Folia Forestalia Polonica, series A, 2010, Vol. 52 (2), 89–97

ORIGINAL ARTICLE

Knottiness of spruce stems from the Dolomites as the basis for distinguishing quality zones in roundwood

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Abstract

The study was conducted on 9 sample of Norway spruce [*Picea abies* (L.) Karst] trees, aged 150 years, from three upper subalpine stands in the region of the Dolomites. The knots were classified into three categories of healthiness and three categories of intergrowth with the surrounding wood. Differences in diameters and relative diameters of knots classified into three categories of healthiness and three categories of intergrowth with the surrounding wood was shown on a merchantable bole divided into 10 equal sections.

The frequency of occurrence of knots under the analysed categories was the basis for distinguishing zones of different quality on the examined spruce stems. Healthy and intergrown knots occurring mainly in the upper half of tree stems prevailed. Rotten and not intergrown knots occurred mainly in the section 0.2 to 0.5 of the merchantable bole length. The research results may be of practical importance for the wood processing industry, as the knot structure in roundwood affects the quality of *P. abies* sawn timber.

Key words

Picea abies log, the Dolomites, knot categories, knot zonation

Introduction

Knottiness in spruce [*Picea abies* (L.) Karst] timber, which is an essential issue in wood processing, is the subject of many studies. The location and differentiation of knot diameters is often analysed in roundwood and sawn timber. Knots are, to a large extent, influenced by external factors and are somehow related to stand and tree characteristics. The negative impact of knots is, depending on their size, location and category, particularly important in the applications of wood where its strength plays an important part.

Modern research methods allow to develop models to predict the occurrence of knots in roundwood, depending on the conditions of tree development, and, subsequently, to predict the properties of the sawn timber obtained from it (Vestøl and Høibø 1998; Moberg 2001 and 2006; Kantola et al. 2007). Comparative studies on the quality of wood of a given tree species from various geographical regions, thus growing in different environmental conditions, can lead to some interesting results, important from a practical point of view.

Received 31 March 2010 / Accepted 9 September 2010

The aim of the study was to determine, on the example of Norway spruce, the frequency of occurrence of knot categories and to analyse changes in their dimensions in sections of every one tenth of the length of merchantable boles of sample trees. This was the basis for distinguishing characteristic zones in the roundwood varying in quality depending on the number of knots. The size of knots, as well as their healthiness and degree of intergrowth with the surrounding wood are important features affecting the quality of semi-finished and finished timber products. Therefore, the research findings may have some implications for the rationalization and optimization of roundwood processing. The research was conducted in one of the main regions of spruce occurrence in Europe, in the territory of the Alps, in the Dolomites.

The present study is a continuation of analogous research conducted earlier in *P. abies* stands in Poland and Norway. The research was financed from the means of COST E53 Action and implemented in the framework of a short-term scientific mission in Italy (IVALSA, San Michele).

Materials and methods

The research was carried in 2009 out in the Dolomites, in northern Italy. After consultations with the Trees and Timber Institute, San Michele all Adige and local foresters, three mature *Picea. abies* stands in the upper montane zone were selected for research. The age of stands was about 150 years; they were of natural origin, situated at an altitude of 1,450 to 1,740 metres above sea level, on the western, northern and north-western slopes. The stand volume ranged from 285 to 479 m^3/ha; the stands grew on moderately fertile sites which were assigned to classes 5 (two stands) or 6 (one stand) on a nine-point scale, starting from the most fertile sites.

Three sample trees with a breast-height diameter of minimum 40 centimetres were randomly selected from among the trees harvested under the planned cuts from each stand. The same method was used to measure trees and knots as in the earlier research conducted in Poland and Norway (Barszcz 1995; Barszcz and Gjerdrum 2008). The measurements comprised the length of the whole tree, the length of the merchantable bole up to the diameter not smaller than 7 cm over bark (PN-93/D-02002... 1993), diameter at each meter of the length of the merchantable bole, and the height of the crown base.

Each knot visible at the ½ of the girth of the merchantable bole was subject to classification according to a three-point scale of knot healthiness and a three-point scale of knot intergrowth with the surrounding wood (PN-79/D-01001... 1980). Knot diameters (PN-EN 1310... 2000) and their distances from the butt-end were measured. By means of interpolation, the timber diameter was determined at the point of occurrence of each knot registered. This was the basis for the calculation of relative diameters of knots (as a relation of the knot diameter to the timber diameter). The relative height of tree crown base was determined.

At the data analysis stage, the length of the merchantable bole was divided into 10 equal sections and average diameters, relative diameters (including standard deviations), as well as the relative height of knot location according to knot category were calculated for each section. The coefficients of correlation ($p = 0.05$) were determined, indicating the strength of the relationship between the relative height of knot location and the diameters or relative diameters of knots. The frequency of occurrence of various knot categories in the sections of the merchantable bole length became the basis for distinguishing zones on the stems differing in quality. In the discussion, the results were compared to the results obtained in the analogous studies conducted in Poland (Beskidy Mountains) and in south-eastern Norway.

Results

The characteristics of sample of *Picea abies* trees were as follows: the average lenght of the whole tree was 30.6 metres (23.3 to 36.0), merchantable bole length – 28.0 metres (21.0 to 33.6), diameter at breast height – 49.5 centimetres (40.0 to 67.0), volume of merchantable bole under bark – 2.49 m^3 (1.20 to 4.39), height of the crown base – 9.6 metres (5.4 to 14.0), relative height of the crown base 0.34 (0.20 to 0.46).

Over 1/2 of the merchantable bole girth, a total of 1,070 knots were measured. Up to 0.3 of the length of the merchantable bole inclusive, *i.e.* up to the crown base, there were few sound knots (about 9% of all knots in this category) and their diameters were smaller than

in the subsequent five sections (from 0.4 to 0.8) towards the thinner end of the merchantable bole (Fig. 1). In the two highest sections, with the share of approximately 33% of all sound knots, a clear decrease in the value of diameters of knots in this category was noted. Relative diameters showed a regular increase in value, exceeding 0.1 of timber diameter in the last three sections. With the low absolute values of knot diameters in these three sections, the result is influenced by the fact that the bole was thinner and had large taper. The coefficient of correlation (R = –0.35) between the relative height of knot location and the diameters of sound knots indicates the average strength of the relationship. Relative diameters of the knots were much stronger, dependent on their location (R = 0.62). All knots in this category (classified according to their healthiness) constituted up to 74.7%, so their impact on the quality of the examined spruce timber was significant.

The unsound knots (9.7% of all knots) had the largest diameters in the bottom half of the merchantable bole (Fig. 2). The relationship between the diameters and the height of knot location was weak. The relative diameters increased irregularly up to the top of the stem (R = 0.51). Unsound knots were recorded mostly in sections 5 and 6 of the merchantable boles but did not occur in the top zone.

Rotten knots (15.6%) with generally small diameter values also showed small differentiation of this feature along the bole (Fig. 3). However, a clear impact of knot location on relative diameters of this category of knots can be noted (R = 0.69). The analysed category was most often recorded immediately under the crown and in its lower part, corresponding to 0.4 and 0.5 of the length of the merchantable bole.

Intergrown knots (according to the degree of intergrowth), constituting 60.2% of the total number of knots, therefore significantly affecting the quality of spruce timber, showed, up to section 8 inclusive, small differentiation of diameter values (Fig. 4). In sections 9 and 10, the diameter values decreased sharply (R = –0.54). The relative diameter values increased from the bottom towards the top of the merchantable bole (R = 0.50). They occurred mostly in the upper half of the merchantable bole, where a total of nearly 86% of knots were recorded.

Few partly intergrown knots (4.1 per cent) revealed an irregular decrease in diameter values along the merchantable bole (R = –0.46) and a lack of a clear relationship between their location and relative diameters (Fig. 5).

Not intergrown knots (Fig. 6) showed an irregular decrease in diameter towards the top of the stem (lack

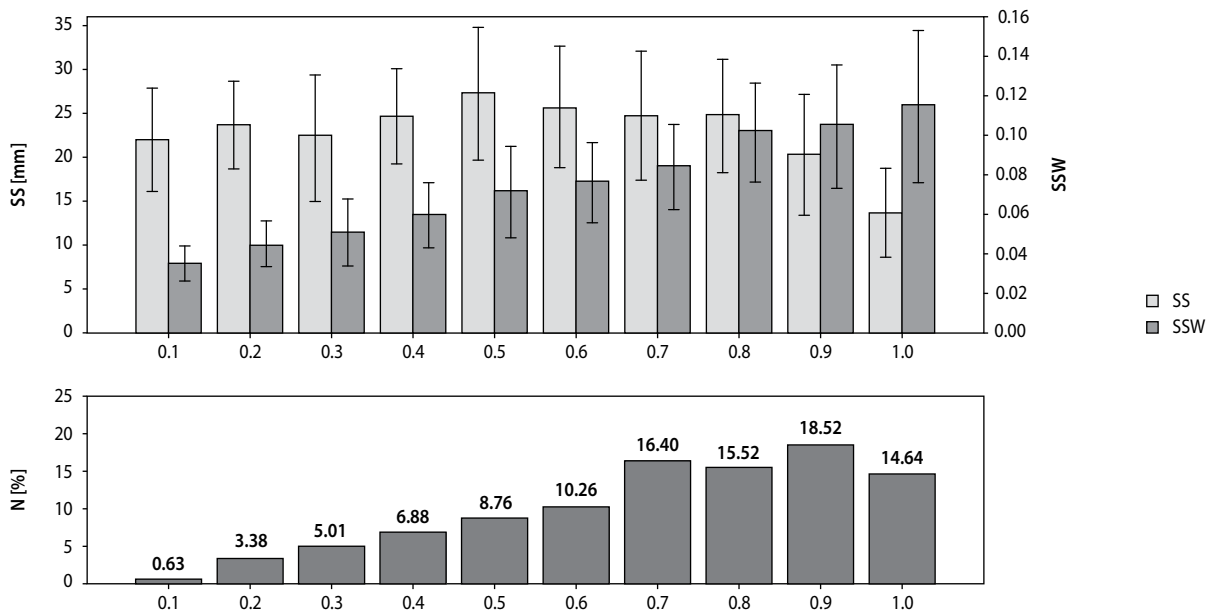

Fig. 1. Variation in diameters (SS) and relative diameters (SSW) of sound knots and their percentage share in the sections of the merchantable bole length

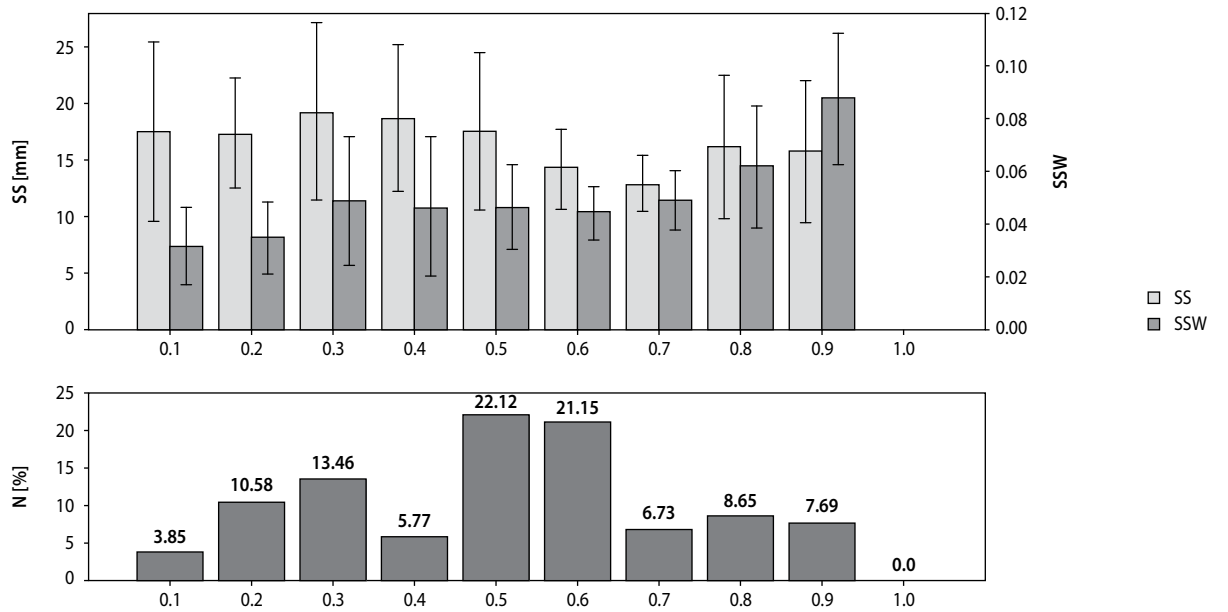

Fig. 2. Variation in diameters (SS) and relative diameters (SSW) of unsound knots and their percentage share in the sections of the merchantable bole length

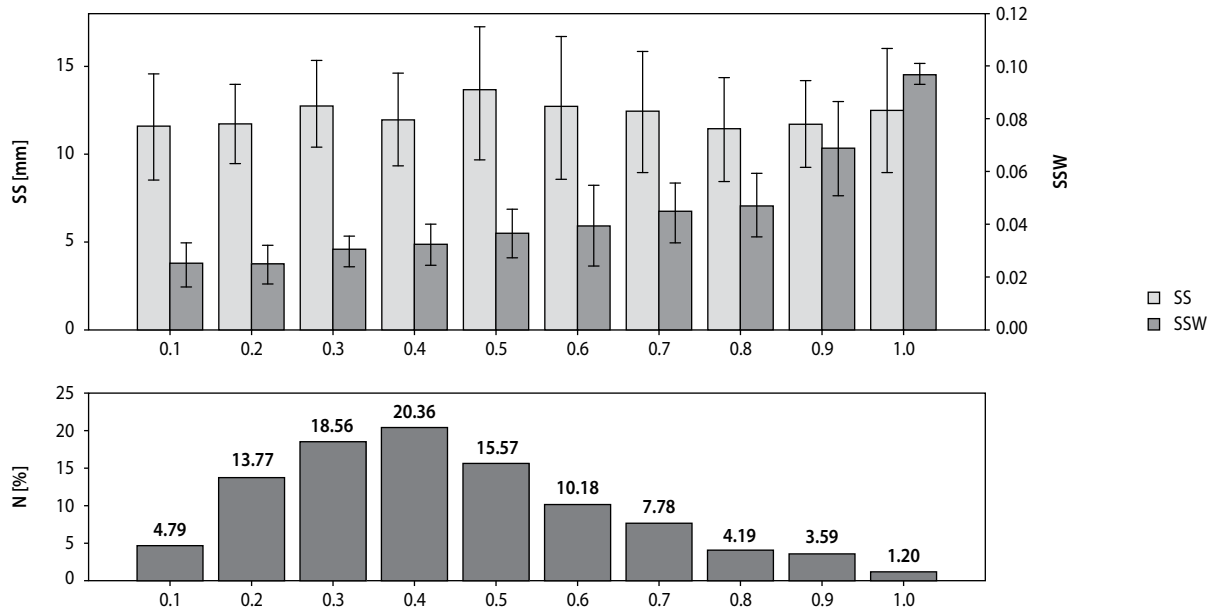

Fig. 3. Variation in diameters (SS) and relative diameters (SSW) of rotten knots and their percentage share in the sections of the merchantable bole length

of a significant relation to the height of knot location), their relative diameter values increased with the growing distance from the butt-end of the stem (R = 0.48). They were most numerous in sections 0.2 to 0.5 of the merchantable bole length.

The diameters of all knot categories (altogether) increased up to section 8 of the merchantable bole, and then decreased (Fig. 7). The relationship between diameters and the location of knots on the stems was very weak and statistically not significant. Relative

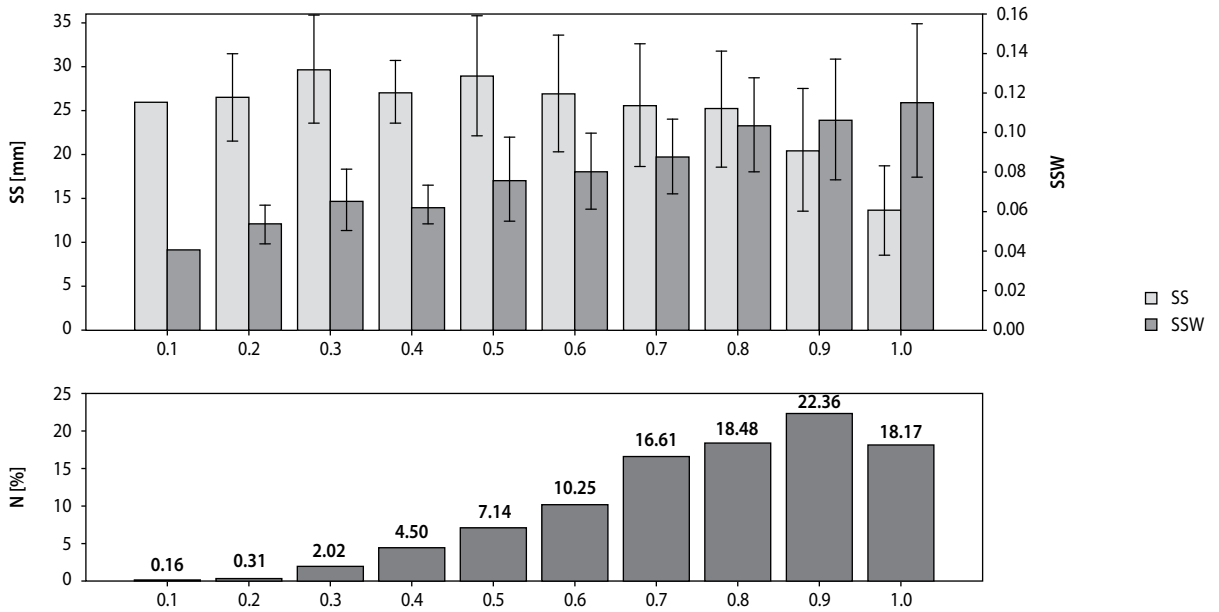

Fig. 4. Variation in diameters (SS) and relative diameters (SSW) of intergrown knots and their percentage share in the sections of the merchantable bole length

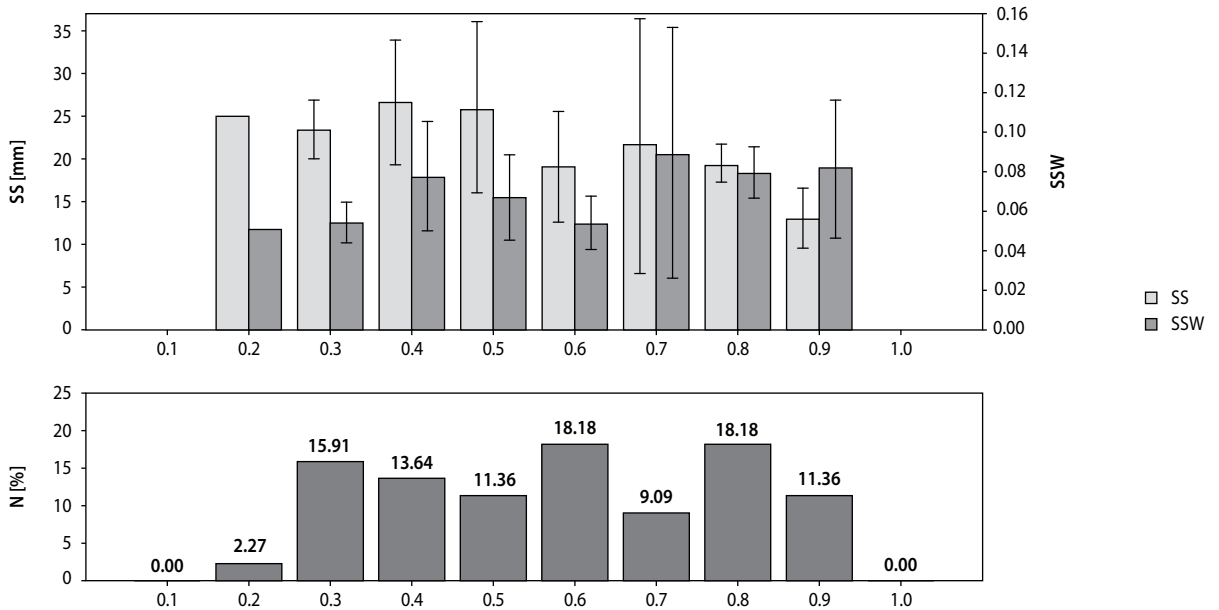

Fig. 5. Variation in diameters (SS) and relative diameters (SSW) of partly intergrown knots and their percentage share in the sections of the merchantable bole length

diameters regularly increased towards the top end of the merchantable bole, and the coefficient of correlation indicated a strong relationship between both features (0.69). Knots in general showed a tendency towards growth in their number in the successive sections towards the top of the stem and only in section 10 (because of a small bole thickness) they were less numerous.

Changes in the number of knots (per merchantable bole section) allow distinguishing areas on the stem

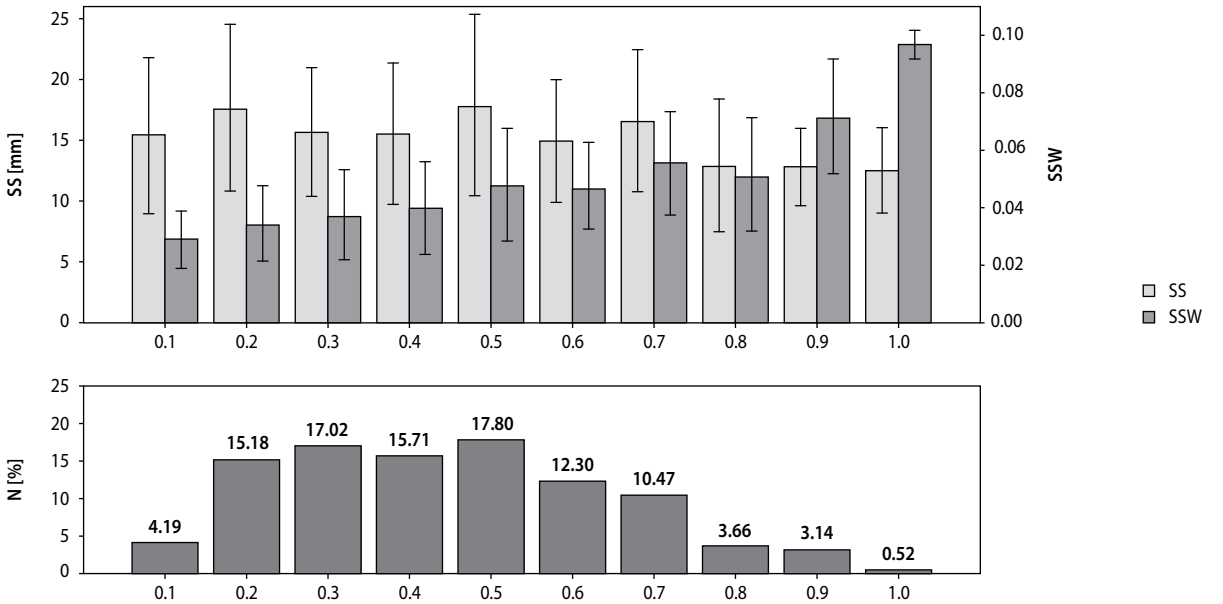

Fig. 6. Variation in diameters (SS) and relative diameters (SSW) of not intergrown knots and their percentage share in the sections of the merchantable bole length

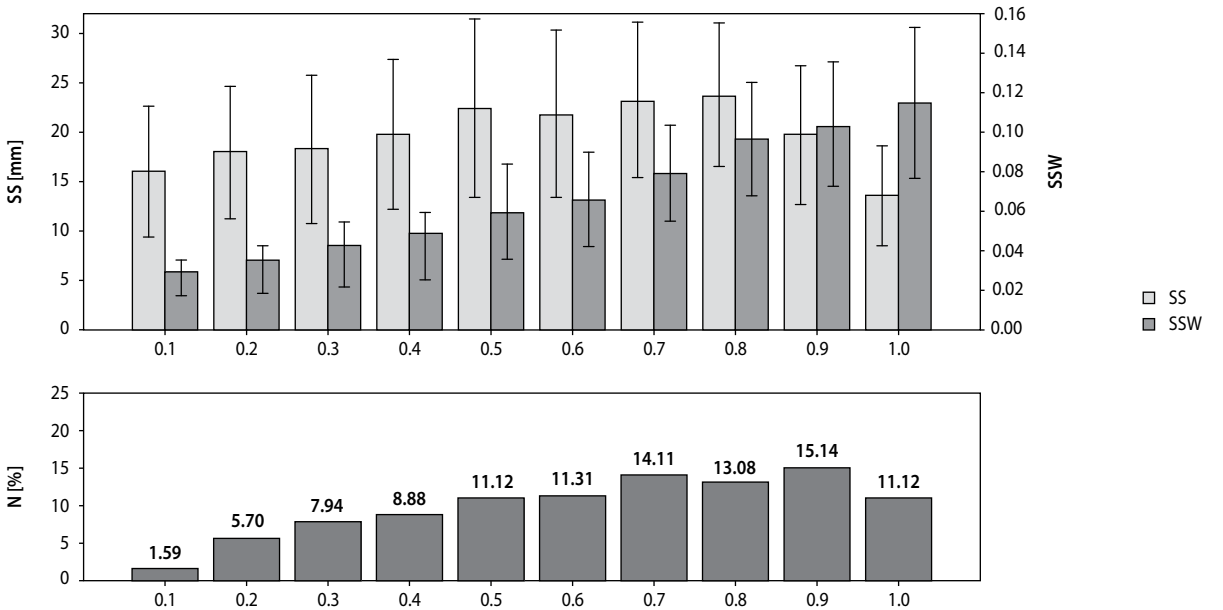

Fig. 7. Variation in diameters (SS) and relative diameters (SSW) of knots taken together and their percentage share in the sections of the merchantable bole length

varying in knot density. In the case of knots classified into the category of healthiness (Fig. 8), zone I can be distinguished; it includes the first five sections from the base of the merchantable bole where the effect of all knot categories is observed, however, the prevalence of rotten knots is clearly visible. The upper half of the merchantable bole – zone II is characterised by the dominance of sound knots, mostly in sections 7 and 9 (29.1 and 32.9 knots per section, respectively), and the disappearance of other knot categories.

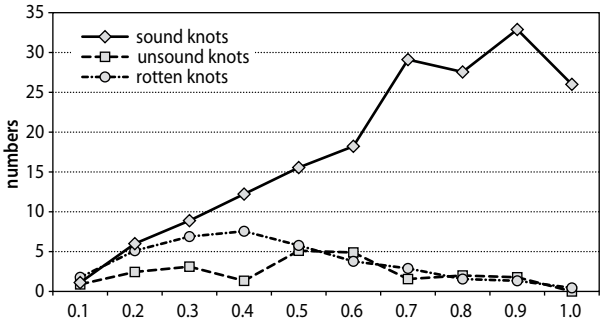

Fig. 8. The numbers of knots along the merchantable bole – categories of healthiness

Figure 9 gives a more complex picture; the division of knots was made according to the degree of intergrowth. Like in the division described above, zone I includes the first five sections from the base of the merchantable bole. It is dominated by the not intergrown knots and the number of intergrown knots increases. Zone II located higher on the stem is divided into two parts. Zone IIa is within sections 6 and 7 where a dynamic increase in the number of intergrown knots and a decline in the number of not intergrown knots are noticeable. Also the point of intersection of the abundance curves of these two knot categories is in this zone (at a height of 0.55 of the merchantable bole). Zone IIb contains sections 8, 9 and 10, with prevalence of intergrown knots, with a maximum (32 knots) in section 9 and clearly disappearing other knot categories which in section 10 are no longer recorded.

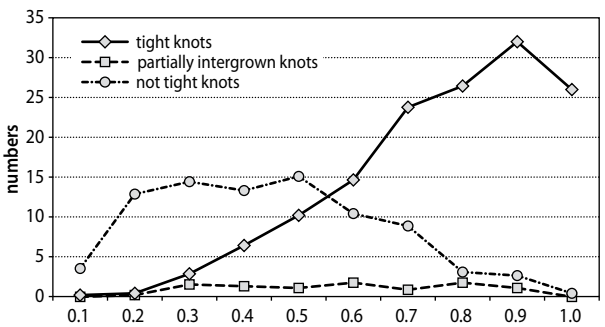

Fig. 9. The numbers of knots along the merchantable bole – categories of the degrees of intergrowth

From the conversion of the share of zones in the merchantable bole length to running meters, with the average length of the merchantable bole equalling 28.0 metres, the following values are obtained: the length of zone I and II is 14 metres for each zone. In the division of zone II into sub-sections a and b – the average length of zone IIa is 5.6 metres and zone IIb – 8.4 metres, respectively.

In the examined spruce timber, there were on average 8.5 knots per metre of the length of the merchantable bole (in relation to the full girth of the stem). An average of 237.7 knots were found on the whole length of the merchantable bole. Considering the frequency of occurrence of all categories of knots taken together merchantable bole sections from 0.5 to 1.0 were confirmed to contain the largest number of knots, while the maximum number of knots (36 knots) were found in section 9 (Fig. 10).

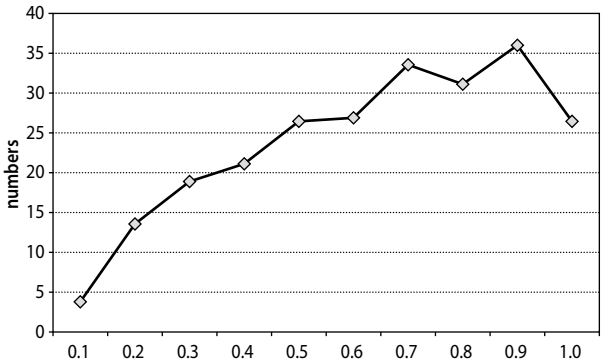

Fig. 10. The numbers of knots along the merchantable bole – knots taken together

Discussion

The analysis of the zones of knot occurrence on the basis of their numbers on *Picea abies* stem can be compared with the results obtained for Polish and Norwegian spruces (Barszcz 1995; Barszcz and Gjerdrum 2008). In all compared groups of data, the number of knots in the intermediate category, *i.e.* unsound knots, especially partly intergrown knots showed no clear relationship with their location along the merchantable bole. Most sound and intergrown knots were reported to occur in the Norwegian spruces in section 8, while in the Polish and Italian spruces the maxima were shifted by one section towards tree tops. The largest number of rotten knots in the spruces from Poland and Italy showed a shift by two sections towards the top of the

stem compared to the results obtained for the spruces from Norway. With the division of knots according to the degree of healthiness, the boundary limits between zones I and II are as follows: in the material from Poland, it is between sections 6 and 7, from Norway – between section 3 and 4 and from Italy – in mid-length of the merchantable bole.

According to the classification of knots into the categories of intergrowth with the surrounding wood, the lengths of zones I, IIa and IIb for spruce trees from Norway included sections 1 to 3, then 4 to 6 and 7 to 10, respectively. In the Polish and Italian spruces, these stayed within the same boundary limits of the relative merchantable bole length, in sections 1 to 5, next 6 to 7 and 8 to 10, respectively. Also, the point of intersection of the abundance curves of intergrown and not intergrown knots in these two groups of spruce timber was at a similar height (in the material from Poland at 0.60 and in that from Italy at 0.55 of the length of the merchantable bole).

The comparison of the average total number of knots on spruce stems from the Dolomites (237.7 knots/tree and 8.5 knots/meter of merchantable bole) with the results of the studies conducted in Poland (Barszcz 1995) and in south-eastern Norway (Barszcz and Gjerdrum 2008) shows that most knots occurred on spruces from Norway, with an average of 253.2 knots/tree, and 10.4 knots/meter of merchantable bole, while the least number of knots occurred on spruce trees from the Polish Beskidy Mountains, with an average of 204.2 knots/tree and only 7.8 knots/ meter of merchantable bole.

The results of this study indicate an increase in the total diameter of knots up to section 8 of the merchantable bole inclusive, while the relative diameters of knots, regardless of their category increased from the base to the top of the merchantable bole. This corresponds to the results obtained by Perstorper et al. (1995) who demonstrated that in spruce the share of cross-sectional area of knots (KAR) at the top of bole was significantly larger compared to the zone located below.

On the basis of his own studies on the quality of spruce timber and with reference to the studies by Kramer and Björklund, Moberg (2001) comes to the conclusion that the small variation in knot diameters at the base of the stems can be attributed to the influence of that tree development stage where the rates of tree height growth and dieback of the lower parts of the crown were similar. It can be assumed that for this reason, also in the material under analysis, the diameters of all knots show small variability in the lower sections of the merchantable bole.

Conclusions

- In the examined *Picea abies* timber all knot diameters along the merchantable bole showed an increase up to section 8 inclusive, while towards the top these values declined. Relative diameters of knots showed a systematic increase in their values from the base to the top of the merchantable bole. Towards the top of the stem, the total number of knots increased in the successive sections of the merchantable bole, while the largest number of knots was recorded in sections 7 and 9.
- Sound and intergrown knots dominating in the examined material contributed, to the largest extent, to the overall picture of the distribution and formation of relative diameters of knots. Rotten and not intergrown knots were located mainly in the butt-end area of the stem in section 0.2 to 0.5 of the merchantable bole. Knots in the intermediate categories – unsound and partly intergrown ones did not show any distinct tendency towards change in their number in individual sections along the merchantable bole. The diameters and particularly the relative diameters of knots were associated with the relative height of knot location.
- According to the division of knots into categories of healthiness, the number of various knot categories in the merchantable bole sections was the basis for differentiating two quality zones on tree stems: zone I up to section 0.5 inclusive, and zone II – above. Taking into consideration the knot categories distinguished according to the degree of intergrowth with the surrounding wood, the differences in the quality of timber on the length of the merchantable bole were more distinct: distinguished were zone I up to 0.5 of the length, zone IIa including sections 6 and 7 and zone IIb corresponding to the three highest sections of the merchantable bole.

Supplement

In the article „Size and localization of knots in timber from mountain spruce stands in the Dolomites" (*Folia Forestalia Polonica*, Vol. 52, No.1, 13–19), in "Materials and methods" there is a sentence (right column, 16th line from the top):

"Subsequently, at the stem half point, the diameters of knots (≥ 1 cm) were measured as well as their distances from the base stem".

Should be:

"Subsequently, over 1/2 of the stem girth, the diameters of knots (≥ 1 cm) were measured as well as their distances from the base stem".

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