

Structural and ecological characteristics of mixed broadleaved old-growth forest (Biogradska Gora - Montenegro)

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Abstract: Biogradska Gora National Park in Montenegro is part of the Dinaric Mountains mixed forest, which belongs to the montane region of the Dinaric Alps. This paper presents some of the main structural and ecological characteristics of the mixed broadleaved old-growth forest with beech [*Fagus moesiaca* (Domin, Maly) Czecz.], sycamore maple (*Acer pseudoplatanus* L.) and European ash (*Fraxinus excelsior* L.) from the preserve area of the Biogradska Gora. These forest ecosystems are characterized by the high species richness and potential productivity. In the study area, 58 vascular plant species were recorded in 4 sample plots of 0.25 ha each. The average timber volume found in the sample plots was 814 m³/ha. This value is twice as high as that of similar pure beech forests in the same preserve area. The results are confirmed the biodiversity and production potential of mixed broadleaved forests, which rarely occur spontaneously. A better understanding of the processes of the pristine forest ecosystems could form a realistic basis for close-to-nature management of similar stands. The obtained data provides overview of the structural characteristics of these forests, which have developed without anthropogenic influence. Exploring the structure of forests in permanent preservation areas could be an excellent basis for close-to-nature forest management.

Keywords: Biogradska Gora, mixed forest, old growth forest, Montenegro

1. Introduction

The forest ecosystem of Biogradska Gora National Park on Mt. Bjelasica in Montenegro developed through natural processes with no direct anthropogenic influences and allows the study of natural developments and structural characteristics as a precondition of close-to-nature forest management. In this paper, we presented structural characteristics of mixed broadleaved old-growth forest with beech (*Fagus moesiaca* (Domin, Maly) Czecz.), sycamore maple (*Acer pseudoplatanus* L.) and European ash (*Fraxinus excelsior* L.) from the preserve area of the park. The knowledge of structural and production characteristics of old-growth forests is an important starting point for defining the goals in forests that are

managed on a regular basis (Vasic et al., 2018). According to a report by the Food and Agriculture Organization of the United Nations (FAO) (2010), only 2.8% of European forest area (Russian Federation excluded) is classified as primary forest. Greater data on these forests allows better control of forest management and its effects on the ecosystem (Frelich et al., 2005; Brang et al., 2011). Old-growth forests also provide opportunities to study long-term environmental changes such as climate change and air pollution as well as the long-term effects of harvesting on productivity, carbon cycling and biodiversity (Nagel et al., 2013; Chivulescu et al., 2018).

On undisturbed beech-dominated sites, mixed stands or development stages are the exception rather

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than the rule (Korpel, 1995). In the reserve of Badinsky Pralesin Slovakia, there is a forest community classified as *Fageto-Aceretum* (Krizová, 2000; Kucbel et al., 2010), but some authors believe this is just the decaying stage of the community *Abieto fagetum* (Ujhazy et al., 2005). According to Orlovic et al. (2006), beside the association *Acereto-Fraxinetum serbicum* which is most commonly found in north-east Serbia, Sycamore just occurs in beech (*Fagetum subalpinum*) and fir-beech (*Abieto fagetum*) type forests in that country.

Remnants of old-growth forest in eastern and south-eastern Europe are typically mixtures of beech and fir. Less shade-tolerant species (i.e. *Acer* sp. *Fraxinus* sp. and *Ulmus* sp.) have recruited successfully where advance regeneration of beech and fir was less abundant. In mixed beech-fir forests, disturbance such as forest fires, windblown or caused by entomological or phytopathological factors creates appropriate conditions for canopy recruitment of more light-demanding species (Firm et al., 2009; Nagel et al., 2014). The formation of gaps, especially the larger gaps, is the dominant factor of forest dynamics in old growth forests (Nagel and Diaci, 2006; Nagel and Svoboda, 2008; Motta et al., 2015). In an old-growth *Fagus sylvatica*–*Abies alba* forest in the Dinaric Mountains of Bosnia and Herzegovina, *A. pseudoplatanus* is the second most abundant gap filler species in the seedling and sapling stages but was considerably less abundant in the pole stage. There was evidence that *A. pseudoplatanus* recruited to later life stages only in larger gaps (Nagel et al., 2010). In the virgin forest of Lom in Bosnia and Herzegovina, Bottero et al. (2015) reported just a few stems of sycamore maple in the dominant layer of the gaps established between 160 and 220 years ago.

Although mixed beech–sycamore maple–common ash old-growth forests are rare, in the area of the Biogradska Gora National Park, they occur in several locations, making them very significant and interesting for research. The forests of Mt. Bjelasica are spread over 6 different ecosystem belts, which is incomparably more than on any mountain in the Balkan Peninsula or Europe (Lakusic et al., 1991). In the wider area of Biogradska Gora, 26 plant communities are identified, among which are mixed forests of beech and scattered hardwoods (sycamore maple and common ash) (*Fagetum moesiaca montanum aceretosum*). Old-growth forests dominated by shade-tolerant tree species are among the forest types most likely to be in equilibrium. However, changes in climate, pathogens and land use are all likely to impact stand characteristics and species composition, even in these forests (Curovic et al., 2013; Runkle, 2013; Curovic et al., 2015). Knowledge of the structure of relatively pristine mixed-species stands can be used to help improve stand stability against predicted climate changes. Species mixtures found in old-growth

forests may be the basis for management approaches that incorporate patterns that may foster adaptation to future climatic changes (Millar et al., 2007).

A partial in situ protection of the forest genetic resources in Montenegro is accomplished only through a network of protected zones within and outside of national parks (Lazarevic, 2011). The mixed broadleaved old-growth forest of beech and scattered broadleaves in Biogradska Gora represents an extremely valuable site for preserving the genetic resources not only of Montenegro but also of Europe. The positive roles of these forests are extremely complex, including ameliorative, ecological, landscape, cultural, educational and recreation roles, as well as their role in avoiding or limiting the flow on slopes, thus limiting flooding and landslides (Sestras et al., 2018, 2019).

Structure of old-growth forests represent a worthy model for management and structuring of managed forests (Chivulescu et al., 2019). The main goal of this paper is to provide an overview of the basic ecological and structural characteristics of intact mixed broadleaved forests in Biogradska Gora National Park as a realistic basis for close-to-nature management of similar stands.

2. Materials and methods

The object of the investigation was mixed-species stands of beech [*Fagus moesiaca* (Domin, Maly) Czecz.], sycamore maple (*Acer pseudoplatanus* L.) and European ash (*Fraxinus excelsior* L.) in the preserve area of Biogradska Gora National Park (Figure 1). In this paper, we analyzed structural characteristics of the mixed broadleaved forests which are at the optimal stage phase according to the Korpel theory (Korpel, 1995).

The field research included collection of data in 4 sample plots in the strict protection zone (Figures 2 and 3). The sample plots of 0.25 ha were clearly marked in the field, with coordinates recorded using a GPS device. Diameters at breast height (dbh) and the heights (h) of the trees were measured by digital tree calliper and Vertex III hypsometer, with a minimum dbh threshold of 10 cm. Timber volume was calculated for each individual tree using Montenegrin volume tables (Markovic, 2004). Due to the strict preservation regime, the volume increment was determined by taking cores out of lying trees. Basic information about plant species richness was collected using the Braun–Blanquet method (1964) of phytosociological study. In total, 5 phytocoenological relevés were taken: 4 within the observation plots and 1 outside of these plots. For each relevé, data of altitude, exposition, slope, total cover of the vegetation, and height of the vegetation are recorded. For each species, the values of abundance-dominance and frequency are recorded.

We used data on soils from our previous research in the region of Biogradska Gora (Spalevic et al., 2004)

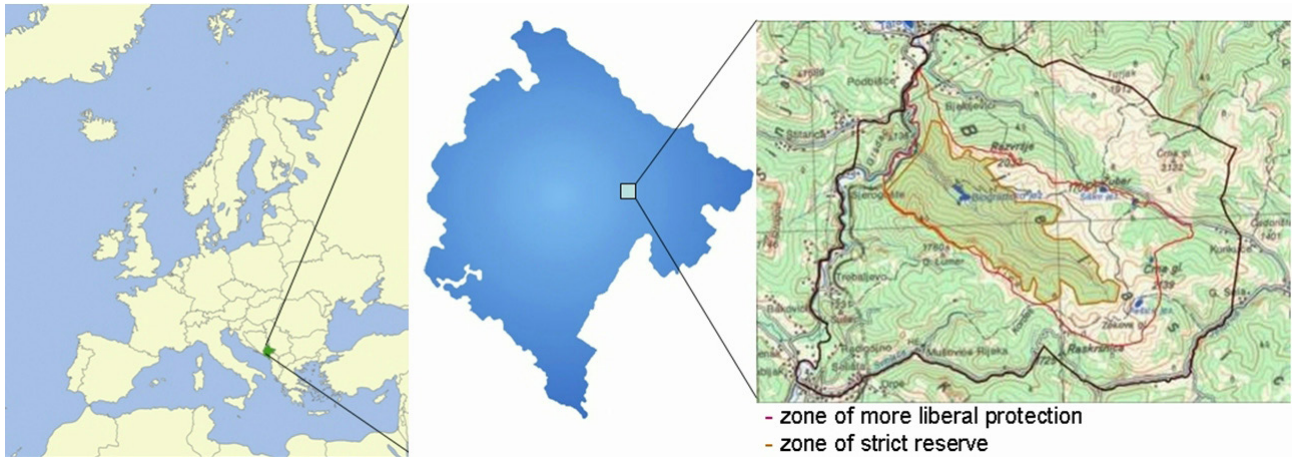


Figure 1. Study area of the Biogradska Gora.



Figure 2. Position of sample plots and Biogradsko Lake.

but also took soil samples from each sampleplot. Four pedological profiles were opened, and 8 soil samples processed. Through analysis carried out in the laboratory of the Centre for Soil Studies of the Biotechnical Faculty in Podgorica, we obtained data on the physical and chemical characteristics of the soil. The granulometric composition of the soil was determined by the pipette method (Gee and Bauder 1986); the soil samples were air-dried at 105 °C and dispersed using sodium pyrophosphate. The soil reaction (pH in H₂O and nKCl) was determined with a potentiometer. Total carbonates were determined by the volumetric Scheibler method (Thun and Herrmann, 1949); the content of the total organic matter was determined by the Kotzman method (Jakovljevic et al., 1995); easily accessible phosphorous and potassium were determined

by the Al-method (Egner et al., 1960), and the adsorptive complex was determined by the Kappen method (Kappen, 1929).

3. Results

3.1. Soil properties

The soils of the mixed deciduous forest zone are characterized by low acidity. The humus horizon (horizon 1) of the D4 and D1 profiles (Table 1) had pH values of 6.25 and 6.48. The D2, D4 and D1 profiles of the subhumus horizon (horizon 2) are also slightly acidic to a neutral reaction with values of 6.1, 6.7, and 6.8, respectively.

The mechanical composition of the soil in the mixed deciduous forest zone is characterized by a greater share of sand fractions and less clay and dust compared to



Figure 3. Sample plot D4.

Table 1. Physical and chemical properties of soil.

Profile	Horizon	Depth	Share of particles of different sizes in%				Total sand	Silt + loam	% skeleton	Humus (%)	pH in KCl	pH in H ₂ O	mg P ₂ O ₅ /100 g	mg K ₂ O/100 g
			2-0.25	0.25-0.02	0.02-0.002	<0.002								
D1	1	0–15	31.06	40.39	20.55	8.00	71.45	28.55	54.708	11.4	6.48	6.86	2.2	10.5
D1	2	15–30	22.86	46.34	22.65	8.15	69.20	30.80	38.631	6.4	6.8	7.19	1.8	5.8
D2	1	0–15	9.64	45.76	25.75	18.85	55.40	44.60	44.564	5.7	3.75	4.88	1.5	8.9
D2	2	15–35	23.73	31.97	24.63	19.67	55.70	44.30	34.932	2.6	6.1	6.4	1.9	4.2
D3	1	0–7	22.15	31.38	24.48	22.00	53.52	46.48	33.274	6.1	4.04	4.79	1.7	18.4
D3	2	7–30	16.81	25.24	27.60	30.35	42.05	57.95	27.371	2.6	4.12	5.54	1.1	5.8
D4	1	0–10	41.13	41.82	10.57	6.48	82.95	17.05	36.061	6.4	6.25	6.91	1.0	4.2
D4	2	10–40	72.28	19.42	3.95	4.35	91.70	8.30	50.931	2.8	6.7	7.01	1.4	2.6

soils in the clear beech forest zone. The total sand in the humus horizon of all profiles ranges from 52% to 63%, while in profile D1, was 71% and 83% in profile D4. In the subhumus horizon in profiles D1 and D4, the participation of clay proportion was 8% and 4%, respectively, which is the lowest measured clay content in the entire area of Biogradska Gora.

3.2. Characteristics of the flora

During the preparation of phytocenological relevés, 58 plant species were recorded (Table 2). *Fagus moesiaca* was the dominant species in the sapling layer. Other species with high abundance-dominance are, among trees, *Acer pseudoplatanus*, *Fraxinus excelsior* and *Ulmus montana*. In

the stands of beech with sycamore maple and European ash, there is a great coverage and diversity of terrestrial flora. Wild garlic (*Allium ursinum*) as well as *Asperula odorata*, *Salvia glutinosa* and *Euphorbia amygdaloides*, had the greatest abundances. From the point of view of soil moisture, mesophilous species were dominant.

3.3. Forest structure

In the studied mixed stands of beech, sycamore and ash distribution of the number of trees per diameter class of each individual species, overall, is characterized by a large variation and the appearance of several maxima. These forests can be defined as structurally irregular, uneven-aged stands.

Table 2. Phytocoenological relevés.

	D-1	D-2	D-3	D-4	(D-5)	
Altitude (m)	1080	1110	1110	1110	1110	
Exposition	N	N	NE	-	SW	
Inclination (°)	5-7	10	3-5	0	3	
Floor I						
Canopy/Total cover	1.0	1.0	1.0	0.8	0.9	
<i>Fagus moesiaca</i>	3.3	4.4	4.4	1.1	4.4	V
<i>Acer pseudoplatanus</i>	1.1	1.1	1.2	3.3	2.2	III
<i>Fraxinus excelsior</i>	2.2	1.1	+	2.2	+	II
<i>Acer platanoides</i>	+	+			+	II
<i>Ulmus montana</i>		+		+		I
<i>Tilia grandifolia</i>				+		I
Floor II						
Canopy/Total cover	0.2	0.6	0.5	0.4	0.2	
Average high (m)	3	5	4	4	5	
<i>Fagus moesiaca</i>	1.2	3.3	3.3	2.3	1.2	V
<i>Evonymus latifolia</i>	+					I
<i>Abies alba</i>		+	+			I
<i>Corylus avellana</i>	+2					I
<i>Sambucus nigra</i>	+				+2	I
<i>Rhamnus fallax</i>				1.1		I
<i>Ribes grossularia</i>				+		I
Floor III						
Canopy/Total cover	1.0	0.8	0.8	1.0	0.9	
<i>Asperula odorata</i>	+	3.3	3.3	2.3	+2	V
<i>Lamiaeum galeobdolon</i>	1.2	1.2	1.2	2.2	1.2	V
<i>Cardamine bulbifera</i>	+2	+2	+2	+2	+2	V
<i>Festuca drymeia</i>		1.2	+2		+2	IV
<i>Fagus moesiaca</i>	1.2		1.2	+2		IV
<i>Dryopteris filix-mas</i>	+	+	+2		+2	IV
<i>Abies alba</i>		1.1	+2	+2		III
<i>Oxalis acetosella</i>	+2	+2	+2	1.2	+2	III
<i>Prenanthes purpurea</i>	+		+			III
<i>Mycelis muralis</i>			+	+		III
<i>Mercurialis perennis</i>	1.2	+2	+2			III
<i>Geranium robertianum</i>	1.2		+	+	+2	III
<i>Fraxinus excelsior</i>	+2	+2	+	2.3		III
<i>Anemone nemorosa</i>	+2	+2	+			III
<i>Viola sylvestris</i>		+	+			III
<i>Veronica urticifolia</i>		+				II
<i>Acer platanoides</i>		+	+			II
<i>Acer pseudoplatanus</i>			+			II
<i>Evonymus latifolia</i>	+	+	+			II

Table 2. (Continued).

<i>Lilium martagon</i>	+	+	+			II
<i>Calamintha officinalis</i>	+					II
<i>Paris quadrifolia</i>	+	+	+	+		II
<i>Polygonatum verticillatum</i>	+	+			+2	II
<i>Sambucus nigra</i>	+		+		+2	II
<i>Prunus avium</i>	+	+	+			II
<i>Salvia glutinosa</i>	+2	+2	+2	+2		II
<i>Euphorbia amygdaloides</i>	+	+	+		+	II
<i>Athyrium filix-femina</i>			+			I
<i>Galium silvaticum</i>	+					I
<i>Neotia nidus-avis</i>			+		+	I
<i>Asarum europaeum</i>	+2					I
<i>Rhamnus fallax</i>				+2		I
<i>Lathyrus vernus</i>		+				I
<i>Luzula sylvatica</i>				+		I
<i>Sanicula europaea</i>		2.2	+2			I
<i>Arum maculatum</i>		+	+			I
<i>Melica uniflora</i>		+2	+2			I
<i>Hepatica nobilis</i>		+2				I
<i>Ulmus montana</i>		+	+	+		I
<i>Daphne mezereum</i>		+		+		I
<i>Euonymus verrucosa</i>		+				I
<i>Lonicera alpigena</i>		+				I
<i>Carex sylvatica</i>			+2			I
<i>Circae lutetiana</i>			+		+	I
<i>Isopyrum thalictroides</i>			+			I
<i>Vicia oroboides</i>			+			I
<i>Aremonia agrymonioides</i>			+			I
<i>Actaea spicata</i>	+		+			I
<i>Allium ursinum</i>	5.5			3.3	5.5	I
<i>Stachys silvatica</i>	+					I
<i>Lunaria rediviva</i>				+	1.2	I
<i>Impatiens noli-tangere</i>				1.2		I
<i>Senecio nemorensis</i>				+		I

The line of distribution of trees by diameter classes (Figure 4) is wavy, which is typical for uneven-aged stand structure. This irregular distribution indicates the existence of several strata/layers of trees this ecological unit. In these stands, the deviation from the regular structure can be explained by a rather weak and periodic regeneration enabled by periodic gaps that open the closed canopy of these stands.

The studied stands are characterized by beech dominance in all diameter classes. Sycamore maple is

present in almost all size classes (except the largestones), while the distribution of common ash is quite narrow, characterized by the dominance of trees of medium-sized dimensions with a maximal presence in the diameter class of 47.5 cm.

The average number of trees is 382.95 per ha with the proportion of scattered hardwood at 29.86%. Unlike sycamore and ash, the broad size distribution of beech and its presence in all height classes could be explained by differences in shade tolerance..

In addition to the irregular reverse J-shaped beech distribution, the height curves of sycamore and ash display bell-shaped distribution separately with 2 maxima, indicating their adaptability to the conditions of the beech dominance. The trees are distributed in a large number of height classes, which displays a multilayered structure of these forests (Figure 5).

Timber volume by diameter class was irregularly distributed and exhibited 4 peaks in the distribution, with a maximum in the 82.5 cm class (Figure 6). Medium-sized and large trees contributed the most to the total timber volume that was 813.9 m³/ha with a 61.3% share in beech.

4. Discussion

Information recorded in ‘virgin’ and other untreated forest reserves contribute to defining the reference point for nature-based management of similar forests (Standovar and Kenderes, 2003). Previous research on the forest ecosystems of Biogradska Gora National Park, because of the park’s specific regime of protection, has mainly focused on the diversity of flora. The recorded 58 species in our research is higher compared to 3 different types of beech forests in the Biogradska Gora, where 30-39 species are found on the same size sample plots, with the greatest species richness in a subassociation of *Fagetum*

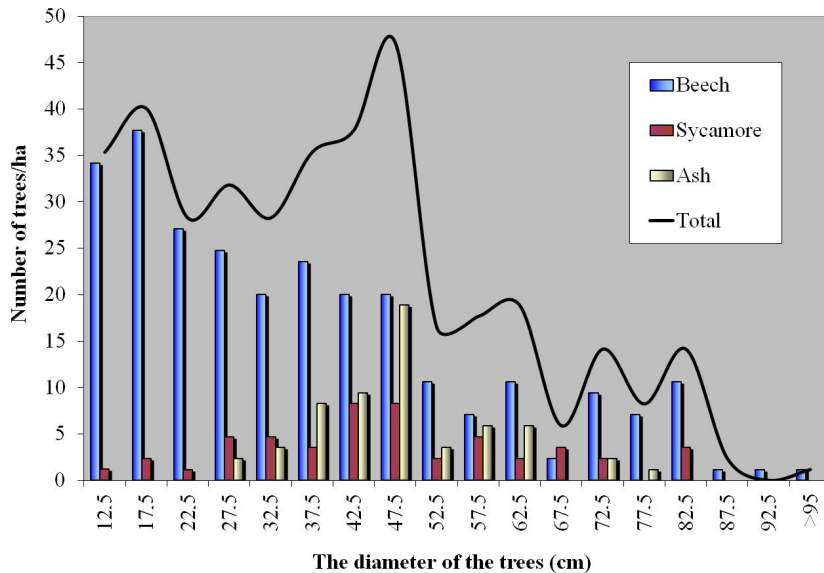


Figure 4. Structure of the trees based on trunk diameter (thicknesses).

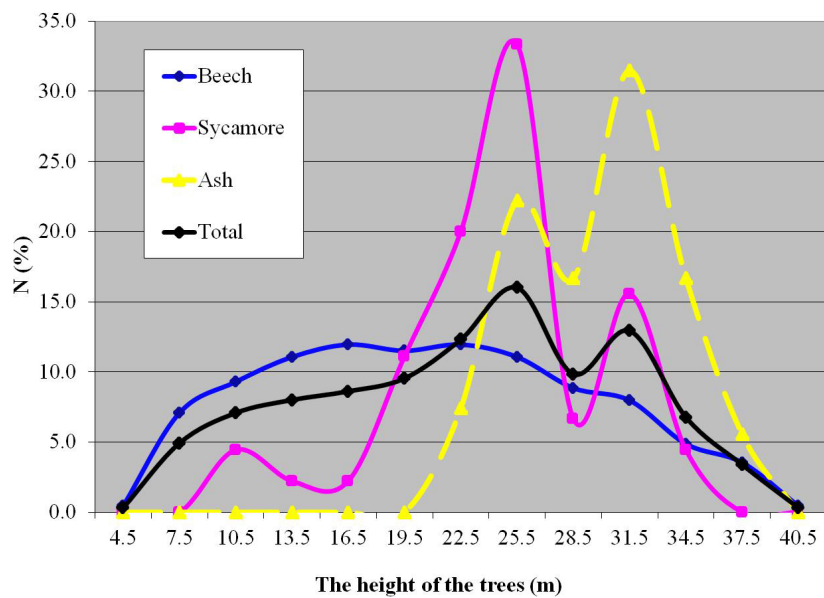


Figure 5. Trees height structure.

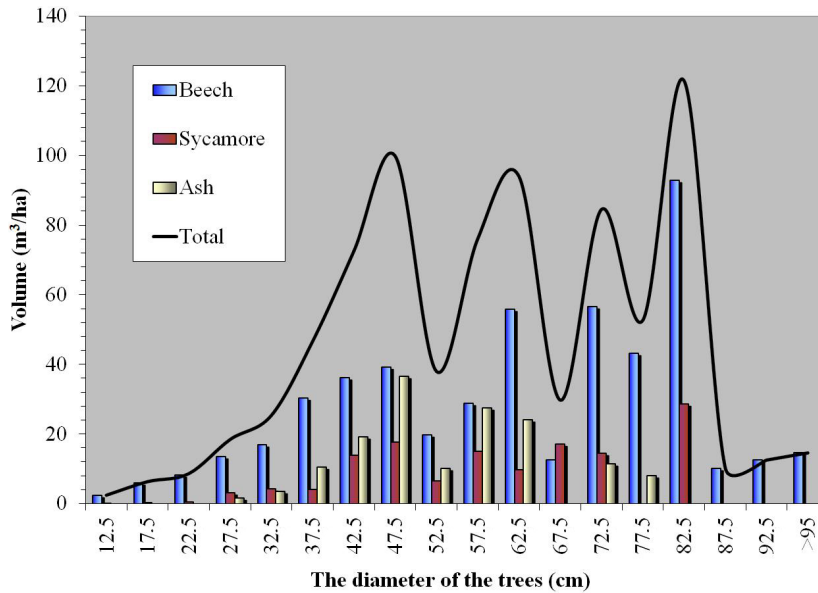


Figure 6. Structure of timber volumes.

moesiaca montanum drymetosum (Curovic et al., 2011). This corresponds with some research where it has been shown that mixed-species forests usually exhibit greater biological diversity than single-species forests (Pretzsch et al., 2017). In the spectrum of floral elements dominant species in Biogradska Gora belong to Central European floral element, which is an indicator that the community develops in mesophilic conditions of temperate zone (Milosevic et al., 2019). Despite the close-to-nature strategy employed in managed forests, species richness of various taxa was lower in the managed than the unmanaged forests (Gossner et al., 2013; Kara and Lhotka, 2020). In addition to greater species richness, areas of national parks also preserve some endemic or rare species. (Medarevic et al., 2004; Stesevic and Petrovic, 2004; Nicolin and Imbrea, 2009). The soils of the studied forests are shown lower acidity than the soil in the zone of pure beech forests in Biogradska Gora (Curovic, 2011). This can be explained by better decomposition of litter in studied mixed forests than in pure beech forests. According to Jacob et al. (2010) decomposition rates of leaf litter in temperate deciduous forest stands will increase along a gradient of decreasing fraction of the beech. This cannot be seen as a rule and therefore as an advantage of mixed forests. In mixed *Quercus* and *Fagus* stands in Belgrad forests in Turkey, for example, litter decomposed more slowly than pure-stand litter (Çakır and Makineci, 2019).

The exceptional potential of mixed forests of beech, sycamore and ash can be seen in the large wood volume of 813.87 m³/ha is compared with the timber volume of the pure beech forests in Biogradska Gora, which ranges from 402 to 521 m³/ha (Curovic et al., 2011). These facts

point to a better use of space by the mixed broadleaved forest than by pure beech forests both in production and in biodiversity.

Studying 3 stands of beech, sycamore, mountain elm and white ash near Biogradsko Lake, Tomanic (1991) determined the volume of 989 m³/ha, 1,275 m³/ha and 1,324 m³/ha, which he explained by the presence of trees of exceptional dimensions. During the first inventory of the forest of Biogradska Gora National Park, a timber volume of 971.2 m³/ha was determined for 1 patch (cluster 59) of beech mixed with noble hardwoods, where the beech share was 51.3% (Stijovic, 2017). The extraordinary productive potential of stands of this type of forest are apparent also in Djerdap National Park in Serbia, where timber volumes between 441 and 536 m³/ha were recorded (Medarevic, 2005).

The current volume increment of 7.67 m³/ha is significantly greater than the production potential found in the pure beech forests, where increment ranges from 4.94 to 5.71 m³/ha. In similar forest types in Djerdap National Park in Serbia (Medarevic, 2005), the current increment ranges from 5.9 to 7.3 m³/ha. In structurally even-aged forests, it amounts to 5.93 m³/ha, while in structurally uneven-aged stands of mixed broadleaved forests of beech, sycamore and ash, the increment is on average 6.53 m³/ha.

Similar forests of beech (*Fagus sylvatica*), ash (*Fraxinus excelsior*), and maple (*Acer pseudoplatanus*) found on rich sites in Germany have growing stocks between 421 and 1042 m³/ha, with 140–336 trees/ha (Zuge, 1986). The silvicultural aim is to have 40%–60% beech and 60%–40% ash, maple and other scattered valuable hardwood species in mature stands (Wagenhoff, 1974). To achieve this goal, it

is necessary to provide maple and ash with a sufficient lead in juvenile height growth enables the maple and ash to hold ground in the long run against the increasingly competitive beech. To achieve this goal, silvicultural intervention is needed and managed forests should be oriented to open up larger gaps in the canopy. In a disturbance regime characterized by small-scale disturbances, there is not enough light for new regeneration of scattered broadleaved species and it is much more difficult for them to compete with beech.

In broadleaved mixed forests with beech, other species only could show higher proportions in the early stages of development, before their proportions decreased in later stages and occurred only occasionally (Rotach, 1998). Although in the Uholka virgin forest of Ukraine that is an almost pure beech forest with only 3% admixture of maple and beech in the overstory 62% of saplings smaller than 130 cm were maple (*A. pseudoplatanus* and *A. platanoides*), 10% were ash, 3% elm, and 25% beech, beech dominated the layer above 1.3 m (Commarmot et al., 2005). In managed forests in Bosnia and Herzegovina that have a constant share of light-demanding sycamore maple in the upper story, the regeneration of sycamore and ash remains more abundant than in the virgin forest (Visnjic et al., 2013; Keren et al., 2017).

The different needs of species requires for careful silvicultural treatment in the early stages of the development of managed stands. This may be the main reason why such stands in managed forests are rare despite their great potential.

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5. Conclusion

The forest ecosystems of Biogradska Gora National Park, 1 of the last preserved European primeval forests, represent an ideal starting point for the observation of natural processes in the forests of the temperate zone. This is also the case with mixed forests of beech, sycamore maple and ash. In this paper the structural and ecological characteristics of these stands at specific sites are described.

The achieved tree dimensions and timber volume in pristine forests can also serve as an indicator of the productivity of these stands. Mixed forests of beech, sycamore maple and ash on the studied sites represent forests of high site classes, in which determined timber volume of 813.9 m³/ha which is a clear indicator of the production potential of these forests. The determined number of 58 species per hectare in the stands is considerably higher than the number of species in pure beech forests in the same reserve, which is 30-39. This demonstrates the remarkable biodiversity potential of the studied mixed forests.

The presented results can contribute to the understanding of these forest ecosystems and provide insight into the structural characteristics of forests of this type that have developed without anthropogenic influence. The presented structural characteristics can be a good starting point for creating objectives for close to nature forest management of similar managed stands.

Conflicts of interest

The authors declare no conflict of interest.

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