Potential of natural regeneration of *Quercus robur* L. in floodplain forests in the southern part of the Czech Republic

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ABSTRACT: The most common way of pedunculate oak regeneration on the floodplain sites in the Czech Republic is artificial regeneration by clear-cutting. However, what is the real potential of natural regeneration of pedunculate oak? In our research object (3,355 ha of floodplain forest in the southern part of the Czech Republic – Zidlochovice region), we inventoried about 8 ha of successful natural regeneration of pedunculate oak with density ranging between 15,000 and 100,000 individuals per ha on the plots after final cut. All harvested oak dominated parent stands showed a lower stock density that ranged between 0.5 and 0.8. In the next analysis of the survival of oak natural regeneration spontaneously established in different light conditions under the shelter of parent stands we observed the highest occurrence of saplings closer to the forest edge. A sufficient density of regeneration (above 10,000 individuals per ha) was found at the distance up to 18 m from the edge, where more than 24% of direct and 30% of indirect site factor were discovered. In the stand with the full canopy closure (DSF about 10% on average and ISF about 24%) the oak regeneration is missing and was replaced by other tree species (especially ash and field maple). In the examined area the natural regeneration of pedunculate oak should be one of the possible alternatives of floodplain forest regeneration if certain conditions are met.

Keywords: pedunculate oak; light conditions

There are about 67,000 ha of forests on the water-influenced floodplain sites in the Czech Republic (CZ), and out of these, typical floodplain sites represent about 33,000 ha (Maděra 2007). The largest complexes of floodplain forests in CZ can be found on the lower reaches of the Morava and Dyje rivers (overall about 15,840 ha), in central Pomoraví (10,400 ha) and in the Labe river basin (6,300 ha) and Odra river basin (about 600 ha) (Klimo et al. 2008). Specific site conditions turn floodplain forests into very valuable ecosystems, both from production and non-production aspects. Even though from the current economic aspect the main tree species of floodplain forests is pedunculate oak (*Quercus robur* L.) (Poleno, Vacek 2009), according to Vrška et al. (2006) this current approach to floodplain forests differs from the natural development and is more likely the result of human activity. Today, the majority of well-preserved remnants of "virgin" floodplain forests are characterized by disintegration of the overaged oak trees in the overstorey and advance of the multi-layered understorey of ash, hornbeam, field maple and linden almost without any natural regeneration of oak (Vrška et al. 2006). That is apparently related to the regeneration ecology of pedunculate oak.

Pedunculate oak is a light-demanding tree species, slightly more demanding than sessile oak (Röhrig et al. 2006). According to conclusions of Palátová et al. (2011) from floodplain forests in CZ, the ideal conditions for successful development of oak regeneration are a sufficient amount of light, and it is therefore necessary to remove the overstorey immediately after the acorns fall or not later than after one year of regen-

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eration development. In the full-canopy stands the oak seedlings are dying within 3 years and by stocking 0.5 their growth stagnates and they lose vitality (Houšková et al. 2007). On the other hand, Dakov (1953) or similarly Košulič (2010) documented the adverse effect of direct radiation on the oak seedlings up to 2–3 years of age; until that time, the seedlings prefer diffuse light. Dakov (1953) then recommends in the first phase of regeneration a decrease of the stocking around 0.5, when the average density of oak regeneration is around 14,000 indd·ha^{-1}. The rest of the overstorey hinders the expansion of weeds and is removed later. According to Weinreich (2000) the gaps with relative light intensity exceeding 32% do not affect fundamentally the quality of oak. Diaci et al. (2008) recommended the size of gaps to be 0.03–0.05 ha (diffusion radiation 8–18%) for the successful regeneration of pedunculate oak. Similarly, Matič (2000) and Oršanić and Dvodelić (2007) considered pedunculate oak to be a tree species with climax strategy and in the floodplain forests in Croatia they recommended the traditionally used natural regeneration of oak under the shelter of the parent stand. Shelterwood felling in three cuts (preparatory, seeding and final) with the regeneration period of 6–10 years is used, when the average density of oak seedlings and other species is around 40,000–50,000 individuals per ha.

Currently, the most common way of pedunculate oak regeneration on floodplain sites in the Czech Republic is artificial regeneration by clear-cutting (up to 2 ha) and soil preparation. However, what is the real potential of natural regeneration here? The goal of this article is to inventory and describe successful examples of the natural regeneration of pedunculate oak on a typical example of the floodplain forest region in CZ and analyse the light conditions which led to the survival of natural regeneration of oak spontaneously established under the shelter of parent stands.

MATERIAL AND METHODS

The surveys were conducted in forest stands with a dominant share of pedunculate oaks on Židlochovice floodplain sites, Czech Republic (49°0'N, 16°37'E) at altitudes ranging around 177 m a.s.l. with average annual air temperature of 9°C and 550 mm of annual precipitation. The experimental area is situated on the northern margin of the area (Židlochovice forest district with 3,355 ha of forests). The potential vegetation type is defined as elm-pedunculate oak woodlands (*Querco-Ulmetum*) (Neuhäuslová 1998).

The research was designed on two levels:

– Within the given forest area – Židlochovice forest district with about 3,355 ha, the area-wide inventory of successful examples of the natural regeneration of pedunculate oak a few years after the final cut was done. This regeneration originated mainly from the mast year 2006. For a rough description of the oak regeneration attributes three plots of 5 × 5 m in size for each example were randomly placed. On these plots the criteria of the successfully established young stand according to Czech forestry law were evaluated: sufficient density, even distribution across the area, permanent height increment, no weed competition and no game damage.

– In the next analysis of the natural regeneration of oak and other tree species spontaneously established under the shelter of adult parent stands three stand variants A, B, C with different light levels were chosen and evaluated. A and B are separated variants within the same forest stand 236C12b (Table 1) divided by the clear strips (about 60 m wide). Therefore light distribution under the canopy is here mainly affected by the edge effect. The variant C is the full-canopy part of the stand 121A11 (Table 1).

In each variant eight transects were established, each 32 m long directed from four edges (according to the cardinal points – NE, SE, SW, NW) inside the stand. At each transect at the distance of 4 m circular plots of 4 m^2 in size were established, where the attributes of natural regeneration were evaluated: density of all tree species, height and height increment of the last 2 years (i1, i2) of oak, diameter at the root collar of oak (d.r.c.), game damage to oak and the coverage and species composition of herb vegetation. In the centre of these circular plots, hemispherical photographs were taken with the Nikon 4500 camera and FC-E8 fisheye converter (Nikon Inc., Tokyo, Japan).

Table 1. Stand variants

Variant	Sign	Age (year)	Area (ha)	Tree species (composition %)	Stock (density)
A	236C12b	120	8.6	oak 85, ash 14, alder 1	0.9
B	236C12b	120	8.6	oak 85, ash 14, alder 1	0.9
C	121A11	109	10.7	oak 63, ash 37	0.7

Table 2. Examples of successful oak regeneration

Stand	Original mature stand					New stand generation				
	area (ha)	age (yr)	stock (density)	species composition (%)	cut (yr)	area (ha)	age (yr)	species composition (%)	oak density (indd·ha^{-1})	height (cm)
113a1a	5.9	127	0.7	oak 100	2009	2.1	5	oak 85, ash 5, robinia 5, boxelder 5	100,000	70–200
113b1a	1.8	143	0.5	oak 65, pine 20, robinia 10, horse chestnut 5	2008	1.3	6	oak 70, robinia 27, spruce 3	80,000	200
120d1	1.5	124	0.8	oak 100	2008	0.8	6	oak 70, elm 20, ash 10	15,000	80–400
122a1b	3.3	129	0.7	oak 75, spruce 20, ash 5	2007	1.8	7	poplar 70, oak 27, boxelder 3	60,000	200
130e1	3.9	129	0.8	oak 95, alder 3, poplar 2	2008	3.9	6	oak 65, poplar 19, ash 10, elm 5, cherry 1	15,000	200

The Kruskal-Wallis nonparametric test, Spearman's correlation and linear regression were used to estimate the differences and relations of the regeneration and light conditions. WinsCanopy software was used for the evaluation of the hemispherical photos – gap fractions (GFr %), direct (DSF %) and diffuse (ISF %) site factor were calculated.

RESULTS

The oak regeneration inventory

The extent of natural oak regeneration amounts to about 8 ha (0.24%) from the whole forest area (3,355 ha). Overall, 8 young stands were inventoried, while 5 of them (Table 2) meet the criteria for the stand establishment according to the Czech forestry law (see the Methodology). Regeneration density of oak and other tree species ranges between 15,000 and 100,000 individuals per ha with even distribution across the area and sufficient permanent height increment. Before the harvesting all original parent stands showed stock density about 8 and lower. The clear felling was done once between 2007 and 2009, apparently after the falling of acorns and the current age of these young oak stands thus ranges between 5 and 7 years (Table 2).

Analysis of spontaneous regeneration of oak under the canopy

As expected, light conditions were the least favourable in all examined attributes in the full-canopy variant C (significant difference from the other variants) and the most favourable in variant B, which was most affected by the edge effect. In variant A, there are significantly lower values of GFr and ISF compared to variant B (Table 3).

The natural regeneration of variants A and B is dominated by oak and ash, however with different density. The significantly highest density of regeneration of both species was observed in variant A. In variant C, the oak regeneration is completely missing and a wider spectrum of other tree species appears, with the dominance of ash and field maple (Table 4).

No significant differences in growth parameters were found out between variants A and B (Table 5).

The average coverage of herb vegetation with different species composition was highest in variants A and B, above 90% (Table 6). The average number of

Table 3. Light characteristics over the stand variants (in %) (A, B – edge effect, C – full canopy)

	A			B			C		
	GFr	DSF	ISF	GFr	DSF	ISF	GFr	DSF	ISF
Average	22.17	25.57	29.02	26.32	28.79	36.21	14.16	9.47	24.11
Median	21.89	21.98	28.49	25.89	26.69	35.50	14.21	6.96	24.34
SD	3.44	13.91	4.49	3.44	15.40	5.49	1.22	5.42	1.64
Minimum	12.56	5.60	17.11	21.18	7.73	23.97	12.05	3.54	17.51
Maximum	34.17	71.82	43.58	35.32	80.99	50.66	17.52	30.39	26.92
Signif. differences	B,C	C	B,C	A,C	C	A,C	A,B	A,B	A,B

GFr – gap fractions, DSF – direct, ISF – diffuse, SD – standard deviation

Table 4. Tree species composition and density of regeneration according to the stand variants (A, B – edge effect, C – full canopy, SD – standard deaviation) (in indd·ha^{-1})

	Total	Oak	Field maple	Ash	Norway maple	Dogwood	Hawthorn	Linden	Elder
Variant A									
Average	21,563	10,508	1,484	9,102	391	0	78	0	0
Median	8,750	0	0	2,500	0	0	0	0	0
SD	33,519	18,582	3,141	20,165	1,848	0	438	0	0
Minimum	0	0	0	0	0	0	0	0	0
Maximum	205,000	82,500	17,500	142,500	10,000	0	2,500	0	0
Share %	100.00	48.73	6.88	42.21	1.81	0.00	0.36	0.00	0.00
Variant B									
Average	2,461	1,289	0	1,172	0	0	0	0	0
Median	0	0	0	0	0	0	0	0	0
Std. dev.	4,682	2,921	0	2671	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0
Maximum	20,000	17,500	0	15,000	0	0	0	0	0
Share %	100.00	52.38	0.00	47.62	0.00	0.00	0.00	0.00	0.00
Variant C									
Average	8,789	0	2,109	5,469	234	859	39	39	39
Median	5,000	0	0	1,250	0	0	0	0	0
SD	10,245	0	5,160	8,284	1,875	2,100	313	313	313
Minimum	0	0	0	0	0	0	0	0	0
Maximum	40,000	0	25,000	37,500	15,000	10,000	2,500	2,500	2,500
Share %	100.00	0.00	24.00	62.22	2.67	9.78	0.44	0.44	0.44

oak recruits that were damaged by game amounted to 34% in variant A and even to 63% in variant B.

Though the correlations of oak regeneration with the examined factors – distance from the forest edge and light parameters were evaluated as significant with the logical direction, their values are too low (Table 7).

The real edge effect could be studied only in variant A with the highest density of oak regeneration without overlapping of the effect of forest edges (see variant B – Fig. 1). Here the sufficient regeneration density for the oak management (ca 10,000 individuals per ha) can be found at a maximum distance of about 18 m from the forest edge (Fig. 1), which corresponds to more than about 24% of direct radiation, and/or to more than about 30% of diffusion radiation (Fig. 2).

DISCUSSION AND CONCLUSIONS

When it comes to the question of the potential and use of natural regeneration of pedunculate oak in the studied floodplain forest region these findings can be commented.

Table 5. Growth parameters of oak regeneration according to the stand variants (A, B – edge effect)

	Height (cm)		Height increment-i1 (cm)		Height increment-i2 (cm)		D.r.c. (mm)	
	A	B	A	B	A	B	A	B
Average	33.06	27.53	6.02	5.99	4.49	5.30	3.94	3.65
Median	29.00	25.50	5.50	5.25	4.00	4.75	4.00	3.00
SD	18.57	13.48	3.58	4.65	2.99	3.34	1.78	1.35
Minimum	6.00	12.00	1.00	0.30	0.00	0.00	1.00	1.00
Maximum	91.00	73.00	18.00	18.00	16.00	14.00	11.00	7.00

D.r.c. – diameter at the root collar of oak

Table 6. Coverage and species composition of herb vegetation according to the stand variants (A, B – edge effect, C – full canopy) (in %)

Variant	Coverage total	*Rubus*	*Aegopodium*	*Urtica*	*Lamium*	*Dactylis*	*Galium*	*Poa*	*Euonymus*	*Lysimachia*	*Solidago*	*Calamagrostis*
A	90.2	42.5	36.0	3.1	0.6	3.8	3.1	0.0	0.0	0.0	0.0	1.1
B	94.5	11.3	35.6	6.0	14.8	11.5	2.4	4.8	0.7	1.1	0.1	6.3
C	83.0	39.9	6.9	8.9	23.3	0.0	0.0	1.0	0.0	3.0	0.0	0.0

Table 7. Spearman's correlations (*α = 0.05) of the oak regeneration and factors

	Distance	Density	Height	Height increment		D.r.c.
				i1	i2	
Distance	x	–0.26*	–0.26*	–0.25*	–0.24*	–0.27*
GFr	–0.28*	0.35*	0.37*	0.36*	0.37*	0.38*
DSF	–0.06	0.31*	0.27*	0.29*	0.31*	0.28*
ISF	–0.10	0.28*	0.32*	0.31*	0.31*	0.32*

D.r.c. – diameter at the root collar of oak, GFr – gap fractions, DSF – direct, ISF – diffuse

Examples of successful natural regeneration of pedunculate oak (overall about 8 ha) that originated from the mast year were inventoried. An important attribute of all harvested parent stands from which the natural regeneration originated is a lowered stock density ranging between 0.5 and 0.8. It can correspond with the results of Martiník et al. (2014) from the same area, when a considerable positive effect of gradual opening up on acorn production was proved.

In the variant with the full-canopy closure with unfavourable light conditions (about 10% of direct and 24% of indirect site factor), the oak regeneration is totally missing and is replaced by other species – especially by ash and field maple. This finding fully corresponds with the results of Vrška et al. (2006) from the dynamics of development of the remnants of virgin floodplain forests in CZ.

Spontaneously established oak seedlings survive and grow under the influence of the forest edge with the average height around 30 cm (and height increment around 5 cm) for a longer time than was reported by Houšková et al. (2007) (max. 3 years). The regeneration, however, is located closer to forest edges, where the positive effect of the higher amount of radiation was observed. Oak regeneration with sufficient density of more than 10,000 individuals per ha can be found at a maximum distance of 18 m from the forest edge, where values of relative radiation above 24% of direct and above 30% of indirect site factor were detected. Although the light limits of pedunculate oak regeneration occurrence can be even lower (diffuse radiation 8–18%) according to findings of Diaci et al. (2008), our results correspond with the conclusions of Weinreich (2000) about the qualitatively better growth of pedunculate oak at relative radiation values above 32%.

Reasons for the predominant artificial regeneration of floodplain forests in CZ are: insufficient acorn crops, weed competition and negative influence of small and large vertebrates (Houšková et al. 2007). However, our results showed that the natural regeneration of pedunculate oak should

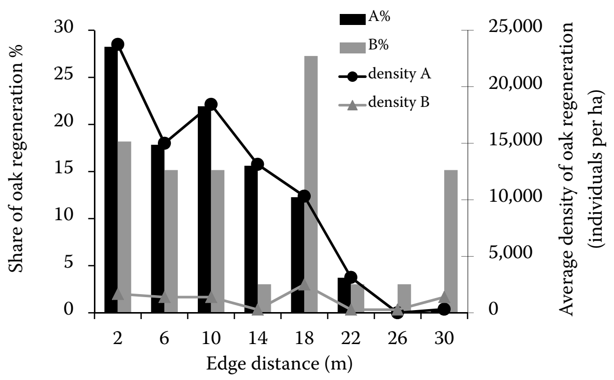

Fig. 1. Share and average density of oak regeneration according to a distance from the forest edge in variants A, B

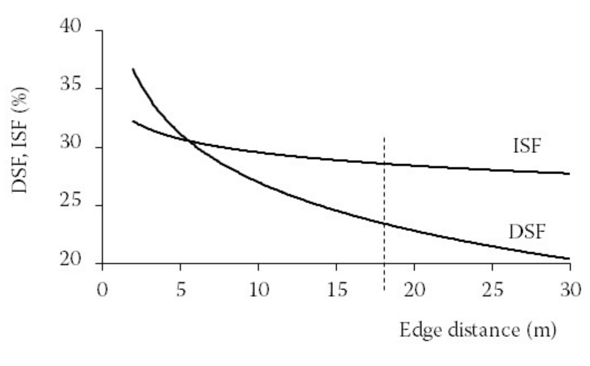

Fig. 2. Development of direct and diffuse site factor (DSF, ISF) according to a distance from the forest edge in variant A

be one of the possible and useable alternatives of floodplain forest regeneration in the examined area, if certain conditions are met. There is a lot of silvicultural methods how to initiate and support the natural regeneration of oak. We showed the success of natural regeneration using the one-time clear felling after the acorn fall. There are also possibilities of using shelterwood felling in three cuts according to Matić (2000) or irregular group felling according to Diaci et al. (2008). However, in the Czech Republic these regeneration methods are limited mainly by the pure even-aged structure of adult oak stands which causes too strong weed expansion (in our research stands the coverage higher than 90%) and also stem sprouting, i.e. increase of economic costs and decrease of wood quality as well. The analysis of the spontaneously developed regeneration of pedunculate oak also showed a possibility of using border cutting (the width of the clear strip up to ½ of the height of the harvested stand). However, an important prerequisite of the use of natural regeneration will always be the early preparation of young and middle-aged stands consisting of systematic support through crown releasing of the future crop trees and gradual opening up. Likewise, the creation of multi-layered stand structure (Oršanič, Dvodelić 2007) is a big challenge for the future floodplain forest management in the Czech Republic.

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