Establishment and selected characteristics of the Hády coppice and coppice-with-standards research plot (TARMAG I)

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ABSTRACT: The paper deals with the establishment of the coppice and coppice-with-standards research object under the project Biodiversity and Target Management of Endangered and Protected Species in Coppices and Coppices-with-Standards Included in the System of NATURA 2000. It summarizes reasoning which preceded the selection of the site and provides a detailed description of the methodology of experimental site establishment. It specifies the rules of felling which was planned with the objective to simulate the impact of coppice and coppice-with-standards on biodiversity of endangered and protected species. It also describes the stand condition prior to and after the implemented felling, with additional emphasis on coppice-with-standards. Individual felling variants which were implemented were characterized by varying felling intensity. Close attention is paid to the evaluation of standards which is expressed by a system of score classes.

Keywords: biodiversity; coppice; coppice-with-standards; conversion; NATURA 2000

There has been a renewed interest in a coppice-with-standards silvicultural system in the last two decades (Buckley 1992; Harmer, Howe 2003, Machar 2009). The most discussed advantage of so-called open forests is their higher biodiversity (Ash, Barkham 1976; Mason, MacDonald 2002; Van Calster et al. 2008). In 2008, an experimental research plot was established in the Bílovice Forest District, Křtiny Training Forest Enterprise "Masarykův les" at (Czech Republic) under the TARMAG project (Biodiversity and Target Management of Endangered and Protected Species in Coppices and Coppices-with-Standards Included in the System of NATURA 2000). The aim of the TARMAG project is to develop management guidelines intended for conserving biodiversity in the landscape through supporting coppices and coppices-with-standards (further referred to as c-w-s) in the context of the current economic conditions of forest management while meeting the nature conservation aims of Natura 2000. The research plot was established to mimic a well-established c-w-s, to simulate the influence of such forest on the biodiversity of endangered and protected species and to provide individual research teams of the TARMAG project with a joint field laboratory. Because of a short life span of the TARMAG project it was necessary to skip the long-term conversion period and to create c-w-s instantly through a strong thinning intervention.

The aim of this paper is to describe the state of the research plot prior to and after the intervention, the extent and intensity of prescribed felling and changes in the species composition and quality of the tree collective invoked by the felling intervention. The main scope of this article is the c-w-s. Therefore,

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the parts where clear cut was applied will not be mentioned.

Basic facts on conversion into c-w-s and its silviculture

The c-w-s silvicultural system has been described in expert literature many times (Konšel 1931; Polanský 1947; Polanský et al. 1956). Since thicker timber yields higher financial returns, there are efforts to leave as many standards as possible. Therefore both Polanský et al. (1956) and Poleno (1999) distinguished the following types of c-w-s:

- low standing volume (< 100 $m^3\cdot ha^{-1}$) and number of standards (50–100 trees$\cdot ha^{-1}$),
- medium standing volume (100–200 $m^3\cdot ha^{-1}$) and number of standards (100–160 trees$\cdot ha^{-1}$),
- high standing volume (200–400 $m^3\cdot ha^{-1}$) and number of standards (160–200 trees$\cdot ha^{-1}$).

The number of standards in c-w-s should be as high as to allow the lower storey to thrive, as the latter produces fuel wood as well as it fulfils the soil-protection function. The lower storey also contributes to natural pruning of standards (Kadlus 2005).

The most important tree species of coppice and c-w-s in central Europe was the oak (sessile and pedunculate). Unfortunately, no papers have been published recently describing the conversion of high forest into coppice-with-standards. On the contrary, the conversion of pedunculate or sessile oak coppice into high forest was described for instance by Kostov (1989), Pintarić (1999) and Durkaya et al. (2009). According to Ciancio et al. (1995) and Röhrig and Kühne (2005) coppice-with-standards could be utilized as interlink in conversion from coppice to high forest. Krenzler (2007) reported on return to c-w-s management in a former 40-years abandoned c-w-s. From the historical point of view, there are several methods of conversion of high forest (possibly also false high forest) applied in the past. According to Cotta (1845), in a forest enterprise to be converted, mature stands should be cut after natural regeneration appeared. Mid-aged stands should be treated as high forest except for future standards which should be released carefully. Younger stands, after they reached the age of coppice rotation, should be clear cut except for a certain number of future standards. Polanský et al. (1956) did not recommend conversions of larger forest units via one-off cutting down into c-w-s, because this would disrupt the felling balance and thus yield continuity. Nanquett's method (Doležal 1951; Sigotský et al. 1953; Vyskot 1958; Utinek 2004) appeared in the mid-19th century in France as a combination of direct and indirect conversions of coppice forests. It was divided into four stages with respect to the biology of oak. It does not predominantly take into account artificial regeneration. Wiehl's method (1912) recommended the integration of the fast-growing European larch into the conversion process to minimize production losses. We also need to mention the methodology applied in municipal forests of Moravský Krumlov (Czech Republic) in recent years (Utinek 2004, 2006), as well as the methodology of another project supported by the Ministry of Agriculture of the Czech Republic for 2007–2011 (Flora et al. 2009; Kadavý et al. 2009).

MATERIAL AND METHODS

Research plot establishing, data collection methodology and implemented felling measures

In 2008, an experimental research plot was established in forest stand 380C10 at the Křtiny Training Forest Enterprise Masarykův les, Bílovice Forest District. The plot is situated approximately 0.5 km north-east of the Brno city border, in the South Moravian Region of the Czech Republic (GPS coordinates: 49°13'29.87''N, 16°40'55.391''E). According to the currently valid Forest Management Plan (2003–2012), it is a single-storey, fully-stocked, 98-year-old stand comprising 54% of sessile oak, 18% of Norway spruce, 15% of hornbeam, and 10% of European larch. The predominant forest type is 2H2 (i.e. loamy beech-oak forest on plateaus and gentle slopes with *Carex pilosa*), while a minor part covers the 2 × 2 forest type (cornelian cherry-oak forest with admixed beech on rendzina). Despite being of vegetative origin (nowadays at the stage of so called false high forest), the stand belongs to management set of stands No. 245 (oak stands on rich sites at lower altitudes) with rotation period of 150 years. The plot covers 200 × 200 m and is divided into 16 cells (50 × 50 m each). Four neighbouring cells constitute an area of 100 × 100 m within which four variants of different felling intensity and therefore of varying number of standards are represented. In all cells, the position of every living tree with DBH 5 cm at minimum has been surveyed and recorded in the project database along with its species code, DBH, total tree height, and living crown bottom.

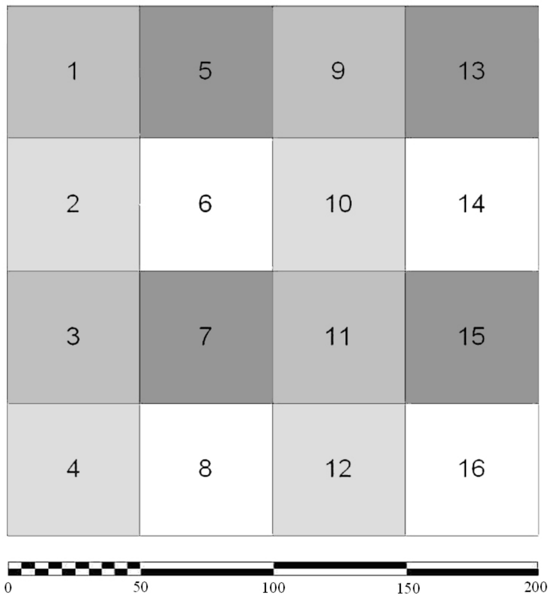

Fig. 1. Design of the research plot

In Fig. 1, white colour depicts clear cut (cells No. 6, 8, 14 and 16), light grey colour depicts very high felling intensity (cells No. 2, 4, 10 and 12), mid-grey colour depicts high intensity (cells No. 1, 3, 9 and 11) and dark grey colour depicts medium high felling intensity (cells No. 5, 7, 13 and 15). Furthermore, two control plots (each 50 × 50 m) were established in neighbouring forest stands.

Stand data prior to felling attest the presence of two strata with diameter frequency peaks at approximately 12 cm and 28 cm. We took advantage of the presence of two diameter strata to mimic a well-established c-w-s by establishing two quasi storeys (thinner–younger, thicker–older). Although we did not test the age difference of the strata, we further refer to them as the younger and the older storeys.

A standard has to meet general qualitative requirements (Konšel 1931; Utinek 2004):

(a) perfect health condition (no dead branches in the crown, no wounds),
(b) at least 6 m long straight branchless trunk,
(c) a dense, long and healthy crown.

According to the plot design, on average 24, 35 and 46 future standards were marked in cells with very high, high and medium high felling intensity, respectively. In all cells, we attempted to achieve a 1:3 ratio between the number of standards in the older and the younger storey.

Preferentially, individuals of *Quercus petraea* and *Sorbus torminalis* that met the given quality criteria were selected as future standards. The thickest trees (DBH over 50 cm) were not marked as standards due to advanced age.

Prior to felling, all future standards (in both older and younger storey) were marked by a green stripe on the trunk. At the turn of 2008/2009, all unmarked trees and shrubs were cut down and transported out of the plot. Subsequently, the whole plot was fenced.

Data processing

Standing volume of all trees was calculated using volume equations published by Petráš, Pajtík (1991). Furthermore, the score number expressing a complex value was calculated for each standard:

$$SN = \frac{(T^2 + V + P + K^3)}{4} \qquad (1)$$

where:
SN – score number,
T – diameter class (from 1 to 4),
V – height class (from 1 to 4),
P – trunk length class (from 1 to 4),
K – crown length class (from 1 to 4).

Score numbers were subsequently used to describe the change caused by the felling in a complex way. The score number is a modification of the original quality number published by Vyskot (1949).

The individual trees were then classified into three score classes A, B and C which included standards of high score ($1 \leq SN \leq 8.6$), medium score ($8.7 \leq SN \leq 13.4$) and low score ($13.5 \leq SN \leq 22$), respectively.

Subsequently, release indices and felling intensities were calculated. The release index is defined as the extent of release of standards for the analysed cell (50 × 50 m). Index I_A evaluates the extent of planned felling volume per standard. Index I_B provides information on the number of felled trees per standard:

$$I_A = V_F/N_S \qquad (2)$$

$$I_B = N_F/N_S \qquad (3)$$

where:
V_F – volume of scheduled felling ($m^3 \cdot ha^{-1}$),
N_F – number of trees planned for felling ($trees \cdot ha^{-1}$),
N_S – number of standards ($trees \cdot ha^{-1}$).

Felling intensity I_{FA} defines the percentage rate of felling from the total volume. On the other hand, I_{FB} provides information on the percentage share of trees scheduled for felling from the total number of trees.

$$I_{FA} = (V_F/V) \times 100 \qquad (4)$$

$I_{FB} = (N_F/N) \times 100$ (5)

where:

I_{FA}, I_{FB} – felling intensities (%),

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

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

N_F – number of trees to fell ($trees \cdot ha^{-1}$),

N – total number of trees prior to planned felling ($trees \cdot ha^{-1}$).

Finally, the aggregation index according to Clark and Evans (1954) was calculated to record the stand structure in individual cells prior to and after the implemented felling:

$$R = \frac{\sum_{i=1}^{N} r_i}{N} \times \left(\frac{\sqrt{\left(N/F\right)}}{2} \right)^{-1} \quad (6)$$

where:

R – aggregation index,

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

N – number of trees on the site,

F – area of the site in m^2.

Generally, the aggregation index ranges from 0 to 2.1491. $R < 1$ suggests clustering while $R > 1$ suggests ordering.

RESULTS

Basic characteristics of individual tree species prior to felling

A total of 16 tree species have been recorded in the research plot. The most frequent is *Quercus petraea*, which accounts for 47% of the total number of treey and/or for 78% of the total volume. The second most frequent species is *Carpinus betulus*. Prior to the implemented felling, there were on average 660 trees per hectare, with average standing stock of 308 m^3. The principal level of the upper canopy is composed primarily of *Quercus petraea* (approx. 20 m). On average, trees of *Quercus petraea* reach 29 cm in diameter and 11 m in crown bottom height. *Larix decidua* and *Pinus sylvestris* reach above this level. The remaining tree species fill in the below-crown space and are individually uniformly distributed over the plot area.

Site structure with regard to marked standards

On average, 141 standards were marked and left per 1 ha. These include individuals of *Quercus petraea* (76%) and *Sorbus torminalis* (2 %). The percentage ratio of standards with respect to storeys (older to younger) is 39:61. The older storey is almost exclusively composed of *Quercus petraea* (93%). The younger storey consists of *Quercus petraea* (65%) and *Sorbus torminalis* (35%). The diameter structure of the standards is slightly right-skewed.

In cells subjected to very high felling intensity six trees were removed from the vicinity of each standard (a total of 2.71 m^3) and 77% of the volume (82% of the number of trees) were felled on average (Table 1). In cells subjected to high felling intensity, on average four trees were removed per standard (1.32 m^3) and 63% of the volume (82% of the number of trees) were felled on average, while in areas subjected to medium-high felling intensity three trees were removed from the immediate vicinity of a standard (0.86 m^3) and 54% of the volume (84% of the number of trees).

Scores, numbers and volumes of standards

On average, the volume of standards left in cells subjected to very high felling intensity is 19 m^3 (76 $m^3 \cdot ha^{-1}$) (Table 2). Out of this volume, approximately 40% account for trees which are classified in the older storey. The ratio of percentage distribution according to score classes (A:B:C) is 28:66:6. Areas subjected to high felling intensity have an average volume of 28 m^3 (112 $m^3 \cdot ha^{-1}$) left. Out of this volume, approx. 59% account for trees which are classified in the older storey. The ratio of percentage distribution according to score classes (A:B:C) is 31:56:13. Areas subjected to medium-high fell-

Table 1. Mean values of release indices (I_A and I_B) and felling intensities (I_{FA} and I_{FB})

Felling intensity	Release index		Felling intensity	
	I_A (m^3 o.b.)	I_B (pcs)	I_{FA} (% from m^3 o.b.)	I_{FB} (% from No.)
Very high	2.71 ± 0.250	5.9 ± 0.76	77 ± 3	82 ± 4
High	1.32 ± 0.329	3.8 ± 0.55	63 ± 4	82 ± 5
Medium-high	0.86 ± 0.071	3.5 ± 1.36	54 ± 6	84 ± 16

Table 2. Mean numbers and volumes of standards classified according to score classes, storeys and felling intensities

Felling intensity	Storey	Number of trees per cell (trees per 0.25 ha) (standing volume per cell [m^3 o.b. per 0.25 ha])			
		score class			total
		A	B	C	
Very high	older	1.3 ± 0.94 (2.14 ± 1.431)	3.8 ± 1.30 (5.22 ± 2.536)	0.0 ± 0.00 (0.00 ± 0.000)	5.0 ± 1.55 (7.35 ± 2.435)
	younger	3.8 ± 0.43 (3.12 ± 0.581)	11.5 ± 2.06 (6.93 ± 1.243)	3.5 ± 2.18 (1.12 ± 0.924)	18.8 ± 4.11 (11.17 ± 2.593)
	total	5.0 ± 1.25 (5.26 ± 1.043)	15.3 ± 4.24 (12.15 ± 2.173)	3.5 ± 2.18 (1.12 ± 0.924)	23.8 ± 3.77 (18.52 ± 2.547)
High	older	4.0 ± 1.22 (6.06 ± 3.003)	8.5 ± 1.66 (8.68 ± 2.093)	1.8 ± 0.43 (1.59 ± 0.294)	14.3 ± 3.06 (16.32 ± 3.614)
	younger	3.0 ± 0.71 (2.56 ± 0.809)	12.8 ± 3.11 (6.86 ± 2.320)	5.3 ± 2.05 (2.02 ± 1.538)	21.0 ± 4.71 (11.44 ± 2.736)
	total	7.0 ± 1.12 (8.62 ± 2.808)	21.3 ± 3.28 (15.54 ± 2.389)	7.0 ± 2.29 (3.61 ± 1.128)	35.3 ± 4.13 (27.76 ± 3.307)
Medium-high	older	5.8 ± 2.17 (5.71 ± 2.816)	14.8 ± 2.68 (14.27 ± 2.486)	1.5 ± 0.5 (1.50 ± 0.660)	22.0 ± 5.88 (21.48 ± 5.748)
	younger	5.8 ± 2.38 (3.83 ± 2.071)	14.5 ± 3.57 (7.34 ± 2.819)	4.0 ± 1.87 (1.54 ± 1.243)	24.3 ± 5.33 (12.71 ± 3.208)
	total	11.5 ± 2.28 (9.54 ± 2.644)	29.3 ± 3.16 (21.61 ± 4.365)	5.5 ± 1.85 (3.04 ± 0.995)	46.3 ± 5.6 (34.19 ± 4.879)

ing intensity have an average standing volume of 34 m^3 (136 $m^3·ha^{-1}$) left in the form of standards. Out of this volume, approx. 63% account for trees which are classified in the older storey. The ratio of percentage distribution according to score classes (A:B:C) is 28:63:9.

Stand structure in cells prior to and after implemented felling

The implemented felling slightly tipped the horizontal structure towards an ordered distribution in all cells (Table 3). Cells with very high felling intensity were subjected to the highest impact on the horizontal structure. After felling the aggregation index increased by 7% towards the ordered structure. Cells with high felling intensity showed an increase of 4% and those subjected to medium-high felling intensity an increase of 2% towards the ordered horizontal structure.

DISCUSSION

In the past, former c-w-s forests growing in this country were converted into high forests for various reasons (timber production purposes being stressed the most frequently). At present, we may witness an increased focus on the re-introduction

Table 3. Mean values of Clark-Evans aggregation indices

		Felling intensity		
		very high	high	medium-high
Prior to felling	*Quercus petraea*	1.15 ± 0.09	1.14 ± 0.07	1.11 ± 0.12
	Sorbus torminalis	1.31 ± 0.20	0.99 ± 0.20	0.98 ± 0.29
	total	1.16 ± 0.04	1.13 ± 0.05	1.14 ± 0.05
After felling	*Quercus petraea*	1.34 ± 0.11	1.35 ± 0.16	1.22 ± 0.12
	Sorbus torminalis	1.38 ± 0.33	0.95 ± 0.10	1.02 ± 0.31
	total	1.30 ± 0.04	1.22 ± 0.12	1.19 ± 0.06

of coppice and c-w-s silvicultural systems into the forest management not only in this country (detailed surveys e.g. in Utinek 2004, 2006 or Konvička et al. 2006). Recommendations for the re-introduction of these silvicultural systems are also declared in the National Forest Program for the period by 2013 (Anonymous 2008).

The establishment of the Hády research plot (TARMAG I) drew on general principles of management of c-w-s. Let us then emphasize those which we consider essential and which affected the plos establishment, and as such became the basis of c-w-s conversion in the site. Obviously, it is of immense importance to primarily consider the history (origin) of the converted stand, tree species composition, type and age of the site. Only then we may deduce its feasible sprouting capacity and the consequent reaction of standards to their release. This means that we may determine the actual occurrence and degree of the so-called open stand increment. A sufficient number of good-quality standards forms a basis of c-w-s. The trees should primarily be of generative origin and the conversion method through false c-w-s should be well applied. Numbers of standards and their distribution into individual canopy layers should not be set mechanically. The conversion should be implemented gradually to make sure that forest stands are well prepared with respect to both their management and biology. Primarily the Nanquett's method can be considered highly inspirational (Doležal 1951; Sigotský et al. 1953; Vyskot 1958; Utinek 2004).

Data obtained from the established experimental c-w-s forest site reveal that the implemented felling failed to follow the recommended tree distribution according to individual storeys (Konšel 1931; Polanský 1947; Polanský et al. 1956), which may primarily be ascribed to the fact that only two storeys occur at the research site at present. Nevertheless, the achieved state may be assessed as satisfactory, as the percentage distribution of standards according to storeys (older storey to younger storey) corresponds to the ratio 39:61. If we desired to characterize the cells within the established experimental research plot in accordance with the diagram of c-w-s types (Polanský et al. 1956; Poleno 1999), then the very high felling variant may be characterized as c-w-s with low standing volume and a small number of standards, high felling variant may be characterized as c-w-s with standard standing volume and an average number of standards and the medium-high felling may be seen as c-w-s with standard standing volume and a high number of standards.

Paradoxically, the most intensive intervention (very high felling intensity) did not lead to the highest percentage of score class A. It was probably caused by the lower initial quality of trees in the respective cells.

We are confident that in the long-term perspective the results from our research plots will enable us to answer the question whether this management approach may be viewed as viable or not.

CONCLUSION

A coppice and c-w-s research plot was established in the Křtiny Training Forest Enterprise "Masarykův les", Czech Republic. To simulate a coppice and c-w-s forest structure, the four-hectare-plot was divided into 16 cells (50 × 50 m each) in which four felling intensities were applied in four replications. On average, the implemented measures reduced the total tree number from original 660 to 141 individuals per hectare. The average standing volume was reduced from 308 to 108 $m^3 \cdot ha^{-1}$. In cells with high felling intensity on average 6 trees were removed per one standard, while under high felling and medium-high intensity variants only 4 and 3 trees per one standard were removed, respectively. An average of 96 standards per hectare (76 $m^3 \cdot ha^{-1}$) were left in cells where high felling intensity measures were implemented, an average of 140 trees per hectare (112 $m^3 \cdot ha^{-1}$) in cells subjected to high felling intensity and 184 trees per hectar (136 $m^3 \cdot ha^{-1}$) in cells subjected to medium-high felling intensity. The performed measures increased the relative numbers of trees in the medium and highest score classes. However, the felling interventions did not change the relative distribution of timber volume in score classes and thus copied virtually the distribution prior to the measures. The medium score class is of dominant volume occurrence. The implemented measures did not improve the mean score numbers of individual score classes significantly. Trees classified in the older storey tended to reach better score numbers than those in the younger storey.

Relative frequencies of standards in score classes (A:B:C) were balanced and corresponded to the mean ratio of 22:63:15. The relative distribution of timber volume in score classes (A:B:C) was also balanced and corresponded on average to the final ratio of 29:62:9. The analysis of aggregation index has shown that the implemented felling slightly shifted the horizontal structure from group-wise towards an ordered distribution. In cells subjected to very high felling intensity the mean aggregation index increased by 8%, in those subjected to high felling intensity it rose by 10% and under medium-high felling intensity the resulting increase was 5%.

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