Quality and Timber Value of European Beech (*Fagus sylvatica* L.) Trees in the Karavanke Region

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Abstract – Nacrtak

The paper studies the quality of beech trees in the Karavanke mountain range. The data obtained for this study came from the permanent sample plots (here in after PSPs) of the studied area. The timber assortment structure of mature beech trees in stands was calculated on the basis of the estimated quality of a total of 7,154 beech trees from 2,088 plots and a small sample of harvested trees. The established timber assortment structure and the prices of timber ex forest road were then used to determine the value of beech wood. The study showed that the assortment structure was extremely unfavorable, with the share of trees with sliced and peeled veneer quality lower than 1%, and the share of sawlogs totaling 1.6% of the net volume of analyzed trees. The quality is highest in beech trees measuring 50–55 cm in diameter at breast height. Quality values were higher in rejuvenation stands, and in stands with a comparatively high share of fir or a low share of conifers (spruce). The value drops with altitude and inclination and is higher on slope sites. Undamaged trees from higher social layers are also more valuable. Furthermore, beech timber value is positively affected by high harvesting intensity. In dense stands with a basal area exceeding 60–65 m^2/ha, the value begins to decline. In order to improve the quality structure of beech stands, beech would have to be grown in beech-dominated clusters or stands, and thinned at the correct time. Particular attention needs to be paid to minimize the damage to dominant trees during harvesting. Quality assessment carried out within the forest inventory enables to assess the stand quality and value potential of forests at different spatial scale. The research has highlighted several possibilities to use quality data in connection with other parameters to enhance the efficiency of forest management.

Keywords: European beech, stem quality, assortment structure, timber value, influential factors, the Karavanke range

1. Introduction – *Uvod*

European beech (*Fagus sylvatica* L.) is one of the most common tree species in Europe (Ellenberg 1986). In Slovenia, beech is present on almost 89% of total forest area. With the share of growing stock greater than 50%, it occupies merely 25% of total forest area (Ficko et al. 2008). In the Alpine territory, beech has been generally recognized as an economically less valuable species since the beginning of forest management. Beech wood was used as firewood and as raw material in charcoal-making (Veber 1986). There were also several attempts to replace beech with more profitable conifers, in particular spruce (Johann 2006). In Slovenia, the distribution range of beech has been declining for centuries; however, in the recent decades its distribution range and abundance increased (Poljanec et al. 2010), predominantly as a result of changed forest management concepts (Mlinšek 1968) and natural disturbances (e.g. windthrow and insect attacks) resulting in a decreasing proportion of conifers (mainly spruce).

With increasing abundance of beech and the changing role of beech timber, however, the beech management measures in the Alpine territory should be determined in detail. Such an investigation requires various types of information, including the data on the quality structure of forest stands, wood value characteristics of tree species, and the factors influencing wood value.

Such information is required to define forest management goals and silvicultural objectives, determine the harvest maturity of trees and stands, and decide on the intensity and frequency of various forest management measures. Moreover, it is important to consider these data in assessing the value of forest stands, in optimizing yields and in determining the expected economic effects (Rebula and Kotar 2003).

The quality and value of beech trees have been the subject of several studies in Slovenia and abroad (e.g. Petráš and Nociar 1991; Rieder 1997; Gfeller 1998; Krpan 2003; Kadunc 2006; Prka 2010). Most of these focused on the average quality (Petráš and Nociar 1991) and value (Omahen 1998; Prka 2003a) of trees in certain harvesting sites and on the factors influencing beech quality and value (e.g. Rebula and Kotar 2003). Numerous studies investigated the occurrence of heartwood discoloration in beech, the factors behind this defect (Knoke 2003; Prka 2003b; Kadunc 2006), and the impact of heartwood discoloration on the value of harvested trees (e.g. Šmajdek 2001). The research into the quality and value of standing trees and beech stands (e.g. Rebula 2005) has been less frequent. Normally, such studies are based on timber quality assessments of standing trees from various research plots (Pirc 1997) or on the assessments of the quality of trees measured during forest inventories (Rebula 2005; Čavlović 2010, Rebula 2011). The first approach, based on the stem analysis of a small sample of harvested trees, is destructive; however, it gives very accurate results, and enables an appropriate determination of internal stem defects. The second approach, which is based on the assessment of standing trees during a forest inventory, is non-destructive and, normally, representative for larger areas. In this paper we combine the strengths of both presented methods in order to improve the quality assessments at PSPs. Therefore the quality assessments from PSPs were improved with a detailed analysis of the quality obtained from a small sample of harvested trees in comparable sites (Kadunc and Poljanec 2011).

Apart from the methodology developed within the framework of this research to estimate the timber assortments of standing trees from PSPs, the primary aim of the study was:

⇒ to analyze the quality and value-based structure of beech trees and stands,

⇒ to develop models to examine the mutual influence of tree, stand, site, and forest management variables on the quality and value of standing mature beech trees in the Karavanke region.

The Karavanke mountain range was chosen due to its geological diversity (Buser 1991) and because the Karavanke mountains are high enough to cover the complete range of altitude and soil gradients in which beech constitutes an important or even a dominating share.

2. Materials and methods – *Materijal i metode*

2.1 Study area – *Područje istraživanja*

The Karavanke is a mountain range which stretches west-east for 120 km from Tarvisio, Italy to Slovenj

Fig. 1 Location of the study area and distribution of PSPs

Slika 1. *Područje istraživanja i distribucija trajnih pokusnih ploha (TPP)*

Gradec, Slovenia (Fig. 1). The study area is characterized by a considerable diversity of relief and geological composition. The altitude of the forest area ranges from 400 m to 1,900 m above sea level. The area belongs to the alpine continental climate zone, but local climatic conditions can change rapidly as a result of varied terrain. The temperature extremes vary according to the relief, with the lowest temperatures between –24°C and –21°C, and the highest between 25°C and 32°C (ARSO 2004a). Precipitation decreases from west to east. The western part of the Karavanke receives up to 3,600 mm in precipitation, whereas the lower-lying areas of the eastern part receive only 1,300 mm (ARSO 2004b). Karstic terrain and clastic sedimentary rock cover most of the territory, while the presence of felsic, igneous and various metamorphic rocks is sporadic.

Forests cover 82% of the total study area (Fig. 1). They are characterized by a small-scale system management, using irregular shelterwood and group systems. The mean growing stock amounts to 322 m^3/ha. There are 38 different tree species recorded in the study area; Norway spruce (*Picea abies* Karst.) (66%) and European beech (16%) account for the highest proportion of growing stock, followed by European larch (*Larix decidua* Mill.) with 6% (SFS 2010b). The zonality of forest vegetation in the Karavanke is quite clearly defined due to distinctive orographic factors, different soil substrata and climatic conditions. According to the terminology used in forestry practice (Kutnar et al. 2012), the forests with beech in the study area could be classified into 12 forest types: *Adenostylo-Fagetum, Anemone-Fagetum, Arunco-Fagetum, Castaneo-Fagetum, Luzulo-Fagetum, Ostryo-Fagetum, Hacquetio-Fagetum, Homogyno-Fagetum, Aceri-Fraxinetum, Aposeri-Piceetum, Bazzanio-Abietetum* and *Pinetum subillyricum.*

2.2 Data collection and statistical analysis
Prikupljanje podataka i statistička analiza

Two datasets were used to analyze the quality and value of beech trees in the Karavanke region. The first dataset was composed of a timber quality assessment of standing trees on PSPs, which is maintained by the Slovenia Forest Service (SFS 2010a). PSP inventory covers the entire area of Slovenia and is carried out by overlaying a systematic grid of PSPs, which are mainly distributed on a 250×500 m grid. The re-measurement interval is 10 years and a scheduled number of plots are surveyed every year. The size of an inventory plot is 500 m^2 and consists of two concentric circles with radii of 7.98 m and 12.61 m, to measure small (10 ≥ *DBH* < 30 cm) and large trees (*DBH* ≥ 30 cm), respectively. The basic records for each plot include latitude, longitude, elevation, slope, aspect and topographic position. On each plot, every sample tree is georeferenced according to its polar coordinates (i.e. distance and azimuth from the plot centre) and the following data are recorded in every measurement: tree species, *DBH*, social status, major stem and crown damages, identification code (standing tree, standing dead tree, thinned tree, recruited tree) and timber quality. Timber quality is limited to larger trees (*DBH* ≥ 30 cm), where every tree is categorized in one of five quality classes (Table 1). For the purpose of this study 7,154 large beech trees on 2,088 PSPs in the Karavanke region were selected from the entire original dataset (Fig. 1).

The second dataset contained 26 plots (900 m^2 each), established in mature, fully stocked stands dominated by beech on 8 locations in the wider Alpine region. All trees within the plot with *DBH* equal or greater than 10 cm were measured and cut (a total of 1,057 trees; 495 trees with *DBH* ≥ 30 cm were included in the research). For each tree species, social status, *DBH*, height, crown length and volume were recorded (Kotar 1989, 1991). All trees were cut into 7–10 sections for the purpose of conducting a stem analysis. The quality of trees was assessed during harvesting: log parts were classified into assortment classes according to JUS standards (1979), and internal trunk defects (e.g. heartwood discoloration) were also considered. The size of this sample was small and therefore only used as an auxiliary sample to convert the quality assessed on PSPs into assortment classes (Table 1).

Firstly, the gross volumes of standing trees measured at PSPs were converted into net volumes on the basis of previous studies (Čokl 1981; Rebula 2002). The established conversion factor was between 0.85 and 0.98 and was DBH dependent. Furthermore, on the basis of *DBH* analyses and recommendations by Kotar (2003) and Kadunc (2006), the trees were assigned volume shares by individual segments. For Čokl's (intermediary) tariffs up to the tariff class 4 and for Schaeffer's tariffs up to the tariff class 4/5 trees were assumed to be conical, which meant that the butt log took up 43.54% of the stem volume, the second segment made up for 29.89%, the third for 18.09%, and the fourth segment took up 8.48% of the stem volume. For other tariff classes a more cylindrical shape was assumed, with the butt log taking up 37.50% of the stem volume, the second segment 29.17%, the third segment 20.83%, and the fourth segment 12.50% of the stem volume.

The quality classes of beech trees from PSPs (SFS 2010a) were further transformed into six assortment classes (sliced veneer, peeled veneer, sawlog I, sawlog II, sawlog III including sleeper, firewood). As some quality classes contained more than one assortment class for certain segments (e.g the first segment of trees

Table 1 Conversion of quality classes evaluated on PSPs into assortment classes according to JUS standards (1979)
Tablica 1. *Konverzija razvrstavanja kakvoće ocijenjene na TPP u klase prema JUS-u (1979)*

Quality class *Klasa kakvoće*	Segment *Segment*	*DBH*, cm *Prsni promjer*, cm	Assortment class *Klasa sortimenata*
Excellent (1st segment is veneer, peeled veneer, or sawlog I, 2nd segment is at least sawlog II) *Odlična* *(prvi je segment furnirski trupac, trupac za ljuštenje ili pilanski trupac I. klase, drugi je segment najmanje pilanski trupac II. klase)*	1.	30–37	Sawlog I, 100% – *Pilanski trupci I. klase,* 100 %
		38–43	Sawlog I 60%, peeled veneer 40% *Pilanski trupci I. klase* 60 %*, trupci za ljuštenje* 40 %
		44–55	Sawlog I 55%, peeled veneer 35%, sliced veneer 10% *Pilanski trupci I. klase* 55 %*, trupci za ljuštenje* 35 %*, furnirski trupci* 10 %
		56–60	Sawlog I 45%, peeled veneer 55% *Pilanski trupci I. klase* 45 %*, trupci za ljuštenje* 55 %
		61–65	Sawlog I 30%, peeled veneer 70% – *Pilanski trupci I. klase* 30 %*, trupci za ljuštenje* 70 %
		> 65	Sawlog I 35%, peeled veneer 65% *Pilanski trupci I. klase* 35 %*, trupci za ljuštenje* 65 %
	2.	30–34	Sawlog II 100% – *Pilanski trupci II. klase* 100 %
		35–39	Sawlog II 96%, sawlog I 4% *Pilanski trupci II. klase* 96 %*, pilanski trupci I. klase* 4 %
		40–54	Sawlog II 70%, sawlog I 30% *Pilanski trupci II. klase* 70 %*, pilanski trupci I. klase* 30 %
		55–59	Sawlog II 55%, sawlog I 45% *Pilanski trupci II. klase* 55 %*, pilanski trupci I. klase* 45 %
		> 60	Sawlog II 40%, sawlog I 50%, peeled veneer 10% *Pilanski trupci II. klase* 40 %*, pilanski trupci I. klase* 50 %*, trupci za ljuštenje* 10 %
	3.	≥ *30*	Firewood 100% – *Drvo za ogrjev* 100 %
	4.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
Very good (1st and 2nd segment are sawlog II, or 1st segment is of higher quality, and 2nd segment is of slightly lower quality) *Vrlo dobra* *(prvi i drugi segment su pilanski trupci II. klase ili je prvi segment bolje kakvoće, a drugi malo slabije kakvoće)*	1.	≥ 30	Sawlog II 100% – *Pilanski trupci II. klase* 100 %
	2.	≥ 30	Sawlog II 100% – *Pilanski trupci II. klase* 100 %
	3.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
	4.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
Good (1st segment is sawlog II, 2nd segment is sawlog III or sleeper) *Dobra* *(prvi segment pilanski trupac II. klase, drugi segment je pilanski trupac III. klase ili trupac za željezničke pragove)*	1.	≥ 30	Sawlog II 100% – *Pilanski trupci II. klase* 100 %
	2.	≥ 30	Sawlog III or sleeper 100% *Pilanski trupci III. klase ili trupci za željezničke pragove* 100 %
	3.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
	4.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %

Satisfying (1st and 2nd segment are sawlogs III or sleepers, or 1st segment is of higher quality, and 2nd segment is of slightly lower quality) *Zadovoljavajuća (prvi i drugi segment su pilanski trupci III. klase ili trupci za željezničke pragovove, ili je prvi segment bolje kakvoće, dok je drugi segment malo slabije kakvoće)*	1.	≥ 30	Sawlog III or sleeper 100% *Pilanski trupci III. klase ili trupci za željezničke pragove* 100 %
	2.	≥ 30	Sawlog III or sleeper 100% *Pilanski trupci III. klase ili trupci za željezničke pragove* 100 %
	3.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
	4.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
Bad (1st segment is sawlog III, sleeper, or lower, 2nd segment is industrial wood or firewood) *Loša (prvi segment je pilanski trupac III. klase, trupac za željezničke pragove ili slabije, drugi segment je industrijsko drvo ili drvo za ogrjev)*	1.	≥ 30	Sawlog III or sleeper 40%, firewood 60% *Pilanski trupci III. klase ili trupci za željezničke pragove 40 %, drvo za ogrjev 60 %*
	2.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
	3.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %
	4.	≥ 30	Firewood 100% – *Drvo za ogrjev* 100 %

classified as excellent, could either be veneer, peeled veneer or sawlog I quality; see also Table 1), the conversion of quality classes into assortment structure was based on the ratios assessed from the second (harvested) dataset. For the purpose of conversion, each tree from the PSP was assigned the average quality value, although in reality this phenomenon is frequency-based. For example, a tree of excellent quality and a 50 cm *DBH* was assigned 10% of sliced veneer, 35% of peeled veneer and 55% of sawlog I although veneer quality is only achieved in 10%, peeled veneer quality in 35%, and sawlog I in 55% of trees classified as excellent.

The calculations of wood value ex forest road were based on the price lists for 2011 published by 10 major beech traders in Slovenia. In order to obtain the value of the net volume of trees ex forest road (in €/m^3), the volume of each quality class was multiplied by the average price and then the sum was divided by the net volume of the tree. The influence of the actual harvesting, bucking and sorting of the logs on final tree value was not considered in the calculations. Furthermore, the value was not reduced by the costs of silvicultural measures, harvesting operations, construction and maintenance of forest roads, overhead costs, public forest service, and various taxes and duties (Table 2).

Table 2 Average prices of beech timber assortments ex forest road, €/m^3

Tablica 2. *Prosječne cijene drvnih sortimenata bukve fco. šumska cesta, €/m^3*

Assortment class *Klasa sortimenata*	Yearly average price ex forest road, €/m^3 *Godišnja prosječna cijena fco. šumska cesta, €/m^3*
Veneer logs *Furnirski trupci*	192.83
Peeled veneer *Trupci za ljuštenje*	100.04
Sawlogs I *Pilanski trupci I. klase*	71.85
Sawlogs II *Pilanski trupci II. klase*	56.19
Sawlogs III, sleepers *Pilanski trupci III. klase, trupci za željezničke pragove*	42.28
Firewood *Drvo za ogrjev*	40.44

Table 3 Independent variables tested in the binary logistic and multivariate linear regression model
Tablica 3. *Nezavisne varijable testirane u binarnom logističkom i multivarijantnom linearnom regresijskom modelu*

Level *Razina*	Variable *Varijabla*	Variable type and dependency form *Tip varijable i oblik ovisnosti*	Dummy variables coding Kodiranje »dummy« varijabli	
			Name *Naziv*	Transformation *Transformacija*
Tree-level variables *Varijable na razini stabala*	DBH, cm *Prsni promjer,* cm	Continuous/parabolic *Kontinuirana/parabolična*	–	–
	Basal area increment, cm^2/year *Prirast temeljnice*, cm^2/*god.*	Continuous/parabolic *Kontinuirana/parabolična*	–	–
	Social status *Socijalni status*	0/1	Upper layer *Gornji sloj*	1 = trees in upper stand layer; 0 = trees in other layers 1 = *stabla u gornjem sloju sastojine;* 0 = *stabla u ostalim slojevima*
	Damage presence *Prisutnost oštećenja*	0/1	Damage presence *Prisutnost oštećenja*	1 = presence of major damages; 0 = no damages 1 = *prisutnost većih oštećenja;* 0 = *bez oštećenja*
Stand-level variables *Varijable na razini sastojine*	Stand type *Tip sastojine*	0/1	Rejuvenation stand *Pomlađene sastojine*	1 = rejuvenation stand; 0 = other 1 = *pomlađene sastojine;* 0 = *ostalo*
			Uneven-aged stand *Preborne šume*	1 = uneven-aged stand, two-layer stand; 0 = other 1 = *preborne šume, dvoslojne sastojine;* 0 = *ostalo*
	Stand basal area, m^2/ha *Temeljnica*, m^2/ha	Continuous/parabolic *Kontinuirana/parabolična*	–	–
	Spruce share in stand basal area, % *Udio smreke po temeljnici,* %	Continuous/linear *Kontinuirana/linearna*	–	–
	Fir share in stand basal area, % *Udio jele po temeljnici,* %	Continuous/linear *Kontinuirana/linearna*	–	–
	Share of coniferous tree species in stand basal area, % *Udio četinjača po temeljnici,* %	Continuous/linear *Kontinuirana/linearna*	–	–
Site-level variables *Varijable na razini staništa*	Altitude, m *Nadmorska visina,* m	Continuous/parabolic *Kontinuirana/parabolična*	–	–
	Inclination, ° *Nagib,* °	Continuous/linear *Kontinuirana/linearna*	–	–
	Landscape position *Položaj u krajoliku*	0/1	Ridge position *Greben*	1 = ridge; 0 = other 1 = *greben;* 0 = *ostalo*
			Slope position *Padine*	1 = slope; 0 = other 1 = *padina;* 0 = *ostalo*
	Aspect *Reljef*	0/1	Sun-exposed site *Prisojna strana*	1 = SE/JI, S/J, SW/JZ, 0 = other 1 = *SE/JI, S/J, SW/JZ,* 0 = *ostalo*

Forest management variable *Varijabla gospodarenja šumama*	Harvesting intensity, m²/ha, year *Intenzitet sječe,* m²/ha, *godišnje*	Continuous/linear *Kontinuirana/linearna*	–	–

Timber value as well as the quality of beech trees was assumed to depend on tree traits and stand characteristics, site conditions, and forest management variables. All independent variables were acquired from the PSP inventory (Table 3). The influence of independent variables on the quality and timber value was tested using bivariate and multivariate statistical analyses. The Kruskal-Wallis (*KW*) test was used to assess the existence of differences between the sliced veneer and peeled veneer shares by forest types for the trees classified into diameter class 45–49 cm or 50–54 cm, which normally achieves the highest value. Differences in the average value of beech wood between forest types were tested using univariate analysis of variance, while differences across diameter classes were tested using a median test. Since the relationship between the quality or timber value and the independent variable is often parabolic (e.g. Knoke 2003; Rebula 2005), a quadratic term was added in the models for certain continuous variables when so indicated by the bivariate analysis and data survey. All categorical variables with *n* categories were transformed into *n –1* dummy variables (Table 3).

Given the binary response of the dependent variable (1 if quality was sliced veneer or peeled veneer; 0 for other assortment classes), the probability of the presence of high quality beech timber was modeled using a binary logistic regression. In order to avoid multicollinearity, only variables with a tolerance factor higher than 0.2 were included in the model (Knoke 2003). The model was estimated using a backward stepwise procedure where removal testing was based on the probability of the likelihood-ratio statistic based on the maximum partial likelihood estimates (Kleinbaum and Klein 2002). The Nagelkerke pseudo-R^2 was used to evaluate goodness-of-fit for the model.

The relation between timber value and independent variables was examined with the standard multivariate linear regression. The model was estimated using a stepwise procedure. Independent variables used in the modeling procedure were the same as those used in the binary logistic model (Table 3). As in the logistic model, the variables were tested for multicollinearity. The final model was derived by using the adjusted R^2 as the criterion for goodness-of-fit. All statistical analysis was carried out in the PASW SPSS Statistics 18.

3. Results – *Rezultati*

3.1 Quality and assortment structure of beech trees – *Kakvoća i struktura sortimenata bukovih stabala*

The share of trees classified as excellent or very good amounted to 22.9%. The number of excellent beech trees was highest in diameter class 50–54 cm, whereas the highest number of very good quality beech trees was found in diameter class 55–59 cm. The share of good quality timber was highest in the lowest-diameter trees and decreased with thickness. Conversely, the share of satisfactory and poor quality timber was highest in the thickest trees and rose with diameter (Table 4; upper part). In the assortment structure, firewood was followed in proportion by sawlog II and sawlog III. Sliced veneer, peeled veneer, and sawlog I amounted to a 2.3% (Table 4, lower part). The proportion of veneer quality wood was highest in trees measuring approximately 50 cm in DBH, whereas the share of peeled veneer was highest in very thick trees (> 65 cm).

The differences between the forest types were statistically significant for sliced veneer shares (KW = 24,527; P = 0.011) as well as for peeled veneer shares (KW = 23,854; P = 0.013). Forest types with the highest total shares of sliced and peeled veneer (above 2%) included *Aceri-Fraxinetum*, *Aposeri-Piceetum* and *Hacquetio-Fagetum*. In the forest types *Castaneo-Fagetum*, *Bazzanio-Abietetum* and *Adenostylo-Fagetum* sliced/peeled veneer quality logs were not recorded (Fig. 2). Similar relations between forest types as determined for sliced and peeled veneer shares were also ascertained in the timber class of sawlog I.

The variability in the quality of beech trees can be partly explained by selected tree, stand, site, and forest management variables. In the binary logistic regression model, the main effects of eight independent variables significantly influenced the beech quality (Table 5, left part). The model explained 22% of the total variability (Nagelkerke R^2 = 0.220).

In the group of variables denoting tree characteristics, the model included DBH, social status and presence of any major damage to the tree. There was a parabolic relationship between diameter at breast

Table 4 The shares (in %) of beech trees by diameter classes with regard to the quality assessment and assortment structure (modes are marked bold)

Tablica 4. *Udio (%) bukovih stabala po debljinskim razredima s obzirom na procjenu kakvoće i strukturu sortimenata (modovi su označeni podebljano)*

Quality class (tree share), % *Klasa kakvoće (udio u stablu), %*	Diameter class, cm – *Debljinski stupanj,* cm								Average *Prosjek*
	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65+	
Excellent – *Odlična*	2.8	3.5	5.4	6.2	8.1	5.0	1.5	6.0	4.2
Very good – *Vrlo dobra*	16.9	20.0	19.3	20.1	18.8	22.3	18.2	14.9	18.7
Good – *Dobra*	50.1	47.5	45.8	43.3	39.4	28.7	33.3	32.8	46.2
Satisfying – *Zadovoljavajuća*	22.2	22.0	22.8	24.4	22.4	27.2	36.4	28.4	23.0
Bad – *Loša*	8.0	7.0	6.5	6.0	11.2	16.8	10.6	17.9	7.9
Total – *Ukupno*	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Assortment class (volume share), % *Klasa sortimenata (udio u obujmu), %*	Diameter class, cm – *Debljinski stupanj,* cm								Average *Prosjek*
	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65+	
Veneer logs – *Furnirski trupci*	0.0	0.0	0.1	0.3	0.3	0.1	0.0	0.0	0.1
Peeled veneer – *Trupci za ljuštenje*	0.0	0.2	0.8	0.9	1.2	1.0	0.4	1.8	0.6
Sawlogs I – *Pilanski trupci I. klase*	1.1	1.2	1.8	2.0	2.6	1.6	0.4	1.8	1.6
Sawlogs II – *Pilanski trupci II. klase*	32.0	33.0	32.1	31.8	29.8	27.3	25.2	23.6	30.9
Sawlogs III – *Pilanski trupci III. klase*	31.0	30.2	30.0	30.2	28.3	29.2	36.3	30.8	30.4
Firewood – *Drvo za ogrjev*	35.9	35.4	35.3	34.9	37.8	40.9	37.6	41.9	36.5
Total – *Ukupno*	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

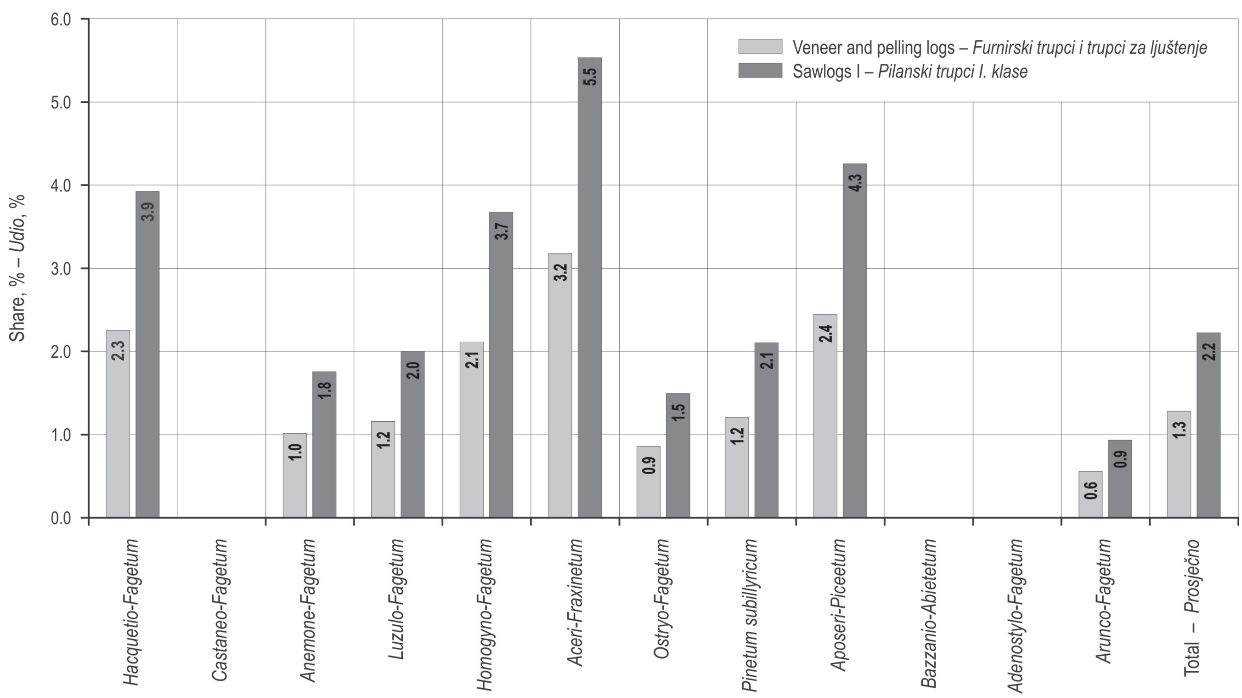

Fig. 2 The shares of highest-quality beech assortment classes by forest type

Slika 2. *Udio bukovih sortimenata odlične kakvoće po tipovima šuma* height and the probability of highest-quality beech assortments (sliced veneer and peeled veneer), with the probability rising with *DBH* up to 55 cm, and then dropping again. The presence of considerable structural damage in beech trees decreased the probability of sliced veneer and peeled veneer while the trees reaching the upper stand layer were more likely to develop the highest-quality beech timber assortments.

The probability of this phenomenon increased with the basal area and the share of fir, but decreased in stands with a higher share of conifers. Furthermore, the chances for sliced veneer and peeled veneer timber quality increased as a result of forest management activities, which were evident through harvesting intensity.

In the group of tested site variables, only elevation was included in the model. The probability for sliced veneer and peeled veneer occurrence increased up to 1,100 m above sea level, and decreased at higher elevations.

3.2 The value of beech trees – *Vrijednost debla bukovih stabala*

The average value of beech wood in the study region was 46.3 €/m^3 and varied significantly between forest types (univariate analysis of variance, *DBH* was used as a covariate, $F = 7.357$, $P = 0.000$), as well as across diameter classes (Median test statistic = 228.93, $P = 0.000$). In most forest types, beech value was highest in diameter class 45–50 cm and diameter class 50–55 cm, whereas in forest types *Bazzanio-Abietetum* and *Adenostylo-Fagetum* it culminateed in the thickest trees. In terms of beech timber value, the best results were obtained on high-productivity beech sites (e.g. *Hacquetio-Fagetum* and *Homogyno sylvestris-Fagetum*), and the timber values were lowest in secondary spruce and pine forests (e.g. *Aposeri-Piceetum Pinetum subillyricum*).

The influence of selected variables on the value of beech timber (in €/m^3) was tested using the multivariate regression analysis. Despite testing the same set of

Table 5 Parameters of binary logistic regression (the outcome variable is the presence of sliced veneer or peeled veneer logs) and multivariate regression (using value in €/m^3 as dependent variable)

Tablica 5. *Parametri binarne logističke regresije (izlaznu varijablu označuje prisutnost rezanoga ili lјuštenoga furnira) i multivarijantne regresije (koristeći vrijednost u €/m^3 kao zavisnu varijablu)*

Predictor – Independent variable *Pokazatelj – Neovisna varijabla*	Binary logistic regression *Binarna logistička regresija*			Multivariate regression *Multivarijantna regresija*		
	β	Exp(β)	P	β	SE(β)	P
Constant – *Konstanta*	–30.252	0.000	0.000	43.5778	0.9903	0.000
DBH – *Prsni promjer*	0.644	1.904	0.000	0.0901	0.0365	0.014
DBH^2 – *Prsni promjer*^{2}	–0.006	0.994	0.000	–0.0013	0.0004	0.001
Altitude – *Nadmorska visina*	0.018	1.018	0.002	–	–	–
Altitude^2 – *Nadmorska visina*^{2}	–0.000	1.000	0.002	–0.0000	0.0000	0.001
Inclination – *Nagib*	–	–	–	–0.0319	0.0071	0.000
Stand basal area – *Temeljnica*	0.015	1.015	0.022	0.1147	0.0204	0.000
Stand basal area^2 – *Temeljnica*^{2}	–	–	–	–0.0007	0.0002	0.001
Basal area increment^2 – *Prirast temeljnice*^{2}	–	–	–	–0.0001	0.0000	0.003
Harvesting intensity – *Intenzitet sječe*	0.423	1.527	0.000	0.8936	0.1238	0.000
Share of fir – *Udio jele*	1.386	4.000	0.045	2.1142	0.5799	0.000
Share of conifers – *Udio četinjača*	–1.064	0.345	0.009	–3.2919	0.2538	0.000
Landscape position – *Položaj u krajoliku*	–	–	–	0.7932	0.2389	0.001
Rejuvenating stand – *Pomlađene sastojine*	–	–	–	0.5365	0.2013	0.008
Upper layer – *Gornji sloj*	1.092	2.981	0.000	1.8303	0.1736	0.000
Lower layer – *Donji sloj*	–	–	–	–3.0394	0.3659	0.000
Damage presence – *Prisutnost oštećenja*	–0.918	0.399	0.057	–2.1289	0.2763	0.000

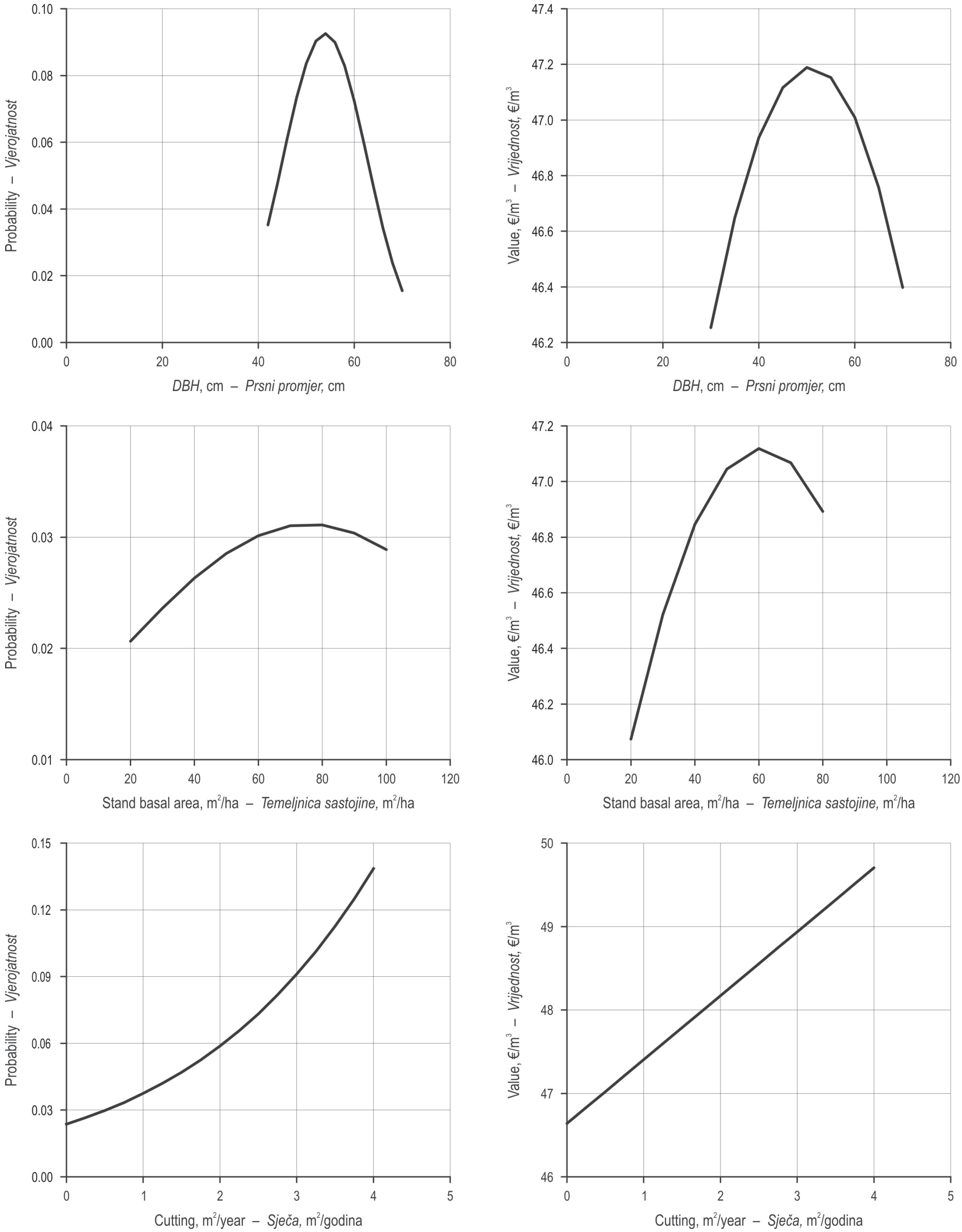

Fig. 3 The probability of highest-quality beech timber assortments and beech timber value (€/m^3) in relation to DBH, stand basal area and harvesting

Slika 3. *Vjerojatnost bukovih sortimenata odlične kakvoće i vrijednosti bukovih stabala (€/m^3) u ovisnosti o prsnom promjeru stabla, temeljnici sastojine i sječe* variables as in binary logistic regression, only 9.2% of variance (R^2 = 0.092) was explained. The lower performance of the regression model could be explained by a high proportion of low and medium quality timber (e.g firewood, sawlogs III) with similar timber prices, which makes the dependant variable (tree value) less distinctive.

The differences in the value of beech trees were clearly explained through the following tree characteristics: *DBH* and basal area increment (both have a parabolic effect on timber value); social status (the upper layer has a positive effect on timber value); damage presence (displays a negative effect; Table 5, right part).

Regarding stand variables, the study showed that the values of beech trees were comparatively higher in rejuvenation stands than in other stand types. Moreover, the share of silver fir increased the value, while the share of other coniferous tree species (spruce is strongly dominating) decreased the value. On the other hand, the value of beech trees increased with increasing stand basal area up to 60 m^2/ha, and then started lowering.

In the group of site factors, altitude and inclination have a negative effect on beech timber value. The timber value was also affected by the site location, with beech timber from sloped sites normally reaching higher values.

Harvesting intensity as an indicator of forest management activities undertaken in the area during the past ten years had a positive influence on the value of beech wood.

4. Discussion with conclusions – *Rasprava i zaključci*

This study presents the quality and value potential of beech forest stands in the Karavanke region to illustrate the differences between forest types and to outline the factors influencing the quality and value of beech timber. The information illustrating the quality of complete stands derived from forest inventory data was used as the basis for the study. The forest inventory data offers clear advantages, but also raises certain concerns. The main advantages of quality assessment at PSPs are the following: it enables representative quality assessment for selected spatial units, it is simple to conduct, and, consequently, inexpensive. Furthermore, the quality assessment on PSPs is part of numerous measurements and estimates and as such enables researchers to determine the underlying principles and connections between variables. However, although multiple parameters have been measured and assessed on PSPs, it would be sensible to include other parameters (e.g. rockiness), in particular if such a parameter is only recorded upon the first measurement and can be obtained through a simple process or assessment. It can therefore be concluded that the method is useful with the assumption that it is carried out correctly. Its main weakness, however, is that the quality assessment is only based on external signs, i.e. external tree defects. In order to calculate the percentage of various timber classes from the assessments of standing trees, an analysis should be made of a small sample of felled trees or certain assumptions should be set based on expert opinions or experiences (e.g. the ratio of sliced veneer : peeled veneer : sawlog I).

The assortment structure established for the Karavanke mountain range is considerably less favourable than the stands of comparable site quality determined for Slovenia by Kadunc and Kotar (2005), and by Kadunc (2006). For the Karavanke, low percentages of sliced veneer and peeled veneer logs were ascertained. A higher percentage of veener quality trees and a better assortment structure than the one established for the Karavanke were also found in several other countries such as Croatia, Slovak Republic, and Switzerland (Petráš and Nociar 1991; Štefančič 1998; Gfeller 1998; Krpan 2003; Prka and Krpan 2007; Prka 2010). The results of the Croatian National Forest Inventory showed a high percentage of excellent trees (14%) and an even higher share of very good trees (24%) (Čavlović 2010). On the other hand, the analysis of the quality grading of felled beech trees in the Austrian Federal Forests (in the period 1995/1996) showed an even more unfavorable assortment structure (Rieder 1997).

A certain degree of caution is required when comparing the quality classes obtained in various analyses, largely because the assessed quality grades are heavily dependent on relevant standards used (Prka and Poršinsky 2009), as well as on the assessors (Paladinić and Vuletić 2006; Prka and Krpan 2010). Although the differences in standards may lead to a difference in percentage for a particular timber class, the ratios between quality classes are more or less stable (Prka 2008). In all comparisons, a distinction must be made between forest stand assortment structure and harvest assortments (Prka 2006).

Nevertheless, since the assortment structure of a forest stand depends on the efficiency of silvicultural measures (Prka 2006), the less favorable assortment structure of beech trees in the study area is mainly the result of past forest management practice. In the Alpine territory, beech has always been considered a tree species used primarily for firewood, and forest owners relied on coniferous tree species, in particular spruce and larch, to generate revenue and produce technical timber. Beech is frequently found as admixed species in stands (either as individual trees or in clusters), which is not promising for the growth of quality beech trees. Beech trees develop best among other trees of similar age. In addition, due to low marketing appeal, the beech stands in the study area were intensively tended, as was common practice in certain other parts of Slovenia (e.g. Kordiš 1993; Pirc 1997).

Multivariate analysis accounted for a low percentage of variability of timber quality and tree value, as can be expected for such research into beech trees (e.g. Kadunc 2006), whereas in oak and fir a higher percentage of variability was explained (Kadunc 2009; Kadunc 2010). The formation of heartwood discoloration, commonly known as red heart, reduces the predictability of the quality and value of beech trees and timber. Nevertheless, we believe that there are a number of other methodological reasons for the low level of accountability. Evidently, several studies have shown that the efficiency of explaining the beech timber values could be substantially improved (Rebula and Kotar 2003; Rebula and Kotar 2004). Up to a certain extent, the models would be made more efficient by including other variables, e.g. rockiness, soil type (or other ground characteristics), and proximity to the nearest forest edge, which were unfortunately not available in the present case.

Diameter at breast height was found to have a significant influence on beech tree quality and timber value. The analyses showed that the diameter of the highest-quality and most-valuable trees is between 50 and 55 cm, which is in line with the findings of several other researchers (e.g. Štefančić 1998; Hapla et al. 2002; Prka 2003a; Kadunc 2006). In addition to *DBH*, the value of beech trees is also considerably affected by several other tree traits: the social status of a tree (higher value is assigned to trees in the upper stand layer, and vice versa), presence of damage (damaged trees carry a lower value), and basal area increment (fast growing trees develop larger crowns and, as a result, lower-quality trunks).

In the group of stand variables, stand basal area, percentage of fir, percentage of conifers, and stand type were also found to influence the value of trees. Analyses showed that stands of excessive density reduce the timber value, and, on the other hand, trees with very relaxed crowns seem to be deficient in quality. It is interesting to note that the presence of fir in stands has a positive influence on the value of beech wood. On the other hand, the presence of other coniferous tree species reduces this value. The high percentage of conifers might point to the fact that beech did not grow in a group of broadleaved trees, which would improve the quality of their stems. The positive effect of fir, however, is indicative of better growing conditions. The fact that the quality was higher in rejuvenation stands than in mature forests and in uneven-aged stands of similar *DBH* showed that better-quality trees are left to grow longer in regeneration stands.

Altitude, inclination, and landscape position are included in the list of site variables that have a characteristic effect on the value of beech trees in the analyzed area. The effect of altitude is largely seen as the influence of the stand site quality, as one of the key entry data for the forest timber product table (Prka 2003a). The trees at higher elevations are less straight, their branches are stronger, and they grow to commercially attractive dimensions at a higher age, all of these factors contributing to less favorable quality structure. Adding to the extreme site conditions, inclination reduces the value of beech stems. The occurrence of damage caused to trees during harvesting operations is higher on steep sites; the crowns of trees on steep sites are asymmetrical (higher red heart probability, Kadunc 2006), and the shape of the stem deviates more frequently from the circular. It was also found that sites on slopes are more favorable than other sites, with ridge sites as the most prevalent. Moreover, the results of the analysis also showed that the value of trees rises with the felling in stands; which further stresses the importance of active management of stands where beech takes up a considerable percentage.

Prka and Krpan (2007) conclude that the quality of trees and/or stands is a result of various abiotic and biotic factors, including human action. Low management intensity of the studied stands is also evident in the low percentage of damage to trees during timber harvesting. Damage averaged at 6.2% of beech trees, which is lower than observed in intensively managed stands (Prka 2006).

The present beech timber value depends on the prices of forest timber products. When these prices, or the relations between them, change, other underlying principles may also be affected. Prka and Krpan (2010) conclude that the market for beech timber products is relatively unstable. The recent growth of beech firewood prices has been driven by the rise in the prices of fossil fuels. On the other hand, the decline in the production of beech hardwood furniture has led to a drop in the prices of beech sawlogs (EUWID 2011). According to the current market trends, the future of the technical use of beech timber looks rather uncertain.

Under these conditions, it is very difficult to make predictions into the assortment structure of beech trees, in particular because the occurrence of defects, their size and numbers are coincidental in nature and fail to correlate with many tree parameters (Prka and Krpan 2010). Heartwood discoloration in particular presents a serious obstacle to beech yield planning (Prka et al. 2009). Highly volatile market poses another issue.

If the quality of beech trees and stands continues to be an important forest management goal in the future, it is sensible to cultivate beech trees in groups of broadleaved trees, favorably mixed up with fir, to strive to prevent damage to selected trees during harvesting, and to carry out thinning.

In our opinion, quality assessments carried out on PSPs enable the researchers to assess the stand value potential, the differences in the quality of certain forest areas and/or forest stand types (strata) as well as the impact of different silvicultural systems on stand quality and yield value. This will lead to enhanced forest management, both with regard to determining investment priorities as well as with regard to setting priority regeneration measures.

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Sažetak

Kakvoća i vrijednost oblovine obične bukve (Fagus sylvatica L.) na Karavankama

Bukva je u Alpama dugo vremena bila sinonim za ekonomsko manje vrijednu vrstu drveća. U posljednjim se desetljećima, posebno zbog promjene načina gospodarenja šumama, povećava udio bukve i njezina važnost u alpskom prostoru. Zato se nameće pitanje o načinu gospodarenja bukovim šumama u budućnosti. Za pravilnu procjenu stanja potrebne su mnoge informacije, kao što su poznavanje strukture kakvoće šumskih sastojina i vrijednosnih svojstava vrsta drveća te svih čimbenika koji na to utječu. Svrha je ovoga rada utvrditi kakvoću i vrijednost svojstava bukve u Karavankama i identificirati čimbenike koji utječu na vrijednost bukovih stabala.

Za ocjenu kakvoće stabala služili smo se podacima trajnih pokusnih ploha (7154 stabla na 2088 ploha) te podacima manjega uzorka posječenih stabala (495 stabala, 26 ploha). Vrijednost bukovih sortimenata izračunali smo *pomoću njihove utvrđene strukture te cijene sortimenata na kamionskoj cesti. Testirali smo čimbenike koji utječu na kakvoću ili vrijednost bukovih stabala. To su stablimični, sastojinski, stanišni i šumskogospodarski parametri koje prikupljamo za vrijeme inventure šuma na trajnim pokusnim plohama.*

Istraživanje je pokazalo izuzetno nizak postotak stabala dobre kakvoće. Tako je udio furnirskih trupaca (klasa F) iznosio tek 0,1 posto, 0,6 posto je iznosio udio trupaca za ljuštenje (klasa L), dok je udio pilanskih trupaca prve klase (najviše kakvoće) bio 1,6 posto. Najveći zajednički udio furnirskih trupaca i trupaca za ljuštenje utvrdili smo na staništima asocijacija Aceri-Fraxinetum, Aposeri-Piceetum *i* Hacquetio-Fagetum, *dok klasu F ili L nismo našli na staništima* Castaneo-Fagetum, Bazzanio-Abietetum *i* Adenostylo-Fagetum.

Na kakvoću i vrijednost bukovih stabala ima, od svih istraženih parametara, najveći utjecaj prsni promjer. Analize su pokazale da stabla najviše kakvoće i vrijednosti imaju prsni promjeri od 50 do 55 cm. Od ostalih parametara na kakvoću bukovih stabala najviše utječu socijalni status, oštećenja na stablima te prirast temeljnice. Neoštećena su stabla u gornjem sloju općenito bolje kakvoće i njihova je vrijednost veća.

Od sastojinskih parametara na vrijednost stabala utječu temeljnica sastojine, udio jele, udio četinjača te tip sastojine. Analize su pokazale da sastojine veće gustoće smanjuju vrijednost, a, s druge strane, ni sastojne sa slobodnim krošnjama nisu najbolje kakvoće. Zanimljiv je rezultat istraživanja o pozitivnom utjecaju udjela jele te negativnom utjecaju udjela četinjača. Velik dio crnogoričnih stabala upućuje na to da bukva vjerojatno nije rasla u grupi listopadnoga drveća, što bi sigurno poboljšalo njezinu kakvoću. Pozitivan udio jele vjerojatno upućuje na povoljne stanišne uvjete. U pomlađenim je sastojinama kakvoća starih stabala veća nego u optimalnim razvojnim fazama, što je posljedica načina rada, kada se za vrijeme obnove šume najbolja stabla ostavljaju duže razdoblje. Analiza je također pokazala da vrijednost trupaca raste s povećanjem sječe u sastojini. To je svakako dokaz o potrebi aktivnoga gospodarenja sastojinama za većim udjelom bukve.

Nadmorska visina, nagib i položaj u krajoliku su varijable staništa koje su značajno utjecale na vrijednost bukovih stabala na području istraživanja. Utjecaj nadmorske visine uglavnom odražava utjecaj boniteta sastojine. Stabla na većim nadmorskim visinama manje su ispružena, grane su deblje, komercijalno zanimljive dimenzije stabla dostižu u starijoj dobi, što sve pridonosi nepovoljnijoj strukturi kakvoće. Povećanjem nagiba padina smanjuje se vrijednost trupaca: prilikom njihova privlačenja često dolazi do većih oštećenja, krošnje su stabala asimetrične (povećava se vjerojatnost nastanka crvenoga srca), oblik je trupaca obično također asimetričan. Pokazalo se da su padine primjerenije u usporedbi s položajima na grebenima.

Visoka kakvoća bukovih stabala i sastojina, kao važan cilj gospodarenja šumama u budućnosti, upućuje na potrebu uzgoja takvih sastojina u grupama listopadnih stabala kod kojih je poželjan manji udio jele. Posebnu pozornost valja posvetiti privlačenju drva radi smanjenja oštećenja dubećih stabala. Potrebno je provoditi redovite prorede. Ocjena kakvoće na trajnim pokusnim plohama može biti koristan pokazatelj za procjenu vrijednosnih mogućnosti sastojina te za utvrđivanje razlika u kakvoći pojedinih područja ili tipova (stratuma) šuma. To pridonosi boljemu upravljanju šumama, osobito pri odlučivanju o intenzitetu i učestalosti različitih uzgojnih mjera te o početku i načinu obnove šume.

Ključne riječi: obična bukva, kakvoća debla, sortimentna struktura, vrijednost drvne oblovine, utjecajni čimbenici, Karavanke

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