous solutions skin.

The peculiarities of splice of the forms by the example of form 'Pyramidalis' were studied with the help of a cross-section (Fig. 10).

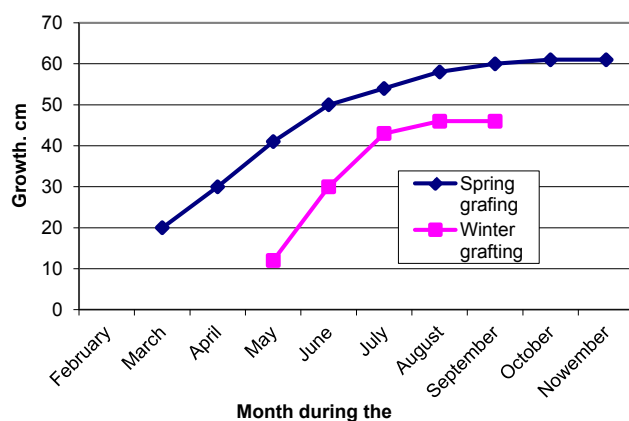
We should also note the importance of callus in the process of rapid splice of the grafted elements. Under the pressure of newly growing cells in the insulating layer between the scion and the rootstock gaps emerge, through which callus comes to the surface of connects and helps the graft components to grow together. Simultaneously the differentiation process takes place (forming of a prior callus), which connects with the cambium of the rootstock and the scion and creates elements of xylem and phloem. After that the



**Fig. 10.** Longitudinal incision at the place of graft, where: 1 – bark, 2 – bast, 3 – cambium, 4 – wood.

places of grafting grow rather quickly during the growing season.

Figure 11 shows the dynamics of linear growth of grafted form of *M. alba* in winter



**Fig. 11.** Dynamics of linear growth of the grafted forms during the growing period.

(a container plant of indoor keeping during the whole growing period) and in spring (an open soil keeping during the whole growing period) that allow to compare its duration at different temperature and humidity conditions.

Analysing Figure 11 we can note a long period (February–November) of the linear growth of shoots in carrying out the winter grafting of *M. alba* forms (in containers), followed by the maintenance of these plants in green house conditions during the entire vegetation period. That allows the grafted plants to end their vegetation with a sufficient level of aging of one-year shoots. Large differences are observed in the formation of the crown forms. Winter graft of these plants in containers greatly shortens the forming period.

## Conclusions

Based on the research of vaccination forms of *M. alba*, we have determined that:

- The best way of winter grafting is the improved capulation, which is carried out in early March, where the best results observed in vaccination forms '*Tatarica*' (70 %) and '*Macrophylla*' (60 %). The February grafting of the same forms turned less effective – 64 % and 55 % accordingly. The lowest results in vaccinated method of improved capulation recorded in form '*Pyramidalis*' – 37 % in early March and 32 % in February and in form '*Contorta*'. The lowest results in vaccinated method of improved capulation recorded in form '*Pyramidalis*' – 37 % in early March and 32 % in Feb-

ruary and 'Contorta', accordingly 35 % and 30 %. The greatest success in these forms was when vaccinated with a method of splitting – 61 % and 54 % accordingly.

- In spring grafting by improved copulation, the best result was in 'Tatarica' – 88–92 %. The high percentage was also registered in 'Pendula' (78–84 %) and 'Macrophylla' –65–75 % accordingly. The lowest rates were observed in 'Contorta' – from 54 % to 62 %.

- The vaccination for the bark gave a high result in 'Tatarica'– from 87 % to 91 %, high percentage of taking as in the improved copulation –in 'Pendula' (73–77 %) in 'Macrophylla' (64–72 %). And the lowest success rates were noted in 'Contorta'– from 45 % to 55 %.

- It was discovered that *M. alba* and tested forms have similar internal structure; the places of inosculation grow together rapidly enough and enter the resting period completely covered with protective tissue.

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## CRANIAL VARIABILITY AND SEXUAL DIMORPHISM OF GOLDEN JACKAL IN BULGARIA

Stoyan Stoyanov

Wildlife Management Department, University of Forestry, 10 St. Kliment Ohridski Blvd., 1797  
Sofia, Bulgaria. E-mail: stoyans@abv.bg

Received: 11 September 2019

Accepted: 26 November 2019

### Abstract

Craniometric characteristics and sexual dimorphism have been described for many carnivore species in Europe. However, very few studies have focused on cranial variability of golden jackal (*Canis aureus* Linnaeus, 1758) in Europe, despite its expanding distribution in recent decades. Although numerous works have addressed sexual dimorphism in carnivore skull size, only few studies have attempted to study dimorphism in overall cranial shape. The present study proposes the first comprehensive analysis of golden jackal skull morphometry in Bulgaria, trying to clarify shape and size related cranial variability and differentiation. Extensive morphometric data of jackal skulls were analysed by applying recently developed statistical tools to answer the following questions: (i) is there a geographic variation in skull size and shape among golden jackal population in Bulgaria, (ii) are there age-related cranial differences, and (iii) how pronounced is the sexual dimorphism in skull shape and size? A total of 176 skulls of golden jackals, collected all over the country, were analysed by univariate and multivariate statistical methods. Principal component analysis and linear discriminant analysis were applied on the standardized and log-transformed ratios of the original measurements to clearly separate specimens by shape and size. Skulls of golden jackal in Bulgaria show considerable individual variability but weak intrapopulation differentiation. The differences in shape and size of the jackal skulls, as far as they exist, are age-related, but only juveniles younger than 11 months could be easily distinguished. Subadult and adult jackals largely overlap in skull size and shape. Sexual dimorphism in jackal skulls is weakly pronounced, with older males a little bit larger than females. The results of the present research are consistent with recent genetic and morphological studies and give new insights on patterns in cranial variability and population structure of golden jackal in Bulgaria.

**Key words:** *Canis aureus*, cranial variability, geographic variation, sex dimorphism, skull morphometry, skull shape.

### Introduction

Craniometric characteristics and sexual dimorphism have been described for many carnivore species in Europe (Petrov et al. 1992, Gittleman and Valkenburgh 1997, Milenković et al. 2010). Sexual size dimorphism is common among verte-

brates, with males usually being the larger sex (Ralls 1977). In the end of the last century, the extreme dimorphism in Mustelidae (Moors 1980, Wiig 1986), Felidae (Wiig and Andersen 1986) and Pinnipedia (Stirling 1975), and the reversed dimorphism in predatory birds (Andersson and Norberg 1981, Pleasants 1988) attracted

particular interest, and new theories were proposed, associating the sexual dimorphism with divergent selection pressures on males and females (Moors 1980, Wiig 1986, Wiig and Andersen 1986). However, sexual dimorphism in Canidae, when present at all, is usually minimal, with males being slightly larger than females (Jolicœur 1959, Hell et al. 1989, Simonson et al. 2003, Schutz et al. 2009, Sillero-Zubiri 2009). In African jackals (*Canis lupaster* Hemprich and Ehrenberg, 1832; *Lupulella adusta* (Sundevall, 1847); and *Lupulella mesomelas* (Schreber, 1775)) sexual dimorphism varies among regions and is even less pronounced than in other canids (Van Valkenburgh and Wayne 1994). Up to date, very few studies have focused on cranial variability of golden jackal (*Canis aureus* Linnaeus, 1758) in Europe (Kryštufek and Tvrković 1990, Stoyanov 2012, Markov et al. 2017, Rezić et al. 2017, Krendl et al. 2018), despite its expanding distribution in recent decades.

Golden jackal is one of the most widely distributed canid species and is found in many areas of Europe and Asia (Jhala and Moehlman 2004, Arnold et al. 2012, Hoffmann et al. 2018, Moehlman and Hayssen 2018, Spassov and Acosta-Pankov 2019). Since 1980s, jackals have increased in their distribution and abundance in what is arguably the most dramatic recent expansion among native predators on the continent (Jhala and Moehlman 2004, Šálek et al. 2014, Koepfli et al. 2015, Trouwborst et al. 2015). The jackal expansion in the last two decades has been rapid and still ongoing. The jackals reached Switzerland, Lichtenstein, Germany, Denmark, Poland, France, Netherlands, Baltic states, Belarus, and, in 2019, also Finland (Pyšková et al. 2016, Krofel et al. 2017, Potočník et al. 2019). The ongoing expansion of the species in Europe has caused concerns

regarding possible negative effects its presence could exert, due to excessive predation of other wildlife species or livestock, and the transmission of pathogens (Rutkowski et al. 2015, Ćirović et al. 2016). In addition, there are several uncertainties regarding jackal management and policies, often in association with the unknown origins of jackal populations (Trouwborst et al. 2015). Jackal expansion in the last decades has triggered research interest in Europe. Many aspects of golden jackal's ecology, diet, population density, genetics, legal implications of range expansion, and management have been studied in the last two decades in Europe (see full review in Potočník et al. 2019). Bulgarian territory is considered the core area of golden jackal distribution in Europe with the highest population density (Stoyanov 2013, Spassov and Acosta-Pankov 2019), but morphometric studies, including skulls from Bulgaria, were very scarce and local so far (e.g. Markov et al. 2017, Krendl et al. 2018). Despite numerous studies of sexual dimorphism in carnivore skull size, only few studies have attempted to study dimorphism in overall cranial shape (Schutz et al. 2009, Rezić et al. 2017).

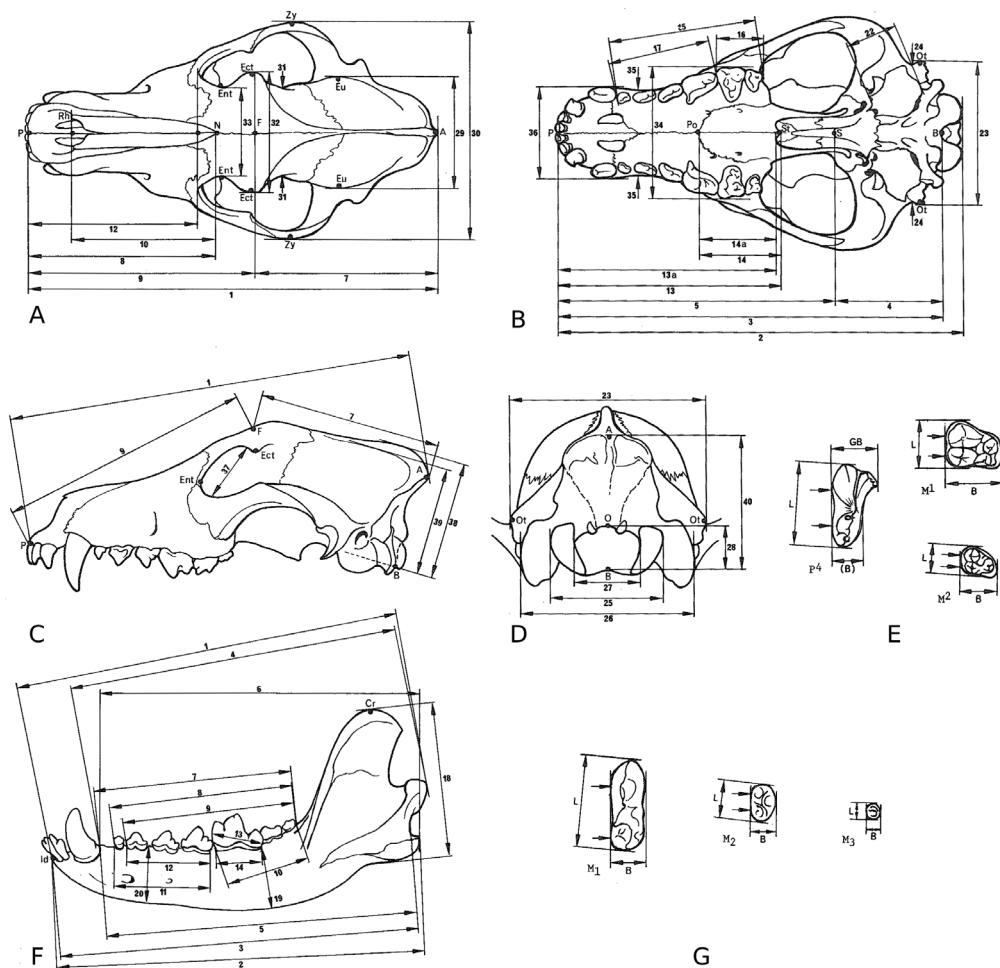
The present study is the first comprehensive analysis of golden jackal skull morphometry in Bulgaria, trying to clarify shape and size related cranial variability and differentiation. Extensive morphometric data of jackal skulls were analysed by applying recently developed statistical tools to answer the following questions: (i) is there a geographic variation in skull size and shape among golden jackal population in Bulgaria, (ii) are there age-related cranial differences, and (iii) how pronounced is the sexual dimorphism in skull shape and size? Although modern genetic methods have been applied recently in phylogeny and taxonomy, understanding



patterns in cranial variability of golden jackal still provides very valuable insights on population structure. Furthermore, it is not only crucial for understanding the phylogeny, but also for management and conservation. Moreover, integration of genetic techniques and morphometrics represent a valuable tool in the resolution of taxonomic uncertainty.

## Material and Methods

A total of 176 skulls of golden jackal from Bulgaria were analysed. The sample comprised of 84 specimens, collected between 1998 and 2007 from 20 different sites all over the country, but most of them coming from three main regions with highest jackal's population density: Yambol,



**Fig. 1. Skull measurements employed in the analyses (following von den Driesch 1976).**

Note: See measurements description in Table 1: A. *Canis* cranium, dorsal view; B. *Canis* cranium, basal view; C. *Canis* cranium, left side view; D. *Canis* cranium, nuchal view; E. *Canis* maxillary teeth ( $P^4$ ,  $M^1$  and  $M^2$ ), length (L) and breadth (B); F. *Canis* mandible, left side, lateral view; G. *Canis* mandibular teeth ( $M_1$ – $M_3$ ), length (L) and breadth (B).



Veliko Tarnovo and Burgas. It also included 57 skulls, collected by Stoyan Vassilev in the end of 1980s, 20 specimens from the scientific collection of the National Museum of Natural History dating back to the last century, and 15 skulls, collected between 2008 and 2012, measured at a national trophy exhibition in 2012. The skulls with unknown sex were excluded from the analyses. The age of jackals was determined in consideration of upper incise teeth wear (Lombaard 1971) and for some individuals also by counting the annual cementum layers in canines (Klevezal and Kleinenberg 1967). Both methods are reliable enough for the pur-

poses of the study and provide accurate results, with precision up to one year for the first one (Harris et al. 1992, Rajchev 2002). The skulls were assigned to three age groups: juveniles, subadults and adults. Juveniles were defined as individuals with fully developed second dentition but less than 10 months of age, subadults as individuals older than 11 months, when they reach sexual maturity, but less than two years of age, and adults as two years old and over. On each specimen 70 measurements were taken by digital sliding calliper, i.e. 47 cranial and 23 from mandibles (see Fig. 1 and Table 1), following von den Driesch (1976).

**Table 1. Description of *Canis* skull measurements (following von den Driesch 1976).**

| No  | Measurements description                                                      | Abbreviation |
|-----|-------------------------------------------------------------------------------|--------------|
|     | Cranium                                                                       |              |
| 1   | Total length: Akrokranium – Basion                                            | Tl           |
| 1a  | Greatest skull length: Akrokranium – front border of the Incisivi Anteriori   | Maxl         |
| 2   | Condylbasal length: aboral border of the occipital condyles – Prosthion       | Cbl          |
| 3   | Basal length: Basion – Prosthion                                              | Bl           |
| 4   | Basicranial axis: Basion – Synsphenion                                        | Bca          |
| 5   | Basifacial axis: Synsphenion – Prosthion                                      | Bfa          |
| 6   | Neurocranium length: Basion – Nasion                                          | Ncl          |
| 7   | Upper neurocranium length: Acrocranium – Frontal midpoint                     | Uncl         |
| 8   | Viscerocranium length: Nasion – Prosthion                                     | Vcl          |
| 9   | Facial length: Frontal midpoint – Prosthion                                   | Fl           |
| 10  | Greatest length of the nasals: Nasion – Rhinion                               | Nasl         |
| 11  | Length of braincase                                                           | Brcl         |
| 12  | Snout length: oral border of the orbits – Prosthion                           | Snl          |
| 13  | Medial palatal length: Staphilion – Prosthion                                 | Mpl          |
| 13a | Palatal length: median point joining deepest intersection Choanae – Prosthion | Pl           |
| 14  | Length of the horizontal part of the palatine: Staphylion – Palatinoorale     | Mplh         |
| 14a | Length of the horizontal part of the palatine corresponding to 13a            | Plh          |
| 15  | Length of the cheektooth row                                                  | Lp1m2        |
| 15a | Length from oral border of C <sup>1</sup> to aboral border of M <sup>2</sup>  | Lc1m2        |
| 16  | Length of the molar row                                                       | Molr         |
| 17  | Length of the premolar row                                                    | Prmr         |
| 18  | Length of the carnassial, measured at the cingulum                            | Lp4          |
| 18a | Greatest breadth of the carnassial                                            | Bp4          |
| 19  | Length of the carnassial alveolus                                             | Lp4a         |

| No    | Measurements description                                                                                           | Abbreviation |
|-------|--------------------------------------------------------------------------------------------------------------------|--------------|
| 20    | Length of M <sup>1</sup> , measured at the cingulum                                                                | Lm1          |
| 20a   | Breadth of M <sup>1</sup> , measured at the cingulum                                                               | Bm1          |
| 21    | Length of M <sup>2</sup> , measured at the cingulum                                                                | Lm2          |
| 21a   | Breadth of M <sup>2</sup> , measured at the cingulum                                                               | Bm2          |
| 22    | Greatest diameter of the auditory bulla                                                                            | Bull         |
| 23    | Greatest mastoid breadth: Otion – Otion                                                                            | Mst          |
| 24    | Breadth dorsal to the external auditory meatus                                                                     | Mstau        |
| 25    | Greatest breadth of the occipital condyles                                                                         | Occb         |
| 26    | Greatest breadth of the bases of paraoccipital processes                                                           | Poprb        |
| 27    | Greatest breadth of the foramen magnum                                                                             | Fmagb        |
| 28    | Height of the foramen magnum: Basion – Opisthion                                                                   | Fmagh        |
| 29    | Greatest neurocranium breadth: Euryon – Euryon                                                                     | Skb          |
| 30    | Zygomatic breadth: Zygon – Zygon                                                                                   | Zyg          |
| 31    | Least breadth of skull: breadth at the postorbital constriction                                                    | Pob          |
| 32    | Frontal breadth: Ectorbitale – Ectorbitale                                                                         | Fb           |
| 33    | Least breadth between the orbits: Entorbitale – Entorbitale                                                        | Iob          |
| 34    | Greatest palatal breadth: measured across the outer borders of the alveoli                                         | Palb         |
| 35    | Least palatal breadth: measured behind the canines                                                                 | Lpalb        |
| 36    | Breadth at the canine alveoli                                                                                      | Rb           |
| 37    | Greatest inner height of the orbit                                                                                 | Orb          |
| 38    | Skull height                                                                                                       | Skh          |
| 39    | Skull height without the sagittal crest                                                                            | Skhs         |
| 40    | Height of the occipital triangle: Akrokranium – Basion                                                             | Otrh         |
| <hr/> |                                                                                                                    |              |
|       | Mandible                                                                                                           |              |
| 1     | Total length: from condyle process – Infradentale                                                                  | Mand         |
| 2     | Length: the angular process – Infradentale                                                                         | Mlapid       |
| 3     | Length: the indentation between condyle process and angular process – Infradentale                                 | Mlapcpid     |
| 4     | Length: the condyle process – aboral border of the canine alveolus                                                 | Mlcpc        |
| 5     | Length: the indentation between the condyle process and the angular process – aboral border of the canine alveolus | Mlapcp-ca    |
| 6     | Length: the angular process – aboral border of the canine alveolus                                                 | Mlapca       |
| 7     | Length: the aboral border of the alveolus of M <sub>3</sub> – aboral border of the canine alveolus                 | Mlcam3       |
| 8     | Length of the cheektooth row, M <sub>3</sub> –P <sub>1</sub> , measured along the alveoli                          | Mlp1m3       |
| 9     | Length of the cheektooth row, M <sub>3</sub> –P <sub>2</sub> , measured along the alveoli                          | Mlp2m3       |
| 10    | Length of the molar row, M <sub>1</sub> –M <sub>3</sub> , measured along the alveoli                               | Mmolr        |
| 11    | Length of the premolar row, P <sub>1</sub> –P <sub>4</sub> , measured at the cingulum                              | Mprmr        |
| 12    | Length of the premolar row, P <sub>2</sub> –P <sub>4</sub> , measured at the cingulum                              | Mlp2p4       |
| 13    | Length of the carnassial, measured at the cingulum                                                                 | Mlm1         |
| 13a   | Breadth of the carnassial, measured at the cingulum                                                                | Mbm1         |
| 14    | Length of the carnassial alveolus                                                                                  | Mlm1a        |
| 15    | Length of M <sub>2</sub> , measured at the cingulum                                                                | Mlm2         |

| No  | Measurements description                                                      | Abbreviation |
|-----|-------------------------------------------------------------------------------|--------------|
| 15a | Breadth of $M_2$ , measured at the cingulum                                   | Mbm2         |
| 16  | Length of $M_3$ , measured at the cingulum                                    | Mlm3         |
| 16a | Breadth of $M_3$ , measured at the cingulum                                   | Mbm3         |
| 17  | Greatest thickness of the body of jaw below $M_1$                             | Mjaw         |
| 18  | Height of the vertical ramus: basal point of the angular process – Coronion   | Manh         |
| 19  | Height of the mandible behind $M_1$ , measured on the lingual side            | Mhm1         |
| 20  | Height of the mandible between $P_2$ and $P_3$ , measured on the lingual side | Mhp2         |

## Statistical methods

All measurements were tested for normality by QQ plots and Shapiro-Wilk test. Differences in size of skull between age groups were tested by one-way analysis of variance (ANOVA) and visualized by applying Tukey's Honestly Significant Difference test (Tukey's HSD). Statistical significance of the difference in means between males and females for each cranial measurement was examined by using Student's t-test. Multivariate analyses were employed in order to explore the most significant variation in size and shape of skulls. Shape in general tends to provide more reliable information than size on the morphology of organisms (Jolicoeur and Mosimann 1960). Size is often considered as a nuisance because it is strongly dependent on ecological factors (McCoy et al. 2006), but separation of size and shape in multivariate studies of morphological data is problematic (Claude 2008).

This problem was addressed by using principal component analysis (PCA). The first principal component of PCA is usually considered as a general size axis, while the remaining principal components represent the shape space. However, it also includes size related shape information (Jolicoeur and Mosimann 1960) and has been identified by Jolicoeur (1963) heuristically as a multivariate allometric size

axis. The mixture of size and size related shape information in the first component makes the interpretation of the other components of a PCA rather difficult. Baur and Leuenberger (2011) have developed new methods allowing interpretation of principal components in terms of ratios and clear separation of size and shape. The authors defined an isometric size axis, called 'isosize', as the geometric mean of the original measurements and thus comprising only differences in scaling. For the exact definition of 'isosize', see Baur and Leuenberger (2011). Allometry free shape variables could be obtained by projecting the measurements orthogonal to isosize. A PCA calculated on the covariance matrix of these shape variables then accounts solely for differences in proportions. Baur and Leuenberger (2011) suggested to plot the isosize against each significant shape component in order to assess the amount of allometry in the data.

Hence, for clear separation of shape and size, the PCA was applied on the standardized (dividing each measurement by geometric mean) and log-transformed ratios of the original measurements (Claude 2008, Baur and Leuenberger 2011). To examine how well the skulls of males and females are separated, the data were subjected to a linear discriminant analysis (LDA). The performance of the LDA was assessed by means of cross validation (Rencher 2002), where one

specimen is omitted from the analysis and classified according to the discriminant function found for the remaining specimens in the data set.

Geometric interpretation of PCA and LDA was made by using graphical tools developed by Baur and Leuenberger (2011). The 'PCA ratio spectrum' was applied for the interpretation of principal components in shape space, and the 'LDA ratio extractor' was used for finding the best ratios that separate the skulls of males and females. The amount of allometry in the data was assessed by the 'allometry ratio spectrum'. For detailed mathematical description and statistical framework of the applied methods see Claude (2008) and Baur and Leuenberger (2011).

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

## Ethics Statement

The skull samples used in this study were obtained from individuals that died in vehicle collisions, due to natural causes or as a result of legal hunting. Specimens from the National Museum of Natural History and private collections were measured, as well. No animal was killed for the purpose of this study.

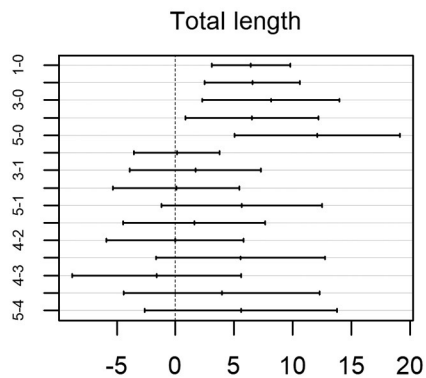
## Results

Shapiro-Wilk tests and QQ plots showed that all measurements did not deviate significantly from normal distribution.

It allowed applying t-test and one-way ANOVA. However, for most of the following statistical methods the assumption of normally distributed data is not strongly suggested. The results from ANOVA and Tuckey's HSD test showed that in the most skull traits juveniles, i.e. jackals between 7–10 months of age, differed from the older animals (Fig. 2). Only in two measurements, zygomatic breadth and least breadth between the orbits, there were significant differences between subadult and adult specimens. Hence, summary statistics of the skull measurements were calculated for joint group of subadult and adult jackals. Sexual dimorphism in skull size was examined by t-test (Table 2). Almost in all skull measurements differences in means between males and females were statistically significant. However, there is a large overlap in all skull traits, therefore both sexes could be hardly differentiated only by skull size (Fig. 3). The very high level of statistical significance, as demonstrated by t-test, is due to a large sample size.

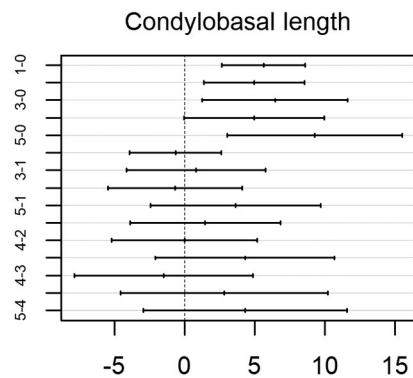
The PCA was applied on specimens from all age groups. The first principal component in shape space accounted for 17.98 % of the variance. Projecting the data along isosize and first principal component in shape space did not reveal any specific patterns in distribution or clustering of the individuals (Fig. 4). Only 12 specimens of the whole sample belonged to juveniles, i.e. below 11 months of age. Although with some overlap, their cluster was well separated from subadult and adult animals as it is shown by the ellipses enclosing 95 % of the confidence interval for each age group (Fig. 4A). Most of subadults are enclosed by adults on a plot. The sex dimorphism in shape and size of the skull is not pronounced and there is a large overlap between males and fe-

95% family-wise confidence level



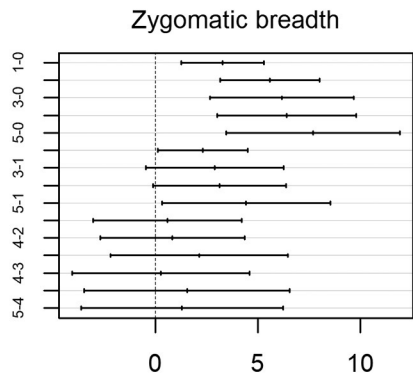
Differences in mean levels of age

95% family-wise confidence level



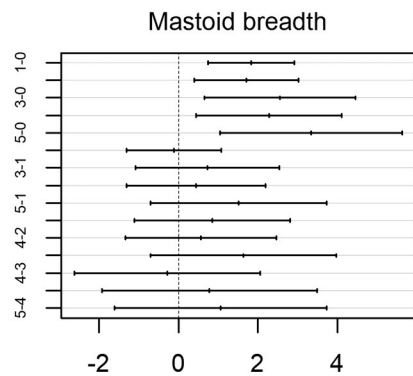
Differences in mean levels of age

95% family-wise confidence level



Differences in mean levels of age

95% family-wise confidence level



Differences in mean levels of age

Fig. 2. Differences by age in some basic cranial measurements. Results from Tukey's Honestly Significant Difference test.

Table 2. Descriptive statistics of basic skull measurements and statistical significance of the differences examined by Student's t-test.

| No      | Abbreviation | Males ( <i>n</i> =83) |       |           |          | Females ( <i>n</i> =51) |       |           |          | <i>p</i>  |
|---------|--------------|-----------------------|-------|-----------|----------|-------------------------|-------|-----------|----------|-----------|
|         |              | min                   | max   | $\bar{x}$ | <i>s</i> | min                     | max   | $\bar{x}$ | <i>s</i> |           |
| Cranium |              |                       |       |           |          |                         |       |           |          |           |
| 1a      | Maxl         | 154.1                 | 183.4 | 168.8     | 6.2      | 158.0                   | 175.5 | 164.6     | 4.4      | 0.0000*** |
| 1       | Tl           | 152.0                 | 181.0 | 166.5     | 6.3      | 155.9                   | 175.4 | 162.3     | 4.4      | 0.0000*** |

| No       | Abbreviation                   | Males (n=83) |       |           |     | Females (n=51) |       |           |     | p         |
|----------|--------------------------------|--------------|-------|-----------|-----|----------------|-------|-----------|-----|-----------|
|          |                                | min          | max   | $\bar{x}$ | s   | min            | max   | $\bar{x}$ | s   |           |
| 2        | Cbl                            | 144.8        | 168.7 | 158.1     | 5.3 | 147.8          | 162.9 | 154.0     | 3.7 | 0.0000*** |
| 10       | Nasl                           | 52.9         | 68.0  | 59.7      | 3.7 | 50.9           | 64.8  | 58.0      | 3.2 | 0.0058**  |
| 18       | P <sup>4</sup>                 | 15.6         | 18.6  | 17.2      | 0.6 | 15.0           | 18.0  | 16.8      | 0.6 | 0.0004*** |
| 22       | Bull                           | 22.0         | 28.6  | 25.1      | 1.4 | 21.9           | 27.1  | 24.5      | 1.2 | 0.0206*   |
| 23       | Mst                            | 51.2         | 61.4  | 56.5      | 2.0 | 52.1           | 60.4  | 55.2      | 1.5 | 0.0001*** |
| 29       | Skb                            | 49.5         | 56.0  | 52.5      | 1.4 | 47.8           | 54.5  | 51.5      | 1.4 | 0.0000*** |
| 30       | Zyg                            | 82.0         | 97.2  | 89.3      | 3.6 | 77.6           | 94.1  | 86.6      | 3.7 | 0.0001*** |
| 31       | Pob                            | 23.9         | 34.2  | 28.3      | 2.1 | 22.2           | 33.5  | 27.9      | 2.0 | 0.2609    |
| 32       | Fb                             | 36.1         | 51.0  | 42.2      | 3.0 | 35.9           | 46.6  | 41.5      | 2.9 | 0.1685    |
| 33       | lob                            | 21.4         | 31.5  | 26.3      | 1.8 | 22.6           | 30.7  | 25.4      | 1.7 | 0.0066**  |
| 34       | Palb                           | 49.7         | 59.0  | 53.9      | 1.8 | 50.0           | 57.0  | 52.9      | 1.6 | 0.0004*** |
| 36       | Rb                             | 26.0         | 32.3  | 29.7      | 1.3 | 26.8           | 30.7  | 28.7      | 1.0 | 0.0000*** |
| 38       | Skh                            | 44.7         | 53.0  | 48.5      | 1.8 | 43.4           | 55.1  | 47.8      | 1.9 | 0.0405*   |
| Mandible |                                |              |       |           |     |                |       |           |     |           |
| 1        | Mand                           | 109.5        | 133.4 | 121.9     | 4.5 | 113.0          | 127.6 | 118.9     | 3.3 | 0.0000*** |
| 8        | P <sub>1</sub> –M <sub>3</sub> | 59.1         | 69.1  | 65.6      | 2.0 | 61.1           | 68.0  | 64.6      | 1.8 | 0.0057**  |
| 13       | M <sub>1</sub>                 | 17.6         | 20.9  | 19.2      | 0.7 | 17.6           | 20.0  | 18.8      | 0.6 | 0.0007*** |
| 18       | Manh                           | 41.8         | 53.4  | 48.7      | 2.5 | 43.1           | 52.9  | 46.8      | 2.2 | 0.0000*** |

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

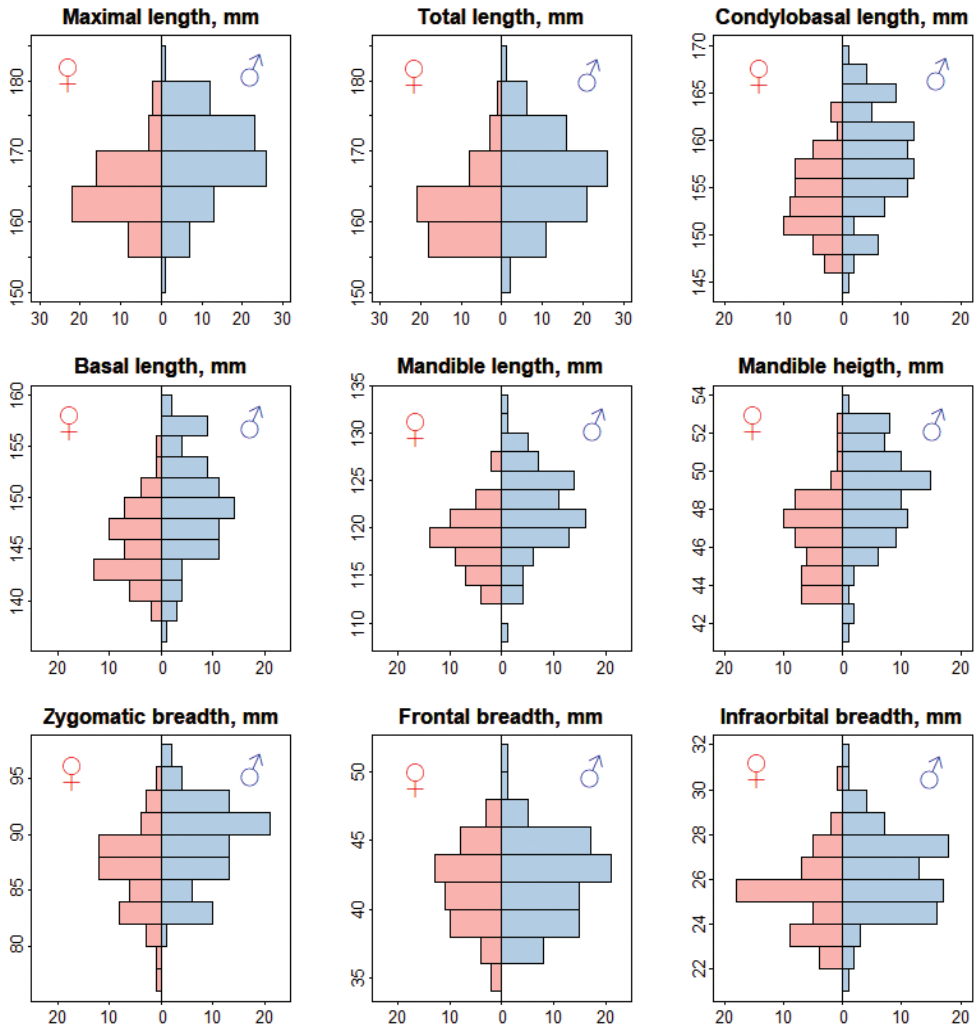
males. Differences are mainly in size but not in shape. Older males have bigger skulls, but this does not depend on their exact age. Most of subadults and females could not be separated by size and shape of the skull. The differences in cranial size and shape did not depend on the geographic region as well (Fig. 4B).

The first two principal components in shape space accounted for 28.66 % of the variance (Fig. 5). Projecting the data along first and second principal components reveals only differences in skull shape. The group of juvenile jackals could be distinguished from subadults and adults only along first principal component, but with a large overlap between clusters. There are no differences in skull shape between

males and females (Fig. 5A), and between jackals from different regions, as well (Fig. 5B).

The 'PCA ratio spectrum' allows the interpretation of principal components in shape space (Fig. 6). It is statistically stable because of the narrow confidence intervals shown on the graph. Considering factor loadings, ratios between least breadth at the postorbital constriction (Pob), least breadth between the orbits (lob), greatest diameter of the auditory bulla (Bull), frontal breadth (Fb), length of the nasals (Nasl), height of the mandible (Manh), and some dental measurements, such as length and breadth of the upper and lower molars, explained a large proportion of the variance of the first and





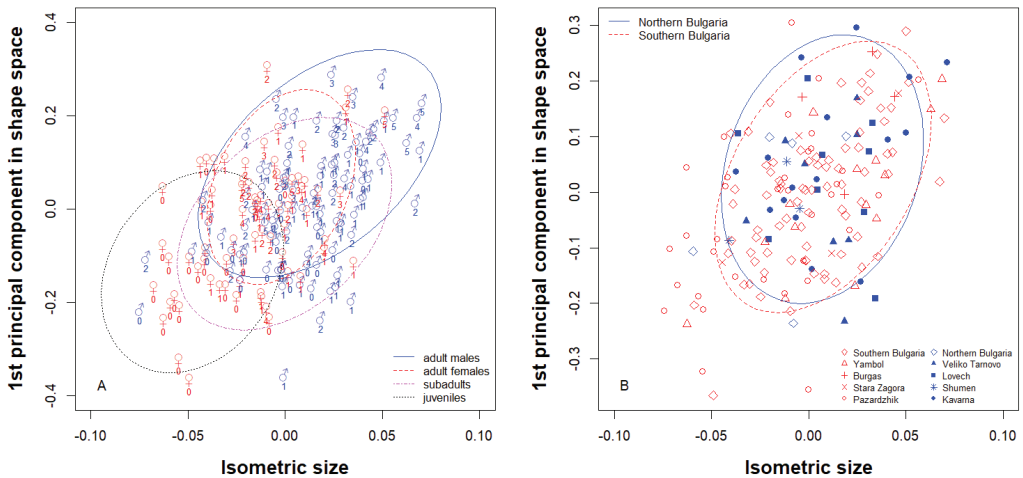
**Fig. 3. Histograms showing differences in basic cranial measurements between adult males and females.**

Note: Bars represent number of animals falling in each interval on the measurement scale.

second shape principal components. The same ratios, however, showed the most distinctive allometric behaviour as could be seen from the 'allometry ratio spectrum' (Fig. 7). Presence of allometry could be assessed as well, while projecting the first shape principal component orthogo-

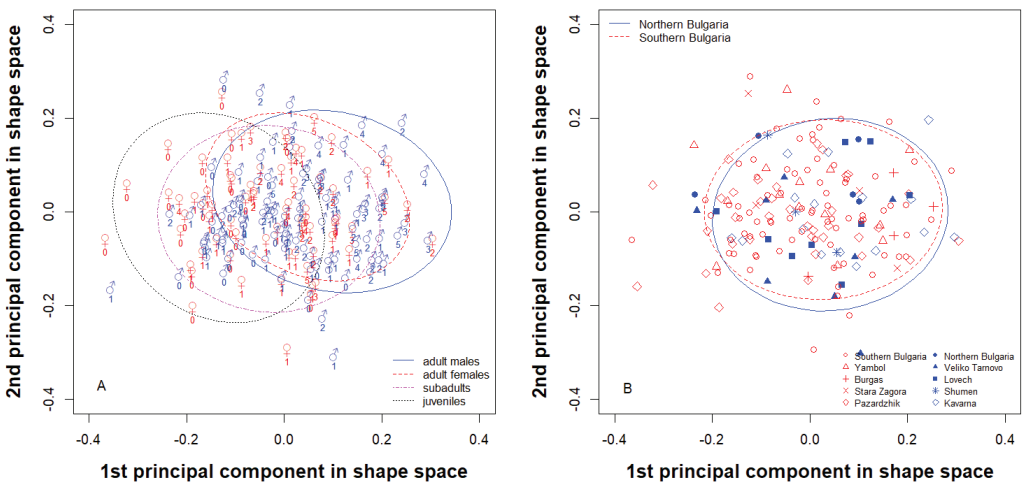
nal to the isometric size (Fig. 4A). Judging from the graph, there is only a very moderate correlation between shape and size. Hence, allometric variation was of marginal importance concerning my data set.

Following the distribution patterns from PCA, only adult and subadult jackals (83



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

Note: Ellipses enclose 95 % confidence interval for each group. A. Sex and age of each individual are shown. Numbers represent age in years. B. Collection sites of individuals are shown.

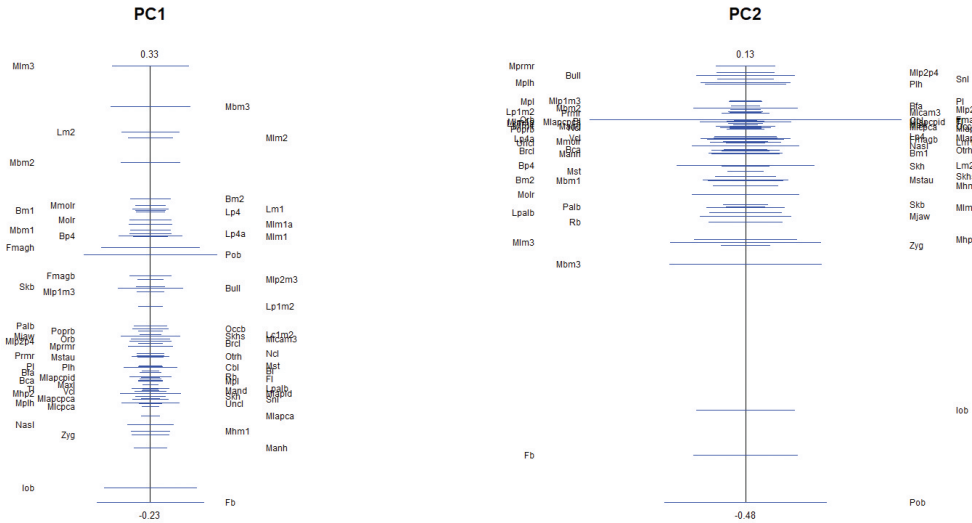


**Fig. 5. Principal component analysis. Projection of individuals along first two principal components in shape space.**

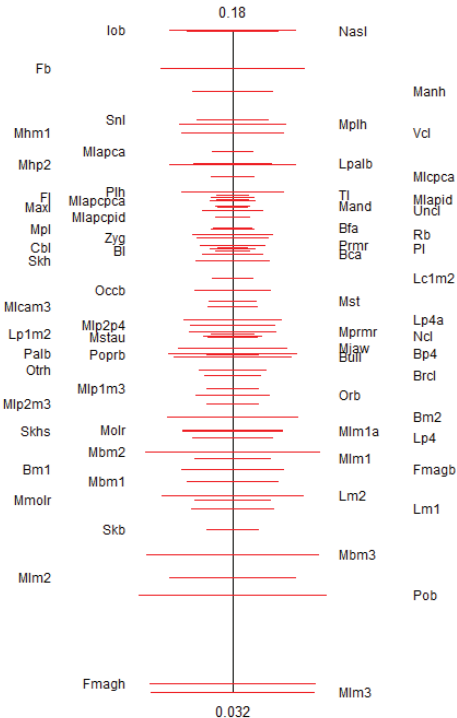
Note: Ellipses enclose 95 % confidence interval for each group. A. Sex and age of each individual are shown. Numbers represent age in years. B. Collection sites of individuals are shown.

males and 51 females) were subjected to linear discriminant analysis in order to separate males from females. The LDA indicated the presence of differences

between sexes (Wilks  $\lambda=0.372$ ,  $F=1.52$ ,  $df=1, 132$ ,  $p=0.047$ ,  $D^2=2.66$ ) and their possible separation by shape and size of skull (Fig. 8). However, the LDA per-



**Fig. 6. PCA ratio spectrum for the first and second principal component in shape space.**  
Note: Bars represent 68 % confidence intervals based on 500 bootstrap replicates.

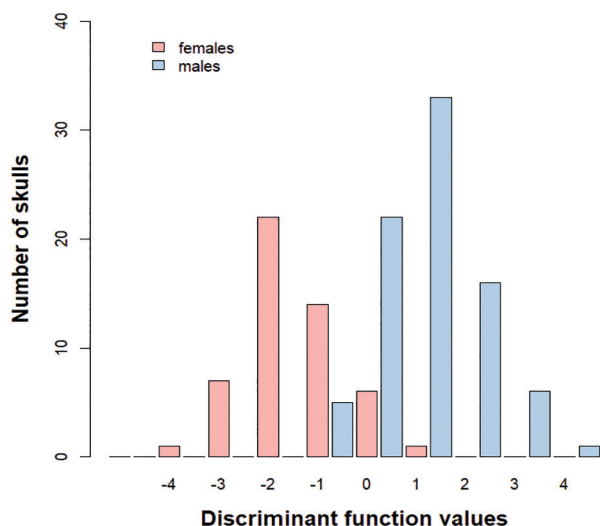


**Fig. 7. Allometry ratio spectrum.**

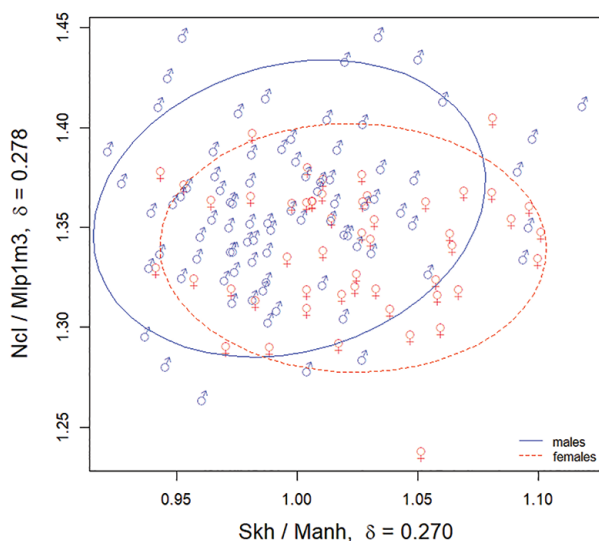
Note: Bars represent 68 % confidence intervals based on 500 bootstrap replicates.

formance estimated by cross validation was problematic. It showed that 49 % of females (25 skulls) and 35 % of males (29 skulls) were misclassified, meaning that almost 40 % of all specimens (regardless the sex) were not assigned correctly to the group they belong. Hence, the use of discriminant function for classification of jackal skulls with unknown sex is more than doubtful.

For practical reasons, a few characters that would allow quick and easy identification of most specimens might sometimes be useful, for instance in field work. One or two ratios would be preferable, as these are easily calculated and differences in proportions can sometimes even be estimated by eye (Reichenbach et al. 2012). Hence, the LDA ratio extractor was applied (Baur and Leuenberger 2011) to find the best ratios that could easily separate the skulls of male and female jackals. However, even these ratios could not clearly separate males from females (Fig. 9).



**Fig. 8.** Distribution of specimens along the discriminant function axis.



**Fig. 9.** Projection of individuals along best separating ratios revealed by LDA ratio extractor.

Note: The measure  $\delta$  indicates how well shape discriminates in relation to size. A value of  $\delta$  close to unity means that separation is mainly due to size, whereas for a value close to zero mostly shape is important. Ellipses enclose 95 % confidence interval for each sex.

## Discussion

The results suggest that the differences in shape and size of the jackal skulls, as far as they exist, are age-related. However, there is no clear differentiation between subadult and adult jackals. Only juveniles, i.e. younger than 11 months, could be separated by shape and size of skull. Univariate analyses showed that in all skull traits juveniles differed from the older jackals (Fig. 2). In most canine species skull growth slows, and even stops after reproductive maturation (e.g. Larter et al. 2012). In many species, however, growth continues throughout life, so that the oldest individuals in the population are generally the largest. Golden jackals reach sexual maturity at the age of 10–11 months (Taryannikov 1976), but they rarely reproduce at this age. In Tanzania 70 % of known surviving pups were observed helping with the next year's litter and thus didn't rear their own offspring (Moehlman 1987). According to the same author, retaining helpers potentially increases the parents' reproductive success, that is, it increases the parents' chances of passing on their genes to future generations. My results showed that the jackals in reproductive age reach full growth of the skull, but some cranial dimensions continue to increase in size. Obviously, the skull breadth grows up even after the jackals reach sexual maturity. Still, most of the traits did not show any significant differences

between subadults and adult jackals. Subadults differ from adults only by zygomatic breadth and least breadth between the orbits. All inferences about skull growth, based on such studies, however, should be treated cautiously. The data did not allow following ontogenetic development of jackal skulls because we compare different individuals. Usually more viable and healthy individuals reach senescence, while weaker and smaller animals die earlier and do not reach more than 2–3 years of age (Stoyanov 2013). Thus, post mortal comparison of skulls leads to biased data. On the other side, all such studies rely on samples collected post mortal and such bias could not be overcome.

Dividing the whole sample to three age groups is based on population demography of golden jackal and differences in the reproductive value of subadult and adult individuals. However, even multivariate analyses did not clearly separate subadults from adults. There was large overlap between both groups on the plots (figs 4A and 5A). The results suggest that there is no clear differentiation among Bulgarian jackals in skull size and shape, excluding juveniles. Although the sample size included in the analyses was relatively large, the projected data form a homogenous cluster but with large individual variability. Furthermore, there could be hardly seen any differences in skull shape between jackals from different regions of the country (figs 4B and 5B). The amount of geographical variation in Bulgarian population is comparable with sex and age differences. The similarities in skull morphology and morphometrics of the jackals from Bulgaria, Serbia, Hungary, Croatia and Austria were confirmed also by other studies (Markov et al. 2017, Rezić et al. 2017, Krendl et al. 2018). The results are consistent with recent genetic research as well. Studies

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

The sexual dimorphism in skull size was not pronounced, despite statistical significance of the differences in mean values of all measurements between males and females. The same results were confirmed by other studies, as well (Markov et al. 2017, Krendl et al. 2018). The high level of statistical significance, as demonstrated by t-test, was due to the large sample size, and could be misleading. However, there is large overlap between males and females in all skull traits, and they could be hardly differentiated only by skull size (Fig. 3). Furthermore, principal component analysis did not reveal any differentiation in skull size and shape between males and females.

The LDA performance in separating jackal skulls by sex was problematic. About 40 % of all specimens were not assigned correctly to the group they belong. Hence, the use of discriminant function for classification of skulls with unknown sex is more than doubtful. Even the best ratios, revealed by the LDA ratio extractor, could not clearly separate males from females. Differences between sexes on these two ratios, as far as they exist, are primarily related to the shape of the skull ( $\delta < 0.5$ ).

Sexual dimorphism in Canidae, when present at all, is usually minimal, with males being slightly larger than females (Sillero-Zubiri 2009), although studies on wolves from the Balkans show significant sexual dimorphism in adult individuals (Trbojević and Ćirović 2016). Such sexual dimorphism of golden jackal skulls,

with males a little bit larger than females, could be explained with monogamous reproductive system of jackals, and the presence of male parental care (Moore 1981, Moehlman 1987). Golden jackals form pair-bonds that are characterized by friendly behaviour and last the 6 to 8 years of their usual lifespans, there is little sexual dimorphism, either physically or behaviourally, and they share equally in most activities, such as marking and defending their territory, foraging and resting (Moehlman 1987). Such low degree of sexual dimorphism in Canidae was confirmed by other studies, as well (Jolicoeur 1959, Hell et al. 1989, Simonsen et al. 2003, Schutz et al. 2009).

## Conclusion

Skulls of golden jackal in Bulgaria show considerable individual variability, but weak intrapopulation differentiation. The differences in shape and size of the jackal skulls, as far as they exist, are age-related, but only juvenile specimens younger than 11 months could be easily distinguished. Subadult and adult jackals largely overlap in skull size and shape. Sexual dimorphism in jackal skull is weakly pronounced, with older males having slightly larger skull than females. My results are consistent with recent genetic and morphological studies and give new insights on patterns in cranial variability and population structure of golden jackal in Bulgaria.

## Acknowledgements

I am grateful to Stoyan Vassilev for the possibility to measure all skulls from his own collection, and to Nikolay Spassov

who provided the access to the collection of the National Museum of Natural History, Sofia.

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## MATURATION AND FECUNDITY OF *BARBUS CYCLOLEPIS*, HECKEL FROM THE CHEPINSKA RIVER, MARITSA RIVER BASIN, BULGARIA

Vasil Kolev<sup>1\*</sup> and Galerida Raikova<sup>2</sup>

<sup>1</sup>University of Forestry, Faculty of Forestry, Wildlife Management Department, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria. \*E-mail: vassilkolev@ltu.bg

<sup>2</sup>St. Kl. Ohridski' Sofia University, Faculty of Biology, Department of General and Applied Hydrobiology, 8 Dragan Tzankov Str., 1164 Sofia, Bulgaria. E-mail: galerida@abv.bg

Received: 17 April 2019

Accepted: 27 November 2019

### Abstract

The set of reproductive parameter estimates, determined by this study, gives the first quantitative estimates for this population. The study was conducted in the autumn during the period of years 2010–2011. A total of 97 fish specimens were caught by electrofishing. The study found that both sexes mature sexually in the second year. The females become sexually mature, once they reach a length of 122 mm and 25 g weight. The males become sexually mature once they reach a length of 90mm and 7 g weight. The fecundity of barbel population from the Chepinska River ranges from 2000 to 17,969 eggs. The average fecundity was 5246 eggs. The absolute fecundity was positively correlated with the growth of the length and mass of the fish. Consequently, the five years old Maritsa barbels had the highest fecundity rate. The average values of the relative fecundity were 115 eggs per kg.

**Key words:** *Barbus cyclolepis*, Chepinska River, fecundity, sex composition.

### Introduction

The Maritsa barbel (*Barbus cyclolepis* Heckel, 1937) is an endemic species for the Balkan Peninsula. It is found in watercourses of the Aegean watershed as well as in some rivers of the Black Sea watershed (Chichkov 1935, Heckel 1937, Kottelat and Freyhof 2007). This is the most abundant fish species in the middle zone of the Maritsa River tributaries including the Chepinska River (Kolev 2013, 2016). The Maritsa barbel is not a com-

mercial fish, but it is one of the most popular sports fishes in Southeastern Bulgaria. The fish is included in Council Directive 92/43/EEC/ 21.05.1992 Annex II (as *B. plebeus*).

The first study of the fish's breeding season in the Maritsa water basin of Bulgaria was conducted by Mihaylova (1965). Almost twenty years later Marinov (1986) published data about the spawning season and fecundity of the barbels in the rivers: Chepinska, Mesta, Struma and Stroumeshnitsa. Recent studies of the it's

reproductive biology, sex composition, maturity and fecundity in the Bulgarian stretch of the Maritsa River was undertaken by Rozdina (2009), Raikova-Petrova and Rozdina (2012). In Northern Greece the species has been examined by Vasiliou and Economidis (2005), the sex composition and the reproduction being described. However, the research has not yet explored the maturation and fecundity of the Maritsa barbel fish, inhabiting the Bulgarian tributaries of the Maritsa River.

The aim of this research was to study sex composition and the fecundity distribution, according to age and sex distribution of the Maritsa barbel in the Bulgaria rout of the Maritsa (or Evros) River.

## Study area

The study area includes the Chepinska River, a right tributary of the Maritsa River. Chepinska River originates in the West Rhodopes Mountains; its springs are located underneath the peak Mala Siutkia (2078.7 m a.s.l.) (Fig. 1). In its upper reaches the river flows to the Northwest and is called Bistritsa. Once it reaches the town of Velingrad the river runs northwards and near the village of Vetren it enters the Upper Thracian Valley. Chepinska River flows into the Maritsa River near the village of Kovachevo (close to the town of Pazardzhik). The Chepinska River is 81.7 km long with a catchment area of 899.6 km<sup>2</sup>.

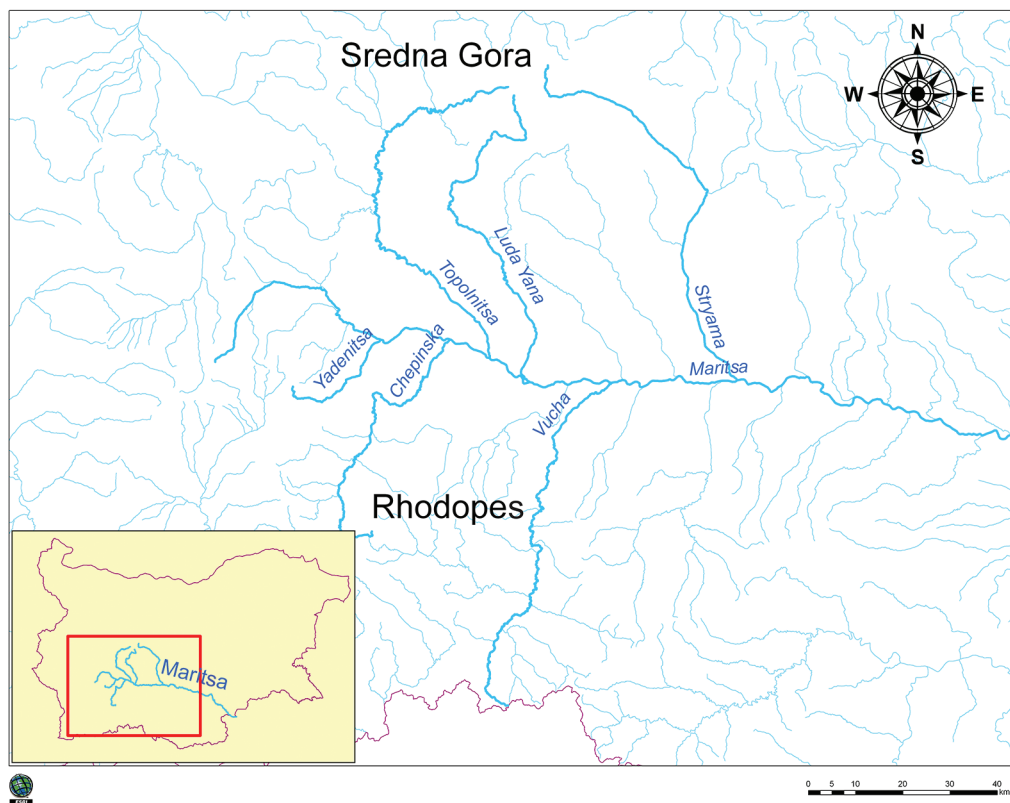


Fig. 1. Location of the Chepinska River, Arc Map 10.0 (ESRI – ArcGIS 2013).

## Materials and Methods

The specimens for this study were collected from seven sampling sites (Table 1).

The specimens were collected in the 2010–2011. A total of 97 Maritsa barbel specimens were caught in the Chepinska River by using the method

of electrofishing. A SAMUS 725G converter was used, providing up to 640 V direct current (DC), with a frequency of 50 Hz and output power reaching up to 200 W. The catch was performed according to the EN 14011:2004 instruction (Water quality – Sampling of fish with electricity).

**Table 1. Sampling sites.**

| No | Location                                                       | Geographic coordinates |              | Altitude, m a.s.l. | Date of sampling |
|----|----------------------------------------------------------------|------------------------|--------------|--------------------|------------------|
|    |                                                                | N                      | E            |                    |                  |
| 1  | In the vicinity of the mineral baths of the village of Varvara | 42°07'42,02"           | 24°07'24,53" | 401                | 13.06.2010       |
| 2  | In the vicinity of the railway station M. Nikolov              | 42°06'24,78"           | 24°06'20,11" | 465                | 14.06.2010       |
| 3  | In the vicinity of the mineral baths of the village of Varvara | 42°07'42,02"           | 24°07'24,53" | 401                | 26.07.2010       |
| 4  | In the vicinity of the village of Draginovo                    | 42°05'43,81"           | 24°04'54,82" | 523                | 27.07.2010       |
| 5  | In the vicinity of the railway station M. Nikolov              | 42°06'24,78"           | 24°06'20,11" | 465                | 08.04.2011       |
| 6  | In the vicinity of the village of Draginovo                    | 42°05'43,81"           | 24°04'54,82" | 523                | 09.04.2011       |
| 7  | In the vicinity of the village of Lozen                        | 42°11'09,62"           | 24°09'45,65" | 240                | 18.11.2011       |

The standard length (SL), to the end of the scales cover with a precision 1 mm and specimen's net weight without guts (NW) were measured with a precision 1 g. The sex was determined microscopically.

Scales were used to determine the age. It was reported by counting the annual rings of the scales. The number of fish eggs was counted by using the weighting method. In 1 g of gonads, the eggs were counted by using a counting chamber. Both operations were performed with a microscope Olympus CX 31, at a 40× magnification.

The maturity was determined by the co-

efficient  $b$  from the equation:  $g = a + b \times W$ , recommended by Morozov (1964) and Zhivkov (1985) which describes the relationship between the gonads' mass (g) and the mass of a fish without its entrails (NW).

The relative fecundity (RF) was explained directly by the ratio of fishless gut ( $F/NW$ ) (Spanovskaya and Grigorash 1976). Another method to determine the RF, proposed by Zotin (1961) and Zhivkov (1999), was also used. According to this method the coefficients  $a$  and  $b$  were calculated from the equation:  $F = a + b \times NW$  (the equation reveals the dependence between absolute fecundity –  $F$  and  $NW$ ).



Results

Table 2 presents the age and sexual composition of the Maritza barbel population in the Chepinska River. The sample included five age groups. Three and four years old barbels were the most abundant.

The average sex ratio was ♂:♀

1.5:1. This difference was not statistically significant,  $d = 1$ , calculated  $\chi^2 = 2.48$ ,  $\chi^2_{critical} = 3.83$  – the value over which the null hypothesis  $H_0$  (i.e. ♂:♀ 1:1) must be rejected;  $P < 0.005$ , thus, the sex ratio did not differ from the normal ♂:♀ 1:1. Figure 2 shows the relationship between fecundity and length of the body to the end of the scales cover.

Table 2. Sex composition.

| Size class<br>SL, mm          | Age, years |   |   |      |      |   |      |      |   |    |    |   | n   | %  |     |
|-------------------------------|------------|---|---|------|------|---|------|------|---|----|----|---|-----|----|-----|
|                               | 1          |   |   | 2    |      |   | 3    |      |   | 4  |    | 5 |     |    |     |
| Sex                           | juv.       | ♂ | ♀ | juv. | ♂    | ♀ | juv. | ♂    | ♀ | ♂  | ♀  | ♂ | ♀   |    |     |
| 61–70                         | 1          |   |   |      |      |   |      |      |   |    |    |   |     | 1  | 1   |
| 71–80                         |            |   |   | 9    | 2    |   | 5    | 1    |   |    |    |   |     | 17 | 18  |
| 81–90                         |            |   |   |      | 3    |   | 8    | 4    |   |    |    |   |     | 15 | 16  |
| 91–100                        |            |   |   |      |      |   | 15   | 8    |   | 6  |    |   |     | 29 | 30  |
| 101–110                       |            |   |   |      |      |   | 1    | 4    |   | 4  |    |   |     | 9  | 9   |
| 111–120                       |            |   |   |      |      |   |      | 2    |   |    |    |   |     | 2  | 2   |
| 121–130                       |            |   |   |      |      |   |      |      |   | 1  |    |   |     | 3  | 3   |
| 131–140                       |            |   |   |      |      |   |      |      |   |    | 1  |   |     | 2  | 2   |
| 141–150                       |            |   |   |      |      |   |      |      |   |    | 1  |   |     | 11 | 11  |
| 151–160                       |            |   |   |      |      |   |      |      |   |    |    |   | 5   | 5  | 5   |
| 161–170                       |            |   |   |      |      |   |      |      |   |    |    |   | 2   | 2  | 2   |
| 171–180                       |            |   |   |      |      |   |      |      |   |    |    |   | 1   | 1  | 1   |
| Sum                           | 1          | 0 | 0 | 9    | 5    | 0 | 29   | 19   | 0 | 11 | 2  | 0 | 21  | 97 | 100 |
| % of the total number of fish | 100        | 0 | 0 | 69.2 | 38.5 | 0 | 60.4 | 39.6 |   | 85 | 15 | 0 | 100 |    |     |
| ♂:♀                           |            | 0 | 0 |      | 100  | 0 |      | 100  | 0 | 85 | 15 | 0 | 100 |    |     |

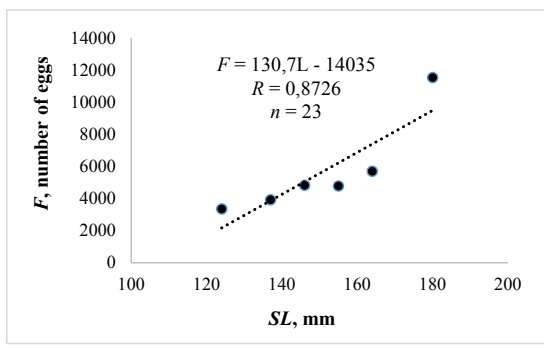


Fig. 2. Relationship between the absolute fecundity (F) and the standart length (SL).

This relationship is described by a linear equation with a high degree of reliability. As the length was increasing, absolute fecundity was also increasing. The individual fecundity of the Maritza barbel was between 2000 and 17,969 eggs. The average individual fecundity rate was 5246 eggs. These results have been obtained from 23 specimens with a length between 122 mm and 183 mm. The most fertile female barbel, found in the sample, was a five years old fish,

183 mm in length and weighing 88 g. Its fecundity was 17,969 eggs. In the sample, the specimen with the lowest fecundity of 2000 eggs was a three-year-old female,

147 mm long and weighing 40 g.

The average absolute fecundity of the Maritsa barbel in different length classes is shown in Table 3.

**Table 3. Change of absolute fecundity by length classes.**

| Length class (L), mm | Average length, mm | Range, number of eggs | Average ( <i>F</i> ), number of eggs | <i>n</i> |
|----------------------|--------------------|-----------------------|--------------------------------------|----------|
| 121–140              | 132                | 3350 – 4896           | 3711                                 | 5        |
| 141–160              | 148                | 2000 – 7560           | 4826                                 | 14       |
| 161–180              | 168                | 2652 – 8784           | 5522                                 | 3        |
| 181–190              | 183                | 17 969                | 17 969                               | 1        |

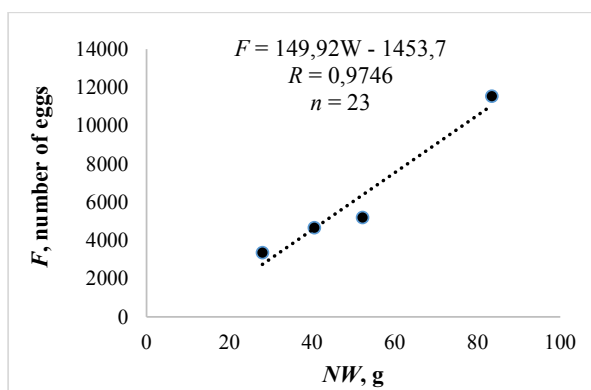
The average *F* increases naturally with increasing of the body length. In the weight class 181–190 mm it is very high.

In Figure 3 is present the relationship between *F*/NW of the Maritsa barbel from

the Chepinska River.

It was very well expressed by a linear equation with very high degree of signification ( $R = 0.9746$ ). The graph shows that fecundity is positively correlated with the weight of the fish. This results confirms the suggestion of several authors (Nikolsky 1965, 1974; Zhivkov 1999) that the main factor which increase fecundity according to the fish growth in weight.

In Table 4 the absolute fecundity of the Maritsa barbel from the Chepinska and Maritsa Rivers were compared according Zhivkov's (1999) method. This method is very appropriate for comparing the fecundity of fish from different watercourses.



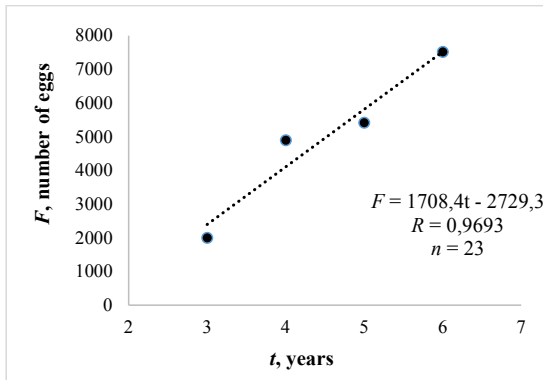
**Fig. 3. Relationship between the absolute fecundity (*F*) and the average net weight (*NW*).**

**Table 4. Absolute fecundity (*F*) of the Maritsa barbel calculated at same Weight (*NW*).**

| Author (year),<br>(river)                  | <i>F</i> /NW Relationship                            | Net weight ( <i>NW</i> ), g<br>Absolute fecundity ( <i>F</i> ), number of eggs |      |      |        |        |
|--------------------------------------------|------------------------------------------------------|--------------------------------------------------------------------------------|------|------|--------|--------|
|                                            |                                                      | 12                                                                             | 25   | 50   | 100    | 200    |
| Aur data (2015–2016),<br>(Chepinska River) | $F = 149.92NW - 1453.7$ ;<br>$r = 0.9746$ , $n = 23$ | 345                                                                            | 2294 | 6042 | 13 538 | 28 530 |
| Rozdina (2009), (Maritsa<br>River)         | $F = 81.33NW + 2203.3$ ;<br>$r = 0.99$ , $n = 61$    | 3179                                                                           | 4237 | 6270 | 10 336 | 18 469 |

The result shows that the absolute fertility of the barbel in the Maritsa River is greater than in the Chepinska River in the first three weight classes. An increase in the fecundity occurs with larger specimens.

The relationship between  $F$  and age showed an increase in absolute fecundity according to age (Fig. 4).



**Fig. 4. Relationship between total fecundity ( $F$ ) and age ( $t$ ).**

Table 5 shows the changes of the relative fecundity of the Maritsa barbel according to size and weight.

**Table 5. Relative fecundity ( $RF$ ) of Maritsa barbel from the Chepinska River.**

| Size classes<br>( $NW$ ), g | Weight<br>( $NW$ ), g | $RF$ ,<br>number<br>of eggs | $n$ |
|-----------------------------|-----------------------|-----------------------------|-----|
| 11.0–30.9                   | 28                    | 120                         | 2   |
| 31.0–50.9                   | 40.5                  | 115                         | 15  |
| 51.0–70.9                   | 52.2                  | 100                         | 4   |
| 71.0–90.9                   | 83.4                  | 138                         | 2   |
| Average and<br>sum          | -                     | 115                         | 23  |

## Discussion

Barbel population from the Chepinska River is relatively young. Six, seven and eight adult barbels were absent. The smallest sexually mature specimens found was a two-year-old male, over 90 mm in length. Female's fish in Chepinska River developed sexually at the earliest in the fourth year. The smallest sexually mature female captured was 122 mm in length. Males are more numerous in the first three age groups. Vasiliou and Economidis (2005) reported that in the Doirani River the Maritsa barbel males start mature in the second year, while the females in their third years. According to Raikova-Petrova and Rozdina (2012) in the Maritsa River both sexes start mature in their second year. The same authors also found the smallest sexually mature male in Maritsa River and it was 55 mm in length and the smallest sexually mature female was 63 mm long. In the both rivers Doirani and Maritsa, the Maritsa barbel reaches an older age than in the Chepinska River. In the Doirani River 9 age groups were found (Vasiliou and Economidis 2005), while in the Maritsa River – 8 age groups were established respectively (Raikova-Petrova and Rozdina 2012). The absence of 6, 7, 8 and 9 age groups in the population in the studied Chepinska River shows that this species is under strong pressure from the sport fishing.

The comparison of the  $F$ , calculated for the same weight, showed that for fish weighing up to 50 g, the fecundity of the Maritsa barbel from the Chepinska River is lower than that of a barbel from the Maritsa River (Table 4). Similar result was obtained by comparing the coefficient  $a$  from the equation  $F = a + b \times NW$  (Zotin 1961, Zhivkov 1999), described

the fecundity-mass ratio of the barbels from both rivers. The coefficient  $a$ , the so-called 'initial fecundity', from the equation for the Chepinska River in absolute value is  $a = 1453.7$ ; while this from the equation for the Maritsa River is  $a = 2203.3$ .

The main flow of the Chepinska River and its tributaries (the Matnitsa River) passes through many villages and cities. Therefore, the industrial and domestic pollution of the waters is very high after the town of Velingrad (Tsachev et al. 1977, MOEW 2012) and it deteriorates the living conditions. In the lower stretch of the river, the steel processing plant of the village of Varvara has built water basins in order to meet its needs. A quarry for aggregates was also built right inside the river bed. These modifications of the river bed drastically reduce the water runoff in the lower stretch of the Chepinska River, before its confluence with the Maritsa River, and disturb the migration. Considering that the rate of fish growth is a reflection of the living conditions (Nikolsky 1965, 1974; Zhivkov 1999), the anthropogenic disturbance has also impacted the growth of the species in the Chepinska River.

Average fecundity of Maritsa barbel in the Chepinska River increased with an augmentation of the length (Table 3). In the last size class, the average  $F$  increased rapidly. At length of over 181 mm, the value of the individual fecundity was more than three times higher than that in the other size classes.

Some authors like Vasiliou and Economidis (2005), Raikova-Petrova (1992), Rozdina (2009), Raikova-Petrova and Rozdina (2012) established that older Maritsa barbels produce more eggs due to its higher weight. Our results (Figure 4) also confirm that with increasing body mass, absolute fertility increases.

$RF$  of the barbels from the Chepins-

ka River decreases with increasing the weight. Only in large fish, weighing over 71 g, it increases. Similar results have been obtained for this species also from other authors – Rozdina (2009), Raikova-Petrova and Rozdina (2012).

## Conclusions

Male Maritsa barbels become sexually mature during the second year. The females reach sexual maturity after the second year. In October and November the barbels have already spawned. During these months, the Maritsa barbel has already formed the new caviar for the next year. The caviar in this period is much smaller than the breeding period and is greyish in color.

The absolute fecundity varies between 2000 and 17,969 eggs. The average individual fecundity rate is 5246 eggs. The sex ratio does not differ from the normal sex ratio of 1:1. The average relative fecundity is 115 eggs per kg female fish.

The set of reproductive parameters estimated, determined in this study, provides the first quantitative estimates for this population and will improve the scientific knowledge about the reproductive potential of the Maritsa barbel. The improved understanding of the population status will also hopefully lead to a more sustainable management of this endemic and protected fish.

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## LABORATORY OBSERVATIONS ON LARVAL HATCHING OF *THAUMETOPOEA PITYOCAMPA* EARLY DEVELOPING PHENOLOGICAL FORM IN EASTERN RHODOPES, BULGARIA

Margarita Georgieva\*, Gergana Zaemdzhikova, Plamen Mirchev,  
and Georgi Georgiev

Forest Research Institute, Bulgarian Academy of Sciences, 1756 Sofia, 132 St. Kliment Ohridski  
Blvd., \*E-mail: margaritageorgiev@gmail.com

Received: 28 July 2019

Accepted: 16 November 2019

### Abstract

The hatching dynamics of larvae of early developing phenological form of pine processionary moth (*Thaumetopoea pityocampa*) based on 93 egg batches was monitored under laboratory conditions. The egg batches were collected on July 12, 2018 in a 30-year-old *Pinus nigra* plantation, at an altitude of 450 m in the region of Fotinovo village, Kirkovo State Forestry, Eastern Rhodopes. Newly hatched larvae started appearing at the beginning of July 2018, and continued for a month, until August 8, 2018. The peak lasted for 13 days, from the 19th to 31st of July, during which 80.6 % of the larvae hatched. Field observations conducted in parallel, showed that the larval development in the studied habitat lasted for about three months.

**Key words:** larval development, larval phenology, pine processionary moth.

### Introduction

Pine processionary moth, *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae) is a Mediterranean species which is one of the most dangerous pests in these latitudes. The species was subject of many studies regarding its geographic expansion, in response to the increasing winter temperature and other climate anomalies (Battisti et al. 2005, 2006; Toffolo et al. 2006; Robinet et al. 2007; Mirchev et al. 2011a). In this regard, observations of the seasonal phenology within its natural range are very important to understand pest's response to such climatic patterns

(Bellin et al. 1990; Schmidt 1989, 1990; Battisti et al. 2015; Roques et al. 2015; Mirchev et al. 2017). The phenology of *T. pityocampa* varies with climatic conditions (Démolin 1969; Robinet et al. 2015). Adult emergence, immediately followed by mating and egg laying, occurs between June (in colder mountainous areas) and October (in areas with Mediterranean climate) (Aimi et al. 2006). A unique population of summer phenological form was discovered in 1997 in Leiria, Portugal (Pimentel et al. 2006), where it continues to be present at high densities. In the same stands and trees, the summer form coexists with the typical winter one. Studies have been conducted and hypotheses put forward



about the variations in the phenology of the species and the emergence of new phenological forms (Santos et al. 2007, 2011, 2013; Battisti et al. 2015; Burban et al. 2016).

*T. pityocampa* was found for first time in Bulgaria in 1906 (Drenovsky 1923). The biology of the species was initially observed in the region of Belovo, located between Rila, the Rhodopes and Sredna Gora Mountains (Buresch 1915). It was established that adult moths start to emerge in June, and new-hatched larvae can be found at the end of August. Russkoff (1929–1930) reported that adults emerged from the end of June to late August, with the highest intensity in July, based on observations in the region of Velingrad, Rakitovo and Asenovgrad (Western Rhodope Mountains). According to the author, the time of pine processionary moth development does not always coincide with data published in the entomological literature. He pointed out that in several regions of the country, two phenological forms occurred, with identical morphological aspect. For example, in the region of Devin, Velingrad (Western Rhodopes) and Karlovo (Central South Bulgaria), the larvae usually descend for hibernation in the soil, unlike Kostenets (Rila) and Chepelare (Western Rhodopes) where the larvae spend winter in the nests.

Zankov (1960) studied *T. pityocampa* biological features across many regions in Bulgaria and highlighted the variations in its phenology. In the regions of Razlog, Blagoevgrad and Sandanski (Southwestern Bulgaria) it was noticed that larvae of the pine processionary moth hibernated in the nests. The period of pupation was quite extended, the first larvae descending to the soil at the end of April, and the last ones during the first part of June. In Velingrad, Hissarya and Karlovo

the larvae hatched at the end of July or the beginning of August. In the middle of October, approximately 40 % of larvae in single nests descended for hibernation in the soil, and the remaining until the second half of February. Tsankov et al. (1996) reported that in the region of Banya near Karlovo, pine processionary moth development started a month earlier, by comparison to the rest of the country. Studies carried out in Bulgaria significantly contributed to clarify the distribution of both forms, the early developing form, and the typical Mediterranean, or winter (late developing) one (Zankov 1960; Tsankov et al. 1996; Mirchev et al. 2011b, 2016, 2017, 2019).

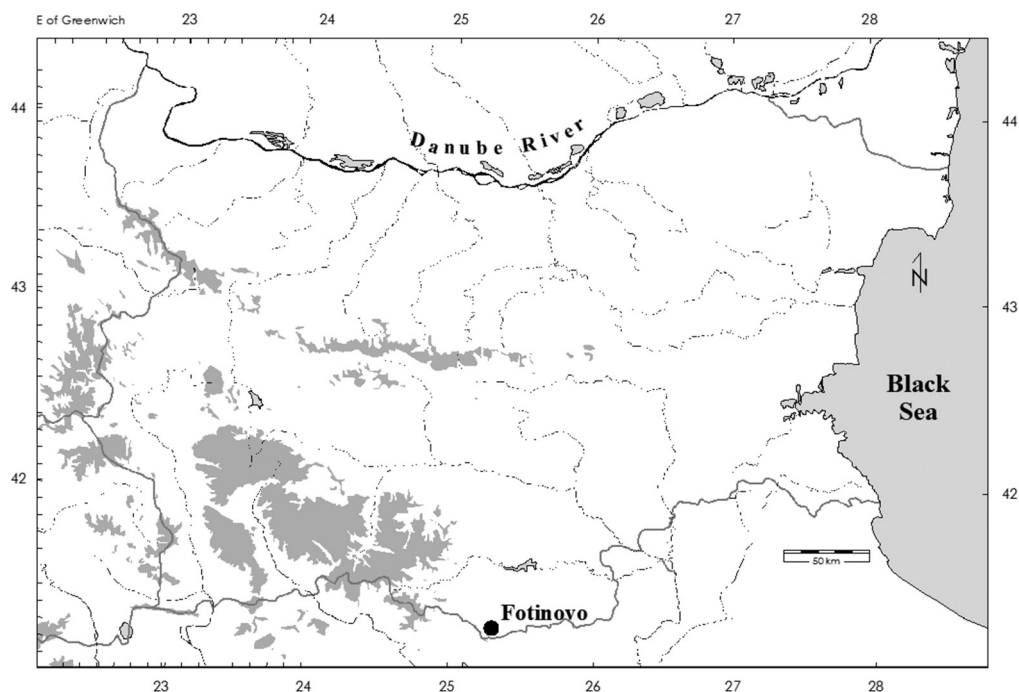
Recently, the early developing phenological form of *T. pityocampa* was observed in pine stands of Kirkovo State Forestry in Eastern Rhodopes (Mirchev et al. 2019). However, the larval hatching period and dynamics of this form have not been previously studied, neither in Kirkovo nor in other localities in Bulgaria.

This note presents the results of a laboratory study on larval hatching of the early developing phenological form of *T. pityocampa* in a new habitat in Bulgaria.

## Materials and Methods

Ninety-three egg batches of *T. pityocampa* were collected on July 12, 2018 from a 30-year old plantation of *Pinus nigra* Arn. in the region of Fotinovo village (Kirkovo State Forestry, Eastern Rhodopes) (Fig. 1). The site is located at an altitude of 450 m AMSL, coordinates 41°22'37.5" N, 25°19'18.5" E.

After collection, egg batches were transported to the laboratory of Forest Research Institute in Sofia. Each egg batch was put in a test tube covered with cotton



**Fig. 1. Studied locality of *T. pityocampa* in Bulgaria.**

stopper, and kept under laboratory conditions at 20–22 °C. The samples were observed daily for the presence of larval hatching.

Additionally, in the studied site, the contents of 20 nests of *T. pityocampa* were investigated on the 25th of September and 9th of October 2018, in order to determine the larval instars and the time of descending for pupation in the soil.

## Results

The population density of *T. pityocampa* was high in the pine stands studied, with over 10 egg batches on a single tree (observation 12.07.2018). During the collection of biological material, larval hatching was recorded in five egg batches (5.4 %). The neonate larvae were found feeding at

the base of the needles, near the batches (Fig. 2). It was assumed that the larvae were 3–4 days old, i.e. hatching occurred around 7th–10th of July 2018.

Under laboratory conditions, the period of larval hatching lasted for one month – from 7th of July to 8th of August 2018 (Fig. 3). Mass hatching was observed for 13 days (July 19–31), when the percentage of newly-hatched larvae attained 80.6 %. In this period, daily hatching ranged from 2.2 % to 16.1 %. This rate was significantly higher and over 6 times larger than at the beginning and end of the period.

The analysis of 20 nests on 25th September 2018 showed that pine processionary moth larval population was in 4th–5th instar, with 5th instar larvae dominating. The observation carried out on 9th of October 2018 showed that, in two of

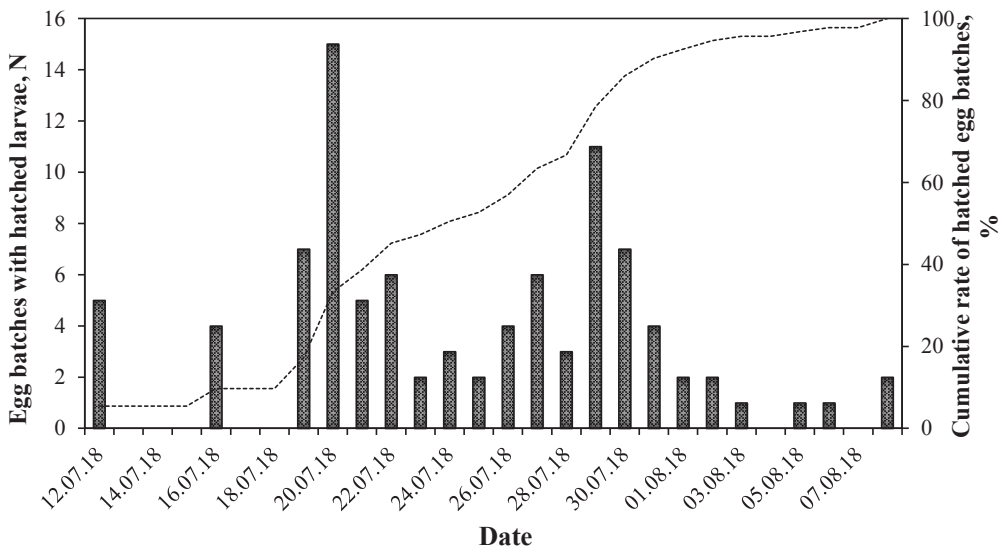


**Fig. 2. Neonate *T. pityocampa* larvae emerging from an egg batch.**

20 studied nests, the larvae had already descended into the soil for pupation, and in the remaining nests all larvae were in 5th instar. Thus, the larval development of early developing phenological form lasted for about three months.

## Discussion

The region studied is located at 40 km from the Aegean Sea, but the influence of the sea is obstructed by Gyumyurdzhinski Snezhnik ridge in the Eastern Rhodope Mountains. The region is characterized by relatively mild winters with average temperatures above 0 °C, and hot, dry summers. The period with temperatures above 32 °C (critical for the development of pine processionary moth eggs and young larvae) lasts only for 10–12 days. In the region of Sandanski, the habitat of the winter phenological form of *T. pityocampa*,



**Fig. 3. Hatching period in the laboratory.**

Note: daily number of egg batches showing the first hatched larvae (columns); cumulative percentage of egg batches with hatched larvae (dotted line).

that period lasts on average 20 days, although in some years, like between 2012 and 2015, it varied between 38 and 43 days (Mirchev et al. 2018).

Several authors published data on the phenology in various regions of its natural range. Thus, in areas under typical Mediterranean climate, adult emergence can be delayed until September (Battisti et al. 2015). For example, in Greece (Kassandra peninsula and Kalogria), larval hatching was observed from the end of September to the end of October (Schmidt 1989, Bellin et al. 1990). In most of the other areas (colder sites at high elevation, or high latitude), the flight period can last from late June – early July to late August – early September, with a flight peak in July (Roques et al. 2015). In the atypical phenological form in Bulgaria, hatching was observed from early July to early August. In the summer form in Portugal, egg laying lasts from the end of April to the beginning of July, and hatching starts a month later, between the end of May and the beginning of July (Battisti et al. 2015).

Variations in the phenology of *T. pityocampa* have been explained by habitats' climatic conditions. Battisti et al. (2015) reported that egg hatching in colder sites in Greece occurred in July and in warmer sites in October. A similar interpretation was proposed for the closely related species *T. wilkinsoni* Tams in Turkey, where egg hatching occurred in August at colder sites, and in November in warmer ones (Battisti et al. 2015). Yet, these assertions were not completely confirmed by the data obtained in Bulgaria. In the coldest habitats, corresponding to the Northwestern zones of *T. pityocampa* range expansion, only the winter form phenology of the species was observed (Mirchev et al. 2011b, 2016).

Santos et al. (2011) pointed that the

summer its form found in Portugal, should be regarded as a separate phenological population. According to Santos et al. (2007), the case under consideration refers to a mode of sympatric speciation in which the differentiation of populations is primarily due to a phenological shift without habitat or host shift. Comparing the summer phenological form of *T. pityocampa* with the winter one, Santos et al. (2013) found the presence of phenotype differentiation: variations in the fertility of female moths, in the shape and colour of the covering scales of egg batches, as well as in the species composition and the impact of the egg parasitoid complex on *T. pityocampa* population density. Both monitoring of adult flight patterns and genetic analyses demonstrated that these two forms are strongly isolated from each other (even where they are sympatric) (Burban et al. 2016). Since the Portuguese summer population already differs significantly in its genetics, morphology, ecology and physiology, it should not be directly compared with all other phenological forms of *T. pityocampa* (Godefroid et al. 2016).

In conclusion, the results of the present survey expand the knowledge on larval hatching and development of the established atypical (early developing) form of pine processionary moth in Bulgaria. The phenological changes in this economically important insect pest can affect both its management and public health in attacked forest areas.

## Acknowledgement

This study is supported by RILA Project DTNS France 01/8/09.05.2017 'Standardizing Automated large-scale Monitoring' to understand atypic phenologies

at both ends (France and Bulgaria) of the climate-driven expansion front of a European urticating pest, Pine Processionary Moth (SAM3PM) financed by the National Scientific Fund.

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