The Incidence of Rot in Norway Spruce and its Influence on the Value of Trees in Slovenia

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Abstract – Nacrtak

*Rot is one of the most important defects in timber assortments of Norway spruce (*Picea abies*). With the aim to investigate this phenomenon, we analyzed 1,334 spruce trees from 65 locations across Slovenia. The study showed that the incidence of rot was higher in even-aged stands compared to uneven-aged stands. Lower-trunk rot (for the purpose of this study, lower-trunk rot is rot that affects the stem up to 5 m above ground) is significantly connected with the diameter of the tree, whereas rot in the upper part of the trunk, i.e. upper-trunk rot, does not show such dependence. Rot is most commonly associated with dolomite bedrock. Its incidence increases with tree age, site productivity, and site altitude. Mechanical stem injury is another contributing factor. On the other hand, slender trees, sun-exposed sites, and uneven-aged stands carry a lower risk for the studied defect. The incidence of rot may decrease the value of usable timber by as much as 19 €/m^3, with the decrease being highest in 50 to 70 cm tree diameter.*

Keywords: rot, Norway spruce, Slovenia.

1. Introduction – *Uvod*

In North and Central Europe, Norway spruce (*Picea abies* (L.) Karst.) is generally considered as the leading tree species in terms of economic value (Kenk and Guehne 2001; Jöbstl 2011). However, the species' distribution outside its natural sites and the unstable structure of its stands (monocultural stands, even-aged stands) have prompted forestry to look for suitable methods to convert these forests into more stable and more natural structures (Knoke and Plusczyk 2001). Despite the high risks associated with artificial spruce stands and their questionable value in terms of ecology, contemporary studies have confirmed that a significant addition of spruce in broadleaved stands is economically justifiable (Knoke et al. 2008).

The high commercial value of spruce, as well as numerous dilemmas and issues related to the management of forest stands, where spruce holds a significant or even predominating share, have become the driving force following the analyses of the quality and value characteristics of Norway spruce and its stands.

The incidence of rot is one of the most important problems in spruce management (Kohnle and Kändler 2007). The organisms responsible for the decay process are various fungi, including *Heterobasidion annosum* s.l., *Armillaria* spp., and *Stereum sanguinolentum* (Graber 1996; Čermák et al. 2004, Korhonen and Holdenrieder 2005; Arhipova et al. 2011). The decay normally starts through the infection of the roots, which then spreads to the trunk. Alternatively, a tree may become infected through a wound in its bark or stem (Kohnle in Kändler 2007), which either occurs during mechanical harvesting (Ivanek 1976; Vasiliauskas 2001) or is caused, in certain cases, by animals fraying against the tree or consuming its bark (Čermák et al. 2004).

Assessments of timber value losses clearly demonstrate that spruce rot is a serious economic issue. For EU countries, value loss due to rot caused by the fungus *Heterobasidion annosum* s. l. (Woodward et al. 1998) was assessed at EUR 790 million for 1998, but may be well above that mark (Seifert 2007).

The negative effects of spruce rot, however, reach beyond timber assortment structure (Gonthier et al. 2012); they affect volume increment growth (Oliva et al. 2010) and mechanical stability (Dimitri in Tomiczek 1998) of stands, and increase the cost of harvesting operations (additional log shaping).

The occurrence of the disease is associated with a variety of factors, including past land use, stand characteristics, soil factors, and silvicultural measures (Woodward et al. 1998; Jurc 2001). Nevertheless, the results of the studies are often inconclusive (Rönnberg and Jørgensen 2000) and the disease has not been thoroughly studied in all its complexity (Seifert 2007; Arhipova et al. 2011). Furthermore, a comprehensive study of spruce rot would need to take into account considerable differences in the studied rot that exist between climatic regions and soil conditions (Seifert 2007; Gonthier et al. 2012).

Spruce rot can be caused by a variety of causal agents, which the studies find difficult to distinguish reliably (Kohnle and Kändler 2007). Also, fungal taxonomy is a complex task requiring extensive laboratory work (Arhipova et al. 2011). In the light of the above, the present study only focuses on determining the presence of rot in a tree, without studying its cause and decay rate.

The aim of this study was to (1) determine the incidence of rot in spruce trees by tree diameter, stand type, and site conditions; (2) illustrate the effect of rot on loss in timber value; and (3) outline the stand characteristics which may lead to the occurrence of rot.

2. Matherials and Methods – *Materijal i metode*

2.1 Study area – *Područje istraživanja*

The aim of the research was to cover the maximum range of growth site conditions under which Norway spruce becomes an important element for forest stands. The sample included even-aged and uneven-aged stands, with the main focus on mature stands. Aware of the fact that only felled trees would be analyzed and that the choice of trees to be harvested was often rather subjective (Matić et al. 2003; Prka 2006), the study area was expanded to include a higher number of locations, thereby covering a large part of Slovenian territory where spruce is a common element of commercial forests. The first focal area covered the forests of North Slovenia in the Alpine arc (Gorenjska, Koroška, Pohorje), and the second encompassed the Dinaric part of South Slovenia (Dolenjska, Kočevska); the study plots in Central Slovenia are relatively dispersed.

In total, the study included spruce trees from 65 sites, i.e. 20 different plant associations, which allowed us to cover all the major site strata. In the course of the study, a total of 1,334 spruce trees were felled, of which 1,015 came from even-aged stands and 319 from uneven-aged stands. The average diameter at breast height (hereafter: DBH) amounted to 47.5 cm (maximum DBH was 98.5 cm) and the average height was 30.8 m (maximum height 53.8 m). The average age of the analyzed trees was 112.8 years, and the oldest analyzed tree was 224 years old.

2.2 Research methods – *Metode istraživanja*

Prior to the felling, all sample trees were measured for diameter at breast height (DBH) and checked for other special characteristics, e.g. forked tops, stem or butt log damage (mechanical injury), and broken tops.

During harvesting operations, stem analyses of sample trees were carried out (Pranjić and Lukić 1997; Husch et al. 2003; Kahle et al. 2008). Each section of the stem was classified into a quality class according to the JUS standard for coniferous logs (D.B4.029 1979). This standard was used because it continues to be the prevalent standard used in timber trade in Slovenia. The length from the stump to the crown base was also measured. The obtained data were used to calculate the relative crown length (RCL) with the following formula:

Relative crown length: (tree height – crown base)/tree height

Stem analysis data were used to calculate the mean ring width and slenderness ratio (tree height /diameter at breast height).

Each stem cross-section was checked for rot, and the presence or absence of rot was recorded. However, as the extension of rot was not consistently measured in all the sampled trees, these data were not included in the analysis. The stage of wood decay was also not consistently assessed. For the above reasons, the occurrence of rot was only studied as a binary variable (present/not present). However, since all stem sections were checked for signs of the disease, we were able to distinguish between the rot that affected the lower part of the trunk up to 5 m from the ground (hereafter: lower-trunk rot), and rot in the upper sections of the trunk, above the 5 m mark (hereafter: upper-trunk rot). Clearly, in certain spruce trees, rot was present in the lower as well as upper sections of the tree. However, as spruce rot is more common in the lower parts of the trunk and lower-trunk rot has the highest effect on timber value, most analyses were only carried out for this form of disease.

At each harvest site an appropriate number of dominant (thickest) trees were also harvested, in addition to other trees, to provide the data required for the calculation of the site index (Kotar 2005; Charru et al. 2010). Using standardized methodology (Kotar 2005; Van Laar and Akça 2007), the site index for reference age of 100 years (hereafter: SI_{100}) was determined by measuring the tree height and age.

The value of wood at the roadside was calculated by multiplying the volume of each assortment class by the price for that quality class. To calculate the prices for timber assortments at the roadside, we first calculated the current average prices offered by 10 Slovenian forestry companies dealing in timber trade and relevant for the studied tree species.

The following price list was used for the calculation of prices at the roadside:

⇒ veneer logs 205.68 €/m^3,
⇒ sawlogs, class I, 92.00 €/m^3,
⇒ sawlogs, class II, 66.58 €/m^3,
⇒ sawlogs, class III, 54.31 €/m^3,
⇒ pulpwood, 24.23 €/m^3.

With a view to calculating the differences in value between rot-infected trees and healthy trees by individual strata, we first used a second order parabola, commonly applied in similar analyses (Prka 2003), to determine the dependence of the price at the roadside on DBH.

In the second step, the values for rot-infected trees (by strata) were deducted from the values for trees without rot.

On account of the high number of forest associations or site units included in the study, the results of these analyses were divided by stand type (even-aged and uneven-aged stands), and type of bedrock (limestone, dolomite, silicate).

After studying the scatter graph data, we decided to use linear regression to calculate the dependence of the share of rot-affected trees on diameter class.

Then, the study focused on determining the factors associated with the incidence of rot (in the lower and upper sections of the stem). The following parameters were tested as predictors: DBH, height, age, slenderness ratio, average ring width, relative crown length, SI_{100} (in parabolic form), altitude, sun exposure (a dichotomous variable: trees from south facing locations are coded 1, other trees 0), trunk damage (a dichotomous variable: trees with wounded stems are coded 1, other trees 0), top breakage (a dichotomous variable: trees with broken tops are coded 1, other trees 0), forked tops (a dichotomous variable: trees with forked tops are coded 1, other trees 0), stand type (a dichotomous variable: trees from even-aged stands are coded 1, other trees 0) and bedrock (two dummy variables were formed: silicate, where silicate bedrock is coded 1, and limestone and dolomite are coded 0, and dolomite, where dolomite bedrock is coded 1, and the other two are coded 0).

The probability of rot presence (lower-trunk rot or upper-trunk rot) was modeled using a binary logistic regression. Rot-affected trees were coded 1 and healthy trees were coded 0. The model was estimated in PASW SPSS Statistics 18 using the 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.

All statistical analyses were conducted in PASW SPSS Statistics 18.

3. Results – *Rezultati*

3.1 Occurrence of rot with regard to stem part, stand type and bedrock – *Pojava truleži s obzirom na dio stabala, tip sastojine i matičnu podlogu*

Signs of rot were detected in more than a third of all spruce trees in the analyzed sample (Table 1). The data show that the occurrence of lower-trunk rot and upper-trunk rot is relatively more frequent in even-aged stands. Considerable differences exist, however, in the frequency of lower-trunk rot and upper-trunk rot: lower-trunk rot was found in 34% and 26% of all trees in the sample in even-aged and uneven-aged stands, respectively, whereas in only 14% and 11% of trees rot was found in the upper part of the stem.

In even-aged stands, the share of trees that have succumbed to lower-trunk rot is substantial already in relatively small trees. In trees from uneven-aged stands, the share of trees with lower-trunk rot is initially very low, but rises markedly with the diameter. In both stand types, the share of trees with lower-trunk rot varies considerably between diameter classes.

The share of trees with upper-trunk rot is moderate in relatively small trees, but shows no clear trend when the diameter increases.

The increase in DBH has no effect on the increase in the share of upper-trunk rot (Fig. 1). The grey straight lines are not statistically characteristic (Appendix 1); however, they indicate that the disease is slightly less common in uneven-aged stands. The in-

Table 1 Share of rot-infected trees by diameter class, with regard to stand type and rot location

Tablica 1. *Udjel natrulih stabala po debljinskim razredima s obzirom na vrstu sastojine i mjesto javljanja truleži*

Diameter class *Debljinski razred*	Even-aged stand – *Jednodobna sastojina*				Uneven-aged stand – *Raznodobna sastojina*			
	Share of rot-infected trees, % *Udjel natrulih stabala, %*			Number of analyzed trees *Broj stabala*	Share of rot-infected trees, % *Udjel natrulih stabala*, %			Number of analyzed trees *Broj stabala*
cm	Lower-trunk rot *Trulež u donjem dijelu debla*	Upper-trunk rot *Trulež u gornjem dijelu debla*	Lower and upper-trunk rot *Trulež na oba kraja debla*		Lower-trunk rot *Trulež u donjem dijelu debla*	Upper-trunk rot *Trulež u gornjem dijelu debla*	Lower and upper-trunk rot *Trulež na oba kraja debla*	
2.5	–	–	–	–	0.0	0.0	0.0	5
7.5	–	–	–	–	0.0	0.0	0.0	5
12.5	18.9	2.7	18.9	37	0.0	12.5	12.5	8
17.5	15.2	6.1	18.2	33	0.0	0.0	0.0	5
22.5	41.4	17.2	48.3	29	7.7	30.8	38.5	13
27.5	26.7	22.2	37.8	45	16.7	0.0	16.7	12
32.5	19.7	14.5	31.6	76	5.6	11.1	16.7	18
37.5	38.6	17.1	50.0	140	0.0	14.3	14.3	14
42.5	40.8	16.7	46.7	120	26.5	26.5	47.1	34
47.5	31.3	15.3	43.5	131	31.3	6.3	34.4	32
52.5	36.1	12.6	45.4	119	44.0	4.0	44.0	25
57.5	37.5	15.0	46.3	80	36.7	10.0	40.0	30
62.5	31.3	10.0	35.0	80	35.7	3.6	35.7	28
67.5	36.5	19.2	42.3	52	27.0	5.4	32.4	37
72.5	42.9	2.9	42.9	35	40.0	6.7	40.0	15
77.5	57.9	21.1	68.4	19	35.7	7.1	35.7	14
82.5	41.7	25.0	50.0	12	30.8	30.8	53.8	13
87.5	50.0	16.7	50.0	6	25.0	25.0	25.0	8
92.5	100.0	0.0	100.0	1	–	–	–	–
97.5	–	–	–	–	33.3	0.0	33.3	3
Total ***Ukupno***	**34.2**	**14.5**	**42.4**	**1015**	**26.0**	**11.0**	**33.2**	**319**

cidence of lower-trunk rot rises with DBH, reaching higher shares in even-aged stands. In these stands, the disease is quite common in small trees. On the other hand, the incidence of rot rises more markedly in uneven-aged stands, but even in large-diameter trees the value stands below the figures for even-aged stands. A similar upward trend is also observed in the share of trees where rot is present in the lower or upper part of the trunk, mainly due to the increase in the share of trees showing signs of lower-trunk rot. In trees with DBH greater than 50 cm, the share of lower-trunk rot stands at 30%, and pushes towards 40% or higher in large-diameter trees. Regression parameters are given in Appendix 1. The regression analysis only explains a small part of the variability, which confirms its stochastic nature.

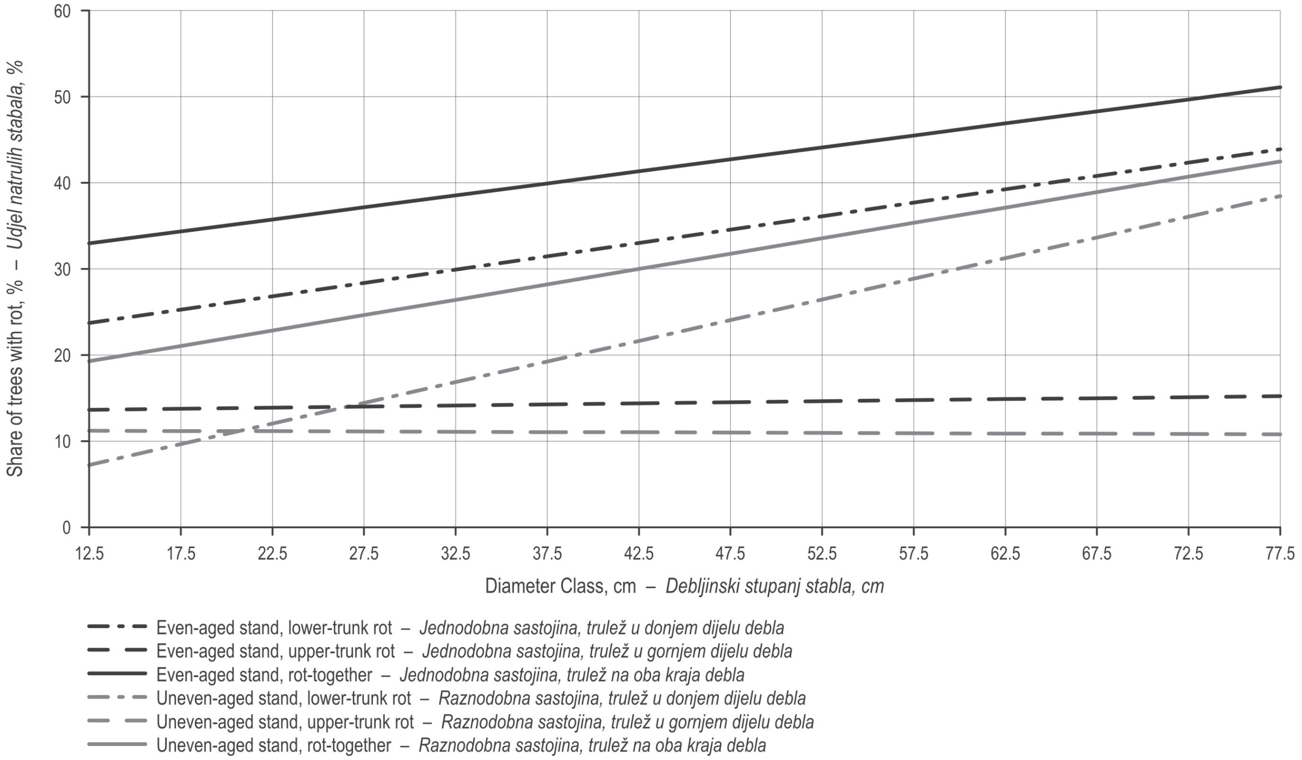

Fig. 1 Share of rot-infected trees with regard to stand type and rot area
Slika 1. *Udjel natrulih stabala s obzirom na vrstu sastojine i mjesto javljanja truleži*

Table 2 Relationship between lower-trunk rot and upper-trunk rot (contingency test)
Tablica 2. *Povezanost pojave truleži u donjem i gornjem dijelu debla (test slučaja)*

$\chi^2 = 8.752$ $P = 0.003$		Upper-trunk rot – *Trulež u gornjem dijelu debla*				Total – *Ukupno*	
		Not present – *Nije prisutna*		Present – *Prisutna*			
		Observed frequency *Izmjerena frekvencija*	Expected frequency *Očekivana frekvencija*	Observed frequency *Izmjerena frekvencija*	Expected frequency *Očekivana frekvencija*	Observed frequency *Izmjerena frekvencija*	Expected frequency *Očekivana frekvencija*
Lower-trunk rot *Trulež u donjem dijelu debla*	Not present *Nije prisutna*	798	780.7	106	123.3	904	904
	Present *Prisutna*	354	371.3	76	58.7	430	430
Total – *Ukupno*		1152	1152	182	182	1334	1334

In the next step of the study, we decided to verify whether the presence of lower-trunk rot is connected with the occurrence of rot above the 5 m mark. To this aim, a contingency test was conducted (Table 2), which showed that the relationship between the phenomena is statistically significant. If rot has affected the lower part of the stem, the probability that it will also affect the upper sections of the trunk is higher, and vice versa.

Taking into account the higher incidence of lower-trunk rot compared to upper-trunk rot and close relationship between the two phenomena, we decided to carry out a more detailed analysis into the dependence of lower-trunk rot upon stand type, bedrock and di-

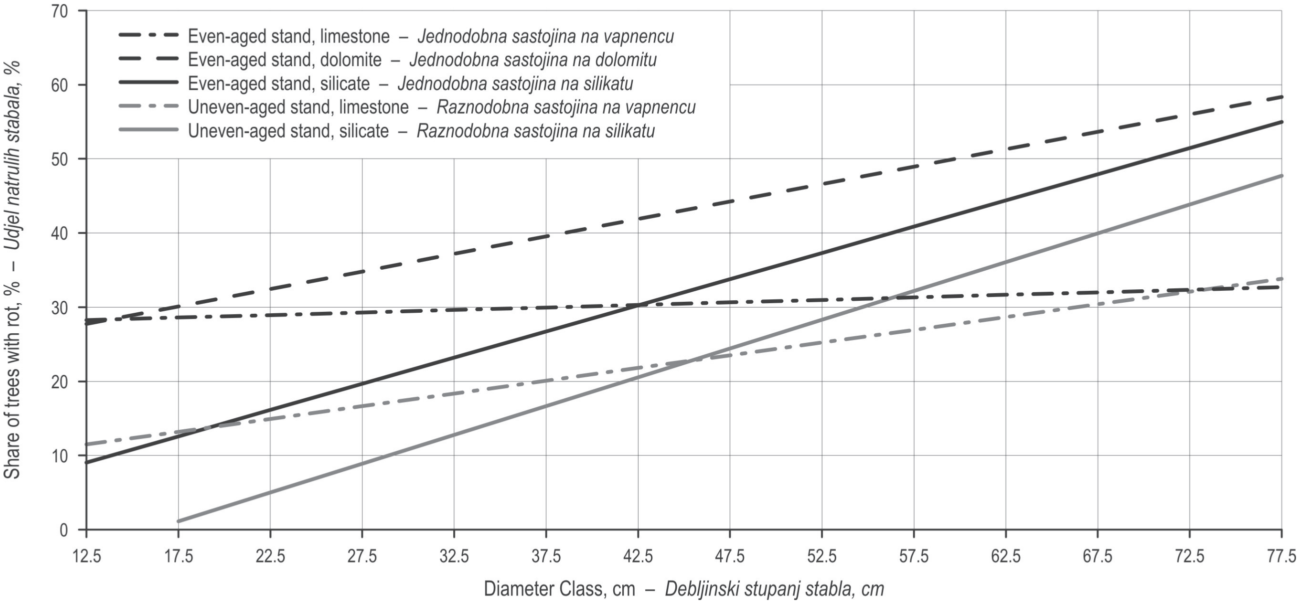

Fig. 2 Share of trees with lower-trunk rot with regard to stand and bedrock type

Slika 2. *Udjel natrulih stabala (trulež u donjem dijelu debla) s obzirom na vrstu sastojine i matičnu podlogu*

ameter (Fig. 2). The differences between bedrock types are substantial. Even for small trees, the share of rot is high in even-aged stands on limestone and dolomite, and obviously increases with diameter. On limestone sites (even-aged stands), the share of rot-infected trees rises slowly. Large-diameter trees growing on limestone bedrock show no difference between even-aged and uneven-aged stands. On silicate bedrock, the share of rot is low in small trees, particularly in uneven-aged stands. It increases with the diameter in both stand types, but the difference between stand types is preserved. In large-diameter trees, rot inci-

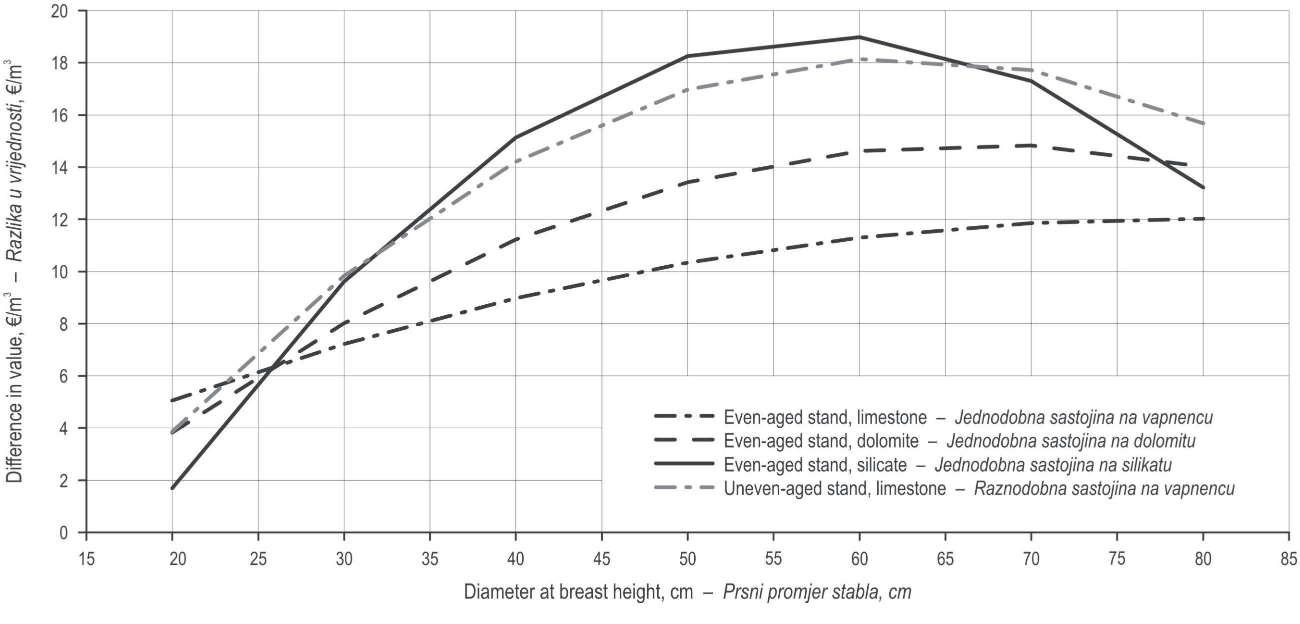

Fig. 3 Differences in average usable timber values by stand and bedrock type

Slika 3. *Razlike u vrijednosti drva s obzirom na vrstu sastojine i matičnu podlogu*

Table 3 Parameters for the binary logistic regression (for the left part the outcome variable is lower-trunk rot and for the right part the outcome variable is upper-trunk rot)

Tablica 3. *Parametri binarne logističke regresije (za lijevi dio ishodna je varijabla: trulež u donjem dijelu debla, a za desni dio ishodna je varijabla: trulež u gornjem dijelu debla*

Predictor – *Prediktor*	Lower-trunk rot – *Trulež u donjem dijelu debla*			Upper-trunk rot – *Trulež u gornjem dijelu debla*		
	β	Exp(β)	P	β	Exp(β)	P
Constant – *Stalnica*	-3.961	0.019	0.0000	-5.715	0.003	0.0000
Stand type – *Vrsta sastojine*	0.275	1.317	0.0976	–	–	–
SI_{100} – *Bonitet staništa*	0.068	1.070	0.0000	0.055	1.057	0.0134
Dolomite – *Dolomit*	0.841	2.318	0.0000	1.282	3.603	0.0000
Silicate – *Silikat*	–	–	–	1.849	6.354	0.0000
Altitude – *Nadmorska visina*	0.001	1.001	0.0006	–	–	–
South-facing site – *Stanište s južnom ekspozicijom*	-0.285	0.752	0.0936	–	–	–
Age – *Dob*	0.007	1.007	0.0105	–	–	–
Slenderness ratio – *Mjera vitkosti*	-0.019	0.981	0.0005	–	–	–
Trunk damage – *Mehaničke ozljede debla*	1.696	5.450	0.0000	1.101	3.009	0.0000
Top breakage – *Slomljen vrh*	–	–	–	3.195	24.409	0.0000
Forked tops – *Rašljavo stablo*	–	–	–	2.424	11.296	0.0000

dence is highest on dolomite bedrock (even-aged stands), followed by even-aged stands on silicate ground, and uneven-aged stands on the same bedrock. In general, rot is less frequent in uneven-aged stands. As regards tree diameter, rot affects about 45% of trees with DBH about 50 cm on dolomite ground, between 25% and 35% of such trees on silicate bedrock, and between 25% and 30% of such trees on limestone. In large-diameter trees, the share of rot on dolomite pushes above 50% and above 40% on silicate. The regression parameters are given in Appendix 1. The regression analysis explains a relatively small part of variability (Appendix 1).

3.2 Value loss due to rot – *Gubitak vrijednosti drva zbog pojave truleži*

Value loss, i.e. the difference in the value of spruce timber due to rot, was determined for all strata for which sufficient data was obtained, in relation to the tree diameter (Fig. 3). The loss in €/m^3 is highest on silicate ground, in even-aged stands, and on limestone, in uneven-aged stands. It is lowest, however, in even-aged stands on limestone bedrock. The loss is relatively low in small trees (less than 8 €/m^3), and considerably higher in trees with DBH between 50 and 70 cm (15–19 €/m^3). In larger diameter trees, the loss drops again. Regression parameters are given in Appendix 1.

3.3 Value factors affecting the incidence of rot *Čimbenici koji utječu na pojavu truleži*

A binary logistic regression method was used to test both types of disease, lower-trunk rot and upper-trunk rot, for factors affecting its occurrence. Lower-trunk rot is more likely to occur on high-productivity sites, on dolomite bedrock, at higher altitude, in older and wounded trees (Table 3, left). Tree slenderness reduces the probability of lower-trunk rot. The results also indicated that the disease is more likely to occur in even-aged stands and less on south-facing sites. The model explained a total of 17.8% pseudovariance (Nagelkerke's $R^2 = 0.178$).

Upper-trunk rot is also more likely to develop on high-productivity sites, on dolomite and silicate bedrock, in wounded trees, trees with broken tops, and trees with forked stems (Table 3, right). The model explained a total of 30.0% of pseudovariance. (Nagelkerke's $R^2 = 0.300$).

4. Dicussion and conclusion – *Rasprava i zaključci*

Rot infection in trees can be assessed using a variety of methods. These can be either destructive or invasive (tree felling, extracting increment cores) or non-destructive (vibro-acoustic diagnostics, electromagnetic radiation methods) (Oliva et al. 2011). According to the existing study results, non-destructive methods lack accuracy (Oliva et al. 2011) and, surprisingly, the results of extracting cores have also shown to be relatively unreliable (Stenlid and Wästerlund 1986).

The present study has shown that the frequency of rot mainly increases with the diameter at breast height. However, the relationship between the two is not tight, in particular on limestone bedrock and on high-productivity sites. Besides, the incidence of rot in the upper sections of the stem is not related to tree diameter. The analyses conducted by Kotar (2006) also confirmed the high stochastic value of rot in Norway spruce, pointing to a high local variability of the phenomenon. This supports the finding that rot occurs in clusters of trees (Piri et al. 1990). Most studies state that rot is more likely to be found in large stumps (Arhipova et al. 2011; Gonthier et al. 2012). There are two possible explanations for that: first, infected trees try to compensate for the loss of their decaying tissue through faster increment growth, or, secondly, large trees are more at risk because their growth is faster and they are quick to get in contact with infected stumps (Arhipova et al. 2011).

Our results show that rot is less frequent in uneven-aged stands, which confirms the findings of other studies (Gorše 2009) and, indirectly, supports the observation that the quality of usable timber is higher in selection forests (Knoke 1998; Hanewinkel 2001).

Mechanical injury to trees (trunk and roots) resulting from timber harvesting is closely related to the occurrence of rot (Ivanek 1976; Vasiliauskas 2001). A German study showed that practically all spruce trees with bark injury were infected with rot (Kohnle and Kändler 2007). The latter points to a high importance of careful planning and implementation of forestry operations in spruce stands, since the share of wounded trees in these stands increases greatly with the number of thinning operations (Košir 1998, 2008), whereas the extent and type of wound damage depend on the selected technology and management intensity (Fjeld and Granhus 1998; Košir 2008).

The occurrence of rot is associated with considerable losses in usable timber value, in particular in Norway spruce (Piškur 2001). The study showed that the loss amounted to 20 €/m^3, which is 5–25% of timber value. In Italy the direct financial loss caused by rot was assessed at 18–34% of timber value (Gonthier et al. 2012). Piškur (2001) stated a 23% decrease in the timber value of spruce trees which were subject to a mechanical injury that normally leads to the decay of the wounded part. This drop in price was considerably higher than observed in fir, which is less vulnerable to mechanical injury (Kohnle and Kändler 2007). In Scandinavian sites, rot is responsible for a 2–9% loss in timber values on the stump, depending on the degree of infection, (Möykkynen et al. 1998), but in most cases the infected trees were low in diameter. According to this study, the value loss is highest with regard to the trees with DBH between 50 and 70 cm. In large-diameter trees, loss due to rot is slightly lower, primarily because these trees are normally of lower quality, largely on account of their high branch quantity and conical shape.

The share of rot-infected trees could be considerable already in young spruce trees or in trees of low diameter. In Latvia, for example, the incidence of rot in 30-year-old trees ranged from a few specimens to 30% of trees (Arhipova et al. 2011). As for Germany, every second tree in spruce stands older than 20 years has been found to be affected by an agent causing decay (Dimitri and Tomiczek 1998).

In the event of rot occurring as a result of bark removal by deer, the share of rot-infected trees is highest in polewood stands, but drops in higher-diameter trees due to salvage cutting (Čermák et al. 2004). In trees with mechanical injury the damage reaches 2–4 m up the stem, and rot develops in more than a half of injured trees. Injuries which make the tree particularly vulnerable to rot are those where the injury affects the wood tissue below the removed bark (Pawsey and Stankovicova 1974).

The rot, spreading from the roots or butt log, normally reaches from 2.2 to 6.5 m up the stem in Germany (Zycha et al. 1970), 4.3 m in Southern Finland (Tamminen 1985), and between 2.3 and 2.7 m in France (Perrin and Delatour 1976). Based on these findings, we decided to distinguish between the incidence of rot in the lower five meters of the stem (lower-trunk rot) and above that mark (upper-trunk rot), as we predicted that the incidence of rot in the higher sections of the stem would be largely driven by a different set of factors.

The study showed that rot in the higher sections of the trunk mainly resulted from a mechanical stem injury, broken tree top or forked top. The latter is caused by a dying off or breaking of the terminal shoot in the past. Furthermore, upper-trunk rot is more common on high-productivity sites and on silicate and dolomite bedrock. High-productivity sites tend to be more intensively managed, which increases the risk of injury to the stand. Higher rot incidence on silicate and dolomite sites can be explained through a higher content of sand and lower content of organic matter compared to limestone sites (Kralj 2008), which increases the probability of rot incidence (Stenlid and Redfern 1998). On silicate and dolomite sites, where bedrock outcrops are rare, agricultural use was frequently predominating in the past, although silicate bedrock is also characterized by a long tradition of spruce management in many places. Both causes, past agricultural use and succession of (artificial) spruce stands, increase the incidence of rot (Woodward et al. 1998; Jurc 2001).

The occurrence of rot in the lower-trunk rot is more likely on dolomite bedrock, on high-productivity sites, at higher altitude, and in older stands, for less slender trees and mechanically injured trees. Rot is more frequent in even-aged stands and less frequent on sun-facing sites.

In the past, dolomite sites were often intended for agricultural use, which contributed to higher rot incidence. On the other hand, limestone is more favorable for the occurrence of rot because of lower sand share and higher content of organic matter (Kralj 2008). High sand content, low organic matter content, and high pH all contribute to the occurrence of rot (Stenlid and Redfern 1998).

Increased rot incidence on high-productivity sites has already been established in previous studies (Korhonen and Stenlid 1998; Thor et al. 2005; Mattila and Nuutinen 2007), although it was not confirmed by all (Nilsen 1983). Site productivity may have an indirect effect on the incidence of rot, in particular because highly productive sites tend to be more intensively managed, which increases the probability of injury and, consequently, the incidence of rot.

This study confirmed the positive effect of altitude on the incidence of rot, which is in contradiction to several other studies (Korhonen in Stenlid 1998; Jurc 2001), although certain more recent studies point to a high share of rot-infected trees at high elevations (Gonthier et al. 2003).

The age-related increase in rot incidence corresponds with the findings of previous studies (Thor et al. 2005, Arhipova et al. 2011).

In our study sample, slender trees were more rarely infected with rot, which may be due to the fact that these trees are normally younger, thinner, and grow more slowly (narrower rings), all of these negatively affecting the occurrence of rot. A recent study conducted in Switzerland has shown that slowly-growing spruce trees reach an older age. Evidently, a hypothesis was developed that fast-growing trees are more vulnerable to infections with the fungi *Heterobasidion annosum* and *Armillaria* sp. (Rötheli et al. 2011).

The well-established connection between mechanical injury and rot was confirmed a long time ago and has been explained in detail (Vasiliauskas 2001; Kohnle and Kändler 2007).

According to this study, the incidence of rot is lower on sun-facing sites, which corresponds to the findings of most recent research (Korhonen and Stenlid 1998).

When a considerable number of spruce trees in a stand are infected with rot, the recommended measures are as follows: a shorter production period (Bachmann 1968; Korhonen et al. 1998; Möykkynen et al. 2000), thinning when the temperatures fall below zero (Jurc 2001), well considered thinning concept (Möykkynen in Miina 2002), replacement of Norway spruce with other tree species (Korhonen et al. 1998; Kohnle and Kändler 2007), measures to minimize mechanical injury during timber harvesting (Korhonen et al. 1998), and removal or coating of infected stumps (Korhonen et al. 1998; Möykkynen et al. 2000). Several researchers propose that economically over-mature stands with already high rot incidence should be assigned the status of protected forests (Arhipova et al. 2011).

The present study has clearly highlighted the complexity of any research aimed at explaining the occurrence of rot. It is a stochastic issue, associated with a number of inter-related factors. To a certain extent, the results of the study could be improved through consistent recording of the rot type, rot rate, and extent of rot infection. The occurrence of rot remains one of the crucial issues in Norway spruce management, but its extent and frequency can be reduced through the formation of more appropriate stand structures, well considered tending, and careful planning and implementation of timber harvesting.

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Appendix: Regression parameters – *Dodatak: parametri regresije*

Figure – Slika	Stratum – *Izvor podataka*	Curve form – *Oblik krivulje*	R^2	*P*
1 y = the share of rot-infected trees (%); x = DBH (cm) *y = udjel natrulih stabala%); x = prsni promjer stabla (cm)*	Even-aged stand, lower-trunk ro *Jednodobna sastojina, trulež na donjem dijelu debla*	$y = 19.067+1.551x$	0.098	0.000
	Uneven-aged stand, lower-trunk rot *Raznodobna sastojina, trulež na donjem dijelu debla*	$y = 0.050+2.400x$	0.257	0.000
	Even-aged stand, upper-trunk rot *Jednodobna sastojina, trulež na gornjem dijelu debla*	Not significant – *Nije značajno*	0.001	0.273
	Uneven-aged stand, upper-trunk rot *Raznodobna sastojina, trulež na gornjem dijelu debla*	Not significant – *Nije značajno*	0.000	0.868
	Even-aged stand, rot-together *Jednodobna sastojina, trulež na oba dijela debla*	$y = 28.781+1.393x$	0.071	0.000
	Uneven-aged stand, rot-together *Raznodobna sastojina, trulež na oba dijela debla*	$y = 13.919+1.785x$	0.156	0.000
2 y = share of trees with lower-trunk rot (%); x = DBH (cm) *y = udjel stabala zaraženih s truleži na donjem dijelu debla (%); x = prsni promjer stabla (cm)*	Even-aged stand, limestone *Jednodobna sastojina na vapnencu*	$y = 27.232+0.340x$	0.009	0.045
	Even-aged stand, dolomite *Jednodobna sastojina na dolomitu*	$y = 20.686+2.355x$	0.137	0.000
	Even-aged stand, silicate *Jednodobna sastojina na silikatu*	$y = -1.544+3.533x$	0.431	0.000
	Uneven-aged stand, limestone *Raznodobna sastojina na vapnencu*	$y = 6.331+1.718x$	0.321	0.000
	Uneven-aged stand, dolomite *Raznodobna sastojina na dolomitu*	Not significant, not enough data *Nije značajno, premalo podataka*	0.044	0.199
	Uneven-aged stand, silicate *Raznodobna sastojina na silikatu*	$y = -14.390+3.881x$	0.522	0.000
3 y = difference in value (€/m³); x = DBH (cm) *y = razlika u vrijednosti drva (€/m³); x = Prsni promjer stabla (cm)*	Even-aged stand, limestone *Jednodobna sastojina na vapnencu*	$y = (4.820+1.924x-0.014x^2) - (5.282+1.608x-0.012x^2)$	0.484 0.305	0.000 0.000
	Even-aged stand, dolomite *Jednodobna sastojina na dolomitu*	$y = (-4.816+2.447x-0.020x^2) - (2.760+1.777x-0.015x^2)$	0.759 0.498	0.000 0.000
	Even-aged stand, silicate *Jednodobna sastojina na silikatu*	$y = (-11.762+2.966x-0.025x^2) - (9.851+1.574x-0.013x^2)$	0.538 0.258	0.000 0.000
	Uneven-aged stand, limestone *Raznodobna sastojina na vapnencu*	$y = (-11.675+2.746x-0.021x^2) - (1.200+1.749x-0.013x^2)$	0.396 0.208	0.000 0.006
	Uneven-aged stand, dolomite *Raznodobna sastojina na dolomitu*	Not significant, not enough data *Nije značajno, premalo podataka*	0.044 0.236	0.665 0.133
	Uneven-aged stand, silicate *Raznodobna sastojina na silikatu*	Not significant, not enough data for trees with rot *Nije značajno, premalo podataka o stablima s truleži*	0.596 0.035	0.000 0.765

Sažetak

Pojava truleži kod obične smreke i njezin utjecaj na vrijednost stabala u Sloveniji

*U sjevernoj i srednoj Europi obična smreka (*Picea abies */L./ Karst.) slovi za vodeću vrstu po gospodarskom značenju (Kenk i Guehne 2001; Jöbstl 2011). Velik je problem pri gospodarenju smrekom pojava truleži (Kohnle i Kändler 2007). Stoga je cilj istraživanja bio: 1) uočiti frekvenciju pojavljivanja truleži na smrekovim stablima s obzirom na prsni promjer stabla, vrstu sastojine i sastojinske prilike, 2) prikazati utjecaj truleži na gubitak vrijednosti drva i 3) ustanoviti koji parametri utječu na pojavu truleži.*

Istraživana su smrekova stabla na 65 mjesta u Republici Sloveniji, odnosno na 20 različitih biljnih asocijacija. Posječena su 1334 smrekova stabla, od toga 1015 u jednodobnim i 319 u raznodobnim sastojinama.

Prije sječe svakomu je stablu izmjeren prsni promjer i zabilježena pojava više vrhova stabala, mehaničkih oštećenja stabla odnosno žilišta te odlomljenoga vrha stabla. Svaki je dio debla razvrstan u razred kakvoće s obzirom na norme prema JUS-u (D.B4.029 1979) koje se i dalje primjenjuju u Sloveniji. Daljnja je analiza značajki oborenih stabala omogućila izračunavanje prosječne debljine godova i mjere vitkosti (visina stabla/prsni promjer stabla). Na svakom je prerezu stabla zabilježena prisutnost truleži. Trulež je provjeravana na svim poprečnim presjecima te je ustanovljena prisutnost truleži na donjem dijelu debla (do visine 5 m od tla) i na gornjem dijelu debla (na visini većoj od 5 m od tla).

Analiza pokazuje da je pojava truleži u donjem i gornjem dijelu debla relativno češća u jednodobnim sastojinama. Između frekvencije pojavljivanja truleži u donjem i gornjem dijelu debla razlike su velike. Trulež se javila u donjem dijelu debla 34 % (jednodobne sastojine) odnosno 26 % (raznodobne sastojine) stabala, a trulež u gornjem dijelu debla samo kod 14 % (jednodobne sastojine) odnosno 11 % (raznodobne sastojine) stabala. S povećavanjem prsnoga promjera udio se truleži u gornjem dijelu debla nije povećao. Trulež je u donjem dijelu debla veća ako se povećava prsni promjer te je češća u jednodobnim sastojinama.

Razlike su između matičnih podloga pojedinih sastojina osjetne. Već kod tanjih stabala udio truleži u donjem dijelu debla veći je na vapnencu i dolomitu u jednodobnim sastojinama. Gubitak vrijednosti drva zbog pojave truleži najveći je na silikatnoj podlozi u jednodobnim sastojinama i na vapnencu u raznodobnim sastojinama. Najniži je gubitak vrijednosti drva u jednodobnim sastojinama na vapnencu. Najveći je novčani gubitak zbog pojave truleži kod stabala s prsnim promjerom od 50 do 70 cm (15 – 19 €/m^3).

Za trulež u donjem i gornjem dijelu debla uz pomoć binarne logičke regresije provjereno je koje varijable utječu na spomenute pojave. Pojava truleži u donjem dijelu debla vjerojatnija je na produktivnijim staništima, na dolomitnoj matičnoj podlozi, na višoj nadmorskoj visini, kod starijega i ozlijeđenoga drveća. Vitkost stabla pridonosi manjoj vjerojatnosti pojave truleži u donjem dijelu debla. Također se vidi da je pojava više vjerojatna u jednodobnim sastojinama, a manje na južnim ekspozicijama. Pojava truleži u gornjem dijelu debla vjerojatnija je na produktivnijim staništima, na dolomitu i silikatu i kod ozlijeđenih stabala, na stablima sa slomljenim vrhom te stablima s više vrhova.

Istraživanje je pokazalo da je teško objasniti pojavu truleži zato što mnogi čimbenici utječu na njezin nastanak. Rezultate bi istraživanja trebalo dopuniti podacima o tipovima truleži, stupnju natrulosti i obujmu pojave. Trulež kod smreke ostaje jedan od većih problema gospodarenja tom vrstom.

Ključne riječi: trulež drva, obična smreka, Slovenija

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