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Comparison of structure, regeneration and dead wood in virgin forest remnant and managed forest on Grmeč Mountain in Western Bosnia

Ć. VIŠNJIĆ[1], S. SOLAKOVIĆ[2], F. MEKIĆ[1], B. BALIĆ[1], S. VOJNIKOVIĆ[1], M. DAUTBAŠIĆ[3], S. GURDA[1], F. IORAS[4], J. RATNASINGAM[5] & I. V. ABRUDAN[6]*

[1]*Faculty of Forestry, University of Sarajevo, Bosnia and Herzegovina;* [2]*Unsko-Sanske Sume, Bosanska Krupa, Bosnia and Herzegovina;* [3]*University of Sarajevo, Bosnia and Herzegovina;* [4]*Centre for Conservation and Sustainability, Buckinghamshire New University, United Kingdom;* [5]*Forestry Faculty, University of Putra, Malaysia and* [6]*Faculty of Silviculture and Forest Engineering, Transilvania University of Brasov, Romania*

Abstract

This paper compares the forest structure, regeneration and distribution of dead wood in a virgin forest remnant and a close-to-nature managed beech–conifer mixture situated on Grmeč Mountain in Western Bosnia. The investigations were carried out in a 1 ha permanent sample plot and 35 circular plots (20 m radius) in the virgin forest and in 17 circular plots (25 m radius) in managed forests. The number of trees in the managed forest was significantly ($p = 0.05$) higher than that in virgin forest and the distribution of the number of trees per diameter classes had a decreasing trend, but with a different shape in the virgin forest compared to the managed stands. In the lower diameter classes, the stock volume recorded in virgin forest was half of that in the managed forest, whilst for higher diameter classes the cumulated volume of the growing stock was almost double in virgin forest. The young crops had a significantly lower presence in the virgin forest and a larger volume of dead wood was identified in the virgin forest than in managed stands. The study results are important in assessing the consequences of close-to-nature management on the forest structure and regeneration when compared to the condition in virgin forests.

Keywords: *Dead wood, growing stock, managed forest, structure, virgin forest, Western Bosnia*

Introduction

Bosnia Herzegovina's (BiH's) forests (1,266,000 ha) are part of the *Piceo-Abieti-Fagetum* association, with common beech, silver fir and Norway spruce representing more than 80% of BiH's forest area (Pintarić 1978; Ioras et al. 2009). Mixed forests of beech–fir and beech–fir–spruce account for around 44% or more than 560,000 ha (Matic et al. 1971; Visnjic et al. 2009).

Virgin/pristine forests are important remnants of valuable and rare forest ecosystems in BiH. They provide a basis for close-to-nature silvicultural research and applications and for designing national networks of protected forest and they represent a reference for naturalness assessment of other managed forests (Abrudan and Mather 1999; Abrudan 2000; Ioras et al. 2009; Visnjic et al. 2009; Dautbasic et al. 2010).

In 1905, about 50% of the total forest area of BiH (2 million ha) was considered virgin forest (Fröhlich 1954), i.e. forest that has not had any human-induced treatment (Lund 2002). Nowadays, most of these forests have lost their virgin status, as in the last century they have been managed mainly for wood production, especially under the uniform or irregular shelterwood systems (Pintaric 1999). Twenty-seven "strict forest reserves" totalling 3125 ha in area remained in Bosnia (Parviainen et al. 2000); however, only five of these reserves can be considered as "virgin forest reserves" (Pintaric 1999). The total area of virgin forest remnants in Europe is difficult to estimate since this area depends on the definition of the notion "virgin forest" (Lund 2002). Strictly protected forest areas cover more than 100,000 ha in Austria, Belgium, the Czech Republic, France, Germany, Hungary, The Netherlands, Poland, Slovakia and Switzerland (Parviainen et al. 2000).

Correspondence: I. V. Abrudan, Faculty of Silviculture and Forest Engineering, Transilvania University of Brasov, 1, Sirul Beethoven, 500123 Brasov, Romania. Tel: + 40 723 533512. Fax: + 40 268 476808. Email: abrudan@unitbv.ro

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Figure 1. Mt. Grmeč location in Bosnia–Herzegovina.

However, only a minor part of these forests can be classified to be virgin forests. In Scandinavia and Eastern Europe, larger patches of forest that have suffered human impact still exist (Parviainen et al. 2000).

Under the present ownership and socio-economic context, the vast majority of forests in BiH are managed primarily for wood production (Ioras et al. 2009; Avdibegovic et al. 2010); however, BiH has less than 0.3% of its forests classified as pristine (virgin) forests, namely Perucica, Janj, Lom and Trstionica forests (Ioras et al. 2009; Dautbasic & Ioras 2010). The only pristine forests in BiH that have been the subject of several scientific investigations in the past are Perućica, Ravna vala, Mačen do and Plješevica (Pintarić 1978; Leibundgut 1993; Beus & Vojniković 2002; Sebastia et al. 2005; Meskovic 2006; Visnjic et al. 2009).

In this study, the authors conducted a vegetation survey in the managed beech–fir–spruce mixed forests on Mt. Grmeč in Western Bosnia. The obtained indicators were compared with structural indicators of "Bobija" pristine forest that is located in the same area. The study endeavoured to assess the impact of the application of the group selection system on the structure and regeneration of mixed

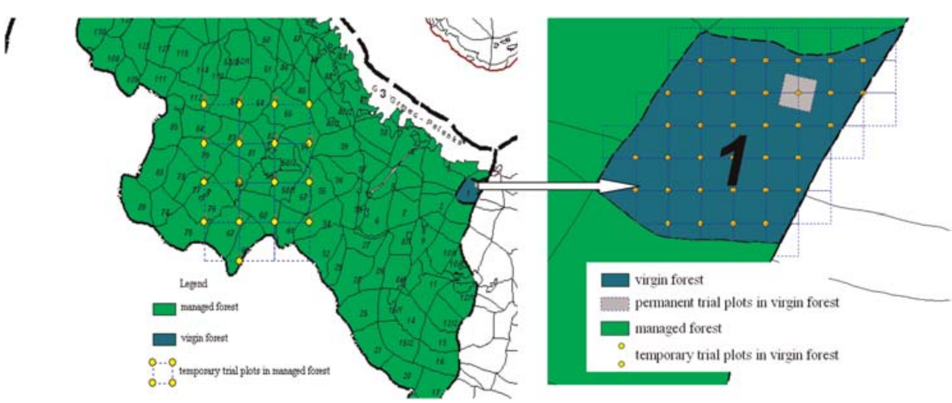

Figure 2. Location of the study area and sample plots.

beech–fir–spruce managed forests compared to pristine forest.

Material and methods

Study area

The research was conducted on Mt. Grmeč in Western Bosnia (Figure 1), which has a total forest area of 5473.8 ha. The study was carry out in a 17-km^2 section of Mt. Grmeč, dominated by beech–fir–spruce mixed forests found on limestone–dolomite substratum (Stefanovic 1988) at an average altitude of 1200 m (latitude: N 44°40′27.19″; longitude: E 16°21′59.62″). These forests are relatively homogenous according to their ecological and vegetation features (bedrock, soil, climate, forest type, structure and management).

Mountain Grmeč is a Class 4 type (UNEP-WCMC classification) with a maximum altitude of 1605 m above sea level (Anonymous 2006). Group-selection silvicultural system has been applied in the managed mixed forests in the last decades (Matic et al. 1977; ŠGD Unsko-sanske šume 2010), whilst a small part of the forest – Bobija pristine forest, with an area of 56 ha (most of it situated in compartment 1 – Figure 2) – has remained untouched and was proposed for designation as a forest of special interest.

The dominant soil types are black soils and limestone brown soils. The climate of the area is moderate continental with mild impact of the Atlantic climate (the main climate characteristics are summarized in Table I). However, as altitude increases above sea level, the climate becomes more continental.

Table I. Climate characteristics of the studied area.[a]

Mean air temperature (°C)		Mean rainfall (mm)		Length of the growing season (days)	Potential evaporation in April–September (mm)
Annual	April–September	Annual	April–September		
7.6–8.7	12.4–14.6	1,198–1,350	625–630	156–170	503–528

[a]Based on data provided by Drinic and Bosanski Petrovac meteorological stations.

Methodology

Species composition, distribution of the diameter classes and development stages, proportion of dead wood and dieback trees were assessed in a 1 ha (100 × 100 m) permanent sample plot (the sides of which had a north–south by east–west orientation) and in 35 circular plots (with a radius of 20 m) located at the intersection of a 100 m by 100 m overlaid grid in the virgin forest. This systematic sampling is recommended for relatively small forest areas like the virgin forest investigated in this study, although similar studies show that a 20-m-radius plot size is sufficient to describe the structural characteristics of mixed stands (Leibundgut 1993; Abrudan and Mather 1999; Beus & Vojniković 2002; Sebastia et al. 2005; Visnjic et al. 2009). In the managed stands, data were collected from 17 circular plots (25 m radius) located at the intersection points of a

Table II. Basic statistical parameters for the number of trees (N), basal area (G) and growing stock (V) of the investigated managed forest (MF) and virgin forest (VF).

Parameter/Statisticstatistic	Variable					
	N_MF	N_VF	G_MF	G_VF	V_MF	V_GF
Number of plots	17	35	17	35	17	35
Minimum value	713	162	32.99 m^2/ha	19.12 m^2/ha	457.51 m^3/ha	340.42 m^3/ha
Maximum value	1518	1158	52.44 m^2/ha	62.61 m^2/ha	844.88 m^3/ha	2040.51 m^3/ha
Mean value	1001	429	37.99 m^2/ha	45.28 m^2/ha	611.53 m^3/ha	725.23 m^3/ha
Coefficient of variation	22.8%	78.6%	15.7%	29.2%	16.4%	46.8%
t	9.74		2.49		3.32	
P *p* value	0.05		0.01		0.01	

1 km by 1 km overlaid grid, situated in the centre of the studied forest area (Figure 2).

In each circular plot located in the virgin forest, the number of trees per species, diameter at breast height (dbh) for each tree (>5 cm), basal area and growing stock were recorded/calculated. The permanent plot was divided into 100 quadrates, 10 by 10 m. At the crossing points of these quadrates, 81 circular plots with a radius of 3 m were established and young seedlings were recorded in each plot, per the method described by Matić (1977). Recording of dead wood volume was conducted in the permanent plot from the virgin forest according to the methodology defined by Albrecht (1990).

In the managed forest, all trees above 5 cm dbh were recorded in each of the 17 circular plots. Seedlings were recorded in circular plots of 3 m radius located at the intersection of the diagonals of the 1 km by 1 km squares. For all seedlings/trees with a diameter less than 5 cm dbh and a height greater than 10 cm as the recording method described by Matić (1977) was applied. The volume of dead wood was recorded, in circular plots of 25 m radius, with the same point of origin as the 3-m-radius plots. Recording of dead wood volume was conducted in the permanent plot from the virgin forest as well as in the managed forest according to the methodology defined by Albrecht (1990). Thus, in each circular plot dead wood that was thicker than 7 cm was recorded and diameter and height/length was measured to calculate the volume. Also, the category of dead wood (lying dead wood, standing dead wood, broken dead wood, stump and assortment) and the degree of decomposition (freshly dead wood, rotten, and decomposed) were recorded.

To assess the statistical significance of differences between the mean number of trees (N), basal area (G) and volume of growing stock (V) in virgin and managed forests, an independent samples *t*-test was applied.

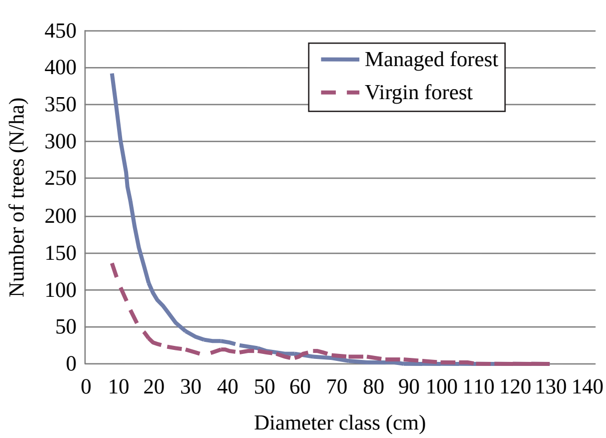

Figure 3. Distribution of the number of trees per diameter classes (virgin forest and managed forest).

Results and discussion

Number of trees

The total number of trees per hectare recorded in the virgin forest was 429 trees. Of these, 201 were silver fir (*Abies alba* Mill.), 1 Norway spruce (*Picea abies* L.), 165 common beech (*Fagus sylvatica* L.), 23 sycamore (*Acer pseudoplatanus* L.), 8 ash (*Fraxinus excelsior* L.), 26 elm (*Ulmus glabra* Huds.) and 5 lime (*Tilia cordata* Mill.) trees. The average number of trees in the managed forest was 1001 trees per hectare, of which 445 were silver fir, 94 Norway spruce, 386 common beech, 40 sycamore, 20 ash, 11 elm, 4 rowan/mountain ash and 1 lime tree. The independent samples *t*-test revealed a statistically significant difference between the number of trees in managed forest and virgin forest (Table II).

Distribution of the number of trees per diameter classes is mainly used as an indicator of the structural composition of the stands. Early research by Leibundgut (1945), Pintaric and Izetbegovic (1980) and Parviainen (2005) indicated that in some cases virgin forests could have a structure typical to a forest that has undergone selection system.

The hyperbolic distribution in Figure 3 is clearly reflecting the structure of a forest managed under the selection system, with the number of trees decreasing in direct correlation with dbh increase. Despite the

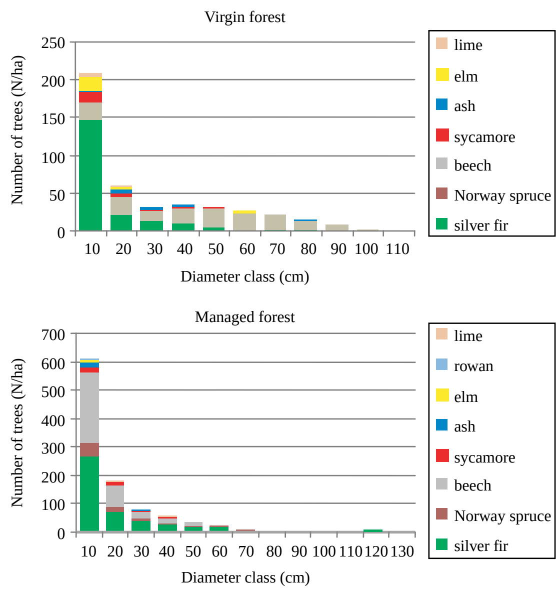

Figure 4. Distribution of the number of trees per tree species and diameter classes (virgin forest and managed forest).

fact that the two curves follow a similar trend it does not automatically follow that virgin forest has a structure typical for a forest managed under the selection system (Anic and Mikac 2008). It can be seen in Figure 3 that the number of trees in the 5- to 30-cm diameter classes is significantly smaller in the virgin forest than in the managed forest, whilst the distribution curve shows several peaks for diameter classes bigger than 31 cm. In the case of managed forest for diameters classes above 90 cm, the curve is actually relatively flat, without significant variations.

Distributions of the number of trees by diameter classes in virgin forest and in managed forest followed different patterns for the same tree species (Figure 4). A high decrease in the number of trees as the diameter increased was recorded for silver fir in virgin forest. It can be noticed in Figure 4 that for diameter class 1–10 cm, the proportion of beech in managed forest was much higher than that in virgin forest; this might be due to the application of the group selection cutting correlated with a mast year. Also, for the diameter class 11–20 cm, the decrease of the number of fir trees was much higher in virgin forest than in managed forest. For common beech, the trend was different in the studied plots. The number of trees per diameter classes was less variable in the virgin forest. Similar to common beech, ash had a relatively even distribution. In the managed forest, the distribution of the number of trees of silver fir and common beech followed a hyperbolic pattern similar to the one in Figure 3, namely the higher the diameter class was, the lower the number of trees present.

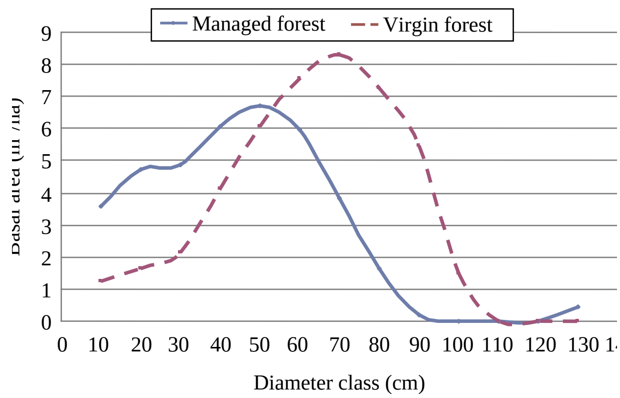

Figure 5. Distribution of the basal area per diameter classes in virgin forest and managed forest.

Basal area

Basal area in the investigated virgin forest was 45.28 m^2/ha, whilst in the managed forest it reached 37.99 m^2/ha. The independent samples *t*-test indicated a statistically significant difference between the basal area in the managed forest and virgin forest (Table II).

Figure 5 shows a mild left-skewed distribution of basal area, which for the virgin forest is more accentuated. This is due to a higher share of larger size trees. It is also evident that as a result of the presence in the managed forest of a large Norway spruce tree (diameter class 121–130 cm), both the basal area and the volume for the respective diameter class was higher in managed forest than in virgin forest (Figures 5 and 6). In the virgin forest, the basal area pick was recorded in the 71- to 80-cm diameter class whilst in the managed forest it was recorded in the 31- to 60-cm diameter class, which is understandable, since the increment actually happens in this diameter class. In virgin forest, there is no felling and in managed forest a selective silvicultural system has been conducted, so the basal area of managed

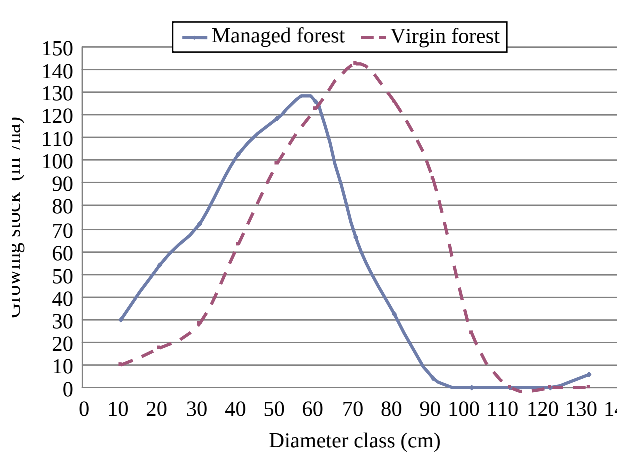

Figure 6. Distribution of growing stock per diameter classes in virgin forest and managed forest.

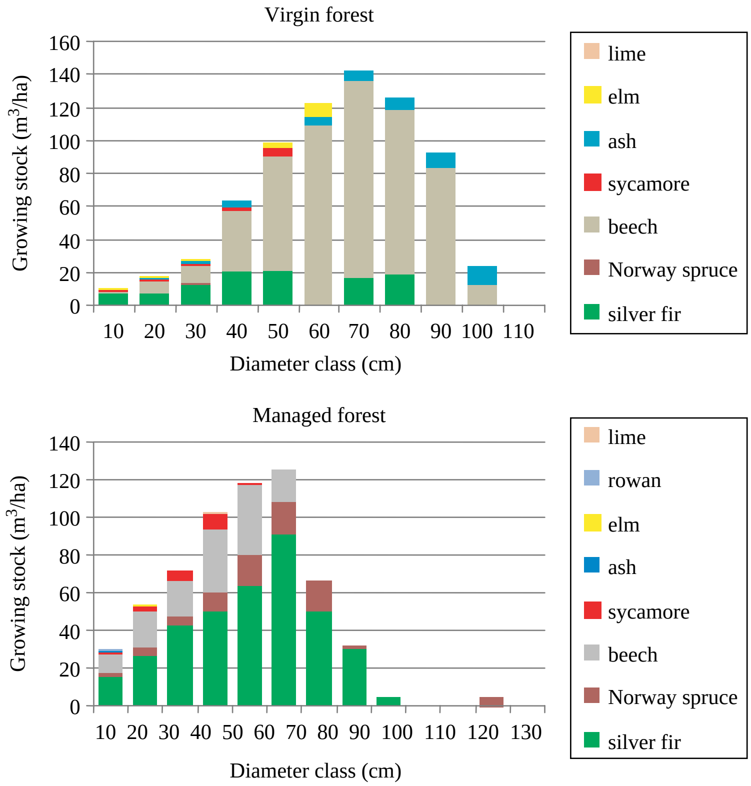

Figure 7. Distribution of growing stock per tree species in virgin forest and managed forest.

forest recorded a lower value than the basal area of virgin forest. The results of the study show that in the virgin forest the trees with a diameter of up to 50-cm diameter classes accounts for 33% of the total basal area whilst those over 51 cm in diameter account for 67%; in the managed forest, the proportion was 69% and 31%, respectively, of the total basal area.

Growing stock

The average volume of the growing stock in the virgin forest was 725.23 m^3/ha, of which silver fir represented 14%, Norway spruce 0.8%, common beech 76% and other broadleaves trees 9%. In the managed forests, the average volume of the growing stock was significantly lower – 611.53 m^3/ha (Table II).

Figure 6 shows an almost normal Gaussian distribution, with a slight left-skewed shape, especially in the case of virgin forest. In the virgin forest, the highest volume was recorded in the 61- to 90-cm diameter class, whereas in the managed forest it was recorded in the 31- to 60-cm diameter class, the distribution for the latter showing a lower pick.

As shown in Figure 7, in the case of the virgin forest, common beech was dominant in all diameter classes, whilst in managed forest, silver fir was the

Table III. Abundance of young crops in virgin forest and managed forest.

	Abundance in virgin forest				Abundance in managed forest			
Tree species	Height (cm)		dbh (cm)	Total	Height (cm)		dbh (cm)	Total
	10–50	51–130	< 5		10—50	51–130	< 5	
Silver fir	51	55	82	188	3284	581	303	4168
Norway spruce	677	102	4	783	884	101	202	1187
Beech	27	8	4	39	859	606	936	2401
Sycamore	337	207	8	552	2526	126	101	2753
Ash	1519	70	4	1593	859	202	253	1314
Elm	51	43	8	102	76	25	75	176
Lime	67	121	23	211	0	0	0	0
Rowan	0	0	0	0	682	177	25	884
Total	2729	606	133	3468	9170	1818	1895	12,883

Table IV. Total volume of dead wood in virgin forest and managed forest.

Form of dead wood	Virgin forest Type of decomposition (m^3/ha)			Total	Managed forest Type of decomposition (m^3/ha)			Total
	Freshly d.w.	Rotten	Decomposed		Freshly d.w.	Rotten	Decomposed	
Lying d.w.	0	80.97	22.42	103.39	2.45	2.79	26.22	31.46
Standing d.w.	0	30.09	4.19	34.28	0.09	2.58	0.43	3.10
Broken h > 1.3 cm	0	16.87	0.98	17.85	0	1.96	0.52	2.48
Stump h < 130 cm	0	0.60	0.88	1.48	0.60	1.90	12.98	15.48
Assortment	0	0	0	0	1.14	3.08	4.92	9.14
Total	0	128.53	28.47	157.00	4.28	12.31	45.07	61.66

Note: d.w., dead wood.

dominant species and showed a left-skewed distribution of volume by diameter classes. The higher proportion of silver fir and Norway spruce in managed forests is a clear result of the previous management, which favoured these more economically valuable conifer species compared to beech, as was common practice in many European beech–conifer mixtures (Abrudan 2000). Norway spruce, common beech and sycamore maple were present in almost all diameter classes in the managed forest. Common beech, similar to silver fir, in the managed forest also showed a left-skewed distribution of volume by diameter classes, being present together with ash in almost all diameter classes in the virgin forest.

Juvenile trees

Table III presents the abundance of juvenile crops (dbh < 5 cm) per species and height, per hectare in the virgin forest and managed forest.

In the studied forests, the most common species in the juvenile category were silver fir, sycamore, ash, common beech, Norway spruce and elm. Rowan seedlings were not found in virgin forest because no mature trees were present, whilst lime was present only in the upper standing layer of managed forest.

Amongst the abundance of the juvenile crops, within the virgin forest, ash was the dominant species (55%) in the height class of 10–50 cm, followed by Norway spruce (25%) and sycamore. In the juvenile category, the least represented tree types were common beech, elm and silver fir. Silver fir and sycamore were found in a significantly higher number in the managed forest, with silver fir seedlings accounting for 35% and Sycamore maple for 27%. The least present juvenile crop in the managed forest in the 10–50 cm height category was elm. In the height class of 51–130 cm, this was not so. In virgin forest, the highest number of juvenile crops belonged to sycamore (34%), then lime and Norway spruce and the lowest presence was recorded of common beech. On the other hand, in the same height class in managed forest, the highest number of juvenile crops belonged to common beech (33%) and silver fir (32%), and the lowest presence was for elm. For juvenile crops with the dbh less than 5 cm and the height greater than 130 cm, in virgin forest the highest number belonged to silver fir (62%) and lime (17%), and in managed forest it was common beech (49%) and silver fir (16%). This could be a direct consequence of the close-to-nature approach adopted in managed forest, which favoured common beech and silver fir as the main component species of the local natural forests (Ciancio and Nocentini 2011).

Some of the early reports on Bosnian virgin forests mention competitive interactions between and within tree species. For instance, the observed shade tolerance of seedlings and saplings of *A. alba* Mill. and *F. sylvatica* L. was used to explain their ability to outcompete light-demanding species

Table V. Total volume of living and dead wood in virgin forest and managed forest.

Tree species		Virgin forest Living wood	Dead wood	Total	Managed forest Living wood	Dead wood	Total
Conifers	m^3/ha	105.1	40.9	146.9	451.3	43.9	495.2
	%	71	29	100	91	9	100
Broadleaves	m^3/ha	620.2	116.1	736.3	160.0	17.7	177.7
	%	84	16	100	90	10	100
Total	m^3/ha	725.2	157.0	882.2	611.3	61.6	672.9
	%	82	18	100	91	9	100

(Cermak 1910). These facts were studied and very evident in the investigated virgin forests, where stand structures often differed from those found in managed forests.

Dead wood

The presence of dead wood is important to biological diversity within a forest, and it is a critical factor for the development of particular species like mushrooms, lichens, mosses, arthropods, rodents and birds. On the basis of research focused on optimising tree stand diversity, it has been suggested that the proportion of dead wood in relation to the total wood mass should be around 20–25% (Siitonen 2001; Alexander 2003; Diaci et al. 2010; Keeton et al. 2010) in unmanaged forests. In managed forests that share is much lower, at around 1–10% (Meyer 1999b; Stancioiu and O'Hara 2006).

Table IV shows the structure of dead wood per form of occurrence and type of decomposition, whilst Table V presents the total volume of living and dead wood, by conifers and broadleaves, in both virgin forest and managed forest.

In virgin forest, no fresh dead wood was found due to the absence of any silvicultural operations or recent natural disturbance. The dead wood present was in the form of lying wood (due to wind-throws and parts of broken trees), with rotten dead wood accounting for 81% of the dead wood present. In the managed forest, the most common dead wood was represented by wood left behind after silvicultural interventions (small and even larger branches as a result of felling). It is important to notice that a significant proportion of dead wood (15%) is represented by various wood assortments left in the forest after felling (15%). Other studies in similar forests in Austria and Slovakia describe variation in the rate of dead wood due to disturbance events (Splechtna and Gratzer 2005; Kucbel et al. 2010). In support of this, dendroecological reconstructions of disturbance history in old-growth fir–beech forests in Slovenia and Austria found peaks in the disturbance chronology likely related to past storm events that caused intermediate levels of mortality (Splechtna et al. 2005; Nagel et al. 2007), and direct observations of the storm consequences were made in such old-growth stands (Nagel & Diaci 2006).

Total wood volume in the investigated virgin forest was 882.2 m^3/ha. Of this wood volume, living wood represented 725.2 m^3 (82%) and dead wood accounted for 157.0 m^3 (18%). In virgin forest, 29% of the total conifers volume is represented by dead wood whilst the proportion is much smaller for broadleaves (16%). These volume proportions of dead wood for conifers and broadleaves are close to those described in studies carried out in other European forest reserves (Saniga & Schütz 2001; Christensen et al. 2005; Pasierbek et al. 2007; Müller and Bütler 2010). In managed forest, the total stock of living and dead wood was 672.9 m^3/ha. Of this wood volume, living wood represented 611.3 m^3 (91%) and dead wood 61.6 m^3 (9%).

Conclusion

This study identified that the number of trees in managed forest was significantly higher (almost 2.5 times) than in virgin forest. The distribution of the number of trees, per diameter classes, had a decreasing trend, but with a different shape in virgin forest compared to the managed stands. The distribution of growing stock by diameter classes was different in virgin forest compared to the managed stands; for lower diameter classes (up to 50 cm), the stock volume in virgin forest was half that of the volume of managed forest, whilst for higher diameter classes (over 51 cm), the cumulated volume of the growing stock was two times higher in the virgin forest than in the managed stands. The juvenile crops had a significantly lower presence in virgin forest compared to managed forest (almost four times). Also, the study identified a larger volume of dead wood in the virgin forest than in managed forest. The volume of dead wood in the investigated virgin forest was slightly lower than the volume reported in other similar studies, whilst in the managed forest under the group selection system the proportion of dead wood was similar to the one reported in the existing literature.

Forest structure cannot be considered as static, and natural forest structure cannot be limited to a stable environment (Boncina 2000). Thus, the structure of a forest at any given moment in time is always determined by current environmental factors (including management) as well as of the natural processes underway in the forest (Schnitzler and Borlea 1998; Boncina 1999; Travaglini et al. 2012). The study revealed that the group selection system still had a significant impact on the stand structure and regeneration, compared to virgin forests, and therefore in cases where virgin remnant forest is surrounded by managed forest it might be prudent for the management to let the natural processes dominate and where possible reduce the intervention in the course of forest development.

Notes

1. Email: c.visnjic@sufasa.org
2. Email: solakovic@bih.net.ba
3. Email: f.mekic@sufasa.org
4. Email: balicbesim@yahoo.com
5. Email: mirzad@bih.net.ba

6. Email: s.gurda@sufasa.org
7. Email: florin.ioras@googlemail.com
8. Email: jegaratnasingam@yahoo.com

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