Structure and site potential of fir-spruce forests in Bosnia

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Background and purpose:
Regarding official management prescriptions managed fir-spruce forest stands, among others, in Bosnia are supposed to have all-aged structure. We compared the differences between actual and targeted structure in three fir-spruce stands in central Bosnia with special attention given to volume distribution throughout diameter classes. Therefore the aim of the research is to suggest silvicultural measures in order to achieve "ideal" structure on high potential forest sites.

Material and methods:
Collecting of field data was conducted in three managed fir-spruce stands (*Abieti – Piceetum illyricum*) at Dnolucka planina in central Bosnia. In each of them by one square-shaped sample area (0,25 ha) was set and inventory data were obtained by following standard procedure for permanent sample plots (total inventory). Data processing was performed by applying basic statistical methods.

Results and Conclusion:
It is known that timber overexploitation harms structure of forest stands; on the other hand, as the results in this paper show, scant management intensity doesn't provide "ideal" structure in fir-spruce stands on high potential sites either. Wood volumes obtained from sample plots in the stands range between 720,6 m^3/ha and 976,7 m^3/ha, which is quite above "normal" values established for managed all-aged forest stands, and hence neither of them has all-aged structure but rather some of transitional forms of uneven-aged structure.

Key words:
fir-spruce forest, stand structure, site potential, silvicultural measure

INTRODUCTION

The mixed fir-spruce forests in Bosnia and Herzegovina mostly represent secondary forest communities, i.e. transitory vegetation stage with progressive succession toward climate- regional communities of beech and silver fir with or without Norway spruce (1, 2). Optimization of choice of silvicultural system and skillfulness of its application in the field enable forest stands to develop in the direction of positive natural succession. However, fir-spruce stands often represent ultimate developmental stage due to a number of reasons (disorganized or illegal cuttings in the past, specific topography and soil properties, etc.).

In central Bosnia silver fir and Norway spruce occupy different soil types, while the bedrock is usually composed of limestone. Productivity of uneven-aged forests depends on the range of factors like: tree distribution, soil type, rainfall, light availabilty, etc. Biomass production can be positevely influenced by employing suitable silvicultural techniques with the aim of effective use of site potential, and thereby forest professionals do not pursue stand overstocking with trees of largest size but rather appropriate distribution of trees and volume throughout diameter classes, which provides ecological stability of a stand, high site potential and various structure of merchantable assortments.

Quantitative description of forest stand structure serves as a set of relevant information that forest practitioners use for regulating forest development dynamics and biomass production. Stand structure is often the primary component of the management regime because of its importance in multi-aged stocking control (3). In multi-aged stands, stand structure affects increment (4) and probably also species composition.

Nevertheless data collecting in the field is demanding and expensive, it is concurrently necessary for successful management planning. Once the field data are collected the forest structure can be swiftly and precisely described so that we can efficiently use it for assessment of silviculture influence on wood production.

Regarding that forest management of shade tolerant species (with different levels of tolerance) has „target" to form and maintain all-aged structure, the subject of special interest among forest professionals is the degree of deviation of actual-stand structure elements from „balanced" values that characterize all-aged selection stands.

However, all-aged structure is not only the result of natural processes. It is actually obtained and can be perpetually maintained only by regular and proper selection cuttings (5).

For that reason, all-aged forest cannot be identified with virgin forests as they are the result of nature and selection management (6). From management point of view, it is believed that those fir-spruce forests that have all-aged structure actually have ideal form of managed forest.

Specifically, our research was focussed: (i) to determine site potential of the mixed fir-spruce stands in central Bosnia and structural deviation of analyzed stands from standard equilibrium values, and (ii) to propose the most suitable silvicultural measures in order to achieve „targeted" structure.

MATERIAL AND METHODS

Research was carried out in three forest (sub) compartments 81b, 82b and 82c sitauated at the elevation 1150 to 1250 m within management unit »Dnoluka«, forest management area »Srednjevrbasko« in central Bosnia.

These managed stands cover small areas of 4 to 12 ha each. In terms of phytocoenology the stands belong to the forest community *Abieti – Piceetum illyricum*, and according to eco-vegetation regionalization (1) they are located in the region of inner Dinaric massifs of central Bosnia. The stands fall into the class of high fir-spruce forests on deep brown soils and luvisols on limestone. Their topography is mostly in form of slight slopes (inclination 5° do 15°) with numerous depressions and they are exposed to north and northeast. Climate characteristics were determined by employing the method of Thornthwaite – Mather, and thereby the data from meteorological station in Jajce were used.

Annual climate class for the research area indicates moderate humid climate, while in the vegetation period subhumid wet climate predominates in the area.

In each stand by one square-shaped sample area (0,25 ha) was set and inventory data were obtained by following standard inventory procedure for permanent sample plots.

All trees with dbh above 5.0 cm are noticeably numbered, their diameters at breast height (1,30 m) and heights were measured, and 5 increment cores were taken from each diameter class in order to determine radial and volume increment. Data processing was performed by applying basic statistics with two-dimensional space, where axes represent the variables (X on the horizontal axis and Y on the vertical axis) and appropriate linear and non-linear regression lines (functions). Measured trees are grouped in diameter classes with a span of 5.0 cm. For analysis of radial increment, the number of statistical pairs (X, Y) is equal to the number of diameter classes multiplied by 5.

Tree height lines were constructed using Prodan's growth function (7). Site classes are determined by comparing the resulting height lines with the standardized height lines for silver fir and Norway spruce in Bosnia and Herzegovina, and wood volume by species was determined by using the existing volume tables (8). Volume increment was determined by applying Mayer's differential method (7).

RESULTS AND DISCUSSION

Structural elements of the stands

In the subject stands next structural elements were analyzed: dbh, height, number of stems per unit area, basal area, volume, and radial and volume increment.

Tree heights

Height curves clearly show that Norway spruce has somewhat bigger heights at the same dbh in comparison to silver fir in all subject stands. This regularity also was observed in virgin forests Perućica, Janj and Lom (9).

Table 1 *- Stand structure elements*

Stand structure elements per ha												
Stand	Number of trees			Basal area m^2			Volume m^3			Ann. vol. increment m^3		
	fir	spruce	total	fir	spruce	total	fir	spruce	total	fir	spruce	total
81b	212	312	524	17,9	29,4	47,3	299,3	501,0	800,3	4,0	7,6	11,6
82b	420	352	772	21,0	26,9	47,9	319,8	400,8	720,6	3,5	4,1	7,6
82c	324	216	540	34,8	22,6	57,4	580,5	396,2	976,7	8,3	7,2	15,5

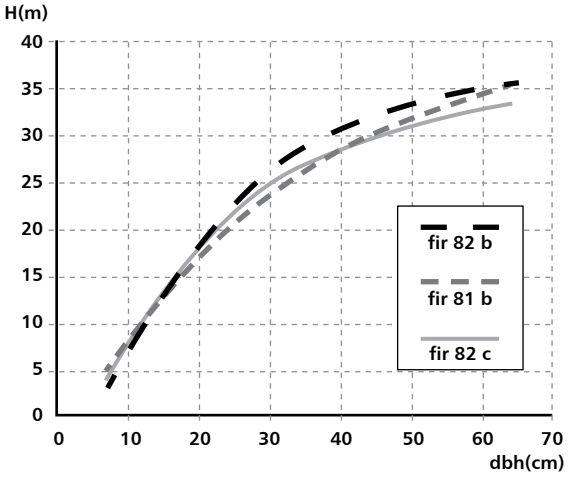


Figure 1 *- Height curves for silver fir*

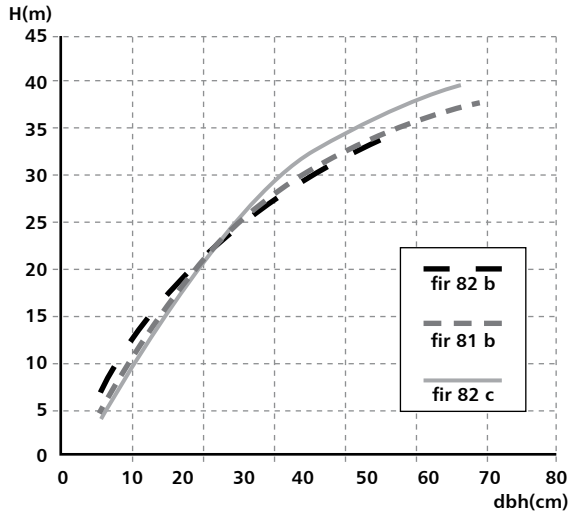


Figure 2 *- Height curves for Norway spurce*

For silver fir subcompartments 81b and 82b represent site class I and subcompartment 82c site class II. There are very suitable conditions for Norway spruce as well since subcompartments 81b and 82c represent site class I and subcompartment 82b provides site class II for spruce.

Tree distribution

Number of trees in a forest stand depends on numerous factors like: site class, canopy closure, composition ratio, management intensity, etc., which makes this element more susceptible to significant variations in comparison to other stand structure elements. In the subject stands tree distributions throughout diameter classes are shown in figures 3, 4 and 5.

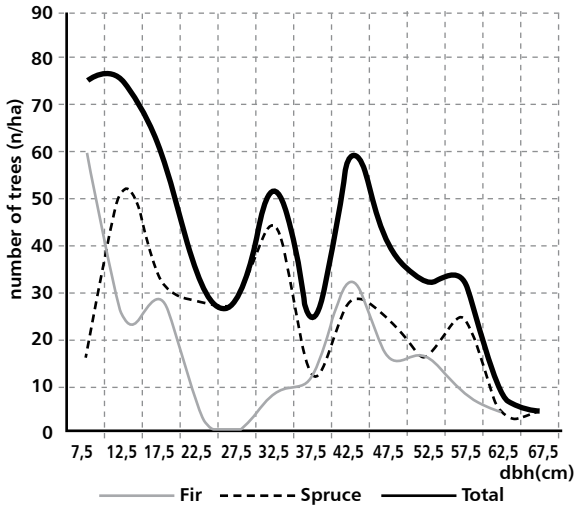


Figure 3
Tree distribution through diameter classes 81b

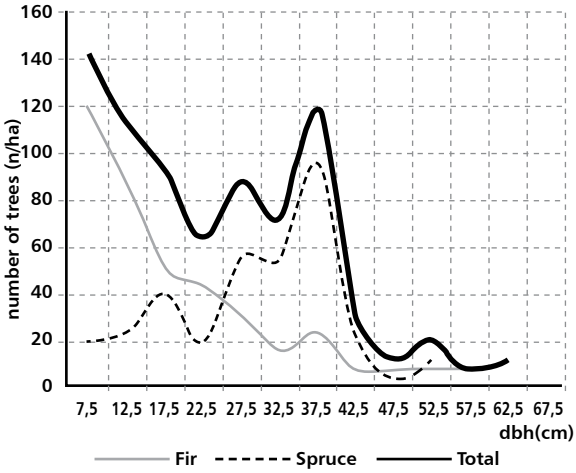


Figure 4
Tree distribution through diameter classes 82b

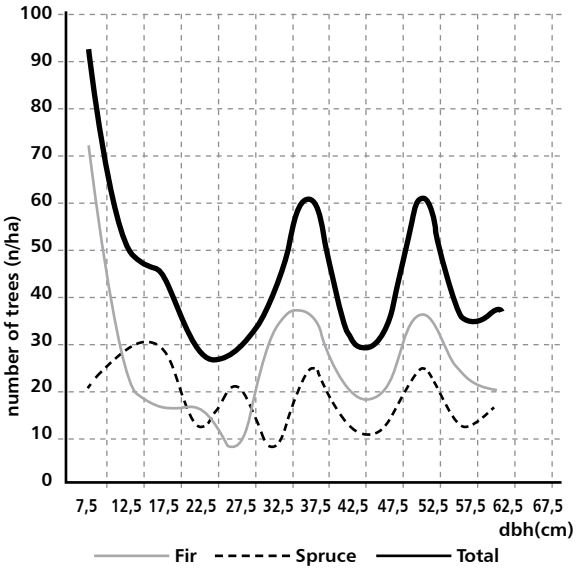


Figure 5
Tree distribution through diameter classes 82c

In the stand 81b Norway spruce predominates with 312 stems/ha or 59,5 %, and silver fir participates with 212 stems/ha or 40,5 %. In another two stands silver fir is more numerous.
In the stand 82b it has 420 stems/ha (54,4 %) compared with spruce that has 352 stems/ha (45,6 %); in the stand 82c silver fir predominates with 324 trees/ha (60 %) in relation to spruce that participates with 216 trees/ha (40 %).
Tree distribution of ideal all-aged forest stands mirrors in the notion that number of trees decreases gradually in form of hyperbola with an increase of diameter classes.
The figures 3, 4 and 5 clearly show that neither of analyzed stands meets the prerequisite to be called "balanced" or "ideal" from management perspective. Generally, we can say that all three stands have uneven-aged structure, but neither has „targeted" all-aged structure.

Basal area and stand volume

Basal area in the stands 81b and 82b is similar and amounts to 47,3 m^2/ha and 47,9 m^2/ha, respectively, while in the stand 82c it has noticeably higher value of 58,4 m^2/ha.
Silver fir has basal area ranging from ranging from 17,9 m^2/ha or 37,8 % (81 b), and 21 m^2/ha or 43,8 % (82 b) to 34,8 m^2/ha or 59,6 % (82 c). Norway spruce has basal area ranging from 22,6 m^2/ha or 40,4 % (82 c), and 26,9 m^2/ha or 56,2 % (82 b) to 29,4 m^2/ha or 62,2 % (81b).
Wood volume in the analyzed stands ranges from 720,6 m^3/ha (82 b) and 800,3 m^3/ha (81 b) to 976,7 m^3/ha (82 c).
Percentage share of silver fir in total volume is smallest in the stand 81b reaching 37,4 % or 299,3 m^3/ha, while in the stand 82c it has largest share with 59,4 % or 580,5 m^3/ha. Consequently, percentage share of Norway spruce is smallest in the stand 82c reaching 40,6 % or 396,2 m^3/ha, and largest in the stand 81b where it predominates with 62,6 % or 501,0 m^3/ha.
Percentage share of volume of silver fir and Norway

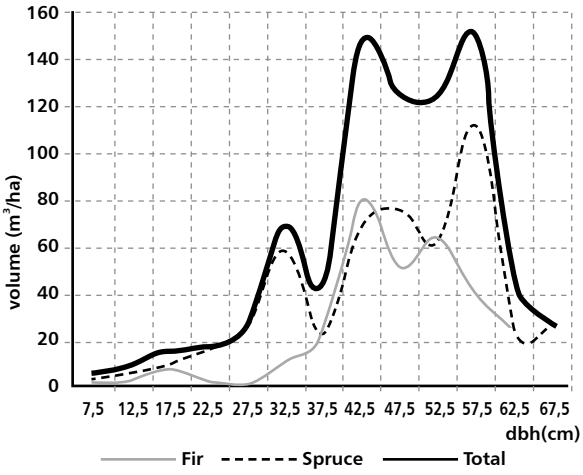


Figure 6
Volume distribution through diameter classes 81b

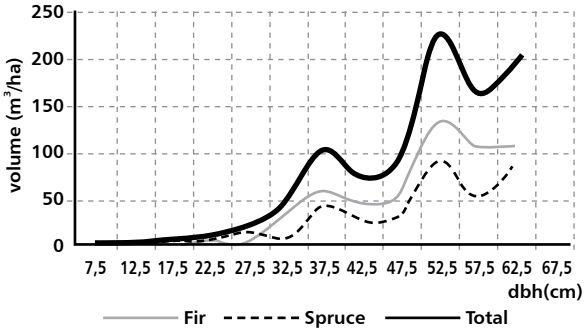


Figure 7
Volume distribution through diameter classes 82b

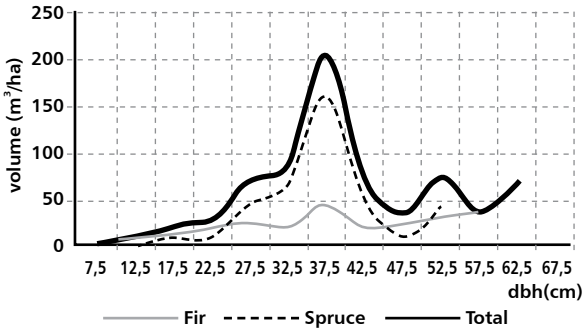


Figure 8
Volume distribution through diameter classes 82c

spruce in the stands 81b and 82c does not differ much from percentage share of tree distribution in the same stands. On the other hand, although the number of silver fir trees is greater from the number of spruce trees in the stand 82b (54,4 % fir : 45,6 % spruce), Norway spruce in total stand volume participates more than silver fir (55,6 % spruce : 44,4 % fir), which comes as a result of very emphasized domination of Norway spruce in diameter class with mid-point 37,5 cm.

Radial and volume increment

Radial increment

Dependence of current radial (diameter) increment on tree diameter is expressed with polynomial function of second order that says:

$$i_d = a + bd + cd^2$$

a, b, c – equation parameters
d – diameter at breast height (cm)
i_d – radial increment (mm)

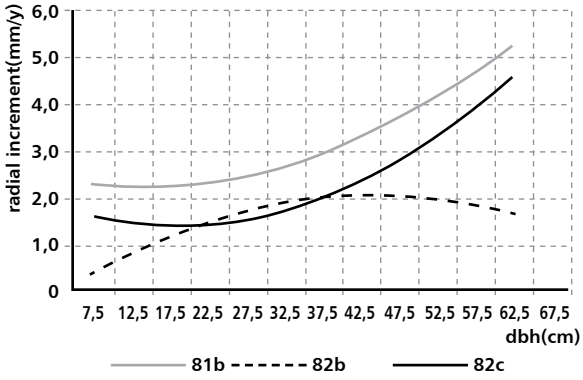


Figure 9
Influence of dbh on current radial increment of fir

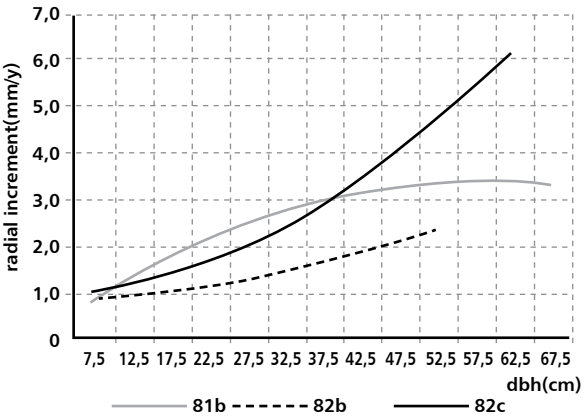


Figure 10
Influence of dbh on current radial increment of spruce

Influence of dbh on current radial increment proved to be statistically significant at p-level 0.05 for both species. Figures 9 and 10 show that both species (except fir in the stand 82b) mostly do not reach the culmination of current radial increment at smaller diameter values.
Values of current diameter increment for silver fir range from 1,4 mm/year to 3,1 mm/year, and for Norway spruce from 1,3 mm/year to 2,9 mm/year. Average current diameter increment amounts to 2,3 mm/year for both species.

Volume increment

Current volume increment in the stands ranges from 7,6 m³/ha (82 b) and 11,6 m³/ha (81 b) to 15,5 m³/ha (82 c). Each year on average silver fir participates with 3,5 m³/ha (82 b) and 4,0 m³/ha (81 b) to 8,3 m³/ha (82 c), while Norway spruce contributes with 4,1 m³/ha (82 b) and 7,2 m³/ha (82 c) to 7,6 m³/ha (81 b). In the stand 82b total number of silver fir trees is bigger

Table 2
Basic indicators of statistical dependence of dbh increment on dbh size

Silver fir						
Stand	**Site index**	**a**	**b**	**c**	**R^2**	**Se (mm)**
81 b	**I**	**2,5478**	**- 0,0377**	**0,0013**	**28,0**	**1,45**
82 b	**I**	**- 0,3212**	**0,1087**	**-0,0013**	**41,5**	**0,60**
82 c	**II**	**1,9449**	**- 0,0586**	**0,0016**	**45,8**	**1,18**
Norway spruce						
Stand	**Site index**	**a**	**b**	**c**	**R^2**	**Se (mm)**
81 b	**I**	**- 0,0709**	**0,1172**	**-0,001**	**33,7**	**1,02**
82 b	**II**	**0,7488**	**0,0037**	**0,0005**	**25,2**	**0,77**
82 c	**I**	**0,3456**	**0,0476**	**0,0007**	**63,5**	**1,30**

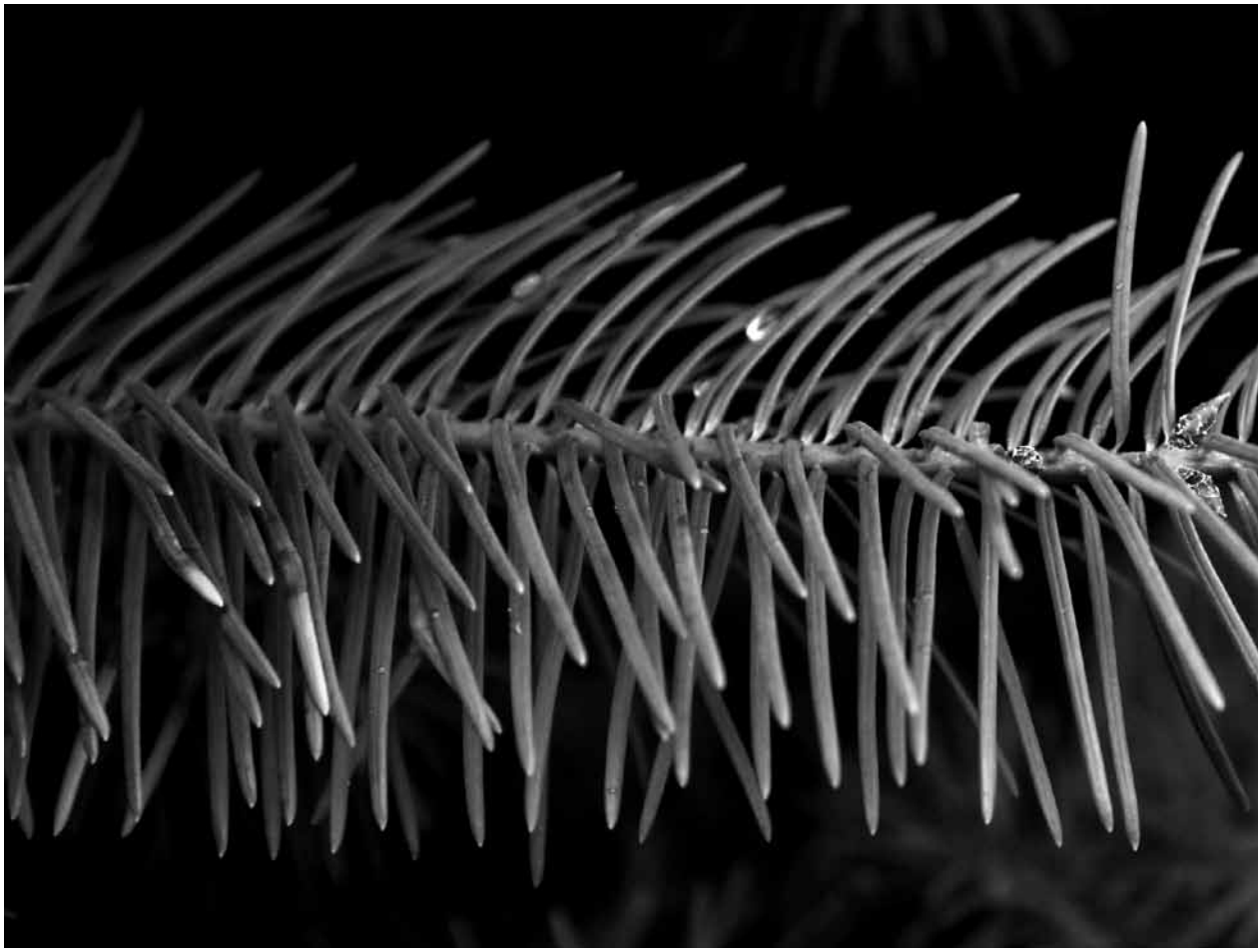
compared with spruce, but spruce is more frequent in diameter classes with mid-points ranging from 32,5 cm to 42,5 cm where maximum intensity of volume increment appears, which led to greater share of spruce in total volume increment in the stand.

Table 3
Targeted structure elements for fir-spruce stands according to current management prescriptions

Tree species	Composition ratio	Canopy closure	Diameter class (cm)					
			5,1 - 10,0	10,1 - 20,0	20,1 - 30,0	30,1 - 50,0	50,1 - 80,0	Total
			m^3/ha					
Silver fir	0,3		3,86	7,65	24,99	61,78	32,5	130,78
Norway spruce	0,6		9,91	17,13	52,5	113,39	50,08	243,01
Beech	0,1		2,26	3,67	9,79	16,85	2,48	35,05
Total	1	0,8	16,03	28,45	87,28	192,02	85,06	408,84

„Normal" volume

For high forests with natural regeneration that are managed by group selection and individual tree selection methods, planning of biotechnical measures relies inter alia on „normal" volume of forest type in the middle of harvesting cycle.
„Normal" or „balanced" volumes for forest types within forest management area „Srednjevrbasko" are calculated by simplified method of determination of normal state in selection forests (10).
Similar wood volumes were determined in small fir-spruce stands of virgin forest type at mountain Zlatar in Serbia (11).
Harvesting prescriptions take into account relationship between actual and "normal" volumes for all



forest types that naturally have uneven- or all-aged structure.
Although fir and spruce are predominant species in the studied stands a certain small ratio of beech is also expected to take part in this forest type.
According to prescribed silvicultural goals beech is considered to be a desirable species if it took part about 10 % (Table 3).
In the studied stands there are only 3 – 4 mature beech trees per hectare, so statistical analysis for beech was not possible. Targeted structure in Table 3 is not given for a particular stand but for the average stand of the fir-spruce forest type.
Rule book in effect for arrangement of management prescriptions for these forests contains next principle: if in a forest stand the actual volume is lower than optimal then harvesting intensity should be lower from volume increment for a given period of time; on the other hand, if the actual volume of a forest stand is greater than "normal" then harvesting intensity can be higher from volume increment for a given period of time, but total wood volume after harvesting operations should not fall below "normal" values at stand and forest type level.

Mere total wood volume, however, is not adequate gauge of stand structure.
Better insight we get when we distribute total volume throughout diameter classes. In well-managed selection forest neither too great nor too small wood volume is desirable.
"Balanced" volume enables intensive regeneration throughout the stand, dynamic ingrowth of juvenile trees in lower and transition to higher stands stories, and more vital trees (12).
Therefore forest managers tend to create a selection stand with optimal volume distribution throughout diameter classes.

CONCLUSIONS

It is known that timber overexploitation harms structure of forest stands; on the other hand, as the results in this paper show, scant management intensity does not provide "ideal" structure in fir-spruce stands on high potential sites either.
Wood volumes obtained from sample plots in the stands range between 720,6 m^3/ha and 976,7 m^3/ha, which is quite above "normal" values established for managed all-aged forest stands, and hence neither of them has all-aged structure but rather some of transitional forms of uneven-aged structure.
The difference between actual and targeted structure should be used to decide how many trees, and of which size, should be removed.
Most suitable silvicultural system for the class of high fir-spruce forest on deep brown soils and luvisols on limestone is group selection system. As of next management cycle silvicultural measures in form of harvesting operations should be intensified and allowable cut should be higher from volume increment for a given period of management (usually 10 years).
Targeted structure of the subject stands, however, does not have to be achieved in one-time harvesting cycle. Final desicion on how to conduct the transition from overstocked to „normal" forest stands also needs to be brought in agreement with scientific experience from applied forest ecology for a given forest type.
Regarding stand mixture beech proved to be endangered species in the studied stands. Therefore, it would be justifiable at least from ecological point of view, that silvicultural measures help beech regeneration to grow around individual beech trees within current fir-spruce stands so that beech as an inherent species can take greater part in the future stand mixture.
In future planning of silvicultural activities some breakdown within forest type might also be useful, for instance, if different targeted values for fir-spruce stands on different site classes be determined rather than base their management on the structure of average forest stand of the forest type.

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