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TREE QUALITY AND FOREST STRUCTURE CHANGES IN THE FIRST STAGE OF CONVERSION OF HIGH FOREST INTO COPPICE-WITH-STANDARDS

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Abstract

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The work is aimed on evaluation of the effect of thinning on stand structure and changes of the quality of the trees under strong thinning measures in the forest stand with prevailing *Quercus petraea* in South Moravian Region of the Czech Republic. Three thinning variants with 100, 140 and 180 remaining trees per hectare were applied in four replications to simulate structure of a coppice-with-standards forest on a four hectare plot of high forest. On average, the implemented thinning reduced the total tree number from 717 to 140 individuals per hectare. After the thinning, the ratio of potential standards according to stories (the youngest, medium and the oldest) was 68:29:3, which corresponds with 46:44:10 ratio according to the volume. An average of 70–83% of the volume (76–85% of trees) was harvested in individual cells with different thinning variants. Relative frequencies of potential standards in quality score classes (A:B:C) were balanced and corresponded to the mean ratio of 11:49:40. The relative distribution of timber volume in score classes was also balanced and corresponded on average to the final ratio of 22:46:32. After the thinning it almost reached the generally recommended diameter distribution of standards in a coppice-with-standards. So far the applied measures did not significantly increase the overall quality of the remaining tree stand.

Keywords: coppice-with-standards, strong thinning, stand structure, sessile oak, score number

INTRODUCTION

Coppice and coppice with-standards has a long history in European forests (e.g. Hochbichler, 1993; Szabó, 2010). In the past, coppices-with-standards (c-w-s) in the Czech Republic were converted into high forests for various reasons, mainly to increase the quality in timber production (Sigotský, 1953). However there has been an increased interest in re-introduction of coppices and c-w-s silvicultural systems in the Czech Republic and also in other European countries (Utinek, 2004; Konvička *et al.*, 2006; Utinek, 2006). The National Forest Program of the Czech Republic recommends the re-introduction of coppices (Anonymous, 2008). Change of forest management methods and an increase in area of so called open forests is particularly favored by biologists (e.g. Buckley, 1992; Harmer and Howe, 2003). Their main argument is the worrying decline of biodiversity in contemporary high forests and the need to enhance biodiversity aspects for the future (Ash and Barkham, 1976; Mason and MacDonald, 2002; Camprodon and Brotons, 2006; Gondard *et al.*, 2006; Konvička *et al.*, 2006; Spitzer *et al.*, 2008; Van Calster *et al.*, 2008; Machar, 2009a; Vodka *et al.*, 2009; Hédl *et al.*, 2010; Szymura, 2010).

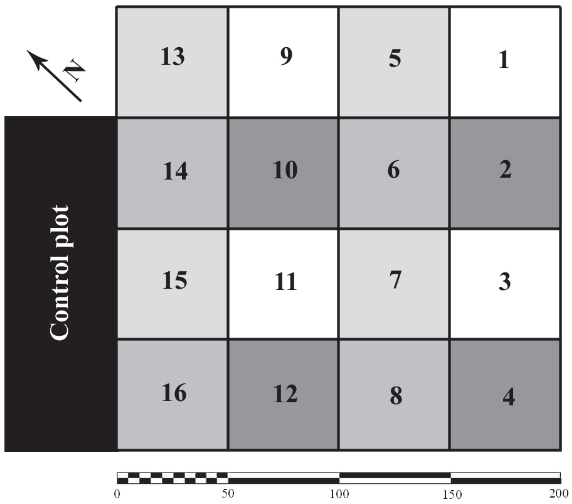
So far few actively managed c-w-s forests are currently present in the Czech Republic (eg. Machar, 2009b). Several experimental research plots were established at the Training Forest Enterprise "Masarykův les" Křtiny (Czech Republic) in 2008 (Kadavý *et al.*, 2011) and 2009 in order to approach a well-established c-w-s system and simulate influence of such forest structure on the biodiversity of endangered and protected species. In order to achieve such conditions and skip the usual long-term conversion periods, strong thinning interventions were applied.

The aim of our research was to evaluate the effect of thinning measures on stand structure (1), to connect the extent and intensity of thinnings with changes of the stand structure (2) and to evidence eventual changes of the quality of the trees under strong thinning measures (3).

MATERIAL AND METHODS

The experimental research plot was established in 2009 at the Training Forest Enterprise "Masarykův les" Křtiny in the South Moravian Region of the Czech Republic (49°14'42.629" N and 16°35'59.736" E). The mean annual air temperature in the area is 7.5 °C and the total annual precipitation around 550–650 mm. According to the currently valid management plan, the forest stand was 73 years old, single-storied and fully stocked. According to the Czech forest ecosystem classification (Viewegh *et al.*, 2003), the prevailing unit on the research plot is rich oak-hornbeam forest with meadow-grass and soft leaved sedge on plateau and rounded ridges and on some smaller part dry oak-hornbeam forest with meadow-grass on slopes.

The research plot, 4 hectares in size (200×200 m) was divided into 16 cells (50×50 m). A separate control plot (approx. 50×150 m) was established next to the experimental plot (Fig. 1).



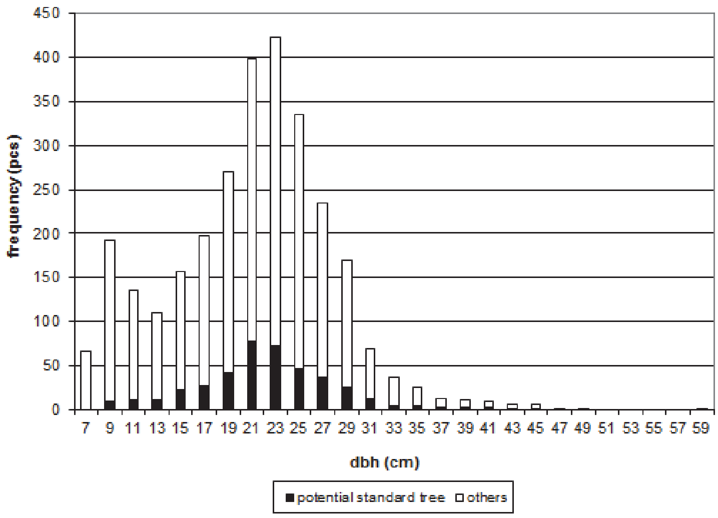
1: *Research design with different thinning intensities (white squares = clearcut, light gray squares = thinning variant PS25, mid gray = thinning variant PS35 and dark grey = thinning variant PS45)*

Before thinning, the position of every living tree with diameter at breast height (DBH) of at least 5 cm has been recorded along with its DBH, tree height and branchless trunk length.

Fifteen tree species were recorded on the research plots (Tab. I) with prevailing *Quercus petraea* (sessile oak) that accounted 95% of the total number of trees, or 96% of the total stock volume. There was an average of 717 trees per hectare, with an average standing volume of 232 m³·ha⁻¹. The upper canopy

I: *Basic characteristics of individual tree species within the research plot prior to the felling*

Tree species	Count	Composition (%)	Standing Volume	Composition (%)	Mean DBH	Mean Height	Mean Stem length
	(pcs)	(pcs)	(m³ o.b.)	(m³ o.b.)	(mm)	(m)	(m)
Quercus petraea	2711	94.6	889.82	95.9	209 ± 66	15.6 ± 3.5	11.0 ± 3.2
Pinus sylvestris	44	1.5	22.48	2.4	283 ± 75	18.9 ± 1.6	14.6 ± 1.6
Carpinus betulus	43	1.5	2.38	0.3	112 ± 50	9.1 ± 3.1	3.7 ± 2.1
Pinus nigra	13	0.5	5.04	0.5	264 ± 54	16.6 ± 3.1	12.7 ± 2.6
Tilia cordata	13	0.5	2.30	0.2	157 ± 81	11.1 ± 4.8	5.8 ± 4.7
Larix decidua	13	0.5	3.62	0.4	227 ± 60	18.8 ± 1.6	15.6 ± 1.5
Quercus robur	9	0.3	1.93	0.2	176 ± 64	13.6 ± 4.2	10.0 ± 3.7
Acer campestre	7	0.2	0.10	0.0	99 ± 28	6.1 ± 1.5	2.1 ± 1.2
Prunus avium	4	0.1	0.27	0.0	117 ± 41	10.3 ± 2.9	4.9 ± 3.5
Sorbus torminalis	3	0.1	0.17	0.0	126 ± 38	10.9 ± 1.8	3.3 ± 1.1
Acer platanoides	2	0.1	0.07	0.0	94 ± 34	7.6 ± 4.3	2.9 ± 1.9
Tilia platyphyllos	2	0.1	0.02	0.0	73 ± 20	5.0 ± 0.7	1.5 ± 0.3
Pyrus communis	1	0.0	0.00	0.0	92	6.4	4.9
Picea excelsa	1	0.0	0.02	0.0	105	7.2	2.3
Pinus strobus	1	0.0	0.01	0.0	86	7.2	4.2
Total	**2867**	**100.0**	**928.23**	**100.0**	-	-	-
Average per ha	**717**	-	**232.06**	-	-	-	-



2: *Diameter structure of the research plot (4 ha) before and after thinning*

consisted primarily of *Quercus petraea* with an average height of 16 m and admixture of *Larix decidua* and *Pinus sylvestris*, reaching above this level (height of 19 m). Sessile oak reached an average DBH of 21 cm and an average branch-free trunk length of 11 m.

Although the management plan indicated only one storey, the diameter structure of the initial stand, constructed upon our inventory data, attested to the presence of three strata (Fig. 2) with frequency peaks at 9 cm (the thin storey), 23 cm (medium storey) and 36 cm (the thick storey). Although we did not test the age difference of the strata, Gura (2010) proved that the thickest stratum trees reached an average age of 128 years. Therefore we further referred to the strata as the youngest, medium and the oldest stories, respectively.

Presence of strata was evidenced and consequently released in three storeys: thinner – youngest medium thick – medium aged and thicker – oldest to instantly mimic well established c-w-s structure. According to plot design published by Kadavý *et al.* (2011), on average 25, 35 and 45 potential standards have been marked in three thinning variants (PS25, PS35 and PS45), all in four replications. Also clearcut was applied in four cells (Fig. 1).

On all cells except in clearcuts, we attempted to achieve an approximately a 65:25:10 ratio of the number of potential standards in youngest : medium aged : oldest stories respectively. *Quercus petraea* trees that indicated at least a 6 m long, straight, branchless trunk without wounds and a dense, long, and healthy crown (quality criteria for c-w-s standards according to Konšel, 1931 and Utinek, 2004) were marked as potential standards before thinning. In December 2009, all unmarked trees and shrubs were cut and removed from the plot. The entire plot was then fenced.

To evaluate three thinning variants, tree volumes were calculated to 7 cm top diameter over bark (m^3) using volume equations from Petráš and Pajtík (1991).

Release indexes (I_A, I_B) and thinning intensities (I_{FA}, I_{FB}) for every treatment were evaluated. The release index is defined as the release extent of potential standards for the analyzed cell (50×50 m). Index I_A evaluates the extent of planned thinning volume per potential standard, while index I_B provides information on the number of felled trees per standard:

$$I_A = \frac{V_F}{N_S}, \quad (1)$$

$$I_B = \frac{N_F}{N_S}, \quad (2)$$

where

V_F.......... volume of scheduled thinning ($m^3 \cdot ha^{-1}$),

N_F.......... number of trees planned for thinning ($trees \cdot ha^{-1}$),

N_S..... number of potential standards ($trees \cdot ha^{-1}$).

Thinning intensity I_{FA} defines the percentage rate of thinning from the total volume of the 50×50 m cell, while I_{FB} defines the percentage of number of trees scheduled for thinning from the total number of trees in a cell.

$$I_{FA} = \left(\frac{V_F}{V}\right) \times 100, \quad (3)$$

$$I_{FB} = \left(\frac{N_F}{N}\right) \times 100, \quad (4)$$

where

I_{FA}, I_{FB} ... thinning intensity (%),

V_F.......... planned thinning volume ($m^3 \cdot ha^{-1}$),

V........... standing volume prior to planned thinning ($m^3 \cdot ha^{-1}$),

N_F.......... number of trees to fell ($trees \cdot ha^{-1}$), N .... total number of trees prior to planned thinning ($trees \cdot ha^{-1}$).

The aggregation index (Clark and Evans, 1954) was also calculated to record the stand structure in individual cells before and after thinning.

$$R = \frac{\sum_{i=1}^{N} r_i}{N} \times \left(\frac{\sqrt{F/N}}{2} \right)^{-1}, \quad (5)$$

where

R .... aggregation index,

r_i .... distance of the i-th tree to its nearest neighbor tree,

N .... number of trees on the plot,

F .... area of the plot in m^2.

Generally, the value of the aggregation index ranges from 0 to 2.1491. R < 1 suggests clustering while R > 1 suggests ordering arrangement in the forest stand.

Score numbers (SN), a modification of the original value numbers (Vyskot, 1949) were calculated to express the qualitative change caused by the thinning:

$$SN = \frac{D^2 + H + S + C^3}{4}, \quad (6)$$

where

SN......... score number,

D .... diameter class (from 1 to 4),

H .... height class (from 1 to 4),

S .... branchless trunk length class (from 1 to 4),

C............ crown length class (from 1 to 4).

Increasing value of the score number indicates decreasing quality of a tree. The individual trees were then classified into three score classes A, B and C which were standards of high score (A: $1 \le SN \le 8.6$), medium score (B: $8.7 \le SN \le 13.4$) and low score (C: $13.5 \le SN \le 22$), respectively (Vyskot, 1949).

RESULTS AND DISCUSSION

After thinning, an average of 140 trees per hectare were marked and left as potential standards on the site. Remaining trees were exclusively sessile oaks. Applied thinning on the research plots drew on general principles as in case of the c-w-s forest management (Konšel, 1931; Polanský *et al.*, 1956; Vyskot, 1958; Korpeľ *et al.*, 1991; Saniga, 2007), especially regarding the conversion of a quasi high forest to a c-w-s stands (see eg. Cotta, 1845; Sigotský *et al.*, 1953; Polanský *et al.*, 1956; Vyskot, 1958; Utinek, 2004).

The ratio of potential standards according to storeys (the youngest, medium and the oldest trees) corresponded to 68:29:3 according to tree numbers and 46:44:10 according to the tree volume. Applied thinning measures have nearly reached the generally recommended distribution of standards in stories of c-w-s (65:25:10) described by Konšel (1931), Polanský (1947) and Polanský *et al.* (1956). Our result shows lower share of the oldest storey standards, which may be attributed to previous management practices.

Release indexes of potential standards (I_A and I_B) show that in individual cells where the thinning variant PS25 was applied, on average 6 trees (a total of 1.9 m^3) were removed from the vicinity of a single potential standard (Tab. II), while in cells with thinning variant PS35, on average 4 trees were removed from the vicinity of potential standard (a total of 1.23 m^3). In cells with thinning variant PS45, in average 3 trees were removed from the surroundings of the potential standard tree (a total of 0.93 m^3). In average 83% of the total volume (85% of trees) was harvested in cells with thinning variant PS25, 78% of volume (80% of trees) was harvested in cells with variant PS35, and 70% of volume (76% of number of trees) was harvested in thinning variant PS45.

Implemented thinning slightly altered the horizontal structure (Tab. III). The cells in thinning variant PS45 showed a 13% increase in the aggregation index. The cells in thinning variant PS35 showed a 10% increase in the aggregation index and the cells in the thinning variant PS25 showed an 8% increase in the aggregation index. The implemented thinning shifted the aggregation index values towards an ordered horizontal structure.

Before thinning the ratio of tree numbers according to score classes (A:B:C) was 7:41:52 and distribution of tree volume according to score classes was 15:46:39, respectively. The implemented thinning adjusted the percentage ratio of remaining trees – potential standards – according to score classes to 11:49:40 and the percentage volume ratio of same trees according to score classes to 22:46:32.

An average of 25 potential standards (100 $trees \cdot ha^{-1}$) were left in individual cells that were part of thinning variant PS25 (Tab. IV).

Approximately 67% of these trees were classified as the youngest storey, 31% as the medium-aged

II: *Mean values of release indexes (I_A and I_B) and thinning intensities (I_{FA} and I_{FB}) with standard deviations are presented*

Thinning variant	Release index		Thinning intensity	
	I_A (m^3)	I_B (pcs)	I_{FA} (% from m^3)	I_{FB} (% from pcs)
PS25	1.91 ± 0.241	5.9 ± 0.97	83.1 ± 1.76	85.1 ± 2.11
PS35	1.23 ± 0.044	4.0 ± 0.33	78.4 ± 2.14	80.3 ± 1.24
PS45	0.93 ± 0.172	3.3 ± 0.67	70.2 ± 6.84	75.9 ± 3.84

III: *Mean values of Clark-Evans aggregation indexes with standard deviations*

		Prior to thinning		After the thinning	
		Quercus petraea	Total	Quercus petraea	Total
Thinning variant	PS25	1.11 ± 0.090	1.12 ± 0.090	1.29 ± 0.076	1.29 ± 0.076
	PS35	1.12 ± 0.054	1.12 ± 0.063	1.34 ± 0.094	1.34 ± 0.094
	PS45	1.05 ± 0.154	1.03 ± 0.155	1.32 ± 0.062	1.32 ± 0.062

IV: *Mean numbers and volumes of potential standards classified by the score classes, stories and thinning intensities with standard deviations*

Thinning variant	Storey	Number of trees per cell [trees per 0.25 ha] (standing volume per cell [m³ per 0.25 ha])			
		score class			total
		A	B	C	
PS25	oldest	1.0 ± 0.00 (1.63 ± 0.395)	0.0 ± 0.00 (0.00 ± 0.000)	0.0 ± 0.00 (0.00 ± 0.000)	1.0 ± 0.00 (1.63 ± 0.395)
	medium	1.5 ± 0.50 (1.14 ± 0.413)	4.3 ± 1.09 (2.30 ± 0.504)	2.0 ± 1.22 (1.23 ± 0.756)	7.8 ± 0.43 (4.67 ± 0.462)
	youngest	0.0 ± 0.00 (0.00 ± 0.000)	9.0 ± 1.58 (2.66 ± 0.355)	7.5 ± 0.87 (1.97 ± 0.688)	16.5 ± 2.06 (4.62 ± 0.636)
	total	2.0 ± 0.71 (1.95 ± 0.883)	13.3 ± 2.38 (4.96 ± 0.588)	9.5 ± 1.80 (3.19 ± 1.417)	24.8 ± 1.92 (10.11 ± 0.793)
PS35	oldest	1.0 ± 0.00 (1.56 ± 0.000)	1.0 ± 0.00 (0.96 ± 0.000)	0.0 ± 0.00 (0.00 ± 0.000)	1.0 ± 0.00 (1.26 ± 0.300)
	medium	1.3 ± 0.47 (0.91 ± 0.360)	5.0 ± 2.12 (2.52 ± 1.030)	4.0 ± 2.24 (2.10 ± 1.066)	10.0 ± 0.71 (5.31 ± 0.911)
	youngest	1.3 ± 0.43 (0.38 ± 0.248)	11.8 ± 1.48 (3.10 ± 0.530)	11.3 ± 1.92 (2.57 ± 0.755)	24.8 ± 1.79 (6.05 ± 0.894)
	total	2.5 ± 1.12 (1.45 ± 0.857)	17.0 ± 2.74 (5.86 ± 1.221)	15.3 ± 3.77 (4.68 ± 1.817)	35.3 ± 1.48 (12.00 ± 1.189)
PS45	oldest	1.3 ± 0.43 (2.23 ± 1.747)	1.0 ± 0.00 (1.06 ± 0.000)	1.0 ± 0.00 (1.31 ± 0.000)	1.8 ± 0.43 (2.82 ± 1.460)
	medium	4.3 ± 3.49 (2.96 ± 2.837)	5.8 ± 1.64 (3.09 ± 0.789)	4.0 ± 2.16 (1.93 ± 0.914)	13.0 ± 0.00 (7.50 ± 1.222)
	youngest	1.7 ± 0.47 (0.61 ± 0.280)	14.3 ± 4.15 (4.30 ± 1.971)	14.8 ± 4.82 (3.06 ± 1.489)	30.3 ± 2.05 (7.83 ± 1.613)
	total	6.8 ± 4.44 (5.65 ± 4.880)	20.3 ± 2.86 (7.66 ± 1.333)	18.0 ± 6.71 (4.84 ± 2.972)	45.0 ± 2.12 (18.15 ± 1.943)

storey and 2% as the oldest storey. The percentage distribution of their numbers according to score classes (A:B:C) corresponded to 8:54:38, respectively. In cells with thinning variant PS35, on average 35 potential standards (140 trees·ha^{-1}) were left; 70% in the youngest storey, 28% in the medium-age storey and 2% were in the oldest one. The percentage distribution of score classes (A:B:C) corresponded to 7:49:44. In cells with thinning variant PS45, on average 45 potential standards (180 trees·ha^{-1}) were left, 67% were classified as the youngest storey, 29% as the medium-age storey and 4% as the oldest storey. The percentage distribution of tree numbers according to score classes (A:B:C) corresponded to 15:45:40.

In cells with thinning variant PS25, on average 10 m^3 of timber (40 m^3·ha^{-1}) were left. Approximately 46% were classified in the youngest storey, approximately 46% were classified in the medium-age storey and 8% were classified in the oldest storey. The percentage distribution of their volumes according to score classes (A:B:C) corresponds to the ratio 19:49:32. In cells that were part of thinning variant PS35, an average of 12 m^3 of timber (48 m^3·ha^{-1}) were left. Approximately 50% were classified in the youngest storey, approximately 44% were classified in the medium-age storey and 6% were classified in the oldest storey. The percentage distribution of their volumes according to score classes (A:B:C) corresponded to the ratio 12:49:39. In individual cells, that were part of thinning variant PS45, an average of 18 m^3 of timber (72 m^3·ha^{-1}) was left as potential standards. Approximately 43% were classified in the youngest storey, approximately 41% were classified in the medium-age storey and 16% were classified in the oldest storey. The percentage distribution of the volumes according to score classes (A:B:C) corresponded to the ratio 31:42:27.

According to Polanský *et al.* (1956) and Poleno (1999), the cells with a thinning variant PS25 may be characterized as a c-w-s with a low standing volume and a low number of standards, the cells with thinning variant PS35 may be characterized as a c-w-s with a low standing volume and an average number of standards and the cells that belonged to a thinning variant PS45 can be characterized as c-w-s with a low standing volume with a high number of standards. To our surprise, the most intensive intervention (thinning variant PS25) did not lead to the highest percentage of the A score class, most probably because of lower initial quality of trees in the treated cells.

CONCLUSION

We applied three strong thinning measures in four replications. Our intention was to instantly create both horizontal and vertical stand structure, similar to that of an ideal coppice-with-standards. We found out, that it is possible to perform such a change, when the initial structure allows it, e.g. the initial diameter distribution must contain a broad range of tree diameters. It is therefore temporarily possible to create a c-w-s like stand structure.

As we presented, stand structures created in such way indicate similarity with coppice-with-standards, as far as ratio of diameter (age) classes and horizontal distribution are concerned. On the other hand, no significant change of stand quality connected with our measures was confirmed. It is probably because we had to respect a demand for a regular horizontal distribution of potential standards without gaps. That is the reason why the demand for vital quality trees may not be easily achieved.

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