Structural characteristics of the mixed spruce - fir - beech forests on Mountain Bjelasica in Montenegro

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Abstract

Biogradska Gora National Park in Montenegro is part of the Bjelasica Mountain which belongs to the montane region of the Dinaric Alps. Biogradska Gora is one of the largest long-term preserved forests in the Southeast Europe. In this paper there were compared the main structural characteristics of the old-growth mixed forest of spruce (*Picea abies* L.), fir (*Abies alba* L.) and beech (*Fagus moesiaca* (Domin, Maly) Czecz.), from the preserved area of the Biogradska Gora, with similar managed forests from the same mountain. Basic insight into the structural characteristics of forests of spruce, fir and beech was obtained by analyzing tree species composition and two basic structural elements - number of trees and wood volume per unit area. The obtained data provides overview of the structural characteristics of these forests. The results revealed the production potential of the studied mixed forests. The average quantity of standing volume in old-growth forests of Biogradska Gora indicates very valuable and productive forest ecosystems. Presented data shows that forest ecosystems of spruce, fir and beech in the protected area of the National Park Biogradska Gora are characterized by structurally irregular forests with presence of old trees with relevant growing stock and optimal balance of beech and conifer species, while in managed forests on the same mountain, growing stock is very low and with structure which is far from optimal.

Keywords: Biogradska Gora; Bjelasica; mixed forest; Montenegro; old-growth forest

Introduction

Mixed mountain forests of beech (*Fagus moesiaca* (Domin, Maly) Czecz.), fir (*Abies alba* L.) and spruce (*Picea abies* L.) represent one of the major forest types in Eastern and Southeast Europe (Horvat *et al.*, 1974; O'Hara *et al.*, 2018). The three-dominant forests of beech, fir and spruce (*Piceeto-Abieti-Fagetum* s. lat.) in

Montenegro are forests of high site class in which all three species reach high dimensions in terms of height and thickness, especially in old-growth stands.

Norway spruce, silver fir, and European beech are three of the most widely distributed and economically important tree species in Europe (Torresan *et al.*, 2020). Mixed mountain forests of beech, spruce, and fir at elevations between 600 and 1400 m above sea level cover an area of more than 10 million hectares in Europe (Brus *et al.*, 2012). The forests of fir, spruce and beech (*Piceo-Abieti-Fagetum* Čol. 1965.) according to the First National Forests Inventory of Montenegro (MARD, 2013), occupy 4.7% of the total area covered by forest in Montenegro.

European mixed mountain forests have been stable in terms of volume growth in relation to climate change (Hilmers *et al.*, 2019). Three species mixture of beech, spruce, and fir in optimal climate and site conditions shown higher productivity than neighbouring pure stands (Pretzsch *et al.*, 2015) and ecologically are more resilient than single-species forests (Griess *et al.*, 2012; Lebourgeois *et al.*, 2013; Pretzsch *et al.*, 2013). This could be very important for adaptability and for mitigating climate change impacts. Knowledge of structural elements and species composition of old-growth forests should be base for management approaches according to the future climate changes (Millar *et al.*, 2007). Structural characteristics of old-growth forests are important starting points for defining the goals in forests that are managed on a regular basis (Vasic *et al.*, 2018) and represent a worthy model for management and structuring of managed forests. Natural selection in primary forests may provide solutions for forest management that could lead to stands with higher stability and superior wood quality (Chivulescu *et al.*, 2019). The significance of this research according to Bosela *et al.* (2015) is also resembled in the fact that there is modest knowledge about competitive and facilitative interactions between trees and species in the mixed spruce-fir-beech forests. Studies of old-growth forests structure and comparison with similar managed forests are becoming increasingly important for the improvement of silviculture and for understanding environmental changes (Diaci *et al.*, 2011). Many studies in recent years increasingly support the idea of nature-based silviculture (Lafond *et al.*, 2015; Nolet *et al.*, 2017).

Intensive forest exploitation in Europe caused their compositional and structural homogenization and simplification, leaving only remnants of old-growth temperate forest ecosystems (Axelsson and Oestlund, 2001) which is main reason why comparison studies between old-growth forests and similar managed forests in Europe are rare. The Biogradska Gora mixed *Abies-Picea-Fagus* forest on the Mountain Bjelasica in Montenegro is one of the largest remaining old-growth forests in the Southeast Europe (Motta *et al.*, 2015).

The main goal of this paper is to provide an overview of the structural characteristics of the mixed forests of beech, fir and spruce in Biogradska Gora National Park as a realistic basis for close-to-nature management of similar stands. Because of the rarity and fragmentation of old-growth forests, comparative research of those and managed forests is especially important for understanding forest ecosystem functioning and for the development of close-to-nature forest management strategies. Those studies are needed to improve knowledge on how anthropogenic factors are influencing compositional and structural changes of the forests. In this paper we compared the main structural characteristics of the mixed forest from the preserved area of the Biogradska Gora with similar managed forests from the same Mountain Bjelasica (Figure 1).

Materials and Methods

For the forest measurement of Management Unit (MU) Bjelasica has been used a conventional forest inventory sampling procedure regular with 100 m grid of sample plots. Each grid intersection defined the centre of a circular sampling plot (radius = 17.84 m, area = 1000 m²). In each plot, all live trees with the diameter at breast height (DBH) >10 cm were tallied and sorted by species (MARD 2013).
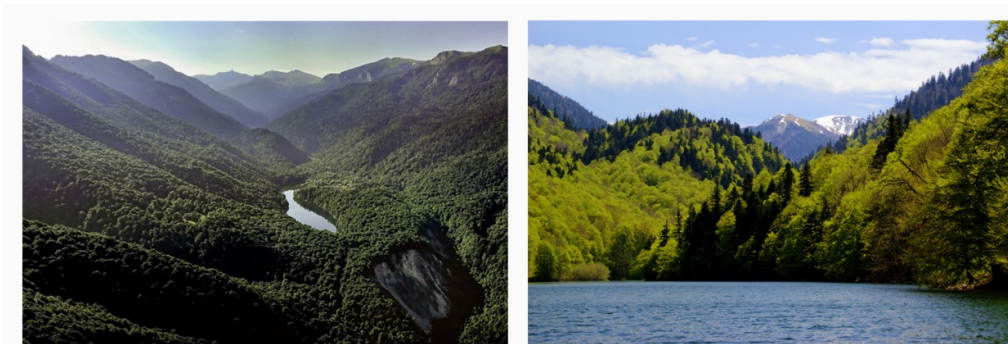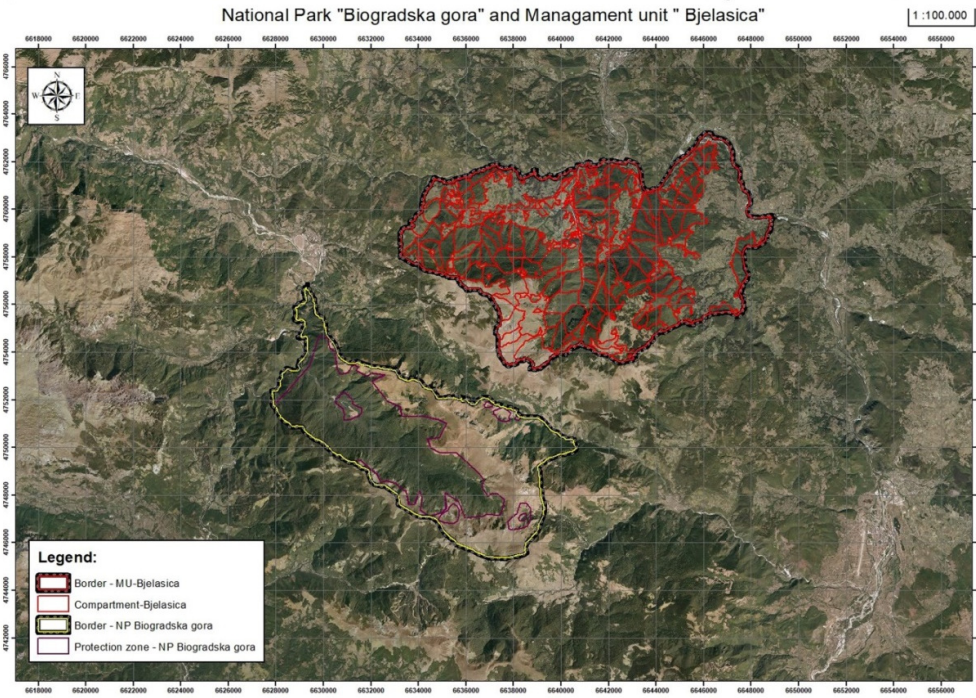
Figure 1. Position and panoramic view of National Park Biogradska Gora and Management Unit (MU) Bjelasica

The field research in Biogradska Gora included collection of data in four sample plots in the strict protection zone. Selection of the areas for sample plots was focused on forest stands at the optimal stage phase according the Korpel theory (Korpel, 1995). The sample plots of 0.25 ha were clearly marked in the field, with coordinates recorded using a GPS device. Diameter at breast height and the heights (h) of the trees were measured for all live trees with a minimum DBH threshold of 10 cm. The diameter at breast height in the research plots was measured using tree callipers to the nearest 1 mm at 1.3 m height.

Volume was calculated for each individual tree by the method of direct equalization of volumes, according to Schumacher-Hall's function:

$$V = a\, d^b\, h^c \tag{1}$$

Where 'd' is diameter at breast height, and 'h' is high of the tree.

Value of coefficients 'a', 'b' and 'c' for all three species in Montenegro was calculated using Montenegrin volume tables (Markovic, 2004).

The final calculations were obtained by using software "Osnova v 6.4.2.".

Results

The Structure of mixed forests of beech, spruce and fir of the Mountain Bjelasica in Montenegro were examined by accessing data of three basic stand parameters: (1) stand diameter and volume structure (2) number of trees per ha and (3) tree species composition. The forest structure data were aggregated separately for old-growth forests of National Park Biogradska Gora and for managed forests of Management Unit (MU) "Bjelasica".

MU Bjelasica

Mixed fir, spruce and beech forests in better habitats (Management class 103) make up 34.3% of the total area of commercial forests of the MU Bjelasica (Stijovic, 2017). These stands are found in quite heterogeneous habitats, on soils whose depth ranges from to medium deep to deep. The total area of these forests in the management unit is 804.4 ha.

The number of trees per unit area is 811 trees per hectare. The total wood volume is 229159 m³ or 284.8 m³ / ha. The volume structure by diameter classes and tree species is shown in Table 1. The total current annual volume increment in these forests is 6.7 m³/ha. The average intensity of increments is 2.4%.

Table 1. Timber volume structure of MU Bjelasica

Species	Management unit (MU) Bjelasica Volume per diameter classes										
	Sum (m³)	Sum (%)	10-20 cm	21-30 cm	31-40 cm	41-50 cm	51-60 cm	61-70 cm	71-80 cm	81-90 cm	above 90 cm
			I	II	III	IV	V	VI	VII	VIII	IX
Beech	163.4	57.3	23.4	29.9	31.8	31.0	20.1	12.5	7.7	3.6	3.4
Fir	50	17.5	13.1	15.7	9.9	5.7	1.6	1.6	0.8	0.7	0.9
Spruce	32.6	11.4	5.1	9.3	7.9	5.2	2.1	1.2	0.7	0.4	0.7
Other species	39.2	13.8	12.5	14.0	5.5	2.4	1.6	1.1	0.6	0.5	1.0
Total	285.2	100.0	54.1	68.9	55.1	44.3	25.4	16.4	9.8	5.2	6.0

Stands in the MU Bjelasica, except for rather low values of the standing timber volume, are characterized by a low proportion of the volume of the timber in the diameter classes above 50cm DBH (Table 3). There is also a large participation of accompanying species. The share of the main tree species in the mixture is 86.2%. The share of fir and spruce in the mixture of 28.9% is very far from the optimal state (80%), while on the other hand there is an excess of beech (57.3%) and other accompanying species (*Populus tremula* L., *Betula pendula*

Roth., *Acer pseudoplatanus* L., *Fraxinus excelsior* L. and other species) of as much as 13.8%, which will require a longer period of time to achieve the optimal scale ratio of the mixture.

Biogradska Gora

The achieved tree dimensions and timber volume in old-growth forests can serve as an indicator of the productivity of these stands (Curovic et al., 2020). Although a smaller number of trees occurred per unit of area (on average, 349 trees/ha), the presence of remnant trees of large dimensions resulted in substantially high growing stock of 795,6 m³/ha.

Table 2. Timber volume structure of Biogradska Gora

Species	Biogradska Gora Volume per diameter classes										
	Sum (m³)	Sum (%)	10-20 cm	21-30 cm	31-40 cm	41-50 cm	51-60 cm	61-70 cm	71-80 cm	81-90 cm	above 90 cm
			I	II	III	IV	V	VI	VII	VIII	IX
Beech	169.7	21.3	5.2	14.1	25.8	33.2	23.9	27.8	23.1	16.6	0.0
Fir	361.0	45.4	4.5	16.4	27.9	25.5	40.1	62.0	61.2	55.9	67.5
Spruce	264.9	33.3	0.9	3.3	5.0	18.9	30.0	24.5	27.5	6.7	148.1
Total	795.6	100	10.6	33.8	58.7	77.6	94.0	114.3	111.8	79.2	215.6

The share of coniferous species is quite favourable and amounts to 78.7%. This is especially pronounced in diameter classes above 50cm. The accompanying species in these stands have no share in the wood volume.

The difference in the volume distribution by wider diameter classes (Table 3) between the stands of MU Bjelasica and Biogradska Gora best shows the structural difference of the studied stands.

Table 3. The structure of growing stock by wider diameter classes

Diameter classes	MU Bjelasica (%)	Biogradska Gora (%)
DBH < 30 cm	43.1	5.6
DBH 31–50 cm	34.9	17.1
DBH > 50 cm	22.0	77.3

The average timber volume found in the sample plots in Biogradska Gora was more than twice greater than the volume in the managed forests in the same Mountain of Bjelasica. The distribution by diameter classes shows that the stands of MU Bjelasica have a structure close to selective forests, while the stands on Biogradska Gora have structure characteristic for old-growth forest communities, with a small number of trees in the lowest diameter classes.

Discussion

An optimal growing stock for mixed forests of spruce, fir and beech between 320 and 430 m³/ha, depending on habitat conditions in Montenegro, has been accepted as an axiom in forestry science and practice. The optimal growing stock for those forests in better habitats is 410 m³/ha, with optimal mixture of 80% of conifers (fir 50 and spruce 30) and 20% of beech (Medarevic, 2006; Curovic *et al.*, 2013).

In the best managed spruce-fir-beech stands on the Mountain Ljubišnja in Montenegro average tree volume of 404.3 m³/ha at the Vukodol site and 584.4 m³/ha at the Sula site were recorded (Curovic *et al.*,

2011). According to presented structure, growing stock and tree species composition, forest stands from MU Bjelasica completely deviates from the optimal ones. The reason should certainly be sought in the management practice, due to the intensity of cutting in the past period and due to the uneven treatment of felling of beech and coniferous species. The above data indicate that the existing wood volume in these forests is lower by 125 m³ / ha than optimal. The share of conifers in the mixture is below 30%. A high percentage of accompanying species is also evident as a consequence of greater disturbance of the canopy and inadequate felling.

On the other hand, the average quantity of standing volume of 795.6 m³/ha in forests of Biogradska Gora indicates quite different situation. Growing stock is almost twice the average. The ratio of beech and coniferous species is very close to optimal. According the results of the studies on mixed beech, fir and spruce forests in Serbia in the best sites of the national park Tara the average growing stock is 462.84 m³/ha (Medarević *et al.*, 2007) and Mountain Zlatar 510 m³/ha (Matović, 2005). Govedar *et al.* (2006), studying the old-growth forests Lom in the Bosnia and Herzegovina, recorded a volume from 600 to 1343 m³/ha.

The achieved tree dimensions and timber volume in old-growth forests can serve as an indicator of the productivity of these stands. Presence of large-diameter trees is an attribute of the old-growth forests (Bahus *et al.*, 2009; Keren *et al.*, 2017). The high percentage of volume in diameter classes above 50 cm dbh in Biogradska Gora shows the old-growth forest character of these stands. The right asymmetry of the volume structure is particularly pronounced in spruce. Norway spruce is important for the productivity but in dense stands, regeneration growth of spruce could be suppressed (Stancioiu and O'Hara, 2006).

Despite the high degree of forest naturalness, the share of fir in European blending forests is decreasing (Jaworski *et al.*, 2002; Diaci *et al.*, 2010; Bottero *et al.*, 2011; Vacek *et al.*, 2014). Primeval forest structure and full canopy is especially suited for fir. In the studied stands on Biogradska Gora, the share of fir is quite good, while it is not case in managed forests of MU Bjelasica. Natural regeneration of fir in the full canopy parts of the mixed forests is much higher than in the open parts (Klopčić *et al.*, 2010). Completely fencing virgin forests is currently the only way of ensuring relatively natural spontaneous development of mixed spruce-fir beech forests (Vrska *et al.*, 2006).

Models and silvicultural guidelines may consider our findings by regulating the species and size distributions in order to reach higher values of growing stock. As a general principle, silvicultural interventions should foster J-shaped size distributions in European spruce-fir-beech mountain forest stands (Torresan *et al.*, 2020).

In our study, noticeable differences between managed selection forests and corresponding virgin forests were detected in diameter structure, stand volume and the presence of large-diameter trees. Similar differences in the analysed stand parameters were found in other studies (Goodburn and Lorimer, 1999; Štefančik *et al.*, 2006; Janowiak *et al.*, 2008; Diaci *et al.*, 2010). The single-tree selection system is similar to a natural gap disturbance regime in old-growth forests (Angers *et al.*, 2005). Forest management practice of selective forests in Montenegro used more often group selection than individual tree selection (Bončina *et al.*, 2014). The results presented in this paper show that this principle of management has not given good results in practice.

Conclusions

The analysis of structural parameters of three-dominant spruce, fir and beech forests (*Piceo-Abieti-Fagetum*) on Bjelasica Mountain in Montenegro showed significant differences in the condition of managed forests in relation to protected old-growth forests. In the managed forests of the MU "Bjelasica" in addition to the smaller growing stock, tree species composition seen through share of beech and coniferous species has also been significantly disturbed. In the forests of the Biogradska Gora National Park, the species ratio is close to optimal, while the growing stock is almost three times higher in relation to the managed forests of the same Mountain. This shows that the current situation in managed forests is far from the potential of habitats. A

significant share of accompanying species is also noticeable in managed forests and it will take a long time for these stands to reach the optimal condition.

The presented comparison showed the advantage of the close-to-nature management and individual tree selection. These results are in line with presented recent trends in forestry. The presented structural elements of intact forests in this case preserved area of the Biogradska Gora National Park, can serve as a good guide in creating management goals for similar forests.

Authors' Contributions

Conceptualization: MC and VS; Work on the field: MC, AS and VS; Methodology: MC and AS.; Software: MC, AS and VS.; Calculations: MC, MP, BD and AS; Formal analysis, MC and MP; Literature: MC and MP; Data curation, MC, MP; Writing - original draft preparation, MC; Writing - review and editing: MC, MP and VS; Visualization: AS, VS and MP; Supervision, VS; Project administration: BD; Funding acquisition, BD.

All authors read and approved the final text of the manuscript. All authors read and approved the final text of the manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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