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Knot soundness and occlusion time after the artificial pruning of oak

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Abstract. Artificial pruning of trees can improve wood quality as well as enhance timber value. Currently, pruning is quite common when veneer timber or plywood is in demand. Cutting off branches, however, creates open wounds in the form of knots, which are exposed to infections. While the pruning of coniferous trees is well-studied, less research has been conducted on broadleaved trees. The objective of this study was to determine 1) if the artificial pruning of oak can lead to decaying knots, 2) if so, how big is the decaying zone around the unsound knot, and 3) how much time is needed for full knot occlusion after artificial pruning. 13- and 16-year-old oak trees located in northern Poland (Lidzbark Forest District) were choosen for this study. Ten years after pruning, sample trees were selected in order to determine if the knots were sound and how many years it had taken for each knot to occlude. The results were compared with those of knots on trees caused by natural pruning. In total, 419 and 104 knots resulting from artificial and natural pruning, respectively, were analysed. It was found that 95% of the artificially pruned knots had very little decay, showing an average of 1.13 cm of unsound knot zone. On the naturally pruned control trees, 98% of the knots were unsound with nearly double the amount of knot decay zone. Additionally, the artificially pruned knots needed less than five years to overgrow, while it took over eleven years for the naturally pruned knots to occlude. Therefore, pruning oak trees is recommended, even though a very small decay zone may appear on the knots, because it takes half the time for these artificial knots to occlude in comparison to unpruned trees.

Keywords: sound knot, decayed knot, natural pruning, broadleaved trees

1. Introduction

The procedure of pruning was already being used at the turn of the 16th and 17th centuries in Japan, and the first European country in which this topic was mentioned was the Kingdom of England (Evelyn 1670). Since then, many changing studies, instructions and guidelines have been published, which often present extremely different views (Giefing 1999). In certain periods, there was great interest in this procedure or, on the contrary, it was considered fairly ineffective (Leibundgut 1966, Pazdrowski 1992).

The first non-scientific German publication on pruning is from 1713 (Carlovitz 1713), and the first scientific publication on this topic was published in 1764 (Duhamel du Monceau 1764). It presented the effects of pruning live branches of trees on their growth. German foresters published their first results of studies on pruning in the form of scientific studies only about one hundred years later. These works showed the growth effects of pruning. For example, Heyer (1872) found double the growth of spruce at the beginning of the growing season after performing the treatment.

The suggestions of many practitioners regarding the allegedly unfavorable impact of pruning trees led Lorey (1907), Lakari (1920), Hilf (1933) and Koehler (1934) to undertake research to verify the expressed opinions. The research of these authors showed that discoloration may occur, or even wood decay, from the knots left after removing live branches. These results caused the pruning of live branches of trees to be discontinued in many countries, including Poland. However, subsequent years of the work of Mayer-We-

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gelin (1936) shed new light on the issue of the impact of removing live branches on the health status of trees. After re-testing spruce, Paterson (1938) did not find the above-mentioned disadvantages resulting from pruning live branches. Similarly, Romell (1940) believed that there was no need to ban the removal of live parts of tree crowns. In later periods, similar statements were expressed by Krigul (1961) and Lucke (1968), who believed that the pruning wounds of live branches are flooded with resin, which inhibits fungal infection, and therefore – the development of decay. Other authors also confirmed the observation that infections did not occur or appeared sporadically after branches were removed (Kramer 1962, Henman 1963, Pazdrowski 1985).

Aßman (1961) noted the significant impact of the age of the tree being pruned and the quality of the pruning. He stated that the danger of infection increases in medium and older age classes, and also when the wounds are large and dirty. The threat of infection was determined to be particularly high when thick, live branches were removed, in which one could expect that heartwood had already developed (Giefing 1987). For this reason, it is recommended that pruning treatments should be performed before the age of the culmination of tree growth (Giefing 1999).

The most beneficial seems to be pruning before the tree reaches 20 years of age. Dudik (1930, after Giefing 1999), took a similar position in 1930, writing that the procedure should be performed in younger stands, aged no more than 25-30 years. Due to the cost-effectiveness of the treatment and the possibility of decreased growth, and thus the prolongation of occlusion time, pruning should be done to tree stands in the best habitats (Žumer 1966, Giefing 1987). It is not economically justified to prune all trees in the stand. The best trees should be used for the treatment, the so-called "elite" of the stand (Szymański 1991), and thus trees from the I and II Kraft classes. Pruning these trees, characterized by inherently high growth dynamics, will allow, on the one hand, a rapid increase in the volume of the knotless zone, on the other hand, the shortest possible time of achieving knot occlusion in the given tree stand.

In order to achieve good tree health after the treatment, the technical aspects are important, that is, the type of tools used and the choice of pruning methods. Although pruning is considered one of the oldest breeding treatments used in forestry, it was only about one hundred years ago that the first publications appeared about the impact of the tools and methods used on the quality of the treatment (May 1889, 1890, 1891, Guillebaud 1933, Laar 1966).

Following the research, the approach of practitioners to this procedure changed. Initially, various tools were used, which resulted in damage to the tree (Giefing 1993). Then, starting with Germany, impact tools were eliminated: axes, cleavers and barking irons, with hand saws being recommended (Lelbach 1859). Studies on the use of shears and secateurs showed that micro-cracks were formed during cutting, which in combination with small snags, promoted infection (Mayer-Wegelin 1952, Aboney 1981). In the end, hand saws were considered to be the best tools for pruning, making an even and smooth cut surface, enabling branches to be cut evenly with the side of the trunk, and not harming the tree itself. Such a view was already published in 1930 by, among others, Dudik (after Giefing 1999).

The main advantage of pruning is to obtain a wider zone of knotless wood, characterized by significant homogeneity, and also to improve such features as density, compressive strength along the fibers as well as shrinkage (Pazdrowski 1984) and hardness (Pazdrowski, Cybulko 1988).

Obtaining a larger zone of knotless wood is one of the factors that justifies pruning. However, this treatment exposes wood tissue to being impacted by external factors. While coniferous species are well known in terms of their response to pruning, which is probably caused by their percentage share in the composition of stands and their great economic importance, there are significantly fewer studies on deciduous species. The increasing share of these species associated with the reconstruction of tree stands indicates the need to analyze the deciduous species.

One economically important species is oak, which is the subject of the study presented in this paper. High quality and knotless oak wood achieves high prices. It is usually sold in auctions or submissions and achieves particularly high prices due to its lack of knots and other features enabling it to be used for veneer (Paschalis-Jakubowicz et al. 2015). Bearing in mind the high requirements expected of veneer oak wood, the aim of this study is to determine the health of oak knots and the rate of their time occlusion after pruning.

2. Materials and methods

The research material was taken from the Lidzbark Forest District of the Regional Directorate of State Forests in Olsztyn. A total of five sample plots were designated for pruning, one each in subcompartment 63d, 72b, 82a, and two in subcompartment 82d (Table 1), all in a mixed forest on site with average moisture.

In the spring of 1995, oaks were pruned on plots of 50-are area. The treatment was performed by the selection method (classical) using handsaws for pruning. The trees from the highest biosocial groups, with a well-developed crown: towering and prevailing, that is, from Kraft class I and II (Giefing 1999), were selected for pruning. Such trees have high growth increments and a low risk of a reduction in their biosocial position in the future, and thus are characterized by a very long life. It was assumed that trees with a longer life-

Table 1. Characteristics of sample plots and selected oak trees

Feature	Pruned					Unpruned
Subcompartment	63d	72b	82a	82d	82d	165c
Share of oak in species composition [%]	20	10	10	20	20	30
Site index	2	2	2	2	2	2
Age of trees at the age of pruning [years]	13	16	16	16	16	26
Age of felled trees [years]	23	26	26	26	26	36
Number of trees [n]	3	3	3	3	3	3

span will grow to a greater thickness more intensely (Szewczyk, Guz 2012), resulting in the knot becoming occluded in a shorter time and decreasing the risk of infection.

As a rule, branches were removed evenly from the side of the trunk so as not to leave snags. Each plot constituted a separate study area. The age of trees at the time of pruning in one sample plot (63d) was 13 years, in the remaining ones – 16 years.

In 2005, at each plot, the diameters (DBH) were measured of all pruned trees, and several of them had their heights measured at each two-centimeter degree of thickness. Using the Urich II method, the dimensions of three model trees in each plot were calculated. Then, three sample trees with dimensions closest to the model trees were selected in the plots, for a total of 15 trees. The trees were cut with a chainsaw and two ca. 2 m logs from the pruned areas were obtained from each. The pruned logs were then cut into 30-cm long sections with the occluded knots, which were taken as samples for further study. The obtained logs and short sections were described in such a way as to be able to determine the position of the knot with respect to the base of the stem.

With the aid of an ax (or hummer) and wedges, trunk sections were split in such a way as to reveal the course of the knot formation in a radial plane. The area around the occurrence of knots was determined on the basis of a drawing of the bark on the occluded knot.

The features of the exposed knots were measured with an accuracy of 1 mm: a) maximum knot width, b) width of the sound knot zone, c) width of the unsound knot zone, and d) width of the wood zone without the knot, in which the number of years required for the full occlusion of the knot was established (Fig. 1).

In December 2010, three unpruned (naturally pruned) trees from the control sample in subcompartment 165c (of the same site conditions) were tested (Table1). The selection of trees was made according to the same methods as in the case of the artificially pruned trees, logs were cut and sections prepared for analysis of the knot occlusion process

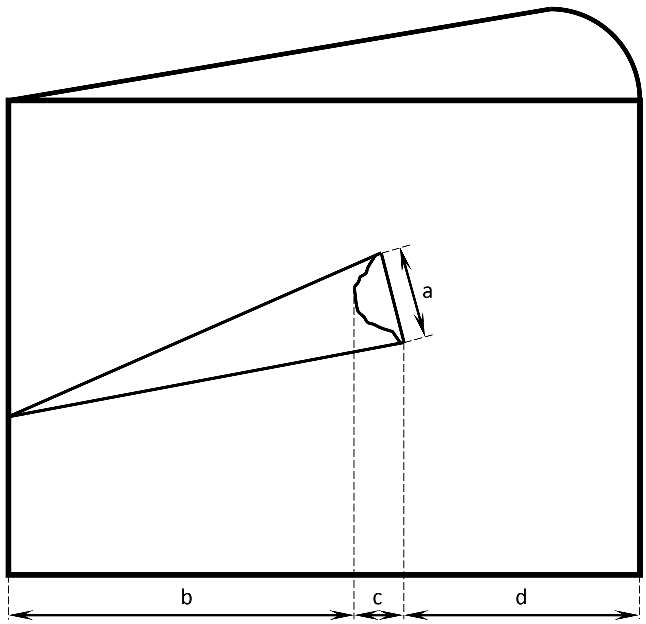

Figure 1. Parameters of knot and surrounding areas: a) knot thickness, b) width of sound knot zone, c) width of unsound knot zone, d) width of wood zone without knot

in the unpruned trees, as was done with the artificially pruned trees. The age of the trees at the time of felling was 36 years. Additionally, a tree stand 10 years older than the pruned trees was selected for the comparison. It was assumed that the process of knot occlusion in trees of a stand about 10 years older will occur at heights similar to those of the pruned trees, i.e. at approx. 4 m.

The parameters of the knots and adjacent zones from pruned trees were compared with the corresponding elements of the knots from the unpruned trees. For this purpose, position statistics were calculated and the data of both groups were compared (pruned and unpruned) using the U Mann-Whitney test at a=0.05. The non-parametric test was chosen due to the lack of normal distributions (verified with the Shapiro-Wilk test) and the diversity of the number of data (knots) from the pruned and unpruned trees. The Spearman test was used in the case of correlation. The tests were performed using the Statistica 13.3 program, positional statistics were calculated in Excel.

3. Results

In total 419 knots from artificially pruned trees and 104 knots from the unpruned trees were obtained for further analysis (Table 2). The average diameters of the stem, where the knots were located in the pruned trees, were slightly higher than in the unpruned ones and statistically differed *(p-value* = 0.0004; Table.2). Knots were located at a similar, average height (143 and 140 cm, respectively, in the artificially pruned and unpruned trees) in the analyzed stems, the highest knot of the unpruned trees was located at a height of 325 cm, 60 cm lower than the highest knot of the pruned trees.

Average knot thickness on the unpruned trees was 22% greater than on the artificially pruned trees, but this difference was not statistically significant (Table 2). The sound knot zone was greater by 13% in pruned trees and this difference was statistically significant (*p-value* = 0.0449).

The wood tissue of the annual rings adjacent to the knots in the artificially pruned trees was also sound, no case of any decay or discoloration of a pathogenic nature was found in the wood surrounding the knots (Fig. 2).

Exceptionally, a bark pocket was created (Fig. 3 and 4), which occurred in two knots of the examined 419, constituting less than 0.5% of the studied cases.

The unsound knot zone was much smaller in artificially pruned trees, 37% lower than in unpruned trees (Table 2); this difference was statistically significant (*p-value* = 0.0000). Also, the time of knot occlusion was shorter for the pruned trees. Unpruned trees needed more than twice as much time (over 11 years, Table 2) for their knots to occlude in the examined stem zone of up to 3.25 m (cases of knots occluding for over 10 years means that some of the branches were removed as a result of factors other than planned pruning). The differences observed for the duration of knot occlusion were very distinct and statistically significant (*p-value* = 0.0000).

A detailed analysis of the data also allowed that about 5% of the knots had no signs of decay 10 years after pruning. The unpruned trees had only two knots with no observable signs of decay, constituting approx. 2% of the number of knots studied.

An additional analysis using Spearman's correlation showed a relationship between the thickness of an unsound knot and the width of the unsound knot zone r_S=0.36, with a statistically significant relationship of p<0.05.

Table 2. Characteristics of stems and knots of pruned and unpruned oak trees

Feature	Tree	Mean	Minimum	Maximum	SD	N
Stem diameter at height of knot position near pith [cm]	Pruned	13.70 [a]	7.00	28.00	3.68	419
	Unpruned	11.23 [b]	6.00	20.00	4.13	104
Height of knot position near pith to bottom of stem [cm]	Pruned	143.25 [a]	5.00	385.00	86.18	419
	Unpruned	140.75 [a]	8.00	325.00	90.05	104
Maximal knot thickness, perpendicular to knot axis [cm]	Pruned	1.11 [a]	0.10	8.00	1.10	419
	Unpruned	1.35 [a]	0.20	12.00	1.45	104
Zone width of sound knot [cm]	Pruned	2.85 [a]	0.00	9.50	1.53	419
	Unpruned	2.53 [b]	0.00	8.20	1.45	104
Zone width of unsound knot [cm]	Pruned	1.13 [a]	0.00	8.00	1.24	419
	Unpruned	2.07 [b]	0.00	6.10	1.06	104
Occlusion time [years]	Pruned	4.99 [a]	1.00	19.00	2.66	419
	Unpruned	11.21 [b]	0.00	22.00	4.62	104

SD – standard deviation; different letters next to mean values show statistically significant differences, α=0,05

4. Discussion

Knots are a natural element of wood, although their occurrence can be limited in the process of pruning. Over a period of more than four centuries of pruning, views about this procedure have changed (Giefing 1994). In some periods, pruning was very popular, but there were also times when it was considered ineffective and its use was discouraged (Leibundgut 1966, Korpel 1977). Today's knowledge on the pruning of conifer species, especially pine, is very well supported by broad scientific research and is well-established. Bearing in mind this information, it must be stated that trees can be pruned, removing both dead and live branches, without leaving snags, with even and smooth cuts along the side of the stem. The treatment should be performed before the heartwood develops in the branches to reduce the risk of infection inside the stem (Giefing 1999). It is advisable to perform this procedure on reach forest sites, of the site index 1 or 2, using selection methods. Pruning deciduous species is still debatable, and due to their importance and the related low availability of study results, less well-known.

Figure 2. Example of knot after artificial pruning of branch along with stem surface. Sound knot fully occluded with sound wood tissue around knot.

Figure 3. Sound knot after artificial pruning, fully occluded with small bark pocket. Sound wood tissue around knot.

The obtained results allow to conclude that oak tolerates the pruning of both dead and live branches well, reacting by increasing the share of the knotless zone and reducing the size of the wood zone adjacent to the knots.

Infections and decay occurred, but were very small. The calculated correlation indicates that a larger area of decay may develop on larger knots. This indicates the importance of pruning at the earliest possible stage, when branch diameters are relatively small.

The presented study confirms the rare occurrence of bark pockets. Giefing et al. (2011) also found rather exceptional occurrences of this defect with knots, i.e. one case in 59.

Previous studies of oak pruning show that there were no cases of decay or discoloration in the wood surrounding the knots (Szczawiński, Zawiślak 1997). It should be noted that Pikulik (2007) found discolorations in the area adjacent to the knots of both the wood of pruned oaks that left snags as well as in the wood of pruned oaks without leaving snags. The author studied the pruning of trees which were 27 years old, which can be considered too late of an age for this treatment (Giefing 1999).

Aßman (1961) noted the significant effect of the age of trees being pruned and the quality of the pruning on the quality and health of the wood. He stated that the danger of infection increases in medium and older age classes, and also when the wounds are large and contaminated. For this reason, pruning is recommended before trees reach the age of the culmination of their growth. On this basis, it can be concluded that the most favorable moment to prune is before the tree reaches 20 years of age, that is, before the branches have become too thick (Giefing 1999).

The main purpose of pruning, however, is primarily to increase the share of knotless wood, without increasing the

Figure 4. Knot with bark pocket and signs of infection, but with sound wood tissue around knot. Branch cut off at an angle.

risk of infection and subsequent discolorations of a pathogenic nature or wood decay. In this study it was shown that pruning results in an increase in the share of the knotless zone and this effect was statistically significant.

In the group of knots after pruning, the lack of a knotless zone occurred in about 1% of cases. It should be added that this was most probably due to errors in the pruning technique, where, despite the assumption of removing branches flush with the stem side, small snags were left, which had not occluded before the study samples were collected.

A positive effect of pruning is shortening the time of knot occlusion (Giefing 1999). The research showed that the average time of knot occlusion after pruning was less than 5 years, more than two-times smaller than for the knots of unpruned trees. The shortest duration of knot occlusion of the pruned branches was one year, a total of 25% of the knots occluded in three years, and 75% of the knots from the entire sample occluded in six years or less. By comparison, in 8 years, only 25% of all the knots in the unpruned trees had occluded.

Bearing in mind the above characteristics, it should be noted that pruning the oaks was successful. Some of the knots showed signs of decay, but the tissue next to the knot was always healthy. The treatment allowed us to obtain a larger sound knot zone and a shorter time of knot occlusion.

5. Conclusions

The carried out study of the health of oak knots after pruning indicated that in the process of their occlusion, a small, on average about 1 cm of decay occurs in knots to form an unsound zone. The occlusion of knots with an average diameter of a little over 1 cm took about five years (with the thickest knots having a diameter of 8 cm). At that time, the open knot was exposed to the development of a small infection. The study also showed the occurrence of knots without decay, accounting for about 5% of the total number. Unpruned trees were found to have knots that took significantly longer to occlude, i.e. about 11 years in the examined stem height zone of up to 3.25 m. In the studied population, these knots had a much larger unsound knot zone.

In light of the presented research, pruning oaks should be considered safe from the point of view of the health of the stem and the resulting knots. Pruning accelerated knot occlusion and reduced the unsound knot zone.

Conflict of interest

The authors declare the lack of potential conflicts of interest.

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Authors' contributions

D.F.G., D.S., P.S.M. – research concept and structure of the article; P.S.M. – statistical analysis; D.F.G., D.S., P.S.M., K.N., M.B. – literature review; P.S.M., D.S., K.N., M.B. – manuscript writing, verification of the results and corrections.