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LIPID CONTENT IN BEE POLLEN OF SOME PLANTS IN FORESTRY AREA

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Abstract

Lipids are main components of bee pollen grains, and vary among different pollen taxa. The objective of this study was to determine the lipid content in pollen of 20 popular bee plants and the impact of lipids to honey bees. The analysis showed, that the percentage of the total lipid content in the examined bee pollen ranged from 0.87 % for *Zea mays* L. to 13.6 % for that of *Echinops ritro* L., and the average was 3.91 %. The average level of lipids for the entomophilous plants was 4.20 % and 1.31 % for anemophilous, for Asteraceae was 5.42 % and 1.88 % for Fabaceae. The average weight of one hundred worker bees fed on pollen from *Z. mays* was 8208.2 mg, whereas it was 9882.2 mg for the bees fed on pollen from *E. ritro*. The weight of bees that consumed pollen with higher lipid content is higher compared to that consumed pollen with lower lipid content.

Key words: honey bee, honey bee nutrition, monofloral bee pollen.

Introduction

Honey bees prefer pollen with high lipid levels (Singh et al. 1999), but the quantitative lipid requirements of bees have not been established yet (Manning 2001). The lipid content in samples of bee pollen from Australia ranged from 0 % for *Eucalyptus macrorhyncha* F. Muell. Ex Benth. to 11.2 % for *Hypochoeris radicata* L. and average was 2.52 % (Somerville 2005). The content of the lipids in bee pollen from Poland ranged from 6.74 % to 10.99 % and 8.7 % on average, while in Korean was 5.5 % and in Chinese was 6.2 % (Szczesna 2006).

In the literature there is not much information about lipid content of identified pol-

len grains. The published results are limited (Manning and Harvey 2002). Lipid content of pollen has been estimated through ether extraction (Somerville 2005).

The objective of this study was to determine the lipid content in pollen of 20 popular bee plants and the impact of lipids to honey bees. This study is the first which reports results for lipid content of Bulgarian floral species.

Materials and Methods

The experimental part was carried in Belozem forestry area (42°17'05" N and 25°09'33" E), 142 m a.s.l. Pollen collection was performed by using pollen traps.

In the study were used three honey bee colonies.

Two hundred and ten samples of mixed pollen were collected. They were carefully mixed and a sample of 10 % was taken (Dimou and Thrasyvoulou 2007). Then the pollen pellets were separated according to colour, shape and texture. Melisopalynological analysis was carried out using a similar methodology as described by Louveaux et al. (1978). To identify the pollen database of plants from the area was created.

For lipid content determination, identified pollen was analysed applying methodology used in Laboratory of Apiculture-Sericulture at Aristotle University, Thessaloniki. Results are expressed as a percentage to 2 decimal place for the samples tested. Three replicates from each sample were analyzed, and the results were averaged.

Two groups with five cages 10×10×10 cm each were created. One hundred newly emerged worker bees were placed in each and fed on 20 mL 50 % sugar syrup. Two grams of pollen from *E. ritro* were added to the syrup of the first group and two grams of pollen from *Z. mays* were added to syrup of the second group. The syrup was changed daily. The experimental cages were kept in darkness at 27 °C. In fifteen days, the weight of each cage was recorded every day by using electronic scales KERN. The weight of one hundred bees is reported in milligrams (mg).

The results were statistically processed by using Excel and Anova.

Results and Discussion

The most identified plants were from Asteraceae – 9, followed from Fabaceae – 4,

and 7 families by one representative. Lipid content of bee pollen is presented in Figure 1. It ranged from 0.87 % for *Z. mays* to 13.6 % for *E. ritro*, and the average was 3.91 %. Pollen from different taxa had different lipid content.

Comparison between insect-pollinated and wind-pollinated taxa was made, and significant difference in the lipid content was not found ($F \leq F_{crit}$). No significant difference in lipid content between Fabaceae compared to Asteraceae plants ($F \leq F_{crit}$) was found either.

Chenopodium sp. L., *Eryngium camp-*
*est*re L., *Z. mays* and some floral species from Fabaceae showed lowest levels of lipid content. The cultivated crop *Brassica napus* L., produced pollen with higher lipid content – 9.43 %, compared to the others two frequently cultivated plants *Helianthus annuus* L. – 1.91 % and *Z. mays* – 0.87 %.

Results for lipid content compared with results of other authors are given in Table 1.

Table 1. Comparing pollen lipid contents results in %.

Species	Our present results	Results of other authors
<i>Zea mays</i>	0.87	1.8 ¹
<i>Trifolium repens</i> L.	1.69	2.5 ¹
<i>Helianthus annuus</i>	1.91	1.41 ¹
<i>Brassica napus</i>	9.43	5.92 ²
<i>Centaurea solstitialis</i> L.	4.82	2.83 ¹
<i>Chondrilla juncea</i> L.	5.83	3.43 ¹

Other authors: Somerville (2005)¹, Manning and Harvey (2002)².

Bees which consumed pollen from *E. ritro* were heavier than those consumed pollen from *Z. mays* ($F > F_{crit}$) (Table 2). The average weight of one hundred bees fed on pollen from *Z. mays* was 8208.2 mg, whereas it was 9882.2 mg for the bees fed on pollen from *E. ritro*. The weight of bees

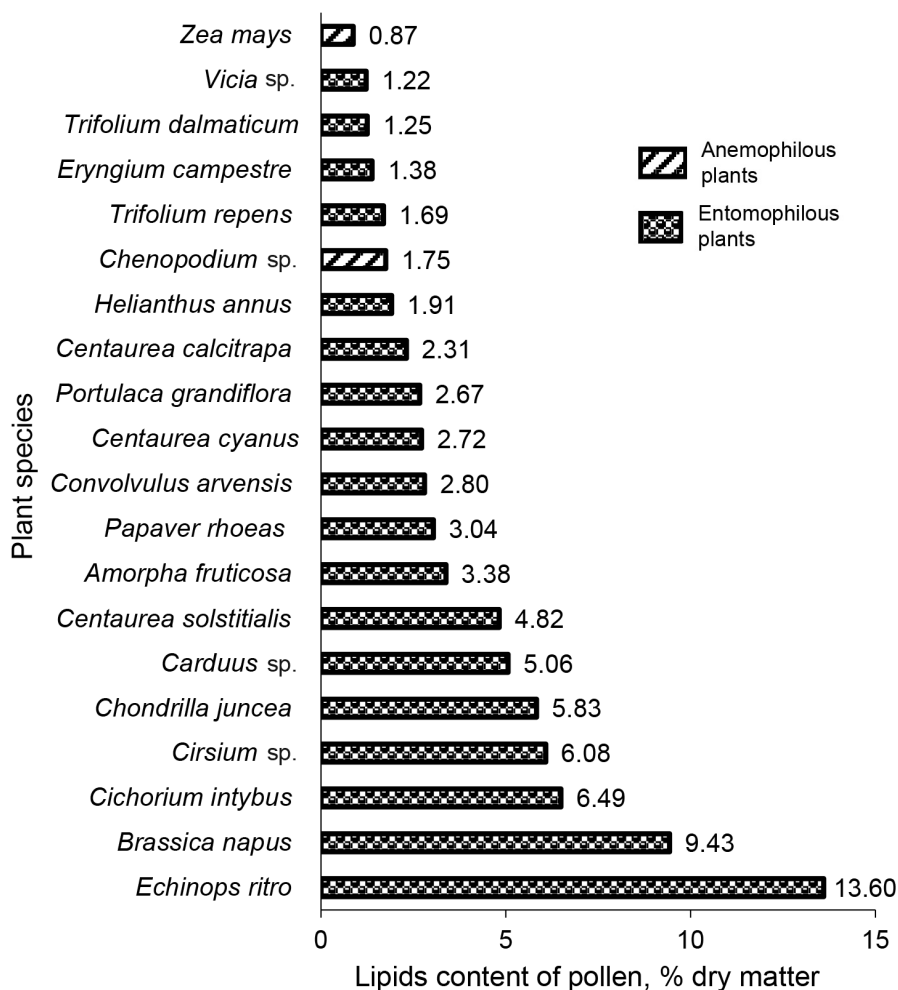


Fig. 1. Lipid content of 20 taxa.

Table 2. Average weight of one hundred worker honey bees in mg.

Groups of honey bees	means±std
Bees fed on sugar syrup and pollen from <i>E. ritro</i>	9882.2±151.87
Bees fed on sugar syrup and pollen from <i>Z. mays</i>	8208.2±76.01

that consumed pollen with higher lipid content is higher compared to those con-

sumed pollen with lower lipid content. The statistical analysis showed highly significant positive correlation ($r = 1$, $p \leq 0.05$).

Asteraceae species play major role in honey bees' nutrition diet, because a large number of them provide pollen till late autumn such as *Centaurea calcitrapa* L., *C. solstitialis*, *Carduus* sp. L., *C. juncea*, *Cirsium* sp. Mill., *Cichorium intybus* L. and *E. ritro*. These plants, especially *E.*

ritro, need to be preserved and spread in the environment, where it is possible, with purpose to provide more quality nutrition and higher vitality for honey bees.

The differences between lipid content of pollen observed in our study and that cited in the literature could be due to differences in geographical origin, soil components or hybrid variety of cultivated plants.

Conclusions

The percentage of the total lipid content in the bee pollen ranged from 0.87 % for *Z. mays* to 13.6 % for *E. ritro*, and the average was 3.91 %. The average weight of one hundred worker bees fed on pollen from *Z. mays* was 8208.2 mg, whereas it was 9882.2 mg for the bees fed on pollen from *E. ritro*. The weight of bees that consumed pollen with higher lipid content is higher compared to those that consumed pollen with lower lipid content.

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COMPARING PROTEIN CONTENT IN BEE POLLEN FROM DIFFERENT FORESTRY AREAS

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Abstract

Knowledge of protein food used by honey bees is important, as proteins are main component of pollen. The objective of this research was to determine and compare the protein content of bee pollen from different forestry areas in Bulgaria of some popular bee plants. The analysis showed that in pollen it depended on the botanical origin. The protein content in the pollen from Oryahovo ranged from 12.8 % for *Taraxacum officinale* L. to 25.35 % for *Cornus sanguinea* L., and the average was 20.66 %, from Borushtitsa ranged from 12.3 % for *Chondrilla juncea* L. to 27.51 % for *C. sanguinea*, and the average was 21.16 %. The protein content in pollen from *Brassica napus* L., *Cornus mas* L., *C. sanguinea*, *Robinia pseudoacacia* L. and *Salix* sp. showed variability for both forestry areas.

Key words: honey bee, honey bee nutrition, monofloral pollen.

Introduction

There are always differences in the protein value in pollen that originates from same taxa according to different ecological factors (Perelson 1962, Stanley and Linskens 1974, Bosi and Ricciardelli D'Albore 1975). Bees need protein to increase their population (Tyurner et al. 1972). Pollen pellets play major role for honey bees' development, reproduction and productivity (Radev et al. 2014). Protein value in pollen more than 20 % meets their nutritional needs (Shaw 1999).

Liolios et al. (2016) found range from 12.8 % of *Smilax* sp. L. to 30.1 % for *Fallopia* sp. Adans., with an average of 20.8 %. Radev (2018) determined protein content in pollen ranged from 11.5 % for *C. juncea*

to 27.4 % for *Cucumis melo* L., and the average value was 19.9 %. In another research in a forestry region Radev (2021) found range from 14.83 % for *Helianthus annuus* L. to 26.14 % for *Prunus cerasifera* Ehrh., and the average value was 20.90 %.

The objective of this research was to determine and compare the protein content of pollen of some floral species from different forestry areas in Bulgaria.

Materials and Methods

Pollen traps were used in three bee hives and pollen grains were harvested every 5 days in April till May at a forestry area near Oryahovo (43°73'06" N and 23°92'74" E),

in North Bulgaria, 173 m a.s.l.; and from April to August at Borushtitsa (42°73'38" N and 25°57'29" E), in Central Balkan Range, Bulgaria, 727 m a.s.l.

Thirty-six samples of mixed bee pollen loads from Oryahovo and 114 from Borushtitsa were collected. Samples of each hive were mixed and 10 % of sample was taken (Dimou and Thrasyvoulou 2007). Pollen grains were separated over white sheet according to colour, shape and texture. The labeled pollen samples were stored in separate vials in a freezer at -20°C . For mellisopalynological analysis we used the methodology proposed by Louveaux et al. (1978). To identify the pollen database of plants from the area was created.

Dry matter measurements were carried out with the method of drying to a constant weight at a temperature of 105°C (Serra

Bonvehi and Casanova 1987). For nitrogen content determination, pollen was analysed using Kjeldahl method. The crude protein content was estimated using factor 5.60 (Rabie et al. 1983). Three replicates from each sample were analyzed, and the results were averaged.

The results were statistically processed by using Excel and Anova with significance level of $\alpha=0.05$.

Results and Discussion

The indicated plants in Oryahovo were from Cornaceae – *C. mas* and *C. sanguinea*, and 6 families by one representative – Asteraceae, Moraceae, Juglandaceae, Salicaceae, Brassicaceae and Fabaceae.

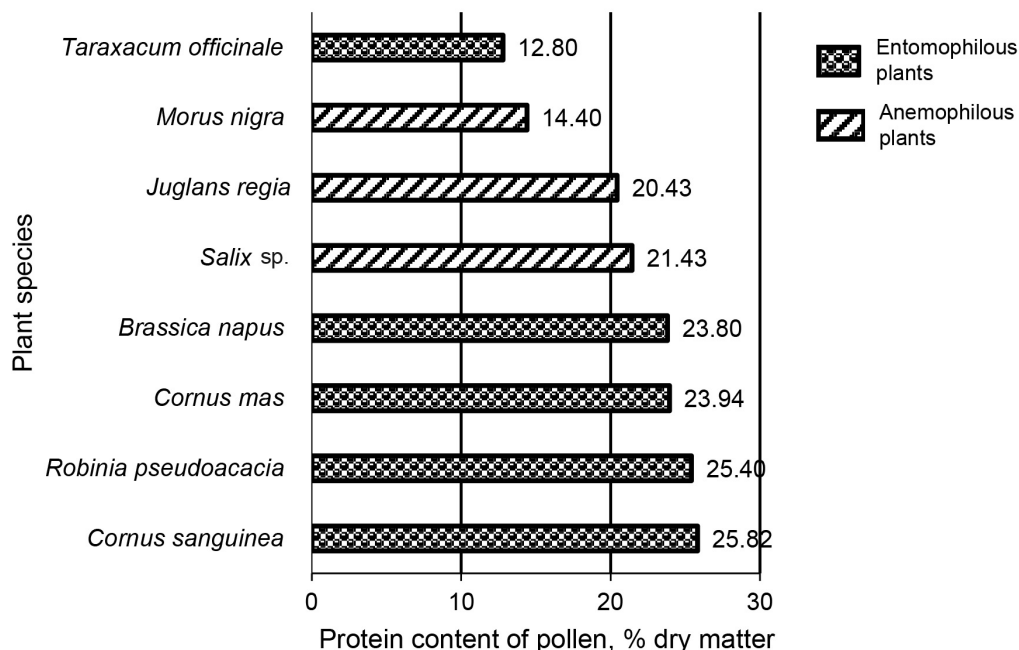


Fig. 1. Protein content of pollen species in Oryahovo.

in the studied bee-pollen grains ranged from 12.8 % for *T. officinale* to 25.82 % for *C. sanguinea*, and the average value was 20.66 %. Pollen from different taxa was found to have different protein content. No significant difference in the protein value between wind pollinated compared to insect pollinated floral species (p -value = 0.35) was found.

In Borushtitsa the identified taxa came from Fabaceae – 4, followed by Cornaceae – 2, Asteraceae – 2, Brassicaceae – 2, and 5 families by one representative – Salicaceae, Tiliaceae, Rosaceae, Loranthaceae and Onagraceae. Protein content data of identified taxa are showed in Figure 2. The protein content in the stud-

ied pollen collected by bees ranged from 12.30 % for *C. juncea* to 27.72 % for *C. sanguinea*, and the average was 21.22 %. Significant difference in the protein content among the families was found only between Brassicaceae compared to Asteraceae (p -value = 0.00).

The results are in the range according to the data from other authors. Protein value in pollen collected by honey bees from different species ranged from 7 % to 30 % (Todd and Bretherick 1942) and from 8 % to 40 % (Herbert 1992).

A comparison was performed between the protein content of the same plant species from both areas – *B. napus*, *C. sanguinea*, *C. mas*, *R. pseudoacacia* and

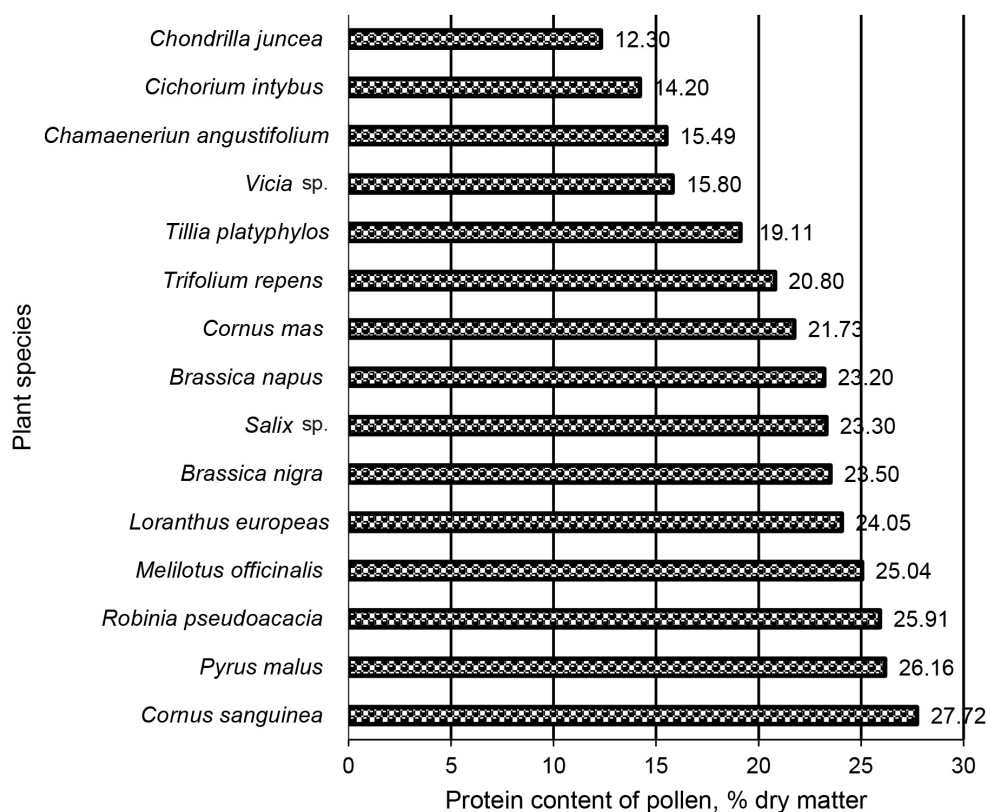


Fig. 2. Protein content of pollen species in Borushtitsa.

Salix sp. and significant differences in the crude protein content of their contents were found (p -value = 0.00). That indicated that the protein content in pollen had variability.

It was noted that the protein content of Asteracea species had the lowest protein content, while *C. sanguinea* had the highest protein content for both areas. The main reason for the different results for the same plants in the two areas can be attributed to the soil composition, geographical area, climate or else factors.

Conclusions

The protein content in bee pollen from Oryahovo ranged from 12.8 % for *T. officinale* to 25.35 % for *C. sanguinea*, and the average was 20.66 %. The protein content in bee pollen from Borushtitsa ranged from 12.3 % for *C. juncea* to 27.51 % for *C. sanguinea*, and the average was 21.16 %. The protein content in pollen in *B. napus*, *C. sanguinea*, *C. mas*, *R. pseudoacacia* and *Salix* sp. showed variability for both forestry areas. Protein content in pollen from *C. sanguinea*, *R. pseudoacacia* and *Salix* sp. in Borushtitsa is higher.

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HARE DYNAMICS IN PLAIN AREAS OF SOUTH BULGARIA: EFFECT OF HABITAT FEATURES AND PREDATOR ABUNDANCE

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Abstract

Modern agriculture often leads to a reduction in small game species and loss of biodiversity. The study area includes MG-14 (35 T) square of the Universal Transverse Mercator (UTM). The density of hares during the study period varied between 0.7–2.7 ind./km². Their number reported in 2014–2015 is significantly higher than in the other years. In 2018, the lowest hare density was reported in the study area. Most were counted in May. The density of hares was positively related to habitat diversity and negatively to Wild cat density.

Key words: *Canis aureus*, *Felis silvestris*, habitat heterogeneity, *Lepus europaeus*, Shannon index, *Vulpes vulpes*.

Introduction

A decrease in small game species has been reported in a number of studies in Europe (Kuijper et al. 2009, Ronnenberg et al. 2016, Sliwinski et al. 2019). European hare (*Lepus europaeus* Pallas, 1778) is an important representative throughout Europe, despite its declining populations (Reichlin et al. 2006, Zhelev et al. 2013, Cukor et al. 2018, Hacklander and Schai-Braun 2019, Schai-Braun et al. 2019). The decline in the species' density has been reported since the 1960s and 1970s (Edwards et al. 2000) and has continued into recent decades (Jennings et al. 2006, Reichlin et al. 2006, Takacs et al. 2009, Karp and Gehr 2020).

A number of studies have attributed the species' population decline to agricultural intensification and crop diversity decrease (Smith et al. 2004, Baldi and Farago 2007, Wrzesien and Denisow 2016, Canova et al. 2020). Other studies have highlighted the importance of shelters for young individuals, which can have a significant impact on certain physiological processes as well as survival (Hacklander et al. 2002, Zellweger-Fischer et al. 2011, Karp and Gehr 2020).

Changes in agricultural practices may also lead to changes in some of the hares' habits, such as an increase in home-range size (Smith et al. 2004, Schai-Braun et al. 2013). European hare live at shorter distances from their shelters, i.e. hedges,

fences etc., in contrast to European rabbit (*Oryctolagus cuniculus* L., 1758) (Santili et al. 2013). In the absence of adequate shelter, they are forced to cover greater distances to reach food resources, hence the likelihood of predation increases (Petrovan et al. 2013, Canova et al. 2020).

The predation rate of European hare population and its preference for certain terrains seem to be largely related to the density of Red fox (*Vulpes vulpes* L., 1758) (Goszczynski and Wasilewski 1992, Reynolds and Taper 1995, Misirowska and Wasilewski 2008, Cukor et al. 2018). Another important factor largely determining losses in hares is climate (Slamechka et al. 1997; Pikula et al. 2004; Smith et al. 2005; van Wieren et al. 2006; Beukovic et al. 2013, 2016).

The average European hare density in Bulgaria between 2012 and 2013 was 1.8 ind. per km² (Zhelev et al. 2013). The population density varied from 1.99 to 8 ind./km²; in 60 % of the habitats, it was mostly less than 2 ind./km² (Zhelev 2015). As a result, Bulgaria ranks among the countries with low density of this hunting species.

The aim of this study is to trace the population dynamics of European hare in a low-density area and to identify some of the factors that limit it.

Material and methods

Study area

The study area is MG-14 (35 T) square of the Universal Transverse Mercator (UTM) system, Fig. 1). It covers mainly Sakar Mountain and a small part of the lower Thracian lowland. It is

characterized by continental Mediterranean climate. Monthly average range of temperature is from 8 to 13.5 °C over the year and the amount of precipitation is between 500 and 900 mm, reaching a maximum in winter and a minimum in summer/autumn.

The duration of the snow cover is shorter compared to all other areas in Bulgaria (Koprarev 2002). The habitats include Austrian pine plantations (3.8 %), Oak forests represented by Hungarian oak (*Quercus frainetto* Ten.), Austrian oak (*Quercus cerris* L.), and Downy oak (*Quercus pubescens* Willd.) (1.27 %), mixed deciduous forests with dominating presence of Downy oak (4.92%); wet riparian forests (1.54 %); shrubs with dominating presence of Jerusalem thorn (*Paliurus spina-christi* Mill.) found in pastures and hay meadows (34.8 %); vineyards including tree and shrub strips (11.07 %); arable lands with tree and shrub strips (37 %); populated locations (mainly small settlements) (3.8 %); and surface waters (1.8 %) randomly distributed in the area. Maritsa River flows through the western part of the MG-14 square.

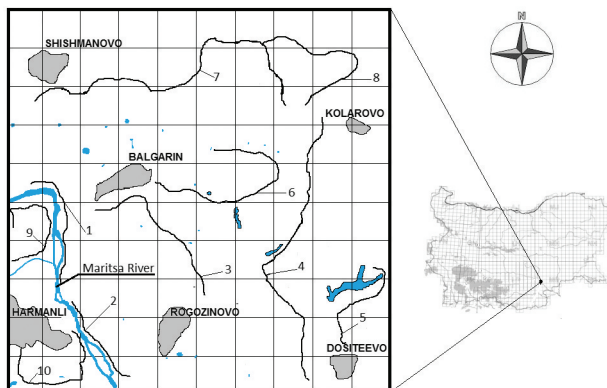


Fig. 1. Study area and transects in MG-14 (35 T).

Note: the black lines are the numbered transects; all water areas are marked in blue and the settlements in gray are marked with the respective names.

Field methods

Density data were collected by means of 10 linear transects measuring 44.39 km in length and 50 m in width, 25 m of each side of the observer (Fig. 1). For better reporting during the field visits, trained dogs were used, which searched at a distance of 50 m on both sides of the observer. They found the hares, but were not allowed to chase them.

The transects were set systematically to represent the whole diversity and percentage distribution of the areas, thus guaranteeing the representativeness of the sample. Six reports were made annually between March and July. Hares are not hunted in the study area due to low density. The density was calculated as the arithmetic mean of all observations during the respective year. Reports were made during daylight hours between 6:30 am and 5:00 pm. For each hare found, its location, the land in which it was found and the time period were recorded. Each transect was counted at different times to avoid data distortion. The number of tracks of Golden jackal (*Canis aureus* L., 1758), Red fox and Wild cat (*Felis silvestris* Schreber, 1777) were recorded during each report. We then calculated the relative density of the three species using the Formozov-Malyshov-Pereleshin formula (1) (Acevedo et al. 2008):

$$D = \frac{\pi}{2} \cdot \frac{x}{S \cdot M}, \quad (1)$$

where: D is population density (ind./km²); x – total number of recorded tracks (on all transects); S – total length of all transects, km; M – daily activity pattern – average distance covered by the species in a day, km.

Based on data from previous studies (Sillero-Zubiri 2009, Sunquist and Sunquist 2009), the following daily average

mobility values were adopted for each of the species: 15 km for the Golden jackal, 5 km for the Red fox, and 7 km for the Wild cat. Habitat diversity assessment was performed using the Shannon diversity index (SDI) (Liding et al. 2008, Kuchma et al. 2013).

Statistical methods

We used the GLMMs model, first testing the differences between densities of European hares over the years and months, then the relationship between hare density, habitat diversity indices, and the relative density of the Golden jackal, Red fox and Wild cat over the years. For each year, the data were taken from all reports made. The dependent variable was the European hare density per km², calculated for each transect; the categorical variables were years, and the independent variables were the diversity indices and the relative densities of predatory mammals. The significance of different habitats for hares was established by calculating the number of individuals per km² for each habitat and comparing them over the years using a GLMMs model with a log link function and Poisson distribution. Hare density was a dependent variable, years and habitat type were categorical variables. The area of each habitat was determined using QGIS 3.10 (QGIS Development Team 2020). All statistical analyses were performed with Statistica 10 StatSoft, Inc. (2011).

Results

Hare density during the study period varied between 0.7–2.7 ind./km². The relative densities of predator species also varied (Table 1).

The number of European hare reported in 2014–2015 was significantly higher than in other years. The lowest density was reported in 2018 (Table 2). The greatest number of hare was counted in May, after which the number of reported individuals decreased (Fig. 2).

During our study fluctuation of the established hare density was observed. It in-

creased monthly from March to May, then gradually decreased (Fig. 2).

Hare density was positively related to habitat diversity and negatively to Wild cat density (Table 3).

There is a positive relationship between hare density and three habitat types: pastures, cereal crops and vineyards (Table 4).

Table 1. Density of species studied.

Year	<i>Lepus europaeus</i>	<i>Canis aureus</i>	<i>Vulpes vulpes</i>	<i>Felis silvestris</i>
	ind./km ²			
2014	1.8 ± 1.6 (0–4)	1.3	0.4	0.4
2015	2.7 ± 2.1 (0–6)	2.65	0.7	0.5
2016	1.4 ± 0.8 (0–2.5)	0.8	0.75	0.75
2017	0.8 ± 1 (0–2.6)	1.4	0.54	0.54
2018	0.7 ± 0.9 (0–2)	1.1	0.57	0.6
2019	1.3 ± 0.7 (0–2)	0.57	0.94	1.06
2020	1.2 ± 1.2 (0–3.4)	0.27	0.47	0.7

Note: for European hare ind./km² ±SD (min-max).

Table 2. Differences between European hare number by year and month in all study periods.

Effect	Level of effect	Column	Estimate	Standard error	Wald - stat.	Lower CL- 95, %	Upper CL- 95, %	p
Intercept		1	0.335565	0.093465	12.88993	0.15238	0.518753	0.00033
year	2014	2	0.297493	0.140594	4.47736	0.02193	0.573052	0.034347
year	2015	3	0.71008	0.111543	40.52596	0.49146	0.9287	0
year	2016	4	-0.09206	0.187471	0.24116	-0.4595	0.275373	0.623367
year	2017	5	-0.28796	0.220847	1.7001	-0.72081	0.144894	0.192275
year	2018	6	-0.66685	0.310523	4.61174	-1.27546	-0.05823	0.031754
year	2019	7	-0.3238	0.227816	2.02011	-0.77031	0.122715	0.155228
month	March	8	-0.13964	0.147411	0.89737	-0.42856	0.149278	0.343487
month	April	9	0.190071	0.11736	2.62296	-0.03995	0.420092	0.105328
month	May	10	0.544767	0.097179	31.42501	0.3543	0.735234	0
month	June	11	-0.51604	0.200581	6.61878	-0.90917	-0.1229	0.010091
Scale			0.643786	0.076947		0.50934	0.813729	

Note: in bold are the values with statistical significant; Column is a column of the model matrix corresponding to parameters; Estimate is estimated parameter value; Lower and Upper CL is confidence interval level; p is value for testing the significance of the parameter to the model.

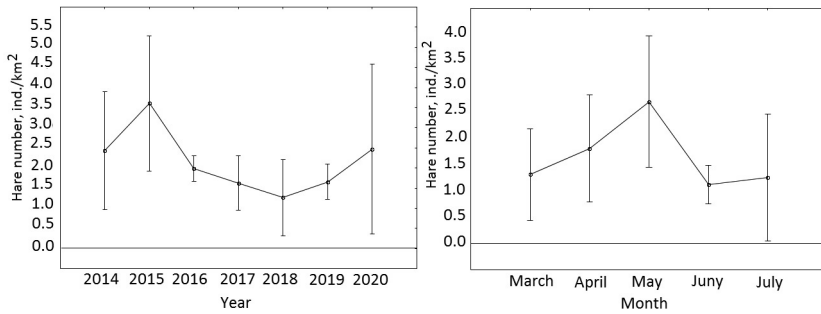


Fig. 2. European hare density (ind./km²; min-max) by year and month.

Table 3. Results of GLMMs model with Poisson distribution and log function between the number of European hare, habitat diversity and density of predator mammals.

Effect	Column	Estimate	Standard error	Wald stat.	Lower CL-95, %	Upper CL-95, %	<i>p</i>
Intercept	1	1.32812	0.445077	8.90438	0.45578	2.200454	0.002845
Shannon	2	0.72462	0.203217	12.71448	0.32632	1.122918	0.000363
Jackal density	3	-0.11179	0.081536	1.87967	-0.27160	0.048021	0.170371
Fox density	4	0.52587	0.443521	1.40581	-0.34342	1.395154	0.235753
Wild cat density	5	-1.81040	0.468689	14.92038	-2.72901	-0.89178	0.000112

Note: in bold is the values with statistical significant.

Table 4. Results of GLMMs model with Poisson distribution and log function between the densities of European hare in different habitats by years.

Effect	Level of effect	Column	Estimate	Standard error	Wald stat.	Lower CL-95 %	Upper CL-95 %	<i>p</i>
Intercept		1	-1.43818	0.938450	2.34856	-3.2775	0.40115	0.125399
year	2014	2	-1.03641	2.597230	0.15923	-6.1269	4.05407	0.689862
year	2015	3	0.10415	2.297978	0.00205	-4.3998	4.60810	0.963850
year	2016	4	1.02121	1.954510	0.27299	-2.8096	4.85198	0.601331
year	2017	5	-0.00152	2.299463	0.00000	-4.5084	4.50535	0.999474
year	2018	6	-0.79727	2.594891	0.09440	-5.8832	4.28863	0.758657
year	2019	7	-0.27950	2.301123	0.01475	-4.7896	4.23062	0.903324
habitat	pastures	8	3.07561	0.950022	10.48082	1.2136	4.93762	0.001206
habitat	cereal crops	9	2.74003	0.960444	8.13889	0.8576	4.62246	0.004333
habitat	vineyards	10	1.95011	0.974020	4.00849	0.0411	3.85915	0.045272
habitat	deciduous forest	11	-0.99531	2.596295	0.14696	-6.0840	4.09334	0.701455
habitat	coniferous	12	-3.16699	3.329380	0.90483	-9.6925	3.35847	0.341489
habitat	meadows	13	-0.43645	2.303234	0.03591	-4.9507	4.07781	0.849706

Note: in bold is the values with statistical significant.

There are no significant relationships with other habitat types, and the general pattern is not significant altogether (Table 4).

Discussion

European hare density reported in this study is lower than the one established in a number of European countries. Wasilewski (1991) reported density between 25 and 30 ind./km² in Central Poland, Panek and Kamieniarz (1999) established hare density from 8 to 28 individuals in relation with landscape structure. In Czech Republic density of hares was established 2.3 to 4.7 ind./km² (Pikula et al. 2004). In Northern Italy Rosin et al. (2009) reported density to 74 ind./km², this is one of the highest densities in Europe. In Germany, hare density was between 1 and 10.7 ind./km² in different areas in 2005 as above from 11 to 14.5 ind./km² from 2002 to 2005 (Strauss et al. 2008). Although significantly lower hare density was reported in Poland (4.1–9.5 ind./km²) (Kamieniarz et al. 2011), it is higher than the one in the present study. The highest density estimate in this study is close to the lowest found for some regions of Europe (Canova et al. 2020). Studies of European hare density in Bulgaria from the last decade confirm the results of the present one. Zhelev (2015) established an average density for the plain habitats of Bulgaria of 1.9 ind./km², which is the lowest recorded density so far. The same author points at a significant decrease in European hare density after 1970, which is clearly expressed after 1994. The results of the current study align with the hare population trend in Bulgaria. During the study period there was no decrease in hare density.

Population trend follows a common pattern increasing from March to May and decreasing in the following months: this latter data can reflect a real decrease of local population due to juvenile's mortality or dispersal, but can reflect a lower visibility of individuals. Studies in some European countries have cited climatic factors (Slamechka et al. 1997; Smith et al. 2005; Beukovic et al. 2013, 2016), predation (Haerer et al. 2001) and diseases (Smith et al. 2005) as causes of mortality of young hares. The increased mortality at an early age has been identified as a determining factor in the decline of hares in Europe. The survival of the young is negatively affected by rainfall, but less so if hares use border habitats (hedgerows, shrubs, etc.) (Karp and Gehr 2020). Previous studies have indicated lower autumn hare density in Bulgaria (Zhelev 2015). According to the author, the lower autumn densities are a result of compromised accuracy of reporting due to vegetation height and reduced visibility.

The abundance of European hare in the present study was positively related to habitat diversity, as expressed by Shannon Index. Some authors (Smith et al. 2004, Canova et al. 2020) have established a positive relationship between hare density and habitat diversity. Various studies in Europe (Canova et al. 2020, Schai-Braun et al. 2020) have found a relationship between hare densities and set-aside places, on one hand, and the length of shelter belts and hedgerows, on the other. These variables were not tested in the present study due to the lack of set-asides; furthermore, hedgerows and shelter belts in the study area are evenly distributed. Hare density in our study was negatively related to Wild cat density. It seems that where there are more cats,

fewer hares are observed. The study area falls into high-density Wild cat habitats (Petrov 1995). At the same time, studies of the food spectrum during the autumn-winter season indicate rodents as the main victims of Wild cats in Bulgaria (Petrov 2003). Due to the low density of hares in this study, they are unlikely to have any effect on the population. Rather, the two species have different habitat preferences. Wild cat is a species found in various habitats, but is most commonly present in forest and shrubs (Sarmiento et al. 2006, Lozano 2010). Probably the negative association between the presence of hares and Wild cats is related to differences in preferred habitats rather than predation in study area. Further research is needed. In the present study, the linear model did not highlight a relationship between the relative densities of Red foxes and Golden jackal and that of hares. However, in a number of studies, predation has been identified as one of the possible causes of mortality in hares (Haerer et al. 2001). Some authors have found that foxes are the most common cause of loss, both in farm European hares (Reynolds and Taper 1995, Karmiris 2006, Sokos et al. 2014, Cukor et al. 2018) and in those from wild populations (Goszczynski and Wasilewski 1992, Misirowska and Wasilewski 2008). According to some studies, predation is responsible for 31 to 50 % of total hare mortality (Goszczynski and Wasilewski 1992, Misirowska and Wasilewski 2012) and hares and foxes density are inversely and significantly related (Vangan et al. 2003). Our model did not find a relationship between fox density and hare density. This may be due to the low densities established in both species. Thus, as a result of the low density of hares, they might not be foxes' priority prey. Golden jackal

is the second predator which our model finds unrelated to hare densities. Studies of the species in Bulgaria discuss hares as accidental rather than priority prey of them (Stoyanov 2012). This is the most probable reason for lack of such a relation between the two species, or they might once again have different habitat preferences.

Pastures, cereal crops and vineyards are areas positively related to the number of reported individuals, although the model is not significant. Previous studies have indicated cereals (Sliwinski et al. 2019) and grass communities (Vangan et al. 2003, Kamieniarz et al. 2011) as having a positive effect on hare density. Grass communities in the study area are dominated by Jerusalem thorn, which offers ample hiding places for hares, while the adjacent arable lands normally represent sources of food that are attractive to hares, as shown by other similar studies (Smith et al. 2004, Kamieniarz et al. 2011, Canova et al. 2020). Vineyards are another example of areas attractive to hares. Vineyards and grass in rotation with winter cereals were positively associated with the number of hares shot in Italy (Santili and Galardi 2006). Zhelev (2015) points to vineyards as high-density (7–10 ind./km²) areas of European hares. The positive associations with the abundance of hares and vineyards may be due to the ecotone effect caused by the vineyards in a monotonous environment. However, the general pattern in our analysis involving habitats is not significant and we cannot say with certainty that these habitat areas are essential for hares. Despite finding a variation in hare density over the years, this study has not confirmed an increase in density, which may be due to other factors limiting hare population in the area.

Conclusion

Present study describes the density of European hare in part of Southeastern Bulgaria. The results showed that the density of hare is lower than in a number of European countries. The density is fluctuated between the study years and the peak of the reported hares is in May. Hare density was positively related to habitat diversity, three habitat types and negatively to Wild cat density. Although hares were not hunted in the study area, their density does not increase. Results obtained in this study should be taken into account in further management of hare's population.

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ACTIVE AND PASSIVE MOSS MONITORING OF TRACE ELEMENTS IN URBAN AND MOUNTAIN AREAS, BULGARIA

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Abstract

The moss *Hypnum cupressiforme* Hedw. was used as biomonitor in three urban and five mountain sites with different pollution loads. The concentrations of 22 macro- and microelements were determined in moss-bags and were compared with those of the same elements in moss samples naturally growing in the Rhodope Mountains area. Most of the elements had highest concentrations in moss-bags exposed in Plovdiv. Strong accumulation of Cd and Pb was registered in all moss-bags with maximum in moss-bags from Sofia, reflecting that urban activities could induce more severe air pollution than mining. Cd reached saturation at the 30th day of exposure, while Pb continued to accumulate. Analysed levels of Hg and Pb during passive monitoring confirmed the Rhodope Mountains as a region with constant high toxic element levels.

Key words: biomonitoring, *Hypnum cupressiforme*, moss-bags, trace elements.

Introduction

Air pollution monitoring is a complex issue, and techniques for air quality monitoring have been the objects of intensive research in past decades (Adamo et al. 2003). Instrumental monitoring cannot be applied for longer periods and large areas due to cost barriers. Biomonitoring is a simple, cost-effective alternative for large-scale monitoring, revealing the spatial pattern and temporal trends of pollution (Goodman and Roberts 1971, Markert et al. 1997, Harmens et al. 2010, Nickel et al.

2014, Bargagli 2016).

Biomonitoring techniques consider organisms, based on their different sensitivity to air pollution or actively, through their capacity to accumulate pollutants in the tissues (Falla et al. 2000, Wolterbeek 2002). Two types of biomonitoring are differentiated in the use of mosses to evaluate atmospheric contamination: (i) passive biomonitoring, using moss that grows naturally in a particular area, and (ii) active biomonitoring, by transplanting moss from other locations. Whilst the use of native moss is more appropriate for extensive studies in

large areas (i.e. regional or national studies), active biomonitoring is more useful for intensive studies in smaller areas (i.e. urban or industrial areas, where mosses absent due to predominantly paved and landscaped surfaces) (Aničić et al. 2009). Active monitoring by moss-bags has been applied on anthropogenic emissions of industry and traffic (Adamo et al. 2003, Zechmeister et al. 2006, Yurukova et al. 2013). The 'moss-bag technique' is the most common type of active biomonitoring with mosses reported in the literature. The technique, which was originally introduced by Goodman and Roberts (1971), involves exposure of moss samples held within mesh bags in order to monitor the presence of contaminants in the air in particular time span.

The aim of this study was to: (i) to identify the spatial distribution of (trace)

elements in selected regions of Bulgaria with *Hypnum cupressiforme* Hedw.; (ii) comparing results from active and passive monitoring; (iii) testing the adequate sampling period for active monitoring.

Materials and Methods

Study sites

The combination of background and impacted sites, determined the interest in a comprehensive study and implementing the biomonitoring approach with mosses. The sites were chosen on the basis of results obtained in previous studies (Gecheva et al. 2016, Gribacheva et al. 2019). The active biomonitoring was carried out in two of the largest Bulgarian cities (Sofia and Plovdiv) – the exposure sites were located in the centres, near main boulevards

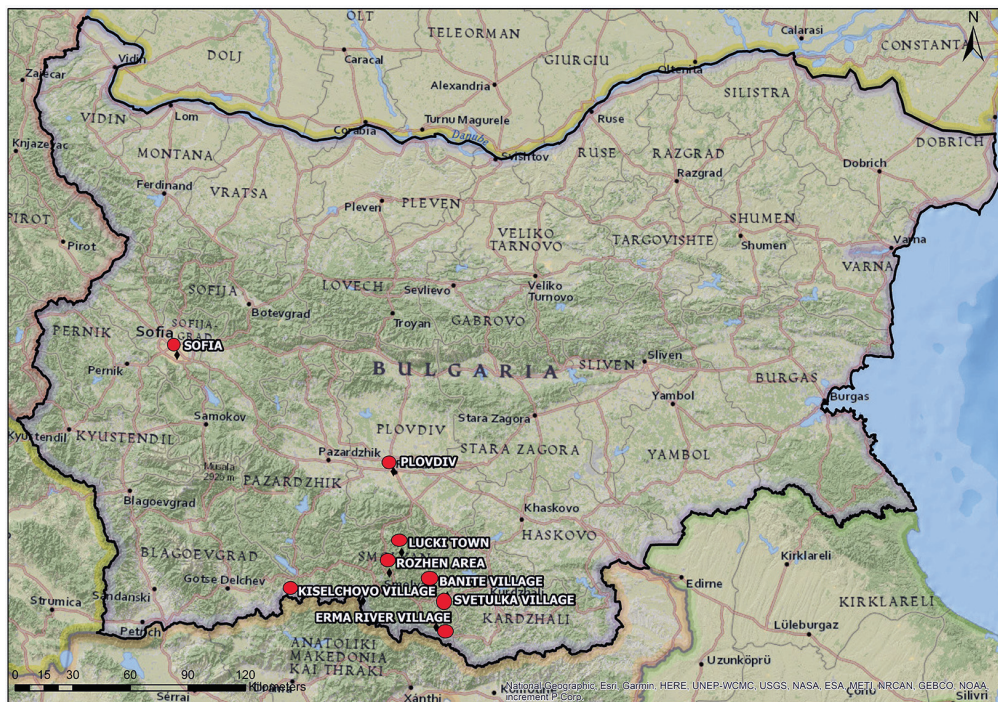


Fig. 1. Map of the studied sites.

wards and in a town affected by mining activities (Luki). Five sites on the territory of the Western Rhodopes were selected for passive biomonitoring, among them three

background sites (Svetulka and Banite villages, and Rozhen area), an old uranium mine (Kiselchovo village), a tailing pond (Erma reka village) (Fig. 1, Table 1).

Table 1. Characteristics of the studied sites.

Sites	Geographical position		Altitude, m a.s.l.	Population, No. of inhabitants	Environmental protection of the region
	Longitude E	Latitude N			
Sofia	23°21'5.14"	42°39'15.07"	601	1,308,412	2 Natura 2000 protected areas
Plovdiv	24°44'42.34"	42° 8'41.43"	166	342,048	2 Natura 2000 protected areas 4 protected territories under the Bulgarian Protected Areas Ac.
Luki town	24°48'33.4"	41°45'58.4"	1000	2393	2 Natura 2000 protected areas
Svetulka village	25°06'05.7"	41°33'59.0"	705	861	-
Banite village	25° 0'22.10"	41°37'0.23"	729	3547	1 Natura 2000 protected area
Rozhen area	24°44'08.6"	41°40'12.03"	1430	-	-
Kiselchovo village	24°34'36.1"	41°32'04.6"	1066	23	2 Natura 2000 protected areas
Erma reka village	25°02'09.7"	41°25'15.05"	580	895	1 Natura 2000 protected area

Note: the data for the population are as of 31.12.2020 (NSI 2021).

Moss sampling and preparation

Active monitoring

H. cupressiforme samples were collected in March 2019 from pristine background mountain area (41.6574 N, 24.7716 E, 1260 m a.s.l. in Western Rhodopes). In the laboratory, the moss was cleaned of soil particles and other foreign substances and air-dried. Moss-bags were prepared by weighing about 3 g of air-dried moss, packed loosely in nylon meshes (10×10 cm) and were exposed at three selected cities (Sofia, Plovdiv, Luki) from April to June 2019. Moss-bags were hung on holders at approximately 10 m above the street level (Vuković et al. 2013). The

mosses exposed for fifteen, thirty and seventy-five days were collected by the end of each period, stored and transported to the laboratory in clean polyethylene bags and proceeded for further chemical analysis as described below.

Passive monitoring

H. cupressiforme was collected at 5 sites (Svetulka and Banite villages, Rozhen area, Kiselchovo and Erma reka villages) in May 2019.

The moss sampling followed the requirements of ICP-Vegetation manual – each sample consisted of up to 5 sub-samples according to the standard-

ized European methodology. Sampling, transport, storage and pre-treatment followed the standardized protocol (Frontasyeva and Harmens 2014).

Chemical analytical methods

The samples collected by active and passive monitoring were carefully cleaned from mechanical particles and other organic material, dried at 40 °C and wet-ashed. About 1 g moss material was treated with nitric acid (65 %) overnight, followed by addition of 2 mL portions of hydrogen peroxide. Samples were sealed and irradiated in Milestone Ethos One microwave digestion system.

Two moss reference materials developed within the European Moss Surveys (EMS) (Frontasyeva and Harmens 2014) (M2 and M3, *Pleurozium schreberi* (Brid.) Mitt.) were applied in the current study. To ensure permanent quality control of the analytical measurements, a portion of the reference material was digested and analysed together with each series of samples. The contribution of the reagents used in the analytical procedure was evaluated with the corresponding blank samples for each batch.

A portion of moss reference material used within EMS (Frontasyeva and Harmens 2014) (M2 and M3, *P. schreberi*) was digested together with every sample series and corresponding blank samples were prepared as well.

The elements P, K, Ca, S, Na, Mg, Mn, Fe, Al, Zn, Cu, Pb and Sr were determined by atomic emission spectrometry with inductively coupled plasma (ICP-AES) using iCAP 6300 Duo, S, Thermo Scientific. The elements Cr, Co, Cd, V, Ni, As, Hg, Se and Sb were determined by ICP-MS (Agilent 7700). Multielement standard solutions Merck (Darmstadt, Germany), traceable

to NIST, were used as calibrators for both methods.

All concentrations were presented as mg·kg⁻¹ dry weight.

Statistical analysis

We performed principal component analysis (PCA) to synthesize our findings and see whether there are any correlations between the studied elements. **PCA** included into CANOCO (Ter Braak and Smilauer 2002) was used to study relationships between different elements in each studied site. The element concentrations were divided by their standard deviation and PCA was species-centered.

The map was produced using ArcMAP, part of ArcGIS, an integrated GIS.

Results and Discussion

Active monitoring

Background concentrations in *H. cupressiforme* exposed had similar levels to *H. cupressiforme* from natural area in Italy (Giordano et al. 2009) except for Al (5 times higher values), Fe and Co (3 times higher values) and Mn (2 times higher values) in the Rhodope Mountains.

Macroelements K, Ca, Mg, Mn and P, as well as Hg did not vary between background sample and exposed moss bags. Al, Co and Fe had no significant accumulation during the 3 exposition periods in all studied cities. Cr and Ni increased twice at the end of the experiment in Plovdiv and Luki, as well as Mn and As in moss bags from Luki, and Cu in Plovdiv.

Cd and Pb were the metals with strong accumulation in moss-bags at all locations with maximum measured in Sofia (Table 2). Cd reached its maximum on the

Table 2. Descriptive statistics of element concentrations (mg·kg⁻¹).

Element	Active biomonitoring (n = 10)				Passive biomonitoring (n = 5)		
	background	min	max	median	min	max	median
Na	60.1	53.3	127.7	71.3	156.5	201.5	183.0
K	5144.3	5144.3	6154.4	5756.7	1892.5	2833.3	2258.2
Mg	1827.4	1817.6	2718.8	1939.2	1160.5	2024.5	1552.0
Ca	7772.6	7600.4	12 298.7	7910.7	7002.8	11 034.2	8652.5
Mn	154.1	134.7	242.8	191.2	59.4	180.7	80.3
Fe	2298.5	2091.9	4600.9	2506.7	1317.4	2941.8	1498.7
Al	3300.2	2982.3	5588.0	3468.2	1242.4	2768.8	1469.4
P	1789.6	1714.1	1947.3	1824.8	602.4	1139.1	917.2
Cr	4.3	4.0	11.1	4.7	12.3	29.7	20.8
Co	1.0	0.9	2.1	1.1	6.1	6.4	n.a.
Ni	2.8	2.6	7.2	3.1	11.1	25.7	15.2
Cu	6.7	6.4	15.4	6.8	3.3	8.7	4.3
Zn	24.8	24.8	101.5	28.5	20.1	97.8	49.4
As	0.7	0.6	1.1	0.7	1.3	26.8	4.8
Cd	0.3	0.3	4.2	1.8	1.4	3.4	2.3
Hg	0.045	0.045	0.045	0.045	3.0	22.3	9.2
Pb	5.5	5.5	29.8	8.8	31.8	93.9	48.6

30th day of exposition, while Pb after the first increase at the 15th day, recorded second increase at the end of the experiment (75th day). Maximum levels of Cd and Pb in two of the largest Bulgarian cities exceeded the thresholds for medium pollution: 0.8 and 12 mg·kg⁻¹ (Ștefănuț et al. 2019). These exceedances reflected that the air pollution as a consequence of urban activities (mainly road transport) is more severe than in settlements affected by mining activities.

Passive monitoring

Medians of K, Mn, Al and P concentrations were more than 2 times lower in samples from passive monitoring in comparison with levels in moss-bags, while Na followed the opposite model (Table 2). Lower Na content could be a result of low retention capacity in moss. Both passive and active samples' medians of the above elements were lower than medians re-

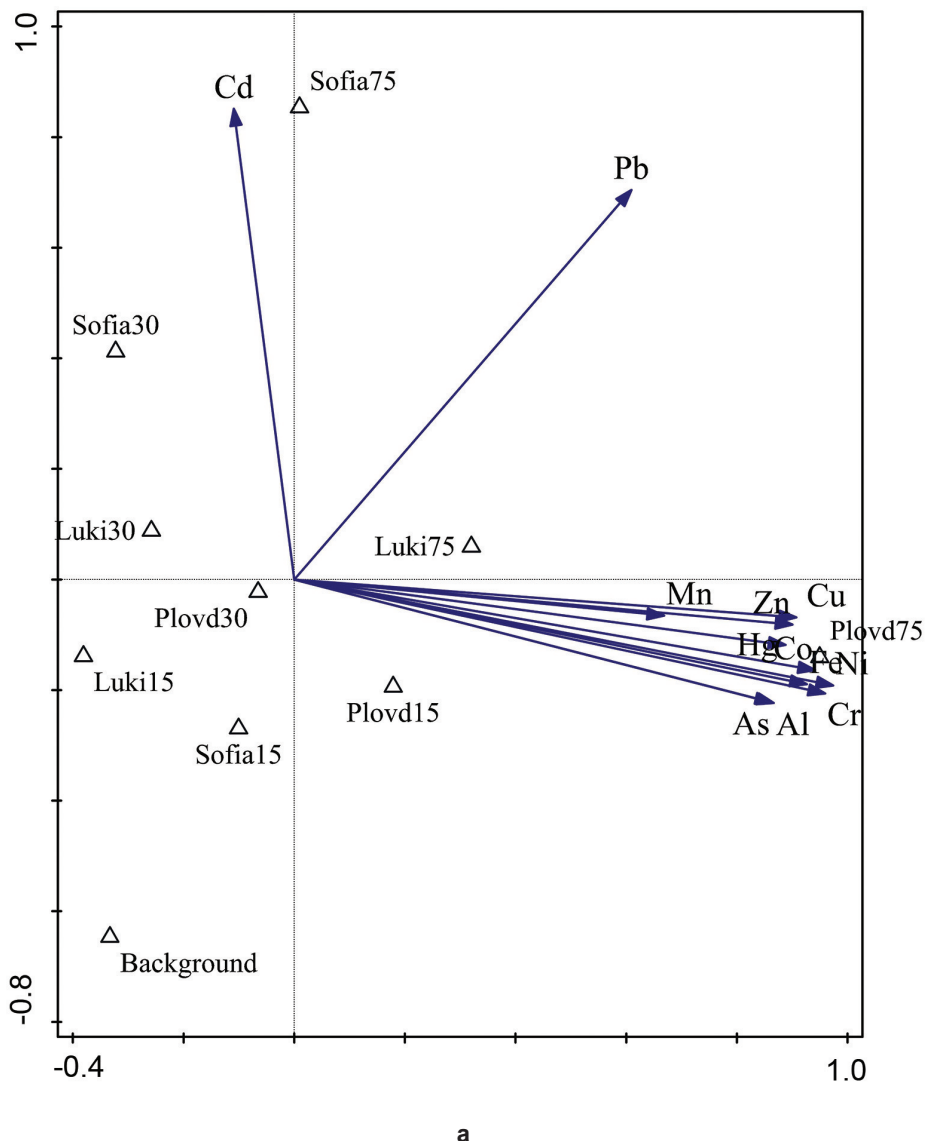
ported for 97 locations on Bulgarian territory (Marinova et al. 2010). This finding reflected specific regional values of these elements.

Mercury varied between 3 and 22.3 mg·kg⁻¹, Pb ranged between 31.8 and 93.9 mg·kg⁻¹ in samples from Western Rhodopes. Maximum concentrations of Hg and Pb were 113 and 5 times (respectively) higher than their maximum levels in Germany during 2015 (Schröder and Nickel 2019). Maximum levels of As were higher than in other countries participating in EMS, except Serbia – 71.1 mg·kg⁻¹ (Frontasyeva et al. 2020). The maximum concentrations of Zn were almost 6 times lower than registered in the Czech Republic (578 mg·kg⁻¹), and 10 times lower for Cr in comparison the Russian Federation – 301 mg·kg⁻¹ (Frontasyeva et al. 2020). Although the Rhodope Mountains are essential in terms of water supply balance and possess high biodiversity and great potential for tourism (Sabev and Yordanov

2014), this study confirmed them as a region with constantly increased toxic element levels due to the mining activities.

PCA of analysed elements in moss-bags showed that the first axis (eigenvalue 0.589) correlated with all heavy metals and toxic elements except Cd (Fig. 2a). Cd accumulation in moss-bags from Sofia contained 4- and 3-times higher concen-

trations during the second and third exposition period. Pb had also maximum in moss-bags from Sofia at 75th day. Moss-bags from Plovdiv at the 75th day (right bottom) contained accumulated maximum of most of the trace elements. The observed maximum values at the end of the experimental period suggested that element saturation level had not been



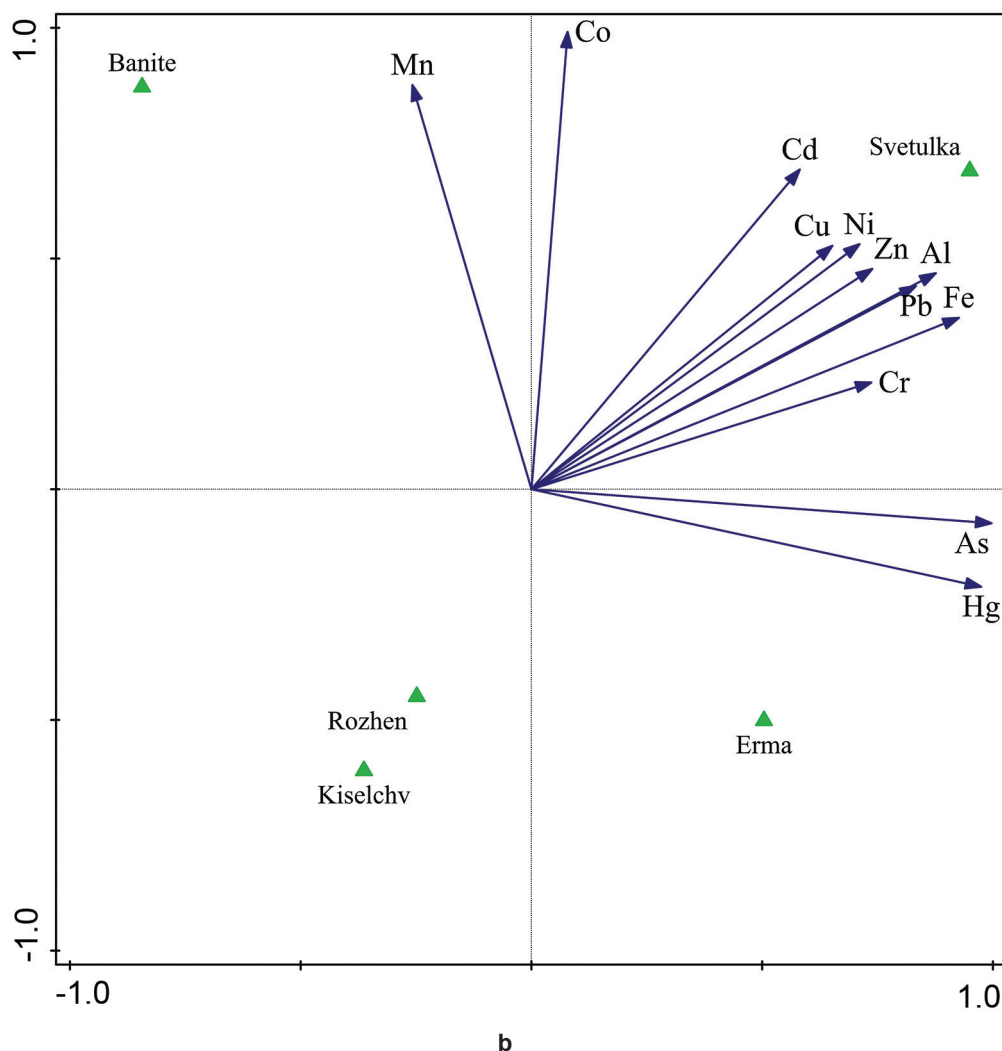


Fig. 2. PCA-ordination diagrams of analysed elements and studied sites: a – active and b – passive monitoring.

reached.

First axis (eigenvalue 0.991) of the ordination diagram from passive monitoring correlated with most of the elements, except Mn and Co (Fig. 2b). Among the studied sites, moss from Svetulka village revealed highest levels of 11 elements (upper right of the plot), probably due to the serpentinites covering the area. Three

locations (Banite, Rozhen and Kiselchovo) were with minimum accumulated levels (left part of the diagram).

Conclusions

Despite natural and anthropogenic specific characteristics of the selected 3 cities,

the accumulation of 11 heavy metals and toxic elements increased at the end of the bag exposure period (except for Hg). Highest number of maximums was registered in moss-bags from Plovdiv (Fe, Al, Cr, Co, Ni, Zn, Cu) probably due to the high number of days with temperature inversion and low wind speed. Pb exceedances of the thresholds for medium pollution in Sofia and Plovdiv, as well as Cd exceedances in the 3 cities, reflected the strong negative transport effect. Based on the results, 4-week of exposure is recommended for rapid assessment of pollution in an urban environment, while 10-week is suggested for detailed monitoring.

We registered high levels of some heavy metals (Pb, Hg) in native mosses due to old and open mines, appeared local emissions, and site-specific characteristics.

This study confirms that both active and passive moss monitoring is suitable for detecting temporal and spatial trends in elements deposition.

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VALUATION OF CARBON SEQUESTRATION AND ESTIMATION OF CO₂ EMISSION IN THE HYRCANIAN FORESTS OF IRAN

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Abstract

The aim of this study was to estimate the aboveground carbon sequestration and the amount of CO₂ emissions at logging operation in Hyrcanian forests of Iran. Required data, such as forest standing stock, annual growth increment of trees, wood density and timber harvesting, were collected from secondary sources. Allometric equation was used for estimating the carbon sequestration. The amount of CO₂ emission was calculated. Results showed that the annual growth per hectare and the amount of carbon sequestration per growth were 3.37 m³·yr⁻¹ and 1.14 t·ha⁻¹, respectively. Results also indicated that the value of aboveground sequestered carbon and its net present value were 71,217.63 (10,000 IRR·ha⁻¹) and 12,668.28 (10,000 IRR·ha⁻¹), respectively. Finally, the amount of carbon emission per hectare was calculated, as it was 0.01078 t·ha⁻¹ per year. The results of emission and carbon sequestration per hectare of the forest show that not only logging per hectare of forest will eliminate annual carbon sequestration, but also leads to an increase in CO₂ into the atmosphere due to harvest activity.

Key words: aboveground biomass, allometric models, NPV, sustainable forest management, wood density.

Introduction

Forest ecosystems services are extremely vital for human beings. In this regard, carbon storage is one of the most important ones. An important criterion for considering the importance of ecosystem services is to assess their economic value. The monetary value of carbon sequestration in forests remains unknown, whereas many ecosystem services have been measured in this way. As a result, market prices do

not reflect the true value of these services. In fact that many decisions made by the government or the private sector are based on market price information for these services, the lack of real value of carbon sequestration leads to erroneous decisions about forest ecosystem management (Brack 2019).

In forest ecosystems, carbon exists in various forms. Different approaches have been used to provide carbon estimation and inventory (Andersson et al.

2009). Two fundamental forms need to be distinguished – carbon in the soil and carbon in the plant biomass (Lal 2005). Carbon in biomass means aboveground biomass and belowground biomass. Woody debris is also added as plant biomass. The carbon content of wood vegetation is quantified by a coefficient of 0.5. Therefore, the amount of carbon is often assessed by stand's biomass amount using a transformational assessment (Tyrrell et al. 2009). These variations are influenced by climate, species, site productivity, and silviculture (Jarvis et al. 2005). By measuring the amount of carbon, we can estimate the stored carbon (Zhang et al. 2009).

There are numerous other ways to estimate carbon store and flux. In the case of access to actual tree values (diameter of the breast height 'DBH' and height) relative to the target population, biomass equations are preferred (Zhang et al. 2009). Allometric models employ distinct tree parameters including DBH and total tree height (ht) from forest inventory for estimating the aboveground biomass volume. A further principle explanatory variable for an allometric model to estimate biomass is the basic density of wood, which is evaluated based on dry mass to green volume ratio of wood samples in the laboratory (Cole and Ewel 2006).

Allometric correlations of tree size parameters (DBH, stem diameter at ground surface and tree height) and the biomass of stem, leaf and total root in different trees from tropical secondary-forest in Sarawak, Malaysia, were established by Kenzo et al. (2009).

Moreover, site-specific and general models were developed by Mugasha et al. (2016) to estimate the aboveground biomass and total tree volume using allometric models. Their findings show that

tree allometry differs significantly between site-specific ht-DBH models of the studied forests, which seems appropriate for tree height estimation. Allometric biomass models that include basic density of wood are strongly recommended to enhance the accuracy of estimates where this information is available.

Miah et al. (2020) used allometric models to determine the aboveground biomass for five homestead tree species in Bangladesh. Their results showed that for most of the species a combination between DBH at 1.3 m above the ground and ht is the explanatory variable that is required.

The need to quantify carbon stocks in various types of forests is equally significant for emerging carbon market mechanisms including emissions reduction and deforestation. To achieve this, suitable allometric patterns are required for a particular type of forest (Molto et al. 2013). Allometric models use separate tree parameters including DBH and ht of the forest inventory and wood basic density for estimating the volume of carbon stored in the stock of aboveground biomass (AGB). This factor is determined as the dry mass to green volume ratio of wood samples in the laboratory (Chave et al. 2014).

The ht-DBH models were developed for four major types of forests (such as plain forests) by Mugasha et al. (2013). Due to the significant changes in ht at various forest areas depending on climate function and other environmental factors, a local ht-DBH model should be developed to better estimate the volume of tree or biomass (Feldpausch et al. 2012).

Manual and mechanized operations in forestry management activities involve fossil fuel usage and there will be emission of CO₂ into the atmosphere. To perform a complete and precise assessment of the

net carbon balance in the forestry ecosystem, quantification of CO₂ emissions from forestry operations is essential (Liski et al. 2001). This amount is generally estimated according to the quantity of fuel consumption during each operation and each fuel's specific emission (Berg and Karjalainen 2003). The quantity of fuel usage during each operation can be calculated directly from real data of the machinery operation (Berg and Lindholm 2005). It maybe also obtained indirectly from the effective working time required for performing the operation and the relevant machine fuel usage per hour work (Schwaiger and Zimmer 2001). Dias et al. (2007) developed and exerted a methodology to evaluate CO₂ emissions of fossil fuel from operations carried out in Portuguese eucalyptus and maritime pine stands. These results suggest that tree logging represents for about 40 % of the total CO₂ emissions per year from these stands. Mohammadi Limaiei (2020) investigated the efficiency of forest management units considering economics and carbon dynamic. Carbon sequestration and CO₂ emissions were considered in efficiency analysis of forest management units in Hyrcanian forests or Caspian forests of Iran.

In forestry studies, there is less attention to carbon sequestration by trees, as well as CO₂ emissions during the harvesting and transportation of raw materials. Ignoring the amount of carbon sequestration of trees and carbon emissions from logging operations in forest areas may adversely affect the appropriate forest management plans. Hence, in this study, the role of the Shafarood forest in Iran in mitigating climate change through carbon sequestration is investigated. In addition, forest management has been evaluated by considering CO₂ emissions during the logging operations. The results of this

study assess the potential economic value of carbon sequestration in Iranian Hyrcanian forests and its potential to contribute to the carbon trade. Moreover, based on the inventory data, we examined the status of the carbon stock and subsequently determined the carbon model using allometric equations in Iranian Hyrcanian forests.

Material and Methods

Study area

This study was performed in Shafarood district No. 7 at Bargah Zamin forests, Guilan province in north of Iran. The altitude ranges from 1000 to 2050 m a.s.l., the latitude is 37°21'50" N, and the longitude is 48°59'00" E (Fig. 1). This forestry district has a total area of 1064 ha and the harvesting site is 437.5 ha. The volume per hectare in this district is 303.96 m³·ha⁻¹. Forest types in the central part of this district are Oriental beech (*Fagus orientalis* Lipsky), Caucasian alder (*Alnus subcordata* C.A.Mey.), common hornbeam (*Carpinus betulus* L.), chestnut-leaved oak (*Quercus castaneifolia* C.A.Mey.) and other industrial species such as Persian maple (*Acer velutinum* Boiss.), large-leaved lime (*Tilia platyphyllos* Scop.), common ash (*Fraxinus excelsior* L.), wych elm (*Ulmus glabra* Huds.), sweet cherry (*Prunus avium* L.), Cappadocian maple (*Acer cappadocicum* Gled.). For brevity, only the generic names of these species are used henceforth. The average annual rainfall is 989.7 mm and the average annual temperature is 15.2 °C. The wood volume per hectare of tree species such as beech, hornbeam, oak, alder, and other species are 170, 77.42, 3.16, 37.11 and 16.26 m³·ha⁻¹, respectively. The

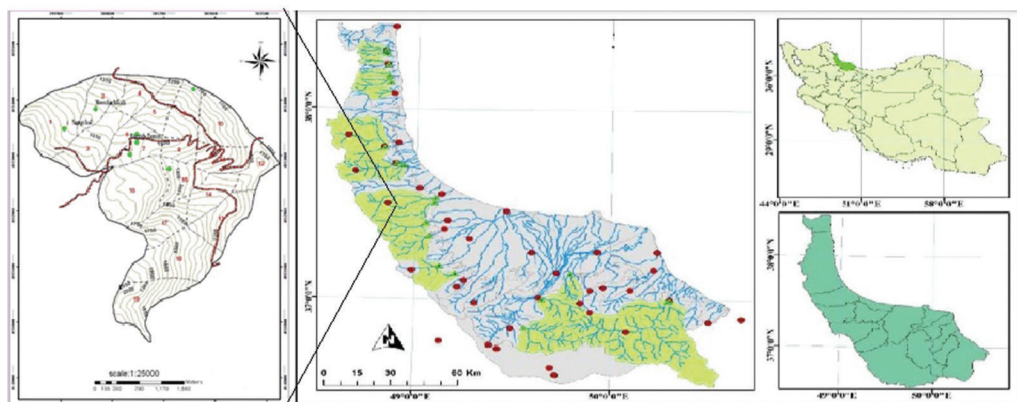


Fig. 1. Geographical location of the study area in Shafarood watershed in the west of Hyrcanian forests, north of Iran.

growth rate in the region is $3.37 \text{ m}^3 \cdot \text{ha}^{-1}$. The amount of harvested timber in Shafarood forests was 1073 m^3 per year for the whole district and $2.45 \text{ m}^3 \cdot \text{ha}^{-1}$ per year (Shafarood forestry plan booklet 2011). In Iran, the policy of harvesting 50 % of the growth rate was on the agenda as a pillar in forest rehabilitation management. The reason for this was that the forest exploitation policy will be in order to create a breathing space in the occurrence of maximum growth potential and volume. This policy was implemented for one or two 10-year periods, and will continue if the volume and growth do not reach to the target. Currently, there is a logging ban in Hyrcanian forests of Iran due to socio-economics problems and environmental issues.

Collecting data

Data such as tree species types, wood density, DBH and stock are essential to use in the allometric model. The wood density of beech, hornbeam, alder, oak, and the other species (maple, ash, elm, etc.) are 0.670, 0.700, 0.58, 0.64, and $0.62 \text{ t} \cdot \text{m}^{-3}$, respectively (Parsa-Pajouh

1995). Therefore, their average wood density is $0.642 \text{ t} \cdot \text{m}^{-3}$. Nevertheless, inventory form sample plots are very difficult and costly. Therefore, required data such as volume per hectare, DBH, species types and harvested timber have been collected from Shafarood forestry plan booklet (2018). Annual growth data was collected from previous research in the study area (Bonyad 2005).

Estimation of stored carbon

The estimation of carbon sequestration quantity in tree species was performed based on inventory and wood density. Then, the carbon model was estimated. Finally, the coefficients of each variable, related to the carbon equation, was determined. Kabiri Koupaei (2009) estimated the allometric equations of tree canopies based on DBH for beech-hornbeam mixture in Kheirud Kenar forest in Iranian Hyrcanian forests. Due to species composition similarity and climatic status between our study region and that area, we used allometric equations estimated by Kabiri Koupaei (2009) (Table 1).

Table 1. Estimated parameters of tree crown in allometric equations for beech-hornbeam mixed forest.

Species	Dependent variable	Independent variable	Parameter		R^2
			b_0	b_1	
Beech	V, m^3	DBH, cm	0.00025	2.4	0.981
	B_{Crt}, kg		0.003	2.802	0.934
Hornbeam	V, m^3		0.00032	2.357	0.922
	B_{Crt}, kg		0.013	2.492	0.955
Other industrial species	V, m^3		0.00027	2.381	0.983
	B_{Crt}, kg		0.005	2.696	0.933

Note: These parameters were provided based on the findings by previous studies (Kabiri Koupaei 2009).

The allometric equation (1) is presented below:

$$Y = b_0 \cdot X^{b_1}, \quad (1)$$

where: Y is dependent variable, b_0 and b_1 are coefficients, and X is independent variable.

The quantity of carbon stored in the biomass is determined based on the dry weight of the biomass (Parsa-Pajouh 1995). In forest trees, 50 % of the dry weight of the mass is assumed to be equal to the weight of stored carbon (Tyrrell et al. 2009). First, the dry weight of the biomass was obtained through volume and volumetric biomass. The dry weight of the biomass for the ground cover of forest trees includes the crown of forest trees and the trunk of forest trees.

The trunk weight of the mass trees in various diameter classes was obtained by using the volume and volumetric mass of the identified species. The canopy mass of forest trees (kg) was also calculated using the number of trees and allometric equations. The weight of the mass trees was obtained by adding the mass of the trunks and crown of the trees ($kg \cdot ha^{-1}$). Subsequently, the amount of calculated carbon is divided by 1000 to calculate the amount of carbon ($t \cdot ha^{-1}$).

Prediction of carbon model for various tree species

Carbon model for each species is obtained using equation (2) (Kabiri Koupaei 2009). The amount of stored carbon ($t \cdot ha^{-1}$) depends on the volume of various diameter classes (cm).

$$QC = \frac{DW}{V_1} \cdot \frac{qc}{DW} \cdot V_t, \quad (2)$$

where: QC is total quantity of carbon stored in the stands per hectare ($t \cdot ha^{-1}$), DW is quantity dry of weight of tree trunks per m^3 ($t \cdot m^{-3}$), V_1 is one m^3 of wood volume, and V_t is total volume of stands per hectare ($m^3 \cdot ha^{-1}$).

Wood density (WD , $t \cdot m^{-3}$) is calculated by dividing the trunk weight (ton wood) per the volume of wood (one m^3). $\frac{qc}{DW}$ is the

ratio of quantity of carbon (qc) per quantity of dry weight of trees trunks (DW) = 0.5. Then, the carbon model is determined by using equation (3) for various species of trees in stands.

$$QC = WD \cdot 0.5 \cdot V. \quad (3)$$

The relationship between stored carbon and volume per hectare was determined for various species by equation (4).

$$Y = a(i)X, \quad (4)$$

where: Y (t·ha⁻¹) is related to the volume of various diameter classes, $a(i)$ represents the quantity of wood density, and X (m³) = 0.5.

The value of sequestered carbon in stumpage or aboveground (V_{cs}) is calculated by equation (5) (Mohammadi et al. 2017).

$$V_{cs} = P_c \cdot \bar{v}, \quad (5)$$

where: P_c is carbon price per ton (Iranian Rials or IRR) and $\bar{v}$ is average volume in compartment (m³·ha⁻¹).

Estimating the net present value for carbon sequestration

The amount of carbon emitted from the stump is calculated based on net present value (NPV) of the shelf life or stable flow of the same cash flows at any time. For estimating carbon sequestration per year, the annual base volume growth for each species was calculated by diameter increment data and tariff. Annual stored carbon is calculated using equation (6) (Mohammadi et al. 2017):

$$C_a = \frac{c_t \cdot g}{\bar{v}}, \quad (6)$$

where: C_a is annual stored carbon per growth (t·ha⁻¹), c_t is total stored carbon (t·ha⁻¹), g is annual volume growth (m³·ha⁻¹).

To determine the annual volume growth in stand, the growth data of previous research by Bonyad (2005) and the volume data per hectare of the forestry plan booklet of the region (Shafarood forestry plan booklet 2011) were used. Then, according to the logarithmic functions between the growth and the volume of different species, the amount of annual volume growth was determined.

The net present value for carbon se-

questration or NPV_c (10,000 IRR·ha⁻¹) is calculated using equation (7):

$$NPV_c = \frac{C_a \cdot P_c}{i}, \quad (7)$$

where: P_c is carbon price per ton (IRR·t⁻¹) and i is real rate of interest.

The real interest rate is calculated from the average between the deposit interest rate and the interest rate of loan after subtracting the inflation. Numerical data of nominal interest rate and inflation rate was collected from the Central Bank of Iran during 2017–2019 (Central Bank of Iran 2019).

Estimate of CO₂ emission

No appropriate data was available on CO₂ emissions from logging in the Hyrcanian forests of Iran. Consequently, the quantity of CO₂ emissions was estimated during the logging operation using chainsaw in various forest management plans. Dias et al. (2007) calculated the average CO₂ emission in operation during the logging by means of chainsaw including cutting and processing (felling, limbing, bucking and debarking), extraction and loading logs onto trucks in Portugal for eucalypt and maritime pine stands. Their results showed that the average CO₂ emission in operation was 0.0044 t·m⁻³. As a result, wood production in various forest management units was multiplied to 0.0044 t and the quantity of carbon emission was estimated. It is important to note that the Hyrcanian temperate forests with mixed hardwood species are completely different from eucalypt and pine stands in Portugal, but the similarity of forest logging using chainsaw in both regions was the major reason for using the results of Dias et al. (2007) as a reference for estimating the CO₂ emission in the present study.

Analysis of Variance

One way Analysis of Variance (ANOVA) performed using Excel software to investigate, whether a significance differences exists among the average carbon sequestration in different diameter classes for five tree species in this study.

Carbon model

Carbon coefficients were determined by dividing the amount of carbon for each tree to the volume of that tree species and used as the coefficient of variables in the

equation of stored carbon in the forest aboveground. Using these coefficients, the stored carbon equation was determined using equation (3) and then the amount of aboveground carbon was determined using equation (4). This amount was 102.87 t·ha⁻¹.

Carbon models of beech, hornbeam, alder, oak, and others in the study region are shown in Table 2. According to the Table 2, because the density of wood is different among the species, the X coefficients in various carbon models change from 0.29 to 0.35.

Table 2. Numerical values of various variables used in the estimation of carbon model in study area.

Species	QC, t·ha ⁻¹	DW, t·m ⁻³ ·ha ⁻¹	V, m ³ ·ha ⁻¹	WD, t·m ⁻³	Carbon model
Beech	57.86	115.72	172.72	0.67	Y=0.335X+0.0000004
Hornbeam	27.54	55.07	78.66	0.7	Y=0.3501X+0.000008
Alder	0.93	1.86	3.21	0.58	Y=0.29X+0.000004
Oak	12.08	24.15	37.71	0.64	Y=0.32X+0.0003
Other industrial species	4.46	8.91	14.32	0.62	Y=0.3107X+0.0002

Statistical analysis

Results of ANOVA between the average carbon sequestrations in various species at different diameter classes is shown in

Table 3. Results indicated that there is a significant difference at significance level of 0.01 in the average carbon sequestration among all species in different diameter classes.

Table 3. Results of ANOVA between the average carbon sequestrations among various tree species in different diameter classes.

Source of variation	SS	df	MS	F	p-value	F _{crit}
Between groups	85.74	5	17.15	38.6667	2.71226E-26	2.27
Within groups	74.50	168	0.44			
Total	160.21	173				

The value of aboveground carbon sequestration

To calculate the aboveground stored carbon in Shafarood forests, the average world price per ton of carbon was used. The price of carbon per ton equals to

27.02 USD (World Bank 2020). Depending on the exchange rate in the free market, this is equivalent to 6,923,064.4 IRR. As a result, the value of carbon sequestration in stumpage using equation (5) is 2779.55 USD equal to 71,217.63

(10,000 IRR·ha⁻¹).

The annual volume growth is 3.37 m³·ha⁻¹. Therefore, the annual stored carbon per growth was determined by equation (6) and it was 1.14 t·ha⁻¹. Moreover, the NPV of carbon sequestration was calculated using equation (7). The real interest rate was 6.23 %. The results indicated that the NPV of carbon sequestration was 494.43 USD or equal 12,668.28 (10,000 IRR·ha⁻¹·yr⁻¹).

The amount of wood harvested is 2.45 m³·ha⁻¹. Hence, the ratio of carbon sequestration will be 0.83 t·ha⁻¹ by using equation (6). The NPV of carbon sequestration was 359.98 USD or equal 9215.488 (10,000 IRR·ha⁻¹·yr⁻¹) by using equation (7).

Estimation of CO₂ emission

The amount of carbon emission estimated by Dias et al. (2007) was equivalent to 0.0044 t·m³, the carbon emission rate was 0.01078 t·ha⁻¹ per year. The carbon emission was 4.72 t in this entire study area per year (the harvesting site is 437.5 ha). The quantity of CO₂ emissions in this study for various species during logging operation was estimated. Results indicated that CO₂ emissions for beech, alder, hornbeam, oak and the other species were 0.0061, 0.0028, 0.00011, 0.0013, and 0.0005 t·ha⁻¹ CO₂ per year, respectively.

Discussion

The results indicated that the amount of volumetric growth and carbon sequestration in this area is 3.37 m³·ha⁻¹ and 1.14 t·ha⁻¹ per year. The forest ecosystem is composed of several elements, each of which is involved in carbon sequestration. Technically, the amount of carbon sequestration is only based on the growth of the

volume of trees in the aforementioned mass, which is in terms of the current situation, not the potential, and at the same time, the shrubs have not been calculated. The amount of volumetric growth and carbon sequestration in the study of Mohammadi et al. (2017) in Asalem forests of northern Iran were 6.023 m³·ha⁻¹ and 2.307 t·ha⁻¹. The volume per hectare and density of trees may be the reason of disproportionate distribution and changes in biomass and carbon sequestration in these forests. The average volume per hectare in study area by Mohammadi et al. (2017) was 453.28 m³·ha⁻¹ and in this study area is 303.96 m³·ha⁻¹.

Various forests can offer similar services, although the value of them may be dependent upon the species. The quantity of CO₂ stored per hectare of forested land is dependent upon local climate, species selection, distribution of age, hydrology, soil type, stocking density and management regime (Lopes and Cunha-e-Sá 2014).

In this study the amount of forest biomass carbon sink of 102.87 t·ha⁻¹ per year worth about 71,217.63 (10,000 IRR·ha⁻¹). Nabavi and Behjoo (2012) calculated the total stored carbon in the leaves, branches, crown and trunk of trees in Shafarood forest by string methods and volume growth and its economical value was calculated as it was 5,601,545 IRR·ha⁻¹·yr⁻¹. Apparently, the diversity among species and case study has resulted the difference in economic value per hectare. In present study, the types of species were beech, alder, hornbeam, oak and others. Furthermore, we estimated crown and trunk weight, while Nabavi and Behjoo (2012) calculated total carbon stored in leaves, branches, crown and trunk of trees. Therefore, forest management methods affects the quantity of carbon stored in soils, biomass and forest products, and the amount

of emissions into the atmosphere (United Nations Economic and Social Council 2014). Moreover, it provides several job opportunities in the area, as well as social, economical, environmental and health benefits. Hence, it can be considered as an economic income source for sustainable forest management to increase the participation of the local community on climate change mitigation and biodiversity protection, and to produce wood biomass (Nejadi and Rahbar 2012, Mohammadi et al. 2017).

Allometric models used in this paper for quantifying biomass carbon will significantly improve capacity to directly estimate the aboveground carbon sequestration at the Shafarood forest in the north of Iran. The species investigated in this study are very important for economically, environmentally and social aspects in the region. The estimated carbon stored models in this study can be applied for carbon balance. These results are consistent with results of Vaidya et al. (2017). Their findings show that different generalized allometric equations were developed to estimate biomass carbon. Under future UNFCCC commitment periods, each country will have to provide detailed statements on its overall carbon budget.

Aabeyir et al. (2020) developed allometric models for assessing modelling aboveground biomass in Ghana's savannah forests. Their study showed that wood density and DBH were the major predictors that had a significant effect on the variability of aboveground biomass modelling. Thus, the allometric model of their research provide an appropriate local allometric tool filling an important gap in estimating of aboveground biomass modelling for Ghana's tropical forests (Aabeyir et al. 2020).

In the present study, the results of allo-

metric relations showed a high significant correlation coefficient. This slight interspecific difference in the allometric relationships of the stem and total biomass with DBH may be obtained from the similarity of wood density among Shafarood forest trees as it is $0.6\text{--}0.7\text{ t}\cdot\text{m}^3$. Kenzo et al. (2009) demonstrated that secondary-forest trees have a less density of wood (0.2 to $0.5\text{ t}\cdot\text{m}^3$) in comparison with trees from the tropical rain-forest in late succession, which extend from 0.2 to $0.8\text{ t}\cdot\text{m}^3$ within the tropical rain timberlands of South-East Asia (Whitmore 1990, Suzuki 1999). In reality, the particular gravity of tree species under our consideration has changed inside a little run from 0.29 to $0.53\text{ t}\cdot\text{m}^3$. Moreover, Hashimoto et al. (2004) have explained the details of similar allometric relations among their tropical secondary-forest trees, which was also similar in wood density, in South-East Asia. Aabeyir et al. (2020) also have similar allometric relationships in Ghana's tropical forests, West Africa. The density of wood in their study was between $0.5\text{--}0.89\text{ t}\cdot\text{m}^3$.

By comparing carbon sequestration by forests with its artificial methods, we can mention, refining carbon with artificial methods such as filters involves heavy costs. Therefore, in order to reduce the atmospheric carbon dioxide and balance the content of greenhouse gases, the atmospheric carbon must be absorbed and deposited in various forms. Carbon sequestration in plant biomass and soils under this biomass is the simplest and most economically viable solution to reduce the atmospheric carbon dioxide (Nelson et al. 1999). Refining carbon with synthetic methods, such as filters, is costly, at around $600\text{ \$}\cdot\text{t}^{-1}$ in the United States (Service 2018).

Therefore, if this carbon was to be refined artificially, it would cost $\$ 61,722$ or

1,581,441.084 (10,000 IRR·ha⁻¹) per hectare (considering the average of \$ 600 per ton of carbon and 256,220 IRR per dollar in 2021). Hence, the damage caused by harvesting of these species in the Hyrcanian forests in terms of carbon sequestration is significant.

The ANOVA test used to determine if the means of carbon sequestrations for various tree species in different diameter classes are significantly different from each other. Results indicated that there is a significant difference at the average of carbon sequestrations in various tree species at different diameter classes at the significance level of 0.05 (tables 1 to 3). Hence, the results of this research is in line with finding of Färe et al. (1989) that failure to credit plants for reducing pollution may seriously distort the classification of plant performance.

Based on the findings of this study, the amount of CO₂ emissions in the logging operation was 0.01078 t·ha⁻¹ per year and carbon sequestration quantity was about 0.083 t·ha⁻¹. Comparing the amount of emissions and carbon sequestration per hectare of forest, it can be mentioned that the amount of CO₂ emissions in logging operations is lower than carbon emissions from other activities in the forest such as transportation operations, wood processing, uncontrolled logging and unsupervised selective wood cutting (Pearson et al. 2014). The volume of harvested wood in this study is equivalent to 2.45 m³·ha⁻¹ with a carbon sequestration of 0.83 t·ha⁻¹. Hence, by harvesting this amount of wood, its deposition function is eliminated in the atmosphere. Furthermore, the machine activities for cutting 2.45 m³·ha⁻¹ cause the emission of 0.01078 t·ha⁻¹ excess CO₂. Although the fact that the amount of carbon emission by the machines is low, but because of being seen it is necessary to be

mentioned.

The economic value of 2.45 m³ of wood is equal to 860 USD based on USD to IRR exchange rate in the market in 2020 and the economic value of its carbon sequestration is 359.98 USD. This is the only value of the tree's aboveground carbon sequestration, which accounts for 30 % of total, and the rest of it (70 %) such as belowground, soil and dead organic matter are not estimated in this study (Pache et al. 2021). Carbon sequestration is only one of the tree services whose value has been estimated in this study and the value of other tree services have not been considered such as soil conservation, water storage and recreational values, etc. Hence, the suggestion is to determine the value of other services also in Hyrcanian forests and determine optimal forest policy based on environmental, economic and social values.

Conclusion

Estimating the monetary value of carbon sequestration as an important forest service is a very important issue. Despite the various studies on economics values of carbon sequestration, it is still required more investigation as this value is highly related to geographical locations and species diversity of forests. In addition, market prices are not reflecting the values of forest ecosystem services. However, a large number of decisions from the public and private sectors are made in response to market information, non-quantified carbon sequestration value could result in poorly informed decisions on forest management. Overall, the amount of carbon storage in forests is declining due to forest degradation and loss in Hyrcanian forests of Iran. The results of this study may serve

as a guideline for policy makers for sustainable forest management considering carbon dynamic.

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PRODUCTIVITY AND COSTS OF CABLE YARDING IN GROUP SHELTERWOOD SYSTEM IN DECIDUOUS FORESTS

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Abstract

The aim of the present study was to improve the use and operational efficiency of the truck-mounted tower yarders in deciduous stands and to determine the time, log's volume transported per turn by the yarder, as well as the yarding costs. The study was carried out in the Sredna Gora Mountains, Central Bulgaria, in deciduous stand with species composition of European beech (90 %), European hornbeam (10 %). The mean productivity of truck-mounted tower cable yarder at shift level is close to the maximum for that type ($9.12 \text{ m}^3 \cdot \text{PMH}^{-1}$ and $8.41 \text{ m}^3 \cdot \text{SMH}^{-1}$). In order to improve the yarder productivity a remote control of the carriage is advisable to be used, also used by the choker-setter. In this way the loaded carriage could wait for the operator before the landing. Another option to reduce choker-setter's fatigue and to decrease the time for lateral outhaul and hook is to use a carriage with mechanical slack-pulling. The gross costs for yarding uphill a whole deciduous tree by the studied tower yarder were calculated at 146.52 € per productive machine hour and 13.02 € per m^3 . In the distribution of the gross costs, labour costs (21.44 %) are lower than variable costs (29.86 %) and fixed costs (26.84 %).

The results from the study are useful to integrate the cable yarders in group shelterwood system and to achieve economic and environmental efficiency of timber transportation in deciduous forests in sensitive sites.

Key words: timber harvesting, economic evaluation, Natura 2000, Sredna Gora Mountains.

Introduction

The cable yarding is taking logs from a stump area to a landing using an overhead system of winch-driven cables to which logs are attached with chokers (Stokes et al. 1989). The standing line is a fixed cable that does not move during logging operations; for example, a skyline anchored at both ends. The mobile cable yarders have a tower – steel mast used

instead of a spar tree at the landing for cable yarding.

The major advantage of cable-based extraction systems seems to be their independency from many system-influencing factors. Planning and implementation can be done almost anytime and on any terrain (Schweier et al. 2020).

The cable yarding is a good alternative to a ground-based skidding where side slopes are greater than 30 % (LeDoux

and Huyler 2000). In general, cable yarding is more complex and expensive than ground-based logging, which places the steep terrain cable yarding operations at a general disadvantage in terms of pure harvesting cost. However, modern cable yarding technology can fill this gap, and productivity models can assist users in refining their work technique, so as to maximize the productive potential of their machines (Spinelli et al. 2015). As the cable yarding is more costly than ground-based systems, this technology requires a multiproduct market and a site with a large volume of quality timber (LeDoux and Huyler 2000), but on steep terrain, cable yarding is the cost-effective alternative to building an extensive network of skidding trails and results in a much lower site impact compared to ground-based logging (Spinelli et al. 2010).

Cable yarding systems are used mainly for uphill yarding due to their much easier and faster rigging. The most common timber harvest unit layouts are parallel or fan-shaped (Peters and LeDoux 1984). Recently, the double-hitch carriages have been developed to allow for full suspension of whole-tree and tree-length material; the double-hitch carriage took longer to load up, but was able to achieve similar productivity through increased inhaul speed, especially for settings with limited deflection, or areas with lower tolerance for soil disturbance (Spinelli et al. 2021).

Interestingly, according to the most researches, it seems that cable yarders operate mainly in coniferous forests. A small amount of studies has been done in deciduous forests – mainly in the Appalachians in the Northeast of United States (LeDoux 1985a,b; Huyler and LeDoux 1997a,b; Visser et al. 2001), Southern Germany (Schweier et al. 2020), Southern Italy (Zimbalatti and Proto 2009, Proto

and Zimbalatti 2016), and Turkey (Melemez et al. 2014).

In Bulgaria approximately 60 % of the forests are located in mountainous areas with steep slopes and complex terrain configurations. Despite the share of deciduous tree species in forest territory is 71 %, whereas the share from total growing stock is 55.5 % (EFA 2021) the recent studies on cable yarding in coniferous forests also prevail (Stoilov 2019, Boyadzhiev et al. 2020, Boyadzhiev and Glushkov 2021, Stoilov et al. 2021). Therefore, the study of yarding operations in deciduous forests is important for improving forest management in Bulgarian forest areas.

Currently, in Bulgaria about 40 mobile tower yarders operate, incl. 3 mountain harvesters. Tractor-mounted tower yarders have been widely used in Bulgaria since 1980 in primary timber transportation. Nowadays, many truck-mounted tower yarders have been introduced (Stoilov 2021).

Lateral yarding consists of moving the trees or logs (load) to a bunching point from where the load is partly or entirely lifted off the ground by a cable (mainline) and moved to a landing. Truck-mounted tower cable yarders are driven by hydrostatic transmission.

Both single- and multi-span layouts are used for tower yarders. For single-span layouts, a crew of 2-, 3-, and 4-members can be used when using solely a yarder and a 3- and 4-member crew when using both a yarder and skidder (Kellogg 1981, Kellogg and Olsen 1984).

According to Huyler and Ledoux (1997b) the yarding delays for operational, mechanical, and non-productive time accounted for approximately 35 % of the total cycle time on steep slopes in the Northeast US. Huyler and Ledoux (1997b)

also proposed that delays should be factored to separate the delay-free time to be able to give an estimate of the total cycle time. The average delay-free-cycle time was 5.72 minutes (Huyler and LeDoux 1997a). The relevant variables used in the time prediction equation were the yarding distance, lateral yarding distance, volume per turn and stem volume.

According to Dimitrov (2012), to increase the productivity of tractor-mounted tower yarder operated in European beech (*Fagus sylvatica* L.) stands located in the Ograzhden Mountains (Southwest Bulgaria), operational times for lateral out-haul (28 %), inhaul (21 %), spare and delays of workers (16 %) and unhook (13 %) should be minimized. He also estimated that the mean productivity of the studied yarder of $3.22 \text{ m}^3 \cdot \text{h}^{-1}$ for 33 m lateral yarding and 230 m outhaul could be defined as moderate. The results are comparable with those of the studies carried out in coniferous stands of Northeast Turkey – $6.6 \text{ m}^3 \cdot \text{h}^{-1}$, $5.5 \text{ m}^3 \cdot \text{h}^{-1}$, and $4.9 \text{ m}^3 \cdot \text{h}^{-1}$, respectively for inhaul distances of 100, 200, and 250 m (Senturk et al. 2007).

Production rates observed by Zimbalatti and Proto (2009) during firewood yarding operations in two Turkey oak (*Quercus cerris* L.) stands in Calabria, Italy, were lower – mean load volume of 0.75 and 0.54 m^3 , and productivity of 2.38 and $3.21 \text{ m}^3 \cdot \text{h}^{-1}$, respectively for coppice and high forest. According to Melemez et al. (2014) the extraction by skyline was determined to be the most efficient extraction method, but the slope of the terrain needs to be greater than 50 % to use this method.

Most operations will be economically efficient when taking place in a high-yield stand and when all factors affecting costs of operations have been considered care-

fully (LeDoux 1985a).

The production costs of the two systems in flat terrains analysed by Schweier et al. (2020) had a comparable range, between $32.5 \pm 5.9 \text{ €} \cdot \text{m}^{-3}$ (Koller K507) and $36.2 \pm 7.5 \text{ €} \cdot \text{m}^{-3}$ (Valentini V400) (both including processing at roadside). However, the K507 system was used to process timber of significantly larger dimensions, which was more cost-efficient.

The aim of the present study was to improve the use and operational efficiency of the truck-mounted tower yarders in deciduous stands and to determine the time, log's volume transported per unit by the yarder, as well as the yarding costs. The knowledge of these parameters is useful to integrate the work of cable yarders in order to achieve economic and environmental efficiency of timber harvesting in deciduous forests included in Natura 2000 network.

Material and Methods

Description of the site and yarding setup

The study was carried out in the Sredna Gora Mountains ($42^\circ 34' 58.53'' \text{ N}$ – $24^\circ 24' 14.96'' \text{ E}$) around the city of Koprivshitsa, Sofia Province, Central Bulgaria. Stand and operation characteristics are shown in Table 1.

The studied stand is a part of Natura 2000 network with function codes BG 0002054 and BG 0001389, listed respectively under the Birds Directive and the Habitats Directive. The type of habitat is 9130 Asperulo-Fagetum beech forests. The species composition includes European beech (*Fagus sylvatica* L.) and European hornbeam (*Caprinus betulus* L.).

Table 1. Characteristics of the test site.

Parameter	Characteristics
Place Name	Stara Baraka, sub-compartment 9067-b
Elevation	1000 m asl
Function	Natura 2000: BG 0001389, BG 0002054
Species composition	European beech – 90 %, European hornbeam – 10 %
Stand age	110 years
Stand type	Natural high forest
Total area	23.2 ha
Relative stocking	0.8
Sylvicultural system	Group shelterwood, removal intensity 25 %
Average tree height	22 m
Average DBH of tree	34 cm
Average slope gradient	24° (45 %)
Growing stock	9120 m ³ (393 m ³ ·ha ⁻¹)
Allowable cut	2080 m ³ (90 m ³ ·ha ⁻¹)
Extraction direction	Uphill
Length of line	Site A: 280 m; site B: 165 m; site C: 195 m
Average lateral outhaul	14.4 m

Three fan-shaped skyline corridors with average skyline length of 300 m were opened on terrain slopes at about 16° (29 %), 20° (36 %), and 24° (45 %). Field observations were carried out on 30 work cycles (turns) at each corridor. Extraction direction was uphill and trees were manually felled and single-span layout was implemented each time.

Cable yarder unit

The study was focused on a Koller K501 truck-mounted tower yarder (Table 2). The work team consisted of three people, of which one was the winch and crane operator, the second one unhooks, delimbs and crosscuts the trees, and the third one was choker-setter at the loading site. The work team had at least 5 years of experience with cable yarding and they were all 30–55-years-old.

The tested mobile tower yarder is designed for uphill logging, mounted on a

truck with pressure air-brakes. The K501 is a powerful yarder, principally used for selective cuts and for regenerative harvesting operations using a carriage SKA 2.5 (Koller Forsttechnik GmbH, Schwoich, Austria) for payloads up to 2.5 t. The mass (9800 kg) was distributed on the rear axles of a Mercedes-Benz truck with special reinforced frames. The logs were yarded laterally to the carriage using the power of the yarder's mainline winch and active skyline clamps (Proto and Zimbalatti 2016).

Productivity study and costs

A detailed time and motion study was conducted to estimate the duration of work elements and productivity of the cable yarders in the given conditions. A yarding work cycle was assumed to be composed of repetitive elements (Kellogg et al. 1996, Olsen et al. 1998, Spinelli et al. 2015, Proto et al. 2016, Munteanu et al. 2017). In this study, six work elements were sepa-

Table 2. Technical data of the studied Koller K501 cable yarder.

Parameter	Value
Skyline capacity 600 m, $\varnothing 24$ mm	120 kN (tension section)
Mainline 600 m, $\varnothing 14$ mm	43 kN (average drum)
Guylines	4×75 m, $\varnothing 16$ mm / 2×15 m (extension)
Foldable telescopic tower, height	13.5 m
Power station	Autonomous engine and hydrostatic transmission
Engine power of the autonomous engine	250 kW (340 hp)
Brakes of skyline	Manually actuated band brake
Brakes of mainline	Hydraulically actuated band brake
Operation	Hydro-mechanical / electro-hydraulic single lever operation with dead-man's control
Carriage	Koller SKA-2.5 manual slack-pulling carriage
Choker system	Bardon choker
Lifting moment of the crane	270 kNm
Carrier	6×4 Mercedes-Benz truck

rated and taken into account in order to estimate the work cycle time (Huyler and LeDoux 1997b); they were similar to those described by Proto and Zimbalatti (2016):

- Carriage outhaul (CO) begins when the operator is ready to move the empty carriage from the landing out to the stump and ends when the choker-setter touches the chokers;

- Lateral outhaul and hook (LOH) begins at the end of carriage outhaul and ends when the choker-setter has completed hooking the chokers and signals to begin yarding;

- Lateral inhaul (LI) begins at the end of hook up and ends when the turn is pulled up to the carriage and the carriage begins to move up the corridor;

- Carriage inhaul (CI) begins at the end of lateral inhaul and ends when the load has reached the deck where it can be directly unhooked at the landing;

- Unhook (U) begins at the end of carriage inhaul and ends when the chokers have returned to the carriage;

- Delay time (D) includes the rest, personal delays, organizational delays, service, and repair.

The time-motion study was designed to evaluate duration of work elements and yarder productivity and to identify those variables that are most likely to affect it. Each yarding cycle was individually measured by a stopwatch and the productive time was separated from delay time. The yarding distances and terrain slopes were measured with a professional laser range-finder with clinometer. The load volume per turn was determined by measuring the length and the mid-length diameter of all logs from each load.

The machine costs were calculated using the COST model (Ackerman et al. 2014). In order to calculate the production cost for 1 m³ of timber, the cost analysis employed the following parameters: the number of operators, the hourly cost of an operator, the hourly cost of machines, the volume of extracted timber and the productive machine hours (excluding all

delay times). The machine costs per hour were reported both as productive machine hours and scheduled machine hours. The purchase prices and operator wages required by the cost calculations were obtained from catalogues and accounting records (Proto et al. 2016). The labour cost was set to 37.87 €·SMH⁻¹ inclusive of indirect salary costs. The diesel fuel consumption was measured by evaluating the volume of fuel used to fill the fuel tank to the brim and recording the amount of fuel used during that day. A salvage value of 10 % of the purchase price was assumed and the Value Added Tax (VAT) was excluded. Cost calculations were based on the assumption that companies worked for 150 working days in the year and a depreciation period of 10 years. For extraction work this amounts to 130–150 working days per year (20–21 working days per month), at an average of 6–7 scheduled working hours per day (assuming one to two hours spent on lunch, rest and other breaks). This yielded annual working times of 910–1050 SMHs with a 70 % use coefficient (Spinelli and Magagnotti 2011, Spinelli et al. 2014, Proto et al. 2018).

Data analysis

A regression analysis was performed on the experimental data in order to develop prediction equations for estimating the work cycle time and productivity. The independent variables used in the modelling approach included yarding distance L , lateral yarding distance l , load volume per cycle V , terrain slope angle i , and the load's number of trees n . The descriptive statistics of the variables were computed and a stepwise backward regression procedure was used to model the variability of yarding cycle time and productivity as a function of independent variables.

The confidence level used for regression analysis was 95 % ($\alpha = 0.05$) and the assumed probability $p < 0.05$. Independent variables are significant at $p < 0.05$, i.e. strong presumption against neutral hypothesis. The experimental data was processed by Statistica 8 (StatSoft Inc., Tulsa, OK, USA) software.

Results and Discussion

The summary of experimental data from 90 cycles for each of the selected variables used in the cycle time and production equations is shown in Table 3.

Duration of work cycle elements

The greatest portion of cycle time (Fig. 1) was dedicated to the carriage inhaul (37 % and 29 % respectively, excluding and including delays) and it was most probably related to the low inhaul velocity of carriage with a load. Unhook accounted for the smallest share (10 % and 8 % respectively, excluding and including delays). Lateral inhaul accounted for the second highest share (29 % and 23 % respectively, excluding and including delays), followed by lateral outhaul and hook (13 % and 10 % respectively, excluding and including delays), and carriage outhaul (11 % and 9 % respectively, excluding and including delays). Operational and mechanical delays accounted respectively for 16 % and 5 % of the total cycle time of the studied cable yarder.

Operations related to the lateral yarding (the lateral pull of the main line, the chokers hooking, and the extraction of the load to carriage) occupy 42 % within work cycle time including delays, and 53 % within delay-free work cycle. In the given conditions the tower yard-

Table 3. Mean experimental data.

Yarding variables	Cycle time, s			Distance, m		
	Mean value ±St. dev.	min	max	Mean value ±St. dev.	min	max
Carriage Outhaul (CO)	63.01 ±16.32	20	83	162.6 ±51.3	80	265
Lateral outhaul and hook (LOH)	68.4 ±47.2	27	200	14.4 ±5.6	5	28
Lateral Inhaul (LI)	211.3 ±73.3	75	460	14.4 ±5.6	5	28
Carriage Inhaul (CI)	180.35 ±34.46	186	490	162.59 ±51.3	80	265
Unhook (U)	72.1 ±19.4	30	160			
Delay (D)	180.3 ±79.5	50	450			
Total cycle time	964.6 ±139.7	707	1432			
Delay-free cycle time	883.9 ±112.0	683	1143			
Load volume per cycle (turn), m ³	2.2 ±0.23	1.6	3.0			
Productivity, m ³ per PMH*	9.12 ±1.52	6.76	14.46			
Productivity, m ³ per SMH*	8.41 ±1.61	5.78	13.09			
Number of cycles per SMH*	3.73	2.51	5.09			

Note: * PMH – productive machine hour, SMH – scheduled machine hour.

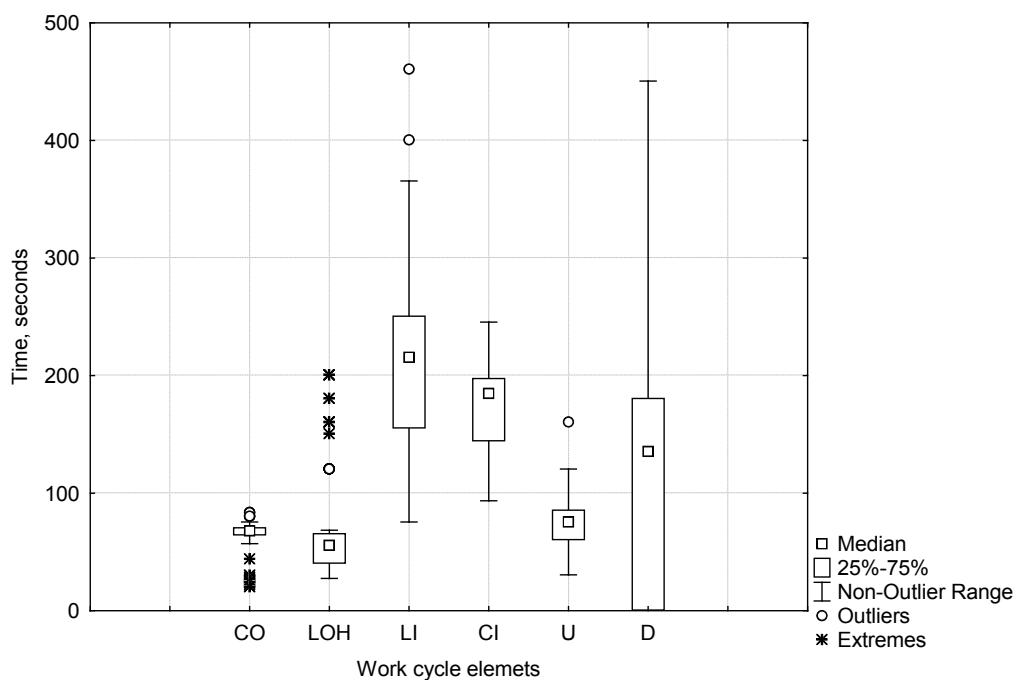


Fig. 1. Elemental time consumption.

er operates at relatively moderate level of yarding distance (mean 162.6 m from nominal length), moderate lateral yarding distance (14.4 m) and slope (20°), and good level of the carriage payload capacity usage.

A regression analysis was performed on the time-study data (using character-

istics of independent variables shown in Table 3) in order to develop a prediction equation for estimating the yarding cycle time by excluding and including delays.

The delay-free cycle time T_{net} regression equation obtained with significant variables is shown in Table 4.

Table 4. Summary of the work cycle time models.

Equations		<i>F</i>	<i>R</i> ²	<i>R</i> ² _{adj}	Std. Error	<i>p</i> -value
$T_{\text{net}} = 8.88 \cdot l + 14.14 \cdot i$	(1)	67.44	0.49	0.46	16.13	< 0.05
$T = 0.49 \cdot L + 3.92 \cdot i$	(2)	4.09	0.20	0.15	112.48	< 0.05

In equation (1) minimum values of delay-free cycle time T_{net} may attain in case of lower rates of lateral yarding distance l and terrain slope angle i . The influence of lateral yarding distance l and terrain slope angle i on delay-free cycle time T_{net} is moderate.

In the equation (2) for cycle time including delays T under the given forest conditions the influence of slope yarding distance L and terrain slope angle i on cycle time including delays T is also moderate (Table 4). Consequently, the minimum duration of total cycle time (including delays) was achieved when slope yarding distance L and terrain slope angle i were minimized.

Productivity of Tower Yarder

To increase delay-free yarding productivity, defined by the equation (3) shown in

Table 5, lateral yarding distance l , and terrain slope i should be at low rates, whereas the load volume per cycle V will be at maximum. The influence of mentioned variable on the delay-free yarding productivity is moderate.

From equations (4) shown in Table 5 it can be seen that, when reducing the terrain slope i and increasing the volume of a load to the allowed maximum, it could be expected that the yarding productivity per scheduled machine hour will increase its maximum.

Generally, the mean yarding productivity per hour at mean slope yarding distance of 162.6 m and mean lateral yarding distance of 14.4 m, excluding and including delays, estimates at 9.12 m³·h⁻¹ and 8.41 m³·h⁻¹ at the given operating conditions. The mean yarding productivity per hour is higher than the maximum for tower cable yarders, compared to the rates

Table 5. Summary of the productivity models.

Equations		<i>F</i>	<i>R</i> ²	<i>R</i> ² _{adj}	Std. Error	<i>p</i> -value
$P_{\text{PMH}} = 6.069 \cdot V - 0.079 \cdot l - 0.24 \cdot i$, m ³ ·h ⁻¹	(3)	13.81	0.45	0.42	1.83	< 0.05
$P_{\text{SMH}} = 6.29 \cdot V - 0.20 \cdot i$, m ³ ·h ⁻¹	(4)	7.41	0.31	0.27	2.49	< 0.05

for hardwood quoted by Senturk et al. (2007), Zimbalatti and Proto (2009), Dimitrov (2012), Melemez et al. (2014), and Schweier et. al. (2020).

On the other hand, in order to improve the yarder productivity, a remote control of the carriage is advisable to be used, also by the choker-setter. This way the loaded carriage could wait for the operator before the landing. Another option to reduce choker-setter's fatigue and to decrease the time for lateral outhaul and hook is the use of carriage with mechanical slack-pulling.

Cost analysis

The hourly fixed operating and labour cost of the studied tower yarder's three operators, are shown in Table 6 and Figure 2. The gross costs of Koller K501 for uphill whole tree yarding in predominantly beech stand were calculated at 146.52 € per productive machine hour (PMH). Thus, when the studied tower yarder was productive, the extraction costs were at 13.02 €·m⁻³. The increase of productive time of a tower yarder would lead to a decrease in extraction costs.

Table 6. Costs characteristics of the studied tower yarder.

Costs	Costs per PMH, €	Costs, €·m ⁻³	Share of gross costs, %
Fixed costs	18.73	1.65	12.70
Variable costs	55.79	5.00	38.41
Labor costs	48.75	4.30	33.06
Net costs(excluding profit)	123.28	10.96	84.17
Overheads and management costs	7.54	0.67	5.11
Gross costs (including profit)	146.52	13.02	100

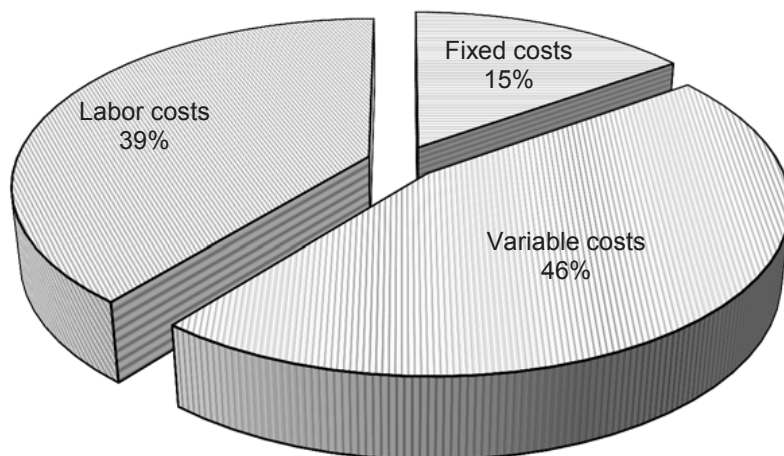


Fig. 2. Percentage distribution of the net yarding costs.

The costs of studied tower yarder are lower compared to the costs of $32.5 \pm 5.9 \text{ €} \cdot \text{m}^{-3}$ for Koller K507 and $36.2 \pm 7.5 \text{ €} \cdot \text{m}^{-3}$ for Valentini V400 (both including processing at roadside) reported by Schweier et al. (2020).

In the distribution of the net costs (Fig. 2) of the studied Koller K501 tower yarder at these conditions, variable costs predominate; they are more than three times higher than the fixed costs. Generally, the variable costs are almost half of the net cost.

Conclusions

The greatest portion of the cycle time was dedicated to the carriage inhaul (37 % and 29 % respectively, excluding and including delays) and it was most probably related to the low inhaul velocity of carriage with a load. Unhook accounted for the smallest share (10 % and 8 % respectively, excluding and including delays). Lateral inhaul accounted for the second highest share (29 % and 23 % respectively, excluding and including delays), followed by lateral outhaul and hook (13 % and 10 % respectively, excluding and including delays), and carriage outhaul (11 % and 9 % respectively, excluding and including delays). Operational and mechanical delays accounted respectively for 16 % and 5 % of the total cycle time of the studied cable yarder, whereas the productive time for the studied cable yarder was about 78 % of the scheduled machine hour. Operations related to the lateral yarding (the lateral pull of the main line, the chokers hooking, and the extraction of the load to carriage) occupy 42 % within work cycle time including delays, and 53 % within delay-free work cycle.

The mean productivity of a truck-moun-

ted tower cable yarder is close to the maximum for that type ($9.12 \text{ m}^3 \cdot \text{h}^{-1}$ and $8.41 \text{ m}^3 \cdot \text{h}^{-1}$, respectively, excluding and including delays). In order to improve the yarder productivity a remote control of the carriage is advisable to be used, also by the choker-setter. This way the loaded carriage could wait for the operator before the landing. Another option to reduce choker-setter's fatigue and to decrease the time for lateral outhaul and hook is the use of carriage with a mechanical slack-pulling.

The gross costs for uphill whole deciduous tree yarding by studied tower yarder were calculated at 146.52 € per productive machine hour and $13.02 \text{ €} \cdot \text{m}^{-3}$. In the distribution of the gross costs, labor costs (21.44 %) are lower than variable costs (29.86 %) and fixed costs (26.84 %).

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VERIFICATION OF FOREST HIGH RESOLUTION LAYERS 2015: TREE COVER DENSITY AND DOMINANT LEAF TYPE IN BULGARIA

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Abstract

The high-resolution layers (HRLs) are Pan-European land cover datasets aimed at monitoring soil sealing (imperviousness, forest, grasslands, wetness and water, and small woody features). The main purpose of this article is to present the methodology and results from verification of two Forest HRL products for the 2015 reference year for Bulgarian territory: Dominant Leaf Type (DLT) and Tree Cover Density (TCD). The verification task aims at identifying systematic classification errors and the results are supposed to be used for improvement in future product updates. Qualitative approach for assessment of the HRL quality is applied in two steps, called General overview of data quality and Look-and-feel verification. The latter is performed within dedicated strata through non-random sampling, checking HRLs for omission and commission errors. We show results from a verification at country level based on local expertise and best available in situ data. We also provide comments and recommendations concerning commission and omission strata. Several cases of both of the above types of errors are identified and analysed in the DLT and TCD high resolution layers. Despite of errors found, both DLT and TCD receive a 'good' mark, and the same rating prevails in the strata level evaluation.

Key words: commission error, high resolution layers, land cover, omission error, qualitative evaluation, verification.

Introduction

COPERNICUS is a European program aimed at providing Europe with Earth observation capabilities. The implementation of the pan-European and local components of the Copernicus Land Monitoring Service (CLMS) is entrusted to the European Environment Agency (EEA). The aim of CLMS is to provide users, working in the fields of environmental protection, ag-

riculture, regional development, transport and energy, with services and information extracted from satellite data combined with data from other sources at EU level and in line with European commitments to international conventions.

Pan-European High Resolution Layers provide information on specific land cover characteristics, like the level of soil sealing (imperviousness), tree cover density and forest type, grasslands, wetness and

water, and small woody features. These raster data sets are produced from satellite imagery through a combination of automatic processing and interactive rule based classification.

The practical application of the HRL technology at European level started in 2006, when the Soil Sealing layer was produced (Stoimenov et al. 2008, Maucha et al. 2011), followed by a series of high resolution imperviousness products for the 2009 and 2012 reference years. HRLs from other topics began its development in 2012 (Forest, Permanent water bodies) (Anonymous 2013) and in 2015 (Grassland, Water & Wetness and Small Woody Features). The different characteristics and especially the thematic accuracy of the products have often been the subject of interest and research by various specialists (Hurbanek et al. 2010, Dimitrov and Lubenov 2014, Congedo et al. 2016, Gallego et al. 2016).

The HRL verification task is part of the second iteration of the CLMS High Resolution Layers for the 2015 reference year. As such, it was included in the Framework Service Contracts between EEA and participating countries as a new post-production verification. The EEA developed guidelines for the verification of the HRLs, but participating countries can modify and improve the methodology, according to their specific needs and available national data sets.

Like other HRLs, the Forest layer is produced by a consortium of established European service providers. All Forest products are in the European Terrestrial Reference System 1989 (ETRS89) and in the Lambert Azimuthal Equal Area (LAEA) projection. Multitemporal satellite data in 20 m spatial resolution, mainly Sentinel-2A data from the European Space Agency (ESA) as well as Landsat 8 data from the

United States Geological Survey (USGS), represent the primary input data source for the 2015 products. The two main layers (20 m spatial resolution) Dominant Leaf Type (DLT) and Tree Cover Density (TCD) provide information on the leaf type (broadleaved /coniferous) and the proportional tree cover at pixel level. Thus, users can apply a (national) definition of forest, taking into account each set of crowns that best suits their specific needs (Anonymous 2017).

The main aim of this article is the presentation of the results from verification of two Forest high-resolution layer products for the 2015 reference year for Bulgaria: Dominant Leaf Type and Tree Cover Density. Qualitative approach for assessment of the thematic quality of HRLs is applied, checking HRLs for omission and commission errors, as required by the guidelines. These results are supposed to be used for improvement in future product updates.

We show results from a verification at country level based on local expertise and best available in situ data. We also provide comments and recommendations concerning commission and omission strata.

Data and Methods

Definition of high resolution layers Forest

The following two lists present the main features and characteristics of the TCD and DLT layers, respectively:

Tree Cover Density:

- Tree Cover Density range of 0–100 %;
- Spatial resolution of 20 m;
- No Minimum Mapping Unit (MMU); pixel-based;

- Minimum Mapping Width (MMW) of 20 m;

- Includes: forests, orchards, groups of trees within urban areas (alleys, wooded parks and gardens), damaged forest parts;

- Excluded are open spaces within forests, shrub-covered areas and dwarf-pine areas.

Dominant Leaf Type (broadleaved or coniferous):

- Spatial coverage identical with that of the Tree Cover Density;

- Provides information on the dominant leaf type: broadleaved or coniferous;

- No MMU; pixel-based;

- MMW of 20 m.

The next list presents the reference data used to verify the Forest high resolution layers, including data provided centrally by the EEA and national in-situ data sets:

- GeoLand Public/LUCAS2012 (EU-ROSTAT), Lucas Points;

- National Forest Inventory Database;

- CORINE Land Cover (CLC) 2012 database for Bulgaria;

- CLC 2018 database for Bulgaria;

- GeoLand/VeryHighResolution2012 – Optical VHR2;

- GeoLand/HRIM_HR_FalseColour_Cov1_2015, 20 m;

- SPOT 2.5 DWH MG2b CORE_03 VHR VNIR imagery;

- National orthophoto map 2011, 40 cm resolution;

- National orthophoto map 2013–2016 (partial coverages) 40 cm resolution;

- IMAGE2012 – Coverage 1: IRS-P6 LISS-III images;

- IMAGE2018 – Coverage 1 and 2;

- Landsat 8 Imagery: Color Infrared, ArcGIS Online, 30 m;

- ESRI world imagery basemap, 1 m or better;

- OpenStreetMap;

- Topographic maps, 1:50,000, scanned.

Verification of high resolution layers Forest

The purpose of the verification task is to identify systematic classification errors. These results are supposed to be used for improvement in future product updates. General overview of data quality and Look-and-feel analysis are applied. The latter are performed within predefined critical strata through non-random sampling and qualitative evaluation, checking HRLs for omission and commission errors.

The verification is characterized by the following principles:

- HRLs are visually inspected on in-situ data for two types of errors: commission and omission;

- Spatial stratification of the territory is applied and the check-up is performed by strata;

- Selecting proper locations requires a-priori knowledge about the country or region;

- Sample selection is not random;

- Performed at full resolution 20 m × 20 m;

- The verification procedure is carried out on three levels:

- General overview of data quality (compulsory);

- Visual inspection by Look-and-feel method of zones of expected errors (compulsory);

- Quantitative verification (highly recommended);

- Result: Verification report. It contains findings and comments, as well as assessments by strata and for the HRL in general, according to a 5-grade scale (Table 1) (Anonymous 2018).

Table 1. Summarised qualitative evaluation of HRLs in five grades.

Evaluation Grade	Description
Excellent	Meaning that accuracy of the HRL is expected to reach almost 100 %; practically no errors can be found in the verified areas.
Good	Meaning that operator is confident that accuracy of the HRL is at least 85 %; only sporadic errors are encountered in the verified areas.
Acceptable	Meaning that accuracy of the HRL is estimated to reach 85 % in most of the verified areas, minor errors can be detected in the verified areas.
Insufficient	Meaning that accuracy of the HRL is not expected to reach the minimum 85 %; several errors are encountered in different regions.
Very poor	Meaning that operator is confident that accuracy of the HRL is bad and much below 85 %; majority of verified areas are wrongly mapped.

Stratification for selection of look-and-feel samples

Stratification is a common technique in sampling and for this, there are many reasons (Cochran 1977). In random selection, one of them is to divide the whole population (the territory of interest in our case) into subpopulations, which are internally homogeneous in respect to the measurements. There are also cases with a reverse focus, where the goal is to capture larger variations rather than find a common core, as in an example of stratified purposeful sampling (Patton 2002).

The verification is done in the course of the project in order to control and improve the result of the classification. Therefore, it should be done relatively quickly and with small resources. Such, for example, is the approach of obtaining qualitative assessments through systematic qualitative examinations (Global_LC2006). For the evaluation of HRLs we also apply qualitative verification, but with the following specifics: a) The main goal is to identify systematic errors in the classification; b) The visual check and the respective assessment shall be carried out by special territorial zones – critical strata; c) the positive effect of improving the products will be realized in their next update.

Based on our own observations, we can say that the stratification in the look-and-feel verification of the HRLs relies on a set of factors, including the role of anticipated and ascertained so far classification errors. In particular, stratification is based on: a) Error type (commission/omission); b) A priori knowledge of the performance of the classifier in the conditions of different land cover types and landscape elements; c) Conclusions based on accumulated data on classification errors registered so far.

The guidelines provide lists of recommended strata (Anonymous 2018). From the lists, it can be concluded that the differentiation of the territories in defining the strata is based on the following main characteristics: land cover type, classes of objects for classification (landscape elements), relevant geographical features (for example, altitude range); situational properties (e.g., areas along rivers and lakes, or areas around built-up zones).

The Tree cover density layer consists of values in the range from 0% to 100%. Previous experience has shown that the accuracy of such layers can be directly assessed only in comparison with in situ data with higher spatial resolution, using more complex and time-consuming procedures (Maucha et al. 2011). Therefore,

the corresponding binary tree cover map was verified, applying a 30 % threshold to the TCD data (Anonymous 2018).

We elaborated the strata based on the vectorised versions of the two verified layers Tree cover map and Dominant leaf type, using the following databases for the territory of Bulgaria: CLC, Physical blocks of Land Parcel Identification System (LPIS) and Forest inventory database. In addition, data on hydrography and settlements were used.

At the General overview stage, we found the recurrence of commission errors in grass-shrub areas falling within the LPIS land cover class 101 polygons – Shrubs and grasslands (Anonymous 2007). This fact necessitated the allocation of this type of area as a separate stratum.

Results and Discussion

The results for each layer are presented in the form of an overview map, a description of the strata with number of samples, assigned evaluation grades and commission and omission error summaries. Discussion texts on the properties of the layer follow in the form of findings and comments. The overview map of DLT is shown in Figure 1.

Dominant leaf type

General overview of data quality of DLT

Dominant Leaf Type is generally correctly mapped. Image data from SPOT 5 (2.5 m) and Digital Orthophoto Map 2013–2016

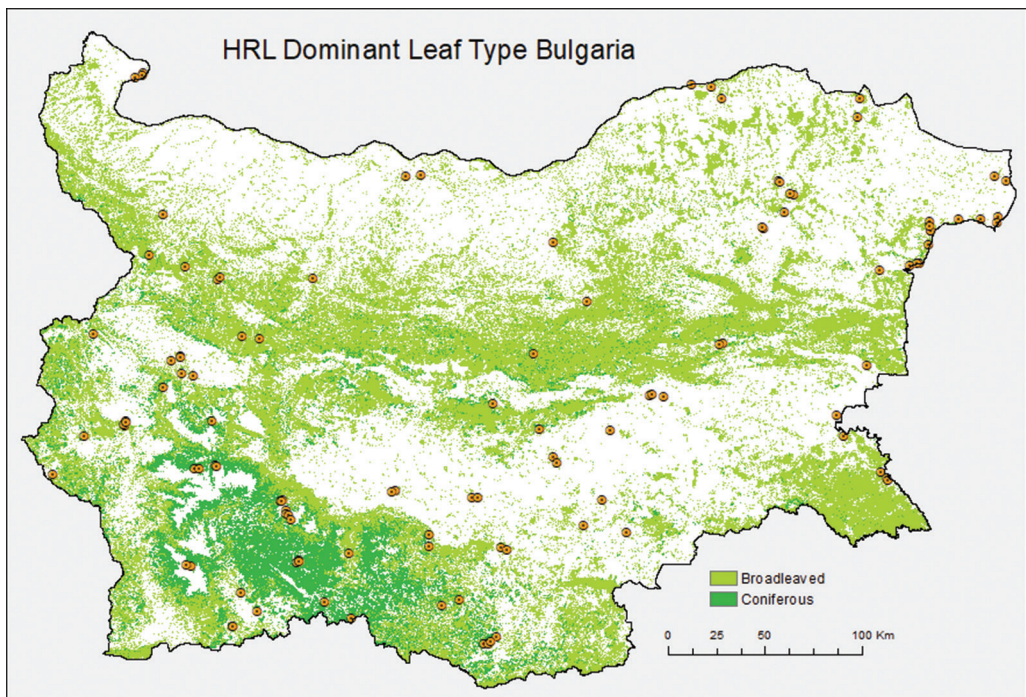


Fig. 1. Overview map of the Dominant Leaf Type layer of Bulgaria with verification locations.

showed normal quality. In some of the satellite scenes, covering the western part of the country the significant cloud cover is often an obstacle. For the general overview of the DLT product, mainly the Forest Inventory Database with its detailed attribute data is used as reference in situ data.

Frequent commission errors are broadleaved patches on shadowed slopes of deep valleys and near roads and rivers being classified as coniferous. In many cases large parts of Scots pine,

spruce and fir forest stands are given as broadleaved forest. In the same time, parts of beech and oak forest stands are classified as coniferous.

Look-and-feel verification of DLT

The strata are divided into two groups, for the respective type of errors (commission and omission), as the names of the strata, the number of samples and the evaluations are presented in Table 2.

Table 2. Look-and-feel analysis of DLT.

Stratum	Name of the stratum	Number of samples verified	Results of the verification by strata
Commission			
1	Transitional woodland-shrub	10	good
2	Moors and heathland and sclerophyllous vegetation	6	very poor
3	Shrubs and grasslands LPIS101	7	good
4	Wetland	6	acceptable
Omission			
5	Urban vegetation	8	good
6	Trees in sport and recreation areas	8	good
7	Orchards, fruit trees	10	acceptable
8	Lowland forests, broadleaved	11	good
9	Lowland forests, coniferous	9	good
10	Mountain forests, coniferous	10	good
11	Mountain forests, broadleaved	10	good
12	Coastal forests	10	good
13	Forest along rivers & lakes	10	good
Overall evaluation			good

Dominant leaf type is generally correctly mapped. It is seen from the list of strata grades above ('Results' column) that most of the problems were found in the commission strata.

Most frequent commission errors found in the DLT

Transitional woodland-shrub stratum – Scots and Austrian pine plantations given

as broadleaved (Fig. 2).

Wetland stratum – broadleaved given as coniferous forest. Treeless grassed and/or wet parts of wetland areas are often mapped as forest.

Moors and heathland and sclerophyllous vegetation – this stratum is totally based on the CLC class 322, for Bulgaria including only dwarf pine, which is not treated as tree cover.

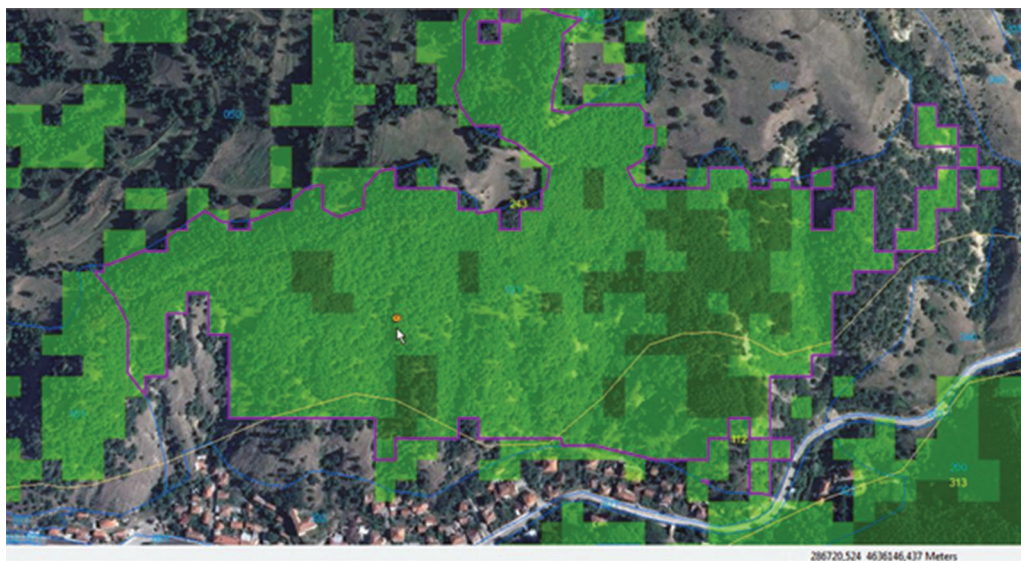


Fig. 2. Shrubs and grasslands LPIS101 – parts of broadleaved forests given as coniferous and Scots and Austrian pine plantations given as broadleaved forests.

Omission errors of DLT

The results from the verification for strata Urban vegetation and Trees in sport and recreation areas are good and in many cases excellent. Forest patches were found which are not mapped in the Dominant Leaf Type layer.

Many of CLC2018 class 222-based abandoned orchards and/or forested fruit tree plantation are not mapped in the Dominant Leaf Type layer.

Lowland forests, broadleaved – copice broadleaved forest is not mapped in the Dominant Leaf Type layer.

Lowland forests, coniferous – Austrian and Scots pine plantations are not mapped in the Dominant Leaf Type layer.

Mountain forests, coniferous – parts of coniferous forest stands are not mapped in the Dominant Leaf Type layer.

Mountain forests, broadleaved – parts of beech and oak forest stands are not mapped in the Dominant Leaf Type layer.

Coastal forests – broadleaved and

coniferous forests are not mapped in the Dominant Leaf Type layer.

Forest along rivers & lakes – parts of broadleaved forest stands and plantations – poplar, oak and locust are not mapped in the Dominant Leaf Type layer.

Tree cover density

General overview of data quality of TCD

The Tree Cover Density (Fig. 3), respectively the Tree Cover Map layer, was examined against most of the in-situ data layers listed above. Image data from SPOT 5 (2.5 m) and Digital Orthophoto Map 2013–2016 show normal quality. In some of the satellite scenes, covering the western part of the country, the significant cloud cover is often an obstacle. For the general overview of the TCD product, mainly the Forest Inventory Database with its detailed attribute data is used as reference in situ data.

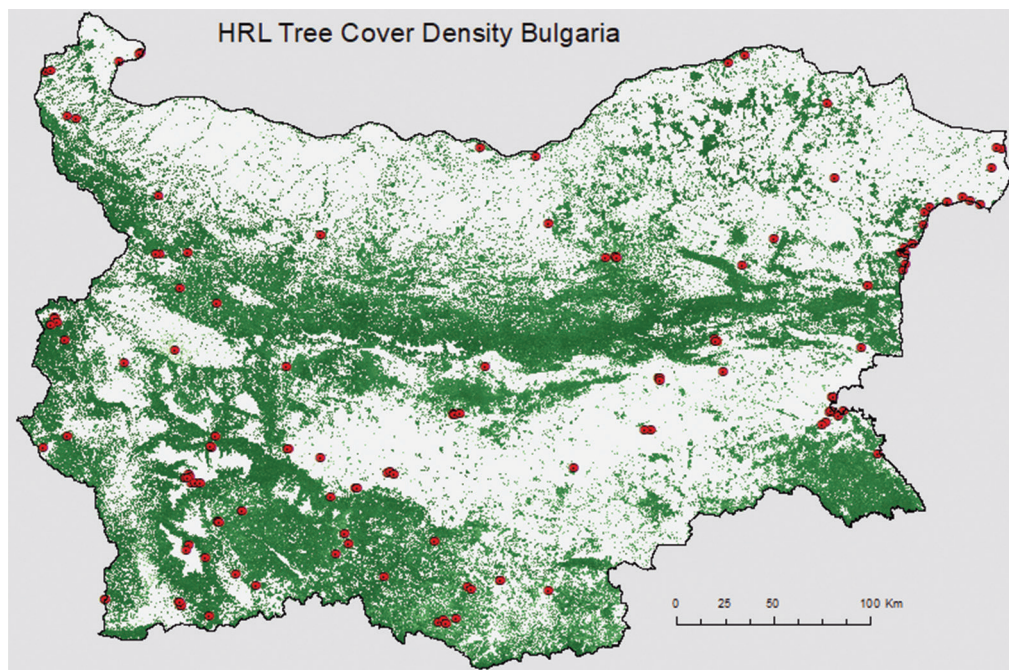


Fig. 3. Overview map of the Tree Cover Density layer of Bulgaria with verification points.

Commission errors occur with grassland patches near forest, grassland with shrubs or grass, sparsely forested areas and clear cuts in CLC classes 243, 324, 211, 231 and in permanent land use classes 040, 101, 050 of LPIS physical blocks. Glades and other open areas in forests and some coastal wetlands – inland marshes, saline and salt marshes were found mapped as tree cover.

Classifier's performance is degraded in cases when urban areas, e.g. roads, house yards and houses, are classified as tree cover. Such is the case with vineyards as well. The mostly widespread commission error is classifying dwarf pine areas as tree cover.

Look-and-feel verification of TCD

The strata, number of samples and assigned grades per stratum and overall

evaluation for the TCD HRL are listed in Table 3.

The most frequent commission errors found in TCD

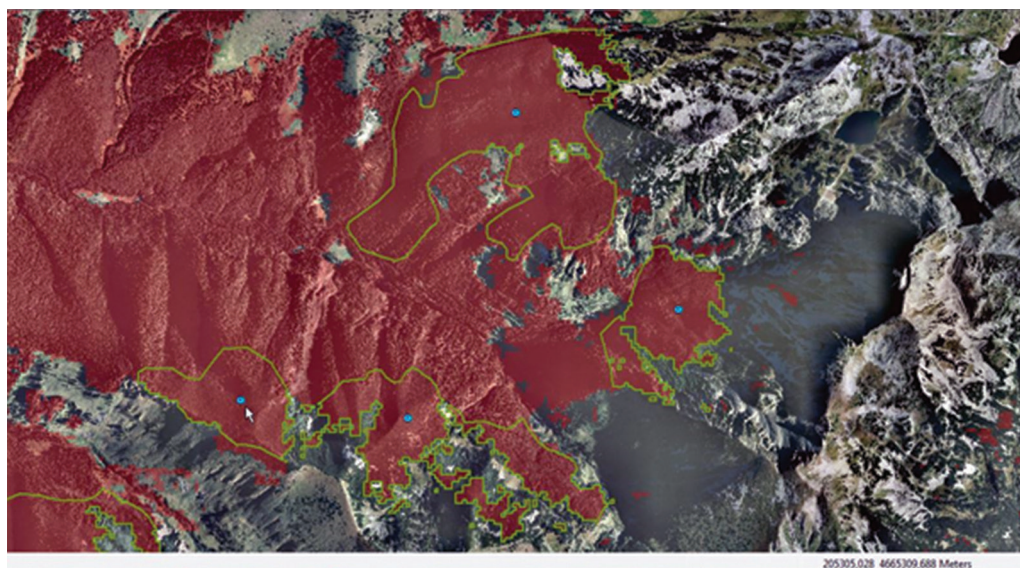
Transitional woodland-shrub – pasture classified as forest, bark beetle damaged forest and clear-cuts in coniferous and broadleaved forests included in the Tree Cover Density layer.

Moors and heathland and sclerophyllous vegetation– the mostly widespread commission error is classifying dwarf pine areas as tree cover (Fig. 4).

Wetland – mainly inland marshes near the Black sea and the Danube River are given as forest. In some cases part of saline and salt marshes are included in the Tree Cover Density layer.

Table 3. Look-and-feel verification of TCD.

Stratum	Name of the stratum	Number of samples verified	Results of the verification by strata
commission			
1	Transitional woodland-shrub	12	good
2	Moors and heathland and sclerophyllous vegetation	11	insufficient
3	Shrubs and grasslands LPIS101	10	acceptable
4	Wetland	11	insufficient
omission			
5	Urban vegetation	10	good
6	Trees in sport and recreation areas	9	good
7	Orchards, fruit trees	12	insufficient
8	Lowland forests, broadleaved	12	good
9	Lowland forests, coniferous	10	good
10	Mountain forests, coniferous	11	good
11	Mountain forests, broadleaved	10	good
12	Coastal forests	10	good
13	Forest along rivers & lakes	10	good
Overall evaluation			good

**Fig. 4. The stratum Moors and heathland and sclerophyllous vegetation.**

Note: This stratum (light green boundary) is totally based on the CLC class 322 for Bulgaria, including only dwarf pine, which is not treated as tree cover. Four examples are marked by blue point symbols – dwarf pine incorrectly classified as forest (semi-transparent red fill).

Omission errors in TCD

Urban vegetation and Trees in sport and recreation areas are generally correctly mapped.

Typical mistakes found are as follows:

- Urban vegetation – groups of park and urban trees;
- Trees in sport and recreation areas – groups of trees in sea, golf and skiing resorts;
- Orchards, fruit trees – missing fruit tree plantations (CLC222);
- Lowland forests, broadleaved – missing broadleaved forest stands (oak, durmast oak, locust trees);
- Lowland forests, coniferous – missing Austrian pine and Scots pine plantations;
- Mountain forests, coniferous – missing Austrian pine, Scots pine and white fir plantations (Fig. 5);
- Mountain forests, broadleaved – missing beech and durmast oak forest

stands;

- Shrubs and grasslands LPIS101 – broadleaved and coniferous forest stands or group of trees are included in shrubs and grasslands;
- Coastal forests – missing both broadleaved and coniferous forests;
- Forest along rivers & lakes – missing groups of trees, broadleaved forest stands and plantations – poplar, oak, locust and aspen.

Despite of errors found, both DLT and TCD HRLs receive a 'good' mark as overall evaluation. The same rating prevails at the stratum level of evaluation.

Conclusions

We have implemented a quality assessment methodology aimed at identifying typical problems that will be useful for

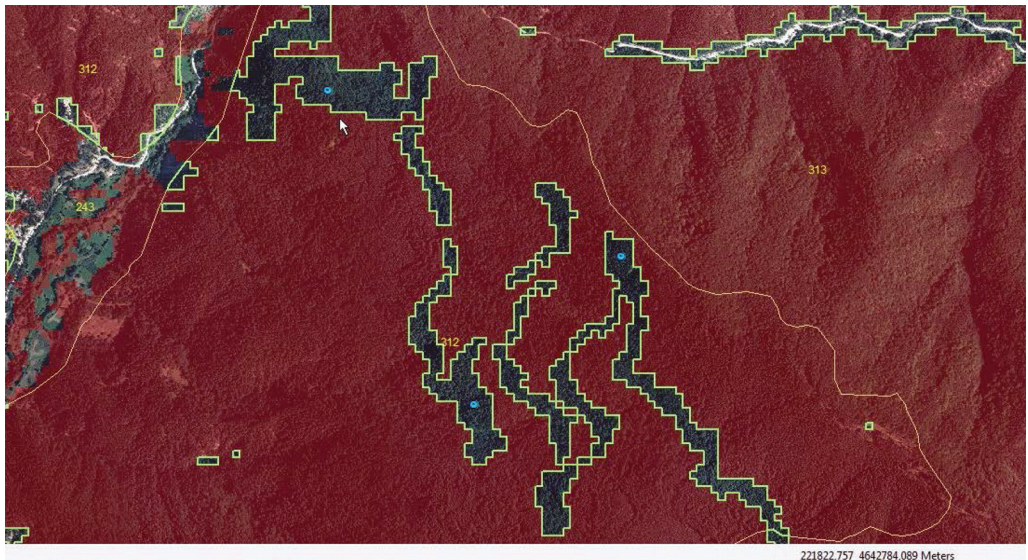


Fig. 5. White fir forest stands are not mapped in the TCD layer (semi-transparent red fill).

Note: These omission errors are identified with the help of the Forest Inventory Database with its detailed attribute table, used as reference in situ data. Three cases are marked by blue point symbols.

product improvement.

Despite the registered and described commission and omission errors, we can conclude that both Tree Cover Density and the Dominant Leaf Type high resolution layers show consistently good results. The list of evaluations by strata in five grades both for the TCD and the DLT are dominated by 'good' evaluations. Overall evaluations are 'good' for both HRLs.

High resolution layers data sets provide a valuable and special view on several important land cover characteristics. Overall results of HRL verification task demonstrate a good general ability of automated analysis of multi-temporal satellite imagery to extract certain land cover types.

It would be useful if, in addition to the status products, change products are provided for verification by countries.

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IMPACT OF THE WATER TEMPERATURE INCREASE IN THE DOSPAT DAM ON THE KEY INDICATORS CHARACTERIZING AQUACULTURE EFFICIENCY

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Abstract

Climate change is among the main challenges for achieving sustainable development of aquaculture. It is likely to cause changes in the temperature and hydrological regimes of inland waters. Air temperatures in the region of Dospat Dam have been rising over the past 15 years. This impacts the water temperature in the dam and on rainbow trout (*Oncorhynchus mykiss*) farming in it. The average water temperatures measured in the surface layer in the 1970s (10.18 ± 6.79 °C), and the 1980s (10.16 ± 7.07 °C) were lower than the ones today (12.40 ± 7.12 °C). Higher summer temperatures of the water in the dam have an unfavourable impact on the key biological indicators which determine the aquaculture efficiency, such as fish growth (AG, g), survival rate of fish (SR, %) and feed conversion ratio (FCR). The water temperatures in July and August are above 18–20 °C. This period is marked by the lowest fish growth and the lowest survival rate of fish. At the same time, feed conversion ratio is 3.3:1 which is higher than recommended in feed charts and it is economically inefficient. Global warming is likely to have a negative impact on the development of cold-water aquaculture in Bulgaria. It will result in a longer production cycle and higher costs.

Key words: climate change, rainbow trout, feed conversion ratio, fish growth, survival rate.

Introduction

The importance of aquaculture for ensuring high-quality nutritional protein has been on the increase over the past decades. It was estimated that by 2030 over 62 % of the fish consumed will come from aquaculture (Kobayashi et al. 2015). The most widely farmed cold-water species in the world over the past 10 years has been rainbow trout (*Oncorhynchus*

mykiss Walbaum, 1792) (Sae-Lim et al. 2015, Zhelyazkov 2015, Singh et al. 2016). The species is of major economic importance in Bulgaria and has good market potential.

The adverse impact of climate change and the increase of water temperature may have a negative effect on fish farming in temperate climate zones, including Bulgaria (De Silva and Soto 2009). According to United Nations Economic Commission

for Europe (2017), in Bulgaria the vulnerability to the expected changes in rainfall is highest in the sectors of tourism, agriculture and aquaculture.

Aquaculture production process is based on the interaction of the species biological requirements with the environmental variables and the economic environment in which it is implemented. The major biological parameters which characterize aquaculture efficiency are fish growth (AG, g), survival rate (SR, %) and feed conversion ratio (FCR) (Noble et al. 2012, Sae-Lim 2013, Besson et al. 2016, Janssen et al. 2017). From an economic point of view, fish growth and survival rates are the major factors affecting revenue, costs of feed and fingerlings for stocking. The feed intake affects mainly feeding costs.

Physiological and biochemical processes of fish are directly related to water temperature (Jobling and Baardvik 1994). Fish growth mainly depends on water temperature, the amount of dissolved oxygen in it and the daily feed intake (Murdian 2016).

Rainbow trout can survive in water temperatures of 0–27 °C, but a narrower range 9–14 °C is required for the normal functioning of its physiological processes. At temperatures of 7–18 °C the appetite is optimal (Wojnarovich et al. 2011). At higher temperatures, cold-water species demand more energy to maintain the metabolism, which reduces their growth rate. The impact of global warming and temperature increase on freshwater fish varies based on the season (Morgan et al. 2001). Although temperature increase in winter may be beneficial for the trout growth, temperatures of 18–23 °C in summer are moderately challenging for the survival of the species but ones of 25–28 °C are considered crucial (Rebl et

al. 2020). When the temperatures exceed 20 °C, the digestive system of rainbow trout does not use the nutrients fully and most of the feed consumed is only partially utilized (Fornshell and Hinshaw 2008). This results in a higher FCR in summer, which is often economically inefficient. Feed intake and digestion may slow down or stop at low water temperatures (Belkovskiy et al. 1991, Hubert and Chamberlain 1996). The lowest temperature at which species growth has been recorded is 3 °C (Fornshell and Hinshaw 2008). According to FAO (2005–2021), the optimal water temperature for intensive rainbow trout aquaculture is below 21 °C.

Rising water temperature in summer may affect water quality in dams, resulting in harmful algal blooms and problems with the level of dissolved oxygen (Fischlin et al. 2007, Bates et al. 2008). There are other production parameters (e.g. rearing density in cages, change of batches) affecting the profitability of the farm also dependent on the temperature regime and growth potential of the fish (Besson et al. 2017). Some diseases (e.g. furunculosis) affecting salmonids are likely to become more prevalent at higher temperatures (Marcos-Lopez et al. 2010, Kibria et al. 2017). One of the frequent problems in cold-water aquaculture in summer is heat stress. The elevation of cortisol as stress-respond in fish may suppress their immune function (Bonga 1997, Mommsen et al. 1999, Webster et al. 2020, Islam et al. 2021), affect growth (Bernier and Peter 2001) and survival rate (Barton and Iwama 1991, Huang et al. 2018). The heat shock response in rainbow trout arises at 21 °C (Shi et al. 2015, ZhiCheng et al. 2019).

Forecasted temperature changes are expected to increase economic uncertainty in aquaculture because ecological problems result in higher production costs

for the farm (Bethke 2015, Cubillo et al. 2021). The impact of climate change on cultured rainbow trout is poorly known in Europe and the risk assessment for this species is still challenging (CERES 2017).

The aim of the present study is to establish if the water temperature in Dospat Dam fluctuates over time and does it impact the major biological indicators in rainbow trout cage aquafarm.

Material and Methods

The study was conducted between 2017 and 2019 in the largest aquafarm in Bulgaria situated in the waters of Dospat Dam. The farm covers an area of 3.5 ha with 150 floating net cages in which rainbow trout is reared. Fingerlings (5–20 g) are stocked in spring and summer. The production cycle is all year round and continues until the fish reach harvest weight. Rainbow trout market size in Bulgaria is 300–400 g. Feeding is carried out twice a day by hand using quality extruded feed with high protein content (>40 %). The daily feed ratio determining is according to recommended feeding levels of the feed producers and depends on the fish weight and the daily water temperature.

Dospat Dam was built in 1969 on the Dospatska river in the Western Rhodope Mountains. It is situated at 1200 m a.s.l. and covers an area of 18.3 km² (41°39'40"N 24°09'05"E). The length of the dam is 19 km and its average width is 3 km. Its flooded area is 22 km². The catchment area covers 432.30 km², the average annual flow is 249.07 million m³, the fill volume is 449.22 million m³ and the usable volume is 447.13 million m³ (National Electricity Company 2021). The

height of the wall from the base is 60 m and the average depth where the cage farm is situated is 35 m. The climate in the region is mountainous with a strong Mediterranean influence. The average year-round air temperature is 9–13 °C. Springs arrive later, summers are cool and wet, and autumns – long and warm. Winter temperatures remain below 0 °C, which results in long-lasting snow cover.

To establish the change of water temperature in the dam, literature data for the temperatures in two periods 1970–1978 (Zhivkov 1987) and 1980–1982 (Boyadzhiev 2007) was used. The third period of study is between 2011 and 2019 when the water temperature was measured at every meter of depth from the surface layer up to 20 m of depth. The majority of the measurements were taken near the cages using combined dissolved oxygen meters (WTW Oxi 1970i and FiveGo/F4).

We used the Julian calendar for operational planning purposes in the aquaculture. We divided the seasons of the year by weeks: spring – weeks 12–24, summer – weeks 25–37, autumn – weeks 38–50 and winter – weeks 51–11 of the year. The weeks are numbered from 1 to 52 for the first year and from 53 to 104 for the second one because the production cycle usually covers two years' period.

The growth performance of two batches of fish was studied in the period 2017–2019. They were divided into groups according to the season of fingerlings stocking the cages – stocked in spring and stocked in summer. Fifteen cages were chosen for the study, in which the growth rate, average individual weight, and survival rate of the same fish were traced from initial stocking until harvest at 300–400 g (Table 1).

Table 1. Data of the cages used in the research.

No cage	Initial body weight, g	Number of fish	Year of stocking
Spring stocking			
I	5.8	80,000	2018
II	5.8	76,480	2018
III	6.2	81,597	2018
IV	5.9	90,832	2018
V	5.5	71,445	2018
VI	5.5	71,237	2018
VII	7.7	31,402	2018
VIII	5.0	115,200	2017
Summer stocking			
I	10.4	52,730	2018
II	10.8	52,300	2018
III	12	55,016	2018
IV	12	36,400	2018
V	10	36,600	2018
VI	10	36,500	2018
VII	13	47,000	2018

We examined the growth performance of the fish stocked in spring separately from the ones stocked in summer. The control measurements of the fish cages stocked in spring were taken in the following weeks: 16, 21, 22, 27, 31, 36, 42, and 47, and of the fish cages stocked in summer: 25, 28, 37, 38, 42 and 47. A Pentair VAKI Fish Pump, which is a fish sorting machine with digital software control, was used to measure the weight and number of the fish in each cage. The custom VAKI software counts and measures, with accuracy over 99%, fish weighting between 0.1 g and 800 g.

Fish absolute growth (AG, g) was calculated using the formula (1) (Busacker et al. 1990):

$$AG = Y_2 - Y_1, \quad (1)$$

where: Y_1 is initial fish weight, g; Y_2 is final fish weight, g.

The extent of the survival rate (SR, %)

within the study period was calculated using the formula (2):

$$SR = \frac{N_F}{N_i} \cdot 100, \quad (2)$$

where: N_F is number of fish at the end of the period; N_i is number of fishes at the beginning of the period.

The feed conversion ratio (FCR) was calculated using the formula (3) (Okumuş et al. 1999):

$$FCR = \frac{FC}{A_2 - A_1}, \quad (3)$$

where: FC is feed consumption, kg; A_1 is total fish weight at beginning of the period, g; A_2 is total fish weight at end of the period, g.

Descriptive analysis was used to determine the mean value and the standard deviation of the water temperature values. We used correlation analysis to determine the impact of water temperature on fish growth. The one-way analysis of variance (ANOVA) was applied to compare the change in fish weight by weeks. Linear regression was used for estimation of the impact of water temperature on the fish growth rate, survival rate and FCR , in which the dependent variables were the parameters determined and the independent variable was the water temperature. The correlation between the fish growth and the quantity of feed was estimated on log-transformed data. The statistical analyses were performed by using the MS Excel and the PAST software (Hammer et al. 2001).

Results and Discussion

Water temperature

The average annual water temperatures measured in the surface layer of the dam

in the first (10.2 °C) and second period (10.2 °C) were lower than the ones in the third period (12.4 °C) (Fig. 1). The coldest month for the three periods is in February (1.9 ± 1.19 °C), while the hottest ones are in July and August (20.5 ± 1.59 °C).

From 1970 to 1982 water temperatures did not exceed 20 °C but in the last 10 years, the temperature in August was higher than 22 °C. Over a period of the last 40–50 years, the average monthly water temperatures have increased by 2 to 3 °C (Fig. 1).

Water temperatures are favourable for rearing farmed rainbow trout from the second half of March until the beginning of July as well as from the beginning of September until the beginning of January. In this period, temperatures were within the tolerance range of the species -4–20 °C. Water temperatures in July and August were above 20 °C, which is associated with a higher risk of adverse effects during rearing. Water temperatures fall below 4 °C from the middle of January until the middle of March and feeding may be discontinued.

Comparing with the results of Boyadzhiev (2007), rearing period of rainbow trout in the Dospat Dam is reduced from 9 to 8 months. At water temperatures of 5–15 °C, rainbow trout reach 250–500 g for 2.5–4.5 months (Woynarovich et al. 2011). However, as water temperatures in Dospat Dam vary quite broadly (2–22.3 °C), several periods fall outside the species' optimum range. In such conditions fingerlings (5 g) need about 12 months to reach a weight of 350 g. A longer production cycle results in higher costs. The present study confirms the predictions of declines in trout habitat of over 50 % given the projected climate warming scenarios (Hartman and Porto 2014, Vinňá et al. 2021).

Impact of water temperature on fish growth

Over the entire rearing period 2017–2019, there has been a weak negative correlation between temperature and growth rate ($r = -0.15$, $p = 0.02$). Fish growth decreases with the increase of temperature

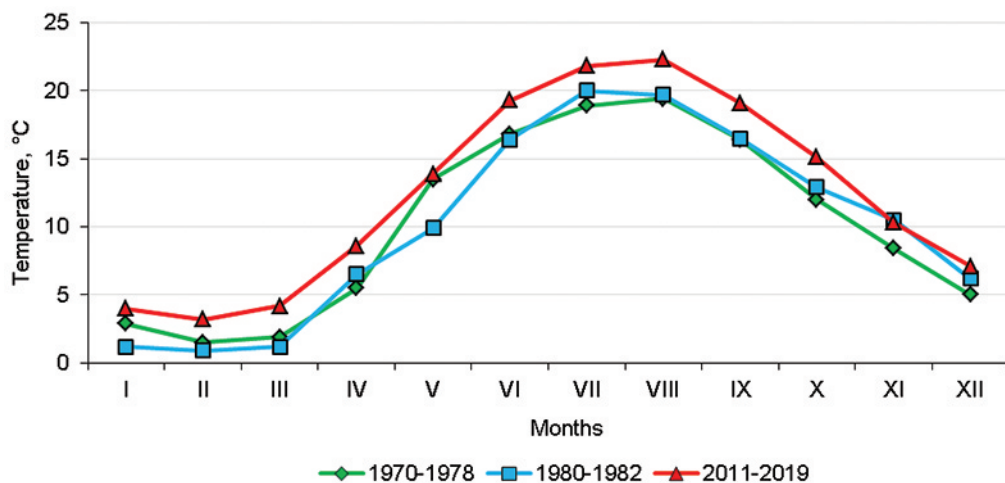


Fig. 1. Dynamics of water temperature in the period 1970–2019.

(Fig. 2). Two peaks of high absolute fish growth are formed at water temperatures of 12.4 °C and 16 °C, but beyond this temperature range, growth rates gradually decrease.

There is a weak negative correlation ($r = -0.06$, $p = 0.58$) between temperature and absolute fish growth in the cages stocked in spring, but it is statistically insignificant. However, if we compare the absolute fish growth mean values of the fish stocked in spring by weeks, there is a reliable difference between them ($F = 8.529$, $p = 0.0091$) (Fig. 3a). A strong negative correlation ($r = -0.69$, $p < 0.0001$) was found between temperature and growth of the fish in the cages stocked in summer (Fig. 3b).

Following the course of the change in water temperature during the seasons, the fish go through the same water temperatures twice a year – once when the water warms up in the spring and a second time when it cools down in the autumn. In spring, the cages were stocked in week 16 when the water temperature was 10 °C, and by week 20 it was already 13.5 °C. Contrary to the expected fish

growth peak at 12.4 °C, such did not occur at the moment of reaching that temperature (Fig. 3a). The likely reason for the different growth rates at identical temperatures in spring and autumn was the weight of the fish at those particular moments. In rainbow trout weighing ≤ 25 g the period of slow growth (hyperplasia) predominates and the period of fast growth (hypertrophy) increases with fish weight (Rowlerson and Veggetti 2001, Dumas et al. 2007).

Low fish growth during the first weeks after the spring stocking of fish can be anticipated, because at that moment rainbow trout weight was 5.93 ± 0.12 g on average, being in a period of slow growth. At the same temperature in the autumn, the average weight is already between 96.5 and 162.3 g and the fish have entered a period of rapid growth and hyperplasia weakens for an account of hypertrophy (Dumas et al. 2007).

During the periods of the highest temperatures (weeks 31–35) there are cages with 'loss of weight' (Fig. 3a). Some authors (Uysal and Albas 2002, Borchel et al. 2014) also establish that the species' weight gain is reduced at temperatures

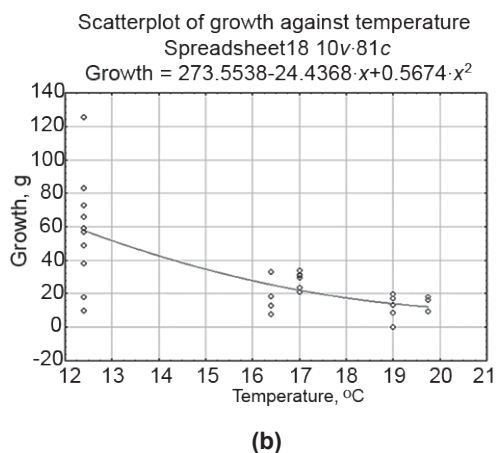
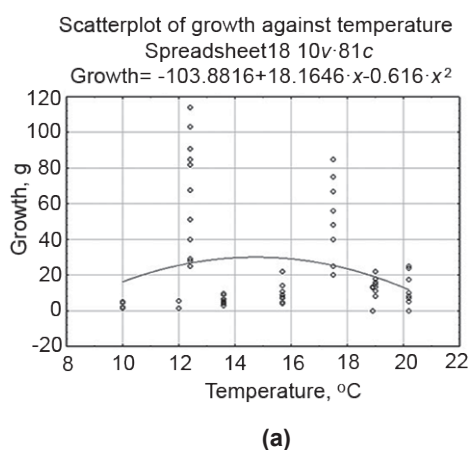
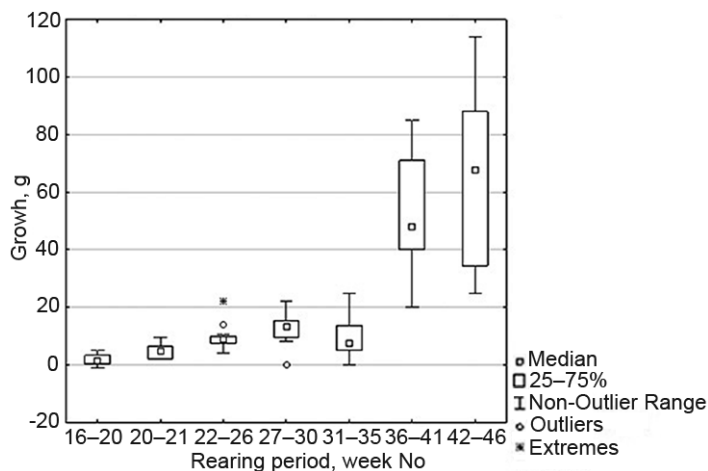
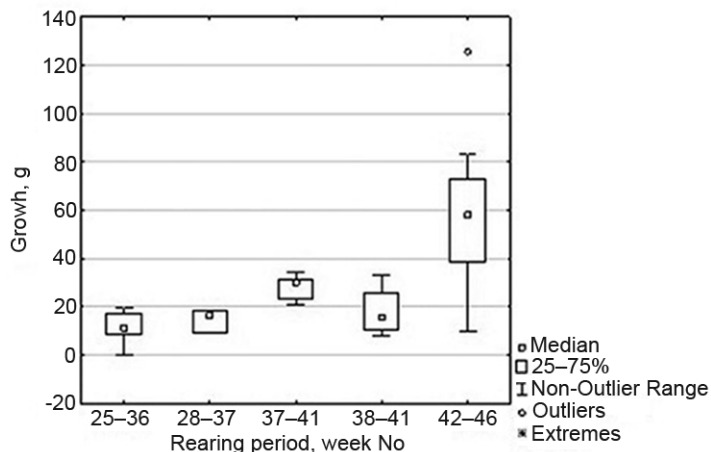


Fig. 2. Distribution of absolute fish growth in spring stocked group (a) and in summer stocked group (b) depending on water temperature.



(a)



(b)

Fig. 3. Growth of spring (a) and summer (b) stocked fish in different weeks of rearing.

above 22 °C. Reduced growth may be explained by the fact that the increase of temperature leads to increased metabolic costs for rainbow trout, as a result of which they have less energy left for growth (Hartman and Porto 2014). The highest absolute growth (65.27 ± 30.61 g) in the fish stocked in spring was measured in autumn between weeks 42 and 46

at an average water temperature of 12.4 °C.

Temperature is the main controlling factor affecting fish growth in the cages stocked in summer. The absolute growth of the fish differs significantly by weeks ($F = 11.89$, $p = 0.0011$). The highest growth rate (57.89 ± 33.07 g) is between weeks 41 and 47 at a temperature of 12.4 °C, and the lowest (10.63 ± 9.0 g) – between weeks 25 and 37 at a temperature of 20 °C (Fig. 3b). In the same period, there were also cages in which no increase but even decrease of fish weight was registered. It seems that the high water temperature in July and August slows down the growth of rainbow trout.

Comparing the growth performance of the fish stocked in spring and summer, it was evidently similar. In spring, the cages were stocked in week 16 when the water temperature was

10 °C, and by week 20 it was already 13.5 °C. Contrary to the expected growth rate peak at 12.4 °C, such did not occur at the moment of reaching that temperature (1.99 ± 2.48 g). The possible reason for the different growth rates at identical temperatures in spring and autumn was the weight of the fish at those particular moments. Low fish growth during the first

weeks after the spring stocking of fish can be anticipated, because at that moment rainbow trout weigh 5.93 ± 0.12 g on average, and hence undergo a period of slow growth.

Both the fingerlings stocked in spring and those in summer display the lowest growth between weeks 26 and 36 when the water temperature is above 20°C . Up to week 31 growth is commensurate with the quantity of feed intake. Afterwards fish growth declines regardless of the feed quantity offered.

Impact of water temperature on survival rate of fish

A significant negative correlation exists between the temperature and the fish survival rate ($r = -0.52$, $p = 0.0053$) (Fig. 4).

The survival rate was highest (94.6%) at water temperatures between 12 and 15°C . At temperature exceeds 18°C , survival rates decreased. The lowest survival rates (37.9 %) were measured at temperatures of 20 – 20.5°C , probably as a result of heat stress. The survival rate of fish in the cages at the temperatures of the winter months was higher than those in summer, so higher temperatures probably affect rearing rainbow trout much more than low temperatures in winter (Fig. 4).

Hence, we may

suggest that the 'loss of weight' of the fish and their lower survival rate observed in summer in Dospat Dam were due to heat stress causing protein denaturation in the cells, which is closely related to cellular responses to hyperthermia.

Impact of water temperature on feed conversion ratio (FCR)

A moderate negative correlation with a high degree of reliability existed between the water temperature and the *FCR* ($r = -0.55$, $p < 0.00001$). The average feed conversion ratio calculated for the farm was 1.9:1 and it fluctuates during the different seasons and rearing periods (Table 2).

The *FCR* in weeks between 31 and 35 was 3.3:1, which exceeded the stand-

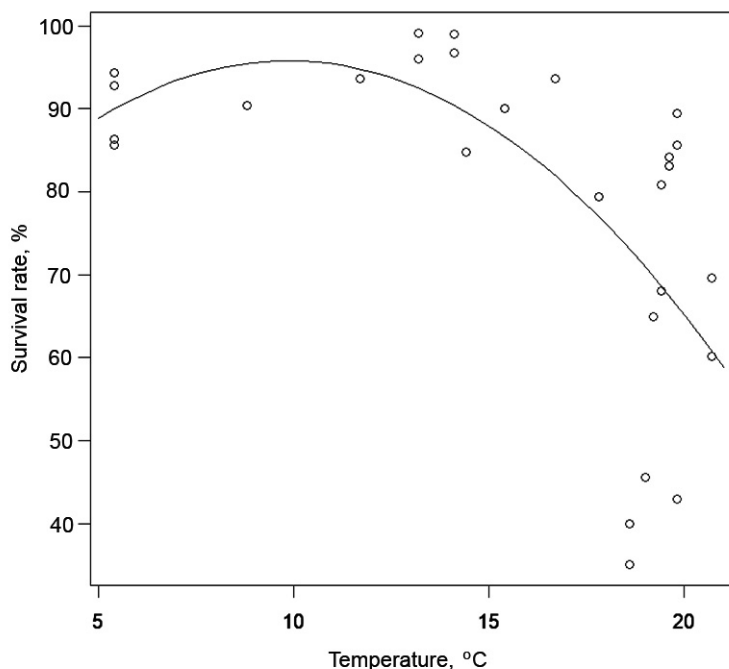


Fig. 4. Distribution of fish survival rate depending on water temperature.

Table 2. Feed conversion ratio (*FCR*) in different periods of fish rearing.

Rearing period, No week	Water temperature, average °C $\pm$ SD	<i>FCR</i> $\pm$ SD
22–26	16.7 $\pm$ 1.93	2.26 $\pm$ 1.06
27–30	20.2 $\pm$ 0.51	1.30 $\pm$ 0.36
31–35	21 $\pm$ 0.36	3.30 $\pm$ 2.35
36–41	17.5 $\pm$ 2.11	1.36 $\pm$ 0.52

Note: the data are collected from spring and summer stocked cages.

and values for the rainbow trout (1.0–2.0). The high feed conversion ratio results in higher costs for obtaining a unit of yield, which reduces production efficiency. In comparison, a net cage fish farm in the Almus Dam in Turkey reports *FCR* of 1.63 in summer and autumn at temperatures of 17.6–19.8 °C during the study period (Kayim et al. 2007). Another similar study calculates *FCR* as 1.57 (Rad and Koksall 2001). The combined data for spring and summer stocked fish batches show that despite the high quantity of feed used in the summer months, the weight gain of fish decreases during this period (Fig. 5).

The study of Hartman and Porto (2014)

also established decreasing feeding efficiency from 1.03 at 20 °C to 1.3 at 22 °C. It may be explained by the fact that at water temperatures above 18–20 °C the proteins that make up the enzymes begin to inactivate, thereby inhibiting the metabolism of fish (Stevenson 1987).

In the conditions of Dospat Dam, a high cost of feed per kilogram of growth is probably due to a lower energetic efficiency of feed, used during the periods of high summer temperatures. Another reason for the high *FCR* during those weeks might be the lower fish survival rate than it is planned in feeding process of the farm.

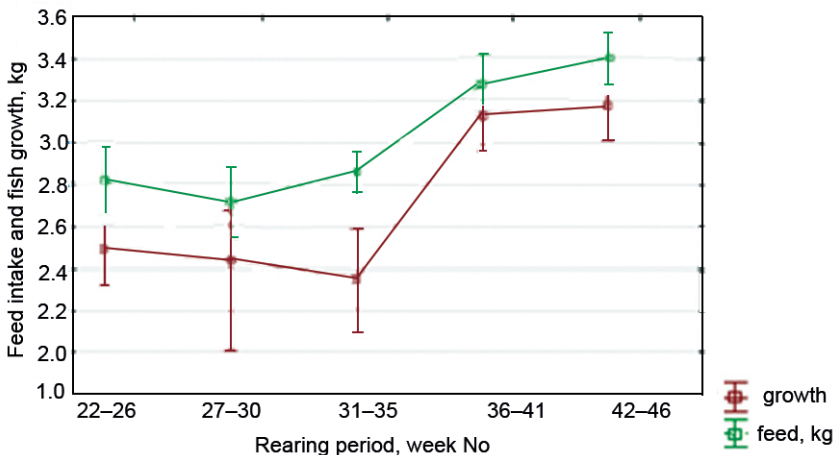


Fig. 5. Combined data of spring and summer batches of feed intake and weight gain of fish by weeks.

Conclusion

Climate change and rising water temperature, particularly during the summer months, in Dospat Dam has an adverse effect on the three main indicators characterizing the production efficiency of rainbow trout aquaculture. The absolute growth and the survival rate of fish are the lowest in July and August, when the water temperatures are above 18 °C. Low feed efficiency in these months leads to higher production costs. In the increasingly warmer climate, the all-year round farming of cold-water species such as rainbow trout in the Dospat Dam is becoming harder and risky.

In the future, the year-round use Dospat Dam for cold-water aquaculture needs could continue if the possibilities of biotechnology and selective breeding programs are used to create more temperature-resistant rainbow trout strains. Another possibility is breeding economically valuable fish species in the dam, adapted to warmer water during the warmer months of the year but more research is needed.

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OPTIMIZATION OF OAK FOREST MANAGEMENT PRACTICES IN SOUTHERN GREECE

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Abstract

The oak forests in Mediterranean are widespread and dynamic natural ecosystems. For millennia, oak forests have provided vital ecosystem services to humans in the Mediterranean including social, economic and environmental services and goods; however, in parallel, human exploitation has altered their structure. Consequently, targeted management approaches are required to optimize the production. In the current study we analyzed the structural characteristics of the Foloï oak forest (*Quercus frainetto*) in the wider area of Ancient Olympia, Peloponnese, Greece. An extensive fieldwork was applied in 29 randomly located plots in order to collect dendrometric characteristics of 938 individual trees. The collected data were used to build models for estimating tree age, tree height and canopy length from diameter at breast height (DBH). All models were found to have an adequate fit and provide useful tool for the assessment of site structural and growth characteristics. Furthermore, we present a model for assessing site quality from topographic characteristics such as slope and exposition. Finally, we employed a stand visualization tool to get a graphical representation of the stand structure, which can be used in order to adopt appropriate silvicultural practices. We believe our findings will provide useful tools to forest managers and practitioners for the sustainable management and restoration of oak forests.

Key words: *Quercus* sp., silviculture, stand structural analysis, stand visualization system (SVS).

Introduction

Deciduous oaks form extensive forest ecosystems across Europe and they are associated with high ecological, cultural and socio-economic importance (Eaton et al. 2016). In Greece oak forests cover

1,471,839 ha representing 22.6 % of the country's forested area (Hellenic Ministry of Agriculture 1992). Hungarian oak (*Quercus frainetto* Ten.), a subendemic south European species (Stupar 2020), is the most common oak species in Greece, forming both pure and mixed stands Q.

petraea (Matt.) Liebl. and *Q. pubescens* Willd. are also common species, with the former forming pure and mixed stands and the latter most commonly found in mixed stands with other thermophilous deciduous oaks (Konstantinidis et al. 2002, Bergmeier and Dimopoulos 2008). Oak forests are characterised by low standing timber volume, largely due to the traditional coppice management, with short rotation cycles, which do not allow the growth of large timber volumes (Chatzifilippidis and Spyroglou 2006). Because deciduous oaks mainly grow at relatively low altitudes, rarely exceeding 700–800 m a.s.l., they are easily accessible, which results in constant interactions with humans. Consequently, intensive human pressure impacts their structure and composition, as well as the soil, potentially degrading the ecosystem as a whole.

Grazing, when it occurs in high intensities, is a common degradation factor in many oak forests, with several negative impacts on their structure, composition and regeneration capacity (Kyriazopoulos et al. 2010, Papachristou and Platis 2011, Milios et al. 2020). Another common degradation factor in those forests is the extensive and often illegal cutting of firewood by the local inhabitants, which leads often to the restriction of well-structured oak forests only to the less approachable areas (Milios et al. 2014). However, the most important degradation factor of oak forests in Greece and elsewhere, including the *Q. frainetto* forests, is the traditional coppice management with rotation cycles rarely exceeding 35 years. This practice, apart from the low productivity, results in poor stem quality, low stem densities and high rates of erosion, due to the relatively low soil coverage (Chatzifilippidis and Spyroglou 2006).

The degradation of oak forests can

be mitigated by elucidating the degradation causes and understanding the ecosystem's functioning and dynamics over time. Appropriate management interventions that facilitate their multifunctional role and achieve sustainable use of forest resources can ensure social acceptance, economic benefits, and efficient environmental protection (Carella 2015). Restoring the structure of oak forests through sustainable management is challenging, but at the same time necessary in order to address the contemporary requirements for biodiversity conservation and environmental protection and at the same time, maximization of economic and employment benefits (Chatzifilippidis and Spyroglou 2004).

A particularly important prerequisite for sustainable management of oak forests is the accurate determination and mapping of site quality and forest structure, which constitute the foundation of proper silvicultural practices (Spyroglou 2004). Site quality is gauged by the amount of wood that a forest can produce. It incorporates the effects of light, humidity, fertility, and general soil properties of forests, as well as the level of photosynthesis (Davis et al. 2001). Thus, site quality can be defined as the ability of a given forest species or forest type to produce wood in a given area (Clutter et al. 1983). In practice, in order to assess site quality, a characteristic must be selected that can be easily and accurately measured, and is relatively independent of stand density and, if possible, relatively independent of the forest species (Spurr 1952). Because site quality is the sum of many interacting factors, the process of finding a simple indicator is extremely complex, and sometimes impossible. Of all the parameters that have been investigated, correlating site quality with tree height represents a long-stand-

ing and reliable approach (Davis et al. 2001). The numerical site quality index, which is defined as total tree height at a fixed age, base age, or reference age, is also employed for assessing site quality. Base and reference age are usually close to the mean age of the forest rotation time. However, in practice the age selected as the reference age is of minor importance for the determination of site quality since it is loosely correlated to tree height, after a certain age threshold (Clutter et al. 1983).

In the current study, we investigated the potential of improving forest management through implementing appropriate analysis and modelling approaches in the Foloi oak forest in southeastern Greece. This was achieved by conducting a detailed evaluation of forest structure, site quality, and dendrometric parameters. The key objectives were to: a) develop a tree age prediction model, b) define and map site quality, and c) statistically evaluate forest structure using simulations in the Stand Visualization System (SVS) program. These analytical tools are expected to provide the opportunity for the forest managers to make rational decisions regarding the sustainable management of this oak forest region.

Materials and Methods

Study area

The Foloi oak forest is situated in Ancient Olympia on the western part of the Peloponnese peninsula in southwestern Greece. This forest region has high ecological, environmental, historical, and mythological value. The ecological and environmental quality of the forest is reinforced by it being an important region for birds of Greece, based on Habitats

Directive (92/43/EEC) of the Council of the European Union, for the conservation of natural habitats of wildlife and native flora. This region is also a Natura 2000 Site of Community Importance (SCI; GR2330002) named 'Oropedio Foloi' (European Commission 2020). The mythological value of the oak forest is widespread, with its namesake being that of the good and hospitable centaur 'Folos', son of 'Silinos' and the nymph 'Melia', and friend of 'Hercules'. Centaurs formed a major component of ancient Greek Mythology, with the body of a horse and chest, arms, neck, and head of a man. The Foloi oak forest covers 18,625 ha at an average altitude of 688 m. The area encompasses dense stands of deciduous oak trees (21.9 % of the area), in addition to conifers 6.2 %, evergreen broadleaves (27.6 %), cultivated areas (27.8 %), and open and rocky areas (16.5 %) (Fig. 1). The climate of the study area is Thermo-Mediterranean with mild winters and dry summers and a period of physiological draught lasting for four months between June and September. The forest is managed since 1969 by the local forest office with selective logging and a revisiting time of 10 years. However, since 2000 no logging activities occurred in the oak forests of the area in an attempt to recover the standing volume, which had been reduced due to the coppicing-based management and the relatively short rotation time.

Data collection

Twenty-nine sampling sites of 0.1 ha each (50×20 m), were randomly located using the Sampling Design Tool extension in the ArcGIS 10.7 platform and precisely placed in the field (Fig. 2). The plots were fenced for protection from grazing and other disturbances and all trees with a di-

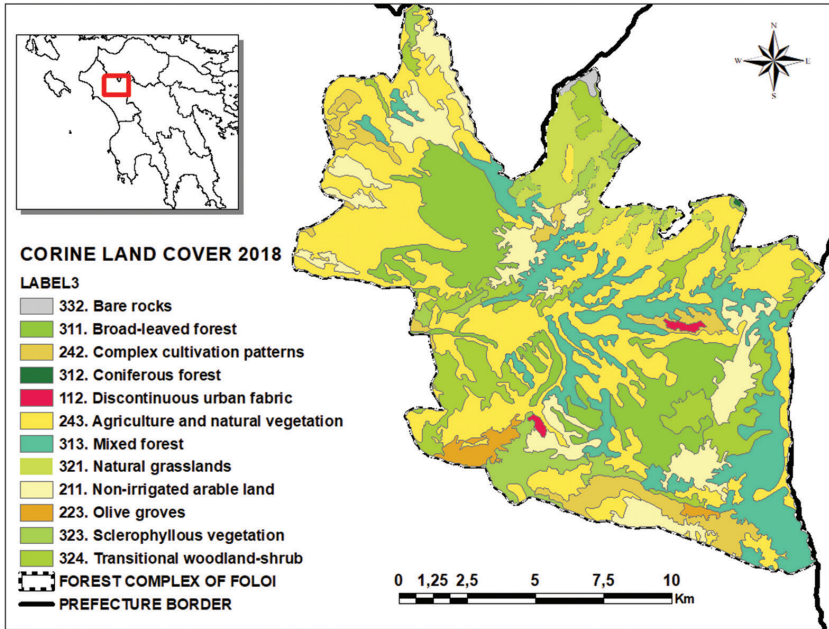


Fig. 1. Study area and land cover of the Foloi Forest Complex, Ancient Olympia, Peloponnese, Greece.

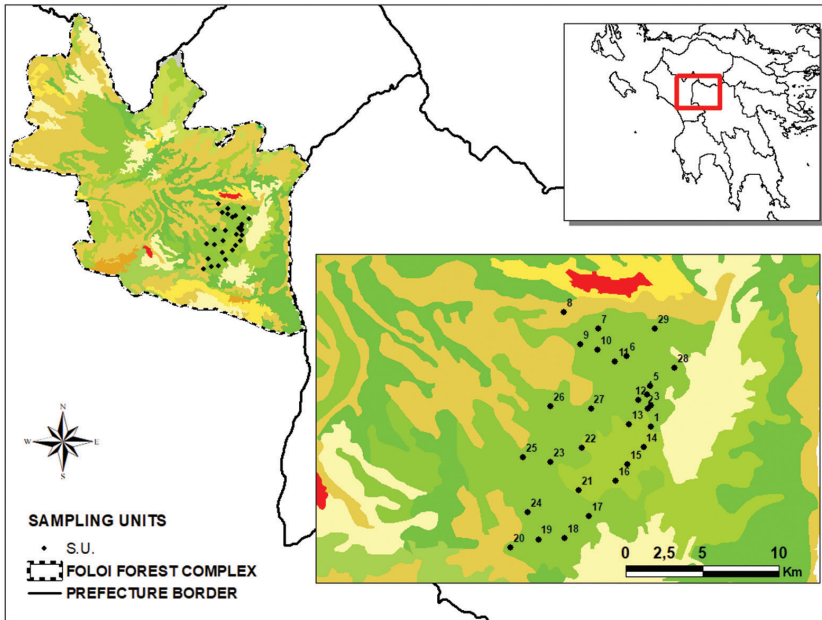


Fig. 2. Distribution of the sampling sites in Foloi Forest Complex, Ancient Olympia, Peloponnese, Greece.

iameter greater than 4 cm were numbered. For these trees, the Diameter at Breast Height (DBH), height, and Canopy Base Height (CBH) were measured, along with the width of the canopy. The CBH was determined as the height until the first live branch. The vertical position of the crown, the vitality, and the dynamic of each tree was evaluated on the field based on the vertical position and the competition parameters of the stand.

Calipers and diameter measurement tapes were used to estimate the diameter

at breast height (DBH) of trees. A Pressler Increment Borer was used to determine age and increment rate. A Vertex Laser Geo hypsometer, an MDL LaserAce 300 distance meter, and a compass were used to determine tree height and the polar coordinates. GPS receivers were used to determine the geographic coordinates. Esri ArcGIS software (GIS) and R-based statistical data processing packages (libraries) were used for the analyses. The statistical correlation of dendrometric and incremental data are shown in Table 1.

Table 1. Overall statistical correlation of dendrometric and incremental cores.

Indicator	N	DBH	H	BA	CBH	CL	V
N	938	-0.841	-0.577	0.027	0.352	0.123	-0.317
DBH		1	0.767	0.252	0.352	0.047	0.604
H			1	0.453	0.788	-0.033	0.875
BA				1	0.600	0.794	0.675
CBH					1	-0.010	0.792
CL						1	0.242
V							1

Note: N – Total number of trees measured, DBH – diameter at breast height, H – height, BA – basal area, CBH – Canopy Base Height, CL – average length of canopy, and V – wood stock.

To formulate the age prediction model, 50 points were randomly selected on a georeferenced map, in order to cover all present diameter classes, and they were located on the ground using a GPS. Using these points, and with a random number of azimuths (0 to 360 degrees), the nearest tree with a diameter greater than 10 cm was selected. A corresponding core was obtained with the Pressler incremental borer to determine age. Furthermore, for the determination of age, 12 tall trees were logged, and their age was recorded at the breast height. Using the DBH as explanatory variable and the age as a dependent variable, multiple models (e.g. linear regression, Poisson, binomial negative, gam) were tested to find the one with

the best fit. The lowest Akaike Information Criterion (AIC) value and the R^2 adjusted were used as criteria for fit. The packages vcd, ggplot2, car and calibrate were used in the programming language R (R Core Team 2016).

Site quality of each plot was initially determined using three different methods. The first one is based on an empirical approach (site succession), which assumes that site quality is affected by the position of a site on the slope, the aspect of the site and the average slope. According to this approach, sites at the bottom of the slope have the highest quality, those in the middle of the slope are of intermediate quality and sites at the top of the slope, on south and west aspects, and on sharp

slopes have the worst site quality. The second method used to determine site quality was based on the model described by (Apatsidis 1995) for oaks, which calculates a site quality index (SQI) based on the highest stand (plot) height according to the equation (1).

$$SQ/90 = \frac{H_o}{1.2380145} \left[\exp\left(-\frac{19.2158}{A}\right) \right], \quad (1)$$

where: $SQ/90$ is the site quality index at a predetermined age of 90 years; H_o is the highest plot height in m; and A is plot age at DBH in years.

The third method which was used for the determination of site quality is similar to the previous one with the only difference being that in equation (1) the highest plot height is replaced with the average plot height. Once the site quality was determined using the three methods described above, multiple regression models were built in order to model the relationship between topographic characteristics (i.e. altitude, slope, aspect) and site quality. The Site quality, as determined by the three methods above, was used as dependent variable in the models and the topographic characteristics as the independent variables. The final products of this modelling approach are maps showing the distribution of site quality classes across the area.

An important parameter of sustainable forests management is the ability of the forest manager to estimate important dendrometric characteristics, such as height and crown length, using simple measurements such as the DBH. For this reason, various models were tested to develop allometric equations between height and DBH (height-diameter model) and Crown Length and DBH (crown – diameter model). For the height-diameter model, five basic non-linear models were tested (Table 2), which were adjusted for the total

sample size. The general format of the models is shown in equation (2). A fixed term of 1.3 was used to avoid predicting individuals with a height less than the breast height when diameter approaches zero. For the crown-diameter model, linear and power models (Table 3) were tested. The goodness of fit of all tested models was evaluated based on the Coefficient of Determination (R^2), the Akaike Information Criterion (AIC) and the Root Mean Squared Error (RMSE) (Huanget al. 1992, Sharma 2009):

$$h_i = f(D_i, b) + \varepsilon_i, \quad (2)$$

where: h_i is tree height (m) of i^{th} observation, D_i is DBH (cm) of the i^{th} observation, b is the vector of the parameters, ε_i is the unexplained part – remaining – which are random and follow the normal distribution.

The forest structure was further simulated using the Stand Visualization System (SVS) program (McGaughey 1997). SVS is a program that allows the automatic design of geometric (vector) representations of forest stand structure (usually a sample plot) primarily using detailed dendrometric data at individual tree level. Descriptive parameters in the model included field measurements that corresponded to the surfaces of 50×20 m (0.1 ha) dimensions. The existing structure of each stand was evaluated using the distribution of diameter classes, degree of soil cover, distribution of height classes, trunk/crown ratio, and the species composition of stands, including subcanopy species.

Results and Discussion

Based on these 62 measurements of age trees (50 trees from increment core and 12 trees from sample disks), average diameter was 32.24 cm (range: 13–57.4 cm;

Fig. 3). Mean measured age was 103.34 years (range: 26–170 years).

Among the models tested to determine tree age based on DBH the linear regression model was found to have a good fit to the data ($F_{1,60} = 146.5$, $p < 0.001$, R^2 adjust-

ed = 0.7045; Fig. 4), which resulted to the model shown in equation 3 and the result was also used as input data in equation (1). The rest of the tested models (Poisson, binomial negative, gam) resulted in an R^2 adjusted not exceeding 0.62).

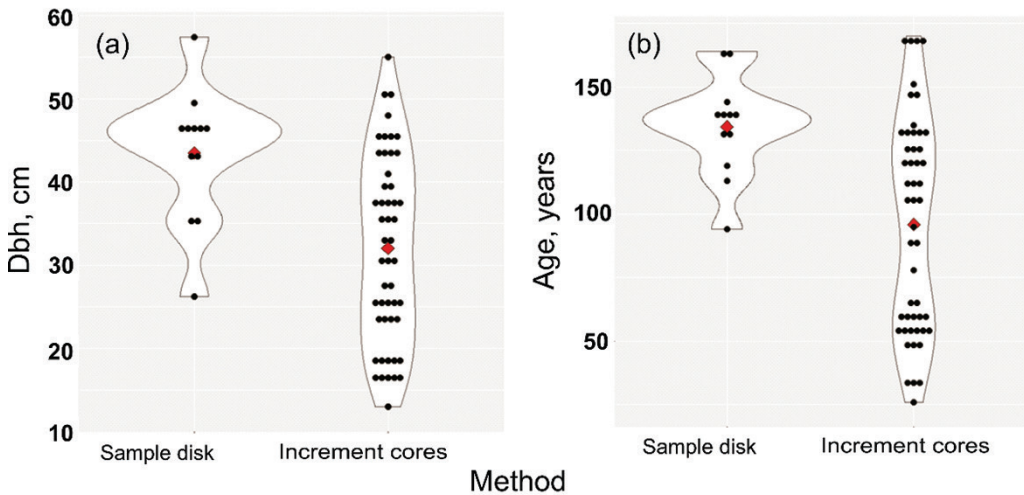


Fig. 3. Violin plots showing the distribution of DBH (a) and age (b) according to sample disk and increment core.

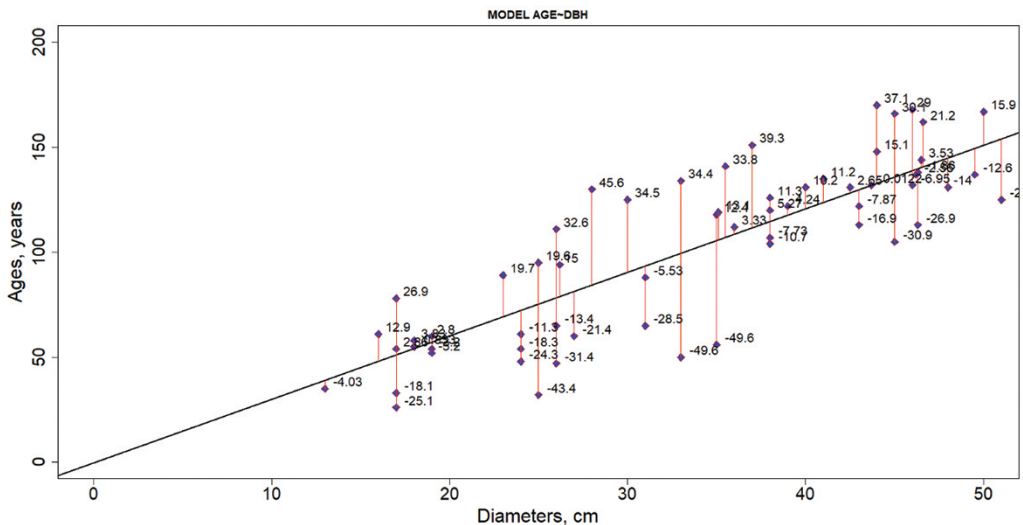


Fig. 4. Relationship between age and DBH based on the General Linear Model, showing predicted values and residuals.

$$A = -0.3373 + D \cdot 3.0280, \quad (3)$$

where: A is age, in years; D is diameter of DBH, in cm.

Regarding the determination of site quality, substantial differences were observed across the three models, which were built based on the three methods for estimating Site quality. The three multiple regression models associating site quality with topographic characteristics are shown in equations (4), (5) and (6) for the estimation of Site Quality (SQ) based on the empirical approach, the equation by Apatsidis (1995) using the highest plot height and the average plot height, respectively.

$$SQ = 3.838 - 0.002 \cdot A + 0.005 \cdot S - 0.903 \cdot N - 0.344 \cdot E, \quad (4)$$

$$SQ = 8.282 - 0.009 \cdot A + 0.006 \cdot S - 0.140 \cdot N - 0.225 \cdot E, \quad (5)$$

$$SQ = 8.129 - 0.014 \cdot A + 0.050 \cdot S - 0.197 \cdot N - 0.291 \cdot E, \quad (6)$$

where: A is altitude, in m; S is slope, in °; N is northness, in °; E is eastness, in °.

The three equations above were employed to map the site quality across the entire area. Based on the researcher's experience of forest conditions and topographical oak forest characteristics, the multiple linear regression model, built using the empirical approach for estimating site quality reflected the actual conditions more accurately than the other two models, while it also had the best fit ($R^2 = 0.7995$; F -statistic = 23.93; p -value < 0.001) when used as explanatory variable in the tested models. Using the developed model, 1265.514 ha (31.03 %) were classified as site quality I; 1687.624 ha (41.38 %) as site quality II; and 1125.219 ha (27.59 %) as site quality III (Fig. 5).

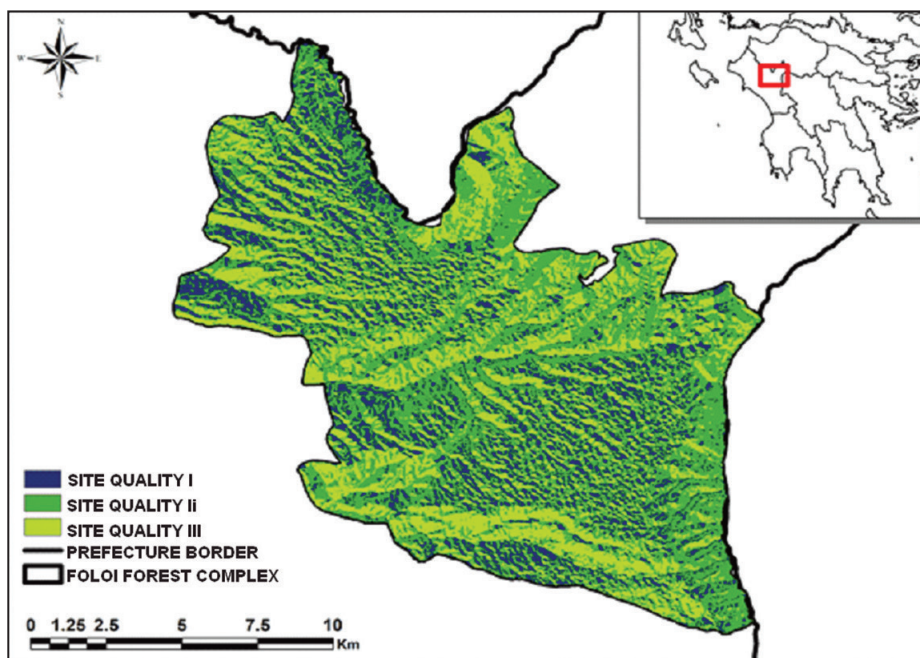


Fig. 5. Spatial distribution of site quality based on the empirical model 'site succession' in Foloi Forest Complex, Ancient Olympia, Peloponnese, Greece.

The distribution of observations regarding Height and DBH exhibited a concave curve, as a result of intense intraspecific competition in the cluster (Fig. 6a). All tested variants for the development of

height-diameter model were found to have an R^2 reaching and exceeding 0.7; however, the Richards model was found to have the best fit to the data with the highest R^2 and the lowest AIC and RMSE (Table 2).

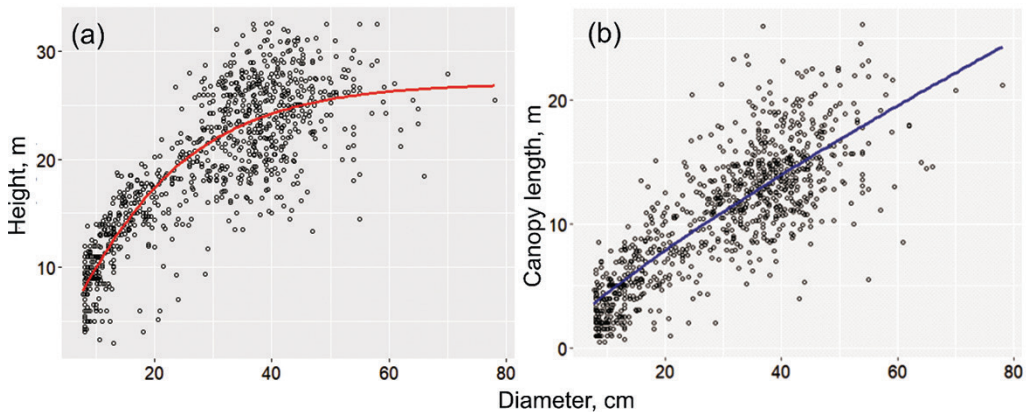


Fig. 6. Graphical representation of the adaptation of (a) the model of Richard's (1959) on height–DBH data for the entire oak sample (including sites of all qualities) and (b) the Power model on crown–DBH data for the entire oak sample (including sites of all qualities).

Table 2. Mathematical expression of the height to DBH models tested, estimated parameters, and good fit criteria.

Model	Reference	<i>a</i>	<i>b</i>	<i>c</i>	R^2	RMSE	AIC
$h = 1.3 + \frac{D^2}{(aD + b)^2}$	Näslund (1936)	0.16	1.66	-	0.73	3.547	5043
$h = 1.3 + a \cdot \exp(-bD)^{-1}$	Schumacher (1939)	31.54	13.08	-	0.73	3.542	5041
$H = 1.3 + aD^b$	Power	2.638	0.58	-	0.70	3.755	5150
$h = 1.3 + a[1 - \exp(-bD)]^c$	Richards (1959)	25.77	0.06	1.45	0.74	3.524	5033
$h = 1.3 + a \cdot \exp\left(\frac{-b}{D+c}\right)$	Ratkowsky (1983)	32.91	15.23	1.428	0.74	3.538	5040

Note: values of all parameters were statistically different from zero ($p < 0.05$).

Canopy length is an important parameter of stand structure reflecting the growing conditions, the photosynthetic ability and the competition between individuals, while it determines to a great extent the necessary silvicultural measures that need to be adopted for improving stand structure

and productivity. As a result, models determining crown length from simple measurements, such as DBH, are of particular importance allowing the estimation of the growing space of individuals and stands (Nutto et al. 2006). Of the two tested models, the power one was found to have

the best fit to the data with the highest R^2 and the lowest AIC and RMSE (Table 3, Fig. 6b). Although R^2 does not exceed 0.7, given the large number of factors involved

in determining the crown length of individuals, it is considered adequate and can be incorporated into forest management practices and decision making.

Table 3. Mathematical expression of the crown to DBH models tested, estimated parameters, and good fit criteria.

Model	Reference	<i>a</i>	<i>b</i>	<i>c</i>	R^2	RMSE	AIC
$cl = aD^b$	Power	0.65	0.82	-	0.68	3.06	477
$cl = a + bD$	Linear	1.13	0.32	-	0.67	3.11	479

Analysis of site structure based on the SVS simulation showed that Foli oak forest primarily had a homogeneous form with a single-layered structure. However, the current form of the majority of the oak forest in the area does not allow the provision of the full range of ecosystem services that could otherwise provide, including biodiversity related services,

social services and of course, economic services. Ideally, stands should contain a mix of ages and a multilayer structure similar to the one observed on plot 17 (Fig. 7). However, this was the exception, rather than the norm in our data and most plots had a vertical structure similar to the one observed on plot 26 (Fig. 8).

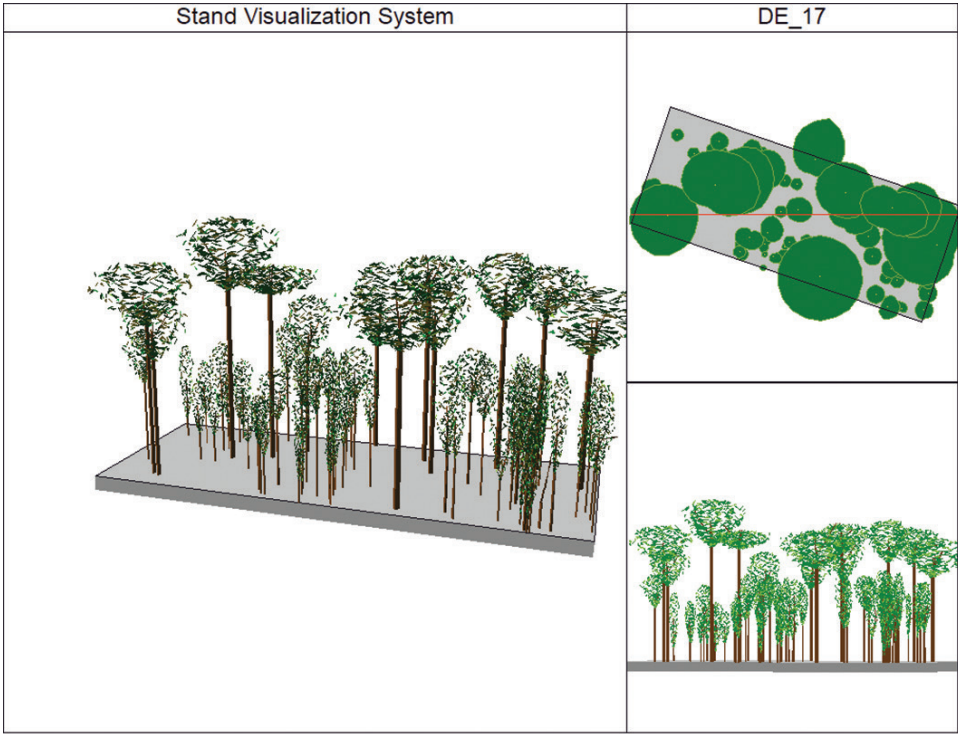


Fig. 7. Three-dimensional display of the profile (left), horizontal structure (top right), and vertical structure (bottom right) of the Sampling Site 17.

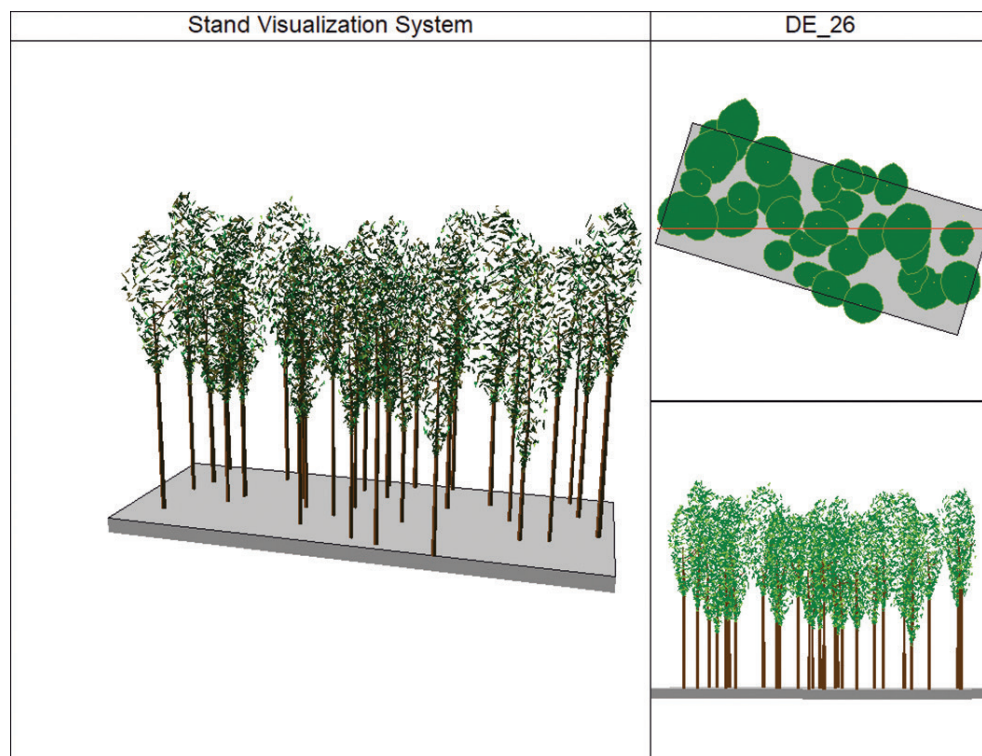


Fig. 8. Three-dimensional display of the profile (left), horizontal structure (top right), and vertical structure (bottom right) of the Sampling Site 26.

Foloi oak forest may constitute a model region for achieving a balance between forest management and conservation measures. The conditions required to enhance growth can be used as a tool to optimize appropriate forestry practices, towards enhancing the protection of the natural environment, which includes a large number of functions and services, like primary production and income generation (Chatzifilippidis 1997). Combining models with remote sensing approaches is expected to further enhance forest management at an applied level (Gering and May 1995). Such growth models simulate the evolution of stands under different management regimes, facilitating improvements in forest management design

(Chatzistathis et al. 1996), with obvious implications in the corresponding silvicultural practices.

Conclusions

Many oak forests in the Mediterranean region are degraded with their sites having lost a significant part of their productivity as a result of overexploitation and mismanagement for several decades if not centuries. Forest management must be implemented with the principles of sustainable forestry to support the economy, provide suitable habitat for many species, increased ecosystem services, and contribute to the creation of sustainable and

resilient natural ecosystems with sufficient adaptability to the projected climate change. Appropriate silvicultural and management measures for the restoration of structure and productivity of those ecosystems should be based on reliable measurements of the dendrometric and structural characteristics of the stands. The current study provides useful tools in this direction. We have presented mathematical models with relatively high accuracy for determining stand age, height and crown length from simple measurements such as DBH. Furthermore, we presented a model for the estimation of site quality based on topographic characteristics, which can be easily estimated using freely available data such as Digital Elevation Models (DTM). Although, one has to be careful when extrapolating models build for a particular site, we believe that the adopted approach is not site-specific and with relevant adjustments can be extrapolated to other areas of similar climatic, topographical and vegetation characteristics. Finally, the stand simulation using SVS is an extremely useful tool for the visual representation of stand structure, which can direct forest managers towards the appropriate silvicultural practices to ensure long-term sustainability of oak forest in the Southern Mediterranean. In our view the forest structure should shift to include trees of mixed ages to correspond better to the typical model of natural forests.

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EVALUATION OF DORMANCY-BREAKING TREATMENTS ON SEED GERMINATION OF TWO LEGUMINOUS TREE SPECIES FROM CHOBE DISTRICT, NORTHERN BOTSWANA

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Abstract

Seed germination experiments were conducted at Botswana University of Agriculture and Natural Resources to determine the best possible pre-sowing treatment methods that maximize seed germination of *Albizia versicolor* and *Faidherbia albida*. The experiments were laid out in a completely randomized design (CRD) with 10 pre-sowing treatments, namely the control, mechanical scarification, soaking in concentrated sulphuric acid with four levels of time exposure (15, 30, 45 and 60 min), immersion in boiling water with three levels of time exposure (1, 3 and 5 min) and soaking in hot water (allowed to cool for 24 h). Treated seeds were germinated for 30 days at room temperature (25 °C). The raw data were subjected to analysis of variance (ANOVA). The results showed that seeds treated mechanically, sulphuric acid (all levels), boiling water (1 and 3 min) and hot water had significantly ($p < 0.01$) higher mean germination percentages than the control and boiling water (5 min) for *A. versicolor*, whereas for *F. albida* seeds treated mechanically and exposed to sulphuric acid (all levels) had significantly ($p < 0.01$) higher mean germination percentages than the rest. Significant ($p < 0.01$) mean germination time and index were revealed among the treatments for the two species.

Key words: *Albizia versicolor*, *Faidherbia albida*, germination index, germination mean time, germination percentage.

Introduction

Natural forests and woodlands play a vital role in the existence and survival of most

of the living organisms in Botswana and other parts of the world (Nduwayezu et al. 2015). They perform multiple functions, such as biodiversity and ecosystem con-

servation, and beautifying landscapes. In addition, they provide numerous goods to mankind and protect the environment (Watson and Dlamini 2003). Despite their importance, indigenous trees and shrubs have not been promoted in afforestation programmes in Botswana because information on their management is limited.

However, in recent years, there has been some effort to use indigenous trees and shrubs in planting programmes in Botswana. The Department of Forestry and Range Resources has been gradually introducing indigenous trees and shrubs in planting programmes as a way of maintaining or restoring the genetic and ecological integrity of local ecosystems. The planting of indigenous tree and shrub species in Botswana is also hindered by lack of information on their seed germination and growth requirements. For this reason, there has been a renewed interest in evaluating seed factors of indigenous trees and shrubs with a view to increase their propagation in the nursery. Seeds of trees and shrubs of arid lands often exhibit poor germination in the nursery and fields, partly because they are constrained by physical dormancy or hard seed coats that are impermeable to water and gaseous exchange (Baskin et al. 2000; Baskin and Baskin 2004, 2014; Linkies et al. 2009; Smýkal et al. 2014).

Albizia versicolor Welw. ex Oliv. (syn. *Albizia mossambicensis* Sim) belongs to the Fabaceae family (Venter and Venter 2016). It is native to Africa, distributed from the Democratic Republic of Congo to Kenya and south to South Africa and Angola (Palgrave 2002), and found in various types of open deciduous woodlands and grasslands up to 1700 m a.s.l. (Lemmens 2007). It is a multipurpose tree that provides numerous goods and services to local communities (Storrs 1995, Rukun-

ga and Waterman 2001, Lemmens 2007, Venter and Venter 2016). The wood is locally used for small boats, tool handles, mortars and other kitchen implements, containers, casks, and musical instruments. It is suitable for light construction, light flooring, joinery, furniture, cabinet work, decorative work, veneer, plywood, draining boards, hardboard, and particle board. It is also used as firewood and for charcoal production. The bark has been used for tanning and the flowers serve as a source of nectar for honeybees. The inner bark is used for making rope. Roots boiled with water can be used as a substitute for soap. The species is planted as ornamental shade tree. Root and bark decoctions are used as an anthelmintic and purgative, and to treat swollen glands and venereal diseases. Dried and powdered roots are taken or sniffed to treat headache and sinusitis, and root maceration is taken against gonorrhoea. A bark decoction is used to treat anaemia, and it is applied externally to treat ophthalmia and skin rash. Bark maceration is taken against cough, and bark powder is sniffed for the same purpose (Lemmens 2007). The roots develop nodules containing nitrogen-fixing bacteria and therefore, *A. versicolor* has a good potential for planting in agroforestry systems.

Faidherbia albida (Delile) A. Chev. (Syn. *Acacia albida*) is a multipurpose leguminous woody tree that belongs to the family Fabaceae (Palgrave 2002, Koech et al. 2014, Venter and Venter 2016). It is widely distributed throughout Africa, from Senegal to Ethiopia and south through Kenya and Malawi into South Africa (Danthu et al. 2002, Orwa et al. 2009, Chuyong and Acidri 2015) and in the Middle East in Israel, Lebanon, Oman, Palestine, Saudi Arabia, Syria, and Yemen (Bofa 1999, Barnes and Fagg 2003, Sileshi

et al. 2020). *F. albida* is well-adapted to a wide variety of soils (Ameri and Daldoum 2017) at low-medium altitudes (270–2700 m a.s.l.) (Barnes and Fagg 2003) in areas with mean annual rainfall of 250–1200 mm and temperatures of 18–30 °C (Orwa et al. 2009).

Faidherbia albida has many uses, including in agroforestry systems, apiculture, charcoal, fodder, fuelwood and gums production, as well as for making ropes, as soap substitute and source of medicine (Teketay 1996a). The trees shed leaves during the start of the rainy season and re-grow them in the dry season, a phenomenon termed reverse phenology (Roupsard et al. 1999, Barnes and Fagg 2003, Sileshi et al. 2020), which allows farmers to grow crops under the trees during the rainy season without competition for water, light or nutrients (Roupsard et al. 1999, Ibrahim and Tibin 2003, Gassama-Dia et al. 2003, Haskett et al. 2019). Unlike other trees, *F. albida* remains leafless during the wet season and, thus, it hardly competes with crops for light and water, while it provides a microclimate favourable for growing crops (Boffa 1999, Barnes and Fagg 2003, Sileshi et al. 2020). The presence of trees in crop fields has been shown to increase yields, a phenomenon termed the ‘albida effect’ (Boffa 1999, Sileshi et al. 2020). This refers to better growth of crops or herbaceous plants under its canopy than in an open field (Akpalu et al. 2020). This phenomenon has been attributed to a combination of factors including improved soil physical and chemical properties (Akpo et al. 2005) reduced soil and air temperatures, symbiosis with rhizobium and arbuscular endomycorrhizae, termite activity and improved nutrient recycling (Haskett et al. 2019, Sileshi et al. 2020).

The green leaves of *Faidherbia albida*

are also rich in protein and carbohydrates, providing a valuable fodder for livestock during the dry season. Pods fall towards the end of the dry season over a period of months, and these are consumed by livestock when other fodder is scarce. Crop yield improvement is the most important benefit of *Faidherbia*-based agroforestry systems, and additional benefits include fodder and fuelwood (Sileshi et al. 2020).

Seed dormancy is a mechanism that prevents seeds from germinating when exposed to suitable moisture, oxygen and soil conditions (Olmez et al. 2008, Rezvani et al. 2021). Seed dormancy is a bottleneck to propagating seeds of woody plants in arid and semi-arid areas. Seeds of woody plants of arid and semi-arid areas are characterised by physical dormancy or thick, tough seed coats impermeable to water and gaseous exchange (Baskin et al. 2000; Baskin and Baskin 2004, 2014; Linkies et al. 2009; Smýkal et al. 2014), which causes delayed and poor germination in the natural environment. Seed dormancy is cause of delayed and sporadic germination in many plants (Slator et al. 2013) and allows plant species to synchronize their germination with availability of favourable environmental conditions, which increases their chances of survival and establishment (Baskin and Baskin 2014, Renzi et al. 2020).

In nature, hard seed coats are scarified by fires (Mbalo and Witkowski 1997, Walters et al. 2004, Briggs and Morris 2008), fluctuating temperatures (Probers 1992), digestive acids in animal stomachs or abrasion by blowing sand (Russi et al. 1992), soil acids and soil organisms (Bewley and Black 1994). There are several methods used to help overcome seed dormancy. Different scarification methods that include mechanical, acid, as well as cold, hot and boiling water, have been

used successfully to break seed dormancy and enhance germination (Teketay 1996a, 1996b, 1998, 2005; Morris et al. 2000; Alamgir and Hossain 2005; Cetinbas and Koyuncu 2006; Fang et al. 2006; Cirak et al. 2007; Al Absi 2010; Azad et al. 2011; Rasebeka et al. 2014; Fredrick et al. 2017; Mojeremane et al. 2017, 2018, 2020; Maldonado-Arciniegas et al. 2018; Opoku et al. 2018; Botumile et al. 2020).

Scarification methods break seed dormancy within a relatively short period of time (Tadros et al. 2011; Mojeremane et al. 2017, 2018; Odirile et al. 2019; Setlhabetse et al. 2019), thereby improving germination. Each scarification method has advantages and disadvantages, which depend on the plant species. There is little information on the effect of pre-sowing treatments on breaking dormancy, and the germination response in indigenous trees and shrubs in Botswana. Therefore, the objective of this study was to evaluate characteristics of the seeds and identify the best scarification pre-sowing treatments that result in the fastest and highest, as well as uniform germination of *A. versicolor* and *F. albida*.

Materials and Methods

Study site

The study was carried out in the laboratory at the Botswana University of Agriculture and Natural Resources (BUAN) from January to February 2020. BUAN is located at Sebele (latitude 23°34' S and longitude 25°57' E, altitude of 994 m a.s.l.), about 10 km from the centre of Gaborone, the capital city of Botswana, along the A1 North-South highway.

Collection of seed material

Seeds were collected from several mother trees during August 2018 and September 2019 at Kazungula village in the Chobe district, Botswana. Closed *F. albida* pods were picked from the ground under mother trees. For *A. versicolor*, closed pods were collected from tree crowns by shaking with long-hooked sticks. The pods were placed in paper bags and transported to the Department of Range and Forest Resources at BUAN for processing. At BUAN, seeds were extracted by crushing the pods using hands, followed by winnowing to separate the husk. Seeds were kept refrigerated at 5 °C until the experiments were initiated.

Experimental design and treatments

The experiments were laid out in a completely randomized design (CRD) with 10 pre-sowing treatments, namely the control, mechanical scarification, soaking in concentrated sulphuric acid with four levels of time exposure (15, 30, 45 and 60 min), immersion in boiling water with three levels of time exposure (1, 3 and 5 min), and soaking in hot water (allowed to cool for 24 h). Treated seeds were germinated for 30 days at room temperature (25 °C). Before the experiment, seed viability was tested using a floatation method. This involved soaking seeds in water for few minutes and those that sank were regarded as viable, while those that floated were deemed unviable and not suitable for the experiments.

Mechanical scarification

In this treatment, 100 seeds of the study species with four replications of 25 seeds

each were used. The seeds were scarified by using a pair of scissors to cut away 1–2 mm of the seed coat on a convex edge opposite where the embryo is located. Cutting of the seed coat was carried out with care to avoid damaging the cotyledons.

Sulphuric acid scarification

Four levels of time exposure (soaking) of seeds in concentrated sulphuric acid (98 %), i.e. 15, 30, 45 and 60 min, were used by applying the method described by Teketay (1996a). For each soaking time, four replicates of 25 seeds each were put into four 100 ml, heat-resistant, non-corrosive glass beakers containing sulphuric acid by making sure that all the seeds were covered by the acid. Seeds were hand stirred every five minutes during the specific soaking time to ensure they were uniformly exposed to the acid. After the specified periods of soaking, the seeds were sieved out of the acid using an acid-resistant sieve, while the acid was drained off simultaneously into another beaker. Seeds were then thoroughly washed and rinsed to remove all the acid using tap water first and subsequently using distilled water, successively.

Boiling water

Three levels of time exposure (soaking) of seeds of the two study species, i.e. 1, 3 and 5 min. to boiling water were used. For each level of soaking, four replicates of 25 seeds each were put into four separate coffee filter papers and immersed into a cooking pot with boiling water for the specified period. At the end of each soaking period, seeds were removed and immersed in a small bucket containing distilled water to cool them down for a few minutes before sowing.

Hot water scarification

Four replicates of 25 seeds each were put into four separate coffee filter papers and placed into a 250 ml beaker. Boiling water was then poured into the beaker and left to cool for 24 h.

Control

Four replicates of 25 untreated seeds each were used as control for the two species.

In all the treatments, each replicate, containing the 25 seeds, was placed in 8 mm closed petri dishes lined with cotton wool. The cotton wool was continuously kept moist by adding distilled water whenever necessary until the end of the experiments. Seeds were considered to have germinated when the radicle penetrated the seed coat and reached 1–2 mm. The number of germinating seeds was recorded daily for 30 days. Germinated seeds were removed from petri dishes after counting and recording.

Data collected on germinated seeds were used to calculate germination percentage (GP) as indicate in formula (1):

$$GP = \frac{\text{Total number of seeds germinated}}{\text{Total number of seeds sown}} \cdot 100, \% \quad (1)$$

The mean germination time (MGT) was calculated following the formula (2) by Bewley and Black (1994):

$$MGT = \frac{\sum (j \cdot n_j)}{\sum n_j}, \text{ days} \quad (2)$$

where: j is the number of days starting from the date of sowing and n_j is the number of seeds that germinated at the j^{th} day from sowing.

The germination index (GI) was calculated using the equation (3) by Esechie (1994):

$$GI = (G_{1/1}) + (G_{2/2}) + \dots + (G_{x/x}), \quad (3)$$

where: G is the germination day 1, 2, ..., and x represents the corresponding day of germination.

Data analyses

The data collected were subjected to both descriptive statistics and One-way ANOVA using Statistix Software, Version 10 (Statistix 10, 1984–2003). Before the ANOVA, the germination percentage data were arcsine transformed to meet the requirement of normality (Zar 1996). Significant differences of means were tested using Tukey's Honestly Significant Difference (HSD) at the significance level of $p < 0.05$.

Results

Seed germination

Germination percentage (GP), mean germination time (MGT) and germination index (GI) for *A. versicolor* were signifi-

cantly ($p < 0.01$) affected by pre-sowing treatments (Table 1). The highest GP was observed in seeds treated with sulphuric acid (15, 30, 45, 60 min) with 90.10 %, boiling water (1 and 3 min) with 90.10 % and mechanical scarification (90.10 %), hot water (allowed to cool for 24 h) with 89.12 % whereas the untreated/control seeds (66.65 %) followed by boiling water (5 min) exhibited the lowest GP. There were no statistically significant differences across the treatments with the highest GP. The MGT for *A. versicolor* varied among treatments from 1 to 19 days. The highest MGT of 19 days was recorded in the control/untreated seeds. The lowest MGT of one day was recorded in seeds treated with sulphuric acid (15 and 30 min). The highest GI of 0.83 was recorded in seeds treated with sulphuric acid (15, 30, 45 and 60 min), boiling water (1 and 3 min), mechanical scarification and hot water (allowed to cool for 24 h). The lowest GI of 0.49 was recorded in seeds treated with boiling water (5 min).

Table 1. Effect of seed pre-treatment on germination parameters of *A. versicolor*.

Treatments	Germination parameters		
	Germination, %	GMT, days	GI
Control	66.65b	19.00a	0.63b
Mechanical scarification	90.10a	1.08e	0.83a
Boiling water			
1 min	90.10a	7.69b	0.83a
3 min	90.10a	4.07c	0.83a
5 min	50.17c	3.04cd	0.49c
Sulphuric acid (98%)			
15 min	90.10a	1.00e	0.83a
30 min	90.10a	1.00e	0.83a
45 min	90.10a	1.15de	0.83a
60 min	90.10a	1.18de	0.83a
Hot water (allowed to cool for 24 h)	89.12a	9.30b	0.83a

Note: Means separated using Tukey's Honestly Significant Difference (HSD) Test at $p \leq 0.05$. Means within columns followed by the same letters are not significantly different (GMT is germination mean time, GI is germination index).

There were significant differences across treatments for GP, GMT, and GI in *F. albida* seeds (Table 2). The highest GP (90 %) was recorded in seeds treated with sulphuric acid (15 and 60 min) followed by those treated with sulphuric acid (30 and 45 min) and mechanical scarification (89.12 %). However, there were no statistically significant differences among these treatments with the highest germination percentages. The lowest GP was recorded in seeds treated with hot water (allowed to cool for 24 h), boiling water (1 and 3 min), untreated seeds

and boiling water for 5 min (Table 2). The MGT for *F. albida* seeds ranged from 2 to 22 days. The highest MGT (22 days) was recorded in seeds treated with hot water (allowed to cool for 24 h), while seeds treated with sulphuric acid (15, 30, 45 and 60 min) exhibited the lowest MGT ranging from 2 to 2.3 days. GI ranged from 0.08 to 0.83, and seeds treated with boiling water (5 min) exhibiting the lowest GI of 0.08. The highest GI of 0.83 was recorded in seeds treated with sulphuric acid (15, 30, 45 and 60 min) and mechanical scarification (Table 2).

Table 2. Effect of seed pre-treatment on mean germination parameters of *F. albida*.

Treatments	Germination parameters		
	Germination, %	GMT, days	GI
Control	6.40b	16.00a	0.10b
Mechanical scarification	89.12a	3.01b	0.83a
Boiling water			
1 min	13.49b	18.55a	0.17b
3 min	13.40b	21.33a	0.17b
5 min	5.61b	17.50a	0.08b
Sulphuric acid (98%)			
15 min	90.10a	2.15b	0.83a
30 min	89.12a	2.31b	0.83a
45 min	89.12a	2.13b	0.83a
60 min	90.10a	2.00b	0.83a
Hot water (allowed to cool for 24 h)	14.26b	22.24a	0.18b

Note: Means separated using Tukey's Honestly Significant Difference (HSD) Test at $p \leq 0.05$. Means within columns followed by the same letters are not significantly different (GMT is germination mean time, GI is germination index).

Seed germination rate

Albizia versicolor seeds treated with mechanical scarification and sulphuric acid (15, 30, 45 and 60 min) exhibited the fastest and uniform germination, reaching 90 % cumulative germination within three days of sowing, whereas the rest of the treatments were below 40 % (Fig. 1). Seeds treated with boiling water (1 and 3 min) and hot water allowed to cool for

24 h reached >80 % cumulative germination 18 days after sowing. Seeds treated with boiling water (5 min) and their untreated/control counterparts exhibited the lowest germination rate of just above 50 % cumulative over the 30 days of the study.

Faidherbia albida seeds treated with sulphuric acid (15, 30, 45 and 60 min) and mechanical scarification exhibited the fastest and uniform germination and reached >88 % cumulative germination

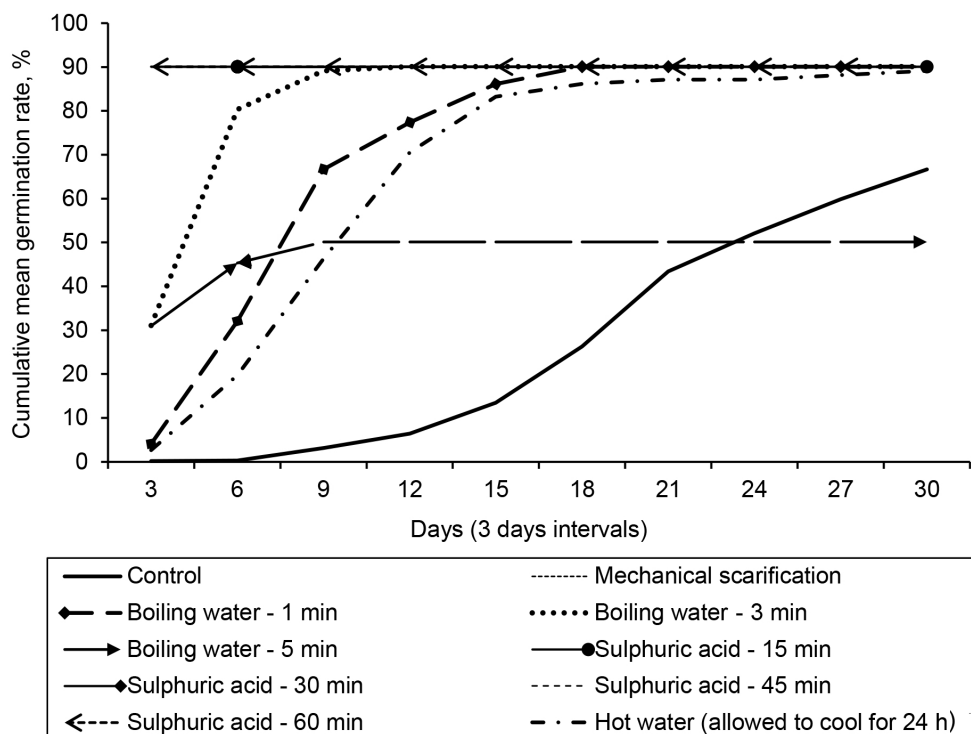


Fig. 1. Cumulative mean germination rate of *A. versicolor* recorded over 30 days.

within six days of sowing (Fig. 2). The untreated/control seeds and their counterparts treated with hot water allowed to cool for 24 h and boiling water (1, 3 and 5 min) exhibited not only the lowest GP, but also the slowest germination.

Discussion

Poor germination is a common phenomenon in many tree and shrub species of arid lands, which limit their propagation in tree nurseries for use in planting programmes. The results of the present study show that seeds of *A. versicolor* and *F. albida* are characterised by hard seed coats, which are impermeable to water. Like in many other leguminous species (Amusa 2011,

Aref et al. 2011, Smýkal et al. 2014), unscarified seeds of the two study species exhibited very low germination percentages. Therefore, breaking dormancy by cracking or softening the seed coat to allow imbibition and gaseous exchange is crucial in propagating tree and shrub seedlings in nurseries.

The results of the present study show that seed pre-sowing treatments affected GP, MGT and GI for both *A. versicolor* and *F. albida*. These results indicate that seeds of the two study species are characterized by physical dormancy, which was broken by mechanical and chemical pre-sowing treatments resulting in improved germination. Mechanical scarification, acid, boiling and hot water treatments improved germination of *A. versicolor* and *F. albida*.

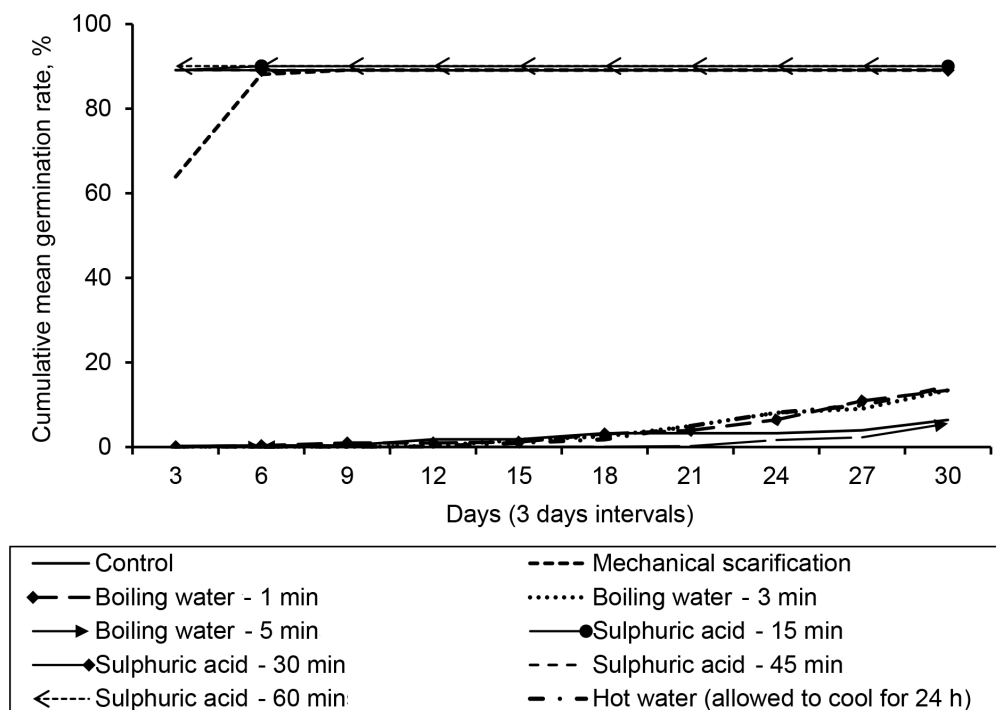


Fig. 2. Cumulative mean germination rate of *F. albida* recorded over 30 days.

Therefore, we can infer that seeds of the two studied species have physical dormancy imposed by hard seed coats. The hard seed coats are impermeable to water and gas-exchange, thus prevent the growth of the embryo (Nasr et al. 2013).

In this study, mechanical scarification significantly increased seed germination of *A. versicolor* and *F. albida* compared with untreated/control seeds. Mechanical scarification reduced MGT for *A. versicolor* and *F. albida* and exhibited higher GI than untreated/control seeds. The reduced MGT in mechanical scarification seeds could imply that dormancy in seeds was broken by partial cracking or cutting of the seed coat. Mechanical scarification create scars on the surface of the hard seed coat, thereby, increasing water imbibition, gas exchange and stimulating

embryo expansion (Kmetz-Gontalez and Struve 2000, Azad et al. 2010, Olisa et al. 2010, Mwase and Mvula 2011, Jayasuriya et al. 2012). These results suggest that in nature very few seeds of *A. versicolor* and *F. albida* germinate due to hard seed coats.

The results are consistent with results of seed germination experiments conducted on several leguminous and other species (Danthu et al. 1995, Mackay et al. 1995, Diallo et al. 1996, Tigabu and Odén 2001, Baes et al. 2002, Shiferaw et al. 2004, Likoswe et al. 2008, Smýkal et al. 2014, Fredrick et al. 2017, Mojeremane et al. 2017, Müller et al. 2017, Botumile et al. 2020), which demonstrated that mechanical scarification is effective and efficient in enhancing seed germination. For example, Shiferaw et al. (2004) reported

that mechanical scarification increased percent germination of *Prosopis juliflora* (Sw.) DC. seeds by 100 %. Diallo et al. (1996) and Fredrick et al. (2017) also reported increased percent germination in seeds of *F. albida* seeds treated by mechanical scarification.

Sulphuric acid (15, 30, 45 and 60 min.) increased germination of the two study species when compared with the control treatment. The sulphuric acid (15, 30, 45 and 60 min) treatment resulted in 89–90 % germination, reduced MGT and exhibited the highest GI for the two study species compared with untreated/control seeds. The highest percent germination observed in this treatment may have occurred because of the effectiveness of the acid in rupturing hard seed coats and speeding the imbibition process and gaseous exchange (Okunlola et al. 2011, Mojeremane et al. 2020), which resulted in rapid and uniform germination (Mojeremane et al. 2020). The fact that the sulphuric acid improved percent germination is an indication that the seed coat is a barrier to germination in *A. versicolor* and *F. albida*. An increase in percent germination, following sulphuric acid scarification, has also been reported in earlier seed germination studies conducted using leguminous and other species (Diallo et al. 1996; Teketay 1996a, 1998; Baskin et al. 1998; Baes et al. 2002; Righini et al. 2004; Finch-Savage and Leubner-Metzger 2006; Naim 2015; Fredrick et al. 2017; Odirile et al. 2019; Mojeremane et al. 2017, 2020; Botumile et al. 2020).

Hot water (allowed to cool for 24 h) was effective in increasing percent germination in *A. versicolor* compared with the untreated/control seeds. The hot water treatment reduced MGT and exhibited higher GI than the untreated seeds, which exhibited a MGT of 19 days and GI of

0.63. The improved germination could be attributed to the hot water, which softened the hard seed coat, resulting in water uptake, gaseous exchange, and stimulation of embryo expansion (Mwase and Mvula 2011). Odirile et al. (2019) reported that seeds soaked in hot water imbibe water and swell as the water cools. The hot water treatment substantially increased percent germination in *A. versicolor* seeds, as reported in other studies (Sajeevukumar et al. 1995, Tigabu and Oden 2001, Teketay 2005, Mwase and Mvula 2011, Odirile et al. 2019, São José et al. 2019, Botumile et al. 2020, Mojeremane et al. 2020). Hot water has been suggested as better, safe and cost-effective treatment when working with large numbers of seeds (Baes et al. 2002, Hopkinson and English 2004, Himanen et al. 2012). In contrast, the percent germination of *F. albida* seeds was not affected by hot water in this study. The lack of any increase in percent germination following hot water treatment has been reported in *F. albida* elsewhere (Diallo et al. 1996, Ameri and Daldoum 2017, Fredrick et al. 2017) and other leguminous plants (Botsheleng et al. 2014; Hasnat et al. 2017, 2019; Mojeremane et al. 2017, 2020; Kanmegne et al. 2020).

The effect of boiling water on germination of different plant species is well documented (de Zwaan 1978; Bell and Bellairs 1992; Burrows et al. 2009; Mojeremane et al. 2017, 2020; Mmolutsi et al. 2020). In this study, boiling water (1 and 3 min) was effective in enhancing percent germination of *A. versicolor* seeds. This result could suggest that dormancy in this species is attributed to the hard seed coat. However, GP declined with increase in boiling beyond 3 min. Seeds treated with boiling water (5 min) exhibited lower GP than untreated seeds. The decline in GP with increasing boiling time has been re-

ported in work undertaken on other tree species (Botumile et al. 2020, Mmolutsi et al. 2020). The decline could probably be attributed to lethal effects of hot water on embryos. In contrast, percent germination of *F. albida* was not affected by boiling water (1, 3 and 5 min). This could suggest that seeds of this species are sensitive to high temperatures. This result is consistent with results of experiments conducted on other legumes, which found that boiling water did not increase GP (Gill et al. 1990, Kahaka et al. 2018, Mojeremane et al. 2018, Botumile et al. 2020), suggesting that the boiling water caused a degree of damage to the seeds.

Conclusion and Recommendations

The results of the present study show that dormancy in *A. versicolor* and *F. albida* is mainly caused by their hard seed coats, which inhibit water uptake and gaseous exchange to initiate germination. Therefore, the hard seed coat needs to be subjected to pre-sowing treatments before seeds can germinate. The study has demonstrated that mechanical scarification, acid, boiling and hot water (boiling water allowed to cool for 24 h) treatments are the most effective methods in improving seed germination of *A. versicolor* and reducing mean germination time. Mechanical scarification and acid treatments are the most effective methods in improving seed germination and reducing mean germination time of *F. albida* seeds. Mechanical scarification, boiling and hot water (boiling water allowed to cool for 24 h) are recommended as cheaper and less hazardous techniques of pre-treating *A. versicolor* seeds in tree nurseries. Mechanical scarification is also recommended for pre-treating *F. albida* seeds. Although sul-

phuric acid was effective in improving germination and reducing mean germination time for the two species, it is not recommended for use in tree nurseries because it is expensive, corrosive and hazardous to nursery workers and requires proper handling techniques.

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EFFECTS OF GEOGRAPHICAL DIRECTIONS ON PHYTOSOCIOLOGICAL ATTRIBUTES AND BIOMASS AT *TAXUS* OCCURRENCE FOREST, NORTH-WESTERN HIMALAYA

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Abstract

Taxus contorta Griff. is an endangered conifer tree species. It is found in patchy habitats throughout its natural occurrences along with certain altitudinal ranges in the Himalayan region. The present study involves the stand structure, regeneration status and biomass of *Taxus* species in the Narkanda forest that occupies an area of 11.4 km² with an altitudinal range of 2400 m to 3000 m a.s.l. in Shimla district of Himachal Pradesh. A total of 24 square plots, each plot of area 0.16 ha, were laid in four main geographical directions (i.e., north, northeast, southwest and southeast) with equal six plots in each slope exposure. The result showed that *T. contorta* is found only in three slopes (north, northeast and southwest) exposures with the main association of *Abies pindrow* (Royle ex D.Don) Royle species. The absence of *Taxus* species occurrences slope exposure (southeast) was dominated by *Quercus semecarpifolia* Sm. Based on the results, this study documented that conservation of an endangered species should be done through silvicultural practices for its sustainable regeneration in northern slope exposure. Additionally, the adult tree of *T. contorta* must be conserved specially for pollination purposes, fertile seed production and dispersion of seeds exposing the open canopy closure through the thinning of common and dominated species. Finally, it is recommended that any kind of human disturbances should be strictly prohibited inside *Taxus* occurrence forest.

Key words: diversity, edaphic parameters, regeneration, shrub habitat.

Introductions

Taxus contorta Griff., known as west Himalayan yew, is an evergreen gymnosperm, dioecious plant with medicinal uses. It belongs to the family Taxaceae with occurrence from Afghanistan to the central part of Nepal (Poudel et al. 2013). Most species of the *Taxus* genus are endangered due to a quantitative decline

in its population (>90 %) and the effects of climate change on its habitat (Thomas and Polwart 2003). It is found to have poor seed germination and slow seedlings growth (the girth increment 0.4–1.3 cm·yr⁻¹ and average ring 8–12 rings·cm⁻¹) in natural habitats, which shows late growing (García et al. 2000, Linares 2013). Excessive harvesting of *T. contorta* for economical and medicinal purposes has caused

substantial environmental concern for its conservation along the north-western Himalaya region (Kunwar et al. 2021, Poudyal et al. 2021).

The local (biotic and abiotic) factors have limited the regeneration of the *T. contorta* in the Himalayan region. So far, there have been no studies related to the effects of geographical directions on its occurrence in forests that have abiotic factors to control the population of *T. contorta* in this area. However, it is suggested that the major possible threat of decline of its population is overexploitation for domestic, as well as medicinal purposes at the fragile ecosystem in the Himalaya region (Haile et al. 2021, Iqbal 2021, Perdiguero et al. 2021). Furthermore, species regeneration was reduced by birds, rodents and monkeys due to the eating of seeds along with the aril part (Onrubia et al. 2011). The growth of species seedlings under shrub canopy also facilitates the growth and establishment of this species (Kwit et al. 2004, Poudel et al. 2013). Assessment of factors, such as soil parameters, species diversity, community, regeneration status and slope exposures supports the conservation of *T. contorta* in the Himalayan region (Masood 2015). The present study was thus undertaken to identify the effects of main geographical directions on regeneration status, the biomass of vegetation and edaphic variables at *Taxus* occurrence hilly temperate forest in the north-western Himalayan region.

Materials and Methods

Study forest

The study was conducted in the Narkanda region of Shimla district, Himachal Pradesh. The Narkanda forest has more

than 56 km² forest coverage but *Taxus* forest has only an area of 11.4 km² at co-ordinates 31.2465° – 31.2548° N and 77.4738° – 77.5344° E with an altitudinal range of 2400–3000 m a.s.l. The annual average temperature varies from -2 °C to 18 °C and annual precipitation of 1200 mm. The dominant vegetation species were *Cedrus deodara*, *Picea smithiana*, *Quercus* sp. and *T. contorta*. The soil is calcareous and siliceous along with limestone pavement slopes (5–21°). This research was carried out in the government-protected forest (the Indian Forest Act of 1927). The site is easily accessible by the local inhabitants and thus the effects of anthropogenic disturbances could be easily studied at this site. The forest management activities started in the 1950s but active management was started in the 1990s while commercial exploitation of *T. contorta*. Since 2010, the forest department strictly prohibited any kind of illegal activities in the forest as the decline of 90 % of its population was observed.

Survey design

The studies were carried out in October 2020. A total of 24 main square plots with area of 0.16 ha (40×40 m²) each, were laid for sampling. Six plots were laid on each slope exposure with totally taken four major slope exposures that were north, northeast, southwest and southeast with considering slope length (*SL*) correction. The *SL* is corrected by formula (1):

$$SL = \frac{AL}{\cos \phi} \quad (1)$$

where: *SL* is slope length, m; *AL* is the actual length i.e. 10 m of each subdivided plot and ϕ is the angle between slope line and horizontal line in 1.3 m height of the ground level of each 10 m length.

The main plot was divided into 16 equal squares with an area of 0.01 ha ($10 \times 10 \text{ m}^2$) for trees (adults) and the saplings layer. Inside every subplot, there was a quadrat with an area of 0.0025 ha ($5 \times 5 \text{ m}^2$) each for seedlings and shrub sampling. Litter biomasses were taken from 0.0625 m^2 ($25 \times 25 \text{ cm}^2$) from all 16 plots (Fig. 1). Therefore, a total of 3.84 ha,

0.96 ha and 6 m^2 area were sampled for saplings and adults, seedlings and shrub and litter layer sampling. The soil moisture and soil bulk density were taken from the centre of 16 subplots from the depth of 0–10 cm, 10–20 cm and 20–30 cm, respectively, by stell corer (radius = 2.04 cm) and made the composite sample for lab analysis.

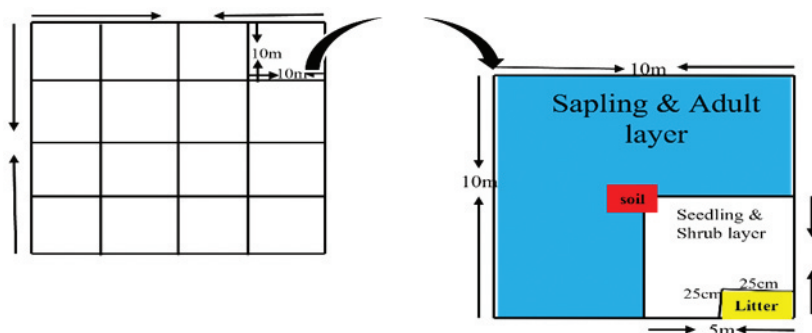


Fig. 1. A nested pattern of squares within each $40 \times 40 \text{ m}^2$ plot.

Methods

Phytosociological attributes for tree species were calculated through given equations (2 to 9) by Sharma et al. (2018). Similarly, dominance, soil bulk density

(BD) and soil organic carbon (SOC) were calculated through equations (10), (11) and (12) given by Simpson (1949), Alshammmary et al. (2020), as well Walkley and Black (1934) and Yigini et al. (2017), respectively.

$$D = \frac{\text{Total number of individual of a species}}{\text{Total number of plant studies} \cdot \text{Area of each quadrat}} \cdot 10000, \quad (2)$$

$$D = \frac{\text{Total number of individual of a species in all quadrat}}{\text{Total number of individual of all species in all quadrat}} \cdot 10000, \quad (3)$$

$$F = \frac{\text{Number of quadrat in which a particular species occurs}}{\text{Total number of all quadrat}}, \quad (4)$$

$$RF = \frac{\text{Number of quadrat in which a particular species occurs}}{\text{Total number of all species in all quadrat}} \cdot 100, \quad (5)$$

$$BA = \frac{\pi \cdot DBH^2}{4}, \quad (6)$$

$$RBA = \frac{\text{Basal area of a particular species in quadrat}}{\text{Total basal area of all species in quadrat}} \cdot 100, \quad (7)$$

$$IVI = RD + RF + RBA, \quad (8)$$

$$H' = -\sum_{i=1}^N \frac{n_i}{N} \cdot \ln \frac{n_i}{N}, \quad (9)$$

$$C = \sum \left(\frac{n_i}{N} \right)^2, \quad (10)$$

$$BD = \frac{\text{Ovendry mass}}{\text{Core volume} - \left(\frac{\text{Mass of coarse fragments}}{\text{Density of rock fragments}} \right)}, \quad (11)$$

$$SOC_{stock} = SOC(\%) \cdot BD \cdot SD \cdot 1000, \quad (12)$$

where: D is Density; RD is Relative Density; F is Frequency; RF is Relative Frequency; BA is Basal Area, $m^2 \cdot ha^{-1}$; DBH is Diameter at Breast Height; RBA is Relative Basal Area, $m^2 \cdot ha^{-1}$; IVI is Importance Value Index; H' is Shannon wiener Diversity Index; N is the total number of all available species; n_i is total number of single species; C is Dominance; BD is Bulk Density, $gm \cdot cm^{-3}$; SOC_{stock} is Soil Organic Carbon stock in $t \cdot ha^{-1}$; $SOC(\%)$ is the SOC content percentage; SD is Soil Depth, cm .

The abundance frequency ratio (A/F) was calculated to the category of distribution pattern (DP) of species in the study forest through given equations (13) and (14). If $A/F < 0.025$, species was cate-

gorised Regular distribution pattern, if $0.025 < A/F < 0.05$, species was categorized in Random distribution pattern and if $A/F > 0.05$, species was categorised Contagious distribution pattern in community.

$$A = \frac{\text{Total no. of individual of the species}}{\text{No. of quadrat per units in which they occur}} \cdot 100, \quad (13)$$

$$\%F = \frac{\text{No. of units in which the species occurred}}{\text{Total number of all quadrat}} \cdot 100, \quad (14)$$

where: A is Abundance; $\%F$ is percentage frequency.

The fresh weight of soil samples was measured in the field then was carried out in the lab, sieved for the separating purpose of stone. Then, the samples were kept at $105^\circ C$ for 24 to 48 h up to constant weight (<0.05 g) in the hot chamber. Finally, BD was calculated depth-wise (Alshammary et al. 2020). For moisture calculation, the dry soil was weighted in the presence of the desiccators and calculated depth-wise method given by Dangal et al. (2017). The fresh weight of the litter biomass was weighted in the field

then carried to the lab for heating at $75^\circ C$ for 48 h and calculations were done method given by Qin et al. (2020). The soil pH measured given method by Ghazali et al. (2020) of 0–10 cm depth. The soil organic carbon (SOC) was determined accordingly to equation (12).

Regeneration category

The seedlings, saplings and tree density regeneration pattern have given the information about regeneration category by

the following formulae (Shankar 2001):

- Good regeneration (GR): when the number of seedlings > saplings > adults;
- Fair regeneration (FR): when the number of seedlings > or < saplings < adults;
- Poor regeneration (PR): when the saplings may be <, > or = adults, but no seedlings;
- No regeneration (NR): if individuals of species are present only in the adult stage;
- New regeneration or not abundant (NA): only occupy in seedlings or saplings.

Biomass and carbon storage

The growing stock volume density (GSVD) was estimated using volumetric equations based on the respective species (Sharma et al. 2018). These volume equations were based on basal area, DBH along with height or form factor. In few cases, volume equations for the desired species were not available. The volumes of those species were calculated as per convention by using volume equations of similar species having similar height, form, taper and growth rate. The estimated GSVD ($\text{m}^3 \cdot \text{ha}^{-1}$) was then converted into above-ground biomass density (AGBD) of tree components (stem, branches, twigs and leaves), which was calculated by multiplying GSVD of the forest with the appropriate biomass expansion factor (BEF) (Brown et al. 1999). The BEF ($\text{mg} \cdot \text{m}^{-3}$) is defined as the ratio of AGBD of all living trees at diameter at breast height (DBH) ≥ 3.34 cm to GSVD for all trees. The BEF for hardwood, spruce-fir, and pine were calculated using the following equations (Sharma et al. 2018):

- Hardwood: $BEF = \exp\{1.91 - 0.34 \cdot \ln(GSVD)\}$, for $GSVD \leq 200 \text{ m} \cdot \text{ha}^{-1}$; $BEF = 1.0$, for $GSVD > 200 \text{ m} \cdot \text{ha}^{-1}$.

- Spruce-fir: $BEF = \exp\{1.77 - 0.34 \cdot \ln(GSVD)\}$, for $GSVD \leq 160 \text{ m} \cdot \text{ha}^{-1}$; $BEF = 1.0$, for $GSVD > 160 \text{ m} \cdot \text{ha}^{-1}$.

- Pine: $BEF = 1.68$, for $GSVD < 10 \text{ m} \cdot \text{ha}^{-1}$; $BEF = 0.95$, for $GSVD 10-100 \text{ m} \cdot \text{ha}^{-1}$; $BEF = 0.85$, for $GSVD > 100 \text{ m} \cdot \text{ha}^{-1}$.

The below-ground biomass density (BGBD, fine and coarse roots) for tree species was estimated using the regression equation (15) in forest association given by Cairns et al. (1997).

$$BGBD = \exp[-1.059 + 0.884 \cdot \ln(AGBD) + 0.284] \quad (15)$$

The AGBD and BGBD were added to get the total biomass density (TBD, $\text{mg} \cdot \text{ha}^{-1}$). Total carbon density (TCD, $\text{mg C} \cdot \text{ha}^{-1}$) was computed using the given equation (16). The C percentage of 46 % was used for forest associations where all conifers together constituted more than 50 % of the forest composition (Negi et al. 2003).

$$TCD = TBD \cdot C, \% \quad (16)$$

Statistical analysis

All collected data, such as total individuals of seedling, sapling and adult, as well as carbon storage, were presented per hectare unit. Correlations between the height of the adult and CBH (cm) of girth were analyzed. Data collected in 2020, plant phytosociological attributes were subjected to analysis of variance (ANOVA) within slope exposure. The graphs were presented individual species per hectare with slope exposure. Shapiro-Wilk test was used to analyse distribution of collected data. Tukey's HSD is used to test differences among diversity among slope exposure. The presented data represent the mean $\pm$ SD. Means were considered significantly different at $p < 0.05$.

Results and Discussion

A total of 9 species with a total number of 1176 individuals belonging to a total of 4 families were recorded from the Nar-kanda forest area. The results in terms of richness of trees, the density of trees, saplings, seedlings and total basal area of study forest were comparable with the KhWLS communities occurrences in the Indian Himalayan Region (Pant and Samant 2008) and similar to Gharwal forest (9–28 species) in the temperate forest, Indian Himalayan region (Rawat et al. 2021). The high richness of trees in the studied forest might be due to the suitable edaphic and climatic factors (Oommen and Shan-

ker 2005). The plant diversity between N and NE slope exposure was found to have significant differences ($df = 3$, $F = 18.71$, $p = 0.004$) but not always (SW and SE, $p > 0.05$) (Table 1). This indicates that slope exposures have a certain role to play in plant diversity. Geographical direction has significant impact on herb density ($p = 0.001$). *T. contorta* was found to have 'no regeneration category' in its occurrence slope exposures. 'No regeneration category' indicated that the forest required immediate conservation activities for returning the endangered species. Some species were found to have 'new regeneration' category, while most species were found absent in the sapling stage (Table 1).

Table 1. Phytosociological variables of tree species in Narkanda Forest.

Aspect	Species	Seedling, ind.ha ⁻¹ (mean ±SD)	Sapling, ind.ha ⁻¹ (mean ±SD)	Adult, ind.ha ⁻¹ (mean ±SD)	TBA, m ² .ha ⁻¹ (mean ±SD)	IVI	H' (mean ±SD)
N	<i>Picea smithiana</i> (Wall.) Boiss.	162.76 ±142.8	14.5 ±4.91	3.13 ±7.65	3.68 ±5.02	4.43	0.22 ±0.21 ^a
	<i>Abies pindrow</i> (Royle ex D.Don) Royle	240.89 ±34.92	null	104.17 ±72.3	35.39 ±25.3	201.4	
	<i>Quercus semecarpifolia</i> Sm.	52.08 ±27.58	null	22.92 ±40.63	6.37 ±12.26	32.25	
	<i>Taxus contorta</i> Griff.	null	null	23.96 ±26.64	2.87 ±1.78	44.09	
	<i>Aesculus indica</i> (Wall. ex Cambess.) Hook	null	null	5.21 ±12.76	1.74 ±1.82	17.80	
	<i>Pinus wallichiana</i> A.B. Jacks	65.10 ±6.74	null	null			
	<i>Quercus floribunda</i> ex A. Campus	32.55 ±9.75	null	null			
	NE	<i>Picea smithiana</i> (Wall.) Boiss.	136.72 ±20.41	12.5 ±11.91	20.833 ±28.7	5.97 ±6.09	
<i>Abies pindrow</i> (Royle ex D.Don) Royle		260.42 ±80.98	null	112.5 ±44.72	29.19 ±22.6	186.2	
<i>Pinus wallichiana</i> A.B. Jacks		45.57 ±3.81	null	1.04 ±2.55	11.76 ±28.6	1.06	
<i>Quercus semecarpifolia</i> Sm.		26.04 ±1.89	null	12.5 ±17.72	2.29 ±2.12	19.27	

	<i>Aesculus indica</i> (Wall. Ex Cambess.) Hook	null	null	5.21 ±12.76	1.4 ±1.6	11.34	
	<i>Taxus contorta</i> Griff.	null	null	35.42 ±17.53	2.68 ±2.17	48.97	
	<i>Cedrus deodara</i> (Roxb.) G. Don	null	null	7.29 ±17.86	2.29 ±3.27	5.99	
SW	<i>Abies pindrow</i> (Royle ex D. Don) Royle	942.41 ±464.5	112.5 ±111.9	147.92 ±108.52	37.98 ±9.25	181.4	
	<i>Quercus semecarpifolia</i> Sm.	625 ±57.39	12.5 ±2.91	82.29 ±56.1	21.32 ±7.93	85.09	
	<i>Picea smithiana</i> (Wall.) Boiss.	310.33 ±04.33	null	29.167 ±59.4	7.52 ±11.21	26.66	0.32 ±0.14 ^{ac}
	<i>Taxus contorta</i> Griff.	null	null	7.29 ±10.01	1.41 ±1.55	6.84	
	<i>Quercus floribunda</i> ex A. Campus	45.57 ±1.68	null	null			
	<i>Quercus semecarpifolia</i> Sm.	943.36 ±562.2	2.5 ±2.91	337.5 ±147.4	36.72 ±3.24	200.7	
SE	<i>Picea smithiana</i> (Wall.) Boiss.	325.52 ±225.9	16.3 ±5.91	104.17 ±15.6	21.18 ±0.81	43.68	
	<i>Pinus wallichiana</i> A.B. Jacks	221.35 ±298.2	6.3 ±7.91	8.33 ±17.53	3.25 ±0.57	14.76	
	<i>Quercus floribunda</i> ex A. Campus	45.57 ±93.80	3.3 ±4.91	2.08 ±5.10	2.65 ±0.57	2.35	0.30 ±0.09 ^{ac}
	<i>Abies pindrow</i> (Royle ex D. Don) Royle	390.63 ±33.58	null	33.33 ±75.69	3.64 ±0.17	36.92	
	<i>Quercus dilatata</i> A. Kein	null	null	8.33 ±2.55	2.1 ±0.81	1.60	
	<i>Cedrus deodara</i> (Roxb.) G. Don	6.51 ±15.95	null	null			

Note: Along the column, different superscript letters indicate significant differences ($p < 0.05$) between geographical directions. Abbreviation: *TBA* is Total Basal Area; *IVI* is Importance Value Index; *H'* is Shannon diversity index.

The spatial distributions of plant species were concentrated in the lower classes of girth, most species concentrated in higher classes in the study site. For example, an endangered species – *T. contorta* was found to have ‘no regeneration’ or lack of individuals in the lower DBH classes, which may be due to disturbance activities affecting its regeneration (Shankar 2001, Chave et al. 2005, Iqbal et al. 2020, Ghanbari et al. 2021). *Picea smithiana* showed fair regeneration (i.e., number of seedlings > or < saplings < adults) at the northern slope

exposure, while *Quercus* spp. and *Abies pindrow* (i.e., number of seedlings > saplings > adults) were described with good regeneration category in southern slope exposure (Table 2). The effects of the regeneration category in between slope exposures have consequences in establishing different community and environmental conditions and sustainability. The DBH and height class distribution relations showed that most species are absent in lower size class, thus should be prioritized for conservation (Molino and Sabatier 2000).

Table 2. Distribution pattern of species in Narkanda forest.

Aspect	Species	Dominance	Richness	Shrubs, ind.ha ⁻¹	Herbs, ind.ha ⁻¹	A/F	RC	DP
N	<i>Picea smithiana</i>	0.64 ±0.32 ^a	7			0.02	GR	Regular
	<i>Abies pindrow</i>			2571.7		0.04	FR	Random
	<i>Quercus semecarpifolia</i>			±1839.1 ^a	1649.9 ±1453.2 ^a	0.01	FR	Regular
	<i>Taxus contorta</i>					0.08	NR	Random
	<i>Aesculus indica</i>					0.13	NR	Contagious
	<i>Pinus wallichiana</i>						NA	
	<i>Quercus floribunda</i>						NA	
NE	<i>Picea smithiana</i>	0.44 ±0.14 ^a	7			0.09	FR	Contagious
	<i>Abies pindrow</i>					0.04	FR	Random
	<i>Pinus wallichiana</i>			8668.5 ±7655.6 ^{ab}	49.28 ±40.714 ^{bd}	0.03	FR	Random
	<i>Quercus semecarpifolia</i>					0.06	FR	Contagious
	<i>Aesculus indica</i>					0.01	NR	Regular
	<i>Taxus contorta</i>					0.06	NR	Contagious
	<i>Cedrus deodara</i>					0.02	NR	Regular
SW	<i>Abies pindrow</i>	0.57 ±0.21 ^a	5			0.07	FR	Contagious
	<i>Quercus semecarpifolia</i>			5087.1 ±3990.8 ^a	218.41 ±149.29 ^{cd}	0.03	FR	Random
	<i>Picea smithiana</i>					0.03	FR	Random
	<i>Taxus contorta</i>					0.04	NR	Random
	<i>Quercus floribunda</i>						NA	
SE	<i>Quercus semecarpifolia</i>	0.59 ±0.14 ^a	7			0.06	FR	Contagious
	<i>Picea smithiana</i>			326.9 ±187.6 ^{ac}	266.68 ±126.69 ^{ad}	0.03	FR	Random
	<i>Pinus wallichiana</i>					0.05	FR	Contagious
	<i>Quercus floribunda</i>					0.03	GR	Random
	<i>Abies pindrow</i>					0.03	FR	Random
	<i>Quercus dilatata</i>					0.05	NR	Random
	<i>Cedrus deodara</i>						NA	

Note: Different letters in superscript indicate significant differences within geographical directions ($p < 0.05$).

The presence of high diversity in certain slope exposures with high-class girth trees indicated that the forest was mature. It was found that *Aesculus indica* and *Cedrus deodara* density was low may be due to invading recruits of *Quercus* spp.

(Lanker et al. 2010). The regeneration status of tree species was determined by the recruitment of saplings and seedlings. Among the identified communities, *Pinus wallichiana*, *Quercus leucotrichophora* and *Picea smithiana* showed the highest

regeneration indicating that these communities were dominant in disturbed habitats (Iszkuło et al. 2012). Even the poor regeneration of the dominant species and no regeneration of endangered species indicate their total replacement by other tree species or the alarm of being endangered of native species more in the coming years (Thomas and Polwart 2003,

Farris and Filigheddu 2008).

The relationship between tree height and diameter on main geographical directions of the study forest was presented in Figure 2 and describes the concept in determining ecosystem structure and community also as estimates of biomass and carbon storage in the study forest (Sharma et al. 2018).

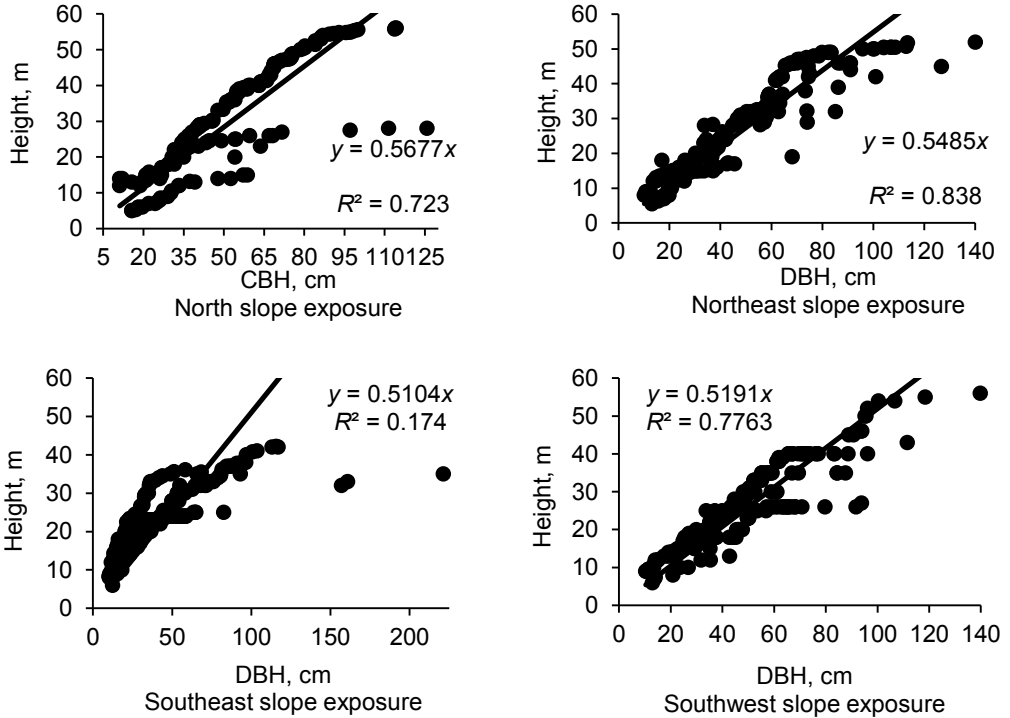


Fig. 2. The relationship between DBH (cm) and height (m) of tree species in study main geographical directions.

The mean tree density varied between different slope exposures and altitudes. It ranges from 425 ± 32 ind. $\cdot$ ha $^{-1}$ at an altitude ranging from 2400 m to 3100 m a.s.l. to 708 ± 153 trees $\cdot$ ha $^{-1}$ at an altitude between 2800 m to 3400 m a.s.l. High density of *Anogeissus latifolia*-*Spondias pinnata* tree (462 ind. $\cdot$ ha $^{-1}$) association was

recorded at moist exposures, i.e. north in Khokhana forest (Sharma et al. 2018). The tree density and total basal cover values were reported as 130–830 trees $\cdot$ ha $^{-1}$ and 6.25–58.88 m 2 $\cdot$ ha $^{-1}$ of *Rhododendron arboreum* forest in Garhwal Himalaya and 440–1180 trees $\cdot$ ha $^{-1}$ and total basal cover 18–123 m 2 $\cdot$ ha $^{-1}$ in *Rhododendron*

arboreum mixed broad-leaved Kumaun Himalaya temperate forest (between 2100 and 2800 m a.s.l.) (Gairola et al. 2011). Tree density ($1107.29 \text{ ind. ha}^{-1}$) and total basal area ($241.39 \text{ m}^2 \cdot \text{ha}^{-1}$) were reported higher in the study forest than research reported by Gairola et al. (2011) in a study of hilly temperate Himalayan forest for density and total basal area (e.g., $100\text{--}860 \text{ trees} \cdot \text{ha}^{-1}$ and $8.42\text{--}59.71 \text{ m}^2 \cdot \text{ha}^{-1}$, $340\text{--}810 \text{ trees} \cdot \text{ha}^{-1}$ and $30.1\text{--}62.2 \text{ m}^2 \cdot \text{ha}^{-1}$ and $337 \text{ trees} \cdot \text{ha}^{-1}$ and $90.16 \text{ m}^2 \cdot \text{ha}^{-1}$, respectively). The basal area was considered an important criterion for evaluating timber production in the forest ecosystem and natural fertility. The basal area of trees has been reported higher in the study forest than other temperate forests, i.e., more than $300 \text{ m}^2 \cdot \text{ha}^{-1}$, Nagarjun hill forest $34.30 \text{ m}^2 \cdot \text{ha}^{-1}$, and $70.00 \text{ m}^2 \cdot \text{ha}^{-1}$ (Shivapuri National park), which indicates study forest has matured and high contain biomass (Jevšenak and Skudnik 2021).

The density of natural regeneration of *T. contorta* was positively correlated with the abundance of shrubs, particularly for small DBH classes (Hulme 1997). The relationship between the recruitment success of *Taxus* species and the presence of shrub vegetation has previously been highlighted in the literature (Linares 2013). The juvenile of the endangered plant was not found in the studied forest, which means that the forest as in unsustainable growth. Diversity index of main geographical directions was obtained lower (0.22, 0.46, 0.32, and 0.30 at N, NE, SW, and SE respectively) than Panthagati conifer forest (1.11) and Gokarna hill temperate forest (1.43) reported by others (Valladares et al. 2016, Dhakal et al. 2021).

Among the study slope exposure, the regeneration curve of species was described in Figure 3. Almost all species

were characterized by a lack of juveniles but not adults. New recruitment was found for some of the species, for example *P. wallichiana* in north slope exposure. Estimates of the number of species in a community also can be calculated of species richness. The regeneration curve has been determined to measure the sustainable process of the species and predict the whole forest community (Sharma et al. 2018).

Biomass varied in between species and main geographical directions (Table 3) of the studied forest due to variation in age, size of the tree and tree density. Moreover, it was noticed that micro-climatic variables played a significant role in the amount of carbon stock in the different species of the forest (Gairola et al. 2011).

The carbon stock was found to be more than $260.46 \text{ t} \cdot \text{ha}^{-1}$ in the studied forest that showed good sequestration of carbon, as previously also reported by Lang et al. (2016) regarding *Pinus roxburghii* Sarg. forest ($269.205 \text{ t} \cdot \text{ha}^{-1}$) in the mixed broadleaf forest, India. Total carbon stock in the studied forest ($720.26 \text{ t} \cdot \text{ha}^{-1}$) was found higher than the global boreal forest and temperate forest reported in previous studies (Dangal et al. 2017). Variation of carbon stock with species diversity is shown in Figure 4. The point curve has demonstrated that diversity has a direct relationship with total carbon density, e.g. northeast slope exposures have the highest diversity with the highest carbon density. The continuous curve has cleared that the relationship between them is not infinite in the forest ecosystem.

The total carbon density of vegetation in north and southwest slope exposure was significantly different ($p = 0.0255$). The herbs carbon stock had a significant difference between N to other slope exposures (Table 4).

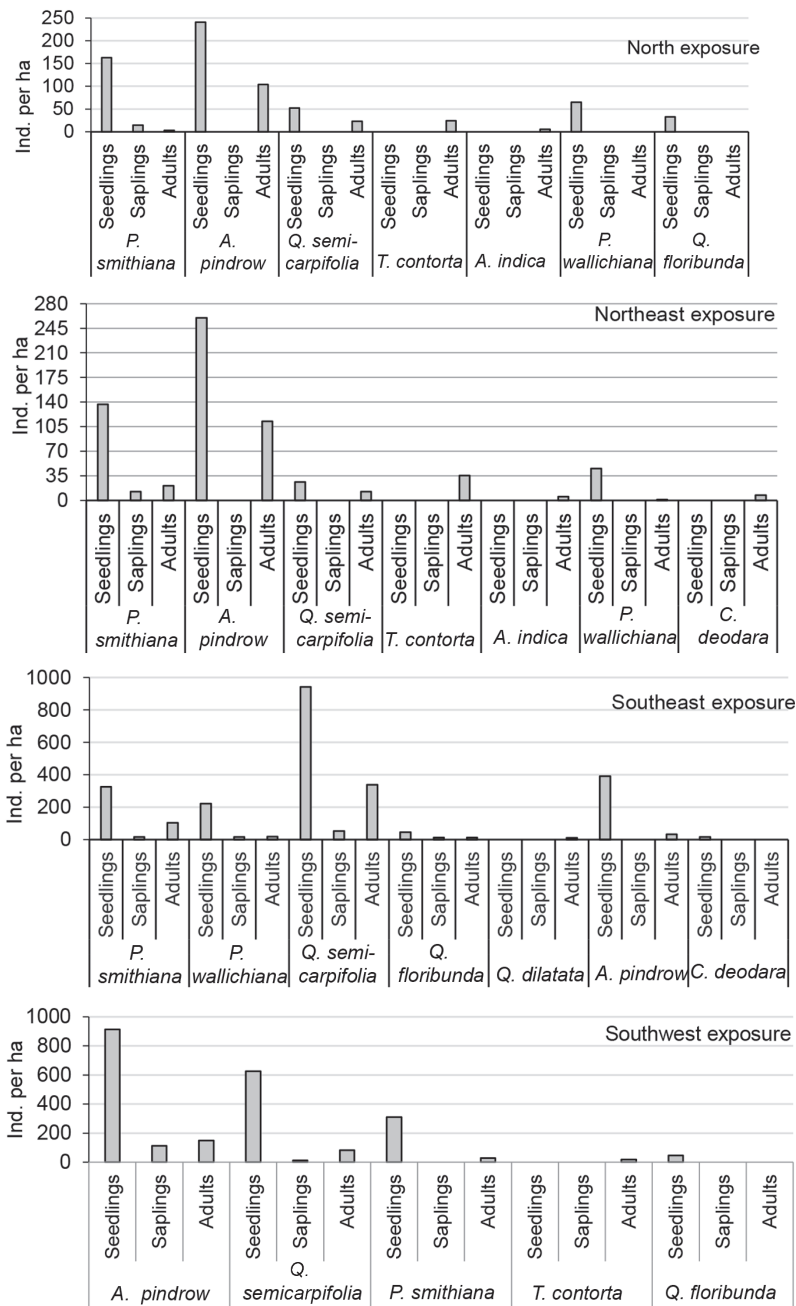


Fig. 3. Regeneration curve of species occurrence in northern and southern slope exposure.

Note: The X-axis belongs to the scientific name of tree species and Y-axis belongs to the number of individuals per ha with regards to species growth form (seedling, sapling and adult) in relative main geographical directions.

Table 3. Species wise biomass in main geographical directions.

Slope exposures	Species	AGBD	BGBD	TBD	TCD
		Mg C·ha ⁻¹			
North	<i>Quercus semecarpifolia</i>	63.0569	17.9633	81.0243	37.2694
	<i>Taxus contorta</i>	11.5889	2.54016	14.1291	6.49943
	<i>Abies pindrow</i>	379.356	87.7605	467.116	214.874
	<i>Picea smithiana</i>	0.42519	0.21636	0.64151	0.29513
	<i>Aesculus indica</i>	3.95258	1.55262	5.50519	2.53244
Total		458.379	110.033	568.412	261.469
Northeast	<i>Aesculus indica</i>	3.95258	1.32409	4.62523	2.12761
	<i>Quercus semecarpifolia</i>	22.0522	7.09631	29.1485	13.9913
	<i>Taxus contorta</i>	18.9775	6.21418	25.1916	11.5882
	<i>Abies pindrow</i>	419.078	95.8363	514.914	236.861
	<i>Picea smithiana</i>	68.8153	19.4059	88.2209	40.5813
	<i>Pinus wallichiana</i>	1.54187	0.67554	2.21741	1.02001
	<i>Cedrus deodara</i>	13.4113	4.57198	17.9832	8.27229
Total		521.824	126.704	648.527	298.323
Southwest	<i>Aesculus pindrow</i>	365.484	84.9159	450.392	207.181
	<i>Picea smithiana</i>	90.1091	24.6284	114.737	52.7796
	<i>Quercus semecarpifolia</i>	109.834	29.3308	139.134	64.0016
	<i>Taxus contorta</i>	2.27666	0.95337	3.22999	1.48575
Total		567.676	139.828	707.493	325.447
Southeast	<i>Picea smithiana</i>	217.454	53.6596	271.109	124.711
	<i>Abies pindrow</i>	43.2852	12.8808	56.1661	25.836
	<i>Quercus semecarpifolia</i>	328.049	77.1813	405.231	213.036
	<i>Quercus dilatata</i>	0.88532	0.41367	1.29899	0.59753
	<i>Pinus wallichiana</i>	34.8465	10.6338	45.4804	20.9209
Total		624.516	154.769	779.286	385.101

Table 4. Total Carbon Density (TCD) in main geographical directions.

Slope exposures	Tree	Shrub	Herb	Litter	Soil Organic Carbon
	Mg C·ha ⁻¹				
N	261.47 ±52.29 ^a	0.032 ±0.023	0.392 ±0.299 ^a	9.57 ±4.892	7.2 ±2.794 ^a
NE	298.32 ±59.67 ^{ac}	0.119 ±0.104	0.041 ±0.035 ^b	10.65 ±6.75	6.9 ±1.953 ^{ac}
SE	385.11 ±77.02 ^{ac}	0.072 ±0.041	0.005 ±0.003 ^b	6.19 ±2.183	6.04 ±1.44 ^{bc}
SW	325.45 ±81.36 ^{bc}	0.071 ±0.054	0.023 ±0.014 ^b	6.92 ±4.154	2.16 ±1.55 ^{ac}
<i>p</i> -value	< 0.002	0.098	< 0.044	0.078	< 0.043

Note: Different letters in superscript indicate significant differences within the geographical directions ($p < 0.05$).

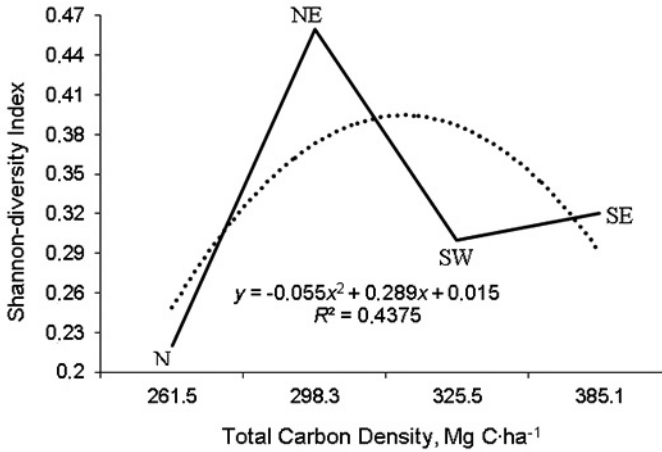


Fig. 4. The relationship of carbon stock density and Shannon diversity Index.

The northern direction of the studied forest was found to have good dominance of the adults of *T. contorta* species, that possessed the ability to survive under north slope exposure due to low temperature, moisture, shady area and acidic soil (Devaney et al. 2018, Pers-Kamczyc et al. 2019, Coughlan et al. 2020). There was a significantly high difference between the northern and southern geographical directions of bulk density (Table 5), i.e. northern to southern ($p = 0.044$) in 0–10 cm depth. But, in the 10–20 cm and 20–30 cm depths

there was no evidence of significant difference ($p > 0.05$) between geographical directions. The soil moisture defined as a percent value of the soil moisture content of the soil. In generally, it is the ratio of water volume to soil volume. There was no significant difference ($p > 0.05$) between the northern and southern geographical directions for soil moisture in 0–10 cm depth (Table 5). While, in 10–20 cm and 20–30 cm depth there was found significantly different ($p = 0.031$) and ($p = 0.021$)

respectively. The pH was slightly higher in the northern than in the southern main geographical directions (Table 5) but no significantly different ($p > 0.05$).

Poor regeneration of *T. contorta* was found in the study forest with limitations from shade-giving species, leaf litter leachates, high soil compaction and absence of fleshy-fruited shrub that may create its regeneration failure. This finding is consistent with Hulme 1997, García et al. 2000, Thomas and Polwart 2003, Linares 2013, Devaney et al. 2018.

Table 5. Edaphic parameters in main geographical directions.

Soil variables	Depth, cm	N	NE	SW	SE	p-value
Bulk Density, g·cm ³	0–10	0.17 ±0.02 ^a	0.17 ±0.06 ^a	0.22 ±0.05 ^b	0.23 ±0.03 ^b	0.044
	10–20	0.22 ±0.04	0.23 ±0.13	0.25 ±0.01	0.25 ±0.05	>0.05
	20–30	0.18 ±0.02	0.18 ±0.06	0.18 ±0.09	0.19 ±0.07	>0.05
Moisture, % by volume	0–10	81.27 ±12.28	80.6 ±19.54	77.21 ±35.52	75.07 ±10.31	>0.05
	10–20	51.01 ±24.65 ^a	73.33 ±18.56 ^{bc}	59.68 ±29.89 ^a	74.72 ±8.01 ^{ac}	0.031
	20–30	45.02 ±31.78 ^{bc}	70.8 ±37.35 ^a	59.76 ±33.07 ^{ac}	42.12 ±26.95 ^a	0.021
pH	0–10	6.3 ±0.3	6.1 ±0.25	6.4 ±0.25	6.8 ±0.28	>0.05

Note: Different letters in superscript indicate significant differences between geographical directions ($p < 0.05$).

Conclusions

It can be concluded that geographical directions change the micro-environment of forests that have effects on diversity. Stand structure, stand species, diversity, the biomass of species, edaphic factors and the vitality of the population depend on geographical directions. *T. contorta* regeneration is found limiting due to less moisture, high soil compaction and disturbance factors in its occurrence of slope exposures. Taking into account the above, immediate actions should be considered for the protection, conservation and restoration of this endangered species in the hilly temperate forest region of the Himalayas.

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SOIL COMPACTION AND EROSION LEVEL DUE TO GAP PLANTING IN INDONESIAN DEGRADED TROPICAL RAINFOREST

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Abstract

Indonesia's natural forests consist of various land and stand qualities, both highly degraded. In the past few years, the forest area has continued to decline. Gap planting is one of the silviculture techniques which can increase the productivity of the low potential tropical natural forest, mainly by using fast-growing species with short cutting rotation. The objective of this research was to study the impacts of gap planting on soil compaction and erosion in the Indonesian lowland tropical rain forest. Soil compaction was measured using Humbolt-Digital Statis Cone Penetrometer, soil erosion was measured using erosion pins and gap area was measured using Hexadecagon Method. The result shows that using gap planting causes soil compaction in gaps with an area of less than or equal to 250 m² and 1250–1500 m². However, the compaction value is classified as very loose soil so that it can be ignored. Otherwise, gap planting, using planting strips and chop off strips, has a positive impact by lowering erosion at gap size less than or equal to 250 to 2000 m².

Key words: chop off strip, cone penetrometer, erosion pin, planting strip, silviculture system.

Introduction

Indonesia's natural forests consist of various land and stand qualities, both highly degraded (Kusmana 2011). In the past few years, the forest area has continued to decline (Hansen et al. 2009, Broich et

al. 2011, KLHK 2015, KLHK 2016). According to KLHK (2017), the total state forest area of Indonesia was 125.96 million ha, and 32.70 million ha of which were degraded forest.

Gap planting is one of the silviculture techniques which can increase the pro-

ductivity of low potential tropical natural forest, mainly by using fast-growing species with short cutting rotation. Gap planting can improve gradually the ecological stability of forests. On the other hand, the research results of Schwartz et al. (2017), Elias and Suwarna (2019) recommended applying gap planting technique in the tropical forest which was at risk of land-use changes. Kusmana (2011) stated that there were several ecological requirements in the application of silviculture systems. These requirements were (1) minimizing disturbances to the soil, (2) maintaining the availability of soil organic matter, (3) maintaining biodiversity and (4) limiting the size and shape of disturbed areas.

Tropical rainforest succession begins when the forest canopy is opened. This open area is called a gap (Halle et al. 1978, Perry et al. 2008, Fischer et al. 2016). Natural gaps can vary in size. Among others were 100–1000 m² (Botkin et al. 1972), 400 m² (Halle et al. 1978), and 32.3–1636 m² (Muin 2009).

Soil compaction and erosion are the ecological indicators in sustainable forest management. Kusmana (2011) explained that ecological factors needed to be considered in the selection of silviculture system. The compacted soil can disturb the growth of tree roots and seedlings (Kozłowski 1999, Matangaran 2002). The results of Matangaran et al. (2010) showed that seedling growth was inversely related to soil compaction. Furthermore, compacted soil increases runoff and erosion (Kozłowski 1999, Alaoui et al. 2017) and leads to soil fertility reduction due to topsoil loss (Kusmana 2011).

The research results of Cornelio and Rao (2011) in Oomsis Village, Morobe Province, Papua New Guinea showed erosion that occurred in the agricultur-

al system, tropical natural forest, and grassland was ranging from 25–28 t·ha⁻¹, 20–23 t·ha⁻¹, and 8–10 t·ha⁻¹, respectively. Elias and Suwarna (2019) also explained that erosion due to gap planting in different cover types (natural forest area, chop of strip area, planting area) was 17.05 t·ha⁻¹, 16.83 t·ha⁻¹, 5.56 t·ha⁻¹, respectively. These results indicated that land use changes can affect soil erosion.

To address issue raised by Schwartz et al. (2017) and also Elias and Suwarna (2019), a study about the impact of gap planting on soil compaction and soil erosion is needed. However, this kind of study has not been so far carried out. Therefore, the objective of this research was to study the impacts of gap planting on soil compaction and erosion in Indonesian lowland tropical rainforest.

Materials and Methods

Research area

This research was carried out in lowland tropical rain forest at PT Intracawood Manufacturing (3°23'26" N, 116°55'19" E) which is in Betayau sub-district, Bulungan District, North Kalimantan, Indonesia. The forest condition was logged over forest. There were found 26 commercial tree species in this research area and 763 trees had a diameter at breast high (DBH) more than 20 cm. The soil type is red-yellow podzolic (ultisol). The topography of this area is 19.70 % flat to moderate slope, 23.70 % steep slope, and 60.50 % very steep slope. During the last 10 years, the average annual rainfall in the research area was 4091 mm·year⁻¹; meanwhile, annual temperature and relative humidity were 27.6 °C and 85.29 % (BMKG 2018).

Tools and materials

The research tools were erosion pin, Humbolt-Digital Statis Cone Penetrometer, measuring tape, clinometer, compass, chainsaw, machete, hoe, sickle and GPS. The research materials were nitrogen, phosphorus, potassium (NPK) fertilizer 15-15-15, seedlings of red jabon (*Anthocephalus macrophyllus* (Roxb.) Havil) and white jabon (*Anthocephalus cadamba* (Roxb.) Bosser). Fertilizer was applied 100 g per planting hole. It applied inside the planting hole before seedlings were planted.

Research area design

To study how to improve degraded forest, a low potential lowland tropical forest has

been chosen as a research location. The area was 10 ha. The research began with mapping the forest area mosaic. It was determined based on topographic classification, soil classification based on erosion vulnerability, tree density, and hydrological map. Topographic and tree density data were collected by the transect survey method. The transect size was 20×400 m and the plot size inside the transect was 20×20 m. Twelve transects were constructed in the research location.

Gap planting areas were planned on the forest area mosaic map (Fig. 1). The maximum of gap areas was 40 % of the total research area. The criteria for gap planting area were (1) the opened area or less productive forest that had volume of commercial species ($DBH \geq 40$ cm) less than or equal to $20 \text{ m}^3 \cdot \text{ha}^{-1}$ and (2)

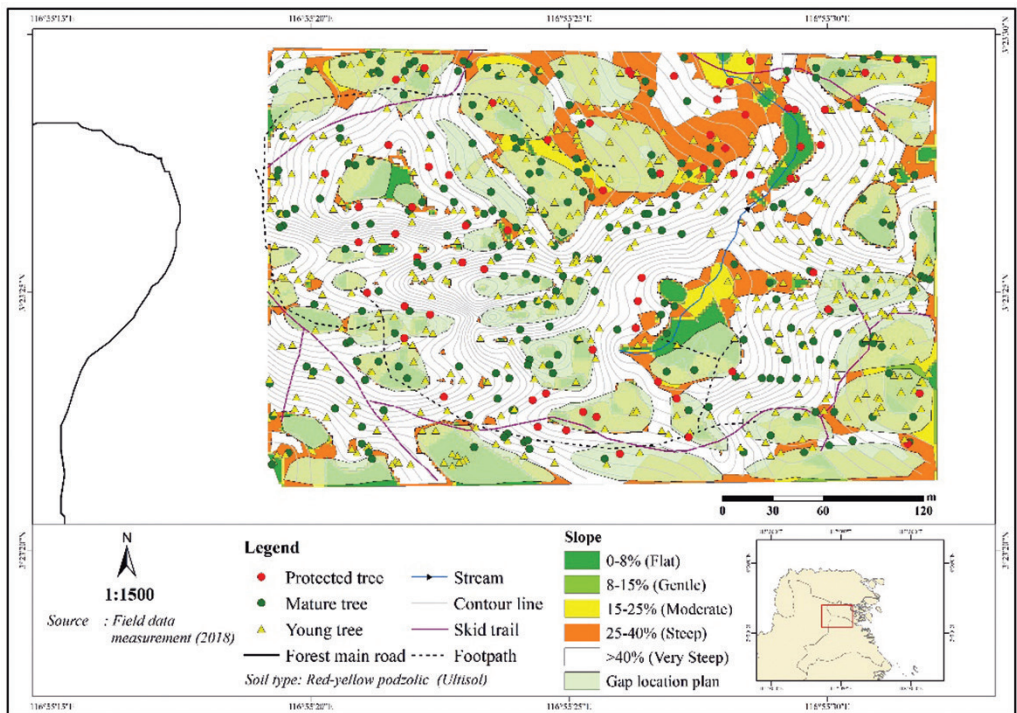


Fig. 1. Forest area mosaic map.

soil type not sensitive to erosion. Gap pattern and shape were constructed by adapting and following the field conditions. The gap was divided into 8 classes (class 1–8) with different areas: $\leq 250 \text{ m}^2$, $250\text{--}500 \text{ m}^2$, $500\text{--}750 \text{ m}^2$, $750\text{--}1000 \text{ m}^2$, $1000\text{--}1250 \text{ m}^2$, $1250\text{--}1500 \text{ m}^2$, $1500\text{--}1750 \text{ m}^2$, and $1750\text{--}2000 \text{ m}^2$.

Artificial gaps were constructed by cutting all trees inside the gap area boundary, except the commercial tree species with $\text{DBH} \geq 20 \text{ cm}$. Gap distance on average was 20 m. After its construction, planting strips and chop off strips were constructed inside the gap. The planting strip was the area for seedling planting. The chop off strip was the area located between 2 planting strips and its width was 3 m in which the understory was cleared as high as knee high. The planting strip width was 2 m in which the understorey was totally cleared. Planting strips and chop off strips were constructed in the east-west direction and the design was presented in Figure 2.

The gap area was measured with Hexadecagon Method (Green 1996, Zhu et al. 2009). Size of gap area was calculated by using the equation (1):

$$A_{sm} = 0.5 \sum_{i=1}^{16} L_{i+1} \cdot L_i \cdot \sin\left(\frac{\pi}{8}\right), \quad (1)$$

where: A_{sm} is gap area (m^2); L_{i+1} is the dis-

tance from the center to the edge of the gap; $i = 1, 2, \dots, 16$; π is radians (180°).

Data collecting

The research was conducted from January–April 2018. Soil compaction and soil erosion were measured after gap, planting strip, chop off strip, seedlings planting and gap area measurement. Soil compaction was measured in the center of the gap, planting strip, chop off strip, and outside the gap in the natural forest. Measurement was performed 3 times at each point using Humbolt-Digital Statis Cone Penetrometer after gap construction, gap planting, erosion pins installation were completed. The point of measurement location was nearby erosion pins (Fig. 3).

Erosion was measured using the field observation method (Elias 2012). Both soil erosion and soil deposition data were collected by erosion pin. The pins were pinned in the center of the gap (1 pin), planting strip (8 pins), chop off strip (8 pins), and outside the gap in the natural forest (8 pins). The first measurement of erosion was performed on 5th March and was used as the basis for the initial ground level benchmark. Erosion measurement was carried out 5 times a day after a rainy day in March which was 7th March, 9th March, 12th March, 19th March, and 22nd

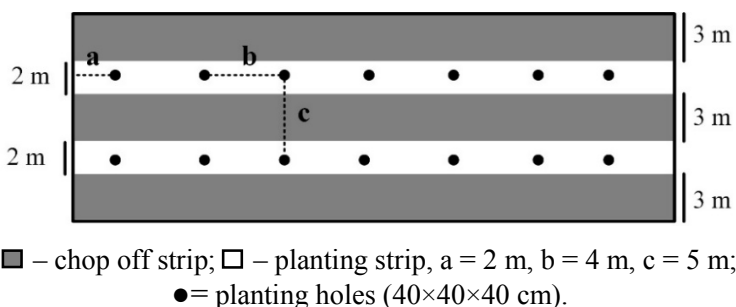
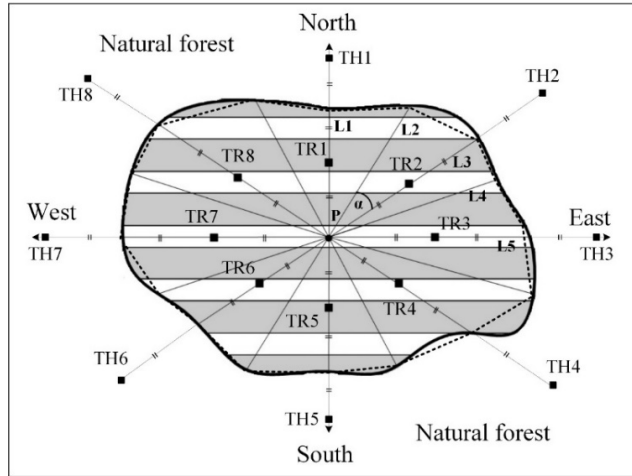


Fig. 2. Planting and chop off strip design.



■ – chop off strip; □ – planting strip; ■ – points of measurement; TR1, TR2, ..., TR8 – measurement points inside the gap; TH1, TH2, ..., TH8 – measurement points outside the gap or in the natural forest; P – gap center; L1, L2, ..., Ln – gap radius order; $\alpha = 22.5^\circ$.

Fig. 3. Illustration of soil compaction and erosion measurement points.

March 2018. Rainfall variations at the research location before erosion measurement were 24.2 mm, 18.4 mm, 11.6 mm, 16.1 mm and 15.5 mm (BMKG 2018).

Data analysis

The examined parameters in this research were soil compaction, erosion height, soil erosion volume, and soil erosion weight on each cover type (planting strip, chop off strip, and natural forest). Soil compaction equation (2) is as follows:

$$EP_j = \frac{1}{n} \sum_{i=1}^n P_{ij}, \quad (2)$$

where: EP_j is average of soil compaction at cover area type j ($\text{kgf} \cdot \text{cm}^{-2}$), j is cover area type, n is number of repetitions, i is the point of measurement in each cover area type (1, 2, ..., 8), P_{ij} is soil compaction at point i and cover area type j ($\text{kgf} \cdot \text{cm}^{-2}$).

Total soil erosion volume per hectare was calculated based on the area proportion of planting strip, chop off strip and natural forest. It was 15:25:60 %. This proportion implied in each hectare research area there were 1600 m^2 of planting strip, 2400 m^2 of chop off strip, and 6000 m^2 of natural forest. The soil erosion weight was calculated by using 0.59 $\text{g} \cdot \text{cm}^{-3}$ of natural forest soil bulk density and 0.67 $\text{g} \cdot \text{cm}^{-3}$ of planting and chop off strip soil bulk density (Handayani and Karmilasanti 2013). These soil bulk density values were used based on the same location of research. Erosion parameters were calculated by using the following equations (3–6):

$$EH_j = \frac{1}{n} \sum_{i=1}^n H_{ij}, \quad (3)$$

$$EV_j = A_j \cdot EH_j, \quad (4)$$

$$EW_j = BD_j \cdot EV_j, \quad (5)$$

$$TE = \sum_{j=1}^3 EW_j, \quad (6)$$

where: EH_j is average of soil surface erosion height at cover area type j (m), j is cover area type, n is number of repetitions, i is the point of measurement in each cover area type (1, 2, ... 8), H_{ij} is ground surface erosion height at point i and cover area type j (m), EV_j is average soil erosion volume at cover area type j ($\text{m}^3 \cdot \text{ha}^{-1}$), A_j is area of cover type j (m^2), EW_j is average of soil erosion weight at cover type j ($\text{t} \cdot \text{ha}^{-1}$), BD_j is soil bulk density cover area type j ($\text{g} \cdot \text{cm}^{-3}$), TE is total erosion in the research area ($\text{t} \cdot \text{m}^{-3}$).

Soil compaction and erosion level due to gap planting were analysed with ANOVA. The first factor was the type of cover areas: planting strip, chop off strip and natural forest area. The second factor was the gap size, which consisted of 8 class areas. They were analysed at a significant level of 5% ($p = 0.05$). Whenever the factors or their interactions were significant, Tukey test was carried out.

Results and Discussions

Soil compaction level

The average of soil compaction on planting strip was $3.38 \text{ kgf} \cdot \text{cm}^{-2}$ which ranged from $2.67 \text{ kgf} \cdot \text{cm}^{-2}$ (gap class 6) to $4.15 \text{ kgf} \cdot \text{cm}^{-2}$ (gap class 1) (Table 1). Soil compaction in planting strip in gap class 1 is 1.55 times larger than gap class 6. The average of soil compaction in chop off strip was $3.23 \text{ kgf} \cdot \text{cm}^{-2}$ which ranged from $2.69 \text{ kgf} \cdot \text{cm}^{-2}$ (gap class 8) to $3.90 \text{ kgf} \cdot \text{cm}^{-2}$ (gap class 1) (Table 1). The lowest soil compaction in chop off strip almost has no difference compared to the lowest soil compaction in planting strip ($0.02 \text{ kgf} \cdot \text{cm}^{-2}$). Otherwise, the highest soil compaction in both cover types has a difference of $0.25 \text{ kgf} \cdot \text{cm}^{-2}$. These results were relatively lower than other results by Elias and Suwarna (2019). They said that the average of soil compaction in planting strip and chop off strip were $3.90 \text{ kgf} \cdot \text{cm}^{-2}$ and $4.42 \text{ kgf} \cdot \text{cm}^{-2}$.

Soil compaction due to gap planting in this research was lower than soil compaction due to skidding in the industrial for-

Table 1. Soil compaction in each gap class and different forest cover types, and ANOVA test value.

Gap class	Soil compaction, $\text{kgf} \cdot \text{cm}^{-2}$			<i>p</i> -value*
	Planting strips	Chop off strip	Natural forest	
1	4.15	3.90	3.21	0.010**
2	3.83	3.88	3.38	0.285
3	3.13	2.79	2.53	0.113
4	3.71	3.31	2.95	0.099
5	3.56	3.46	2.95	0.238
6	2.67	2.88	2.05	0.011**
7	2.81	2.92	2.52	0.197
8	3.17	2.69	2.48	0.078
Average	3.38	3.23	2.76	

Note: *probability value, **significant.

est in South Sumatra (Matangaran 2012). The author also explained, with the same soil type, soil compaction on the skid trail that was not covered with wood harvesting waste was 8.50–10 kgf·cm⁻². On the other hand, soil compaction on the skid trail that was covered with wood harvesting waste before skidding was 5.70–9.00 kgf·cm⁻².

The average of soil compaction in natural forest was 2.76 kgf·cm⁻² which ranged from 2.05 kgf·cm⁻² (gap class 6) to 3.38 kgf·cm⁻² (gap class 2) (Table 1). The difference between the highest and lowest soil compactions in natural forests was 1.33 kgf·m⁻². This result was lower than soil compaction in the undisturbed area of the industrial forest, with the same soil type, in South Sumatera of 4.49 kgf·cm⁻² (Matangaran 2012) and the other gap planting construction of 3.04 kgf·cm⁻² (Elias and Suwarna 2019).

The average of soil compaction in planting strip was the highest when compared to other cover types. In order, the average soil compaction in each forest cover type was planting strip (3.38 kgf·cm⁻²), chop off strip (3.23 kgf·cm⁻²), and natural forest (2.76 kgf·cm⁻²) (Table 1).

The highest soil compaction due to gaps construction was 0.25 times lower than soil density due to harvesting of the industrial forest using heavy equipment (12.96–13.98 kgf·cm⁻²) (Matangaran and Suwarna 2012). The average soil compaction in all cover types after gap construction was classified as a very loose condition (Wesley 2010) and expectedly did not disturb root growth. Sinnett et al. (2008) explained that root growth was relatively undisturbed at soil compaction values ranging from 0–20.39 kgf·cm⁻². According to Wesley (2010), the value of cone penetrometer penetration was: very compacted soil more than 203.94 kgf·cm⁻², compacted soil 122.37–203.94 kgf·cm⁻², medium compacted soil 40.79–122.37 kgf·cm⁻², loose soil 16.32–40.79 kgf·cm⁻², and very loose soil less than 16.32 kgf·cm⁻².

ANOVA test with cover types and gap size revealed a significant result, cover type and gap size class 1 ($p = 0.010$) and gap class 6 ($p = 0.011$) for soil compaction (Tabel 1). Tukey test (Table 2) showed that the significant result in gap class 1 was in planting strip and natural forest ($p = 0.010$). Significant result in gap class

Table 2. Tukey test value.

Gap class	Cover type		<i>p</i> -value*
	Group 1	Group 2	
1	Planting strip	Chop off strip	0.663
	Planting strip	Natural forest	0.010**
	Chop off strip	Planting strip	0.663
	Chop off strip	Natural forest	0.064
	Natural forest	Planting strip	0.010**
	Natural forest	Chop off strip	0.064
6	Planting strip	Chop off strip	0.676
	Planting strip	Natural forest	0.061
	Chop off strip	Planting strip	0.676
	Chop off strip	Natural forest	0.011**
	Natural forest	Planting strip	0.061
	Natural forest	Chop off strip	0.011**

Note: *probability value, **significant.

6 was in chop off strip natural forest and ($p = 0.011$).

Erosion level

Erosion occurs due to interactions between climate, vegetation and topography parameters with humans (Suwarna et al. 2009, Lieskovský and Kenderessy 2012, Gabarrón-Galeote et al. 2013, Ochoa et al. 2016). Topography and vegetation (tree density and cover types) were parameters that were used in research area design. Topography variations and tree density in each gap class can be seen in Table 3.

Topography in each gap class area was determined by weighting the middle point of topography class with its area (Table 4). For instance, the topography of gap class 1 was found to be 33.62 % (or class 4 topography), which was calculated by formula (7).

$$\text{Gap topography}_a = \frac{\sum_{b=1}^n (X_{ba} \cdot W_b)}{\sum_{b=1}^n X_a} \cdot 100 \%, \quad (7)$$

where: Gap topography_a is topography in gap class a; a is gap class 1, 2, ..., 8; X_{ba} is area of topography b in gap class a; W_b is middle point of topography class b;

b is topography class (flat 0–8 %, gentle slope 8–15 %, moderate 15–25 %, steep 25–40 %, very steep class 40–83 %); X_a is area of gap class-a. For example, the calculation of gap class 1 topography:

$$\begin{aligned} & [(26.52+0.13) \cdot 0.04 + (10.14+1.62) \cdot \\ & 0.115 + (24.12+2.57) \cdot 0.2 + (159.61+ \\ & 212.58) \cdot 0.325 + (28.99+33.33) \cdot 0.63] \cdot \\ & 100\% / (249.39+250.25) = 33.62 \% \end{aligned}$$

Gap topography variation in each gap class can be seen in Table 4.

Similarly, tree density was also determined by weighting the middle point of the tree density class with its area (Table 5). For example, the tree density of gap class 1 was 37 trees ha⁻¹ (or class 1 tree density) which was calculated using formula 8.

$$\text{Tree density}_a = \frac{\sum_{d=1}^n (X_{da} \cdot W_d)}{\sum_{d=1}^n X_a} \text{ tree} \cdot \text{ha}^{-1}, \quad (8)$$

where: Tree density_a is tree density in gap class a; a is gap class 1, 2, ..., 8; X_{da} is area of tree density d in gap class a; W_d is middle point of tree density class d; d is tree density class (very low = 0–45 tree·ha⁻¹, low = 45–90 tree·ha⁻¹, moderate = 90–135 tree·ha⁻¹, high = 135–180 tree·ha⁻¹, very high = 180–225 tree·ha⁻¹); X_a is area of gap class a. For example, the calculation of gap class 1 tree density:

Table 3. Topography and tree density.

Gap class	Gap size interval, m ²	Topography class*	Tree density class**
1	≤ 250	4	1
2	250–500	5	1
3	500–750	4	2
4	750–1000	4	2
5	1000–1250	5	2
6	1250–1500	4	2
7	1500–1750	5	2
8	1750–2000	4	3

Note: *Slope of Topography class: 1 = 0–8 %, 2 = 8–15 %, 3 = 15–25 %, 4 = 25–40 %, 5 = 40–83 %. **Tree density class: 1 = 0–45 tree·ha⁻¹, 2 = 45–90 tree·ha⁻¹, 3 = 90–135 tree·ha⁻¹, 4 = 135–180 tree·ha⁻¹, 5 = 180–225 tree·ha⁻¹.

Table 4. Gap topography variation.

Gap class	Gap size interval, m ²	Gap code	Gap area, m ²	Gap topography*									
				Flat		Gentle slope		Moderate		Steep		Very steep	
				m ²	%	m ²	%	m ²	%	m ²	%	m ²	%
1	≤ 250	A	249.39	26.52	10.63	10.14	4.07	24.12	9.67	159.61	64.00	28.99	11.63
		L	250.25	0.13	0.05	1.64	0.66	2.57	1.03	212.58	84.95	33.33	13.32
2	250–500	B	372.19	151.54	40.72	5.01	1.35	17.78	4.78	14.86	3.99	183.00	49.17
		K	476.27	31.36	6.58	10.45	2.19	37.16	7.80	98.27	20.63	299.03	62.79
3	500–750	D	632.11	237.59	37.59	27.47	4.35	123.24	19.50	151.43	23.96	92.38	14.61
		G	538.13	9.31	1.73	16.30	3.03	72.81	13.53	120.96	22.48	318.75	59.23
4	750–1000	C	938.05	123.66	13.18	31.90	3.40	49.84	5.31	184.29	19.65	548.36	58.46
		N	983.19	121.38	12.35	34.28	3.49	188.10	19.13	591.46	60.16	47.97	4.88
5	1000–1250	M	1092.84	53.80	4.92	17.72	1.62	25.62	2.34	216.14	19.78	779.57	71.33
		F	1076.5	39.19	3.64	11.99	1.11	172.05	15.98	378.78	35.19	474.49	44.08
6	1250–1500	I	1250.33	207.39	16.59	34.06	2.72	53.22	4.26	255.95	20.47	699.71	55.96
		H	1489.48	545.15	36.60	57.64	3.87	181.46	12.18	220.30	14.79	484.93	32.56
7	1500–1750	P	1574.67	0.00	0.00	0.00	0.00	162.50	10.32	1318.89	83.76	93.28	5.92
		J	1622.88	8.45	0.52	19.53	1.20	125.64	7.74	527.71	32.52	941.55	58.02
8	1750–2000	O	1834.69	31.98	1.74	36.45	1.99	942.97	51.40	744.27	40.57	79.02	4.31
		E	1907.16	446.36	23.40	35.68	1.87	55.22	2.90	258.31	13.54	1111.59	58.29
Total			16 288.24	2033.82		350.26		2234.30		5453.80		6215.96	

Note: *Gap topography: Flat = 0–8 %, Gentle slope = 8–15 %, Moderate = 15–25 %, Steep = 25–40 %, Very steep class = 40–83 %.

Table 5. Tree density variation of gaps.

Class	Gap size interval, m ²	Gap code	Gap area, m ²	Tree density*							
				Very low		Low		Moderate		High	
			m ²	m ²	%	m ²	%	m ²	%	m ²	%
1	≤ 250	A	249.39	249.35	99.98	0.04	0.02	0.00	0.00	0.00	0.00
		L	250.25	88.82	35.49	161.43	64.51	0.00	0.00	0.00	0.00
2	250–500	B	372.19	243.34	65.38	128.85	34.62	0.00	0.00	0.00	0.00
		K	476.27	329.94	69.28	146.33	30.72	0.00	0.00	0.00	0.00
3	500–750	D	632.11	85.26	13.49	188.89	29.88	357.96	56.63	0.00	0.00
		G	538.13	179.71	33.40	357.77	66.48	0.65	0.12	0.00	0.00
4	750–1000	C	938.05	14.44	1.54	671.49	71.58	252.11	26.88	0.00	0.00
		N	983.19	445.29	45.29	239.93	24.40	297.97	30.31	0.00	0.00
5	1000–1250	M	1092.84	520.03	47.59	162.39	14.86	3.27	0.30	294.11	26.91
		F	1076.5	913.89	84.89	162.61	15.11	0.00	0.00	0.00	0.00
6	1250–1500	I	1250.33	707.16	56.56	543.17	43.44	0.00	0.00	0.00	0.00
		H	1489.48	614.39	41.25	213.96	14.36	0.00	0.00	397.38	26.68
7	1500–1750	P	1574.67	5.09	0.32	1110.86	70.55	458.71	29.13	0.00	0.00
		J	1622.88	1266.21	78.02	244.39	15.06	49.96	3.08	62.33	3.84
8	1750–2000	O	1834.69	0.00	0.00	798.81	43.54	749.32	40.84	0.00	0.00
		E	1907.16	42.77	2.24	1286.57	67.46	577.81	30.30	0.00	0.00
Total			16 288.24	5705.70		6417.49		2747.76		753.82	
										663.36	

Note: *Tree density: Very low = 0–45 tree·ha⁻¹, Low = 45–90 tree·ha⁻¹, Moderate = 90–135 tree·ha⁻¹, High = 135–180 tree·ha⁻¹, Very high = 180–225 tree·ha⁻¹.

tion of gap class 1 tree density:

$$[(249.35+88.82) \cdot 22.5 + (0.04+161.43) \cdot 67.5 + (0+0) \cdot 112.5 + (0+0) \cdot 157.5 + (0+0) \cdot 202.5] / (249.39+250.25) = 37 \text{ tree} \cdot \text{ha}^{-1}$$

Tree density variation in each gap class can be seen in Table 5. With the same technique, topography and tree density classes of other gap classes were determined.

The greatest soil erosion due to gap planting occurred in gap class 7 and the smallest occurred in gap class 8 (Table 6). Soil deposition occurred only in gap class 2. Soil erosion was considerably affected by the size of gaps, topography conditions, and tree density at each gap.

Gap class 8 had the highest tree density (class 3) compared to other gaps and had a relatively more sloping topography (class 4). Otherwise, gap class 7 had class 2 tree density and had the steepest topography (class 5). Sun et al. (2014) explained that denser vegetation provided more protection from erosion. The topography conditions in gap class 8 were relatively balanced between the flat to moderate (41.65 %) and the steep topographic class to very steep (58.35 %) (Table 4). Although gap class 5 had a mid-

size area (1000–1250 m²), it occupied the second-greatest erosion. Gap class 5 had the largest proportion of very steep topography (Table 4). Topographic variations in the gap affected erosion and the greater proportion of steep topography caused greater erosion. Tarigan and Mardiatno (2012), and Zhang et al. (2018) explained that soil erosion was directly related to slope gradient.

Chop off strip had the smallest erosion weight. The soil erosion weight ranged from 4.41 t·ha⁻¹ to 15.39 t·ha⁻¹ (Table 7). The high level of erosion in the natural forest was caused by topography conditions. Unlike gaps that were constructed on relatively flat areas, natural forests were outside the gaps with steep and very steep topography (Fig. 4). Topography, trees and gaps distribution can be seen in Figure 4.

In general, soil erosion weight decreased in the following order: natural forest > planting strip > chop off strip (Table 7). This result was different compared to other results. Cornelio and Rao (2011) said that the highest soil erosion occurred in the agricultural system and soil erosion decreased in the following order: agricul-

Table 6. Soil erosion weight.

Gap class	Cover type, t*			Total, t·ha ^{-1**}
	Planting strip	Chop off strip	Natural forest	
1	0.70	8.34	9.68	18.72
2	-2.28	-1.13	-3.60	-7.00
3	3.97	-3.87	10.10	10.20
4	-0.25	-5.63	13.21	7.33
5	2.04	10.83	12.40	25.28
6	5.71	-0.55	6.89	12.05
7	7.72	0.90	20.47	29.09
8	-2.66	-0.43	4.70	1.61

Note: *The negative numbers represent soil deposition, while positive numbers represent soil erosion. **Cover type area proportion in 1 ha consists of planting strip 1600 m², chop off strip 2400 m² and natural forest 6000 m².

Table 7. Soil erosion weight.

Cover type	Soil surface erosion height, m	Soil erosion volumen, m ³ ·ha ⁻¹	Soil erosion weight, t·ha ⁻¹
Planting strip	0.17	17.44	11.69
Chop off strip	0.07	6.58	4.41
Natural forest	0.26	26.08	15.39

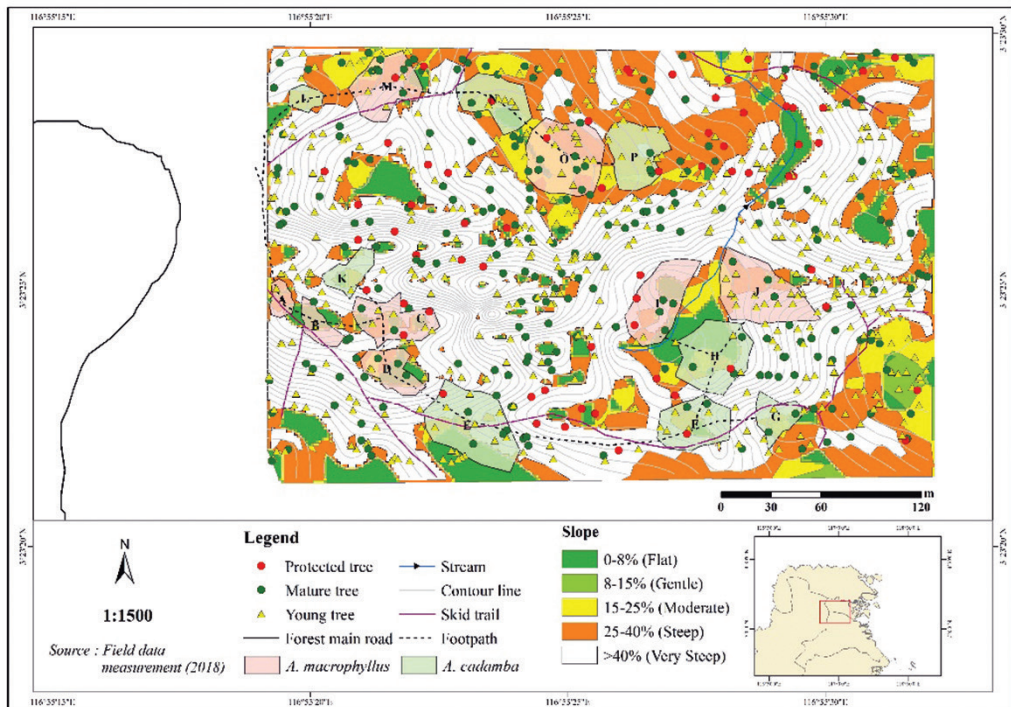


Fig. 4. Topography, trees and gaps distribution.

tural systems > forest systems > grasslands. It was 8–10 t·ha⁻¹, 20–23 t·ha⁻¹, 25–28 t·ha⁻¹. Elias and Suwarna (2019) also explained that erosion due to gap planting in different cover types with the same soil decreased in the following order: forest area > chop of strip area > planting area. The soil erosion weight was 17.05 t·ha⁻¹, 16.83 t·ha⁻¹, 5.56 t·ha⁻¹, respectively.

In addition to relatively flat topographic conditions, gap waste of logs, branches, twigs, leaves and grass in the gap also affect erosion. The waste from gap construc-

tion on chop off strip becomes litter and together with the grass slow down water flow, increase infiltration and reduce runoff. This result was in accordance with the results by Elias and Suwarna (2019) who explained that gap waste and grass in chop off strip reduced soil erosion. Research by Tang et al. (2014), in the upper Yangtze Watershed, China, proved that grass was more effective in reducing surface runoff and sediment than woody plants. Suwarna et al. (2009) also explained that the logged-over forest floor which was cov-

ered by grass or cover crop was more effective in reducing soil erosion.

The study results showed that soil erosion weight variations in each gap class were caused by topographical variations and tree densities. Greater erosion occurs at gaps with steeper topography. This result was also showed by Tarigan and Mardiatno (2012) and Zhang et al. (2018). It explained that steeper topography caused greater run off and soil loss. On the other side, the higher density of trees reduce erosion. Denser vegetation and the root systems of trees slowed overland water flow (Sun et al. 2014). Gap cover types also have a role to reduce the amount of soil erosion weight. Gap planting, using planting strip and chop off strip, has positive impact reducing the erosion. Grass and gap waste slowed down the water flow, increased infiltration and reduced runoff (Suwarna et al. 2009, Cornelio and Rao 2011, Tang et al. 2014, Elias and Suwarna 2019). However, ANOVA test results showed that the cover types and gap sizes were not significant for soil erosion weight.

Conclusion

The results of this study show that using gap planting technique to rehabilitate Indonesian lowland tropical rainforest caused soil compaction. Soil compaction due to gap planting occurs in gaps with an area of less than or equal to 250 m² and 1250–1500 m². However, the compaction value is classified as very loose soil so that it can be ignored. Otherwise, this technique can reduce soil erosion. Gap planting, using planting strips and chop off strips, has a positive impact lowering erosion at gap sizes less than or equal to 250 to 2000 m².

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FURTHERING FOREST EDUCATION – A CASE STUDY FROM GERMANY

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Abstract

This study analyses the implementation of forest education in 13 German federal states in combination with the number of applicants for a vocational education in forestry, as well as the number of students at the faculties of forestry in Germany. Obtained results show that establishing the basics of forest didactics and taking into account educational topics beside the classical knowledge of woodland species, furthers the interest in forests and forest professions in general. The number of students in the university can be considered to be a suitable indicator for a good establishment of forest didactics and a general interest in forests, while the number of applicants in vocational education can be considered to be an indicator for a holistic and sustainable approach to forest education, according to this study.

Key words: forest didactics, forest pedagogics, study motivation.

Introduction

Choosing a profession is an important step in the lives of adolescents worldwide. Studies show that personal interests and inclinations play a major role in choosing a certain vocational path (Akosah-Twumasi et al. 2018). While parental and peer influence both play an essential role in finding a decision for the question ‘what do I want to do for a living?’, education offers an opportunity to explore and develop interests outside the family surroundings. In Germany, professions with a focus on nature and natural sciences, in combination with a technical orientation, have a traditionally low number of students applying for an apprenticeship or academic education,

compared with other vocations (Barman 1999; Bertels and Bolte 2009, 2014; Elster 2009; Taskinen 2010; Frank and Niethammer 2012; Haucke and Parchmann 2012). Studies have come to the conclusion that during their primary and secondary education many students garner negative impressions related to these professions, which result in a low interest in the corresponding vocations.

To further these vocational educations, a positive perception in the minds of pupils needs to be fostered. This means, students have to experience motivating lessons and learning settings during their time at school (Bolte 2004, Bertels and Bolte 2014) to develop a positive concept of a profession for themselves (Taskinen

2010, Bertels and Bolte 2014). During the consultations of the Global Forest Education project of the Food and Agriculture Organisation of the United Nations, the question arose at which age and to what extent forest education should be integrated into the curricula (FAO 2021). To make it short: when forest-related education is well-implemented and taught at school, using good and motivating concepts, the number of students applying for an apprenticeship should be comparatively high.

The study was conducted in regard to the German vocational and academic education system for forestry professions. Due to this, we shall have a brief introduction to the local education system: After four years of elementary schooling, German students perform/visit one form of secondary school – *Hauptschule*, *Realschule* or *Gymnasium*. The latter is especially designed to prepare for an academic education after completing the final exams with the *Abitur*, the certificate for higher education entrance qualification (Dahm and Kerst 2019). For this type of school, a student typically needs good marks (2/B or better¹) in the relevant subjects of mathematics, German and *Sachunterricht* – a subject that is a combination of local history, geography and biology – in elementary school. Most students (90 %) going for a forest-related vocational education, have attended the *Real-* or *Hauptschule*. The *Hauptschule* is considered to be for the less able students, graduating in grade 9, while at the *Realschule* the final exams are one year later. Both of them prepare for a vocational education. The curricula of these two are mostly very similar to each other, while at the *Gymnasium* these are set to prepare students for

an academic education.

In Germany, each of the 16 federal states organizes education autonomously. Some states have forest education as mandatory set of ecosystems, while in others, teachers can choose between forests, meadows, lake, rivers, the sea, etc. Furthermore, even after 30 years of re-unified Germany, there are still cultural differences between the former West and East Germany (Arnhold 2009, Hugendick and Seuber 2019).

Forestry and forest ecosystems have a long-standing history and tradition in German education (Hepper 2017), so this can be considered to be a very well and thoroughly covered subject. This is directly linked to the historical and cultural significance of forests in Germany since the late 19th century (Wilson 2012). Typically this means that students learn, over an extended length of time, how to identify forest plants and trees, as well as tracks of woodland animals. A major focus lies in assessing the closeness to nature of forest ecosystems in secondary schools, while in elementary school students learn to identify typical trees and plants found in the local forest.

This study aims to identify the best practices of primary and secondary forest education from a German point of view. Data comes from 13 large federal states. Due to the very small number of students completing their forest-related exams, the city states of Hamburg, Bremen and Berlin were excluded from this study.

Methods

The study was conducted using a combination of grounded theory and qualitative content analysis. Following the concept of qualitative research to gather and assess

¹ 1 = A = very good; 2 = B = good; 3 = C = satisfactory; 4 = D = pass; 5 = E = with deficits (fail mark); 6 = F = not sufficient (fail mark).

the data generated, grounded theory can be considered to be a suitable approach for working on research questions, with little or no research having been conducted before on this subject (Strauss and Corbin 1994, Tolhurst 2012). For this, a continuous exchange between gathering, analyzing and evaluating data is necessary. Due to the small set of data, the method of the case study can be considered to be a suitable approach as well (Langner 2011).

First, the forest/biology-related curricula of the 13 German states were systematically analyzed (Mayring 2010) regarding the content and extent of forest ecosystems and forestry. This was done without reading any further publications on the subject (Glaser 1965, Tolhurst 2012, Charmaz 2014). The curricula were categorized into:

- school years, where forest ecosystems/forest-related education is an integral and important part of the curriculum (being mentioned as the sole ecosystem to be taught);
- school years, where forest ecosystems/forest-related education is an elective/possible topic in the curriculum (being mentioned as one of many options or the curricula ask for local ecosystems in general);
- school years, where forest ecosystems/forest-related education is not part of the curriculum (no local ecosystem, etc., in the curricula).

After assessing the curricula, two federal states, Lower Saxony and Mecklenburg-Vorpommern, were chosen and compared regarding the number of students applying for a forest worker education in comparison to the total number of students who had completed their secondary education in the respective year. In Mecklenburg, forest ecosystems are the focus in classes 1 to 6, while in Lower

Saxony, it is only one of the many possible ecosystem covered. In both states this habitat has the same importance for the A-level courses² in biology.

After this, first hypothesis was generated and tested against new data from other federal states. Since that reforming the hypothesis was always made after getting new data. This was repeated until a constant/stable pattern was identified (Glaser and Strauss 2010). The approach is more inductive, following Glaser's pragmatism and thorough analysis (Strübing 2002, Kelle 2005).

After curricula analysis, similar kind of approach was done for analyzing students who had passed the necessary examination for entrance to a university. The data on the number of students, who had completed their secondary school education each year in the respective federal state, are available from the Federal Statistical Office of Germany. The data regarding the number of students choosing a forestry-related vocational profession covers a time span of three years (2018–2020) and was thankfully provided by the state forest education agencies of the different provinces. The numbers regarding the university students were provided by the faculties of forestry at the various universities, which was greatly appreciated.

Regarding the students applying for a vocational education, first the percentage of the annual applicants in regard of the total number of students completing their school education was calculated for each state. The same was done for those who pursued an academic education in forestry and forest sciences. After calculating

² The English term A-level is used for better understanding for international readers. In Germany, students choose a A-level course where they will have the examination or write a minor thesis paper.

the standard error, the states were categorized into four clusters. For data analysis, the cluster analysis was used. The ideal number of clusters (k-means) was 4, using the metric variables of interest (percentage of students applying for a vocational forest education of enrolling in an academic education in forestry and forest sciences) in academic and vocational education (Milligan and Cooper 1985, Tuma et al. 2009, Zenina and Borisov 2013). Cluster 4 was formed out of those states, where students had an average interest in a forestry related education. Cluster 3 consisted out of states, where the students had a higher than average interest in a vocational forestry education, compared to the average. Cluster 2 consisted out of states, where the students had a higher than average interest in an academic forestry education, while cluster 1 consisted out of states, where the students had a higher than average in vocational as well as academic forestry educations.

With forestry universities, we have the trouble that no data was available on those applying for an academic education. Some universities normally choose their students based on the *nummerus*

clausus, while others had no admission requirements at all during the time of observation. With a mean NC of 2.1 to 3.0 for these universities (numbers provided by the universities), compared to an average grade of 2.1 to 2.6 in the federal states in the time span observed (KMK 2021), there was a similar chance for students from every state.

Results

Results of clustering federal states in terms of percentages of forest-related students and implementation of forest-related education are shown in Table 1. The first cluster consists of only one state Mecklenburg-Vorpommern with 2.46 % of the students applying for forest-related education (mean = 0.56 %, SD = 0.6 %). Here the percentage of students having an interest in pursuing a vocational education in forestry is nearly five times as high, as the German average. This observation continues in academic education, with this federal state again having a higher number than average, after calculating the mean and standard error.

Table 1. Results of the research with the federal states sorted in alphabetical order.

Provinces	Percentage of applicants in vocational education	Percentage of students in bachelor of science in forestry/forest sciences	Forestry/forest ecology a major subject in classes	Forestry/forest ecology a possible topic/subject
Cluster 1: provinces with a high interest in vocational and academic forestry education				
Mecklenburg-Vorpommern*	2.46 %	0.46 %	1, 2, 3, 4, A-IvI*	5, 6
Cluster 2: provinces with a high interest in academic forestry education				
Baden-Württemberg	0.28 %	0.38 %		1, 2, 3, 4, 5, 6, A-IvI.
Bavaria	0.19	0.45 %		1, 2, 3, 4, 5, 6, 7, 8, 10, A-IvI.
Brandenburg*	0.29 %	0.44 %	4	1, 2, 3, 5, 6, 7, 8

Provinces	Percentage of applicants in vocational education	Percentage of students in bachelor of science in forestry/forest sciences	Forestry/forest ecology a major subject in classes	Forestry/forest ecology a possible topic/subject
Cluster 3: provinces with a higher than average interest in vocational forestry education				
Rhineland-Palatinate	0.73 %	0.1 %	A-lvl.	1, 2, 3, 4, 5, 6, 7, 8
Saxony-Anhalt*	0.94 %	0.13 %	4, 9	1, 2, 3, 5, 6, 10, A-lvl.
Cluster 4: provinces with an average interest in vocational and academic forestry education				
Hessen	0.51 %	0.09 %		1, 2, 3, 4, 5, 6, 7, 8, 9, 10, A-lvl.
Lower Saxony	0.25 %	0.16 %	A-lvl.	1, 2, 3, 4, 5, 6, 7
North Rhine-Westphalia	0.11 %	0.14 %		1, 2, 3, 4, 5, 6, 7, A-lvl.
Saarland	0.49 %	0.13 %	8, A-lvl.	1, 2, 3, 4, 5, 6, 10
Saxony*	0.38 %	0.1 %	4, 6	5, 7, A-lvl.
Schleswig-Holstein	0.24 %	0.09 %		1, 2, 3, 4, 5, 6, 7, 8, 9, 10, A-lvl.
Thuringia*	0.56 %	0.17 %	1, 2, 3, 4	7, 8, 9, 10

Note: Highlighted in bold and darker grey are those countries which stand out with particular high results. States with an asterisk * are from Eastern Germany.

With cluster 2, including federal states Baden-Württemberg, Bavaria and Brandenburg, similar results (0.38–0.46 % of all students completing their A-levels) were visible. Again, no state could be identified in having a significant low number of students applying for forestry programs in university ($\bar{x}$ 0.14 % SD = 0.15 %).

In cluster 3, we find the states Rhineland-Palatinate and Saxony-Anhalt. These two had a higher than average number of students, applying for a vocational education in forestry, but only an average number of students applying for an academic education in forest sciences or forestry.

Hessen, Lower Saxony, North Rhine-Westphalia, Saarland, Saxony, Schleswig-Holstein and Thuringia make up the average cluster in all regards considering forestry education. In all German provinces, we find very similar topics regarding the content of forest related education

(Table 2).

In Mecklenburg-Vorpommern, forest education does not solely focus on the classical forest-related topics, but integrates healthy nutrition with forest plants, fruits and venison, orientation with a map in the forest, the health benefits of going to a forest, etc., as well (Wald-MV 2021). This is the only federal state, where this is done at the moment.

Taking these results into account, Mecklenburg-Vorpommern can be considered to be the state, where forest related education is the most effective in furthering interest in the professions related to this ecosystem. Considering the newly formed curricula, it is one of the two federal states, where relevant content is implemented as the major living environment for educational purposes in elementary school, and as an elective topic in grades 5 and 6. On first glance, this is very similar

Table 2. Results of the content analysis of the curricula.

Provinces	Topics covered in the curricula
Typical topics in all provinces	• species of trees and bushes in the forest
	• forest ecosystems (deciduous and coniferous), especially alluvial forests
	• forest layers
	• typical game animals and wildlife
	• early blossoming plants
	• life in the forest soil
	• forestry professions
Mecklenburg-Vorpommern	• forestry
	Additionally:
	• reading maps and orientation
	• cooking with forest products like edible plants, etc.
	• forests and health
	• sounds and music in the forest

to the situation in Thuringia. Nevertheless, the results are quite different, with Thuringian students only having an average interest in becoming a forest worker or studying forest sciences, etc.

Discussion

First and foremost, successful forest-related education needs to go beyond teaching about trees, forest plants and animals. It needs to teach the skills to integrate the forest into the daily life. Being able to read maps, learn what plants are edible and what dishes to make out of them, encourage sports and other activities in the forest, should be considered to be an integral part for any forest curriculum.

What might as well make a difference is the situation, that in Mecklenburg-Vorpommern, forest-related education ends after grade 6 and only continues in A-level courses. Integration in grades 7–10, like in Thuringia and other federal states, apparently does not encourage further interest in this professional field.

When we take the number of students into account, three more federal states have a significantly higher than average

number of students in forestry bachelor programs, compared to the rest. Even though Bavaria could have a similar percentage of applicants for a vocational education as Mecklenburg-Vorpommern, this seems to be unlikely, due to the little information received during the gathering of data for this study.

While researching possible reasons for the above average number of students in forestry related bachelor of sciences courses, Brandenburg, Bavaria and Baden-Württemberg had one aspect in common, that the other states lacked: all of them have contributed major publications on forest pedagogics (Bolay and Reichle 2016, StMELF 2017, Brucker 2020), similar to the material in Mecklenburg-Vorpommern for elementary schools.

Regarding the motivation in writing a publication, very little research has been conducted so far. Key motivations for experts to publish a textbook are the considerations that such a publication would benefit learners and, most importantly, that they have perceived a gap, which needs to be filled (Collins and Stone 2019). What these publications do is fulfil the basic aspects needed for the implementation for a didactic – this means, these states have

moved from forest pedagogics to the formation of a local forest didactic. In the publication we find aspects of furthering the planning, analyzing and conducting forest-related lessons, they describe the history of forest education, justify and reflect forest pedagogics, as well as giving examples of tried and tested concepts for projects and lessons – all of these are the foundation for forming a didactics for any given subject at school (Klafki 1963, Fuchs and Siller 2007, Tenberg 2017). Compared to Mecklenburg-Vorpommern, the approaches found in the publications still focus on classical forest topics.

When it comes to publications, the two provinces of Rhineland-Palatinate and Saxony-Anhalt, both of them being part of the cluster 3, with a slightly elevated number of students applying for a vocational education in forestry, we find a similar situation. Rhineland-Palatinate offers a 'forest box', a set of material, which can be used by schools and kindergartens for free. This is akin to the approaches for forest-related didactics. Saxony-Anhalt, on the other hand, was the very first province of Germany, which educated forest pedagogues following the standards of the state certificate. This might be an indicator for a well and thoroughly established forest education, which leads to the higher interest in forestry professions.

It could be assumed, that we have differences in the local perception or the public image of forest related professions in Germany. It might even be possible, that provinces with a high percentage of forests have a higher number of students interested in an education in this field. As for the first aspect, the existing studies do not show any differences between the provinces (Bethmann and Wurster 2016). Generally speaking, forest professions apparently have a similar public percep-

tion regarding their image all over Germany. This can be considered to be due to the forest being an important cultural aspect and part of the national identity for several generations (Wilson 2012). As for the second aspect, Mecklenburg-Vorpommern is the state with the third smallest percentage of forested area, with Hessen and Saarland being among the three provinces with the highest forest coverage (State Office of Statistics 2021). So these two possibilities can be ruled out.

Considering the results, establishing a local forest didactics does have an influence on the choice of the subject studied at a university, but apparently not on the choice of vocational education. This might be due to the different motivations for studying and going for an apprenticeship. The latter being influenced by monetary inclinations, while university education has a more motivational and interest-based foundation. To identify the general interest in forests, forest-related issues, etc., the number of university students can be considered to be a good indicator.

When we want to identify excellent approaches, we should take vocational choices into consideration, as well. The lack of economical aspects in forest education is an aspect, which is rarely addressed by teachers but is desired by forest administrations (Hepper 2016).

Conclusions

When we want to develop an interest in forests, we need to implement forest-related content in grades 1 to 6. Apparently lessons in grades 7 to 10 have no beneficial effect. For this, it is necessary to not only address typical forest education topics, like knowledge on forest wildlife, but also on the use of non-timber forest prod-

ucts as food, organizing outdoor activities in the woods, etc.

Furthermore, establishing a local forest didactics, which examines and establishes methodological approaches, regularly evaluates the curricula, and creates lessons, helps to increase the interest in pursuing an academic education in forest sciences and forestry.

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PHYSIOLOGICAL ADAPTATION OF EUROPEAN BEECH (*FAGUS SYLVATICA* L.) AND WILD CHERRY (*PRUNUS AVIUM* L.) SAPLINGS AFTER WINDTHROW

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Abstract

Variations in some physiological parameters of European beech (FS) and wild cherry (PA) saplings were studied in the second (2016), fifth (2019), and seventh year (2021) after windthrow disturbance in a monodominant European beech forest. Net photosynthetic rate (A_N), transpiration rate (E), water-use efficiency (WUE), and total chlorophyll content (TCC) of FS and PA saplings were measured both in a windthrow site (W) and in a closed-canopy site (C). The physiological measurements in C-site were used as a control for the comparisons with W-site. European beech leaves on W-site had a positive photosynthetic response to higher light intensity only in 2019, while in the wild cherry leaves, similar increase was observed in 2016 and 2021. At the end of the study period, E of FS and PA leaves were equalized between W-site and C-site and between the two species. However, two years after windthrow, FS saplings had a similar transpiration rate in the two sample sites, while PA saplings had significantly higher transpiration in the W-site. In 2019, FS leaves managed to increase its E in windthrow site, but it remained high in the PA's leaves. WUE remained unchanged in W-site at the beginning of the experimental period for both species, but this physiological parameter was significantly higher in FS saplings. In 2019, the WUE in FS leaves was stabilized, while in the PA leaves, it even increased. In 2021, both species had stable levels of WUE . In W-site, the FS leaves had the same TCC throughout the experimental period, while such a parameter was higher in W-site in the PA leaves. Better physiological adaptation of PA to changed microclimatic conditions after the windthrow disturbance is probably the main reason for this species' pioneer character and rapid colonization of the territory. The protective role of herbaceous plants, which invade in a windthrow site, allows FS to save the physiological activity and even increase physiological processes and parameters a few years after disturbances.

Key words: photosynthesis, total chlorophyll content, transpiration, water-use efficiency.

Introduction

Windthrow in a forest is a natural process, which is repeated element in the forest dynamics. While canopy gaps may alter

many features of understory microenvironments, their most obvious effects are on understory light regimes. However, even in large gaps, the potential duration of high light levels from direct radiation is

relatively brief and limited to a much narrower range of incidence angles than at an open site (Canham et al. 1990), especially on a northern slope. The relatively brief duration of high light levels provides only a limited time of high potential carbon gain to recover the synthesis and maintenance costs of physiological and morphological acclimation to high light (Canham et al. 1985). Thus, windthrow gaps pose a serious limitation on the sapling's adaptation to high incident light levels.

It has been frequently noted that pioneer and early successional species have higher potential growth rates than tree species capable of responding to small disturbances (Bazzaz 1973, Berry 1975, Chabot 1977, Patterson et al. 1978, Ulanova 2000, Rich et al. 2007). According to Bazzaz (1979), early successional species will have higher physiological flexibility relative to that of species found in later successional habitats. Shade-intolerant species are thought to allocate more resources to rapid growth, especially height growth, instead of overall structural strength. Some authors reported rapid increase in the growth rate of early successional trees when the canopy above them is removed (Marks 1974). Shade-intolerant, fast-growing, short-lived pioneer species (such as wild cherry) should have lower biomechanical safety margins than shade-tolerant, long-lived species of comparable stature (Givnish 1995).

The late-successional species, such as European beech, are considered shade-tolerant (San-Miguel-Ayán et al. 2016, Leuschner and Ellenberg 2017), and their regeneration under intense light is difficult (Collet et al. 2001, Ramírez-Marcial et al. 2010, Malík et al. 2014). Emborg (1998) established that relative light intensity (RLI) increased to about 10 % in beech forest's gaps and

made regeneration of European beech possible, but its saplings did not survive at RLI below 2 %. As Szwagrzyk et al. (2001) points out, even in a strongly shade-tolerant species, like beech, the formation of a seedling bank required the occurrence of canopy openings nearby. According to Ammer (1996), on the shelterwood and the clear-cut plots within the beech forest, height and height increment of European beech and sycamore maple saplings increasingly depend on intra- and interspecific competition effects. In the clear-cut plot, the natural regeneration had consisted almost exclusively of even-aged sycamore maple saplings, which were already established before the cutting and had access to full light (Ammer 1996). Mountford et al. (2006) found that the seedling density in beech forests is highest at the gap edge or just outside the gap. In contrast, the highest plants were recorded in the gap center by Ritter et al. (2005), corresponding to the increased resource availability there.

Many factors may limit tree saplings height within the windthrow patches. Higher illumination leads to increased air temperature and decreases air, and soil water availability provokes reduced water regime and decrease in photosynthetic activity due to leaf damage (Reynolds and Frochot 2003). Stomatal conductance is also negatively affected by light increasing (Tognetti et al. 1997), in addition to drought effects, which leads to a decrease in water-use efficiency.

The present study's main objective was to examine whether an early successional species such as the wild cherry adapts its physiological processes faster and more successfully than a late succession species such as the European beech to a changed microenvironment after windthrow.

Materials and Methods

Site description and plant material

The effect of natural disturbance (windthrow) on gas-exchange, water relation, and chlorophyll content of European beech (*Fagus sylvatica* L.) and wild cherry (*Prunus avium* L.) saplings were studied in Western Balkan Mountains. The measurements were conducted in July 2016, July 2019, and July 2021 at the Petrohan Training and Experimental Forest Range. Eighteen months before the first measurements (December 2014), a stand dominated by the European beech was affected by the windthrow. On a total area of 6 ha, almost all 80-years-old beech trees were uprooted or broken seriously by the snow and wind.

In the summer of 2016, a sample site of 0.1 ha (25×40 m) was set up in part of the stand affected by the windthrow (W-site) and another 0.1 ha (25×40 m) sample site – in the adjacent undisturbed, closed-canopy area (C-site), which was used as a control (Table 1).

Table 1. Sites description of windthrow site (W-site) and closed-canopy site (C-site).

Sites description	W-site	C-site
Latitude	43°11'19" N	43°11'4" N
Longitude	23°7'30" E	23°7'47" E
Altitude, m	862	870
Slope, °	24	20
Aspect, °	54 (NE)	62 (NE)

Note: Latitude, longitude, and altitude were measured with a GPS-device (Garmin Ltd., Schaffhausen, Switzerland). Slope and aspect were measured in a software MapSource v. 6.16.3 (Garmin Ltd., Schaffhausen, Switzerland).

Microclimatic conditions of sample sites were determined during the physiological measurements. Photosynthetic Photon Flux Density (PPFD, $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) was

measured with a Li-190 Quantum sensor (Li-COR, Bioscience, Ltd., Lincoln, USA); CO_2 -concentration (ppm), air temperature (T_{air} , °C) and relative air humidity (RH, %) were measured with internal sensors of the Portable photosynthesis system Li-6400 (Li-COR, Bioscience, Ltd., Lincoln, USA).

Physiological measurements

The measurements were conducted in the second (2016), fifth (2019), and seventh (2021) year after windthrow disturbance, in typical clear-sky July days, between 9:30 and 11:30 AM. Net-photosynthetic rate (A_N) and transpiration rate (E) were measured using an LI-6400 portable photosynthesis system (Li-COR, Bioscience, Ltd., Lincoln, USA) on two mature leaves, selected between 3rd and 5th leaf from the top of fifteen saplings in each site (Tausz et al. 2003). Before measurements, the instrument was calibrated according to standard procedures (LiCor 2012). Measurements were taken under controlled conditions within the chamber: saturated PAR of $1000 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$; ambient for experimental variants leaf temperature and CO_2 concentration; relative air humidity at 40 to 45 % resulting in a leaf-to-air vapor pressure deficit ranging from 1.17 to 1.37 kPa; flow rate of $500 \mu\text{mol}\cdot\text{s}^{-1}$. Water-use efficiency (WUE) was calculated using the formula: $WUE = A_N \cdot E^{-1}$ (Larcher 2003). Total chlorophyll content (TCC) was determined with portable chlorophyll meter AtLEAF+ (FT Green, LLC, Wilmington, USA).

Statistical analysis

Shapiro-Wilk test was used to determine whether the outcome variables were normally distributed. A two-tailed T-test was

used to determine the significant difference between the environmental conditions in W-site and C-site. The two-way ANOVA (Factor A: Species and Factor B: Conditions) was used to test the significant difference among the variants within each year. A multiple-comparison procedure (Tukey Test) was used to test the statistical significance of differences among the variants. All statistical procedures were performed with MS Excel and user-defined functions in Visual Basic for Applications (MS VBA 7.1, Microsoft, Redmond, WA, USA). Only statistically significant results (as defined by a p -value < 0.05) were discussed.

Results and Discussion

Micro-climatic conditions

The environment factor most strongly affected by the windthrow was the illumi-

nation. In 2016, it was 9.47 times higher in the W-site as compared to the C-site ($T = 5.53$, p -value < 0.001), 9.73 times in 2019 ($T = 5.24$, p -value < 0.001), and the difference decreased to 7.69 times in 2021 ($T = 3.20$, p -value = 0.003), mainly due to the growth of the crowns of some remaining adult beech trees, as well as some PA individuals (Fig. 1).

The variation in the relative humidity between sites was lower in the W-site compared to the C-site 2.27 times in 2016 ($T = 8.49$, p -value < 0.001), the difference decreased to 1.67 times in 2019 ($T = 8.05$, p -value < 0.001) and was neutralized in 2021 ($T = 0.94$, p -value = 0.357). This trend may be due to an increase in the presence of herbaceous vegetation over the years. At the air temperature there are no differences between the W-site and the C-site in 2016 ($T = 1.88$, p -value = 0.071), in 2019 it is 2.90 °C warmer in the W-site compared to the C-site ($T = 3.73$, p -value < 0.001), and in 2021 the

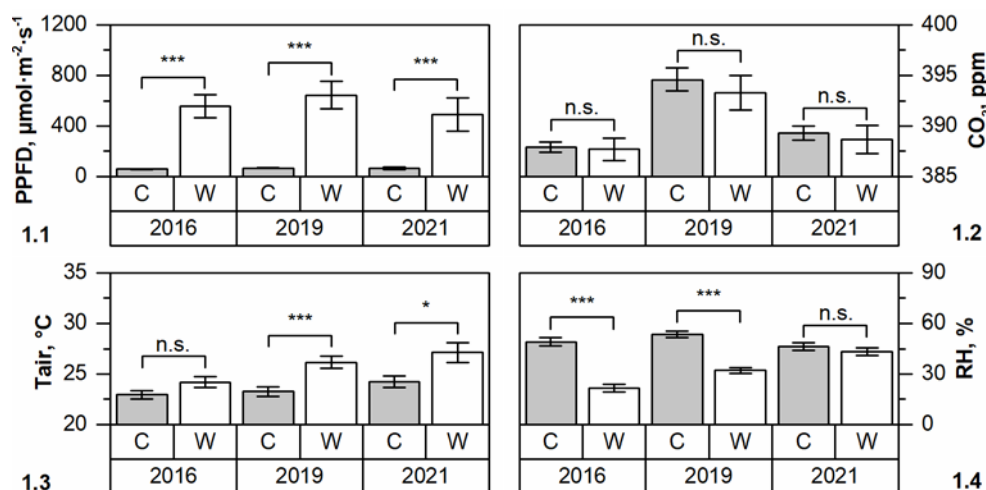


Fig. 1. Microclimatic conditions within windthrow site (W) and closed-canopy site (C) in second (2016), fifth (2019) and seventh (2021) year after the windthrow.

Note: Data represent the mean $\pm$ SE ($n \geq 30$). A two-tailed T-test is applied to estimate the difference between the sites each year. Asterisks denote statistically significant differences (*** p -value < 0.001, ** p -value < 0.01, * p -value < 0.05, n.s.: p -value > 0.05).

difference was almost the same – 2.89 °C ($T = 2.56$, p -value = 0.016). No differences in CO_2 levels were observed between the two sites during any of the years of the experiment.

The effect of the increased solar radiation in the windthrow site is quickly apparent with the rise in the air temperature only two years after the windthrow, in contrast to the slighter decrease in air humidity. Still, as long as the T_{air} remained higher until the end of the study period, then the RH in the C-site is equal to that in the W-site in 2021, probably due to the newly appeared vegetation.

Photosynthetic rate

The net-photosynthetic rate in saturated light (A_N) varied significantly between Species and Conditions interaction in ev-

ery experimental year. The common trend for all years was the higher A_N in PA-W, compared to the other variants. In 2016, it was 2.31, 2.32, and 2.05 times higher than that of PA-C, FS-W-site, and FS-C, respectively. In 2019 the differences increased – 2.65, 2.98, and 6.45 times, and in 2021 they were 2.31, 2.14, and 2.58 times, respectively (Fig. 2).

The maintenance of significantly higher photosynthesis of PA at the W-site shortly after the natural disturbance and keeping it high to the end of the experimental period is indicative of the rapid positive response of this species to the increased light after windthrow probably due to its pioneering character. Since early successional plants generally key in on disturbance, they stand astride pulses of available resources. Rapidly obtaining and using them before they subside and

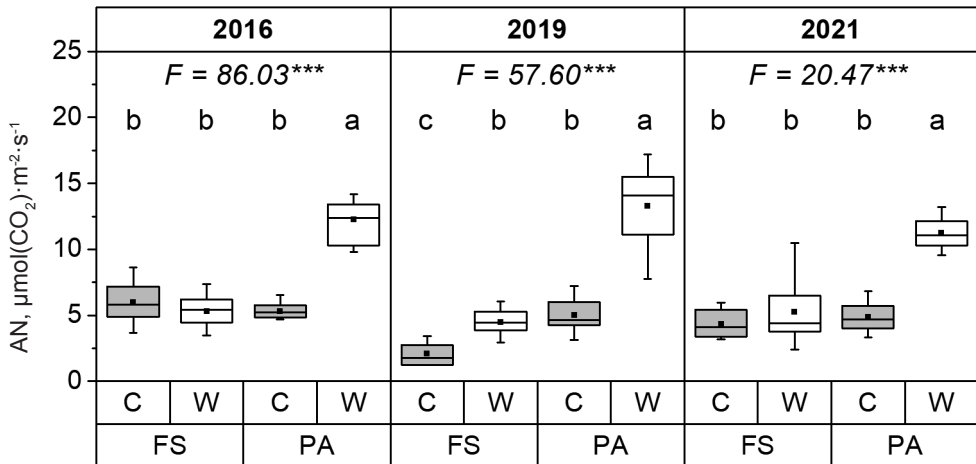


Fig. 2. Net-photosynthetic rate (A_N) of *Fagus sylvatica* (FS) and *Prunus avium* (PA) in windthrow site (W) and closed-canopy site (C) in second (2016), fifth (2019), and seventh (2021) year after the windthrow.

Note: The upper and the lower edges of each box indicate the 75th and 25th percentiles, respectively. The horizontal line within each box is the median, the square represents the mean, and the vertical bars indicate the 1.5 interquartile ranges. Two-way ANOVA (Factor A: Species and Factor B: Conditions) (Tukey test) is applied to estimate the difference between all the variants. Different letters denote statistically significant differences (p -value < 0.05).

preventing competitors from obtaining them may be adaptive. The rapid increase in the growth rate of early successional trees when the canopy above them is removed (Marks 1974) is an example of this strategy. On the other hand, FS as a late-successional species reacts slower to the increased light relative to early successional PA, but it manages to take advantage of the higher irradiance and does not lower the A_N (except for slightly lower values for FS-C in 2019). This is a probable sign of a more conservative mechanism for adaptation to the sudden light.

Transpiration rate

The transpiration rate (E) varied significantly between Species and Conditions interaction for every year of the experiment. In addition to photosynthesis, PA-W

transpiration was also very intensive in 2016 and 2019, but in 2021 the differences with other variants decreased (Fig. 3).

The gradual increase in transpiration intensity in FS-W demonstrates the different potentials for adaptation to changed conditions. The authors (Bazzaz 1973, Berry 1975, Chabot 1977, Patterson et al. 1978) indicate that acclimation to the light environment that the plants experience during their growth seems to be more pronounced in the early than in the late-successional plants. In our experiment, PA reacts very quickly, and FS takes several years to begin to cool down its leaves adequately. Such slow adaptation is probably due to the need for a protective role of quickly settled pioneer vegetation in the herbaceous layer. Reynolds and Frochot (2003) state that young beech trees suddenly exposed to direct solar radiation and

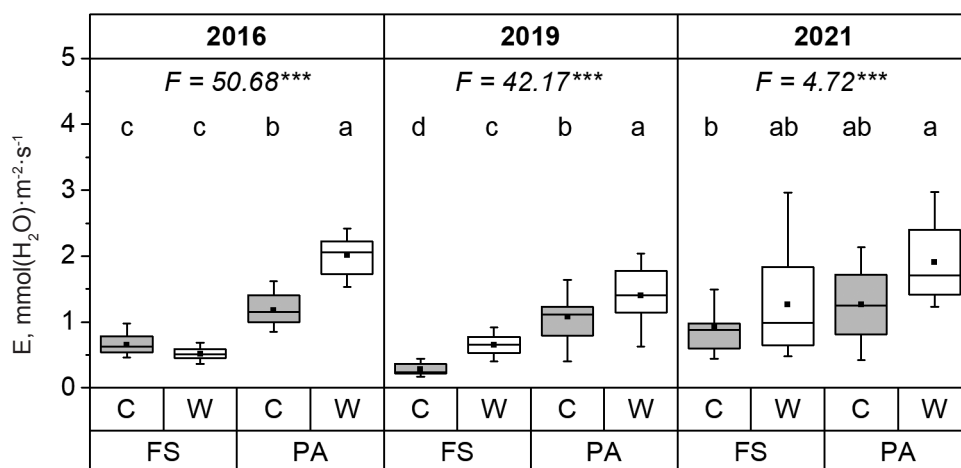


Fig. 3. Transpiration rate (E) of *Fagus sylvatica* (FS) and *Prunus avium* (PA) in windthrow site (W) and closed-canopy site (C) in second (2016), fifth (2019), and seventh (2021) year after a windthrow.

Note: The upper and the lower edges of each box indicate the 75th and 25th percentiles, respectively. The horizontal line within each box is the median, the square represents the mean, and the vertical bars indicate the 1.5 interquartile ranges. Two-way ANOVA (Factor A: Species and Factor B: Conditions) (Tukey test) is applied to estimate the difference between all the variants. Different letters denote statistically significant differences (p -value < 0.05).

higher temperatures after removing parent stand shelter (e.g., wind disturbance) may close their stomata to prevent water deficit. In such a case, the gas exchange through stomata is limited, entailing the reduction of photosynthesis.

Water-use efficiency

The water-use efficiency (*WUE*) varied significantly in 2016 and 2019 but not in 2021 (Fig. 4).

The higher *WUE* in FS in 2016 was due not so much to high photosynthetic potential than to water savings. However, saving water (by reducing transpiration) could lead to increased leaf temperatures and might impose temperature stress. In the following experimental years, there was a downward trend in *WUE* in FS, which in 2021 even equaled that of PA. Bazzaz

and Boyer (1972) point out that usually, under optimal environmental conditions, *WUE* is lower in late than in early succession species. Under moderate stress conditions, a small decrease in stomatal conductivity can protect plants by improving water use efficiency. In shade-tolerant species, the stomata opening in response to increased light is significantly faster than in shade-intolerant species. Transpiration decreases more rapidly even with less negative water potential in shade-tolerant species than in shade-intolerant species (Bazzaz 1979). Thus, using their ability to utilize scattered solar radiation, shade-tolerant species can function better under the forest canopy than shade-intolerant ones but are less able to survive when water is scarce. At PA, *WUE*, except for the increase in PA-W in 2019, had a relatively constant value. Its equalization

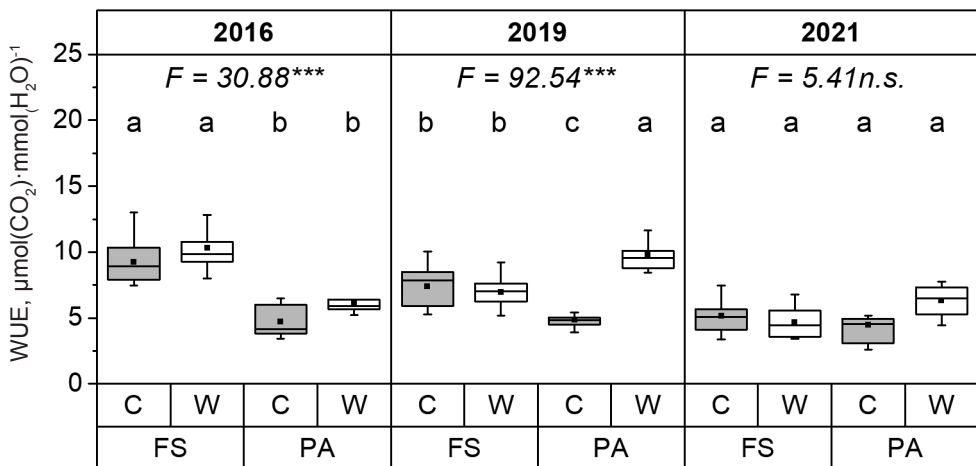


Fig. 4. Water-use efficiency (*WUE*) of *Fagus sylvatica* (FS) and *Prunus avium* (PA) in windthrow site (W) and closed-canopy site (C) in second (2016), fifth (2019), and seventh (2021) year after a windthrow.

Note: The upper and the lower edges of each box indicate the 75th and 25th percentiles, respectively. The horizontal line within each box is the median, the square represents the mean, and the vertical bars indicate the 1.5 interquartile ranges. Two-way ANOVA (Factor A: Species and Factor B: Conditions) (Tukey test) is applied to estimate the difference between all the variants. Different letters denote statistically significant differences (p -value < 0.05).

in PA-W and PA-C in 2021 reflects the ongoing positive acclimatization of the species to changes in the environment.

Total chlorophyll content

The total chlorophyll content (TCC) varied significantly between Species and Conditions interaction in every experimental year. The chlorophyll concentrations in FS leaves remained the same for the five-year period in W-site and C-site (Fig. 5).

A higher concentration of chlorophyll in the W-site than in C-site in PA results from the formation of a sun leaves, characterized by thicker leaf lamella. Although beech has a similar ability to form sun and shade leaves, probably due to the smaller number of chloroplasts in the sun leaves' mesophyll cells, such an increase of TCC was not observed in the W-site. Even after

a natural disturbance such as windthrow, the capacity to keep chlorophyll levels unchanged shows that FS has a wide tolerance for changes in light.

Conclusion

This study indicates that the better physiological adaptation to changed microclimatic conditions after the windthrow disturbance of PA in comparison to FS is probably the main reason for the pioneer character of this species and rapid colonization of the territory. With its more economical water regime, PA increases its leaves' chlorophyll content after increasing the illumination. This allows it to take advantage of higher light and significantly increase its photosynthesis. The protective role of herbaceous plants, which in-

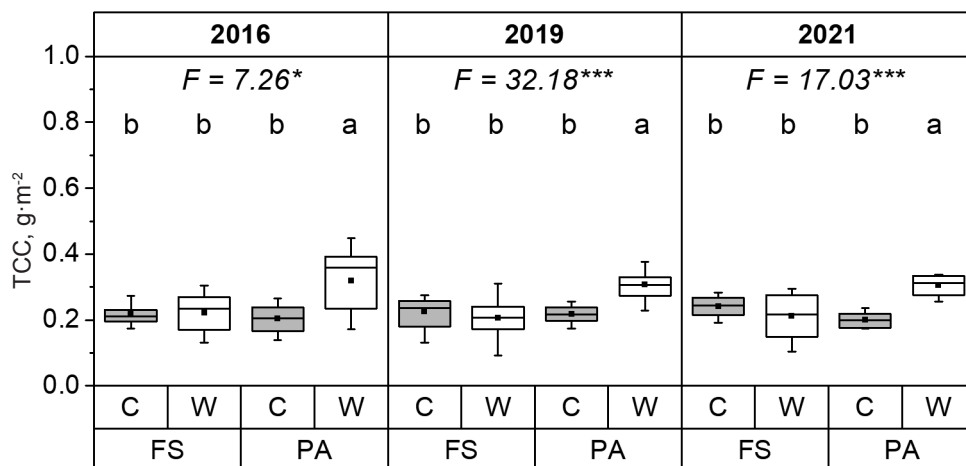


Fig. 5. Total chlorophyll content (TCC) of *Fagus sylvatica* (FS) and *Prunus avium* (PA) in windthrow site (W) and closed-canopy site (C) in second (2016), fifth (2019), and seventh (2021) year after a windthrow.

Note: The upper and the lower edges of each box indicate the 75th and 25th percentiles, respectively. The horizontal line within each box is the median, the square represents the mean, and the vertical bars indicate the 1.5 interquartile ranges. Two-way ANOVA (Factor A: Species and Factor B: Conditions) (Tukey test) is applied to estimate the difference between all the variants. Different letters denote statistically significant differences (p -value < 0.05).

vade a windthrow site, will enable FS to save the physiological activity and even increase physiological processes and parameters recently after disturbances. Such symbiosis between FS and pioneer grasses was also observed in other studies, which show that the appearance of mesophilic species in beech forests does not compete with FS saplings (Nedelin 1991). According to Stipcov and Ivanov (2013), the grass cover formed after disturbance does not interrupt but strengthens the beech undergrowth, which was confirmed, although at an early stage of FS development in our study.

Acknowledgements

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PROSPECTS FOR ECOLOGICAL TOURISM DEVELOPMENT: UKRAINIAN CARPATHIANS FOREST FUND TERRITORIES AS A CASE STUDY

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Abstract

To optimize the use and management of Ukrainian Carpathians forest fund territories, ecological tourism is actively promoted by the government and reflected in the leisure sector. The attention of economists is mainly drawn to the market value of forest areas and forest resources. However, the trend is changing as the non-market values of forests are increasingly assessed and measured. This case study assessed the potential value of ecological tourism development using the contingent valuation method. A total of 235 respondents were interviewed in four regions of Ukraine. The results showed that most visitors to the Ukrainian Carpathians are willing to pay for ecological tourism on these territories. The average value was 35 USD per day in the conditions of organised ecological tourism and 10 USD per day in the conditions of individual ecological tourism on the territories of Ukrainian Carpathians forest fund. The results may justify financial support from the state for the development of ecological tourism and the adoption of relevant regulations. Prospects for it depend on the level of well-being and education of citizens, as well as the distance from the place of residence of the respondents to the territories of Ukrainian Carpathians forest fund. Regarding organised ecological tourism, the prospects for the development depend on certification of tour operators providing services.

Key words: ecotourist, environment, non-market goods, regression analysis, sustainable development, willingness to pay.

Introduction

Carpathian region is one of the most attractive regions of Central and Eastern Europe, which has strategic importance in the development of the territories of eight states, including Ukraine.

Significant recreational, health, and historical and cultural potential is concentrated in the Carpathian region. There are seven sites on the territory of Ukraine included in the UNESCO World Heritage List. Four of these places are located in the Carpathian region, two of

them are transnational.

The Ukrainian Carpathians as a mountainous region, characterized by high natural resource potential and important geopolitical location, has of great importance for the socio-economic development of near-by regions.

Most mountainous areas, which are located at an altitude of 400 m a. s. l. and above, are difficult to access. The resource potential of these territories, inhabited by 978 thousand citizens in 715 settlements, is not realized, and the level of their socio-economic development is much lower than in Ukraine as a whole. This leads to low quality of life, increasing disparities in the system of economic complexes, and deteriorating investment attractiveness of mountainous areas, increasing differentiation of key socio-economic indicators, exacerbates the depression and subsidization of such areas, leads to deterioration of their ecological status, loss of potential for restoration, and hinders the balanced development of Carpathian regions. Therefore, the concept of development of mountainous areas of the Ukrainian Carpathians was recommended to create conditions for further development of rural and ecological tourism in the region (Cabinet of Ministers of Ukraine 2019).

The highest forest cover of Ukraine by natural zones is in the Ukrainian Carpathians (the optimal forest cover is 45 %, and the actual one is 42 %) (SAFRU 2019). The total area of the forest fund in Ukrainian Carpathian region is about 2 million ha. In particular, covered with forest – about 1.8 million ha. The forests areas of green zones are allocated near 44 cities and towns in the region occupy 153.6 thousand ha. Including, squares and parks occupy 44.8 thousand ha. These forests are located mainly in the

Carpathian region and Transcarpathia. The area of resort forests in the region is 35.6 thousand ha (SAFRU 2019).

The Ukrainian Carpathians is a unique and majestic region with an outstanding combination of mountains and forests beauty. They are part of the mountain system of the Eastern Carpathians. Their length is 280 km, width is more than 100 km. The mountains cover the territory of Transcarpathian, Lviv, Ivano-Frankivsk, and Chernivtsi regions. Their territory is delimited by deep valleys, rivers, and lakes located hundreds of meters above sea level. In Transcarpathia, there are 457 objects of the nature reserve fund on the area of 151 thousand ha (e.g. the Carpathian Biosphere Reserve, Uzhansky National Nature Park, National Nature Park 'Sinevir', regional landscape park 'Enchanted land', etc.), which creates significant opportunities for the development of ecological tourism (Vyshneve City Council 2020).

The forests of the Ukrainian Carpathians have a significant impact on the climatic, water-regulating, protective, and recreational functions of the region and surrounding areas (Kravtsiv et al. 2013).

This creates significant prospects for the development of ecological tourism, which brings significant benefits in environmental, social, and economic aspects. Among these benefits of ecological tourism, it is necessary to highlight the socio-economic and environmental benefits for local communities, its potential to reduce the impact on the environment and increase profits (BRM 2020).

The concept of 'ecological tourism' was proposed in the 1980s, but since the concepts of 'ecology' and 'tourism' are used for more than 100 years, during this

period, in different cases, in essence, they were placed side by side (Vyshnevsky 2015).

A significant contribution to the development of the theoretical basis of ecological tourism was made by Dmytruk (2004), who defined the principles, functions and tasks of ecological tourism. Vyshnevsky (2015) studied the driving forces that determine the objects and development of ecological tourism, also the basics of such activities. Problems and prospects of recreational use of forests were shown by Deyneka and Kopach (2001). Modern problems of economic and legal regulation of ecological tourism in Ukraine are covered in scientific articles by Dubovich and Fomicheva (2020). A key elements approach to operationalising of ecological tourism concept was investigated by Bottrill and Pearce (1995). Its development and implementation for wild lands and neighbouring communities was analyzed by Blangy and Wood (1993). Contingent valuation of ecological tourism development in country parks in urban shadow was made by Chen and Jim (2012). Boo (1993), Western (1993) and Weaver (2001) defined it as a responsible nature travel experience, that contributes to the conservation of the ecosystem, creating employment opportunities for local communities, and offering environmental education, etc.

Despite the fact that their scientific achievements served as a theoretical and methodological basis for the research and allowed to identify a number of additional issues in the research of ecological tourism, its current state and prospects in the forest fund of the Ukrainian Carpathians are insufficiently studied today.

In our opinion, ecological tourism is a type of tourism that can be successfully

developed in Ukrainian Carpathians forest fund, as well as in protected areas in recreational areas. It provides for the preservation of the environment, promoting the well-being of the local population and development following the concept of sustainable development (Dubovich and Fomicheva 2020). Ecological tourism is a responsible trip of an ecotourist to natural areas, areas that have minimal impact on the environment and support the well-being of local residents. An ecotourist is a person with an ecological consciousness who makes a responsible trip to natural areas, preserves the natural environment (TIES 2020).

By nature the organisation ecological tourism in the territories of the forest fund can be divided into organised and individual. Organised ecological tourism is group travel organised by a travel agency. Ecotourists have the right to tour by buying a tourist voucher. The number of services may be different. For example, ecotourists can purchase only food services or a range of services, including transportation, food, accommodation, excursions, etc. (Pucenteilo 2007).

Individual ecological tourism is a form of tourism, where tourist services are provided based on amateur ecotourists. Ecotourists themselves choose routes and ways of travel, provide themselves with food, accommodation, and rest, make excursions, and do not use the services of a travel agency. Individual ecological tourism involves the travel of an individual family or a person, or a group according to their plan (Pucenteilo 2007).

A tour operator must pass a system of mandatory certification as a way of state regulation of tourism. Certification – a procedure by which an authorised institution establishes the compliance of the object of certification with the

requirements established by law (Halasiuk 2011).

However, many factors hinder the development of ecological tourism in Ukrainian Carpathians forest fund territories. Among them, there are illegal landfills, illegal logging, fires, mass tourism at the environmental facilities, lack of certification of tour operators, construction of buildings and structures with violation of norms and standards for construction, insufficient number of special recreational areas (Kravtsiv et al. 2013).

This study aims at research the current state and prospects for the development of organised and individual ecological tourism on the territories of Ukrainian Carpathians forest fund by studying the interests of Ukrainian citizens in this area.

Therefore, the study of the prospects will make it possible to assess the forest's non-market values and identify the potential value of ecological tourism development.

Methods

Many methods for estimating the value of public goods have been developed (Hanley et al. 2001, Bateman et al. 2002, Haines-Young and Potschin 2009). To study the main prospects for ecological tourism development on the territories of Ukrainian Carpathians forest fund, we used the contingent valuation method (CV method). It is based on the concepts of willingness to pay (WTP) a certain amount for non-market goods. It is widely used as an effective policy tool in the management of protected areas and biodiversity conservation (Baral et al. 2008).

The willingness to pay for non-market goods is based on the theory of rational choice and utility maximization

(Reynisdottir et al. 2008). CV method is a method that allows people to buy public goods in hypothetical situations, especially in the absence of a real market or available information about a real market scenario (Boyle 2003). It plays a significant role in shaping environmental policy. CV method is used in many areas, including protected areas, endangered species conservation, ecosystem services, and biodiversity conservation (Chen and Jim 2012, Adamu et al. 2015). Other areas of gaining its popularity include improving water quality, energy systems, human health, land conservation, and many of its applications in the outdoor recreation or ecological tourism sphere (Pelyukh and Zahvoyska 2018).

We have used CV method and obtained information by receiving answers from the respondents living throughout Ukraine. The survey was conducted online during year 2020 using Google form and telephone interviews using a computer based on a random sample of mobile phone numbers. The answers were anonymous. For our research, we use a random sample by age, sex and type of settlement. The respondents were mainly people who want to travel responsibly to the Ukrainian Carpathians and have some experience in ecological tourism. The preparation of the questionnaire was based on a study of the current state of ecological tourism and its application on the territories of Ukrainian Carpathians forest fund. It was a study of prospects and obstacles to its development and the impact of independent factors on the willingness to pay for the use of quality natural conditions, environmentally friendly recreation, and food in the context of individual and organised ecological tourism of Ukrainian Carpathians forest fund. The questionnaire contained

twenty main questions on socio-economic aspects of the prospects for the development of ecological tourism and five questions on basic information about respondents who took part in the survey.

To determine the willingness to pay we used a scale. Every factor that affects the willingness to pay is translated into points. For example, age categories: 18–25 – 1 point; 26–35 – 2 points; 36–45 – 3 points; 46–59 – 4 points; 60–70-year-old – 5 points.

Similarly, we divide the gender of the respondent: 1 point – woman, 2 points – man; place of residence: urban – 1 point, urban-type settlements – 2 points, rural areas – 3 points; education and personal income – from 1 to 4 points; distance to the Ukrainian Carpathians – from 1 to 5 points.

In our research, we chose a linear model to determine the impact of key indicators on the willingness of respondents to pay for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation, and nutrition in the conditions of organised and individual ecological tourism on the territories of Ukrainian Carpathians Forest fund because R^2 indicator in that model is the largest.

An economic and mathematical model was constructed in a form of

linear multiple regression equation using regression analysis. It assessed the impact of independent factors ($X_1, \dots, X_n$) on the amount of willingness to pay for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the context of organised (Y_1) and individual (Y_2) ecological tourism. After receiving the respondents' answers, the information was summarised and analysed.

Results and Discussion

It follows from the study, that most of the surveyed citizens of Ukraine (64 %) were ecological tourists. The share of respondents interested in ecological tourism is 86.3 %. This indicator shows its popularity and the need for its development.

The survey involved 235 respondents aged from 18 to 70 years, including 50.8 % of women and 49.2 % of men. The age structure is shown in Figure 1. Most respondents by place of residence are urban (50.4 %), 26.3 % live in urban-type settlements, and 23.3 % – in rural areas.

The study that used CV method was conducted on the territory of all regions of Ukraine. The Western region of Ukraine includes: Lviv, Ivano-Frankivsk, Ternopil,

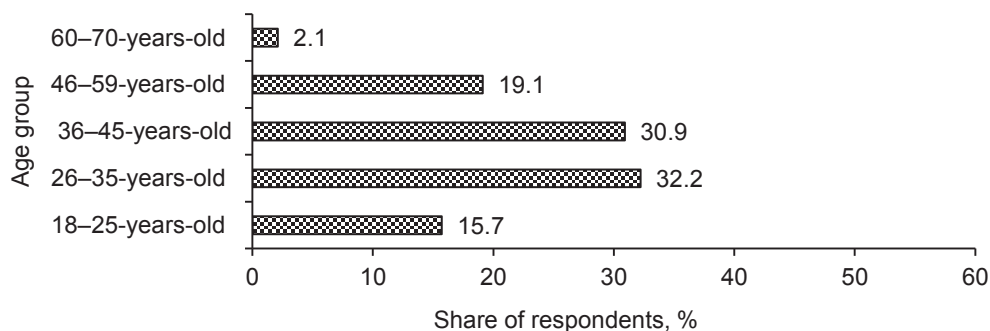


Fig. 1. Age structure of respondents.

Volyn, Rivne, Khmelnytsky, Chernivtsi, and Zakarpattia; the North: Zhytomyr, Kyiv, Chernihiv, and Sumy regions; the South: Zaporizhia, Kherson, Odesa, Mykolaiv regions; the East: Kharkiv, Donetsk and Luhansk regions; the Central – Vinnytsia, Dnipro, Kirovograd, Poltava and Cherkasy regions (Anonymous 2018).

The educational level of respondents is very high (Fig. 2).

Our study shows that 66 % of respondents traveled on the territories of the Ukrainian Carpathians forest fund, and 34 % did not. In addition, 74 % prefer to rest in forests in protected areas (national nature parks, recreational areas, botanical gardens, etc.). This indicator proves that tourists are interested in recreation on the territory of the forest fund in the conditions of ecological tourism, the aesthetics and purity of these objects, get acquainted with local traditions, and in living in the unchanging natural conditions of the Ukrainian Carpathians. Thus, the successful development of ecological tourism on these territories will be facilitated by effective economic and legal regulation of ecological tourism. At the same time, 75.3 % of respondents believe that it is necessary to adopt a Law 'About ecological tourism'. It should be noted that 71.5 % of respondents believe that a tour operator that carries out ecological

tourism in the forest fund should pass a certification system, and only – 28.5 % do not agree. The result of certification is obtaining a certificate of compliance with the level of safety of services provided and is one of the key factors in the development of ecological tourism.

According to the survey, 55.3 % of respondents prefer an individual way of ecological tourism, namely plan their trips, and 27.7 % – prefer an organised way of ecological tourism, and only 13.6 % – carry out both.

Among the surveyed citizens, the largest share (49.8 %) in the conditions of income was made up of respondents with the average monthly family income per person ranged from 180 to 250 USD. In 27.7 % of respondents income ranges from 250 to 350 USD. The income of 18.7 % of respondents is more than 350 USD, and the rest – 3.8 %, have an average monthly income of up to 180 USD per person.

With CV method, the willingness to pay for the potential value of ecological tourism development on the territories of the Ukrainian Carpathians forest fund was determined. In the conditions of organised ecological tourism (Fig. 3) the most respondents (49.8 %) are willing to pay 20–35 USD per day.

As for the willingness to pay for the use

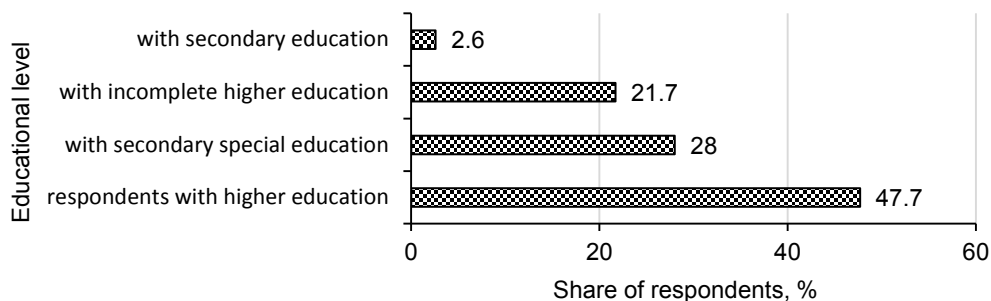


Fig. 2. Share of respondents by levels of education.

of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition of Ukrainian citizens in the conditions of individual ecological tourism, 50 % of respondents are willing to pay 10–20 USD per day (Fig. 4).

The average value was 35 USD in the conditions of organised ecological tourism and 10 USD per day in the conditions of individual ecological tourism.

Using 'Data Analysis' Excel package spreadsheet, we construct ANOVA anal-

ysis of variance table to estimate the regression coefficients for the variables X_1 – X_{14} . The dependence of willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of organised ecological tourism (USD) on a number of factors, such as sex (X_1), age (X_2), average monthly family income per person (X_3), distance to Ukrainian Carpathians (X_4), place of residence (urban, urban – type

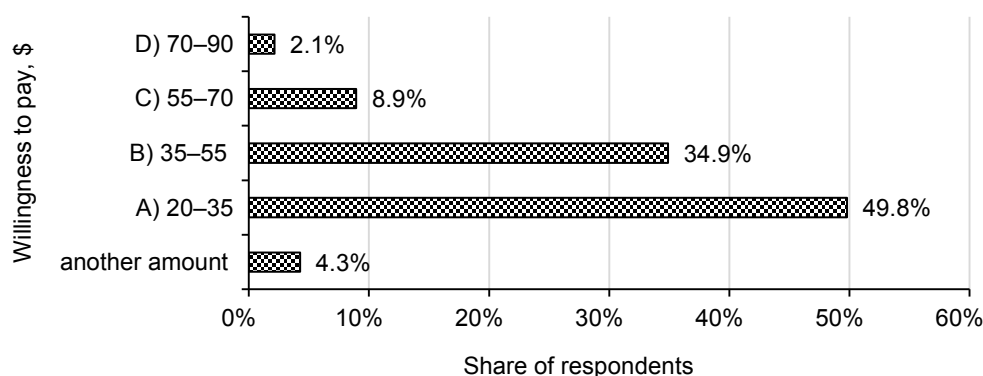


Fig. 3. Willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation, and nutrition of respondents in the conditions of organised ecological tourism.

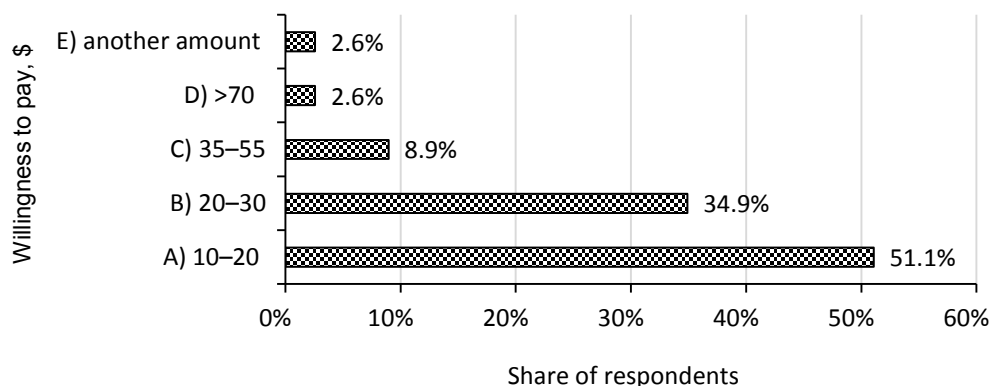


Fig. 4. Willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of individual ecological tourism.

settlements, rural areas) (X_5), level of education (X_6), practicing ecological tourism (X_7), interest in ecological tourism (X_8), travel to the territories of the Ukrainian Carpathians forest fund (X_9), travel to nature protection objects (X_{10}), hotel policy on environmental protection (X_{11}), visiting eco-hotels (X_{12}), obligation for tour operators carrying out ecological tourism on the territory to pass the certification system (X_{13}), possibility of ecological tourism to become a priority for the tourism industry development in the Ukrainian Carpathians (X_{14}) is determined by constructing a linear econometric model.

The econometric model of willingness to pay for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of organised ecological tourism was analysed according to the following indicators: multiple coefficient is equal to 0.9, which indicates a strong correlation between the studied variables; coefficient of determination (R^2) is equal to 0.84. This means that the dependent variable (Y_1) is 84 % explained by the independent ones (X_1 – X_{14}). The other 16 % remain unexplained (they are influenced

by unknown factors); normalized R^2 is equal to 0.83 and is adjusted for the number of observations.

The linear equation of multiple regression of willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of organised ecological tourism on the territories of the Ukrainian Carpathians forest fund has the formula (1):

$$Y_1 = 54.30X_1 + 13.53X_2 + 612.14X_3 - 62.56X_4 - 7.32X_5 + 36.99X_6 + 38.84X_7 + 5.43X_8 + 84.84X_9 - 13.28X_{10} + 5.34X_{11} + 7.25X_{12} + 88.84X_{13} - 3.81X_{14} - 1082.83 \quad (1)$$

To assess the significance of the coefficients, we find the critical values of Student's distribution for significance level 0.05 and the number of degrees of freedom $df = n - k - 1 = 235 - 14 - 1 = 220$. Critical value can be found in Student's table, $t_{220; 0.05} = 1.96$. The actual value of t-statistics should be compared to the value in the table. If $|t_{\text{fact}}| > t_{\text{table}}$, then hypothesis H_0 is rejected (i.e., the parameter estimation is different from 0). In this case, the actual value of t-statistics of variable X_1 does not exceed the table value ($1.722 < 1.96$), so the coefficient is insignificant (Table 1).

Table 1. Results of significance of the factors for both linear equations of multiple regression.

Factors	Y_1			Y_2		
	Coefficients of regression	t-statistics	Significance of factor	Coefficients of regression	t-statistics	Significance of factor
Intercept	-1082.83			-805.50		
X_1	54.30	1.722	insignificant	21.76	0.922	insignificant
X_2	13.53	0.864	insignificant	0.41	0.035	insignificant
X_3	612.14	29.869	significant	462.00	30.125	significant
X_4	-62.56	4.418	significant	-51.46	-4.857	significant
X_5	-7.32	-0.404	insignificant	-4.13	-0.304	insignificant
X_6	36.99	1.938	insignificant	40.99	2.870	significant
X_7	38.84	0.923	insignificant	20.26	0.644	insignificant
X_8	5.43	0.094	insignificant	-8.61	-0.199	insignificant
X_9	84.84	1.874	insignificant	63.93	1.888	insignificant

Factors	Y_1			Y_2		
	Coefficients of regression	t-statistics	Significance of factor	Coefficients of regression	t-statistics	Significance of factor
X_{10}	-13.28	0.271	insignificant	-6.00	-0.163	insignificant
X_{11}	5.34	0.227	insignificant	-1.02	-0.057	insignificant
X_{12}	7.25	0.171	insignificant	-4.89	-0.154	insignificant
X_{13}	88.84	2.127	significant	130.79	1.186	insignificant
X_{14}	-3.81	0.127	insignificant	-9.15	-0.409	insignificant

Therefore, we can conclude that there are statistically significant variables X_3 , X_4 and X_{13} . That is, the willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition a statistically significant effect have the average monthly family income per person, distance to the Ukrainian Carpathians, and the obligation of a tour operator that carries out ecological tourism in the forest fund to pass the certification system.

Fisher's F-test is used to check the significance (adequacy) of the multiple regression equation. We put forward the null hypothesis and the alternative hypothesis: not all regression coefficients are equal to zero at the same time. We choose the level of significance $\alpha = 5\%$, therefore, the confidence level is 0.95. Tabular value $F_{0.05; 14; 220} = 1.55$. The actual value of $F = 84.614$. And the significance $F = 2.94E-80$ is less than 0.05. Thus, we can conclude the statistical significance of the model.

Examining the influence of independent factors on the willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of organised ecological tourism, using regression analysis, we can conclude that the respondents with the highest income are most willing to pay, and the longer the distance to the Ukrainian Carpathians, the less the respondents

are willing to pay for the use of high-quality natural conditions. Also, the willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation, and nutrition per day in the conditions of organised ecological tourism will increase if mandatory certification of the tour operators is introduced.

To study the influence of independent factors on the willingness to pay, regression analysis was performed. The dependent variable (Y_2) is the willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of individual ecological tourism (USD), independent variables ($X_1, \dots, X_{14}$), as in organised ecological tourism. Analysing the influence of independent variables on the willingness to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of individual ecological tourism, it follows that there is a strong correlation between the studied values (multiple correlation coefficient is equal to 0.92). The coefficient of determination (R^2) is equal to 0.85 and indicates that the value of the variable Y (willingness to pay per day in the conditions of individual ecological tourism) is 85 % explained by variables X_1 – X_{14} . The other 15 % remain unexplained, they are influenced by unknown factors.

Tabular value $F_{0.05; 14; 220} = 1.55$. The actual value of $F = 86.896$. And the significance $F = 2.53E-81$ is less than 0.05. Thus, we can conclude the statistical significance of the model.

The linear equation of multiple regression of the amount of willingness to pay per day in the conditions of individual ecological tourism has the formula presented by equation (2):

$$Y_2 = 21.76X_1 + 0.41X_2 + 462X_3 - 51.46X_4 - 4.13X_5 + 40.99X_6 + 20.26X_7 + 8.61X_8 + 63.93X_9 - 6X_{10} - 1.02X_{11} - 4.89X_{12} + 130.79X_{13} - 9.15X_{14} - 805.50 \quad (2)$$

Comparing the values of t-statistics of independent variables X_1 – X_{14} with tabular value $t_{220; 0.05} = 1.96$ it is concluded that statistically significant are: average monthly family income per person, USD (X_3), distance to the Ukrainian Carpathians (X_4), and level of education (X_6) (Table 1).

We can conclude that the respondents with the highest income are most willing to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of individual ecological tourism, and the longer the distance to the Ukrainian Carpathians, the less the respondents are willing to pay for the use of high-quality natural conditions. Also, the higher the level of education, the more the respondent is willing to pay.

Our study showed that 70 % of respondents believe that this type of tourism can become the dominant type of tourism on the territories of Ukrainian Carpathians forest fund as an alternative to mass tourism. Respondents believe that the main factors that will contribute to the successful development of ecological tourism there are:

1) effective economic and legal regulation of ecological tourism (this is the opinion of 30 % of respondents);

2) arrangement of special recreational zones on the territory (26 %);

3) construction of ecological tourism complexes, which will follow special rules and instructions (19 %);

4) introduction of mandatory certification and accreditation of tour operators engaged in ecological tourism (19 %).

The conducted sociological research provides an opportunity to better understand how society perceives the ecological tourism, as well as to study the weaknesses and prospects for the development of this type of tourism.

In our opinion, the answers of respondents are not always sufficiently scientifically substantiated about ensuring legal regulation, formation of culture of ecological tourism, environmental protection, etc. Therefore, it is more effective and expedient to conduct sociological survey from those questions among specialists in the field of ecological tourism.

To create effective conditions for the development of ecological tourism in the Ukrainian Carpathians, it is necessary to solve infrastructural problems. Effective development of ecological tourism is possible with a proper understanding of the concept of 'ecological tourism', development of strategies and specific plans for the development of ecological tourism, as well as relevant legislation and regulations in the field of ecological tourism.

The effective development of ecological tourism in the Ukrainian Carpathians requires a comprehensive science-based approach. Scientific research creates prospects for further developments in the field of ecological tourism in this region.

Conclusions

The conducted sociological survey provides an opportunity to better understand how society perceives the ecological tourism, as well as to study the weaknesses and prospects for the development of this type of tourism. Our socio-economic study shows that the majority of surveyed citizens of Ukraine (86.3 %) are interested in ecological tourism. In addition, 74 % of respondents traveled to environmental facilities. This indicator shows that tourists are interested in ecological tourism on the territories of Ukrainian Carpathians forest fund.

The main problems of effective ecological tourism development on the territory of the Ukrainian Carpathians forest fund are: potential visitors are not informed about the possibility of ecological tourism there and lack of its effective economic and legal regulation.

Theoretical-methodological and scientific-practical research has shown that the successful prospects development of ecological tourism in Ukrainian Carpathians forest fund main factors are: the effective economic and legal regulation of ecological tourism, in particular, the adoption of a Law of Ukraine 'About Ecological Tourism'; a tour operator that carries out ecological tourism on the territory of the forest fund must pass a certification system; the development of tourist facilities should comply with the concept of sustainable development. For the effective development of ecological tourism in the Ukrainian Carpathians, first of all, we need a proper understanding of the concept of 'ecological tourism', to develop the strategies and specific plans of its development, as well as to solve infrastructural problems of the region in this sphere.

According to the regression analysis,

we can conclude that the respondents with the highest income are most willing to pay per day for the use of high-quality natural conditions, receipt of environmentally friendly services of recreation and nutrition in the conditions of organised and individual ecological tourism, and the longer the distance to the Ukrainian Carpathians, the less the respondents are willing to pay for the use of high-quality natural conditions. Also, the willingness to pay will increase if the mandatory certification of the tour operator is introduced.

Perspectives of further theoretical-methodological and scientific-practical research are to study the impact of climate change on the prospects of ecological tourism, as well as to identify additional factors not previously taken into account in the regression model on which depends the willingness to pay per day for organised and individual ecological tourism on the territories of Ukrainian Carpathians forest fund.

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THE VOLUME-SPACE ARRANGEMENT OF THE TREE PLACEMENTS IN NOVOOLEKSANDRIVSKY PARK IN MELITOPOL

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Abstract

This work depicts the plan of the volume-space arrangement of the Novooleksandrivsky park in Melitopol, Zaporizhzhya region, Ukraine. All of the landscape composition structures are present in the park plan. Nevertheless, in some cases the ornamental plant species and forms of the trees aren't regularly used. The low percentage of open spaces doesn't permit to create multiplan compositions. Some species like *Platycladus orientalis*, *Juniperus virginiana* tend to lose their ornamental properties, reducing their aesthetic values. It is not characteristic of a national monument of gardening art.

Key words: functional areas, landscape pictures, planting structure, viewpoints.

Introduction

Park is one of the most important elements of green spaces, implementing functions for improvement of the environment, city landscape enrichment and favouring the environmental protection and recreation organization.

The most important characteristic of the recreation plantings is their spatial structure, which makes them dependent on the aesthetic features of the park (Kolesnikov 1974, Kucheriavyi and Styranivska 2011). The volume-spatial landscape structure consists of the volume (morphological forms, trees, shrubs and grass plantation forms, big buildings and

small forms) and planal (pools, lawns, meadows, etc.). There are several types of three-dimensional structures – closed, semi-open and open (Nehuzhenko 2011). Their proportions make dependent the functional and ornamental importance of the landscape.

Novooleksandrivsky park (in the past – Gorky park) was settled in 1926, as an initiative of I. O. Alekseev, the senior forest keeper of the Staro-Berdianske forest mass. Initially, the area was 3.5 ha. Nowadays it occupies an area of 31.87 ha. During these years, the park has been reconstructed and redesigned (Bilokon et al. 1999, Haritonova 2003). In 1990 it has gained the title of a state monument

of gardening art (MENRU 2013).

Nevertheless, nowadays, despite the numerous reconstructions and its title, the park is planned in a typical way for the most post-Soviet parks of that era. According to Chongova (2013), such 'typicality' has certain disadvantages in the planning structure, the use of the composition techniques, selection of the range of plants, failure to comply with architectural and construction regulations lack of dynamism of the park environment, etc.

The life of modern society imposes new conditions for the complex spatial organization of the park landscape. Few works by both domestic and foreign scientists have been devoted to this issue, namely: historical aspects of the development of the urban park landscape as a liminal space in an increasingly urbanizing world (Jones 2018); communication activity of the park space and valuation (Lv et al. 2013); principles of formation of modern recreational park spaces (Dudarenko 2020); the correlation between modern urban culture and planning and park planning and organization (Shaigardanova 2018); the current state of urban park landscapes (Kovalevskyi et al. 2008, Galey et al. 2017) and others.

The recreation park is a multifunctional space that is able to adapt itself by zoning to the individual requests of the city residents. The global changes in the urban space form the future trends, which, at their turn, are represented in the park development and reconstruction. Therefore, a detailed study at all levels of artistic formation of the landscape will be the basis for work on the renovation and modernization of this park.

The study of the architectural and planning component of the park as an object of landscape art is especially relevant, where the aesthetics of landscape com-

positions come first.

This work aims to characterize the modern volume-space arrangement of the Novooleksandrivsky Park in Melitopol, which is a gardening art monument. Another objective is to develop the recommendations for the park landscape optimizations, considering the regional specificities.

Materials and Methods

The volume-space arrangement evaluation was used by uses of N. Tiulpanov landscape classification (Tiulpanov 1975). This evaluation was related to the normative values for the certain climatic zone and established their ratio to the standard values for a certain natural and climatic zone (Kucheriavyi and Styranivska 2011).

The planning structure evaluation was made by the methods of Kucheriavyi (2005) and Theodoronsky (Theodoronsky and Bogovaya 2003). The planting structure was characterized by Gostev classification (Gostev and Yuskevich 1991).

The landscape views were characterised by Nikolaev methodology (Nikolaev 2005). The landscape views were characterized by horizontal ($<30^\circ$), sectoral ($30-115^\circ$), panoramic ($120-240^\circ$) and circular ($>240^\circ$) projections with short (till 50 m), medium (50–100 m) and far (>100 m) depth.

Results and Discussion

Novooleksandrivsky Park plays the most important role in the green system of Melitopol. As an object of landscape architecture, the park is a green territory with a functional planning structure, typical for recreation parks. The flat terrain of this

area led to a predominantly regular type of layout of the road and trail system of the park. The territory of the park has five functional areas: Silent resting and jogging zone, Cultural events zone, Sports zone, Garden-keeping zone, and Luna-park zone (Fig. 1). The zoning type is developed by natural climatic conditions, territory measures and placement in the urban recreation system.



Fig. 1. Map of the functional-planning structure of Novooleksandrivsky Park.

The Silent resting and jogging zone is designed in a landscape style, including garden arrangement, system of pedestrian walkways and alleys, small architectural forms (sculptures, flower-beds, lanterns, benches, recycle bins). The pedestrian walkways are covered by a solid grey concrete pavement and one of the alleys has colourful coating in the form of Ukrainian traditional dress. The others are ground paths. The zone occupies up to 60–70 % of the total park area.

The Cultural events zone is represented by a park central square. It has a round shape and surrounded by the gardening sections from deciduous breeds. The shrub pale is formed on the square margins. In the centre of the park, in the composition axis intersection, a big fountain is situated. It is surrounded by the square and the flower-beds landscape zone, alongside the lawns of the perennial herbs, stable to stepping over them.

This zone contains small architecture elements – benches, recycle bins, lights, information stands and some buildings – summer stage and cinema. The territory is used for events like Carnival, Municipal Feast, Independence Day, etc. Thus, the plan structure of the central part of the park possesses a regular structure, being used generally for events. The zone occupies up to 8–10 % of the total park area.

The garden-keeping zone maintains the park functions and occupies up to 1–2 % of the total park area. It is an administrating complex containing the garden-keeping area and the administrative building.

The Sports zone is represented by the 'Spartak' football stadium and small sport playgrounds. The IV light athletics facility category was attributed to the stadium in 2017. It permits to host national competitions. The zone contains up to 10–12 % of all the park territory.

The Lunapark zone occupies up to 11–14 % of the total park area with significant number of objects, including dancing poll, kid playground, different attractions, marketplace, museum, café, planetary, shooting gallery and a pool.

The ratio of spatial structures of Novooleksandrivsky Park is different from the normative value, considered for this region (Table 1). As a comparison, the recreation park '250-year-old oaks' in Zaporizhzhya with 57 ha has nearly the same values as the standard (Chongova and Bessonova 2013). This joint reduces the landscape diversity and, as consequence, reduces its picturesque value, which is not

characteristic of the gardening monument parks. But from the point of view of climate control, this position increases the sanitary and hygienic implementation, which is especially actual for the Southern zone. The open areas include the path system, sports playground, football stadium, lunapark territory and fountain square.

Novooleksandrivsky Park plantings possess their different structure, defined by the peculiarity of use of the plant material (Table 2).

The most widespread unit of the park plantings is forest massifs, having up to 81.05 % of the general number. This type is characteristic of landscape-planned

Table 1. The landscape type relation for gardening monument Novooleksandrivsky Park in Melitopol, %.

Monument park	Type of spatial structure		
	Closed (0.7–1.0 filled)	Semi-open (0.3–0.6 filled)	Open (<0.20 filled)
Southern steppe recommended value	55	25	20
Novooleksandrivsky Park, Melitopol	75	16	9
'250-year-old oaks', Zaporizhzhia	80	15	5

Table 2. The planting structure in Novooleksandrivsky Park.

Planting structure		Number of species / percentage of the general number of trees in the park
Solitaires		5 / 0.05
Groups	'bunches'	9 / 0.10
	Small	59 / 0.64
	Medium	29 / 0.31
	Mig	75 / 0.81
Curtains	Uniform	194 / 2.10
	Mixed	80 / 0.87
Aligned plantings	Alleys	222 / 2.40
	Rows	221 / 2.39
	Pales	1499 / 16.23
Masses		6271 / 67.90
Non-formed		572 / 6.19
Total		9236 / 100

parks. Novooleksandrivsky Park has two main mass types – protecting massifs and principal massifs. The plantations of the first group is located on the periphery of the park area and separated it from the roads and protected again wind, dust and noise. The main arrays are plantings that create a background for landscape paintings.

An equally important spatial structural unit are the curtains, which include 3.54 % of all trees and shrubs in the park and 2.51 % of them are uniform and formed from only one plant species. The curtains are a transition element between the forest masses and a more ordered plant group. In the park, they are either part of the array or collected in a separate group. The last of them form a semi-open landscape, manifesting the ornamental properties of the correspondent species. Most parts of the uniform curtains are represented by coniferous tree species (*Pinus pallasiana* D. Don., *Platycladus orientalis* (L.) Fran-

co, *Juniperus virginiana* L.). For example, the curtain of *Juniperus virginiana*, situated in the western part of the park, is part of the gardening sections from deciduous breeds. It provides a contrast between them, provoking the feeling of changes on a crossing route.

The next unit of the park plantations is a group. The groups may be big (11–13 trees, with crown diameter up to 80 m), medium (6–10 trees, with crown projection up to 50 m) and little (2–5 trees, with crown projection no more than 25 m). In Novooleksandrivsky Park it was found that 2.22 % belong to group plantings.

The bunch group has an attractive appearance in the park. This type of plant composition is situated generally in the centre of the park as separate accents in a tree-bush arrangement. The groups are uniform and represented by species like *Morus nigra* L., *Robinia pseudoacacia* L., *Juniperus virginiana* (Fig. 2). Unfortunate-



a



b

Fig. 2. Bunch group with: a) *Morus nigra*; b) *Robinia pseudoacacia*.

ly, this old structural technique is not often found in the system of greening the cities of our country. In Novooleksandrivsky Park, it is correspondent to only 0.12 %.

The solitaire plantings in the park are represented by trees (*Salix babylonica* L., *Quercus robur* L., *Platycladus orientalis*, *Picea pungens* Engelm.), consisting only 0.06 % of the total. Some of them are spontaneous, therefore, their planting hasn't been thought from architectonic point of view and therefore they do not have a high architectonic effect.

One more method of the use of the plant material for park arrangement is the aligned plantings – alleys and hedges – an element of the regular style of gardening landscape. The aligned plantings form up to 5.73 % of the total park trees. The investigated territory contains two metric alleys of closed type, formed by *Pinus palasiiana* and *Tilia cordata* Mill., separating the space from the planting massifs. The main alley of closed type, which acts as a composite axis and starts from the northern entrance to the park, is represented by a single-row *Quercus robur* plantation in combination with a hedge with *Ligustrum vulgare* L. The flowerbeds are situated along its central line with the same interval. This structure forms the impression of façade character and directs the visitors to the main composition node, which is the fountain. The pales are represented by differently kept (cut and grown) shrubs. The low pales (up to 0.5–1 m) with total length 1049 m in some places have a lack of ornamental and protecting function, due to the gap formation in the entire row.

The non-formed plantings form an indefinite structure unit of the parks. They are situated generally in the territory, in which a winter skating-ring was used to be, being a remain of previously formed plantings. According to Table 1, 7.40 % of

total tree plants are non-formed.

The next equally important stage of the study of the three-dimensional structure of the park's plantations is the analysis of the system of species disclosure of landscape paintings. We studied three pedestrian routes – central, walking and transit. The first and second routes start from the main entrance to the park and cover the central alley and the area where the monument to M. Gorky and the fountain are situated. The main part of the central route is represented by two alleys with closed spaces, which are formed by mature mixed plantations with a predominance of *Robinia pseudoacacia*, *Fraxinus excelsior* L. and *Celtis occidentalis* L. The alleys are decorated with ornamental paving in the form of a Ukrainian national ornament. The peculiarity of this route is that it combines the central entrance to the park with the secondary. The length of the central route is 719 m and has 4 viewpoints that are common to the second route (viewpoint 1, 2, 3, 4) (Fig. 3).

The second part of the walking route runs along the pond and café, and then moves to the Lunapark zone. It is characterized by a semi-open space formed by mature mixed plantations with a predominance of *Robinia pseudoacacia*, *Fraxinus excelsior* and *Gleditsia triacanthos* L. The entire second route has a length of 841 m, without height differences. There are six viewpoints on this route (Fig. 4).

There are two transit routes in the park. One of them (route III A) has a length of 705 m, and the other (route III B) – 548 m (Fig. 5). Analyzing these routes, it was found that 80 % of the territory is open and semi-open spaces and 20 % are closed. The open space on these routes is represented by the central square with a fountain, and the semi-open space is represented by two alleys: the Alley of Mem-

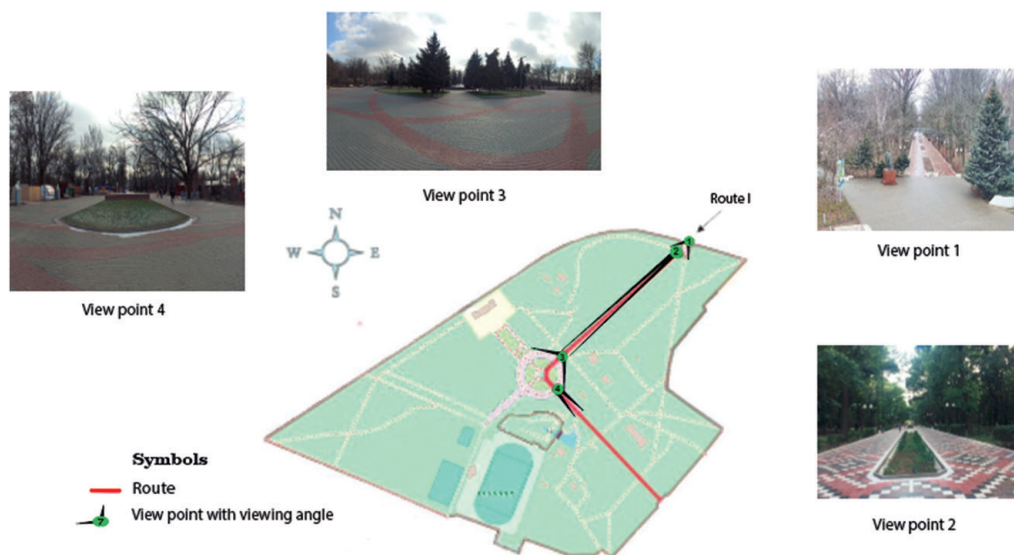


Fig. 3. The schematic plan of the viewpoints in the pedestrian route of the Novooleksandrivsky recreation park.

ory (route III B) and the alley leading to the Sports zone (route III A). The alleys are formed on both sides by low-density plantations with a predominance of *Robinia pseudoacacia* and *Fraxinus excelsior*. The difference between them is that the Alley of Memory contains *Styphnolobium japonicum* L. Schott and the other – *Pinus pallasiana*. The central part of the Alley of Memory is divided by a green strip framed by *Betula pendula* Roth. The central part of the second alley is represented by a flowerbed of regular geometric shape with plantings of *Juniperus scopulorum* Sarg. and chrysanthemums of the 'Multiflora' group.

Viewpoint 1 is situated on the central entrance in the park and is characterized by a wide horizontal angle of the sector type (80°). Nevertheless, its observation depth is short, being 40 m. The frontal plan of the perspective, with Gorky monument and the fir tree geometrical forms with the flowerbeds in the medium is active.

Viewpoint 2 has a perspective (30°) narrow observation angle and far observation depth, equal to 320 m. The medium prospect contains a rabat, which makes blink the view from the far object to a near one. A bilateral prospective frame forms the green backgrounds. Their monotonicity leads the spectator to the main landscape focus, which is the main square.

The landscape view of point 3 is also characterized by a positive horizontal angle of the panoramic type (130°) and has observation depth of 80 m. The frontal prospect contains the stalls, based on a pool and the geometrical forms of the fir-tree. The medium prospect is characterized by the central fountain. The rear prospect has the main park tree massifs, forming a margin of the main view and forming the rear plan of the landscape picture.

Viewpoint 4 is situated on the central square with a fountain and has a viewing angle of 40° and an average viewing

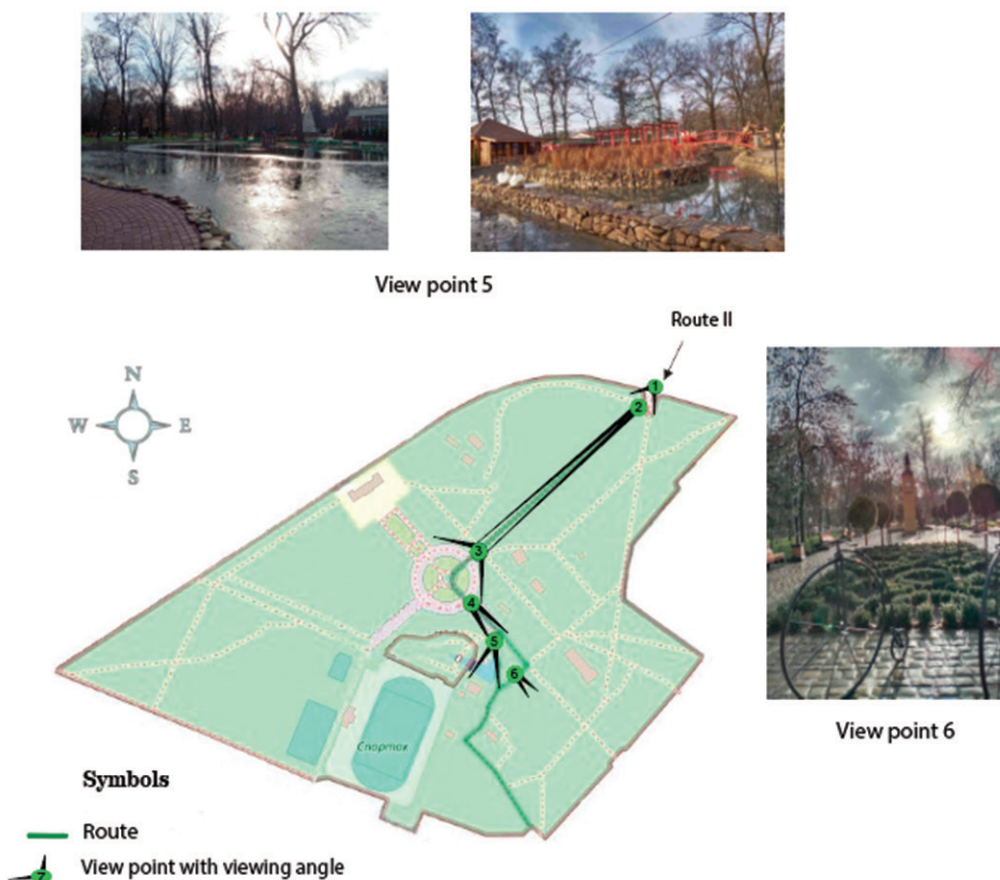


Fig. 4. The schematic plan of location of viewpoints on the pedestrian route of Novooleksandrivsky Park.

depth of 70 m. From this point the view, a small area is revealed with a lawn and a summer stage in the central part. The semantic accents are posed on both sides of the square: on the left side there are busts of poets and writers, and on the right side there is an original installation of a hand holding a 90-year-old oak tree, which symbolizes a careful attitude to nature. On the opposite side to the same area opens viewpoint 8 with a horizontal viewing angle (70°) with an average perspective of the landscape (72 m).

Viewpoint 5 opens onto the pond

through a semi-open space and it is characterized by a sector viewing angle of 70° , as well as the depth of the perspective, which is 50 m. This view is an interesting multifaceted perspective, where the picturesque shores of the reservoir are observed against the background of mixed plantings of *Robinia pseudoacacia*, *Celtis occidentalis* and *Fraxinus excelsior*. After the reservoir, the closed space continues. In the middle plan there is a water structure in the form of a cascade on a stone base.

From viewpoint 6, a view of the 'English

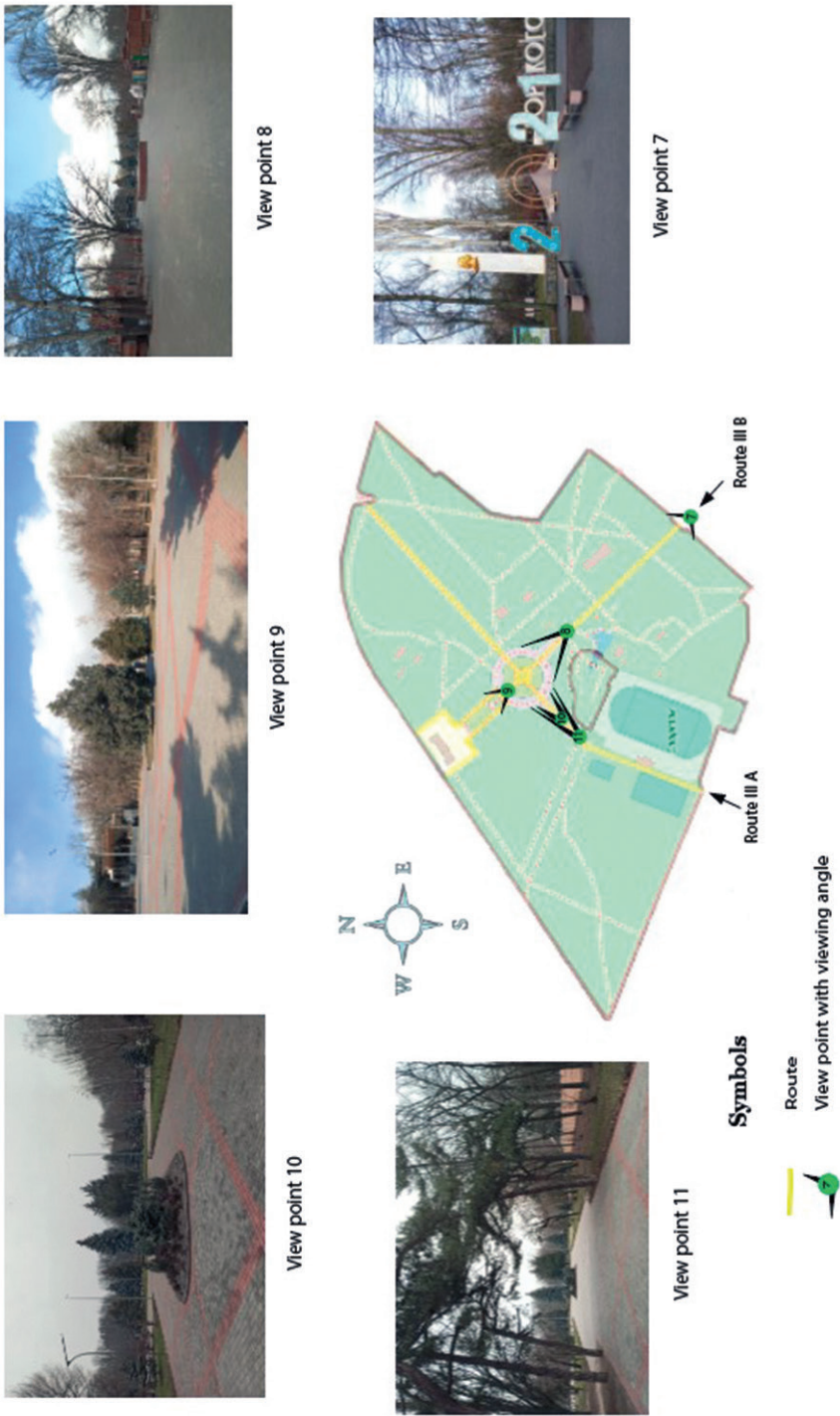


Fig. 5. The schematic plan of location of viewpoints on the transit route of Novooleksandrivsky Park.

Square' reveals, which forms a horizontal viewing angle (35°) with a short depth of perspective landscape (40 m). The territory is framed on both sides by ordinary plantings of *Prunus divaricata* Ledeb. In the foreground there are two bicycles of the popular 'Penny Farting' model in the 1880s, and in the background there is a parterre flowerbed with geometrically shaped arabesques from *Buxus microphylla* Siebold & Zucc. and stable vertical accents formed by *Thuja occidentalis* L. The background is represented by the main compositional dominant of this corner – a miniature copy of Big Ben. Next to it are figures of Police Officer Bobby with a dog, which complete the English-style compositional ensemble.

Viewpoint 7 is situated in front of the second main entrance to the park and is characterized by a wide horizontal angle of sector type (100°), however it has a short viewing depth of 11 m. Its compositional structure is represented by capital letters of the old name of the park and the stele with a bas-relief of M. Gorky. In the background of this landscape picture is an array the park that frames the main entrance.

After passing the central fountain, the visitor can see viewpoint 9 of the sector horizontal viewing angle (60°) with a short depth of perspective opening of the park picture (29 m), the compositional focus of which is a monument to internationalist soldiers surrounded by *Juniperus virginiana*.

Viewpoints 10 and 11 (viewing angle 35° and 40° and viewing depth 24 m and 60 m, respectively) have a common centre of the one-storey landscape – a flowerbed with oval perennials. But here we observe the dynamic disclosure of the park picture along the route III A. Thus, from point 11 reveals a view of the flowerbed, which is conditionally framed in a frame of

Pinus pallasiana, which limits the field of view. Conversely, the openness of space is a characteristic of viewpoint 10, which provides contemplation of the flowerbed, namely the vertical of conifers, which is visually continued by a coniferous group in the background.

Conclusions

So, on the territory of the park-monument of landscape art Novooleksandrivsky to some extent there are all main compositional structures are present.

The stylistic park formation is presented by the combination of regular and landscape park development elements. Nevertheless, in some cases, the ornamental species and forms of the ornamental plants are not used and combined correctly. The low percentage of the open spaces doesn't permit the multiplan compositions, and the existing groups of these spaces haven't been kept for a while. Some of the plants in the compositions, like *Platycladus orientalis*, *Juniperus virginiana*, lose their ornamental qualities, and, therefore need to be totally substituted or cut in order to make them regularly treated. In order to meet the requirements of the status of the park as monument of landscape art of national significance, it is necessary to increase the level of artistic value and expand the range of species composition of plantings with unique specimens of trees and shrubs species. Therefore, to improve the park landscape, we recommend:

- to increase the share of semi-open and open types of the park landscape according to normative values, which would increase their artistic value and practically do not affect the phytomeliorative and sanitary-hygienic properties of plantations (trends in increasing the artistic value and

comfort of park plantings are dominant today);

- to expand the range of ornamental trees and shrubs of the park by including such species as *Albizia julibrissin* Durazz., *Maackia amurensis* Rupr., *Spartium junceum* L., *Koelreuteria paniculata* Laxm. and others in park compositions.

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MODELLING AND FORECASTING THE IMPACT OF CLIMATE CHANGE ON FORESTS OF UKRAINE FOR 21ST CENTURY TIME HORIZON

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Abstract

In Ukraine and elsewhere on the planet, study of climate change effects on forests is of great public interest. The study aimed to evaluate climate humidity dynamics in the 21st century according to Vorobiev indicator under RCP 4.5 and RCP 8.5 scenarios. E-OBS and EURO-CORDEX project climate data were used. Climate humidity indicator by Vorobiev was used to assess the suitability of climatic conditions for forests (suitable conditions are from fresh to wet forest types). In the current climate condition in Ukraine the climate humidity varies from very dry in the south to very wet in the Carpathians. Dry (30 %) and fresh (40.1 %) types dominate. Comparing to 1961–1990, aridity has increased, boundaries of climatic zones shifted by 1 class to the north for the plains of Ukraine and to higher elevation for the Carpathians. In the Forest and the Forest-Steppe zones the fresh climate prevails, wet climate becomes less represented. Climate condition suitable for forests covers about 50 % of the country area. Both scenarios show a further aridity increase and climate zones shift to the north. Under the RCP 4.5, the areas of wet and fresh climate are expected to decrease with substitution by dry climate. In 2040–2060 the area of conditions suitable for forests will decrease to 37 % of the country area, and to 30 % in 2080–2100. Favourable conditions for the forest will remain only in the Carpathians, the western Forest-Steppe and partly in Forest zones. Under the RCP 8.5 scenario, the process of climate aridization will accelerate: dry climate types are expected to dominate. The area suitable for forest conditions will decrease significantly to 30 % in the middle and to 10 % at the end of the century.

Key words: climate zones, main trees species, RCP 4.5, RCP 8.5 scenarios, soil humidity index, Vorobiev climate indices.

Introduction

Climate change is a real threat to forest ecosystems in the temperate climate. Many climate-related studies (Dyderski et al. 2018, Buras and Menzel 2019) predicted shifting of natural ranges of main

forest forming species in Europe due to unfavourable future climate conditions. In such conditions forests become vulnerable to biotic damage and fires.

The earlier study in Ukraine (Shvidenko et al. 2017) predicted deterioration of climate conditions (under scenario A1B)

(IPCC 2000) for forest vegetation due to climate aridization in the 21st century. Water stress is the major limiting factor for forest distribution in Ukraine. Within scenario A1B, the area with unsuitable growth conditions for major forest forming species will substantially increase by the end of the century, occupying a major part of Ukraine. It is expected that the boundary of conditions that are favourable for forests will shift to north and northwest, and forests of the xeric belt will be the most vulnerable.

In this study we used the climate scenarios of The Intergovernmental Panel on Climate Change (IPCC AR5 2014), focusing on average values of climate indices, which gradually change within decades. The study aimed to evaluate climate humidity dynamics in the 21st century ac-

cording to Vorobiev indicator in Ukraine under RCP 4.5 and RCP 8.5 scenarios.

Our tasks were to reveal temperature trends, create maps of climate humidity and its zoning, evaluate total forest area and distribution of main tree species forest stands distribution by climate zones, and perform correlation analysis of local soil humidity of forest stands with climate humidity indices.

Materials and Methods

The area of study was the whole territory of Ukraine. For the classification of the territory we used forestry zones of Ukraine according to Gensiruk et al. (1981) (Fig. 1).

Forests in Ukraine totally cover about

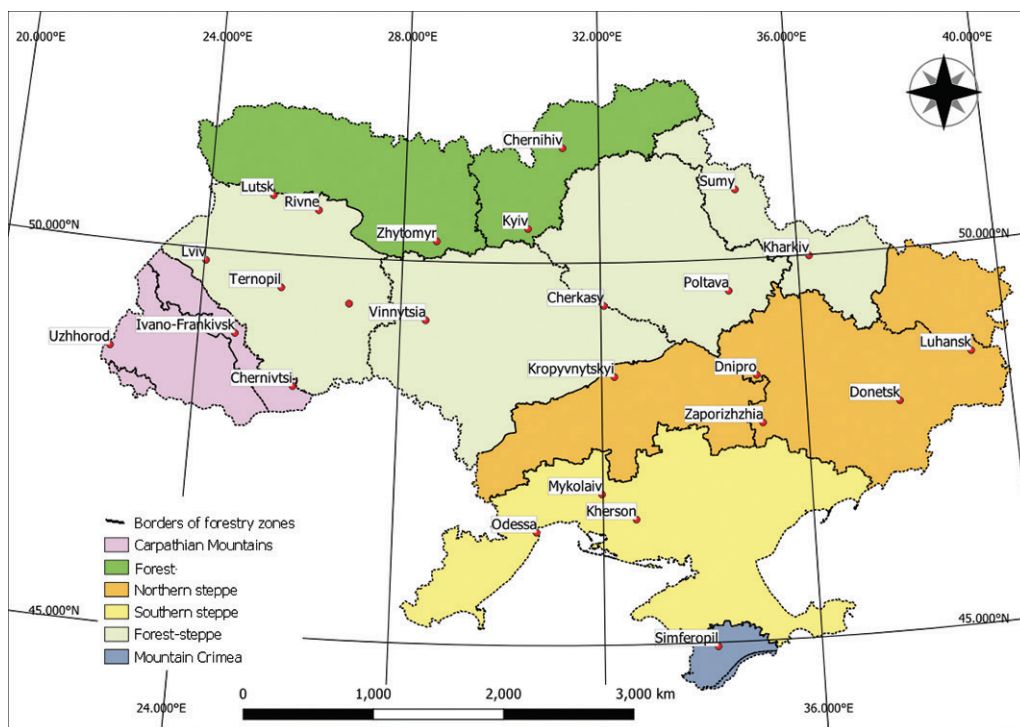


Fig. 1. Forestry zones of Ukraine (Gensiruk et al. 1981).

9.7 mill hectares, which makes 15.9 % of the total country area (Forest ... 2012). Forests are mainly located in three zones: Forest zone, Forest-Steppe and Carpathian Mountains. Each zone is characterized by specific climate and soil conditions, which influence to forest structure and composition.

According to the Forest stand-wise inventory database (2011) in highlands of the Carpathian Mountains, the main forest forming tree species is Norway spruce (*Picea abies* (L.) Karst.), lower in Carpathians and in the western part of Forest-Steppe grow mainly European beech (*Fagus sylvatica* L.) and Common

hornbeam (*Carpinus betulus* L.), in the Forest zone the most widespread tree species are Scots pine (*Pinus sylvestris* L.) and silver birch (*Betula pendula* L.), in the Forest-Steppe zone deciduous stands prevail, with predominance of English oak (*Quercus robur* L.), on sandy soils in this zone grow Scots pine stands, in wet site conditions all over the country grow black alder (*Alnus glutinosa* (L.) Gaertn.) forests (Table 1). The lowest area of forests is in the Steppe zone, and they are mainly artificial with English oak, Scots pine, Crimean pine (*Pinus nigra* subsp. *palassiana* (Lamb)) and black locust (*Robinia pseudoacacia* L.).

Table 1. Distribution of forests of the main trees species within forestry zones of Ukraine, in %.

Forestry zone	<i>F. sylvatica</i>	<i>Q. robur</i>	<i>P. sylvestris</i>	<i>P. abies</i>	All forests
Carpathian Mountains	82.7	6.3	0.7	93.8	22.1
Forest zone	0	13.8	66.7	2.8	31.6
Forest-steppe zone	12.7	66.9	26	3.4	33
Crimean Mountains	4.6	0	0.1	0	3.3
Steppe zone	0	13	6.5	0	9.9
Ukraine (whole territory)	100	100	100	100	100
Share of species areas at country level	9	28	35	7	100
Areas*, mill ha	0.86	1.81	2.40	0.63	7.58

Note: * Data on forest areas subordinated to SFRAU from forest inventory database as of 01.01.2011.

In this study, only forest areas that subordinate to State Forest Resources Agency of Ukraine (SFRAU) (Forest ... 2012) available at the forest inventory database were included in calculations. Distribution of four main forest-forming species in Ukraine of the area covered with forest vegetation, respectively (Forest ... 2012) within climate zones under different time periods and climate scenarios, was evaluated.

Average monthly precipitation and air temperature at 7371 points of climate grids

in Ukraine for the past climate (baseline period) 1961–1990, recent climate 1991–2010 (E-Obs data), and projected climate under scenarios RCP 4.5 and RCP 8.5 for 2021–2040, 2041–2060 and 2081–2100 (EURO-CORDEX Data 2021) were used as primary climate data for further calculations. We compared distributions with those at the baseline period (1961–1990).

Forest management in Ukraine is based traditionally on forest typological basis, which among other includes climate characteristics according to Voro-

biev (1961). The climate classification was developed by Vorobiev (1961) for forest areas of USSR, and detailed for Ukraine, as a component of forest typology classification of forest stands and classification of edaphic conditions. This index is easy to calculate on the basis of monthly average climate data, and results can be compared with data obtained for 1960, when boundaries of climate zones under Vorobiev humidity index were similar to natural climatic zones. The limitations of the method are that decreasing of index values is observed both in case of decreasing precipitation and temperature growth, and in case of decreasing of winter period the index will include data of the annual temperature and precipitations. In this study these limitations were not considered.

So climate change evaluation using Vorobiev humidity index can be the basis for substantiation of changes in traditional silvicultural practice in Ukraine: as differ-

ent silviculture measures, rotation period, tree species for reforestation.

Climate humidity was modelled using Vorobiev's method (Vorobiev 1961), according to which the climate type is a function of heat and moisture availability on the territory. Heat availability (T) and moisture availability (W) were evaluated using the formula (1):

$$W = \frac{\sum R_{T_{mon}>0}}{\sum T_{mon}>0} - 0.0286 \sum T_{mon}>0, \quad (1)$$

where: $\sum T_{mon}>0$ is the sum of average monthly air temperatures for the months with above-zero temperatures; and $R_{T_{mon}>0}$ is the amount of precipitation for the months with above-zero temperatures.

Climate humidity index W was used to assess the suitability of climatic conditions for forests, suitable conditions ranged 2–6 (fresh climate and above) (Table 2), below this range only intrazonal forest vegetation can grow.

Table 2. Climate humidity zones by Vorobiev and main climate indicators.

Climate zone name	Class W	Climate index W range	Colour	Conditions for forest	Average* $\sum R_{T_{mon}>0}$	Average* $\sum T_{mon}>0$
Extremely dry	-1	≤ -2.2		Unsuitable	415.3±11	177.9±2
Very dry	0	-2.2 – -0.8			392.9±7.3	142.8±1.2
Dry	1	-0.8 – 0.6			472.8±6.8	129.1±0.9
Fresh	2	0.6 – 2.0		Suitable	531±5.2	115.7±0.7
Humid	3	2.0 – 3.4			619±13.3	109.8±1.4
Moist	4	3.4 – 4.8			732.6±19	104.4±2
Wet	5	4.8 – 6.2			728.7±11.6	91.4±1.3
Very wet	6	>6.2			772.3±22.6	78.3±2

Note: * average values of indicators used for calculations of W index ± confidence interval.

For description of forest site conditions in Ukraine the classification of Alekseev-Pogrebniak is used (Ostapenko and Tkach 2002), which includes a combination of soil fertility and humidity. In this study we used only soil humidity index (hygrotop) (classes have the same

numbers and names as climate humidity classes (Table 2), and ranged from 0 to 5).

Forest stand-wise inventory database (18,649 forest compartments of 297 forestry enterprises) as of 01.01.2011 was used as a source of forest data and data on soil humidity. GIS of forestry enterpris-

es boundaries, and forestry zones (Gensiruk et al. 1981) were used for mapping and evaluation of forest and climate variables.

QGIS and R were used to create maps, classify data, and calculate areas distribution. Statistical analysis of data was performed using SPSS program.

Results and Discussion

In the recent climate (1991–2010), the average annual air temperature in Ukraine has increased by 0.8 °C compared to the baseline climate (1961–1990). At the same time, the average temperature of the coldest winter month and the warmest summer month has increased significantly (by 2 °C and 1.5 °C, respectively). The RCP 4.5 scenario predicts a steady rise in temperature: compared to the basic climate by 1.2–1.8 °C in 2021–2040, by 1.8–2.3 °C in the middle of the century, and by 2.3–3.0 °C at the end of the century. For the RCP 8.5 scenario the warming rate will accelerate – in the middle of the century expected temperature values will be the same as predicted under the RCP 4.5 at the end of the century, and by 2081–2100 the temperature may increase by 5.1 °C.

At the territory of Ukraine in 1961–1990, climate humidity varied (Fig. 2) from very wet (6) in the Carpathians to very dry (0) in the Southern Steppe, with dry (1) and fresh (2) types predominating. Very dry type prevailed in the Southern Steppe region, dry climate was represented in the Northern Steppe, and partially at the Forest-steppe, fresh type of climate dominated in the Forest-steppe and Forest zones, wet climate was represented in the Western Forest-Steppe, partly in Forest zone; in the Carpathian Mountains the conditions were the wettest: here climate varied

from fresh to very wet.

In the recent climate (1991–2010), compared to the past, an increase in climate aridity in all regions was observed. The zone of very dry climate spread to the south of the Northern Steppe region, and the fresh climate (2) covered almost the whole territory of the Forest zone, while the area of moist climate (3) significantly decreased, and it remained in the Lviv region and in the Carpathians, where the area of very wet (6) climate decreased. In fact, the climate conditions in the Forest zone have become similar to those in the Forest-Steppe (Fig. 2).

Both scenarios of future climate showed further increase in climate aridity and shifts of class boundaries in the northern direction. An extremely dry climate is expected to appear in the south. Under the RCP 4.5 scenario, the areas of wet and fresh types of climates are expected to decrease while dry climate types are expected to grow. In the middle of the century, the total area with dry climate conditions (sum of classes -1, 0 and 1) will occupy 63.2 % of the country's area, and by the end of the century – 70.5 % (Table 3). Climate conditions suitable for forest (fresh type of climate) will remain only at the Carpathians, western part of the Forest-Steppe and the western and northern part of the Forest zone.

If the RCP 8.5 scenario is implemented, the process of climate aridization will accelerate: in the middle of the century it is expected that dry climate types will occupy about 69.6 %, and at the end of the century – 89.7 % of the territory of Ukraine (Table 3). Accordingly, the area of climate conditions suitable for forest (classes 2–6) will decrease significantly: up to 30.4 % in the middle of the century, and up to 10.3 % at the end of the century. If the pessimistic scenario is implemented at the end of the

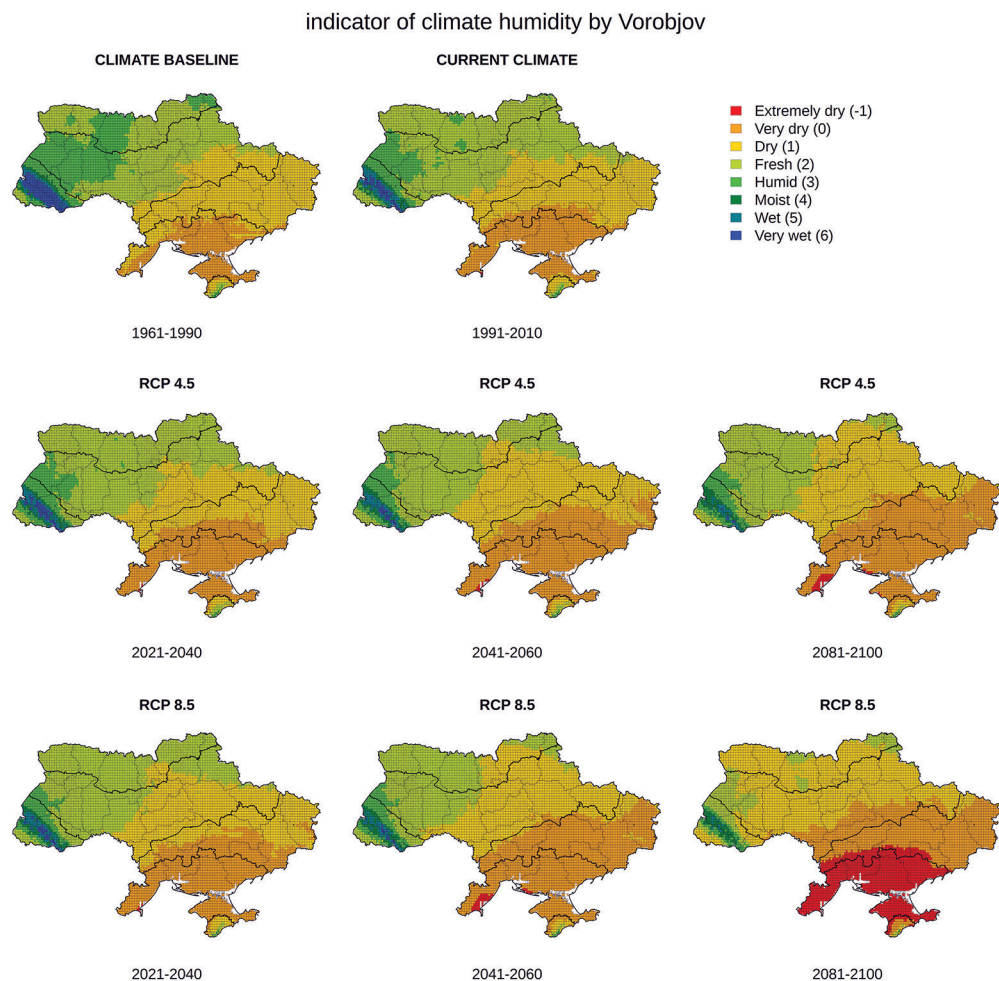


Fig. 2. Climate humidity W zones in past climate, recent climate, projected climate under RCP 4.5 and RCP 8.5 scenarios.

century, favourable conditions for forests will remain in the Carpathians, and in the western Forest-Steppe (Lviv region) and partly in the Forest zone, while in the rest of the territory more arid conditions typical of the Steppe zone will be formed. Boundaries of climate types will shift to the northwest: in the middle of the century the significant changes are expected in the Forest-Steppe zone (except its western part), as well as in the central part of the Forest

zone. Conditions in the Northern steppe will be similar to the Southern steppe.

Analysis of forested area distribution by climate humidity zones (Table 4) showed, that in the past and in recent climates the majority of forests (about 80 %) were located in climate zones from fresh to very wet. Tree species are well adapted to such conditions, because the majority of Ukrainian forests were planted mostly after II World War.

Table 3. Total area of Ukraine distribution by climate humidity zones, in %.

Class W	1961–1990	1991–2010	RCP 4.5			RCP 8.5		
			2021–2040	2041–2060	2081–2100	2021–2040	2041–2060	2081–2100
Extr. dry (-1)	0	0	0	0.2	0.7	0.1	0.7	18.7
Very dry (0)	12.4	18.6	21.9	28.7	36.1	25.4	35.6	28.7
Dry (1)	35.8	31.0	32.4	34.4	33.7	34.8	33.3	42.3
Fresh (2)	31.0	40.1	37.3	30.4	24.0	34.1	25.1	7.8
Humid (3)3	17.2	7.3	5.6	3.9	3.5	3.1	3.0	1.2
Moist (4)	0.8	1.0	1.0	1.1	1.4	1.1	1.3	1.2
Wet (5)	0.7	1.1	1.0	0.9	0.5	1.0	0.8	0.1
Very wet (6)	2.2	0.9	0.8	0.4	0.1	0.5	0.2	0
Total	100	100	100	100	100	100	100	100

Table 4. Forest area of Ukraine distribution by climate humidity zones, in %.

Class W	1961–1990	1991–2010	RCP 4.5			RCP 8.5		
			2021–2040	2041–2060	2081–2100	2021–2040	2041–2060	2081–2100
Extr. dry (-1)	0	0	0	0	0	0	0	3.0
Very dry (0)	2.0	2.6	3.3	6.1	10.2	4.2	9.0	16.2
Dry (1)	18.1	17.8	22.9	26.1	29.7	27.0	30.3	52.3
Fresh (2)	34.3	51.2	48.8	45.5	39.3	47.1	40.6	14.0
Humid (3)3	26.9	12.5	9.7	7.8	8.7	7.2	5.5	9.3
Moist (4)	2.2	4.9	5.2	5.8	11.0	5.8	7.6	5.2
Wet (5)	4.6	5.1	7.9	8.7	1.1	8.7	6.9	0.0
Very wet (6)	11.9	5.9	2.3	0	0	0	0	0
Total	100	100	100	100	100	100	100	100

Projected climate will change the distribution of forested areas within climate zones: by the middle of the century the share of forests in suitable climate condition will amount to 67.8 % in RCP 4.5, and 60.7 % in RCP 8.5. By the end of the century these values will decrease to 60.1 % in RCP 4.5, and only 28.5 % in RCP 8.5.

By the average values soil humidity index in forests, zones can be arranged in descending order: Carpathians (2.9); Forest zone (2.7), Forest-steppe (2.2), Steppe (1.4) and Crimea Mountains (1.3) (Table 5). This ranking generally corresponds to regions ranked by climate humidity (ex-

cept Steppe and Crimean Mountains). Climate humidity in the Carpathians is much higher than the weighted average soil humidity index, which is explained by the high amount of precipitations and mountain relief and low thickness of mountain soils. The opposite figure is in Forest zone: the average soil humidity index is significantly higher than the average W index, which is explained by the low relief and the ability of soils of the region to retain moisture. In the Steppe zone, the average value of soil humidity is higher than the climatic index, which is due to the fact that in this region the forests are intrazonal vegetation and confined to wetter habitats.

Table 5. Average values of soil humidity index (2011), climate humidity index (W) and class (Class W) for 1961–1990.

Zone	Soil humidity index	Climate humidity index W*	Climate humidity class W**
Ukraine	2.2±0.04	1.8±0.1	2.3±0.07
Carpathians	2.9±0.03	6.3±0.2	4.9±0.2
Forest zone	2.7±0.05	1.9±0.04	2.4±0.02
Forest-steppe	2.2±0.04	1.3±0.07	2.1±0.8
Steppe	1.4±0.05	-0.5±0.07	0.7±0.06
Crimean mountains	1.3±0.1	0.7±0.3	1.5±0.2

Note: * Climate humidity index W – absolute values of Vorobiev index, ** climate humidity class W – classified data.

In order to check the relationship, found by Vorobiev (1961), we carried out correlation analysis between the humidity of the modern climate in Ukraine according to the W index, Class W (for the period 1961–1990) and local soil humidity as the weighted average indices for each

forestry enterprise (Table 6). It showed a significant positive correlation between the studied indicators for Ukraine as a whole and its forest regions: Carpathians, Forest, and Forest-Steppe zones. For the Steppe correlation is significant at $p < 0.01$.

Table 6. Results of correlation analysis of average values of soil humidity index with climate humidity index (W) and class (Class W).

Correlation index	Climate index	Ukraine	Forested area	Carpathians	Forest zone	Forest steppe	Steppe
Kendall tau	Class W	0.602**	0.485**	0.275**	0.112**	0.380**	0.076*
	W	0.582**	0.471**	0.260**	0.153**	0.379**	0.065*
Spearman's Rho	Class W	0.746**	0.612**	0.355**	0.140**	0.478**	0.093*
	W	0.773**	0.652**	0.367**	0.229**	0.539**	0.093*
Number of forest sites		2336	1704	344	504	856	560

Note: * Correlation is significant at the level of 0.05; ** Correlation is significant at the level of 0.01.

Climatic conditions according to the humidity index cause the formation of zonal hydrological conditions, respectively, the increase in climate aridity causes changes in humidity: hydrological regime and groundwater levels. In recent years, a decrease in the groundwater level in the Forest zone was observed (State ... 2021) and an increase in the frequency of wildfires in forests and peatlands (Soshenskyi et al. 2021), which indicates that

soils become dryer, and, accordingly, the soil humidity index decreases. On the other hand, local intrazonal conditions formed under certain relief and water availability that may significantly differ from the zonal ones. Some of such places can remain favourable for forests.

Tree species can grow in a certain range of environmental conditions. European beech stands in the current climate grow in a narrow range of soil

humidity (2 and 3). Comparison of the distribution of forest areas of the studied species with the data of climate humidity W (Table 7) showed that in the Western part of the Forest-Steppe zone, conditions for beech will become drier, which will negatively affect their health condition. Norway spruce stands grow in a wide range of soil humidity from 1 to

5, (the weighted average index is 3.0). Stands in more dry conditions will be potentially most vulnerable to increasing climate aridity. Among the studied species, oak is less demanding of soil humidity: it grows in the range of soil humidity from 0 to 4 (average index – 2.1); Scots pine grows in the range from 0 to 5, (average index – 2.3).

Table 7. Main tree species area distribution by humidity climate zones (Class W), in %.

Class W	1961– 1990	1991– 2010	RCP 4.5			RCP 8.5		
			2021– 2040	2041– 2060	2081– 2100	2021– 2040	2041– 2060	2081– 2100
Scots pine								
Extr. dry (-1)	0	0	0	0	0	0	0	1.4
Very dry (0)	1.4	1.4	1.5	3.5	7.1	2.3	5.6	10.3
Dry (1)	13	11.9	16.2	22.2	32.1	22.4	30.6	73.4
Fresh (2)	48.9	77.1	78.5	71.5	58.7	73.2	61.8	14.5
Humid (3)3	36.2	9	3.2	2.4	1.7	1.6	1.5	0.4
Moist (4)	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.1
Wet (5)	0.1	0.1	0.1	0.1	0	0.1	0.1	0
Very wet (6)	0.2	0.1	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100
English oak								
Extr. dry (-1)	0	0	0	0	0	0	0	1.3
Very dry (0)	0.3	1.0	1.5	6.1	13.0	2.7	11.6	27.5
Dry (1)	27.9	29.6	41.4	46.7	46.4	48.1	49.6	59.1
Fresh (2)	42.4	56.1	47.2	40.2	34.0	42.8	33.8	11.1
Humid (3)3	27.0	11.4	8.7	6.0	5.8	5.4	4.0	0.9
Moist (4)	1.0	1.5	0.8	0.9	0.7	0.9	0.9	0.0
Wet (5)	0.8	0.4	0.3	0.0	0.0	0.0	0.0	0.0
Very wet (6)	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100	100	100	100	100	100	100	100
Norway spruce								
Extr. dry (-1)	0	0	0	0	0	0	0	0
Very dry (0)	0	0	0	0	0	0	0	0.1
Dry (1)	0	0.1	0.2	0.5	1.7	0.5	1.6	12.6
Fresh (2)	3.4	7.9	8.5	10.3	13.7	10.4	14.7	9.9
Humid (3)3	9.4	10	9.5	11.7	16.1	11.6	6.3	46.9

Class W	1961– 1990	1991– 2010	RCP 4.5			RCP 8.5		
			2021– 2040	2041– 2060	2081– 2100	2021– 2040	2041– 2060	2081– 2100
Moist (4)	5.3	17.1	22.8	21.9	60.9	21.9	29.3	30.6
Wet (5)	9.1	24.5	43.1	55.5	7.6	55.5	48.2	0
Very wet (6)	72.7	40.4	16	0	0	0	0	0
Total	100	100	100	100	100	100	100	100
European beech								
Extr. dry (-1)	0	0	0	0	0	0	0	0
Very dry (0)	0	0	0	0	0	0	0	2.2
Dry (1)	2.2	2.2	2.2	2.2	2.2	2.2	3	19.4
Fresh (2)	5.3	9.8	9.3	19.6	25.2	20.9	24.4	28.6
Humid (3)3	22.2	34	35.5	28.5	35.5	27.2	22.9	31.3
Moist (4)	7.4	19.7	20.8	26.9	32.8	26.9	35.7	18.4
Wet (5)	26.4	21.6	25.5	22.9	4.4	22.9	14	0
Very wet (6)	36.5	12.7	6.7	0	0	0	0	0
Total	100	100	100	100	100	100	100	100

So taking into account the correlation analysis (Table 6) the indirect impacts of projected climate change at the site level are likely to occur: as lowering groundwater levels, drying of small rivers and other water bodies etc. Such a phenomenon has already been observed in many regions of Ukraine. Consequences of climate change are observed now: forest stands become more susceptible to damaging agents, including biotic (pests and diseases) and abiotic (fires) damage. During last decade massive Scots pine (Tkach and Meshkova 2019, Meshkova 2021) and Norway spruce decline caused by bark-beetles (Parpan et al. 2014), diseases of Norway maple (Meshkova and Davydenko 2016) and common ash (Davydenko and Meshkova 2017) were reported in different regions of Ukraine. According to statistical data of the State Agency of Forest Resources of Ukraine (Bondar 2019) for the period 2009 – 2018 the trend to increasing of forest dieback area (from 176,000 ha in 2009

to 413,000 ha in 2018) was revealed. In 2019 the total area of declined Scots pine (*Pinus sylvestris*) forests was 222,000 ha, Norway spruce (*Picea abies*) – 27,000 ha, English oak (*Quercus robur*) – 100,000 ha and at stands of other species – 64,000 ha (Bondar 2019). In 2018, catastrophic mortality of pine forests caused by bark beetle *Ips acuminatus* outbreaks mainly in Forest zone was observed.

For recent decades the frequency of large wildfires in Ukraine significantly increased, especially in 2020 when the catastrophic fires took place: 74,600 ha of forests were damaged (Soshenskyi et al. 2021), this figure is 4.9 times higher than the previous fire maximum (15,300 ha) registered in 2014 (year of war conflict in the Eastern Ukraine). Large fires took place in pine forests in Forest zone, as well as in Northern Steppe zone. The incidence of forest fires depends species composition of forests and correlates with precipitation amounts during warm period (Zibtsev et al. 2019).

According to the latest data (Shparyk et al. 2020), climatic changes in the Carpathians have already occurred and led to a shift in the altitude boundaries of vegetation zones, changes in trees species composition, Norway spruce decline, and reduction of soil humidity by 1–2 classes. The area of Norway spruce decreases, while the area of beech stands increases. Projected climate change will lead to further changes in the altitudinal zonation of the Carpathians. Unfortunately, the latest data on the soil humidity indices in forests and their dynamics in other regions of Ukraine are not available today, reduction of soil humidity in other regions should be expected.

Projected climate changes are very rapid, so tree species and forest ecosystems cannot adapt to them, so in the business as usual case, decreasing of forest area is expected. The probability of natural zones shifting to the north is very high, even under the optimistic scenario. The extension of the steppe ecoregion is forecasted. Under new climate conditions shifting of natural ranges of the main tree species, e.g. *Pinus sylvestris*, *Quercus robur*, *Fagus sylvatica* to the north is probable (Shvidenko et al. 2017, Dyderski et al. 2018, Buras and Menzel 2019). Conditions favourable for *Picea abies* stands will remain at higher altitudes in the Carpathian Mountains, while at lower elevations they will be replaced by *Fagus sylvatica*.

Measures for adaptation of forests in Ukraine to projected climate change should be developed. It is very important is to maintain existing forests, and gradually replace coppice oak stands with seed, the pure pine stands with mixed one, improvement of species composition, taking into account species adaptive capacity, conservation of the gene pool of native tree and shrub species, improve the tech-

nology of creating forest culture and growing of drought-resistant seedlings. In the steppe zone, special attention should be paid to protection against forest fires.

Conclusions

Our study showed that projected climate conditions in Ukraine in the 21st century due to climate warming and aridization will become unfavourable for forest vegetation across large areas all over the country. Projected climate change negative effect in terms of forest areas is expected to be the biggest in Forest-Steppe and Forest zones. Under new climate conditions by the middle of the century, the share of forests in suitable climate conditions will amount to 67.8 % or 60.7 % of the current forested area, depending on scenario, by the end of the century these figures may amount to 60.1 % or 28.5 % depending on scenario.

Significant deterioration of forest health condition is expected all over the country. There is a big risk of forest decline over large territories, partly caused by outbreaks of pests and diseases outbreaks and forest fires. With unfavourable climate conditions forests may remain only locally, as intrazonal vegetation in wet sites.

To reduce the negative consequences of climate change on forests, it is necessary to develop and implement multiple adaptation measures, taking into account local site conditions and tree species composition.

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EFFECTS OF MYCORRHIZAE INOCULATION AND WATER REGIME ON THE GROWTH OF *CASSIA FISTULA* L. SEEDLINGS

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Abstract

We examined the effects of two mycorrhizae fungi (endomycorrhiza and ectomycorrhiza) and varying moisture supply on certain growth parameters of *Cassia fistula* L. seedlings. The seedlings were inoculated with endomycorrhiza and ectomycorrhiza, compared with no mycorrhiza, and watered every day, every other day and once a week for a period of 12 weeks. The results revealed that mycorrhiza contributed significantly to relative water content while moisture supply also significantly influenced shoot height, collar diameter, leaf number, fresh weight of leaves, turgid weight of leaves, fresh weight of shoots, and fresh weight of roots. However, interaction of mycorrhiza and moisture supply had no significant effect on seedling growth of *C. fistula* but endomycorrhiza at watering every other day had the best growth performance.

Key words: drought, ectomycorrhiza, endomycorrhiza, fungi, moisture supply, seedlings performance.

Introduction

Forests, being an important aspect of land ecosystem have been negatively affected (Keenan et al. 2015) mostly by anthropogenic factors (Kelley et al. 2015, Mohamed Ait El et al. 2019). The loss of natural forests has triggered the establishment and expansion of man-made forest (Warman 2014). The degradation of forest

ecosystem has led to complex changes with negative consequences economically, culturally (Caputo et al. 2017, Qiao et al. 2019) and environmentally. Man-made forests are therefore suitable choice not just to meet up with the increasing demand of wood and wood products, but also to reduce the destructive harvesting of natural forests, protect forest soil and water resources as well as enhancing bio-

diversity and restoration of degraded soil (FAO 2010, Li et al. 2020). The hazardous effects of chemical fertilizers on human and environment (Chandini et al. 2019) have necessitated the need to holistically consider biological and environmentally friendly approaches that could possibly improve the optimum growth and development of plants generally.

A mycorrhizal association with plant is a symbiotic relationship between a fungus and the root of a plant, that is primarily responsible for nutrient transfer (Brundrett 2004). Mycorrhiza fungi are essential representative of the plant microbiome that support its access to soil nutrients and water uptake (van der Heijden et al. 2015). Thus, the use of Mycorrhiza (fungi) to enhance the optimum performance of plants is arguably one approach which cannot be jettisoned. Predominantly, endomycorrhizal also known as arbuscular mycorrhizal (AM) and ectomycorrhizal (EM) fungi are functional types which exhibit symbiotic association with the roots of most terrestrial plants (Tedersoo 2017).

Endomycorrhizal are found in about ninety percent of plant families encompassing grasses, forbs, and some woody plants (Zhu et al. 2010). It has been reported that inoculation of *Cupressus atlantica* Gaussen with endomycorrhiza alleviated the impact of drought stress by improving water and nutrient uptake (Zarik et al. 2016). AM fungi which are soil-borne and capable of significantly improving plant nutrient uptake could as well enhance plant resistance against several abiotic stress factors (Sun et al. 2018). AM inoculation can contribute to water availability and water transport after colonization in plants (Bitterlich et al. 2018).

Ectomycorrhizal fungi known to be associated with woody plant species (Roy-Bolduc et al. 2015) are significant com-

ponents of temperate forests (Toju et al. 2014). Some few plant families that are involved in ectomycorrhizal association include Betulaceae, Dipterocarpaceae, Fagaceae and Pinaceae (Futai et al. 2008). Ectomycorrhizal fungi have also been reported to reduce root pathogens (Liang et al. 2020) and shields the host trees from attack (Futai et al. 2008), thereby preventing diseases and death.

Tree growth is generally affected by low water availability and/or drought which are consequences of climate change (Meineke and Frank 2018). It has been reviewed many times that moisture stress tolerance of various plant mainly depend on their ability to access and efficiently use soil water (Richards et al. 2010) but this also depends on type of tree species and cultivar, time and duration of water availability, and forest conditions (Munns et al. 2010, Richards et al. 2010, Isah et al. 2012). Thus, it is essential to evaluate the inclusive water stress tolerance mechanism of plant species (Lisar et al. 2012, Shamim et al. 2014) for optimum performance.

Cassia fistula Linn. (Caesalpiniaceae) is commonly known as the Golden Shower or popularly called 'Indian Laburnum' because of its beautiful bunches of yellow flowers (Danish et al. 2011). It is a deciduous tree with greenish-gray bark and cylindrical pods containing black seeds. The pulp is dark brown, sticky, sweet and mucilaginous, with odour characteristic (Gupta et al. 2005, Gupta 2010). The plant is native to India, the Amazon and Sri Lanka; it has also been discovered in various countries including Mexico, Mauritius, South Africa, East Africa, West Indies, China (Kumar et al. 2006, Chauhan Neelam et al. 2011). It is a medicinal plant (Orwa et al. 2009, Ali 2014) with the potential to treat infected wound (Siddhuraju

et al. 2002, Nirmala et al. 2008), skin diseases (Singh et al. 2013) health benefits (Rahmani 2015) and other uses.

We therefore proposed to investigate the performances of two mycorrhizal (endomycorrhizal and ectomycorrhizal) fungi, moisture supply, and interaction between mycorrhiza inoculation and moisture supply to determine the best treatment of mycorrhizal fungi as well as the most appropriate water regime suitable for the growth of *Cassia fistula* seedlings.

Materials and Methods

Experimental site

The experiment was carried out at the forest nursery unit of the Department of Forestry and Wildlife Management, Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria. The latitude is within 7° and 7°58' N and longitude is within 3°20' and 3°37' E. The land is gently sloping due to its undulating landscape which permits for easy surface run-off. This area has notably an annual rainfall of 1200 mm with peak in June and July, average monthly temperature of about 35 °C and relative humidity of 82.54 %.

Seedling preparation and mycorrhizae inoculation

The pods (matured) of *C. fistula* were collected from matured and healthy trees in FUNAAB. The matured pods were further processed for seed extraction and treatment; they were then raised on germination bed. Seeds were fully germinated in about 14 days. A total of 54 seedlings of similar height and size were selected from the germination bed and transplanted to polythene pot after three weeks.

Endomycorrhiza soil used was procured from the College of Plant Science and Crop Production, FUNAAB, while ectomycorrhiza soil was collected from the roots rhizosphere of matured and healthy *Pinus caribaea* Mor. tree. Top soil from the forest nursery with close proximity to matured *C. fistula* in FUNAAB was also excavated and used as planting medium to imitate natural soil environment for seedlings growth. Before filling the polythene pots, the soil was sieved to remove debris and soil lumps.

The fungal (endomycorrhiza and ectomycorrhiza) inoculum which contained mixtures of soil and root fragments at 20 g respectively was added to 600 g soil used and properly mixed together before filling the pots. Top soil of the same quantity was used for the control (no mycorrhiza). Water was added to the filled polythene pots and allowed to drain before transplanting. Seedlings of *C. fistula* were then transplanted from germination bed to pots which had been perforated at the base to allow for drainage of excess water and prevent water logging.

Experimental design and treatments

The experiment was conducted with a three-factorial design under randomized block condition. The factors were endomycorrhiza, ectomycorrhiza and moisture supply; where, endomycorrhiza (M_1), ectomycorrhizal (M_2) and no mycorrhiza (M_3), and water supply (watering daily (W_1), watering 1st and 4th day of the week 2/7 (W_2) and watering once a week 1/7 (W_3)). The experiment was designed with 6 replicates. Thus, a total of nine treatments were used for this study and were represented as M_1W_1 , M_1W_2 , M_1W_3 , M_2W_1 , M_2W_2 , M_2W_3 , M_3W_1 , M_3W_2 , and M_3W_3 . For each replicate of the experiment at one

seedling per pot, 18 seedlings were allocated for each sources of mycorrhizae (M_1 , M_2 , M_3) used while 6 seedlings were allocated to each watering regime (W_1 , W_2 , and W_3). At the commencement of the 2nd week of transplanting, seedlings under each treatment were subjected to varying watering regime.

Data collection

The measurements of both the morphological and the physiological parameters during growth were taken fortnightly. The morphological parameters examined include: seedling height (cm) which was determined using a measuring tape, leaf number, leaf area (cm^2), collar diameter (mm) which was determined using a digital caliper, fresh and dry weight, and turgid weight (g) which was determined using a weighing scale. The physiological parameters measured were the relative water content (%) and turgidity.

Fresh weight

After 12 weeks the seedlings of each treatment were harvested from the pot and were separated into leaf, stem, and root. Root and shoot length was measured and fresh weights of each component were recorded.

Dry matter

Dry weights of each component (leave, root and shoot) were obtained after being oven-dried for 24 h at 600 °C.

Relative turgidity

To determine the relative turgidity, the fresh leaf was soaked in water in a petri-dish overnight and was weighed. The

plant turgidity (PT) was calculated by formula (1):

$$PT = (S_{wt} - F_{wt}) / F_{wt} \cdot 100, \quad (1)$$

where: S_{wt} is weight of plant (soaked in water); F_{wt} is fresh weight.

Relative water content

To determine the relative water content (RWC) of the species the formula (2) was employed.

$$RWC = (F_{wt} - D_{wt}) / (T_{wt} - D_{wt}) \cdot 100, \quad (2)$$

where: F_{wt} is fresh weight; D_{wt} is dry weight; T_{wt} is turgidity weight.

Statistical analysis

All the data collected were analysed by two-way analysis of variance (ANOVA) on the general linear model of SAS Software (SAS institute, inc. 1999) and significant means were separated by Duncan's multiple range test.

Results

Seedlings response to mycorrhizae

To establish the performance of *C. fistula* seedling after inoculation with endomycorrhiza and ectomycorrhiza, morphological and physiological parameters listed above were examined. M_1 resulted to increased mean value of shoot height, leaf area, fresh weight of stems, and fresh weight of roots, and dry weight of roots by 11.93 cm (Fig. 1.1), 26.49 cm^2 (Fig. 1.4), 0.34 g (Fig. 1.7), 0.82 g (Fig. 1.7), and 0.39 g (Fig. 1.8) respectively. Furthermore, seedlings with M_2 had the highest mean value for collar diameter – 1.75 mm (Fig. 1.2) and relative water content (29.44 %). However, leaf numbers, turgid weight of

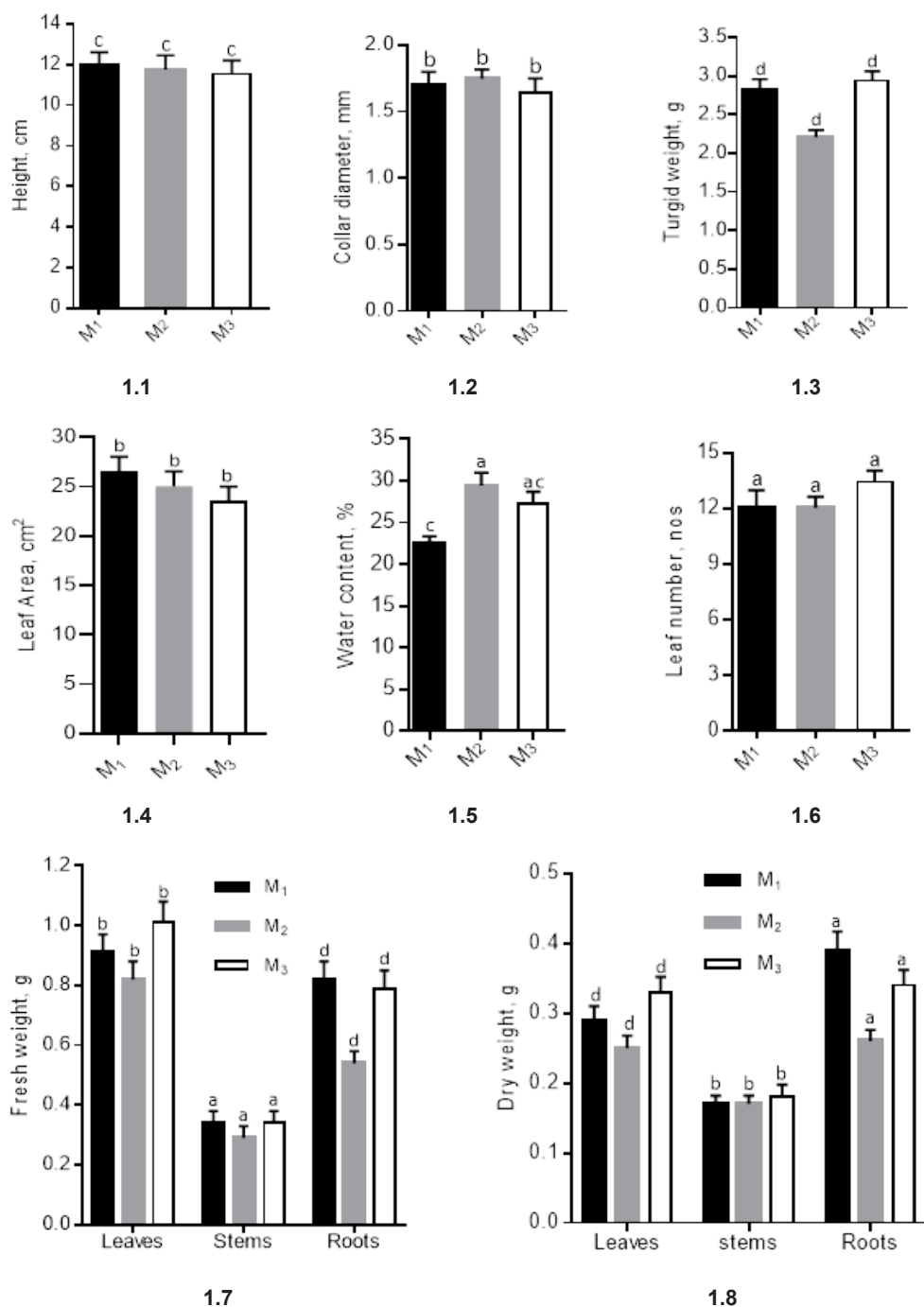


Fig. 1. Effect of mycorrhiza inoculation.

Note: Different letters indicate significant difference between treatments ($p < 0.05$).

leaves, dry weight of leaves, fresh weight of stems and leaves, and dry weight of stems had highest mean value by 13.44 (Fig. 1.6), 1.01 g (Fig. 1.3), 2.94 g, 0.33 g, 0.34 g, and 0.21 g respectively in M_3 . More so, the result showed that seedlings inoculated with M_2 were significantly different ($p < 0.05$) for relative water content having

the highest mean value of 29.44 % (Fig. 1.5) while those inoculated with M_1 and M_3 were not significantly different from each other with mean value of 22.43 % and 27.30 % respectively. Analysis of variance showed that mycorrhiza had significant effect ($p < 0.05$) on relative water content only (Table 1).

Table 1. Analysis of variance (ANOVA).

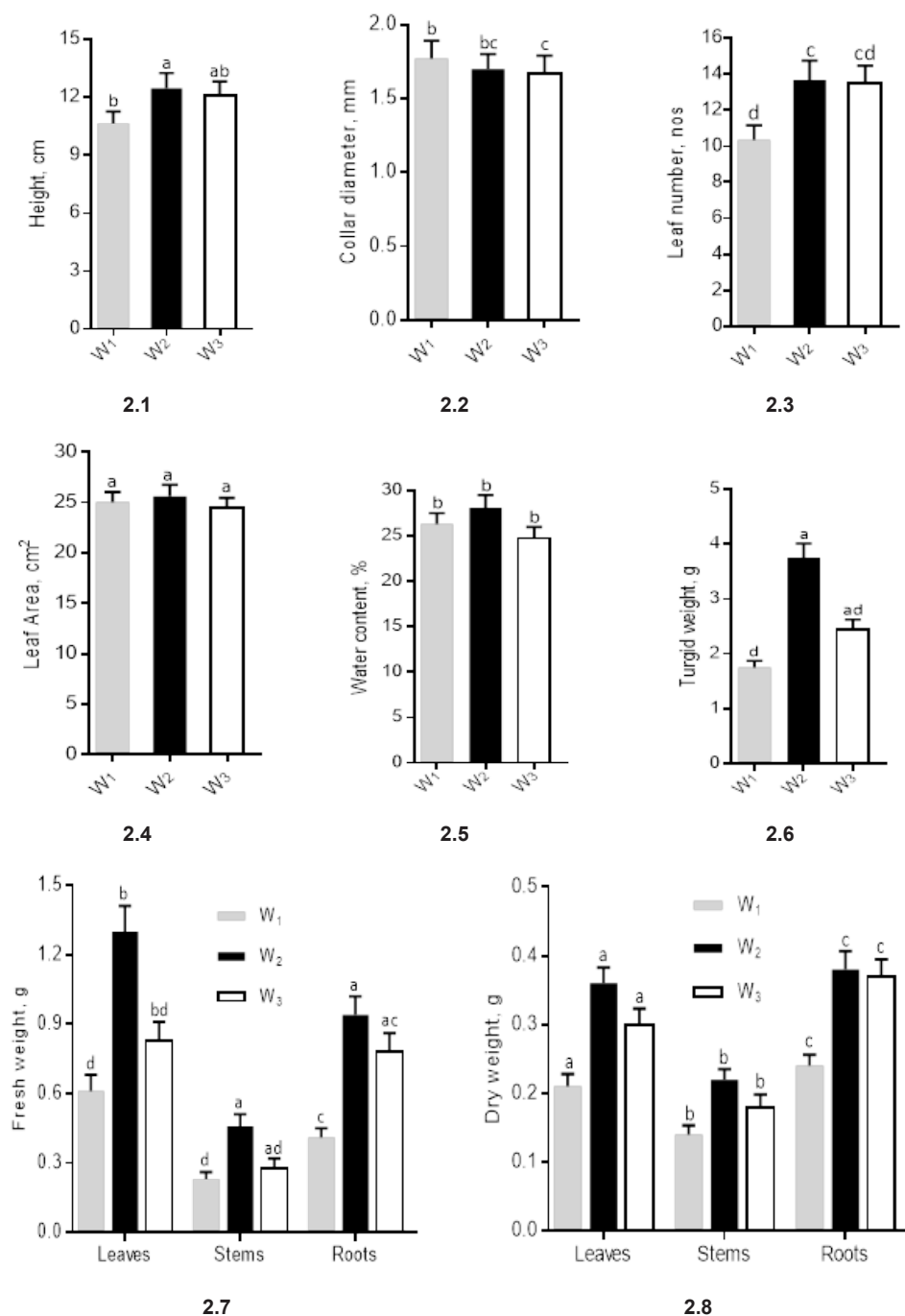
Parameters	Mycorrhiza		Water		Mycorrhiza $\times$ water	
	F	P	F	P	F	P
Shoot height	0.150	0.860	3.410	0.050*	1.400	0.260
Collar diameter	1.620	0.220	3.350	0.050*	1.180	0.340
Leaf area	0.650	0.530	0.100	0.900	0.950	0.450
Leaf number	1.550	0.230	8.320	0.002*	1.350	0.270
Fresh weight of leaves	0.550	0.580	7.740	0.002*	1.640	0.190
Turgid weight of leaves	1.080	0.350	7.480	0.003*	0.970	0.440
Dry weight of leaves	0.460	0.640	1.980	0.150	0.640	0.640
Fresh weight of shoots	0.380	0.690	9.380	0.001*	1.010	0.420
Dry weight of shoots	0.640	0.540	2.170	0.130	0.640	0.640
Fresh weight of roots	2.420	0.120	7.500	0.003*	2.340	0.080
Dry weight of roots	2.010	0.150	2.830	0.080	1.190	0.340
Relative water contents	3.810	0.030*	0.820	0.450	1.460	0.240

Note: * Indicate significant difference of treatments ($p < 0.05$).

Seedlings response to moisture supply

To underscore the effect of various water regimes on the growth performance of *C. fistula* seedlings, morphological and physiological parameters listed above were measured. The result revealed that W_1 seedlings had the highest mean value of 1.77 mm (Fig. 1.1) for collar diameter only. However, W_2 seedlings had the highest mean values of 12.46 cm (Fig. 2.1), 25.61 cm² (Fig. 2.4), 13.69 nos (Fig. 2.3), 1.30 g (Fig. 2.7), 3.76 g (Fig. 2.6), 0.36 g (Fig. 2.8), 0.46 g (Fig. 2.7), 0.22 g (Fig. 2.8), 0.94 (Fig. 2.7), 0.38 g (Fig. 2.8), and 28.10 % (Fig. 2.5) for shoot height, leaf area, leaf number, fresh weight of leaves, turgid weight of leaves, dry weight of leaves, fresh weight of stems, dry weight

of stems, fresh weight of roots, dry weight of roots, and relative water content respectively. The results further revealed that seedlings watered daily were significantly different ($p < 0.05$) for collar diameter (Fig. 2.2) with the highest mean value of 1.77 mm. In addition, seedlings watered every other day were also significantly different ($p < 0.05$) with the highest mean value of 12.46 cm, 13.69 cm², 3.76 g, 1.30 g, 0.46 g, and 0.94 g for shoot height, leaf number, turgid weight of leaves, fresh weight of leaves, stems and roots respectively. Furthermore, W_3 seedlings had no highest mean value for the growth parameters but had the lowest mean value of 1.67 mm, 24.47 cm², and 24.77 % for collar diameter, leaf area, and relative water content respectively. Analysis of variance

**Fig. 2. Effect of varying moisture.**

Note: Different letters indicate significant difference between treatments ($p < 0.05$).

showed that moisture supply had significant effect ($p < 0.05$) on shoot height, collar diameter, fresh weight of leaves, turgid weight of leaves, fresh weight of shoots, and fresh weight of roots (Table 1).

Interactive effect of mycorrhizae and moisture supply

To verify the interactive effect, the same physiological and morphological parameters as above were examined. Considering the effect of endomycorrhiza with varying moisture supply, the result revealed that seedlings inoculated with endomycorrhiza and watered once a week (M_1W_3) had no highest mean value for all the parameters measured. However, seedlings inoculated with endomycorrhiza and watered every other day (M_1W_2) had the highest mean value for most of the parameters measured, which include shoot height (13.98 cm), collar diameter (1.80 mm), leaf area (29.68 cm²), leaf number (14.63), fresh weight of leaves (1.62 g) turgid weight of leaves (4.47 g), dry weight of leaves (0.44 g), fresh weight of stems (0.57 g), dry weight of stems (0.26 g),

fresh weight of roots (1.39 g), dry weight of roots (0.53 g) and relative water content (29.11 %) (Table 2). In addition, seedlings inoculated with endomycorrhiza and watered every day (M_1W_1) had no highest mean value for all parameters measured. Results from the effect of ectomycorrhiza with varying moisture supply showed that seedlings treated with ectomycorrhiza and watered once a week (M_2W_3) had the highest mean value for shoot height (12.64 cm), leaf area (27.63 cm²), leaf number (13.04), dry weight of leaves (0.33 g), fresh weight of roots (0.70 g). More so, seedlings inoculated with ectomycorrhiza and watered every other day (M_2W_2) had the highest mean value for fresh weight of leaves (1.03 g), turgid weight of leaves (3.00 g), fresh weight of stems (0.41 g), dry weight of stems (0.20 g), dry weight of roots (0.31 g) while seedlings inoculated with ectomycorrhiza and watered every day (M_2W_1) had the highest mean value for collar diameter (1.83 mm) and relative water content (29.65 %) only. Furthermore, seedlings treated in the absence of mycorrhiza but watered once a week (M_3W_3) had the highest mean value for shoot height

Table 2. Interactive effect of mycorrhiza and moisture supply.

Treatments		SH, cm	CD, mm	LA, cm ²	LN	FWL, g	TWL, g	DWL, g	FWS, g	DWS, g	FWR, g	DWR, g	RWC, %
M_1	W_3	11.23 ^d	1.58	24.45 ^t	12.50 ^l	0.55 ^u	2.03 ^k	0.21 ⁿ	0.26 ^z	0.13 ^b	0.67 ⁱ	0.43 ^h	17.61 ^l
	W_2	13.98 ^d	1.80 ^v	29.68 ^t	14.63 ⁱ	1.62 ^u	4.47 ^k	0.44 ⁿ	0.57 ^z	0.26 ^b	1.39 ^j	0.53 ^h	29.11 ^l
	W_1	10.58 ^d	1.71 ^v	25.34 ^t	09.13 ⁱ	0.56 ^u	1.95 ^k	0.22 ⁿ	0.19 ^z	0.11 ^b	0.39 ^j	0.21 ^h	20.58 ^l
M_2	W_3	12.64 ^d	1.71 ^v	27.63 ^t	13.04 ^l	0.77 ^u	1.91 ^k	0.33 ⁿ	0.28 ^z	0.18 ^b	0.70 ^j	0.28 ^h	29.20 ^l
	W_2	11.92 ^d	1.71 ^v	23.82 ^t	11.88 ^l	1.03 ^u	3.00 ^k	0.26 ⁿ	0.41 ^z	0.20 ^b	0.56 ^j	0.31 ^h	29.50 ^l
	W_1	10.69 ^d	1.83 ^v	23.58 ^t	11.17 ^l	0.67 ^u	1.74 ^k	0.16 ⁿ	0.20 ^z	0.13 ^b	0.35 ^j	0.20 ^h	29.65 ^l
M_3	W_3	12.38 ^d	1.56 ^v	21.34 ^t	14.92 ^l	1.16 ^u	3.40 ^k	0.38 ⁿ	0.30 ^z	0.24 ^b	0.98 ^j	0.40 ^h	27.54 ^l
	W_2	11.49 ^d	1.59 ^v	23.32 ^t	14.58 ^l	1.26 ^u	3.82 ^k	0.40 ⁿ	0.42 ^z	0.21 ^b	0.88 ^j	0.31 ^h	25.69 ^l
	W_1	10.71 ^d	1.78 ^v	26.21 ^t	10.83 ^l	0.61 ^u	1.60 ^k	0.22 ⁿ	0.30 ^z	0.17 ^b	0.51 ^j	0.32 ^h	28.66 ^l

Note: Mean values with similar letters indicate no significant differences between treatments ($p > 0.05$). SH – shoot height, CD – collar diameter, LA – leaf area, LN – leaf number, FWL – fresh weight of leaves, TWL – turgid weight leaves, DWL – dry weight leaves, FWS – fresh weight of shoot, DWS – dry weight of shoot, FWR – fresh weight of root, DWR – dry weight root, RWC – relative water content.

(12.38 cm), leaf number (14.92), dry weight of stems (0.24 g), fresh weight of roots (0.98 g), and dry weight of roots (0.40 g) while seedlings that were not inoculated with mycorrhiza but were watered every other day (M_3W_2) had highest mean value for fresh weight of leaves (1.26 g) turgid weight of leaves (3.82 g), and dry weight of leaves (0.40 g). Nevertheless, seedlings that were not inoculated with mycorrhiza but were watered every day (M_3W_1) had the highest mean value for collar diameter (1.78 mm), leaf area (26.21 cm²), relative water content (28.66 %).

Discussion

Most trees in the field are exposed to challenging environmental conditions which affect their survival. Drought which is a prevalent and dominant abiotic stress factor that many tree species are subjected to, has led to poor forest health and ultimately death of tree species in the long term. Mycorrhizae are important soil microorganisms present in terrestrial ecosystems that, through establishing a symbiotic relationship with most terrestrial plants, contribute to the growth and development of plant species.

In this study, it was observed that mycorrhiza inoculation contributed positively to the growth of *C. fistula* seedlings. In M_3 , the plants exhibited an increase in leaf number, fresh weight of leaves, dry weight of leaves, dry weight of shoots, and turgid weight of leaves. Inoculation with M_1 was responsible for improved shoot height, leaf area, fresh weight of root and dry weight of root, whereas M_2 contributed to higher collar diameter and relative water content (Fig. 1). However, the result showed that there was a level of significance ($p < 0.05$) only on the relative water content of seed-

lings inoculated with mycorrhizae (Table 1) where ectomycorrhiza had the highest mean value. In a similar research to examine the potential of endomycorrhiza in improving drought tolerance of *C. atlantica*, it was observed that plants inoculated with mycorrhiza maintained higher relative water content when compared with non-inoculated plants (Zarik et al. 2016). The variation in the response of different mycorrhizal fungi could be traced to the plant species in which they interact with to maintain a symbiotic relationship (Ortas and Ustuner 2014); hence it can be said that *C. fistula* is selective in its association with mycorrhiza and ectomycorrhiza significantly contributed to relative water content (Shi et al. 2017) since all the plants were cultivated under the same soil and climatic conditions. In new soil environments, endomycorrhizal fungi within a short time begins to establish itself to improve soil quality/fertility especially soil with poor nutrient conditions. Hence, endomycorrhizal fungi support plant through the provision of water, nutrient, and also help plants to acclimatize to new soil environment. When drought stress is reduced in the presence of endomycorrhizal fungi, plants experience improved growth rate (Huey et al. 2020, Rydlová and Püschel 2020) enhancing physiological and morphological parameters.

Subsequently, response to varying water regime was observed. Considering the three watering regimes examined, seedlings reaction to water stress and general growth response clearly showed that daily watering contributed to increase in collar diameter only, suggesting that daily watering is not the best for this tree species. Also seedlings watered once a week had no highest mean value for all parameters examined. Seedling watered every other day had the highest mean values for all

the parameters except for collar diameter. Furthermore, the result showed significant effect ($p < 0.05$) on shoot height, collar diameter, turgid weight of leaves, fresh weight of leaves, turgid weight of roots, fresh weight of shoots, and fresh weight of roots (Table 1) of the seedlings. Plant response to water availability varies from plant to plant and different plant parts adaptation to water stress condition differs (Gbadamosi 2014). Our findings showed that watering every other day improved about 92 % of all the parameters stressing the fact supported by Sconiers et al. (2020) that plants subjected to moderate water stress were more developed compared to severely stressed plants.

The interactive effect of mycorrhizae and varying moisture supplies showed no significant effect on the parameters of *C. fistula* seedlings. When inoculated with endomycorrhiza, seedlings watered every other day (M_1W_2) exhibited improvement on shoot height, leaf area, fresh weight of leaves, turgid weight of leaves, dry weight of leaves, fresh weight of shoot, dry weight of shoot, fresh weight of roots, and dry weight of roots (Table 2); this interaction contributed to 75 % of the overall parameters, nevertheless there was no significant difference ($p > 0.05$) for all these parameters. More so, the interactive effect of ectomycorrhiza and daily watering (M_2W_1) only contributed to improved collar diameter and relative water content of the seedlings while seedlings watered once a week without mycorrhiza inoculation (M_3W_3) benefited only leaf numbers.

Conclusions

To the best of our knowledge, this is the first test on *Cassia fistula* to examine the effect of mycorrhiza inoculation and water

regimes. Our study reveals that mycorrhiza inoculation at various watering regime can stimulate and enhance the growth of *C. fistula* seedlings. Considering the effect of mycorrhiza, endomycorrhiza (M_1) generally contributed to shoot height, leaf area, fresh weight of stems, and fresh weight of roots, and dry weight of roots while ectomycorrhiza (M_2) generally contributed to collar diameter and relative water content, however, only relative water content was significantly influenced statistically by ectomycorrhiza. Furthermore, there are differences in the rate at which seedlings of *C. fistula* responded to endomycorrhiza (M_1), ectomycorrhiza (M_2) and no mycorrhiza (M_3) at watering daily (W_1), watering every other day (W_2) and once a week (W_3). Watering every other day mostly developed growth parameters such as shoot height, leaf area, leaf number, turgid weight of leaves, fresh weight of leaves, dry weight of leaves, fresh weight of shoot, dry weight of shoot, fresh weight of root, dry weight of root and relative water content. Seedlings with no mycorrhiza at watering every other day recorded best performance for fresh weight of leaves, turgid weight of leaves, dry weight of leaves and fresh weight of shoot. Ectomycorrhiza at watering every other day recorded best performance for fresh weight of leaves, turgid weight of leaves, fresh weight of shoot, dry weight of shoot and dry weight of root while watering every day for ectomycorrhiza enhanced collar diameter. However, endomycorrhiza at watering every other day (Table 2) recorded best performance for all the parameters. Therefore endomycorrhiza could enhance uptake of water and nutrient in plants, reducing environmental (drought) stresses and improve the overall growth condition of plants (Chanda et al. 2014). Hence, application of endomycorrhiza at watering every other

er day is very effective for the growth and development of *C. fistula* seedlings so as to produce healthy and fast growing planting stocks and could be employed under extreme drought condition to prevent death of seedlings due to harsh environment. However, the mechanism by which endomycorrhiza contribute to the overall development of potted plants such as *C. fistula* should be well studied because the resultant effect of this symbiotic association varies among different plant species.

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ALLOMETRIC EQUATIONS FOR ESTIMATING MERCHANTABLE WOOD AND ABOVEGROUND BIOMASS OF COMMUNITY FOREST TREE SPECIES IN JEPARA DISTRICT

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Abstract

Understanding the essential contribution of community forests for industrial development or climate change mitigation principally requires the accurate measurement of merchantable wood and aboveground biomass. However, the quantification of those parameters using the destructive method requires high cost and time consuming. To anticipate these constraints, allometric equations development has a potential contribution to facilitate a more efficient estimation of wood and biomass production without disturbing forest regeneration capacity. Therefore, this study aimed to develop allometric equations for quantifying merchantable wood and aboveground biomass of community forest tree species. The destructive sampling was carried out on 45 trees from three species (15 trees each), namely *Swietenia macrophylla* King, *Falcataria moluccana* (Miq.) Barneby et J.W.Grimes, and *Tectona grandis* L.f. Furthermore, three general allometric equations were examined using some predictor variables, i.e. diameter at breast height (D), quadrat diameter at breast height combined with tree height ($D^2 \cdot H$), as well as D and H separately. The results showed the highest average of merchantable wood and aboveground biomass recorded in *S. macrophylla* ($0.41 \pm 0.10 \text{ m}^3$; $0.33 \pm 0.07 \text{ t}$), followed by *T. grandis* ($0.20 \pm 0.07 \text{ m}^3$; $0.18 \pm 0.06 \text{ t}$) and *F. moluccana* ($0.16 \pm 0.05 \text{ m}^3$; $0.06 \pm 0.02 \text{ t}$). Meanwhile, the relative contribution of foliage biomass to total aboveground biomass gradually declined along with the increasing diameter classes. In contrast, a fluctuating trend was observed in the stem and branch. Also, equation $\ln \bar{Y} = \ln a + b \cdot \ln D$ was best in quantifying the wood and biomass. The addition of H as a predictor variable in the equations did not show a meaningful influence to increase accuracy estimation in the species. Based on these results, it was concluded that the development of allometric equations was reliable to facilitate more efficient estimation of merchantable wood and aboveground biomass for community forest tree species with over 95 % accuracy.

Key words: accurate quantification, best equation, climate change mitigation.

Introduction

Sustainable community forest management for industrial development and climate change mitigation principally require accurate quantification of timber production or biomass accumulation as basic consideration in determining yield regulation scheme. This is exceptionally necessary to optimize the important contribution of community forest in stabilizing wood supply for industries and minimizing carbon emissions. However, the measurement of wood as well as biomass production using the destructive method generally requires high cost and time consuming, which is almost impossible to implement for the overall community forest trees (Wirabuana et al. 2020). To solve these problems, the development of allometric equations can become an alternative solution to support more efficient quantification of timber production and biomass accumulation. Besides providing good accuracy, the development of these equations is also capable to rapidly facilitate their estimation without disturbing forest regeneration (Daba and Soromessa 2019). Moreover, they are reliable in quantifying the individual tree characteristics from different observation periods. This is based on the relationship between tree attributes that are highly responsive to the growth periods, such as height and diameter (Kebede and Soromessa 2018). Previous studies also confirmed that the utilization of the equations indicated an excellent accuracy for predicting wood or biomass production in different types of forest, both in monoculture and mixed (Chen et al. 2017, Zhao et al. 2019, Magalhães et al. 2021).

The construction of allometric equations in the community forest is not easy because there are various species with high variation in age distribution and irreg-

ular planting designs (Baral et al. 2018). Also, the activity of stand management in this site is not conducted intensively, hence, the variation of stand growth is substantially higher than plantation forest (Wirabuana et al. 2021b). Consequently, it is difficult to obtain the number of samples with a balance distribution for every species. Therefore, the development of allometric equations for specific species is the best solution to minimize the bias estimation of wood and biomass production due to the heterogeneous stand condition (Paul et al. 2013). Furthermore, it was reported that the development of these models provided better accuracy to quantify the individual tree characteristics compared to the use of general allometric equations for mixed species (Paul et al. 2013, Goussanou et al. 2016, Wirabuana et al. 2020). Several works stated that its reliability was also affected by the gradient of site quality (Ngomanda et al. 2014, Nugroho 2014, Zhao et al. 2019). Therefore, the best model for a species can differ from one location to the other.

This study was designed to develop allometric equations for estimating merchantable wood and aboveground biomass of community forest tree species in Jepara. This is a district located in the coastal area of Northern Java with a lot of wood industries that play important roles in the economic sector, like carving, furniture, plywood, and veneer. This means the existence of community forests in the town has a fundamental position for industrial development. Furthermore, the total area of community forest in Jepara is relatively higher than the state by approximately 17,495.53 ha which is equivalent to 50.23 % of the total forest area in this district (BPS 2017). This shows the presence of community forests in the town has a higher contribution to climate change

mitigation than the state. Until now, there are no allometric models for estimating merchantable wood and aboveground biomass of community forest tree species in Jepara even though it is highly required to support the effort of sustainable management in the District.

Material and Methods

Study area

The study site was in the community forest in Jepara District, Central Java, Indonesia. The data were obtained from four villages that have a dense cover of community forest, namely Jambu, Sinanggul,

Srobyong, and Karanggondang (Fig. 1), with an altitude range of 70–100 m a.s.l. Furthermore, the land configuration was relatively flat with a slope level of 5–10 %, air humidity varied between 72 and 85 %. The daily mean temperature was 29 °C with a minimum of 22 °C and a maximum of 34 °C. This location has an annual rainfall of approximately 2464 mm·year⁻¹. Also, the most rainfall occurs in February with 34 % of the total in a year. Meanwhile, the dry season occurs for almost five months (May to September). The soil type is dominated by alfisol with an acidity level of 5.5–6.0. In general, in this site predominantly are three species, namely *Swietenia macrophylla* King, *Falcataria moluccana* (Miq.) Barneby et J.W.Grimes,

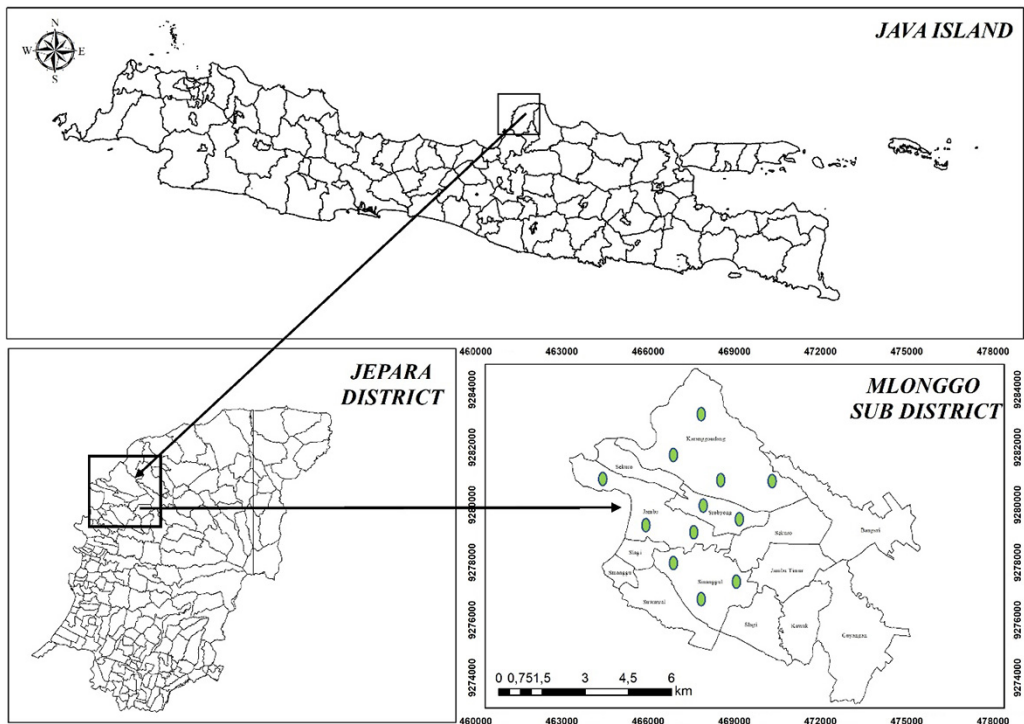


Fig. 1. The study site of community forest around Jepara District.

Note: Green circle indicates a location for destructive sampling to quantify the merchantable wood and aboveground biomass from sample trees.

and *Tectona grandis* L.f. Most stand conditions consisted of mixed species with irregular distribution and high variation in age (BPS 2017).

Data collection

Data collection was conducted step by step in a chronological manner and consisted of three systematic sequence stages, namely tree selection, destructive sampling, and biomass determination. Tree selection stage aimed to obtain several sample trees that represent the growth variation of community forests from four sites. This step was required to derive ideal samples for every species with normal growth performance, not infected by pest or disease, and without defect. Meanwhile, the objective of destructive sampling was to calculate the wood and measure the fresh weight of every tree component before drying the sub-samples in the laboratory. Subsequently, biomass determination was directed to quantify the content in every tree component and the total aboveground for the individual sample. The description of every stage is presented below.

Tree selection

The samples were selected by considering the diameter distribution of every species. This approach was commonly used in several studies to determine the representative sample trees for developing allometric equations, both in monoculture and mixed forest (Altanzagas et al. 2019, Istrefi et al. 2019, Wirabuana et al. 2020, Karyati et al. 2021, Sadono et al. 2021). To facilitate this stage, forest inventory was carried out using the quadrat method with a sampling plot of size 25 m × 25 m (Setiahadi 2017, Wirabuana et al. 2021b).

Sixteen of these plots were distributed randomly at each community forest site, and every village had a total sampling area of approximately 1 ha. The total plots used for the field survey were 64 units. Furthermore, there were three important parameters measured for every tree in each measuring plot, namely type of species, DBH (presented below for brevity as *D*), and height (*H*). *D* was measured using a phi band at 1.3 m from aboveground, while *H* was estimated to top crown using a haglof vertex. Moreover, an identification number was also given to every measured tree using paint to facilitate the identification.

Data were compiled from four sites after completing the field survey. Subsequently, the *D* was classified into four groups as follows, <10 cm, 11–20 cm, 21–30 cm, and >30 cm (Altanzagas et al. 2019, Wirabuana et al. 2020). This step aimed to describe the variation of tree dimensions from small to big. Consequently, samples were selected from every diameter group, with a minimum number of 3 for each species (Table 1). In addition, the distribution of samples in every site was also considered for the selection (Table 2). The total samples from every species were 15, while there were 45 for destructive sampling for the three species. The number of samples used was relatively lower than other studies in the allometric model development of plantation forests. However, several studies explained that a fit model for the equation could be developed using a low number of tree samples (Ketterings et al. 2001, Stas et al. 2017).

Destructive sampling

The process of destructive sampling was conducted systematically from small to

Table 1. Distribution of sample trees by diameter class.

Species	D			
	<10 cm	11–20 cm	21–30 cm	>30 cm
<i>S. macrophylla</i>	4	4	4	3
<i>F. moluccana</i>	5	4	3	3
<i>T. grandis</i>	6	3	3	3
Total	15	11	10	9

Table 2. Total sample trees.

Village	Number of tree samples for every species		
	<i>S. macrophylla</i>	<i>F. moluccana</i>	<i>T. grandis</i>
Sinanggul	4	3	4
Jambu	3	5	3
Srobyong	4	2	6
Karanggondang	4	5	2
Total	15	15	15

big selected trees. The trees were felled using a chain saw with stump height at 0.1 m from aboveground. Subsequently, the components were separated into stem, branch, and foliage, while the stem was divided into several sortiments to facilitate the measurement of merchantable wood. The diameter of every sortiment was measured at two positions (large and small end) using a caliper, while the length measurement was conducted through a measuring tape. Subsequently, the wood volume of the sortiment was calculated using Smalian formula (equation 1) and was classified as merchantable wood when it has a minimum diameter and length of 10 cm and 1.5 m respectively. This criterion was determined based on the minimum requirements of suitable wood for industrial needs in Jepara. The total merchantable wood for every sample was computed based on the accumulation volume that fulfilled the industrial requirements (equation 2).

$$V = \frac{\pi}{8} \cdot (D_L^2 + d_S^2) \cdot l, \quad (1)$$

$$MV = V_1 + V_2 + \dots + V_n, \quad (2)$$

where: V was the wood volume of sortiment (m^3), d_L and d_S indicated the diameter size at the large and small ends (cm) respectively, l represented the length (m), while MV was the total merchantable wood of every sample tree ($m^3 \cdot tree^{-1}$). Besides measuring merchantable wood, the residual wood from the samples was also calculated. This type is commonly used as firewood by local communities.

Moreover, the fresh weight of the components was measured using a hanging balance in the field. In contrast with quantification of merchantable wood, the measurement of stem biomass was conducted for all sortiments. In this case, the existence of wood sortiment would facilitate an easier measurement of biomass since it was difficult to measure stem weight simultaneously. The fresh weight data from the components were recorded. Moreover, the 500 g sub-sample from each part was taken to laboratory for drying (Sadono et al. 2021, Wirabuana et al. 2021a).

Biomass determination

Biomass is defined as a constant dry-weight of each tree component. To determine biomass, the sub-sample from the field was dried using an oven at 70 °C for 48 h before weighting (Wirabuana et al. 2019). Subsequently, each component was quantified by multiplying the ratio of dry-fresh weight from subsample with the total fresh weight of tree component from field survey (equation 3). Meanwhile, the

total aboveground biomass of an individual tree sample was calculated by summing the biomass of every component (equation 4). In addition, the biomass expansion factor (*BEF*) was determined as the ratio of total aboveground and stem biomass (equation 5).

$$W_c = \left(\frac{DW_s}{FW_s} \right) \cdot FW_c, \quad (3)$$

$$W_t = W_s + W_b + W_f, \quad (4)$$

$$BEF = \frac{W_t}{W_s}, \quad (5)$$

where: W_c was the biomass of tree component (t), DW_s and FW_s indicated dry and fresh weight of sub-sample components (g) respectively, FW_c represented fresh-weight of tree component (kg), W_t was total aboveground biomass of individual tree sample (t), while W_s , W_b , W_f were biomass in stem, branch, and foliage (t) respectively.

Data analysis

Statistical analysis was conducted using a significant level of 5 %. The descriptive test was applied to identify the data attributes, including minimum, maximum, mean, standard deviation, and standard error. The normality of data from the total observed variable was evaluated by Shapiro-Wilk test, while homogeneity of variance among species and diameter classes was examined using Bartlett. Comparison mean of the relative contribution from tree components to total aboveground biomass among diameter classes and species was tested using ANOVA and HSD Tukey. A similar method was also applied to compare the relative contribution of merchantable and residual woods with total tree volume. Furthermore, the analysis of correlation was applied to

evaluate the relationship among observed variables. Meanwhile, the allometric models for estimating merchantable wood and aboveground biomass from every species were developed using regression analysis.

Three general allometric equations (6–8) were evaluated, and several independent variables were used for their development, such as D , $D^2 \cdot H$, as well as D and H separately (Dong et al. 2015, Xue et al. 2016, Altanzagas et al. 2019, Sadono et al. 2021).

$$\bar{Y} = a \cdot D^b, \quad (6)$$

$$\bar{Y} = a(D^2 \cdot H)^b, \quad (7)$$

$$\bar{Y} = a \cdot D^b \cdot H^c, \quad (8)$$

where: $\bar{Y}$ was the estimated value of merchantable wood (m^3) or total aboveground biomass (t) and a , b , c were the fitted coefficient.

The use of non-linear models in developing allometric equations commonly resulted in heteroscedasticity (Zeng and Tang 2012). Therefore, to eliminate its influence, the use of data transformation in natural log-form was generally applied in previous studies to convert the non-linear model into a linear equation when determining the fitted parameter for every equation (He et al. 2018, Altanzagas et al. 2019, Wirabuana et al. 2020, Sadono et al. 2021). Therefore, the equations 6 to 7 were changed into the following models (equations 9–11):

$$\ln \bar{Y} = \ln a + b \cdot \ln D, \quad (9)$$

$$\ln \bar{Y} = \ln a + b \cdot \ln(D^2 \cdot H), \quad (10)$$

$$\ln \bar{Y} = \ln a + b \cdot \ln D + c \cdot \ln H, \quad (11)$$

where: $\ln \bar{Y}$ indicated the predicted value of merchantable wood or total aboveground biomass in the logarithmic unit, while a , b , c were the fitted parameters.

Nevertheless, some works explained that the use of anti-log transformation of the predicted logarithmic values into arithmetic units resulted in a systematic bias which could be corrected by the correction factor as presented in equation (12) (Xue et al. 2016, He et al. 2018, Altanzagas et al. 2019).

$$CF = \exp\left(\frac{RMSE^2}{2}\right), \quad (12)$$

where: CF was the correction factor, $RMSE$ indicated the root mean square error from the logarithmic regression, and n was the sample size.

The best allometric equations were determined using seven indicators, namely the significant result of ANOVA test for the model, the significant outcome of fitted parameters (a , b , c), coefficient of determination (R^2), residual standard error (RSE), akaike information criterion (AIC), mean absolute bias (MAB), and root mean square error ($RMSE$) (González-García et al. 2013, Ekoungoulou et al. 2015). Meanwhile, the fitted parameters, ANOVA test, R^2 , RSE , and AIC were used to evaluate the model fitting while MAB and $RMSE$ were used to examine the validation (Sadono et al. 2021). Since the sample size was relatively small (15 trees for every species), the validation test was processed using the leave-one-out cross-validation (LOOCV). This method is commonly applied in developing equations with a small sample size (Castillo-Santiago et al. 2010, Altanzagas et al. 2019, Tetemke et al. 2019). Detailed formula for calculating these indicators are expressed in equations 13–17:

$$R^2 = \frac{1 - \sum(\ln Y - \ln \bar{y})^2}{\sum(\ln Y - \ln \bar{Y})^2}, \quad (13)$$

$$RSE = \left[\frac{1}{(n-2) \cdot \sum(\ln Y - \ln \bar{Y})^2} \right]^{0.5}, \quad (14)$$

$$AIC = n \cdot \log\left(\frac{RSS}{n}\right) + 2k + \frac{2k(k+1)}{n-k-1}, \quad (15)$$

$$MAB = \frac{\sum(|\ln Y - \ln \bar{Y}|)}{n}, \quad (16)$$

$$RMSE = \left[\frac{\sum(\ln Y - \ln \bar{Y})^2}{n-p-1} \right]^{0.5}, \quad (17)$$

where: $\ln Y$ was the actual log-transformed merchantable wood, $\ln \bar{Y}$ represented the predicted total aboveground biomass from the fitted model, n indicated the sample size. Furthermore, $\ln Y$ was the average of actual log-transformed merchantable wood or total aboveground biomass, p signified the number of terms in the model, RSS was the residual sum of squares from the fitted model, while k exhibited the number of independent variables. The best allometric model should demonstrate the significant results of ANOVA and fitted parameter test, the highest R^2 , as well as the lowest RSE , AIC , MAB , and $RMSE$. They would also be compared with other equations from the previous studies as external validation, such as Chave et al. (2014), Ardelina et al. (2015), Khan et al. (2018), and Zahabu, et al. (2018).

To determine the most efficient model for estimating merchantable wood and total aboveground biomass of each species, Extra Sums of Square (ESS) method was conducted to measure the marginal reduction in Error Sums of Squares (SSE) when an additional set of predictors was added to the model (Hector et al. 2016). In this context, this method aimed to assess whether the addition of H as the predictor

variable provided a meaningful contribution to improve the estimation accuracy. However, in the case of insignificant results, the use of a single predictor in the allometric equations was enough to obtain good accuracy.

Results and Discussion

Wood production from three species

The results showed the total wood production at the individual level of community forest tree species was relatively varied. Its highest average was discovered in *S. macrophylla* ($0.58 \pm 0.14 \text{ m}^3$), followed by *F. moluccana* ($0.25 \pm 0.08 \text{ m}^3$), and *T. grandis* ($0.29 \pm 0.10 \text{ m}^3$) (Table 3). A similar pattern was also observed in the trend of merchantable and residual wood. Interestingly, this study discovered that the relative contribution of merchantable and residual wood to the total wood production

differed significantly among the species (Table 4). Despite the biggest mean of total wood production, the percentage of merchantable wood in *S. macrophylla* was considerably lower than *F. moluccana* and *T. grandis* by approximately 66 %. Contrastingly, the proportion of merchantable wood in *F. moluccana* was relatively higher than other species with approximately 71 %. Moreover, this species also indicated the smallest percentage of residual wood than others. This study documented that the relative contribution of merchantable and residual wood across the diameter classes was not significantly different even though there was a fluctuating trend with the increasing diameter classes (Fig. 2). Overall, the relative contribution of merchantable to total wood production was consistently higher than the residual in every diameter class.

The variation of wood production of the species could be affected by several

Table 3. Summary statistics of tree dimensions, wood production, and biomass.

Species	Value	D, cm	H, m	TV, m ³	MV, m ³	RV, m ³	SB, t	BB, t	FB, t	AGB, t
<i>S. macrophylla</i>	Mean	25.8	9.9	0.58	0.41	0.17	0.21	0.08	0.04	0.33
	SD	12.6	4.2	0.56	0.38	0.18	0.18	0.07	0.03	0.29
	SE	3.3	1.1	0.14	0.10	0.05	0.05	0.02	0.01	0.07
	min	8.9	4.8	0.02	0.01	0.01	0.01	0.01	0.00	0.02
	max	41.4	15.6	1.47	1.00	0.54	0.49	0.19	0.09	0.77
<i>F. moluccana</i>	Mean	19.0	7.5	0.25	0.16	0.08	0.04	0.01	0.01	0.06
	SD	11.2	2.0	0.31	0.21	0.11	0.05	0.02	0.01	0.07
	SE	2.9	0.5	0.08	0.05	0.03	0.01	0.00	0.00	0.02
	min	5.4	4.6	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	max	40.1	11.1	0.98	0.62	0.36	0.15	0.05	0.02	0.22
<i>T. grandis</i>	Mean	18.8	8.2	0.29	0.20	0.09	0.10	0.07	0.01	0.18
	SD	11.9	2.5	0.41	0.28	0.12	0.14	0.10	0.01	0.24
	SE	3.1	0.7	0.10	0.07	0.03	0.04	0.02	0.00	0.06
	min	8.9	5.6	0.02	0.02	0.01	0.01	0.01	0.00	0.02
	max	40.4	13.0	1.17	0.83	0.34	0.39	0.27	0.02	0.69

Note: TV – total tree volume, MV – merchantable wood, RV – residual wood, SB – stem biomass, BB – branch biomass, FB – foliage biomass, AGB – total aboveground biomass.

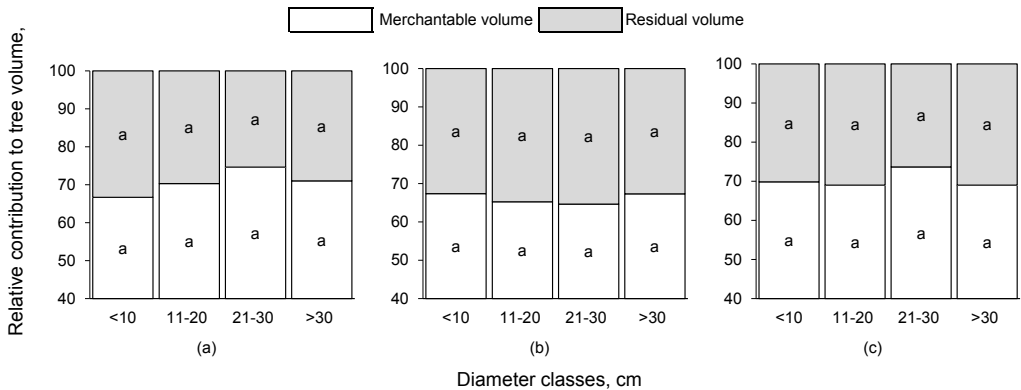


Fig. 2. Relative contribution of merchantable and residual wood to total tree volume.

Note: (a) *S. macrophylla*; (b) *F. moluccana*; (c) *T. grandis*. A similar letter indicated that there was no significant difference in the relative contribution of merchantable and residual wood among diameter classes.

factors, such as genetics, site suitability, age, and silviculture prescription (Xu et al. 2012, Thompson 2013, Resende et al. 2018, Bouriaud et al. 2019). According to the results, community forest species in Jepara consisted of two types, namely slow-growing (*S. macrophylla* and *T. grandis*) and fast-growing species (*F. moluccana*). Genetically, the growth rate of fast-growing species was relatively higher than the slow-growing (Karlinasari et al. 2018), therefore, it was generally harvested in the short rotation of approximately 5–8 years (Siregar et al. 2007). A similar case was also recorded in the community forest at Jepara District, where the majority of the farmers harvested *F. moluccana* at 5–6 years. In contrast, the rotation of *S. macrophylla* and *T. grandis* ranged from 15 to 20 years, which directly confirmed why the average total wood production of *F. moluccana* at the individual tree level was lower than others.

In addition, this study noted that the site suitability was also principally different. The range of altitude in Jepara (70–100 m a.s.l.) was highly suitable for supporting the growth of *T. grandis* and *S. macrophylla* since both were naturally distributed in

the lowland area (Krishnamoorthy et al. 2016, Navarro-Martínez et al. 2018). However, the site suitability in this area was relatively lower for facilitating the growth of *F. moluccana* since it was naturally from the upland area (Munir 2018). Lower site suitability provides more limiting factors which influence plant growth (Abd-Elmabod et al. 2019). Consequently, their growth rate would be substantially lower compared to the higher site suitability. Therefore, the implementation of intensive silviculture prescription is exceptionally required to improve the growth performance of commercial species. Unfortunately, there was no intensive maintenance in the forest; hence, the growth performance of the plant was dominantly affected by its adaptability to the site conditions. This also confirmed why the mean total wood production of *F. moluccana* was the lowest.

Biomass distribution and accumulation

This study recorded that the highest mean total aboveground biomass was observed in *S. macrophylla* (0.33 ± 0.07 t), followed by *T. grandis* (0.18 ± 0.08 t), and *F. moluc-*

cana (0.06 ± 0.02 t) (Table 3). This pattern was similar to the trend of wood production among the species. It signified that higher wood production would improve the accumulation of tree biomass. This could be feasible since more than 61 % of aboveground biomass for all species was distributed in the stem as the prima-

ry tree component for generating wood products (Table 4). This is consistent with some previous studies which stated that there was a significant relationship between wood production and total aboveground biomass at the individual tree level (Viswanath 2011, Romero-Sanchez and Ponce-Hernandez 2017).

Table 4. Relative contribution of tree components to total aboveground biomass.

Species	MV/TV	RV/TV	SB/AGB	BB/AGB	FB/AGB
<i>S. macrophylla</i>	$0.66 \pm 0.04a$	$0.34 \pm 0.04b$	$0.61 \pm 0.07a$	$0.25 \pm 0.08b$	$0.14 \pm 0.04a$
<i>F. moluccana</i>	$0.71 \pm 0.06b$	$0.29 \pm 0.06a$	$0.61 \pm 0.05a$	$0.26 \pm 0.03b$	$0.13 \pm 0.02a$
<i>T. grandis</i>	$0.70 \pm 0.05ab$	$0.30 \pm 0.05ab$	$0.61 \pm 0.08a$	$0.34 \pm 0.08a$	$0.05 \pm 0.02b$

Note: TV – total tree volume, MV – merchantable wood, RV – residual wood, SB – stem biomass, BB – branch biomass, FB – foliage biomass.

According to the results, the accumulation of biomass in-branch and foliage were significantly lower than stem in the species with approximately 25–34 % and 5–14 % respectively (Table 4). This confirmed that all trees allocated more biomass in the stem than the crown, to accelerate the translocation process for water, nutrients, and carbohydrates (Poorter et al. 2012, Kocurek et al. 2020, Wirabuana et al. 2020). The more efficient this process would facilitate better growth performance for every tree (Hasanuzzaman et al. 2018, Tränkner et al. 2018, Sadono et al. 2021). The results were also consistent with other previous studies which stated that the highest biomass accumulation for woody species was discovered in stem (Krejza et al. 2017, Altanzagas et al. 2019, Han and Park 2020, Magalhães et al. 2021). Interestingly, this study documented that *BEF* in the species was almost equal even though the average *BEF* of *S. macrophylla* was slightly lower (1.64) than others (1.67) (Table 5). However, the results for the three species were higher compared to Krisnawati et al. (2012) with a distance of 0.20–0.31. Different site

quality, stand dynamics, and age have the potential to become factors affecting the variety of *BEF* from every species (Teobaldelli et al. 2009).

Table 5. Biomass expansion factor.

Species	<i>BEF</i>			
	Mean	SD	min	max
<i>S. macrophylla</i>	1.64	0.13	1.43	1.9
<i>F. moluccana</i>	1.67	0.20	1.45	2.04
<i>T. grandis</i>	1.67	0.27	1.32	2.51

Note: SD – standard deviation.

It was also reported that the relative contribution of tree components to total aboveground biomass highly varied across the diameter classes. The relative contribution of stem, branch and foliage to total aboveground biomass in *S. macrophylla* was significantly different along with the increasing of diameter classes (Fig. 3). Meanwhile, different results were noted in *F. moluccana* and *T. grandis*, where a significant difference was only indicated in branch or foliage. This showed every species had a different pattern of biomass allocation in its component. Nevertheless, the percentage of foliage bio-

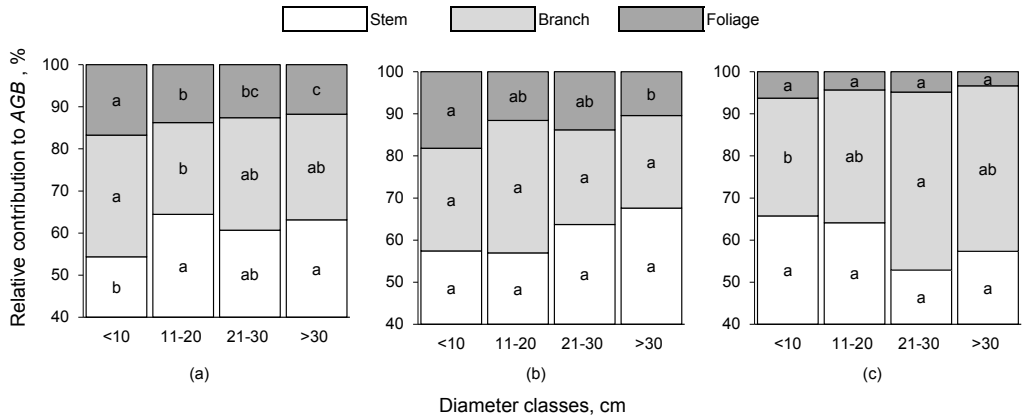


Fig. 3. Biomass distribution in every tree component across the diameter classes.

Note: (a) *S. macrophylla*; (b) *F. moluccana*; (c) *T. grandis*. A similar letter showed that there was no significant difference in biomass allocation among diameter classes.

mass gradually declined across with the increase in diameter classes. This trend naturally occurred since trees would generally allocate their biomass in the trunk along with the increment of diameter to optimize the source and sink distribution.

Allometric models for estimating wood and biomass production

In summary, there was a nonlinear relationship between diameter and height with merchantable wood as well as the total aboveground biomass in the species (Fig. 4). It was clarified that the greater diameter and height resulted in higher wood and biomass production. This was supported by the output of correlation analysis which indicated a significant relationship between the variables with a value greater than 0.9 (Table 6). These results also implied that both can be used as predictor variables for developing allometric equations. Several studies also explained that they were fundamental parameters in the forest inventory and had a high influence on other tree attributes, such as wood volume, biomass production, and

carbon storage (Zeng and Tang 2012, Vega-Nieva et al. 2015, Abrantes et al. 2019, Zhao et al. 2019).

This study reported that every allometric equation demonstrated a good fit (Table 7). More than 90 % of the variation in merchantable wood and total aboveground biomass could be explained using this equation. The value was excellent because the stand characteristics of community forest principally had great variation in species composition and growth distribution (Wirabuana et al. 2021b, Setiahadi 2017). However, the outcome of ESS test confirmed that the addition of H as a predictor variable in the equations did not provide a meaningful contribution to improve the accurate estimation of the wood and biomass (Table 8). These results also demonstrated that the use of a single predictor for allometric equations in the community forest was better and more efficient than two. These results were different from several previous studies which explained that the addition of H as an independent variable provided a significant contribution to increase the accurate estimation of allometric models (Bi et al. 2004, Chave et al.

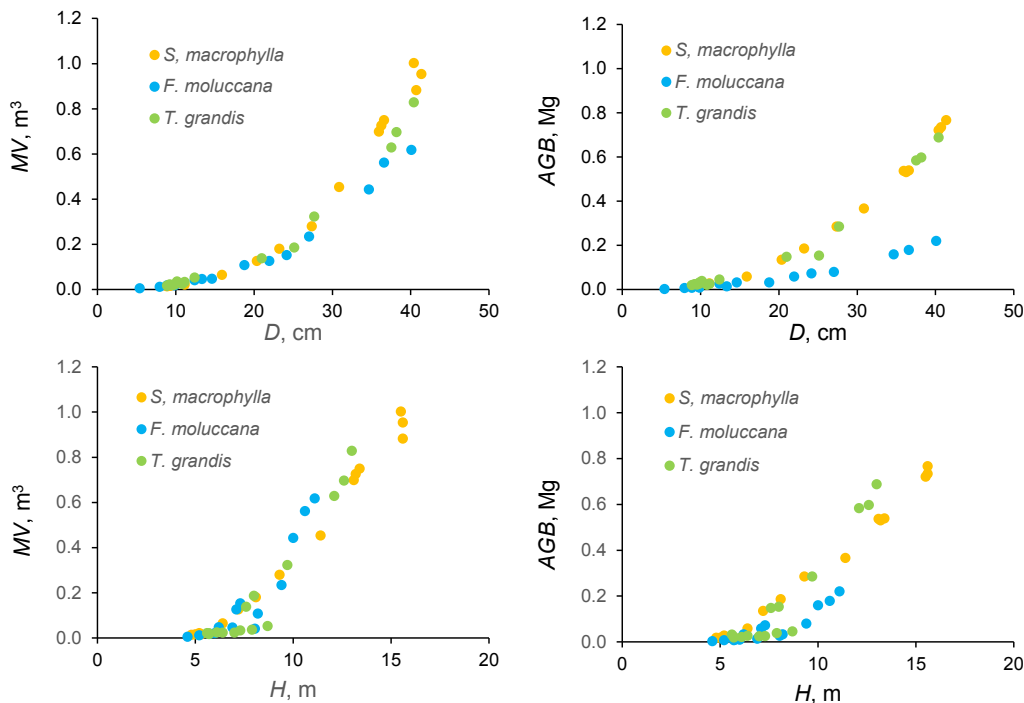


Fig. 4. Scatter plot for demonstrating the relationship between D and H with MV and total AGB .

Table 6. Coefficient of correlation between independent and dependent variables for developing allometric equations.

Predictor variable	TV	MV	RV	SB	BB	FB	AGB
<i>S. macrophylla</i>							
D	0.951**	0.963**	0.883**	0.971**	0.973**	0.979**	0.974**
H	0.984**	0.990**	0.929**	0.994**	0.992**	0.996**	0.995**
$D^2 \cdot H$	0.999**	0.993**	0.970**	0.996**	0.990**	0.991**	0.995**
<i>F. moluccana</i>							
D	0.956**	0.955**	0.943**	0.962**	0.950**	0.979**	0.965**
H	0.911**	0.908**	0.901**	0.898**	0.895**	0.915**	0.903**
$D^2 \cdot H$	0.999**	0.997**	0.989**	0.995**	0.973**	0.984**	0.994**
<i>T. grandis</i>							
D	0.964**	0.966**	0.951**	0.960**	0.977**	0.986**	0.970**
H	0.948**	0.950**	0.935**	0.950**	0.943**	0.941**	0.949**
$D^2 \cdot H$	0.999**	0.998**	0.994**	0.994**	0.997**	0.987**	0.997**

Note: ** indicated a significant correlation. TV – total tree volume, MV – merchantable wood, RV – residual wood, SB – stem biomass, BB – branch biomass, FB – foliage biomass, AGB – total aboveground biomass.

Table 7. Summary evaluation statistics of every allometric equation for estimating merchantable wood and total aboveground biomass.

Variable	Equations**	lna*	b*	c*	R ²	RSE	AIC	MAB	RMSE	CF
<i>S. macrophylla</i>										
MV	$\ln \bar{Y} = \ln a + b \cdot \ln D$	-10.439	2.800	-	0.998	0.081	-28.924	0.082	0.088	1.004
	$\ln \bar{Y} = \ln a + b \cdot \ln D^2 \cdot H$	-10.301	1.017	-	0.997	0.079	-29.431	0.071	0.086	1.004
AGB	$\ln \bar{Y} = \ln a + b \cdot \ln D + c \cdot \ln H$	-10.376	2.410	0.520	0.998	0.066	-34.077	0.059	0.073	1.003
	$\ln \bar{Y} = \ln a + b \cdot \ln D$	-9.533	2.485	-	0.998	0.062	-36.972	0.043	0.065	1.002
	$\ln \bar{Y} = \ln a + b \cdot \ln D^2 \cdot H$	-9.401	0.902	-	0.995	0.099	-22.842	0.084	0.103	1.005
	$\ln \bar{Y} = \ln a + b \cdot \ln D + c \cdot \ln H$	-0.952	2.418	0.089	0.998	0.639	-35.261	0.046	0.078	1.003
<i>F. moluccana</i>										
MV	$\ln \bar{Y} = \ln a + b \cdot \ln D$	-9.342	2.395	-	0.995	0.106	-20.644	0.098	0.114	1.007
	$\ln \bar{Y} = \ln a + b \cdot \ln D^2 \cdot H$	-10.166	0.992	-	0.998	0.065	-35.150	0.060	0.073	1.003
AGB	$\ln \bar{Y} = \ln a + b \cdot \ln D + c \cdot \ln H$	-10.078	2.031	0.883	0.998	0.067	-33.539	0.065	0.079	1.003
	$\ln \bar{Y} = \ln a + b \cdot \ln D$	-9.559	2.170	-	0.979	0.200	-1.822	0.142	0.202	1.021
	$\ln \bar{Y} = \ln a + b \cdot \ln D^2 \cdot H$	-10.291	0.897	-	0.977	0.208	-0.604	0.164	0.211	1.023
	$\ln \bar{Y} = \ln a + b \cdot \ln D + c \cdot \ln H$	-9.763	2.069	0.245	0.979	0.207	-0.030	0.174	0.262	1.035
<i>T. grandis</i>										
MV	$\ln \bar{Y} = \ln a + b \cdot \ln D$	-9.341	2.450	-	0.988	0.161	-8.354	0.137	0.168	1.014
	$\ln \bar{Y} = \ln a + b \cdot \ln D^2 \cdot H$	-10.201	1.005	-	0.998	0.067	-34.639	0.050	0.070	1.002
AGB	$\ln \bar{Y} = \ln a + b \cdot \ln D + c \cdot \ln H$	-10.299	1.954	1.127	0.998	0.067	-33.525	0.057	0.075	1.003
	$\ln \bar{Y} = \ln a + b \cdot \ln D$	-8.922	2.291	-	0.979	0.203	-1.285	0.160	0.212	1.023
	$\ln \bar{Y} = \ln a + b \cdot \ln D^2 \cdot H$	-9.706	0.937	-	0.982	0.185	-4.204	0.141	0.191	1.018
	$\ln \bar{Y} = \ln a + b \cdot \ln D + c \cdot \ln H$	-9.515	1.983	0.698	0.983	0.189	-2.639	0.154	0.208	1.022

Note: ** indicated significant results of ANOVA test for all models, * showed a significant result of t-test, R² was the coefficient of determination, CF – correction factor.

Table 8. Summary evaluation statistics in ESS among allometric equations.

Variable	Predictor	Res. Df	RSS	Df	Sum of Sq	F	Pr (>F)
<i>S. macrophylla</i>							
MV	<i>D</i>	13	0.085				
	<i>D</i> ² · <i>H</i>	13	0.082	0	0.022		
	<i>D</i> & <i>H</i>	12	0.083	1	0.029	0.689	0.203 ^{ns}
	<i>D</i>	13	0.050				
	<i>D</i> ² · <i>H</i>	13	0.048	0	0.078		
	<i>D</i> & <i>H</i>	12	0.049	1	0.079	0.380	0.101 ^{ns}
<i>F. moluccana</i>							
MV	<i>D</i>	13	0.148				
	<i>D</i> ² · <i>H</i>	13	0.056	0	0.092		
	<i>D</i> & <i>H</i>	12	0.055	1	0.001	0.315	0.584 ^{ns}
	<i>D</i>	13	0.521				
	<i>D</i> ² · <i>H</i>	13	0.565	0	-0.044		
	<i>D</i> & <i>H</i>	12	0.514	1	0.051	1.196	0.295 ^{ns}
<i>T. grandis</i>							
MV	<i>D</i>	13	0.337				
	<i>D</i> ² · <i>H</i>	13	0.058	0	0.278		
	<i>D</i> & <i>H</i>	12	0.055	1	0.003	0.730	0.409 ^{ns}
	<i>D</i>	13	0.540				
	<i>D</i> ² · <i>H</i>	13	0.444	0	0.095		
	<i>D</i> & <i>H</i>	12	0.432	1	0.012	0.353	0.563 ^{ns}

Note: ns indicated that the addition of *H* as a predictor variable did not provide a significant contribution.

2005, Meng et al. 2021). Nevertheless, another study conducted at Madiun community forest reported that the development of allometric models with a single predictor, such as *D* was more relevant to apply since it was difficult to obtain the accurate measurement of tree height in this type of forest due to the great variation of canopy and irregular plant distribution (Wirabuana et al. 2020).

Regarding the results, the best allometric equations for quantifying the merchantable wood and total aboveground community forest tree species in Jepara District were $\ln Y = \ln a + b \cdot \ln D$. Besides the simplicity, this model also provided an excellent accuracy with approximately 97.9–99.8 %. The best equation was more reliable to facilitate a rapid esti-

mation of wood and biomass production since it only required *D* as a single predictor. Several studies also proved that the use of *D* as an independent variable possessed an important role to develop an approximate method for quantifying individual tree characteristics (Lumbres et al. 2015, Forrester et al. 2017, Romero et al. 2020).

Compared to other existed allometric equations, the best model had a good validation because it described the similar pattern (Fig. 5). However, it indicated the lower prediction of merchantable wood in *F. moluccana* and *T. grandis*. In contrast, it generated higher estimation in *S. macrophylla*. Fascinatingly, the prediction of aboveground biomass in *S. macrophylla* and *T. grandis* using the best model and

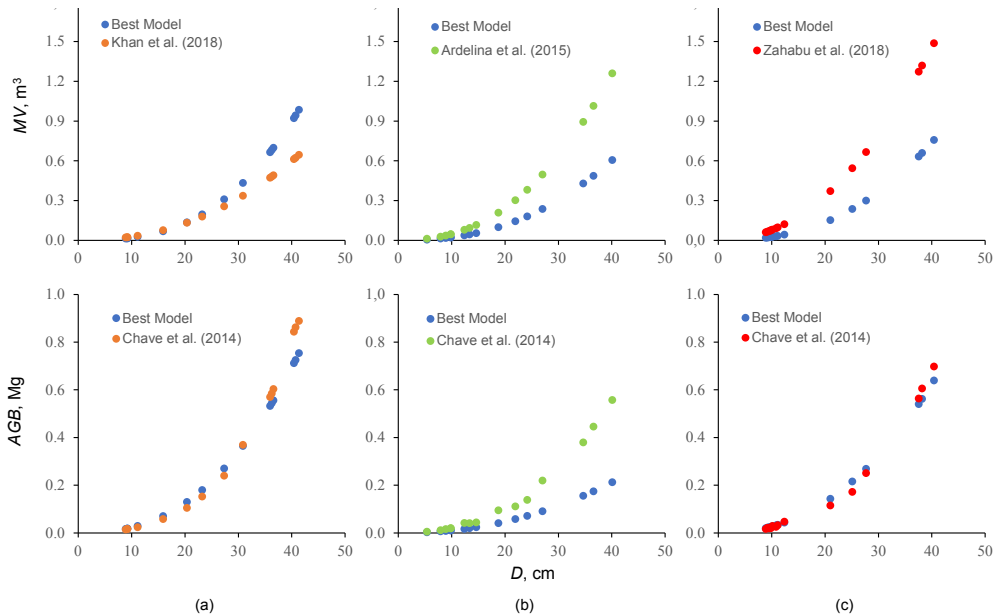


Fig. 5. Comparison of the best model with other equations for estimating merchantable wood and total aboveground biomass from three community forest species.

Note: (a) *S. macrophylla*; (b) *F. moluccana*; (c) *T. grandis*.

Chave et al. (2014) was almost equal. Unfortunately, similar results were not found in the estimation for *F. moluccana*, where the best model showed lower prediction. The different estimation results could be influenced by certain factors, such as sample size, type of forest, and site quality.

In practical, best allometric equation could be used to facilitate a more efficient estimation of merchantable wood and aboveground biomass at the study site. Besides not disturbing forest regeneration, this equation could also support the measurement of both parameters from different periods since it developed using independent variable that generally could represent tree attributes. However, a further validation test was required if this model would be used in the other regions since the influence of site quality had potential to cause a bias estimation.

Conclusion

This study showed the development of species-specific allometric equations had the potential to facilitate more efficient estimation of merchantable wood and total aboveground biomass in community forest tree species. By using the best model, the farmers can conduct a rapid quantification of the wood for determining the trees' commercial value. Moreover, the government can also use this model to estimate the contribution of community forests for carbon reduction.

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