Evaluation of coppice management relics based on coppice stool value variability in the Drahany Highlands

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Abstract: We assessed the value of coppice stools in connection with selected factors in three different areas of the Drahany Highlands (Czech Republic). The stool value was assessed by evaluating the morphological features. Stools were selected in forest stands with an age of 80 years and older. We analysed the potential influence of twenty-five variables (for example, the exposure, forest vegetation zone, potential natural vegetation, actual or historical owner, edaphic category, etc.) on the stool value. We found that the historical ownership, climatic region, and category of potential natural vegetation significantly affect the coppice stool value. We observed the occurrence of stools with a higher stool value in moderate climatic region type 3 (MT3), in scree and ravine woodlands and in the territory of the historical owners of the Mitrovsky and Salm-Reifferscheid families. According to our results, the probability of the occurrence of coppice stools decreases with an increasing stool value.

Keywords: climatic region; historical owner; morphological features; potential natural vegetation; sprouts; historical and cultural value

Coppicing is the oldest known forest management method. A coppice is a stand of shoots growing on stumps left over after logging (Del Tredici 2001; Matula et al. 2012; Pyttel et al. 2013; Svátek, Matula 2015; Dinh et al. 2019). Repeated harvesting and resprouting produces a typical stand structure characterised by the presence of clusters of sprouts, called stools (Giovannini et al. 1992). Deciduous forests of coppice origin are characterised by the occurrence of tree morphologies that are stumps

with sprouts, stump heads with sprouts, headed trees, hollow trees and dendrothelms (Maděra et al. 2016; Buček et al. 2017). The proportion of coppices is currently very low in the Czech Republic, at 1% of the forest area (ÚHÚL 2007). More than 1 000 km² of coppices were converted after World War II. Part of this area has been logged and afforested with seed-origin trees. In the rest of the area, the rotation period has been extended to a normal value for a high forest. These so called quasi-high

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forests were classified as genuine high forests in the inventory, despite their coppice origin and often after their long history of coppicing. These stands could potentially be the last remnants of ancient coppices (Maděra et al. 2017a). Coppices are sites of specific biodiversity (Baeten et al. 2009; Hédl, Szabó 2009; Campetella et al. 2016; Kirby et al. 2017; Hédl et al. 2017) and native gene pools (Sjölund, Jump 2013). They can be considered as part of the cultural heritage and a symbol of sustainable landscape management (Slach et al. 2021; Kamp 2022).

This paper focuses on the morphological variation of stools, which has also been addressed by, e.g. Logli and Joffre (2001), Maděra et al. (2016), and Maděra et al. (2017b). However, these papers did not focus on determining the stool values. This issue has been addressed by Kadavý et al. (2022) in the context of developing and validating a classification system for assessing the stool value according to the stool's morphological features.

Relics of coppices can be considered as a legacy of our ancestors and, therefore, need to be protected and preserved for future generations (Kadavý et al. 2022). Valuable remains of stools are usually found in places for which there are no available records (Slach et al. 2021). Remnant oak standards after abandoning the coppice with standards were also evaluated by Salek et al. (2017). For this reason, it is necessary to map the remnants of coppices and determine their

stool value to identify individuals of exceptional value. Finally, it is important to establish a proposal for the conservation of valuable stools in forest stands.

The aim of this paper is to determine which environmental characteristics (e.g. exposure, vegetation stage, potential natural vegetation, edaphic category, etc.) or other factors (e.g. ownership) may influence the stool value using the example of three sites in the Drahany Highlands.

MATERIAL AND METHODS

Characteristics of the study area. Three sublocations within the broader area of interest of the Drahany Highlands were selected for the purpose of this research, which were named North, Centre and South (Figure 1).

The North site is situated in the central part of the Drahany Highlands (it mainly includes the cadastral areas of Holštejn and Housko). The Centre site is located on the western edge of the Moravian Karst and the Rudice Plateau (mainly the Klepačov and Olomučany cadastral areas). The South site is situated in the southern part of the Drahany Highlands (mainly the cadastral area of Pozořice).

Methodology of data collection and analysis. To be able to determine the potential occurrence of coppices, we used information available from publicly available sources (mainly map servers). First,

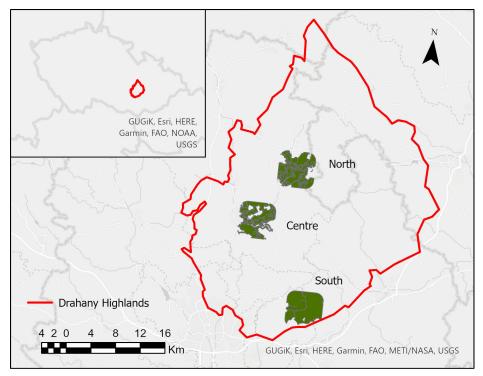


Figure 1. North, Centre and South sites in the Drahany Highlands area

deciduous and mixed stands were selected from the "Species composition - structured stand types" layer of the map application "Forest information" of the Forest Management Institute Brandýs nad Labem (ÚHÚL 2022a). Only oak and beech stand types were selected with the following levels of representation: pure, dominant, and majority. In the next step, the selection was restricted to stands with an age higher than 80 years. For this purpose, online forest management plan maps were used - the stand map of the Forests of the Czech Republic (LČR 2022), the stand map of the Training Forest Enterprise Masaryk Forest Křtiny (ŠLP ML 2022) and forest management guidelines (ÚHÚL 2022b).

In the field, the occurrence of stools was verified in pre-selected stands. In case of a confirmed occurrence, representative stools (it was not a full-scale monitoring of all the stools) were photographed, their geographic location was recorded, and their morphological features were assessed according to the classification (Kadavý et al. 2022) and is presented in Table 1. Field data collection was carried out using ArcGIS Collector, followed by data processing in ArcGIS Online (www.arcgis.com).

In total, 443 stools were evaluated (240 beeches, 146 oaks, 27 hornbeams, 19 limes, 4 sycamore maples, 2 field maples and 1 alder, elm, hazel, rowan and ash).

Table 1. Classification of stools according to morphological features (see Kadavý et al. 2022)

Evaluated morphological features on the stool	Feature level	Feature level percentile (%)	Feature level value	Feature level description	
	0	0	0	no sprout, but there are signs of a former stool at the base and the individual is visibly vital and viable (this is not a "stump torso")	
	1	$11.\overline{11}$	1	one sprout (there are marks of the former stool at the base or trunk)	
	2	$22.\overline{22}$	2	two sprouts	
Number of sprouts per stool (N)	3	$33.\overline{33}$	3	three sprouts	
	4	$44.\overline{44}$	4	four sprouts	
	5	55.55	5	five sprouts	
	6	66.66	6	six sprouts	
	7	$77.\overline{77}$	7	seven sprouts	
	8	88.88	8	eight sprouts	
	9	100	9	nine and more sprouts	
Original stump(s) presence (S)	0	0	0	no (or not)	
	1	50	4.5	yes; visible cutting surface without noticeable stump disintegration	
	2	100	9	yes; stump torso, partly decayed	
	0	0	0	no (there is only one sprout)	
Sprouts branching at the height of the original stump (<i>B</i>)	1	33.33	3	no (fork is formed about 1 m above the ground or higher); it does not have to be a stool, but a fusion	
	2	66.66	6	partially (some yes and some no)	
	3	100	9	yes	
-	0	0	0	no (there is only one sprout)	
	1	33.33	3	yes	
Visible fusion of sprouts (<i>F</i>)	2	66.66	6	partial fusion only (former stool indication)	
	3	100	9	not fused (sprouts far apart – indication of the former stool)	
Presence of a dendrothelm	0	0	0	no	
(D)	1	100	9	yes	

Table 2. Overview of analysed variables

Group of variables	Variable					
	average annual precipitation and temperature for the period 1961–1990 and 1991–2014 (Čermák et al. 2021)					
Natural conditions	slope, aspect and elevation (ČÚZK 2022)					
	forest type, forest type group, vegetation zone, ecological series and edaphic category (ÚHÚL 2022c)					
	climate region according to Quitt (1971)*					
	biochore (Culek et al. 2005)*, bioregion (Culek et al. 2005)*, phytogeographical district (Skalický 1988)*					
Potential vegetation	potential natural vegetation (Neuhäuslová et al. 1998)*, geobotanical map (Mikyška et al. 1972)*					
Past management	past coppice occurrence probability (Szabó et al. 2015; Maděra et al. 2017a)					
	the spread of secondary forest management types in the 19th century and changes in the distribution and representation of coppices coppices-with-standards in the 18th and 19th centuries, respectively (ÚHÚL 2022d)					
Ownership	historical owner (Stará 2018), current owner (ÚHÚL 2022a)					

^{*}obtained from the map server of the AOPK ČR (2022)

Since the individual morphological characteristics had different numbers of rating levels, we converted these levels to percentiles of the maximum value (Kadavý et al. 2022). A scale of 0-9 was used for the final rating. This is due to the fact that all the monitored morphological features of the stool contribute equally to the final stool value. This way of scaling is more convenient because it avoids assigning subjective weights to the individual morphological features. Based on the value of the particular levels of the evaluated morphological features of the stool, the new variable called the stool value was determined. The stool value is a historical and cultural value of the stool derived from its five morphological features (listed in Table 1). The stool value is defined by Equation (1):

$$SV_{i} = N_{i} + S_{i} + B_{i} + F_{i} + D_{i}$$
 (1)

where:

 SV_i – the stool value of stool i;

 N_i – level value of the number of sprouts of stool i;

 S_i — level value of the original stump(s) presence of stool i:

 B_i — level value of the sprouts branching at the height of the original stump of stool i;

 F_i — level value of the visible fusion of the sprouts of stool i;

 D_i – level value of the presence of a dendrothelm of stool i.

The range of stool values is from 1 to 45. The stool value is a discrete variable and for the further anal-

yses (except for generalised linear models), it was divided into three categories, namely stools with a value of 1-15, stools with a value of 16-30 and stools with a value of 31-45 (Kadavý et al. 2022).

For each stool, the following data (Table 2) were entered into the database from the available sources. The basic statistics of these variables are shown in Table S1 [see the Electronic Supplementary Material (ESM)].

We examined whether the resulting stool values depend on the above-mentioned variables. For continuous variables (annual precipitation and temperature data, slope gradient and elevation), generalised linear models (GLMs) with a negative binomial distribution (due to the presence of over-dispersion in the data) and a log link function (Zuur et al. 2009) were used. For the categorical explanatory variables, Pearson's chi-squared test of independence was utilised. The results were processed in STATISTICA [Version 13, 2018; TIBCO Software Inc. (2018)] (chi-squared test of independence, basic statistics) and R [Version 3.6.1, 2019; R Core Team (2019)] (GLM models) software systems at a $\alpha = 0.05$ significance level.

RESULTS

Based on the observed features (according to column 2 in Table 1), the most frequently found type of stool in the area of interest was a specimen (*i*) with 2 stems, (*ii*) without the original stump, (*iii*) with stem branching at the height of the origi-



Figure 2. An example of oak stool with most frequent feature level values

Number of sprouts per stool – two sprouts (2); original stump presence – no (0); sprouts branching at the height of the original stump – yes (9); visible confluence of sprouts – yes (3); presence of a dendrothelm – no (0); total stool value – 14

nal stump, (iv) with confluent stems and (v) without dendrothelms [Figure S1, see the Electronic Supplementary Material (ESM)]. An oak stool with

these features is shown in Figure 2. The basic statistical characteristics of the stool values were calculated for all three sites (Table 3).

Of all the independent variables tested (Table 2), only the historical owner, the potential natural vegetation, and the climatic region had a statistically significant influence on the stool value (Table 4).

We detected three distinct groups of stool value distributions according to historical owners (Figure 3). The first group includes stools on the former property of Prince John II of Liechtenstein and Maria Lernet. Here, the ratio between the stool value categories 1-15 and 16-30 was 2:1 (65%:32%). The second group (historically owned by Count Vladimir Mitrovsky and Prince Hugo Leopold Salm-Reifferscheid) had a balanced ratio between the categories of stool values 1–15 and 16–30. Both categories oscillated around 50% for both owners. The stools with the highest values were represented only in a minority (units of one percent) in all four historical ownerships. The third group of stools with demonstrably different values by historical owner were those mapped on the former property of Count Alfons Mensdorf-Pouilly. Here, stools with the highest values did not occur at all and the ratio between the categories of stools with lower and medium values was 4:1 (82%:18%).

When investigating the effect of the potential natural vegetation on the stool values, we found that four of the five categories have the same distribution in the stool values (Figure 4). These were (*i*) acidophilous woodrush-, silver fir-, birch- and

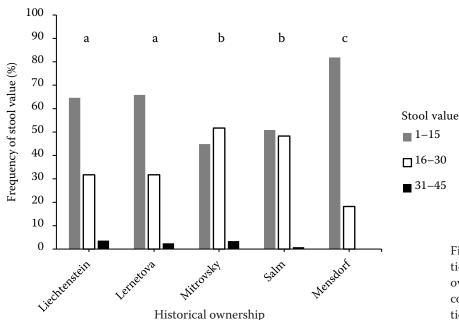


Figure 3. Stool values distribution in relationship to historical ownership (same letters above the columns indicates similar distribution of stools values)

Table 3. Basic statistics of stool values in three research sites

Site	Nih f -t l-	Stool values				
	Number of stools —	mode	interquartile range	minimum value	maximum value	
South	201		6.00	1.00	38.00	
Centre	195	14.00	5.00	5.50	37.50	
North	47		4.50	1.00	25.00	

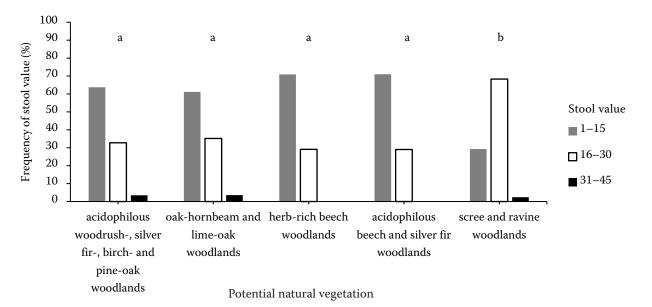


Figure 4. Stool value distribution in relationship to potential natural vegetation (same letters above columns mean similar distribution of stool values)

pine-oak woodlands, (ii) oak-hornbeam and lime-oak woodlands, (iii) herb-rich beech woodlands, and (iv) acidophilous beech and silver fir woodlands. These four categories were dominated

by stool value category 1–15 (60–70%). A third of the values were in the 16–30 category and only a small proportion (or none) were stools of the highest category. A different distribution in the stool

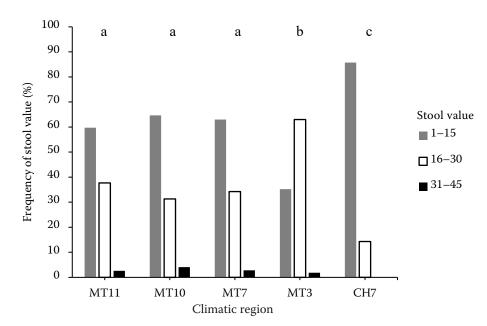


Figure 5. Stool values distribution in relationship to climatic region (same letters above columns mean similar distribution of stool values)

MT11 – moderate climatic region type 11; MT10 – moderate climatic region type 10; MT7 – moderate climatic region type 7; MT3 – moderate climatic region type 3; CH7 – cold climatic region type 7

Table 4. Results of Pearson χ^2 test of independence for significant variables

Independent variable	df	χ^2	<i>P</i> -value
Historical owner		16.241	0.039
Potential natural vegetation	8	24.300	0.002
Climatic region		25.496	0.001

values was found in the scree and ravine woodlands, where the 16–30 category dominated with 68%, the 1–15 category accounted for 29% and the remaining 3% were the highest stool values.

The climatic region had a statistically significant effect on the stool values (Figure 5). In the moderate climatic regions (MT7, MT10 and MT11 – see Quitt (1971)), the representation of category 1–15 was approximately 60%, category 16–30 ranged from 30% to 35% and category 31–45 was within 5%. On the other hand, in MT3 (moderate climatic region type 3), the ratio between categories 1–15 and 16–30 was quite the opposite. In CH7 (cold climatic region type 7), the 1–15 category dominates with 85%, the 16–30 category is represented by 15% and the 31–45 category is completely absent.

DISCUSSION

Remnants of coppices (often with high historical value) can still be found in the Czech Republic. Most of these stands are no longer actively managed in the traditional way. At the same time, these stands are no longer officially registered as coppices (Slach et al. 2021). Our mapping at three selected sites in the Drahany Highlands confirmed this observation. None of the stands in which we recorded the presence of stools is officially currently registered as a coppice. However, it can be assumed that coppicing was a common management practice within the study area, especially at the South site in the past. This assumption is based on spatial modelling of archival data (Szabó et al. 2015) or on the predicted occurrence of ancient coppice woodlands in the Czech Republic (Maděra et al. 2017a). For the two remaining sites (Centre and North), the results of the above-mentioned authors assume a lower probability of a past coppice presence. Nevertheless, even within these two sites, we found the presence of a non-negligible number of stools, mainly beech.

Remnants of past coppice management methods can be considered as part of cultural heritage (Slach et al. 2021; Kamp 2022). Kadavý et al. (2022) de-

veloped a classification that allows the assessment of the stool value through an analysis of the stool's morphological features. The morphological variation of stools has also been assessed by, e.g. Logli and Joffre (2001) or Maděra et al. (2017b), but these authors did not focus on determining the stool value. The approach of Kadavý et al. (2022) allows for the evaluation of stools not only between features, but also within one specific feature level. We consider this necessary in terms of potential stool conservation (management) planning. Indeed, it is important to establish criteria to decide, which stools deserve protection and which ones do not. Therefore, in this paper, we focused on the factors that could influence the value of the stools.

Tree forms in ancient woodlands resulted from various types of human interference and management (Glaves et al. 2009). Ancient stools that have survived in forests are most often multi-stemmed trees, whose massive bases result from the centuries of harvesting and resprouting (Rackham 2008). The number of shoots within a single coppice stool can range from one to several dozens. For example, Logli and Joffre (2001) recorded coppice stools with one and two shoots most frequently in Quercus pubescens coppices. In our study, we observed a similar result, finding the highest number of coppice stools with two shoots in both the most abundant species, sessile oak (Quercus petraea (Matt.) Liebl. agg.) and European beech (Fagus sylvatica L.). Vrška et. al. (2016) found out that only 25% of trees (stools) were single-stemmed and two-, three- and four-stemmed stools prevailed in oaks (Q. petraea) in the Podyjí National Park, Czech Republic. Maděra et al. (2017b) found an average of about five stems in coppice stools for most of the tree species in their study in the Czech Republic. They also recorded relatively high maximum numbers (10 in oak, up to 31 in hornbeam and up to 42 in beech). We did not find such high numbers in our mapping, which may be due to the selection of a different area and, therefore, a different historical context, especially in a possible different way of forest management in the past.

In addition to the occurrence of multi-stemmed individuals, the occurrence of dendrothelms may indicate past coppicing practices. Dendrothelms are frequently observed in coppices because their development is induced by the removal of stems from the living coppice stools (Maděra et al. 2017b). One of the unique studies dealing with the occurrence of den-

drothelms in coppices is the work of Maděra et al. (2017b). They found 80 dendrothelms in 135 ancient coppice stools of 13 tree species. The most frequently represented species with dendrothelms were *Q. petraea* (33.6%) and *Quercus robur* L. (29.0%). In our area of interest, we found a higher proportion of dendrothelms in beeches (6%; 27 pieces) compared to oaks (2%; 10 pieces) out of a total of 443 mapped coppice stools. Despite the overall low number of recorded dendrothelms (compared to the results of other authors), their co-occurrence with other typical features within the stools indicates past coppice management methods.

In the study area, we detected different frequency distributions in the morphological values in the localities of the different historical forest owners. We can only assume that the above-mentioned owners managed the coppices on their properties in different ways (selective versus clear cutting within the stool, different rotation period, unification of stools in order to increase the wood quality, etc.), which is also reflected in today's state of the individual stools. Nevertheless, we cannot clearly confirm our statement by any references connected with our study areas and the tested historical owners. The one available piece of literature (Szabó et al. 2015) on this topic only reports (without further details) the probability of coppicing in the study area.

Based on our results, higher morphological values can be expected in scree and ravine woodlands, as well as in the moderate climatic region MT3. The sprouting of mature trees is usually as a result of a response to damage to an individual by logging. At the same time, individuals that grow in stressful sites (on exposed sites or near the limits of a species range) or sites with frequent disturbances are likely to sprout more vigorously and retain the sprouting ability longer than individuals occurring in less stressful sites or those with less frequent disturbances (Del Tredici 2001). This could partly explain the higher values of stools that we found in the scree and ravine sites, despite the assumed minimal to absent forest management practices in these habitat types.

In the Czech Republic, coppices occur in warm areas of lower elevations (1st oak and 2nd beechoak vegetation zone). However, they are mostly over-aged and gradually decay and disappear because of the absence of any active management. However, stools (individual trunks) can be found in almost every broadleaf-dominated

forest stand in warm regions of the Czech Republic. Presumably, at least a certain part of the stools (or their living root systems) may have been present in a particular place for hundreds of years due to traditional management methods. Therefore, coppices are a living legacy of a high cultural and social value. Our stool value classification system should be utilised and verified in other countries, not only in the Czech Republic.

At the same time, information on stool occurrences could be used to verify the natural (potential) composition of a tree species (Neuhäuslová et al. 1997, 1998, 2001). This could be used, for example, in planning proposals for target tree species composition in the future.

CONCLUSION

Our research confirmed that the stool value determined by the classification scale (Kadavý et al. 2022) varies in the analysed area only depending on the climatic region, potential natural vegetation and between the historical owners. We found that higher stool values can be expected in scree and ravine woodlands and in moderate climatic region type 3 (MT3). Conversely, lower stool values can be found in all the other tested climatic regions and in forests classified according to the natural vegetation as all types of oak, oak-hornbeam and beech forests. Stools with higher values can be mainly found on estates belonging to the Mitrovsky and Salm-Reifferscheid families. In general, the frequency of stool occurrences in the field decreases with an increasing stool value. Therefore, the maintenance of stools with a high stool value is necessary for their conservation.

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