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THE ESTABLISHMENT AND PRESERVATION OF A BALANCED STRUCTURE OF BEECH-FIR STANDS

MOGUĆNOSTI USPOSTAVE I OČUVANJA URAVNOTEŽENE STRUKTURE JELOVO-BUKOVIH SASTOJINA

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Beech-fir forest management in Croatia is currently faced with problems of irregularly structured stands. This is manifested in a considerable proportion of mature trees of large dimensions, poor increment, the non-existence of vertical structure and the absence of satisfactory and permanent natural stand regeneration. The characteristics of such structures show similarity with virgin forests in their terminal stage. On the assumption that a balanced selection structure may only be achieved with intensive and systematic management, the goal is to highlight the relationship between management and stand structure "development". Based on the conducted and published research dealing with concrete forest sites of fir and beech, the following elements of planning the management and structure of irregularly structured fir-beech stands are discussed:

1. The disappearance of a selection structure and the accumulation of the growing stock of large trees with diameters over 70 cm during the past 50-year period resulting from prescribed and applied low-intensity cutting operations;
2. The applicability of the prescribed cut form (based on the difference in the growing stock before and after the selection cut and the rate of curent annual volume increment), which is questionable in conditions of excessive growing stocks and low rates of current annual volume increment;
3. The transition time, recruitment and structure of regeneration as an indicator of the currently disrupted stand structure;
4. Predictions of planned intensity and structure of selection cuts, recruitment (stand regeneration) and "development of stand structure during future cutting cycles, which indicate the need for cuts of higher intensity

(over 25%) in the initial cutting cycle and gradual improvement of the disrupted selection structure; and

5. The results that indicate the negative effect of basal area of fir and beech trees with diameters exceeding 50 cm on natural fir regeneration, as well as the occurrence of natural young growth of regenerated fir (developmental stage of young growth) 5 years after the selection cut of stronger intensity (24%).

Key words: silver fir, common beech, disturbed selection structure, selection cutting intensity, increment.

INTRODUCTION AND PROBLEM
UVOD I PROBLEM

The characteristics of a single-storied structure of the majority of stands in Croatian beech-fir forests, which show similarity with virgin forests in their terminal stage (Korpel 1996), may point to insufficiently intensive planning and management with selection forests. However, the predominance of mature trees of large dimensions, the absence of vertical structure, poor increment, tree dieback and the absence of satisfactory and permanent natural stand regeneration are the consequence of management failures, unfavourable climatic impacts and pollution (Matić et al. 1996), but also of different approaches to forest management through history caused by complex interactions of social, economic and ownership attitudes towards the forest (Božić 2001, Božić 2003, Kalafadžić et al. 1989, Kušan et al. 1994).

In terms of the importance of selection management for Central European forestry (Shütz 1989, 2001, O'Hara 2002), problems of fir dieback, tree species conversion, changed structure and absence of natural regeneration (Čavlović 2000, Korpel 1996, Bončina et al. 2002) pose special challenge to forest planning and management.

Intensive planning and management is based on prescribing annual yields as the necessary framework for the application of silvicultural treatments and appropriate scheduling of selection cut with regard to spatial and structural stand features. According to the ŠGOP (2006) data, the growing stock of fir in the amount of 28.13 million m^3 increased by 1.91 % in 1996. However, the 10-year felling volume (1996 – 2005), which was only 64.2 % of volume increment, shows an extensive approach to planning. The increment volume of 77.1 % indicates the need for more intensive management, which was limited by a regulation (20 % maximal deviation). Partly in connection with these data, the fir growing stock of 27.8 million m^3 increased by only 1.76 % in 2006. To meet the need for more intensive management, the felling volume of 106.0% of volume increment has been planned for the 2006 – 2015 cutting cycle.

Assuming that in conditions in which cutting is lower than the increment, management has all the features of a virgin forest and that the percentage of increment

as a direct indicator of a disturbed structure cannot be used as the key element for planning the prescribed yield, this paper aims to confirm these assumptions by comparing the structural elements of sample forests and research conducted on the relationship between the elements of management planning and stand structures.

MATERIAL AND METHODS
MATERIJALI I METODE

In order to compare and define the indicators of a disturbed structure and the elements of management planning (felling as the necessary framework for the application of management procedures), a mixed theoretical model of fir and beech was used in the second site class for fir. The mixture ratio was 80 and 20% of the total growing stock (399 m³/ha). Two forests (management classes) of fir and beech in the sites corresponding to the second site class for fir were taken as examples of a preserved selection structure on the one hand and a disturbed selection structure on the other.

The management class *Uneven-aged forests of fir, spruce and beech II* within the management unit of Bunarić (Management plan for MU Bunarić 2003) consists of 17 stands covering an area of 994.15 ha. The average growing stock per ha is 412 m³, of which fir and spruce account for 72% and beech and other broadleaves for 28%. The distribution of growing stock per diameter classes (thin, medium large, large tree) is almost theoretical (42 % of the growing stock of large trees). The current annual volume increment is 11.24 m³/ha, which corresponds to the annual increment percentage of 2.73 %. Over the past periods, management has been characterized by intensive selection cutting organized and performed by wood-industrial companies.

Stands showing a disturbed selection structure are situated within the management unit Belevine (*Uneven-aged seed forests of fir II*) over a total area of 266.24 ha (18 stands). Of the total growing stock of 476 m³/ha, fir and spruce participate with 78 % and beech and other broadleaves with 22 %. The share of the growing stock of large trees of 74 % in relation to the total theoretical growing stock indicates a disturbed stand structure. The stands increment by only 1.67 % or 7.97 m³/ha annually. Starting from 1870, management was characterized by the formation of pure coniferous stands of even-aged structure during the 70-year period. In the last 50 years, management with the group selection cut method has been applied (Čavlović 2000).

The following elements of the theoretical structure and annual cut were obtained from the mixed theoretical model; the participation of the growing stock of large trees (>50 cm), current volume increment, the percentage of current volume increment, the average transition time of stands (forest), recruitment, volume and the structure of selection cutting. These elements were juxtaposed with the sample (investigated) forests.

The ratio between the growing stock of large trees and the total theoretical growing stock, and the percentage of annual current increment at the level of individual stands were taken as indicators of a disturbed selection structure. An interaction was investigated between the percentage of volume increment and the participation of growing stock of large trees, and the volume increment and the structure of growing stock within groups of stands in the sample forests.

The applicability of the prescribed cut form (Eq. 1) (based on the difference in the growing stock before and after the selection cut and the rate of curent annual volume increment) was investigated on the example of the representative stands.

$$E = M \times \left(1 - \frac{1}{1{,}0p^{l}}\right) \times f \qquad (1)$$

where M – growing stock of the stand immediately before the cut; p – annual percentage of the current volume increment; l - cutting cycle; f – relationship between the actual and the theoretical growing stock of the stand.

Interactions of elements of a disturbed structure, stand regeneration, cutting structure and intensity, as well as predictions relating to the establishment of a theoretical stand structure were analyzed and discussed on the basis of some published research results.

RESULTS AND DISCUSSION
REZULTATI S RASPRAVOM

The survey and comparison of basic structural elements (Table 1) relating to growing stock distribution per diameter classes, current volume increment and increment percentage, average transition time and recruitment show the extent to which the average structure of fir-beech stands in the MU Bunarić is close to the theoretical one. On the other hand, deviation of the growing stock and its distribution per diameter class from the theoretical structure, the low increment percentage and the high average transition time indicate a disturbed structure of the stands in the MU Belevine. This results in poor stand regeneration, which is indicated by the recruitment of only 4 trees per year per ha.

Sustaining a permanently balanced structure is based on permanent stand regeneration, or the felling of mature trees, which, according to Table 1, amounts to about 50 % of the growing stock of large trees. Can this relationship also be valid in conditions of a disturbed structure as long as the cutting volume plan is within the maximal allowed cutting intensity?

The percentage of the current volume increment can in this context be taken as a direct indicator of the stand's condition, which is caused by its structure. Figure 2 shows the dependence of the percentage of annual current increment on the participation of growing stock of large trees at the level of particular stands for the two forests under study. Disaggregate in the percentages of annual increments of the two groups of stands (forests) coincides with the level of 2 % annual percentage of

Table 1. Comparison of structural elements of the studied fir-beech forests and mixed theoretical model
Tablica 1. Usporedba osnovnih elemenata strukture istraživanih bukovo-jelovih šuma i mješovite normale

			Normal model	MU Bunarić	MU Belevine
Growing stock (m^3ha^{-1}) *Drvna zaliha*		10 - 30 cm	87.0	84.0	50.5
		31 - 50 cm	181.1	159.0	130.5
		> 50 cm	131.1	169.0	295.2
		Total	399.2	412.0	476.2
$V_{>50}/V_N$			0.328	0.423	0.739
Current annual increment *Godišnji tečajni prirast*		m^3 ha^{-1}	11.80	11.24	7.97
		%	2.96	2.73	1.67
Transition time *Vrijeme prijelaza*		year	10.30	10.50	16.00
Recruitment *Priliv*		trees $yr.^{-1}$	14.70	14	4
10-yr. cut *10. god. sječa*	Total / *Ukupno*	m^3	118.0		
	Mature cut / *Zrela stabla*	m^3	66.6		

current increment and indicates considerable differences between the two forests, as well as deviations from the theoretical selection structure. Lower increment percentages of the stands in Belevine in the range of equal rate of large tree growing stock (45 – 65 %) point to generally poorer conditions of increment in the forest of Belevine (stunted trees). It may be concluded that a 2-percent annual decrease in the increment is a direct indicator of a disturbed stand structure.

The negative correlation of the dependence of annual current increment percentage on the participation of growing stock of large trees is clearly visible, which is more distinct within the forest with a preserved stand structure.

The percentage of the annual current increment is an element which is directly used in practice in the formula for planning the prescribed cut (Eq. 1) at the selection stand level. Figure 2 shows a comparison between the representative stands of two sample forests.

According to the basic structural indicators (growing stock, proportion of large tree volume, increment) the stand within the MU Bunarić is very close to the hypothetical selection structure (Figure 2a). By maintaining the current level of regeneration and volume increment, an optimal number of medium large trees may be achieved relatively rapidly. The prescribed cut, which is at the level of normal cutting intensity of 25 %, will be sufficient to achieve this goal.

On the other hand, according to Figure 2b, the structure of the stand in the MU Belevine may be declared significantly disturbed and far from a hypothetical selection structure. With considerable growing stock and proportion of mature volume (92 % of the normal volume), and the percentage of annual increment of only 1.54 %, the prescribed cut was calculated according to the Formula 1 that is identical to the first stand and that is at the level of the normal prescribed cut. Although the prescribe cut form contains the relationship between the actual and the theoretical

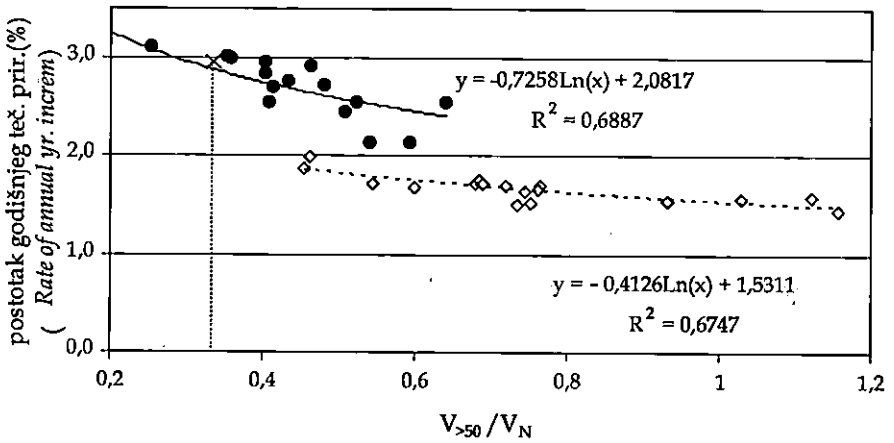

Figure 1: Rate of annual current volume increment and large tree volume proportion dependency. Ringlet and solid line – m.u. Bunaric. Rhombs and broken line – m.u. Belevine.Crosses and broken vertical line – the theoretical model.

Slika 1. Ovisnost postotka godišnjeg tečajnog prirasta i udjela drvne zalihe debelog drva. Kružići i puna linija-gj Bunarić. Kvadratići i crtkana linija-gj Belevine. Križić i crtkana uspravna linija-normala.

growing stock (growing stock exceeds the normal one by 36 %), due to low increment percentage the 10-year cutting intensity is only 19 %.

The ten-year normal prescribed cut of 112 m³ per ha is sufficient to maintain a balanced selection structure. On the other hand, this prescribed cut in the stands with a disturbed structure does not guarantee more intensive stand regeneration, tree increment and the establishment of the selection structure. For this reason, the application of this prescribed cut form is questionable when the relationship between the structural elements in the stand are disturbed (Čavlović et al., 2006b).

The application of the theoretical rate of cutting as a method of determining the prescribed cut is more appropriate in this case. Starting from the normal annual increment percentage of 2.96 % (Table 1), the prescribed cut of 172 m³ per ha would be adequate for the 10-year cutting intensity of 29.6%, which is an increment of as much as 216 %. As it is certain that the entire or almost entire prescribed cut would relate to mature tree felling, or the regeneration of the stand in compartment 2 of the MU Belevine, over 40 % of the mature volume would be affected by cutting. This corresponds to the relations within a balanced selection structure (Table 1).

According to Čavlović et al. (2006b), the prescribed and accomplished 10-year cut in the management unit Belevine in the period 1950 – 2000 was about 17 % and reached the increment level of 114 %. However, the proportion of mature tree growing stock in relation to the total growing stock (total normal growing stock) constantly grew from 44 (52) to 61 (70) %, while stand regeneration was increasingly poor. This confirms the conclusion that intensities below 20 % (the application of the formula of volume difference before and after cutting based on the concrete percentage of annual current increment) are not suitable when structural relation-

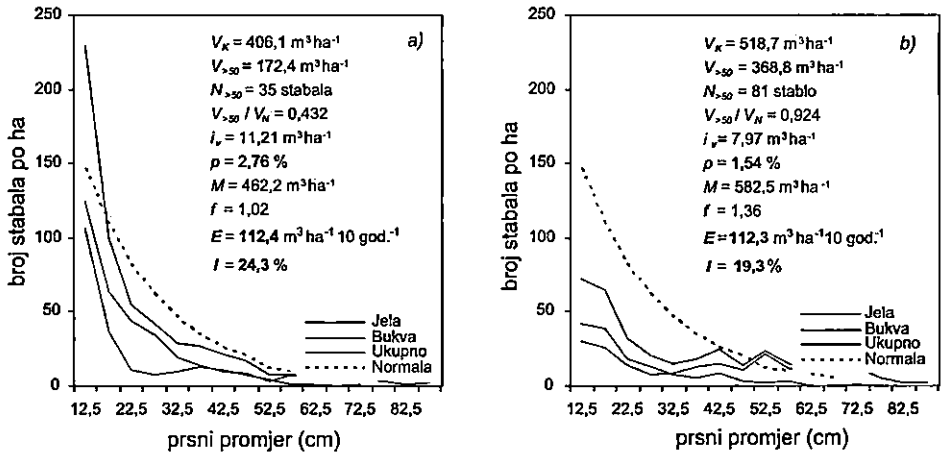

Figure 2: Diameter-class structure endprescribing cut elements for the two representative stands. a) sub-compartment 49a, m.u. Bunaric. b) compartment 2, m.u. Belevine.

Slika 2. Prikaz debljinske strukture i elemenata određivanja sječivog prihoda za dvije reprezentativne sastojine. a) odsjek 49a, gj Bunarić. b) odjel 2, gj Belevine.

ships within a stand are disturbed. Božić (1999) and Klepac (1997) also point to the trend of growing proportions of large tree volume in selection forests of Gorski Kotar.

High transition times expressed with a low increment percentage and excessive loss of transition time within a diameter class indicate a disturbed structure in terms of different conditions of fir tree growth (Čavlović et al. 2006b). In such conditions, a large number of fir trees with poor increment (stunted trees) are found in all diameter classes. Improving and balancing the conditions of fir tree increment, which is mutually dependent on regeneration and the normal selection structure, is one of the requirements to be fulfilled by future intensive approach to management.

The poor condition and structure of fir regeneration correlates directly with the proportion of large trees. Correlation analysis of the impacts of basal area of a particular part of fir and beech stand on the occurrence of the seedlings, saplings and poles of fir and beech confirmed positive correlation between the basal area of thin trees of both fir and beech on the occurrence of saplings and poles. On the other hand, the statistically considerable negative impact was confirmed of the basal area of large fir and beech trees on the occurrence of their saplings and poles. The negative impact of the basal area of large beech trees on the occurrence of the young growth, saplings and poles of fir was particularly distinct (Čavlović et al., 2006b). Such results indicate the necessity of applying cutting treatments in a particular part of a stand so as to encourage and maintain stand regeneration.

Figures 3 and 4 show predictions of fir-beech stands with a disturbed structure on the basis of a continued dynamic model system (CDMS) of the selection stand (Čavlović 1999) based on the assumptions of cause-consequence effect between cutting the mature growing stock and intensifying regeneration and increment.

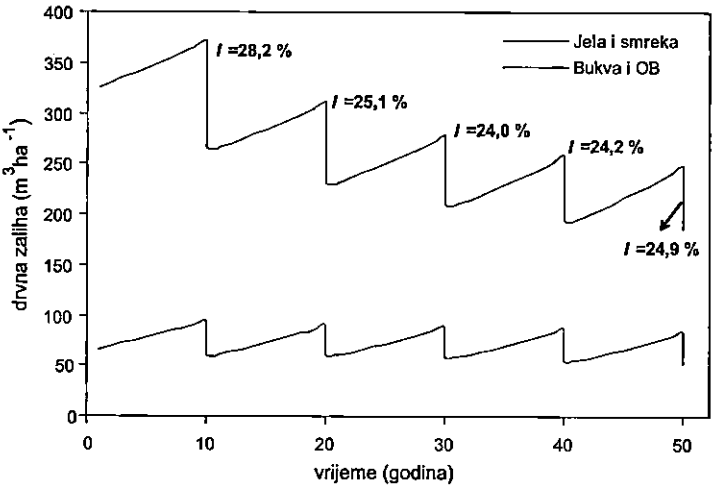

Figure 3: Prediction of growing stock development in the Belevine research site for the next 5 cutting cycles. I means 10-year cutting intensity. (according to Čavlović et al. 2006a)

Slika 3. Projekcija drvne zalihe (m^3 ha^{-1}) prosječne sastojine u gj Belevine tijekom budućih 5 ophodnjica. I je intenzitet 10-godišnje sječe. (prema Čavlović i dr. 2006a)

The prediction of trends in the growing stock (Figure 3) shows considerable decrease in the fir growing stock, especially during the first two cutting cycles. At the end of the first cutting cycle, double increment should be cut with a cutting intensity of 28 %. This coincides with the prescribed cut determined by the method of theoretical rate of cutting on the example of compartment 2 in the MU Belevine. A decrease in the fir growing stock during the first two cutting cycles is based on cutting large-dimension trees and establishing favourable conditions for more intensive regeneration and tree incrementing. However, even after this, the cutting intensities do not fall below 24 %. At the end of the fifth cutting cycle, the total growing stock should be reduced to the bottom critical level of 280 m^3 ha^{-1}, after which a gradual increase in the growing stock might be expected.

Such a cutting scenario is expected to have a positive impact on the development of a stand's diameter structure. However, a shift in approaching the diameter stand structure to the hypothetical one over the 50-year period still seems insufficient (Figure 4).

According to research by Čavlović et al. (2006b), positive impacts were observed of higher intensity cutting (24 %) in relation to the previous ones ranging around 17 %. The structure of stand regeneration 5 years after cutting in relation to the structure of regeneration before cutting is given in Table 2.

A multiple increase in the number of plants/ young trees is evident for all the three developmental stages. The number of germinants is significant as it represents the potential for the developmental stage of small seedlings. The most important is an increase in the number of small seedlings, which is 15 times higher for the fir

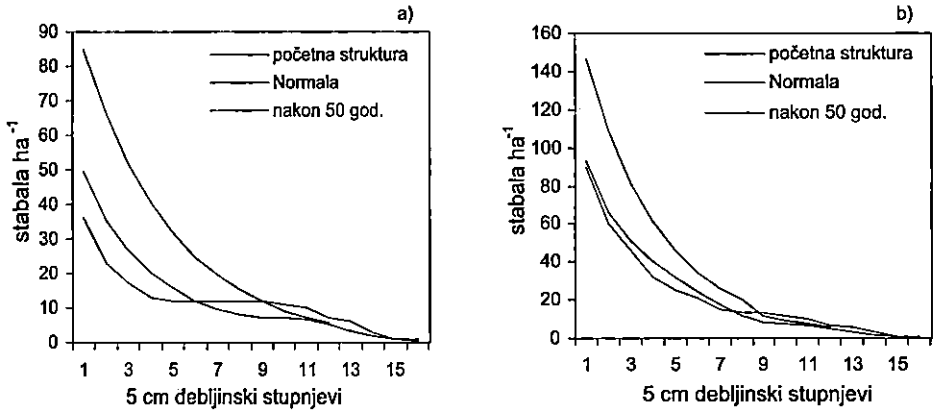

Figure 4: Observed and predicted development of diameter distribution of Belevine research forest at the end of the 50-year period in relation to the hypothetical structure: a) Silver fi and b) Total. (according to Čavlović et al. 2006a)

Slika 4. Početna i projektirana debljinska struktura na kraju 50-godišnjeg razdoblja prosječne sastojine-gj Belevine u odnosu na normalnu strukturu: a) Jela i smreka i b) Ukupno. (prema Čavlović i dr. 2006a)

compared to the situation immediately before cutting. This is a direct indication of positive impacts of the 24 % cutting intensity and distinct stand regeneration.

Table 2. Review of young tree structure according to classes and tree species just before cutting and 5 years after cutting. (according to Čavlović et al. 2006b)

Tablica 2. Prikaz strukture obnove prema klasama i vrsti drveća neposredno prije sječe i 5 godina nakon sječe. (prema Čavlović i dr. 2006b)

Tree species *Vrsta drveća*	Young tree classes (number of plants/trees per ha) *Klase mladog naraštaja (broj biljaka/stabalaca po ha)*					
	Germinants *Ponik*		Small seedlings (≤ 0,3 m tall) *Pomladak (≤ 0,3 m visine)*		Tall seedlings(>0,3 ≤ 1,3 m tall) *Pomladak (>0,3 ≤ 1,3 m visine)*	
	1999.	2005.	1999.	2005.	1999.	2005.
Silver fir / *Jela*	1872	8609	317	4956	2	651
Beech / *Bukva*	0	579	136	2948	0	1076
Total / *Ukupno*	1872	9188	452	7903	2	1727

CONCLUSION
ZAKLJUČAK

Lack of intensive planning in the management with beech-fir forest, which is based on the prescribed cut as a sufficient and necessary framework for the application of regeneration and tending treatments, leads to a disturbed stand structure and processes similar to those in a virgin forest (accumulation of growing stock, cutting/ mortality lower than the increment, falling quantities and qualities of increment, degradation of increment, delay stand regeneration). Permanent maintenance of a theoretical selection structure based on cutting the normal increment is a prerequisi-

te for systematic and consistent forest planning and management. This requirement is even more important and complex in re-establishing the already disturbed stand structure. A low percentage of the annual current volume increment is a good indicator of disturbed relations in the stand structure and the intensity of planning and management in beech-fir forests, but is inadequate as an element for determining the prescribed cut, which leads to low intensities of selection cutting (less than 19 %). To plan the quantity and structure of the prescribed cut, it is more advisable to start from the relationship between the elements of the theoretical structure, theoretical increment percentage (rate of cutting), and even the maximal allowed intensity of selection cutting. This will provide a good basis for intensive management with beech-fir stands.

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MOGUĆNOSTI USPOSTAVE I OČUVANJA URAVNOTEŽENE STRUKTURE JELOVO-BUKOVIH SASTOJINA

SAŽETAK

Gospodarenja bukovo-jelovim šumama u Hrvatskoj je danas suočeno dijelom sa sastojinama nepravilne strukture, koja se očituje u značajnoj zastupljenosti zrelih stabala velikih dimenzija, slabom prirastu, nepostojanju vertikalne strukture i u izostanku zadovoljavajuće i stalne prirodne obnove sastojina. Obilježja takvih struktura upućuju na sličnost s prašumom u njenoj terminalnoj fazi. Uz pretpostavku da se jedino intenzivnim i sustavnim gospodarenjem može trajno podržavati uravnotežena preborna struktura, cilj je istaknuti postojanje veze između gospodarenja (propis i izvršenje intenziteta i strukture prebornih sječa) i „razvoja" strukture sastojine. Na temelju provedenih i objavljenih istraživanja na konkretnim šumskim objektima jele i bukve, razmatraju se sljedeći elementi planiranja gospodarenja i strukture jelovo-bukovih sastojina nepravilne strukture:

1. Nestajanje preborne strukture i gomilanje drvne zalihe krupnog drva promjera iznad 70 cm tijekom prošlog 50-godišnjeg razdoblja kao posljedica propisanih i izvršenih sječa niskih intenziteta;
2. Primjenjivost obrasca razlike drvne zalihe prije i poslije preborne sječe temeljenog na postotku godišnjeg tečajno volumnog prirasta za planiranje etata, koja se pokazuje upitnom u uvjetima velikih drvnih zaliha i malog postotka godišnjeg volumnog prirasta;
3. Vrijeme prijelaza, priliv i struktura obnove kao pokazatelji postojeće narušene strukture sastojina; predikcija planiranog intenziteta i strukture prebornih sječa, priliva (obnove sastojine) i „razvoja" strukture sastojine tijekom budućih ophodnjica, koja u međuovisnom dinamičkom sustavu ukazuje na potrebu za sječama jačih intenziteta (preko 25 %) u prvim ophodnjicama i na polagano popravljanje narušene preborne strukture;
4. Rezultati koji ukazuju na negativan utjecaj temeljnice stabala jele i bukve većih od 50 cm promjera na prirodnu obnovu jele, kao i rezultati pozitivnog reagiranja preborne sastojine prirodnom obnovom jele (razvojni stadij podmladka) 5 godina nakon preborne sječe jačeg intenziteta (24 %).

Ključne riječi: jela, obična bukva, narušena preborna struktura, intenzitet preborne sječe, prirast.