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Structure, Yield and Acorn Production of Oak (*Quercus robur* L.) Dominated Floodplain Forests in the Czech Republic and Croatia

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ABSTRACT

Background and Purpose: The study aims at comparing two (over 100 years old) floodplain oak-predominated forests in the Czech Republic (CZ) with two in of Croatia (HR) with regards to: i) their structure and yield and, more specifically, ii) individual oak tree characteristics including acorn production.
Materials and Methods: In both countries a different silvicultural concept is preferred (CZ: clear-cutting management with artificial regeneration, HR: shelterwood management with natural regeneration). The main research goal was to create a basic decision tool for forest managers and open some questions for future research.
Results: Despite the different natural and management practices, the total standing volume of floodplain forest was found to be similar in both countries, ranging from 500 to 700 $m^3 \cdot ha^{-1}$ (basal area: 34-41 $m^2 \cdot ha^{-1}$). In CZ generally more poor structure diversity was detected. Although in CZ the number of crop oaks (130-160 oaks per hectare) was almost double as compared with HR, the CZ oaks had shorter crowns, almost twice smaller crown projection, lower mean volume and lower share of valuable assortments.
Conclusions: Despite the total standing volume of oaks in HR being lower than in CZ, the total yield was observed in Croatia (loss in CZ ca. 22,000 €$\cdot ha^{-1}$). The acorn density and quality were generally higher in HR with a more even distribution as well. Despite more favourable climatic conditions in HR, the currently used management system in CZ floodplain forests should be gradually converted to the Croatian model with a multi-layered forest structure, more focused on individual tree growth and stability with high economical value and high reproductive potential.

Keywords: floodplain forest, silvicultural system, pedunculate oak, structure diversity, assortment structure of oak, yield, acorn production

INTRODUCTION

Pedunculate oak (*Quercus robur* L.) is considered to be one of the most important economic tree species in floodplain forests in Europe [1]. Natural regeneration of oak, as in the case of other tree species, is a complex process influenced by many biotic and abiotic factors. The main negative factors are fungal infections and diseases (*Microsphaera alphitoides*), consumption by animals (insects, birds, rodents and wild boars), light, water availability and climatic factors such as late frosts [2]. From a different viewpoint, the social position and individual growth characteristics of oak trees such as growing space, crown size and architecture are included amongst the key factors for the abundance and quality of acorns [2-5] and for highly valuable timber production as well [6]. In this

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context, the forest structure (species and spatial diversity) and its targeted management can significantly influence the successfulness ofnatural forests.

In natural forests, pedunculate oak with its high-age growth strategy has enough time and space to create great stem and crown dimensions. Here, one oak generation equals two to four generations of hornbeam and other accompanying species. This makes the spatial structure of natural floodplain forests relatively rich and dynamic in time [7-8].

A predominant silvicultural system in floodplain forests in the Czech Republic (CZ) is clear-felling (with a maximum size of 2 ha) with mechanical soil preparation and artificial regeneration [9]. Reasons for this are: insufficient acorn crops, strong weed competition and high impact of small and big vertebrates [10]. This management results in the floodplain forest structure being less diverse and more homogeneous with a high number of trees in the overstorey and under-developed crowns with poor fructification in adult age [3]. On the other hand, in a number of cases in the southern part of CZ, Dobrovolný [11] and Martiník *et al.* [3] demonstrated success of natural regeneration of oak if certain conditions were met.

Matić [12] and Oršanić and Drvodelić [13] consider pedunculate oak to be a tree species with a climax strategy and recommend, the traditionally used natural regeneration of oak under the shelter of the mother stand in three or two cuts. This method takes into account the biological and economic properties and ecological requirements of acorns and causes minimal stress to the soil and the stand [1, 14]. Diaci *et al.* [27] admit even irregular group felling in floodplain forests in Slovenia.

This study was focused on comparing two types of management of adult floodplain oak-predominated forests in the Czech Republic and Croatia with regards to: i) their structure and yield and, more specifically, ii) oak individual tree characteristics and acorn production. The main research goal was to create a basic decision tool for forest managers and to open some questions for future research.

MATERIAL AND METHODS

In each country (Czech Republic "CZ", Republic of Croatia "HR") in the year 2013, two managed adult floodplain forest stands before regeneration felling that represented a typical species and spatial structure of that experimetal region were selected (Table 1). The selected stands in CZ and HR differed primarily in species composition (CZI - oak and ash, CZII - oak, HRI - oak and ash, HRII - oak, ash and hornbeam).

In CZ, specifically in the South Moravian region (Židlochovice), the research was conducted in floodplain forests (managed by the State), located along the Morava, Dyje, Svratka and Jihlava rivers. The predominating soil type, cambic fluvisol, was slightly gleyic, eubasic in double substrates with chernozem fossils (ca. from 160 cm) on fluvial Holocene sediments. In HR, the research was conducted in the floodplain forests of pedunculate oak within the area of the Sava River. Research encompassed the management unit of "Opeke" (managed by the Faculty of Forestry of the University of Zagreb). The dominant soils included pseudogley level terrains, deep, illimerised brown soil, pseudogleyic, and eugley epigleyic (in micro depressions). A comparison of long-term and short-term HR and CZ climatic data (Table 1, Figure 1) indicates a higher average annual (and monthly) temperature and annual (and monthly) amount of rainfall in HR.

In each of the four selected stands, one representative circular research plot (RP) of 0.25 ha in size was established - CZ I, CZ II, HR I, HR II (Tab. 1). Within each RP, the following variables were collected for all trees with a diameter at breast height (DBH) of more than 7 cm: the coordinates (using Field-Map technology-Institute of Forest Ecosystem Research Ltd., Czech Republic), DBH, tree height (h), crown length (CL) - difference between the tree height and crown base and crown projection (CP). Outside the RP, all the crop oaks (with a DBH above 30 cm) that extended with their crowns into the RP and could affect the abundance of fallen acorns were also measured.

TABLE 1. Basic information on research stands.

Country; Region; Location	Research plot (stand indication)	Altitude; annual precipitation; temperature	Floristic association	Tree composition	Stand age (year)	Area (ha)	Stock density
Czech Republic; Židlochovice; 49°0'N, 16°37'E	CZ I (121A11)	177 m a.s.l.; 550 mm; 9°C	*Querco-Ulmetum*	oak 63%; ash 37%	110	10.7	1.0
	CZ II (236C12b)			oak 85%; ash 14%; black alder 1%	120	8.6	0.9
Croatia; Lipovljani; 45°22´S, 16°50´E	HRI (136)	96 m a.s.l.; 915 mm; 10.3°C	*Genisto elatae-Quercetum roboris*	oak 65%; ash 29%; black alder 5%; OHS 1%	131	32.4	0.9
	HRII (157a)		*Carpino betuli-Quercetum roboris*	oak 58%; ash 16%; black alder 2%; hornbeam 23%; OHS 1%	140	30.9	1.0

OHS - other hardwood species

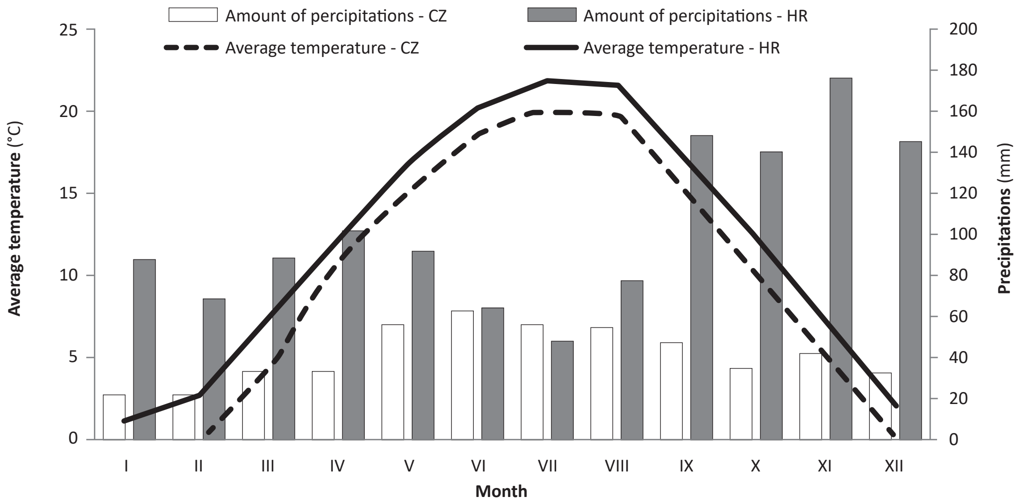

FIGURE 1. Development of the average monthly temperature and average monthly amount of rainfall in CZ and HR (years 2000 - 2012). A comparison of climatic data indicates a higher average annual (and monthly) temperature and annual (and monthly) amount of rainfall in HR.

Model height curve was constructed according to the Michajlov formula [15]. The stem volume without bark (V) was calculated using volume functions [16]. Canopy cover (CC) of the stand was calculated as sum of individual crown projections. The competitive situation or space surrounding each of crop oaks was evaluated as the mean distance (D) of the targeted crop oak to all nearest neighbours of any species (with tree height over 20 m). The following indices of forest structure were calculated with the aid of BWINPro 6.3 (Northwest German Forest Research Station, Germany) [17]: (1) indices of species diversity: (1.a) Shannon index (SI) and (1.b) Evenness (EI) (standardized Shannon) based on the abundance of the species (depending on the number of trees (N) and the basal area (G) - the higher the values, the greater the diversity, (1.c) Species-profile index (API) based on species abundance in three height stand layers - the higher the values, the greater the diversity; (2) indices based on the spatial pattern ofthe zero tree and its three nearest neighbours: (2.a) Mixing index (MI) - the values express the spatial species diversity of each situation (MI=0.00 - all trees belong to the same species, MI=0.33 - one tree belongs to a different species, MI=0.67 - two trees belong to a different species, MI=1.00 - all trees belong to a different species), (2.b) Index of DBH differentiation (DI) (0.0-0.3 = no or low differentiation, 0.3-0.5 = medium differentiation, 0.5-0.7 = high differentiation, 0.7-1 = very high differentiation), (2.c.) Index of DBH dominance (DDI) (the higher the positive values, the greater the dominance of the zero tree over its neighbours; values nearing 0 indicate an indifferent relation and the higher the negative values, the greater the suppression of the zero tree). The spatial patternof crop oaks with the distance to the nearest neighbouring oak was evaluated in ArcGis 10 (Esri, Inc., USA) according to the formula of Clark and Evans [25].

The assortment structure of oak was assessed according to assortment tables of Dejmal [26]. The stems were sorted according to class: I. sliced venner log; II. peeled lower quality veneer log; III.a and III.b saw log; V. pulpwood; VI. fuelwood. The economic profit was assessed according to volume and the current Czech price list of oak assortments.

Acorn abundance was evaluated using 36 seed traps (round wire hoops with collection sacks) per RP, 0.25 m^2 each (r= 0.28 m), arranged in a lattice format and placed 0.5 m above the ground. The spatial coordinates of all seed traps were measured. All the seed traps were installed before the acorns began to fall in September 2013. They were collected every two weeks. The amount of collected acorns was evaluated as the amount of seeds per square metre and the germination capacity was tested according to the Czech and ISTA standards [18].

The statistical differences between the RPs in terms of tree or acorn characteristics were tested using the non-parametric Kruskal-Wallis one-way analysis of variance (using Statistica 10 - StatSoft, Inc., USA). The spatial pattern of acorns (see Figure 7) in 5 categories of density (0; 0.1-5; 5.1-15; 15.1-30; 30.1-50 acorns per m^2) was estimated on each RP using ArcGis 10 with Kernel statistics (interpolation) tool (Esri, Inc., USA). This analysis was a basis for deriving the share of area covered by acorns and the share of crop oaks belonging to different categories of acorn density (see Table 10).

TABLE 2. Basic inventory data of research plots.

Research plot	N total (trees·ha^{-1})	N oak (trees·ha^{-1})	BA total (m^2·ha^{-1})	V total (m^3·ha^{-1})	CC total/oak (%)
CZ I	512	148	40.38	706.4	80/56
CZ II	176	160	34.39	496.4	76/74
HR I	380	100	41.66	712.2	114/66
HR II	332	64	37.75	634.6	143/43

N - tree number; BA - basal area; V - volume stock; CC - canopy cover

RESULTS

Structure and Yield

The standing volume and the basal area were found to be similar in both countries. Surprisingly, for two stands (RP CZ I and HR I) both values were identical - about 700 m^3·ha^{-1} or 40 m^2·ha^{-1} (Table 2). As expected, CZ II (with its poor structure) had the lowest total number of trees and the smallest basal area and standing volume.

The highest number of trees per hectare on CZ I was due to the high number of trees (namely ash) in the lowest diameter classes (Figure 2). The total canopy cover was always higher in HR (over 100%), mainly due to the presence of the middle tree layer (Figure 2 and 4).With respect to tree species composition (Table 3), in CZ, it was ash that dominated on CZ I and oak on CZ II in terms of the number of trees, while in HR it was alder with oak that dominated on HR I and hornbeam on HR II. In terms of basal area and standing volume it was oak that dominated in both countries; however, the total standing volume of oak was higher in CZ.

The most diverse species structure in HR was found for HR I (a total of six species), while in the CZ hornbeam and alder were absent in all cases. A more diverse species structure (even the vertical profile) in HR was confirmed also by the structure indices (SI, EI, API, MI) (Table 4).

The diameter distribution of all species in HR was broader compared to CZ (Figure 2). While in CZ the single- or double-peak distribution indicates the highest representation of trees of moderate thickness or very thin (CZ I) trees (Figure 2), in HR single-peak distribution with the highest representation of thin trees was observed. In HR, oaks were relatively evenly represented within a wider range of diameters, while in CZ oaks were clustered into several diameter classes around 50 cm (Figure 3). Nevertheless, the values of the diameter DI (Table 4) show a relatively high spatial variability on all RPs, unlike the homogenous CZ II. The DDI index indicates a more neutral relationship among the trees.

Similarly, the height structure was more diverse in HR with at least three distinct tree layers formed, the heights being about 10 m, 24 m, and 36 m (Figure 4). In CZ I, only two layers were formed (around 14 m and 36 m) and in CZ II only a single layer was formed (ca. 30 m).

Differences between the countries in oak assortments and values are shown in Table 5. The greatest differences

TABLE 3. The share of species composition in regard to the number of trees (N), basal area (BA) and volume (V).

Research plot	Variable	Oak	Ash	Elm	Field maple	Hornbeam	Alder
CZ I	N (%)	28.9	68.8	2.3	-	-	-
	BA (%)	80.4	19.4	0.6	-	-	-
	V (%)	84.4	15.5	0.1	-	-	-
CZ II	N (%)	93.0	4.7	2.3	2.3	-	-
	BA (%)	91.8	3.5	2.1	2.7	-	-
	V (%)	93.0	3.0	2.3	1.7	-	-
HR I	N (%)	26.3	17.9	21.1	3.2	7.4	24.2
	BA (%)	62.3	29.7	1.9	0.2	0.9	5.1
	V (%)	69.7	27.2	0.4	0.1	0.3	2.4
HR II	N (%)	19.3	8.4	-	-	72.3	-
	BA (%)	52.0	16.1	-	-	31.9	-
	V (%)	62.2	15.3	-	-	22.6	-

TABLE 4. Structure indices.

Structure indices	Research plot			
	CZ I	CZ II	HRI	HRII
SI-N	0.70	0.40	1.63	0.76
SI-G	0.51	0.37	0.94	1.00
EI-N	0.64	0.29	0.91	0.69
EI-G	0.46	0.27	0.52	0.91
API	1.12	1.04	2.07	1.41
MI	0.52	0.19	0.80	0.50
DI	0.51	0.17	0.52	0.42
DDI	-0.07	0.03	0.04	0.00

SI-N - Shannon index based on tree number; SI-G - Shannon index based on basal area;EI-N - Standardized Shannon index based on tree number; EI-G - Standardized Shannon index based on basal area; API - Species-profile index; MI - Mixing index; DI - Index of DBH differentiation; DDI - Index of DBH dominance

between countries were in the share of valuable assortments (classes I and II). There is only about 5% of this class in CZ and about 20-30% in HR. Despite the total volume of oak in HR being lower than in CZ, the total yield was higher (loss in CZ - ca. 22,000 €·ha^{-1}).

Crop Oaks (DBH > 30 cm)

HR was found to contain less crop oaks compared with CZ (Table 6). In general crop oaks in HR reached higher mean DBH and V (Table 6); however, significantly only when CZ I was compared with HR II and CZ II with HR I and HR II (Table 9). Tree heights were similar, except for CZ II. Crop oak crown characteristics, i.e. CL and CP, were significantly greater in HR (except for CL of CZI when compared with HRI); the mean CP here being almost twice as large as those in CZ (Table 6 and 9). Mean distance (D) of the targeted crop oak to the nearest neighbours was greater in HR (significantly only when CZ II was compared with HR I and II) (Table 6 and 9). These results confirmed also the growth relationships (DBH vs. h vs. CP) of CZ-HR oak trees with the similar direction and shape of constructed curves (Figure 5 and 6).

In both countries, oaks showed the same significant and even distribution across the plot with spacing (i.e. the

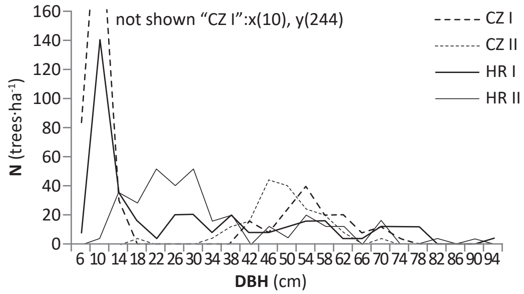

FIGURE 2. Distribution of DBH classes of all tree species. The diameter distribution in HR was more broad compared to CZ.

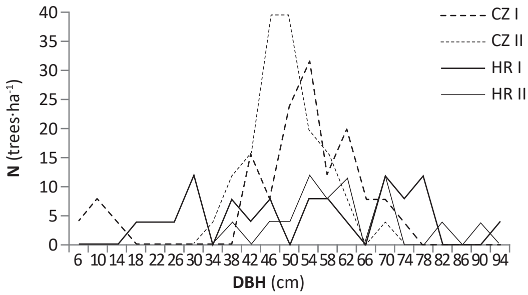

FIGURE 3. Distribution of DBH classes of oak. In HR, oaks were relatively evenly represented within a wider range of diameters, while in CZ oaks are clustered into several diameter classes around 50 cm.

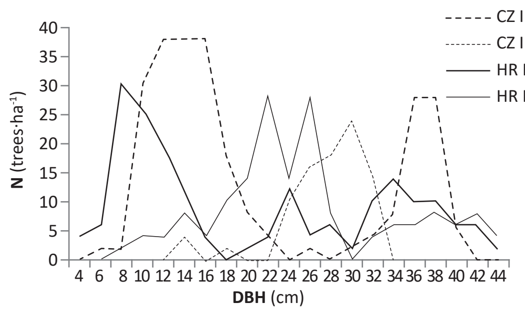

FIGURE 4. Distribution of height classes of all species. The height structure was more diverse in HR with at least three distinct tree layers.

TABLE 5. Share of oak assortments and assessment of economical value.

Assortment	CZ I (%)	CZ II (%)	HRI (%)	HRII (%)	CZ I (€·ha^{-1})	CZ II (€·ha^{-1})	HRI (€·ha^{-1})	HRII (€·ha^{-1})
I.	3.2	5.8	22.3	28.6	8,611.2	12,332.3	50,759.6	51,770.4
II.	0.8	0.0	0.9	0.5	939.2	0.0	892.2	385.4
III.a	55.6	53.9	32.4	28.2	38,795.4	29,138.7	18,805.6	13,005.2
III.b	5.7	6.7	7.2	6.2	3,945.0	3,619.1	4,208.3	2,871.7
V.	26.0	25.3	27.0	26.6	6,423.0	4,837.5	5,544.0	4,350.6
VI.	8.8	8.2	10.2	9.9	2,203.4	1,597.2	2,130.9	1,644.4
Total	100	100	100	100	60,917.3	51,524.8	82,340.5	74,027.7

I. sliced venner log; II. Peeled lower quality veneer log; III.a and III.bsaw log; V. pulpwood; VI. fuelwood

TABLE 6. Individual crop oak characteristics (mean, SD - standard deviation, min - minimum, max - maximum values).

Plot	N (trees·ha^{-1})	DBH mean (SD/min-max) (cm)	h mean (SD/min-max) (m)	V mean (SD/min-max) (m^3)	CL mean (SD/min-max) (m)	CP mean (SD/min-max) (m^2)	D mean (SD/min-max) (m)
CZ I	132	51.3 (15.2/7.4-73.8)	34.7 (6.4/10.2-40.4)	4.1 (2.0/0.01-8.5)	14.5 (4.0/4.3-25.3)	40.2 (27.7/2.5-110.7	7.8 (1.3/5.8-10.7)
CZ II	160	48.9 (7.3/33.1-70.3)	28.2 (3.3/14.5-34.3)	2.8 (1.0/1.3-5.9)	13.8 (3.8/5.4-24.1)	44.7 (19.9/11.8-113.3)	7.2 (1.2/4.9-9.6)
HR I	84	56.5 (15.3/30.9-92.3)	35.1 (5.0/24.5-43.5)	5.0 (3.2/1.0-14.9)	17.2 (3.9/10.5-25.0)	74.1 (39.4/25.8-188.8)	9.0 (2.1/6.1-13.2)
HR II	64	66.6 (12.8/38.2-90.1)	38.8 (3.0/32.5-45.0)	7.2 (3.0/1.9-14.6)	18.8 (3.2/10.0-24.0)	82.1 (37.9/22.6-195.7)	9.3 (1.8/6.4-12.4)

N - tree number; DBH - diameter at breast height; h - tree height; V - volume; CL - crown length; CP - crown projection; D - mean distance of the targeted crop oak to the all nearest neighbours of any species expressed in growth space

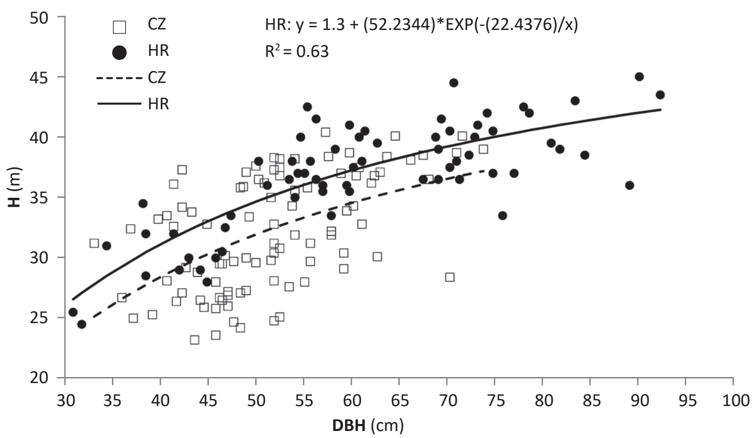

FIGURE 5. Height / diameter curves of CZ-HR crop oaks. HR oaks showed better height growth, but with the similar shape of both curves.

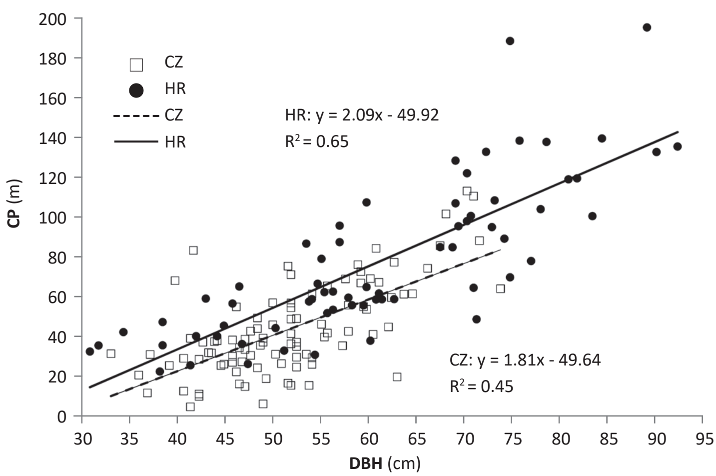

FIGURE 6. Relationships between DBH and crown projection "CP" of CZ-HR crop oaks. HR oaks showed larger crowns, but with the similar direction of both curves.

distance to the nearest neighbouring oak) being greater for HR (Table 7).

Acorn Production

In CZ I, acorn density was the lowest of all plots (Table 8), but not significantly when compared with CZ II (Table 9). In CZ II, the density was significantly lower only when compared with HR I. Differences in acorn abundance in HR were not statistically significant. Despite very different germination rates in each stand, there were generally more germinable seeds per square metre in HR. In HR, more even spatial coverage of the totalarea by acorns was found compared with CZ (Figure7).

The share of covered area by acorns was higher in HR (about 80% of the total area covered by medium or high density of acorns) compared with CZ (about 50-80% of the total area covered by null or low density of acorns) (Table 10). In HR medium or high acorn density / seedfall was observed in 80% of all oak trees, while in CZ null or weak seedfall was observed in 50-80% of all oaks (Table10).

TABLE 7. Distribution pattern of crop oaks.

Research plot	Observed mean spacing (m)	Ratio	z-score	p-value	Distribution pattern
CZ I	5.99	1.31	3.97	0.0001	Even
CZ II	4.87	1.21	2.98	0.0029	Even
HR I	6.53	1.27	3.16	0.0016	Even
HR II	9.17	1.39	4.10	0.0000	Even

TABLE 8. Acorn characteristics (mean, SD - standard deviation, min - minimum, max - maximum values).

Research plot	Acorn density mean (SD/min-max) (No·m^{-2})	Germination capacity mean (%)	Germinable seeds mean (No·m^{-2})
CZ I	1.67 (4.52/0-24)	53	1
CZ II	11.11 (21.25/0-100)	33	4
HR I	16.78 (18.16/0-76)	27	5
HR II	11.22 (14.71/0-60)	70	8

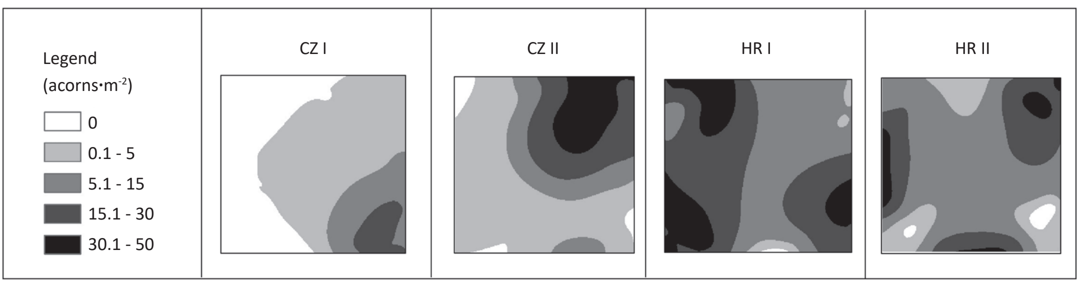

FIGURE 7. Spatial density of acorns with in the RPs. In HR, more even spatial cover age of area by acorns with heigher density was found compared with CZ.

TABLE 9. The results of Kruskal-Wallis analysis of variance.

	H	df	p	Stat. diff. (multiple comparison)
DBH	37.498	3	0.000	CZI vs. CZII+HRII; CZII vs. CZI+HRI+HRII; HRI vs. CZII+HRII; HRII vs. CZI+CZII+HRI
h	93.333	3	0.000	CZI vs. CZII; CZII vs. HRI+HRII; HRI vs. CZII+HRII; HRII vs. CZII+HRI
V	53.896	3	0.000	CZI vs. CZII+HRII; CZII vs. CZI+HRI+HRII; HRI vs. CZII+HRII; HRII vs. CZI+CZII+HRI
CL	35.150	3	0.000	CZI vs. HRI; CZII vs. HRI+HRII; HRI vs. CZII; HRII vs. CZI+CZII
CP	35.713	3	0.000	CZI vs. HRI+HRII; CZII vs. HRI+HRII; HRI vs. CZI+CZII; HRII vs. CZI+CZII
D	17.978	3	0.000	HRI vs. CZII; HRII vs. CZII; CZII vs. HRI+HRII
Acorn density	31.050	3	0.000	CZI vs. HRI+HRII; CZII vs. HRI; HRI vs. CZI+CZII; HRII vs. CZI

DBH - diameter at breast height; h - tree height; V - volume; CL - crown length; CP - crown projection; D - mean distance of the targeted crop oak to the all nearest neighbours of any species expressed in growth space

TABLE 10. The share of area (1 RP = 0.25 ha) covered by different categories of acorn density and the share of crop oaks belonging to different categories of acorn density.

Acorn density - categories ($No \cdot m^{-2}$)	Share of area (%)				Share of crop oaks (%)			
	CZ I	CZ II	HR I	HR II	CZ I	CZ II	HR I	HR II
0 (null)	34.2	3.9	0.4	1.9	50.0	6.4	0.0	4.2
0.1-5 (weak)	47.4	50.8	2.1	14.0	26.2	51.1	0.0	4.2
5.1-15 (medium)	12.9	15.9	39.6	56.6	19.0	12.8	30.3	70.8
15.1-30 (high)	5.5	17.5	39.8	23.1	4.8	14.9	57.6	16.7
30.1-50 (very high)	0.0	12.0	18.1	4.4	0.0	14.9	12.1	4.2

DISCUSSION

Our results based on comparisons of forest structure, yield and acorn production in HR - CZ cleared the way for basic silvicultural decisions (Table 11).

Despite different natural conditions, the volume production was found to be similar in both countries. For two stands (CZ I and HR I) the volume was identical - about 700 $m^3 ha^{-1}$. It is necessary to point out that the analysed stands in CZ were about 20 to 30 years younger than those in HR. According to the existing growth tables for both countries, this involves the most productive stands on top quality soil [19, 20]. The comparable volume yield is also given by the greater number of trees, especially oaks, in the upper layer in CZ, which is related to the silvicultural strategy of the clear-cutting management model applied. Surprising were also the similar oak parameter relationships, which indicate similar dynamics in both countries.

In contrast, the analysis of stand structure confirmed the expected differences between these two countries. While in CZ the poor structure and the tree characteristics observed are given by the clear-cutting management model, the more diverse structure of the forest in HR corresponds to the Croatian model with a multi-layered floodplain forests [12]. Such a model is also closer to the natural conditions in virgin floodplain forests, where the relatively dynamic structure is characterised by a multi-layer distribution of tree species and a distinct diameter differentiation, which particularly applies to the optimum stage [7, 8, 21].

Comparing the individual growth characteristics for crop oaks found in CZ to have up to twice more individuals (130-160 trees per hectare) with smaller spacing than in HR. These oaks, however, had a lower mean volume, shorter crowns and nearly twice smaller crown projection compared with HR oak trees. For instance, Spiecker [6] recommended supporting only about 60 target trees per hectare through crown thinning to optimise the radial increment in oak, which corresponds to the Croatian model. These usually thickest oak trees also have larger crowns (the relationship was confirmed similarly for both countries - see Figure 5 and 6), thus having better prerequisites for fructification [2, 3].Croatian system also provided higher economic benefits. Despite lower cubic volume of oak per ha in HR, we can expect higher economic profit from oak trees in HR due to more valuable assortments (loss in CZ - ca. 22,000 $€ \cdot ha^{-1}$).

The acorn crop values obtained for the analysed stands in both countries (2-17 acorns per square metre) were below the threshold of the mast year (20-50 $acorns \cdot m^{-2}$) [2, 22]. Years of rich crop are likely to occur more frequently in HR than in CZ [1, 9, 23]. While in mast years the presence of richly and regularly fruiting individuals is not crucial for seeding to be sufficient, in the years with medium and lower crop rates the opposite is true [22, 24]. To this end, the size and quality of the crown and sufficient space for growth, where applicable, are the prerequisites for individual trees to be fruiting richly and on a regular basis [3, 24].

In Croatian management with a multi-layered floodplain forests shelterwood felling in three cuts (preparatory,

TABLE 11. Silvicultural decision tools.

Characteristic	CZ	HR	Comparable
Site and forest type of stands			•
Stand age			•
Altitude			•
Annual precipitation	–	+	
Annual temperature	–	+	
Growing stock and basal area			•
Total number of trees per ha			•
Canopy area	–	+	
Structure diversity	–	+	
Oak – number of crop trees per ha	+	–	
Oak – individual tree characteristics	–	+	
Oak – growth relationships (shape of curves)			•
Oak – economic value	–	+	
Oak – acorn production	–	+	

seeding and final) is used with the regeneration period of 6-10 years, when the average density of oak seedlings and other species is about 40,000-50,000 individuals per ha [12]. However, in CZ shelterwood felling is limited by pure even-aged structure of unprepared adult oak stands which (after opening) causes strong weed expansion and stem sprouting. Dobrovolný [11], however, inventoried (in the southern part of CZ in Židlochovice region with 3355 ha of floodplain forests) in total 8 ha of young pedunculate oak stands (with age 5-7 years) established from natural regeneration with density ranging between 15,000-100,000 individuals per ha. The original mother stands, characterized by lower stock density (that ranged between 0.5-0.8), were harvested by clear-cutting immediately after the acorn fall.

The growth relationships of CZ-HR oaks showed a similar trend (or shape of constructed curves). Thus, the stem and crown characteristics (and also the amount and quality of produced acorns) of new CZ oaks could be probably changed if changing silvicultural system. However, based on the results presented in this paper we can not determine exactly which concrete factor caused the observed differences between HR and CZ. Probably there exists a complex of various factors such as climate, water regime, tree vitality and physiological stress, genetic predispositions, etc. This study should be a start and a challenge for future cooperation and long-term research in this field.

CONCLUSIONS

Our results showed elementary differences not only in the forest structure, but also in the management approach in floodplain forests of CZ and HR. While different concepts and stand structures may involve a comparable production level, the approach of clear-cutting management in the Czech Republic brings a range of problems. Despite complex of biotic and abiotic factors and more favourable climatic conditions in HR, the silvicultural system of CZ floodplain forests should be gradually converted to the Croatian model with a multi-layered forest structure, more focused on individual tree growth with high economical value and high reproductive potential. To achieve these goals primarily young and middle-aged stands in CZ should be managed through releasing of crowns of high-quality (and vital) crop trees (60-80 trees per hectare), as well as structuring the stands by preserving the lower tree layers consisting of accompanying tree species.

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