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Quality and timber value of European larch (*Larix decidua* Mill.) trees in the Karavanke region

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Abstract

Although European larch is a commercially important tree species in the Alps, this study is among the first focusing on the quality and value of larch trees. Data from permanent sample plots of the Slovenia Forest Service (802 plots; 1851 trees) was used to model the quality and value of standing larch trees. The share of excellent and very good quality timber amounted to 49%, but the share of veneer logs and sawlogs I was only 11.7%. The quality and value of larch trees were positively influenced by the diameter at breast height and stand basal area, and negatively by altitude and harvesting intensity. In addition, timber value was higher in stands in regeneration and uneven-aged stands and in stands with a low share of spruce or high share of deciduous tree species. Trees from higher social layers and undamaged trees also proved to have more valuable timber. The quality of larch trees was lower on extreme beech and pine forest types.

Key words: European larch, quality assessment, permanent sample plots, binary logistic regression, multivariate regression analysis

Kakovost in vrednost macesna (Larix decidua Mill.) v Karavankah

Izvleček

Čeprav je evropski macesen v Alpah ekonomsko pomembna drevesna vrsta, je ta študija med prvimi, ki obravnava kakovost in vrednost macesnovih dreves. Za modeliranje kakovosti in vrednost macesnovih dreves smo uporabili podatke s stalnih vzorčnih ploskev Zavoda za gozdove Slovenije (802 ploskev; 1851 dreves). Delež dreves odlične in zelo dobre kakovosti je znašala 49 %, delež furnirja in žagovcev I pa 11,7 %. Pokazalo se je, da na kakovost in vrednost macesnovih dreves pozitivno vplivata prsni premer drevesa in temeljnica sestoja, negativno pa nadmorska višina in intenzivnost sečenj. Vrednost je večja tudi v sestojih v obnovi in raznomernih sestojih ter pri nižjem deležu smreke oziroma višjem deležu bukve. Prav tako imajo višjo vrednost drevesa, ki pripadajo zgornji plasti in so nepoškodovana. Kakovost macesna je slabša na skrajnejših bukovih in borovih rastiščih.

Ključne besede: *evropski macesen, ocena kakovosti, stalne vzorčne ploskve, binarna logistična regresija, multivariatna regresijska analiza*

1 Introduction

1 Uvod

European larch (*Larix decidua* Mill.) is a species naturally distributed in the mountains of Central Europe, in particular the Alps, the Carpathians, and the Sudetes (MATRAS *et al*. 2011). In Slovenia, larch is native to the Julian Alps, the Karavanke mountain range, the Kamnik-Savinja Alps, and the northern edges of Trnovski gozd (DAKSKOBLER *et al*. 2010). Its share in the total growing stock of Slovenian forests amounts to 1.2 % (SFS 2011a). Larch is a light-demanding species, which can grow and rejuvenate in very harsh conditions. The natural larch community in Slovenia was classified as *Rhodothamno-Laricetum* (DAKSKOBLER 2006), but it is also commonly found in certain beech, fir-beech, spruce, and pine associations in montane to subalpine vegetation belt (MATRAS *et al*. 2011). Moreover, larch is an important tree species in succession. In several parts of the Alps it has formed extensive forests, most of them pure larch stands, overgrowing abandoned meadows and areas denuded by natural disturbances (e.g. fires, avalanches, erosion) (DAKSKOBLER *et al*. 2010).

In the Alpine region, larch is an ecologically and commercially important tree species. In extreme mountain

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conditions, larch trees are appreciated for their protective function as they decrease the speed of wind, prevent snow avalanches, hold the rocks and prevent soil erosion and drying-out (KOTAR / BRUS 1999). Larch wood is highly valued for its original colouring and favourable technical properties, and is used for construction and furniture (MATRAS *et al*. 2011).

Due to the high economic value of larch in the Alpine region, the information about the quality and value of larch trees, the value increment and the factors affecting the quality and value is of vital importance for efficient forest management. On the basis of this information we can define forest management goals and silvicultural objectives, determine the harvest maturity of trees, and decide on the intensity and frequency of various forest management measures. While the quality and value of beech and spruce timber have been the subject of many studies in Slovenia (e.g. KADUNC / KOTAR 2006, KADUNC 2006, MALI *et al*. 2009) and in Central Europe (e.g. HÖWECKE 1998, KNOKE / SEIFERT 2008), research into the quality and value of larch timber remains rather limited (DIETZE 1976, RAU 2004, GIERLINGER *et al*. 2004, PÂQUES 2004, MIHAI / TEODOSIU 2009).

To our knowledge, the main factors influencing the quality and value of larch trees using forest inventory data have not been studied in Central Europe so far. Thus, the main objective of our study was: 1) to analyze the quality and value-based structure of larch stands and trees, and 2) to develop a model to examine the mutual influence of tree, stand, site, and forest management variables on the quality and value of standing mature larch trees in the Karavanke region.

2 Materials and methods

2 Materiali in metode dela

2.1 Study area

2.1 Območje raziskave

The Karavanke is a mountain range stretching west-east for 120 km from Tarvisio, Italy, to Slovenj Gradec, which marks the beginning of Štajerska (Styria) region (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 1900 m above sea level. The area belongs to the alpine continental climate zone, but local climatic conditions can change rapidly as a result of the varied terrain. The extreme temperature varies 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 3600 mm precipitation, whereas the lower-lying areas of the eastern part receive only up to 1300 mm (ARSO, 2004b). Karst terrain and clastic sedimentary rock cover most of the territory, while the presence of felsic, igneous and various metamorphic rocks is sporadic.

Forest area covers 82% of the total study area. The forests are characterized by small-scale system management, using irregular shelterwood and group systems. The mean growing stock amounts to 322 m^3 ha^{-1}. 38 different tree species have been recorded in the study area; Norway spruce (66%) and European beech (16%) account for the highest proportion of growing stock, followed by European larch with 6% (SFS, 2011b). The zonality of forest vegetation in the Karavanke is quite clearly defined due to its distinctive orographic factors, different soil substrata and climatic conditions. According to the terminology used in forestry practice (VESELIC / ROBIC 2000; KUTNAR *et al*. 2011), the forests with larch in the study area are classified in 28 forest associations, which were further categorized into 10 forest types: *Adenostylo-Fagetum, Anemone-Fagetum, Arunco-Fagetum, Blechno-Fagetum, Luzulo-Fagetum, Ostryo-Fagetum, Homogyno-Fagetum, Aposeri-Piceetum, Bazzanio-Abietetum* and *Pinetum subillyricum.*

2.2 Data collection and statistical analysis

2.2 Zbiranje podatkov in statistična analiza

Two datasets were used to analyse the quality and value of larch trees in the Karavanke. The first dataset is composed of quality assessments of standing trees on permanent sample plots (PSP), which was maintained by the Slovenia Forest Service (SFS 2011a). PSP inventory covers the entire area of Slovenia and follows the division into forest management units (FMU) as a systematic pattern with a predominating sampling net of 250×250 m and 250×500 m and a mean inventory period of 10 years. 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. Basic records for each plot included latitude, longitude, elevation, slope, aspect and topographic position. Tree records included species, distance and azimuth from the plot centre, diameter at breast height, social status of the tree, and tree quality for large trees (Table 1). For the purpose of this study, we selected all large larch trees with the dbh ≥ 30 cm from the PSPs in the study area (Fig. 1). This dataset contains 1,847 larch trees on 802 PSPs.

The second dataset is based on stem analyses of cut larch trees in the same region, using the methodology described in Kadunc (2001). The sample size was small (168 trees from 24 locations) and was therefore only used as an auxiliary sample to facilitate conversion of the quality assessments on PSPs into timber assortments according to JUS standard (1979).

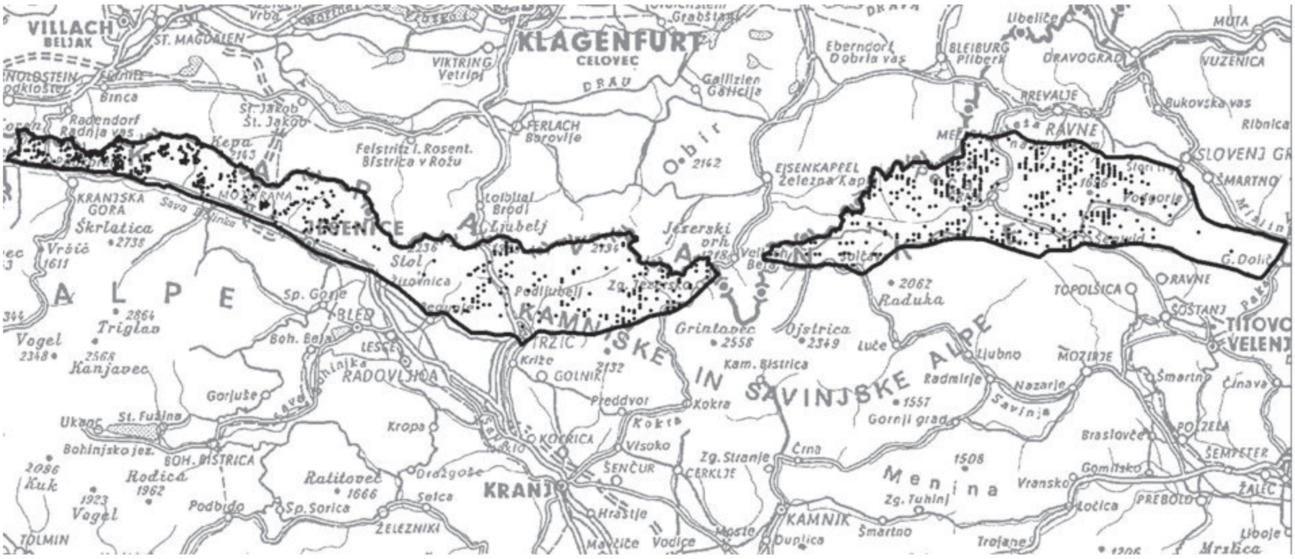

Figure 1: Location of the study area and distribution of PSPs

Slika 1: Območje raziskave in mreža SVP

In order to obtain a detailed assortment structure, gross volumes of standing trees measured at PSPs have been converted to net volumes by segments. Calculations of net volumes for standing trees were based on the conversion factor obtained by means of a stem analysis of the small sample of 168 cut larch trees. The established conversion factor was 0.81. On the basis of the small sample of cut trees and in close consideration of the experiences gained and recommendations given in the previous studies (KOTAR 2003), we determined the shares of segments (each stem is divided into three segments or sections) in net volumes, as follows: the first third of the stem (segment) accounted for 63.71% of net volume, the second third took up 29.87%, and the last third made up 6.42% of total net volume.

The data on the quality of larch trees from PSPs (SFS 2011a), evaluated on a five-degree scale (excellent, very good, good, satisfying, and bad), were transformed into volume shares according to JUS standard (1979) (Table 1). The ratios were analysed by cut trees to determine the volume shares of veneer logs and sawlogs I within the first segment of trees classified as excellent, as well as to determine the assortment structure in the second segment for the same trees and to define the shares of sawlogs III and pulpwood within the third segments.

The calculations of wood value ex forest road were based on the price lists of five major companies selling larch timber in Slovenia. The volume of each quality class was multiplied by the average buying price ex forest road and then divided by net volume of the tree to obtain the value of the net volume of trees ex forest road (in €/m^3), which was not reduced by the costs of silvicultural measures, tree harvesting, construction and maintenance of forest roads, overhead costs, public forest service, and various taxes and duties (Table 2).

Timber value as well as the quality of larch trees was assumed to depend on tree and stand characteristics, site conditions, and forest management variables (Table 3). All independent variables were acquired from the PSP inventory. 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 model for some continuous variables when so indicated by the bivariate analysis and data survey. All categorical variables were transformed into dummy variables (Table 3).

The influence of independent variables on the value and quality of larch wood was tested using binary and multivariate statistical analyses. In the multivariate models we only included variables of non-problematic multicollinearity. The tolerance parameter with a threshold value of 0.2 was used as a criterion. Multivariate regression analysis (method stepwise) was applied to explain the influence of selected independent variables on the value of larch wood. Due to the special interest in most valuable timber occurrence on the basis of binary logistic regression, the significance of predictors on veneer quality presence was tested. In order to analyse the probability of high-quality larch trees, the dichotomous dependent variable was created; its value was 1 if larch quality was veneer, and 0 for other quality classes. In line with the recommendations from previous studies (KLEINBAUM / KLEIN 2002), we used backward stepwise selection, where removal testing is based on the probability of the likelihood-ratio statistic based on the maximum partial likelihood estimates.

Table 1: Conversion of quality evaluated on a five-degree scale into quality classes according to JUS standards (1979)

Preglednica 1: Pretvorba kakovosti, podane s 5-stopenjsko opisno lestvico v kakovostne razrede po standardu JUS (1979)

Quality class	Segment	Dbh (cm)	Assortment class according to JUS standard (1979) assessments
Excellent (1st segment is veneer or sawlog I, 2nd segment is at least sawlog II)	1	30-45	Sawlog I 100%
		If dbh > 45 cm & diameter increment < 6 mm/year & basal area > 50 m^2/ha	Sawlog I 50%, Veneer 50%
		all other combinations	Sawlog I 100%
	2	30 and more	Sawlog II 100%
	3	30-60	Pulpwood 100%
		>60	Sawlog III 65%, Pulpwood 35%
Very good (1st and 2nd segment are sawlogs II)	1	30 and more	Sawlog II 100%
	2	30 and more	Sawlog II 100%
	3	30-60	Pulpwood 100%
		>60	Sawlog III 65%, Pulpwood 35%
Good (1st segment is sawlog II, 2nd segment is sawlog III)	1	30 and more	Sawlog II 100%
	2	30 and more	Sawlog III 100%
	3	30-60	Pulpwood 100%
		>60	Sawlog III 65%, Pulpwood 35%
Satisfying (1st and 2nd segment are sawlogs III)	1	30 and more	Sawlog III 100%
	2	30 and more	Sawlog III 100%
	3	30-60	Pulpwood 100%
		>60	Sawlog III 65%, Pulpwood 35%
Bad (1st segment is sawlog III or worse, 2nd segment is pulpwood)	1	30 and more	Sawlog III 100%
	2	30 and more	Pulpwood 100%
	3	30 and more	Pulpwood 100%

Table 2: Average buying prices of larch timber assortments ex forest road (€/m^3)

Preglednica 2: Povprečne odkupne cene sortimentov macesna na gozdni cesti (€/m^3)

Assortment class	Buying price ex forest road (€/m^3)
Veneer logs	183.30
Sawlogs I, logs for producing sawn timber of first quality	102.08
Sawlogs II, logs for producing sawn timber of second quality	75.65
Sawlogs III, logs for producing sawn timber of third quality	66.30
Pulpwood	24.23

Table 3: Independent variables tested in the binary logistic regression and multivariate regression model

Preglednica 3: Neodvisne spremenljivke, preizkušene v modelu binarne logistične in multivariatne regresije

Level	Variable	Variable type/ Dependency form	Dummy variables coding	
			Name	Transformation
Tree characteristics	DBH (cm)	continuous/parabolic	-	-
	BAI - basal area increment (cm^2/year)	continuous/parabolic	-	-
	Social status	0/1	Upper layer	1 = social position 1; 0 = other
	Damage presence	0/1	Damage presence	1 = 1,2,3,4: 0 = 0
Stand characteristics	Stand type	0/1	Rejuvenation stand	1 = rejuvenation stand; 0 = other
			Uneven-aged stand	1 = uneven-aged stand, two-layer stand; 0 = other
	BA - basal area (m^2/ha)	continuous/parabolic	-	-
	Spruce share in BA (%)	continuous/linear	-	-
	Larch share in BA (%)	continuous/linear	-	-
	Share of deciduous tree species in BA (%)	continuous/linear	-	-
Site characteristics	Altitude (m)	continuous/parabolic	-	-
	Inclination (°)	continuous/linear	-	-
	Landscape position	0/1	Ridge position	1 = ridge; 0 = other
			Foothills position	1 = foothills; 0 = other
	Aspect	0/1	Sun-exposed site	1 = SE, S, SW, 0 = other
Forest management	Harvesting intensity (m^2/ha, year)	continuous/linear	-	-

3 Results
3 Rezultati

3.1 Quality and assortment structure of larch trees
3.1 Kakovost in sortimentna sestava macesnovih dreves

The share of excellent and very good quality timber amounted to 49%, but the share of veneer logs and sawlogs I was 11.7%. The highest share of excellent and very good quality trees was found in diameter class 13 (60-64 cm) (Table 4, upper part). Conversely, the shares of good and satisfying quality were highest in diameter class 8 (35-39 cm). On average, the majority of trees were classified as good or very good. The trees with dbh above 65 cm are generally classified into lower quality classes than the trees with dbh between 50 and 65 cm. As regards assortment structure, the highest share of veneer logs was established for diameter class 13 (60-64 cm) (Table 4, lower part). The share of this quality is very stable for the trees with dbh above 55 cm. The percentage of sawlogs I increased with dbh. On the other hand, the share of sawlogs III decreased until the dbh of 65 cm, rising again in thicker trees. The most stable shares are observed in sawlogs II and pulpwood.

In addition, the shares of veneer logs and sawlogs I were analyzed by forest types (Figure 2). Only the trees with dbh above 45 cm were included in the analysis. The share of veneer logs was outstandingly high on *Aposeri-Piceetum.* The trend is just the opposite on more extreme beech forest types (*Ostryo-Fagetum, Arunco-Fagetum, Adenostylo-Fagetum*) and on pine forest type (*Pinetum subillyricum*). The share of sawlog I between forest types was much more equal. Lower values were registered on more extreme beech sites and on *Pinetum subillyricum*.

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

Preglednica 4: Deleži (v %) macesnov po debelinskih stopnjah glede na kakovostni razred in sortimentno strukturo (modusi so označeni s krepkim tiskom)

Quality class (tree share in %)	Diameter class (cm)								Average
	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65+	
Excellent	8.5	8.8	17.0	17.4	22.2	24.0	**28.0**	15.4	15,2
Very good	25.6	24.0	35.7	42.6	42.3	40.8	**46.0**	42.3	33.8
Good	56.7	**57.3**	38.7	33.9	27.3	32.0	24.0	30.8	43.0
Satisfying	7.3	**8.3**	6.0	5.8	6.2	2.4	2.0	7.7	6.3
Bad	1.8	1.6	2.5	0.3	2.1	0.8	0.0	**3.8**	1.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Assortment class (volume share in %)	Diameter class (cm)								Average
	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65+	
Veneer logs	0.0	0.0	0.0	1.8	2.1	2.9	**3.0**	2.9	1.4
Sawlogs I	5.6	5.8	10.9	9.5	12.2	12.4	14.6	**15.4**	10.3
Sawlogs II	62.7	61.6	63.5	**66.7**	64.0	66.0	66.6	58.7	64.0
Sawlogs III	24.8	**25.8**	18.4	15.5	14.8	12.0	12.0	18.7	17.8
Pulpwood	6.9	6.8	**7.1**	6.5	6.9	6.7	3.8	4.3	6.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

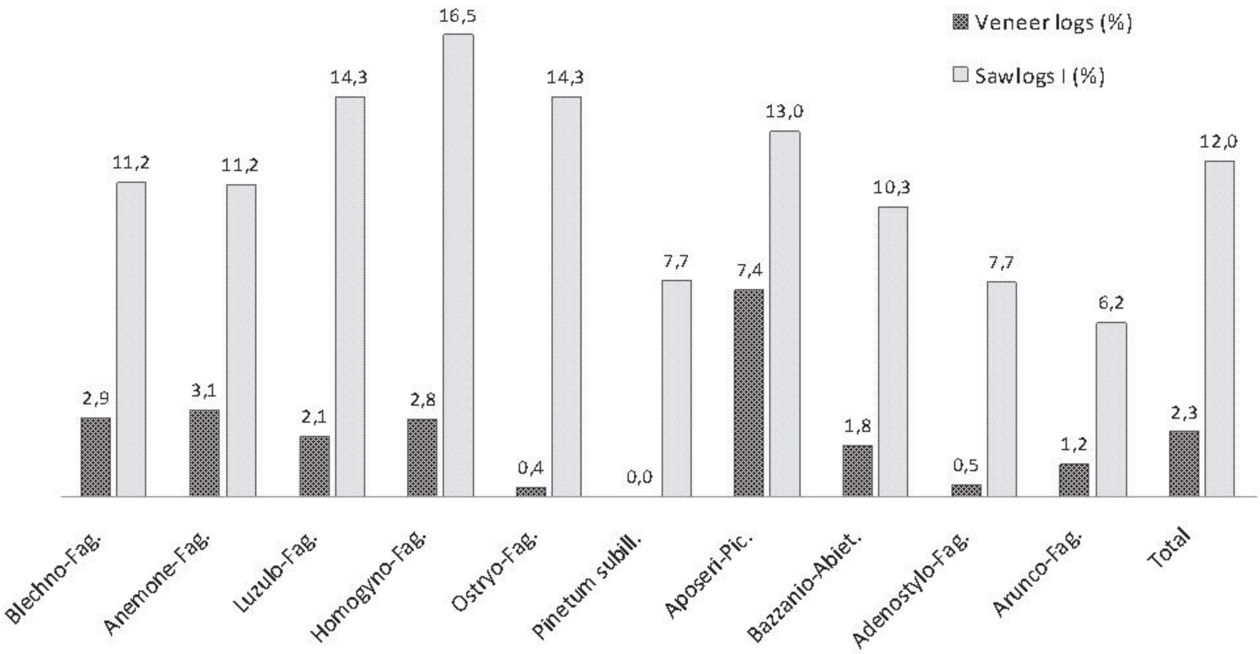

Figure 2: The shares of veneer logs and sawlogs I by forest types

Slika 2: Deleži furnirskih hlodov in žagovcev I po gozdnih tipih

Another aim of the study was to determine which variables influence or predict the veneer quality presence in larch trees (Table 5, left part). Using binary logistic regression, we explained 51.4% of pseudo variance (Nagelkerke's R2 = 0.514). Among the 13 variables (Table 2) selected for the multivariate logistic analysis, eight were included in the model.

In the group of variables denoting tree characteristics, dbh has a positive influence on veneer probability (the chances for veneer quality increase with dbh in a parabolic relationship), while basal area increment increased the probability up to 25 cm^2 $year^{-1}$, and decreased thereupon.

Among stand variables stand type, share of spruce and stand basal area were included in the model. Our results showed that rejuvenation stands increased the probability of high quality larch timber, while the share of spruce in stands decreased it. As regards the stand basal area, the chances for veneer quality increased up to 65-70 m^2/ha, and decreased in larger basal areas.

For site-characteristic variables it could be said that altitude decreased the probability of veneer quality. Surprisingly, the chances for veneer quality were higher on sun-exposed sites and diminished by forest management activities, evident through cutting intensity.

3.2 The value of larch trees

3.2 Vrednost macesnovih dreves

Firstly, the differences in value (in €/m^3) between forest types were analyzed. Taking into account the dependency of value on dbh, we eliminated the influence of this variable on value by obtaining the residuals. For that purpose, the following cubic function was used (P < 0.001):

$$Value = 80.644 - 0.969 \times dbh + 0.0266 \times dbh^2 - 0.000185 \times dbh^3$$

The independent median test showed that differences in residuals between forest types were significant (test statistic = 45.598; P < 0.001). The forest types with significantly higher values of larch trees were *Aposeri-Piceetum* and *Anemone-Fagetum,* while the *Adenostylo-Fagetum, Homogyno-Fagetum* and *Arunco-Fagetum* have lower values.

Furthermore, dependency of value on dbh by forest types (Table 6) was analyzed. On four of the forest types the culmination point was established (parabolic relationship) (Table 6, marked bold), while on the other forest types value increases proportionally at the interval from 30 to 80 cm dbh. On most forest types, the dependency of value on dbh was weak (Appendix 1).

Table 5: Parameters of binary logistic regression (the dependant variable is veneer quality presence in a larch tree) and multivariate regression (the dependent variable is value in €/m^3)

Preglednica 5: Parametri binarne logistične regresije (odvisna spremenljivka je furnirska kakovost) in multivariatne regresije (odvisna spremenljivka je vrednost v €/m^3)

Predictor/ independent variable	Binary logistic regression			Multivariate regression		
	β	Exp(β)	*P*	β	SE(β)	*P*
Constant	-26.177	0.000	0.027	59.722	1.387	0.000
Dbh	-0.849	0.428	0.009	0.219	0.025	0.000
Dbh^2	0.008	1.008	0.006	-	-	-
Upper layer	-	-	-	1.619	0.469	0.001
Damage presence	-	-	-	-6.269	0.975	0.000
BAI	0.122	1.129	0.000	-	-	-
BAI^2	-0.002	0.998	0.001	-	-	-
Rejuven. stand	1.636	5.135	0.014	3.022	0.630	0.000
Uneven-aged st.	-	-	-	1.641	0.674	0.015
Basal area	1.469	4.343	0.000	0.102	0.015	0.000
Basal $area^2$	-0.011	0.989	0.000	-	-	-
Spruce share	-2.979	0.051	0.002	-	-	-
Share of deciduous tree species	-	-	-	3.583	1.259	0.004
Altitude	-	-	-	-0.002	0.001	0.001
$Altitude^2$	-0.000	1.000	0.000	-	-	-
Sun-exposed sites	0.784	2.189	0.051	1.329	0.466	0.004
Harvesting intensity	-2.590	0.075	0.010	-1.014	0.444	0.023

Table 6: The value of larch trees (in €/m[3]) by forest types with regard to dbh

Preglednica 6: Vrednost macesnovih dreves (in €/m[3]) po gozdnih tipih glede na prsni premer

Forest type	dbh (cm)									
	35	40	45	50	55	60	65	70	75	80
Blechno-Fag.	71.8	74.2	76.2	77.7	78.7	79.2	**79.3**	78.9	-	-
Anemone-Fag.	73.1	74.2	75.2	76.1	77.1	78.0	78.9	79.8	80.6	-
Luzulo-Fag.	72.8	74.8	76.3	77.3	**77.6**	77.1	75.9	73.9	-	-
Homogyno-Fag.	69.7	71.4	73.2	75.1	77.0	79.0	81.0	83.1	85.2	-
Ostryo-Fag.	70.2	71.5	72.8	74.1	75.5	76.8	78.1	79.4	-	-
Pinetum subill.	70.4	71.1	71.7	72.3	72.8	73.3	73.7	74.1	-	-
Aposeri-Piceet	73.2	75.7	78.2	80.8	83.3	85.8	88.3	90.9	-	-
Bazzanio-Abiet.	71.0	72.1	72.8	73.6	74.9	77.0	80.3	85.3	-	-
Adenostylo-Fag.	69.0	70.0	71.0	71.8	72.4	**72.5**	72.1	71.0	69.1	66.2
Arunco-Fag.	70.3	72.1	73.6	74.6	75.2	**75.2**	74.8	73.7	-	-

The influence of selected variables on the value of larch wood (in €/m[3]) was tested using the multivariate regression analysis. Despite testing the same set of variables as in binary logistic regression, only about 12% of variance (R^2_{adj} = 0.119) was explained.

The differences in the value of larch trees are clearly explained through the following tree characteristics: dbh (has a positive effect); social status (the upper layer has a positive effect on the value); damage presence (has a negative effect) (Table 5, right part). As regards stand variables, the study showed that values of larch trees were comparatively higher in rejuvenation and uneven-aged stands than in mature stands. Moreover, stand basal area and the share of deciduous tree species increased the value as well. On the other hand, value of larch trees decreased with altitude, and it was higher on sun-exposed sites. Cutting intensity as an indicator of forest management activities in the past ten years negatively influenced the larch timber values.

4 Discussion
4 Razprava

In Alpine areas, larch is a commercially important tree species. However, research into the quality of larch timber is limited in scope and focused mainly on determining the effect of provenance on the quality of timber (e.g. DIETZE 1976, RAU 2004, GIERLINGER *et al*. 2004, PÂQUES 2004, MIHAI / TEODOSIU 2009). Somewhat fewer studies have been undertaken to examine the relations between larch timber quality and stand establishment characteristics (MALINAUSKAS 2003), or the quality of larch trees of natural or semi-natural origin (TEISCHINGER / FELLNER 2000, NAWROT *et al*. 2009).

The research was carried out using forest inventory data, which offered clear advantages, but also raised certain concerns. The main advantage of the approach is that PSP inventory systematically covers the entire study area including various forest types, site conditions, and silvicultural treatments. Furthermore, PSP quality assessment is a fast, low-cost, and robust method and ensures better decision-making in future forest management on the regional and, to a limited extent, local levels. The main weakness of this methodology is classification of larch timber into quality classes. The quality range of the first segment of excellent-quality trees is too wide, and the quality of the second segment, which depends on the quality of the first segment, is rather loosely defined. As a result, calculations of assortment structure from estimated quality classes are not detailed enough and there is urgent need for more detailed research or data. Another weakness of this approach is the division of coniferous species stems into thirds, which means that the upper third of the tree is automatically classified as pulpwood. In our research, this assumption frequently proved incorrect, since sawlog timber can also extend into the upper third of the stem. Furthermore, higher quality timber was rarely present throughout the lower third of the stem, which could cause an overestimation of larch quality on the PSP. The analyses showed that only 1.4% of the 15.2% of excellent-quality trees was classified as veneer logs. Therefore, we can conclude that it would be better to divide coniferous trees into four segments (quarters) as is already a common practice in broadleaves (Pravilnik …, 2010). Such a partition would render classification more precise (for example, the first quarter of the stem would then be classified as sawlog I, the second quarter as sawlog II, the third quarter as sawlog III, and the last quarter as pulpwood). It would also facilitate treatment and management of various timber assortments (e.g. packaging timber, posts and poles and pulpwood). An unsolved issue is also classification of other assortments like thin technical wood or packaging timber.

The performance of the models was relatively low, mainly due to the great variability of the dependent variables, but partly also due to a lack of independent variables comprehensively describing site and past forest management conditions. Among 14 selected tree, stand, site and forest management variables, eight were included in the logistic model and nine in the multiple regression model. Diameter at breast height (dbh) was found to have a significantly positive effect on larch tree quality and timber value. Typically, the value of larch trees did not culminate at certain diameter, but proportionally increased with increasing dbh. This could be explained by a higher resistance of larch to decay or other within-stem defects than normally observed in spruce, fir or beech, in which the relationship between value and diameter is normally parabolic and culminates between 50 and 65 cm (ŠUŠNJAR 2001, REBULA / KOTAR 2004, REBULA 2005). Another factor determining the probability of high quality timber is basal area increment. Furthermore, the value of larch trees is also affected by the social status of a tree and presence of major damages. Since trees in the upper stand layer (dominant trees) receive more light, their growth is regular but still intensive enough to ensure that the value of the tree will increase with dbh (NAWROT *et al*. 2009), while on the other hand, tree quality is negatively influenced by presence of major damage. Crown damage and defoliation both have a negative effect on tree growth (e.g. VEJPUSTKOVÁ / HOLUŠA 2006): both factors reduce timber quality indirectly (*ibid*.), but trunk damage has a direct negative effect on the quality of trees and their values (McCOMB 1955, KOŠIR 2008).

In the group of stand variables, stand basal area (stand density) was included in both models. It was found that the share of broadleaves significantly affects only the value of larch timber, whereas the share of spruce decreases the probability for veneer logs. The influence of stand density on the probability of veneer logs is unexpected. Since larch trees are shade intolerant, the probability of high quality timber was expected to rise in stands with low stand density. Surprisingly, the research showed that the probability was highest in relatively dense stands. A possible explanation could be that in the most valuable coniferous timber tree rings have to be narrow and regular, which means that larches should not be released too early, at a stage when they still experience high growth rates. Therefore, the thinning intensity in middle-aged stands must be conservative until the stands reach maturity. Afterwards, larches can be released to obtain modest growth rates, without risking deterioration to their stem shape and quality.

Furthermore, the presence of broadleaves in stands has a positive influence on the value of larch timber. The presence of spruce reduces the probability for veneer logs. Since mature broadleaves generally achieve lower heights, broadleaved tree species, in particular beech, normally grow in the under-story of larch stands and contribute favourably to the height growth of larch trees and the pruning of their branches. On the other hand, spruce is more competitive to larch trees than beech (McCOMB 1955, MOTTA / EDOUARD 2005); due to crown competition, it negatively affects the diameter growth of larch trees, which might lead to a decrease in the share of most valuable assortments.

Silvicultural treatments create various stand structures and thus different conditions for tree growth and production of high-quality trees. Results showed that the probability for veneer logs was 1.64 times higher in rejuvenation stands compared to mature stands. Higher values of larch trees were also registered in uneven-aged stands. Owing to their light intolerance, larch trees require better light conditions and open stands to thrive, in particular when the trees are older. Therefore, the crown could be released to maintain the increment level when the length of a branch free bole is long enough. Higher quality of larch trees in uneven-aged stands is the result of spatially-variable harvesting intensity, which has led to an increase in more open, uneven-aged stand structures. Such stand structures create favourable light conditions for mature larch trees, and on the other, the trees of various stand heights support and enhance height growth of upper-story larch trees and positively affect the process of pruning.

Unexpectedly, the results of the study pointed out that harvest intensity negatively influenced the probability of veneer logs as well as timber value. A possible explanation could be that keeping more closed stands facilitates pruning and supports modest growth dynamics, while another explanation might be that trunk damage, known to decrease stand quality, is more frequent in more intensively managed stands.

Among site variables, aspect and elevation were included in the model. The probability of veneer logs as well as timber quality was highest on sun-exposed sites. More detailed analyses showed that the highest-quality larch timber in the Karavanke range was often found in secondary forest associations (e.g. *Aposeri-Piceetum*). These stands were most likely established through secondary succession in former high-altitude meadows and currently overgrow sun-exposed slopes (DAKSKOBLER *et al*. 2010).

Besides spruce and beech, European larch is the most abundant tree species in the Karavanke mountains. The study showed that the quality of larch timber in the Karavanke was slightly below the data for the larch distribution area in Slovenia (POLJANEC *et al*. 2010), but still considerably above the data for other commercially important tree species (e.g. beech and spruce) within the study area (data not shown). On account of favourable quality and excellent characteristics of the wood, which make larch suitable for a variety of technical uses, European larch retains its status of a commercially important tree species in the Karavanke range. We can conclude that an increase in the share of larch in the growing stock as well as improved quality structure of mature larch trees will continue to pose a challenge for forest management in the future.

5 Povzetek
5 Summary

Na podlagi stalnih vzorčnih ploskev Zavoda za gozdove Slovenije, na katerih ocenjujemo tudi kakovost debel, smo analizirali kakovostno in vrednostno strukturo macesna. Nadalje smo z logistično regresijo in multivariatno regresijsko analizo preverili, katere izmed značilnosti dreves, sestojev, rastišča in gospodarjenja z gozdovi vplivajo na kakovost in vrednost macesnovih dreves. V vzorec smo zajeli 1847 dreves macesna s prsnim premerom 30 cm ali več. Izbrana mreža stalnih vzorčnih ploskev je pokrila celoten razpon rastiščnih in sestojnih razmer. Na podlagi manjšega vzorca posekanih dreves (168 macesnov) smo kakovost, ocenjeno na stalnih vzorčnih ploskvah po 5-stopenjski lestvici, transformirali v sortimentne razrede. S pomočjo cenika sortimentov in ugotovljenih volumnov drevja po sortimentnih razredih smo ugotovili vrednost lesa na kamionski cesti.

Najugodnejša sortimentna sestava izkazuje drevje 13. debelinske stopnje. Sicer pa ima drevje nad 50 cm praviloma precej podobno kakovostno strukturo. Najvišje deleže kakovostne hlodovine macesna smo registrirali na gozdnem tipu *Aposeri-Piceetum*, najmanj kakovostnih dreves macesna pa smo zaznali na skrajnejših bukovih rastiščih (*Ostryo-Fagetum, Arunco-Fagetum, Adenostylo-Fagetum*) in v borovih gozdovih (*Pinetum subillyricum*). Furnirska kakovost, ki je sicer redka, je odvisna od prsnega premera, temeljničnega prirastka, sestojne temeljnice, sestojnega tipa, deleža smreke, nadmorske višine, lege in intenzivnosti sečenj.

Multivariatna regresijska analiza je pokazala, da na vrednost lesa vplivajo podobni znaki kot na pojav furnirske hlodovine. Podrobnejše analize so pokazale, da vrednost lesa na večini gozdnih tipov z debelino drevja ne kulminira in da tudi sicer debelina drevja pojasni sorazmerno majhen delež variabilnosti vrednosti lesa. Poleg prsnega premera variabilnost vrednosti macesnovih dreves pojasnjujejo še: socialni status, poškodovanost, sestojni tip, sestojna temeljnica, delež listavcev, nadmorska višina, lega in intenzivnost sečenj.

Naše ugotovitve kažejo, da je v odraščajočem obdobju za kakovost oziroma vrednost macesna ugoden tesnejši sestojni sklep, zlasti konkurenca listavcev, kar omogoča, da se deblo zgodaj očisti vej in je debelinsko priraščanje zmerno. Kasneje, ko je dolžina čistega debla že zelo velika in je ni treba povečevati ter je rast starostno že umirjena, je macesen smiselno sprostiti, da se omogoči zmerno priraščanje. Ker se oblika in kakovost debla pri sproščenem, odraslem macesnu praviloma ne poslabšata, so tako mogoči precejšnji vrednostni prirastki tudi pri večjih prsnih premerih.

Karavanke veljajo za območje, kjer je kakovost macesnovih dreves v primerjavi z drugimi drevesnimi vrstami zelo visoka. Poleg ugodne kakovostne zgradbe macesna in cenjenih lastnosti lesa ima macesen v Alpah tudi pomembno ekološko vlogo, zato bi v prihodnje kazalo tej drevesni vrsti posvečati več pozornosti in jo ohranjati in pospeševati tako v primarnih macesnovih sestojnih kot tudi na rastiščih, kjer se pojavlja kot naravno primešana vrsta.

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Appendix 1: The parameters of regression analysis of value dependency on dbh by forest types

Priloga 1: Parametri regresijske analize odvisnosti premera od vrednosti macesnovih dreves po gozdnih tipih

Forest type	N	Function	R^2	P
Blechno-Fagetum	99	$41.306 + 1.203x - 0.010x^2$	0.080	0.018
Anemone-Fagetum	459	$64.978 + 0.253x - 0.0001x^2$	0.024	0.004
Luzulo-Fagetum	152	$49.426 + 0.773x - 0.0000865x^3$	0.043	0.038
Homogyno-Fagetum	274	$58.410(1.005^x)$	0.165	0.000
Ostryo-Fagetum	195	$61.093 + 0.261x$	0.111	0.000
Pinetum subillyricum	70	$54.308(x^{0.073})$	0.053	0.054
Aposeri-Piceetum	152	$55.159 + 0.505x$	0.103	0.000
Bazzanio-Abietetum	136	$19.722 + 3.301x - 0.071x^2 + 0.001x^3$	0.244	0.000
Adenostylo-Fagetum	182	$72.328 - 0.607x + 0.021x^2 - 0.000177x^3$	0.040	0.066
Arunco-Fagetum	128	$51.475 + 0.612x - 0.0000600x^3$	0.086	0.004