Eur J Forest Res (2012) 131:1611–1618
DOI 10.1007/s10342-012-0628-3

ORIGINAL PAPER

Probability model of sessile oak (*Quercus petraea* (Matt.) Liebl.) stump sprouting in the Czech Republic

Markéta Šplíchalová · Zdeněk Adamec · Jan Kadavý · Michal Kneifl

Received: 16 September 2011 / Revised: 13 February 2012 / Accepted: 16 March 2012 / Published online: 5 April 2012

Abstract We modeled the probability of sessile oak (*Quercus petraea* (Matt.) Liebl.) stump sprouting 1 year after harvest. We established seven research plots in forest stands with ages from 31 to 97 years, differing site indexes and elevations ranging from 290 to 410 m above sea level. A total of 862 stumps of sessile oak were analyzed. In each plot, the position (respective to the plot centre), stump surface diameter, age at the time of harvest and regeneration status (successful or unsuccessful) were determined for every stump. The probability of stump sprouting 1 year after harvest was modeled using logistic regression. Stump diameter and parent tree age were both negatively correlated with sprouting probability. No impact of site index on sprouting probability was found. Out of several analyzed models, three models were statistically significant. The model with stump diameter was found to be the most suitable. For stump diameters $\geq$35 cm, the sprouting probability fell below 50 %. For stump diameters up to 20 cm, the probability of at least one living sprout occurrence was $\geq$70 %. When compared with similar models used for three North American oak species (*Quercus velutina* Lamb., *Quercus montana* W. and *Quercus alba* L.), the sprouting probability in sessile oak stumps declines more sharply as stump diameter increases.

Keywords Sprouting capacity · Sessile oak · Coppice · Logistic regression

Communicated by U. Berger.

M. Šplíchalová (✉) · Z. Adamec · J. Kadavý · M. Kneifl
Faculty of Forestry and Wood Technology, Institute of Forest Management, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic
e-mail: xsplich0@node.mendelu.cz

Introduction

Sprouting capacity is understood as a tree's ability to react to various injuries (caused, for example, by game browsing or felling) or to dramatic changes in its environmental conditions (disturbances). Viewed from this perspective, sprouting capacity is a universal attribute among deciduous species, although isolated instances of its occurrence in conifers have been recorded as well. The above-mentioned processes result in the production of sprouts or secondary stems. Sprouting shoots can originate from dormant buds located above ground (axillary, branch epicormic or stem epicormic) or from the base of the plant (i.e., from the collar roots or underground stems (Bond and Van Wilgen 1996). Similarly, sprouting capacity can be classified according to the morphology of the sprouts' origin and occurrence (Del Tredici 2001) as (a) sprouts originating from the root collar on the stem base (both in seedlings and in mature trees), (b) sprouts originating from specialized underground stems, (c) sprouts from roots or (d) opportunistic sprouts from branches lying on the ground. Generally, we distinguish between the sprouting capacity of seedlings and the sprouting capacity of mature trees (Johnson et al. 2009). In seedlings, sprouting capacity aids the trees' survival in various stress conditions, including being in the shade of the parent stand, injury from game browsing and site exposure. On the other hand, sprouting in mature trees helps to increase their longevity (as a reaction to damage), and root sprouting is predominantly a strategy to obtain new living space. Del Tredici (2001) states that species growing under greater stress load (exposed sites or sites with the above-mentioned disturbances) tend to regenerate more spontaneously, for longer time periods and at greater levels.

The primary objective of coppice (sprout) management is to safeguard a balanced production of relatively thin stems in short rotation periods (usually 7–30 years). These stems tend to be used predominantly as firewood. If it is managed systematically, coppices are capable of producing such stems for centuries up to the absolute exhaustion of the created "stump heads" (unless these are adequately replaced and regenerated in the course of their utilization). Most deciduous species with diameters of approximately up to 15 cm produce large numbers of sprouts immediately after felling (Burns and Honkala 1990). This is a typical reaction to felling of individual stems. The resulting sprouts are produced in an effort to replace the harvested stem. However, high sprout mortality (70–90 %) is also characteristic, occurring within the first five to ten years after felling (Johnson 1975, 1977; McIntyre 1936; Wendel 1975). Unlike seedling sprouts, mature tree sprouts require a higher light intensity to replace the removed stem and crown. An enormous advantage of sprouts (with respect to obtaining living space) is the rapid and substantial growth (compared with the growth of seedlings from natural regeneration and artificially regenerated plants) that occurs within the first years of their development. This growth is limited by several factors that include the following: (a) site index, (b) stump age, (c) stump diameter, (d) the time of felling and (e) the harvested tree species. It is argued that in the first ten years of sprout development, their mean annual height increment, in relation to the above-listed factors, may range between 0.5 and 1 m (Burns and Honkala 1990; Cook and Sharik 1998; Johnson 1975; Roth and Hepting 1969). As Del Tredici (2001) observes, all deciduous species of the temperate zone regenerate with a very high vitality, and the probability of this phenomenon's occurrence is high, especially for stump diameters ranging from 5 to 15 cm. Most deciduous tree species regenerate vitally up to stump diameters of 25–30 cm, but the sprouting probability is lower than that in smaller diameter stumps. In tree species whose stump diameter exceeds 30 cm (with the exception of oak—*Quercus* sp.), the probability declines more markedly. On the other hand, oaks show a relatively high percentage of sprouts in relation to the increasing stump diameter when compared with other deciduous tree species (Cook and Sharik 1998; Johnson 1977; Sander 1971; Wendel 1975). According to Vyskot (1958), oak retains its sprouting capacity for a relatively long time, particularly on fertile soils. Oak trees 50 and more years old produce sprouts with 80 % probability. Larger stumps fail to produce sprouts more often, but the number of sprouts per stump tends to be higher, with the sprouts being larger and of higher quality. The best-quality sprouts were observed in stumps of oak trees whose breast height diameter was 16–20 cm. Polanský (1956) discovered that oak stumps under open canopy (shelterwood management system) regenerated better than those in clear-cut areas. The best results were achieved in strips under open canopy, followed by strips under standards, whereas the worst results were obtained for clear-cut areas (only 50 % regenerated).

Materials and methods

At the beginning of the 2009 and 2010 growing seasons, research plots were established in sessile oak natural occurrence sites in the Czech Republic (Moravian part) with the objective of verifying the sprouting capacity of sessile oak (*Quercus petraea* (Matt.) Liebl.) 1 year after harvest. The plots covered an area between 0.25 and 0.50 ha. Sessile oak representation (inferred from the number of stumps) within the plots ranged from 30 to 97 %. The plots were situated in the "Masarykův les" Křtiny Training Forest Enterprise (a special-purpose facility of Mendel University in Brno) at the Bílovice and Vranov forest districts. The annual mean temperature in the area is approximately 7.5 °C, with annual rainfall of 550–650 mm. The research plots were clear-felled in wintertime. The plots were established in such a way as to span the first to third forest vegetation zones on mesotrophic edaphic series according to the Czech forest ecosystem classification (Viewegh et al. 2003) and to come from forest stands of different ages (with a certain ratio of sprout-origin specimens). Detailed characteristics of the sites are listed in Table 1. The sprouting of individual stumps was monitored at individual sites either within the entire research plot (8 sites of approx. 80 m^2 per a single research plot of 0.50 ha: plot 1–3) or within the entire 0.25 ha of the research plots (plots 4–7). The plots constitute a part of a long-term experiment, and the continuous publication of results obtained from the plots established for this purpose is expected. Borders and centers of individual plots and their parts were located in the S-JTSK (Křovák coordinate system). Each stump within the research plot was assigned a registration number (both in the field and in the project database), and its location, diameter and age were recorded. The database of the valid forest management plan provided values of site index (mean height in 100 years) for oak stumps at individual plots. The location of individual stumps was determined using the FieldMap system (IFER, Czech Republic, www.fieldmap.cz). Stump diameters were measured in two mutually perpendicular directions using the Mantax Digitech caliper. Stump heights were not recorded because the parent trees had all been cut at lowest to ground level (up to 15 cm from the ground depending on the parent tree diameter). Parent stand ages derived from management records were not used because of their limited reliability. Instead of it, ages of individual stumps were determined through tree ring count on the stump surface. Absence

Table 1 Basic characteristics of the research plots

No.	Age	%Oa	Si	Alt	Slope	Loc	Stumps	%SA
1	31	33.7	26	325	<5° (W–NW)	49°15′03.596″N 16°41′01.791″E	91	60
2	38	35.6	24	355	<5° (S–SW)	49°15′55.553″N 16°40′26.458″E	48	40
3	40	88.0	24	330	5°–15° (W–NW)	49°14′54.942″N 16°41′15.596″E	270	60
4	72	92.7	18	320	5°–10° (SW)	49°14′47.090″N 16°36′08.830″E	139	90
5	72	97.1	18	280	10°–20° (S–W)	49°14′44.490″N 16°36′05.810″E	172	90
6	97	57.3	22	410	<5° (SE)	49°13′30.065″N 16°40′53.667″E	89	70
7	97	30.3	22	410	<5° (SE)	49°13′30.345″N 16°41′0.587″E	53	70

Age age of the stand at time of harvest (years), *%Oa* oak representation (% of number of stumps), *Si* site index (m) (mean height in 100 years), *Alt* altitude (m a.s.l.), *Loc* geographic location in WGS84 coordinates, *Stumps* number of recorded stumps (pieces), *%SA* assessed representation of apparent sprout-origin trees (% of number of stumps)

(*failure*) or presence (*success*) of at least one living sprout was recorded.

Data analysis

The correlation between site index, stump diameter, parent tree age and the probability of at least a single living stump sprout occurrence was studied. To determine this probability, logistic regression was used because of its suitability for modeling binary data (e.g., “success” or “failure”) (Loftsgaarden and Andrews (1992). In our case, “success” equals the existence of at least one living sprout, whereas “failure” equals the nonexistence of any living sprouts. Generally, the expected probability of the monitored phenomenon can be expressed by the following model (Sands and Abrams 2009):

$$\hat{p}_i = \frac{e^{a+b_j x_i}}{1 + e^{a+b_j x_i}} \quad (1)$$

where a and b_j are model parameters, and x_i is predictor variable.

Logistic regression was used because it enables a more dynamic approach to stump sprout modeling than the commonly used approaches (e.g., registering the number of sprouts per stump and the percentage of stumps with sprouts), (Weigel and Peng 2002). As the logistic regression function is limited by an interval [0,1], it is suitable for survival probability modeling (Hamilton 1986). Models using individual independent variables (age, stump diameter, site index) as well as their mutual combinations were tested. Hypotheses of the significance of a given model were verified by the χ^2 test of maximum log-likelihood, whereas the hypothesis of the significance of individual parameters was verified by the Wald statistic. Significant models were compared by Akaike’s information criterion (AIC).

We also compared the best model for sessile oak with probability models for three different oak species occurring in North America (*Quercus velutina* Lamb., *Quercus alba* L. and *Quercus montana* L.), as proposed by Sands and Abrams (2009). They developed models for each species using stump diameter as an independent variable. We applied all four models to our experimental data and compared them using AIC. According to Burnham and Anderson (1998), a model that yields an AIC value 7–10 units lower than those of other models in the group of nested models is considered better. All hypotheses were tested at $\alpha = 0.05$. All calculations were processed by STATISTICA 9 and MS Excel.

Results

Three models using stump diameter, age of the parent tree and their interaction as predictors were statistically significant. A statistically significant impact on sprouting probability was not found for site index. The first model used stump diameter as the predictor (Model 1), the second used age of the parent tree as the predictor (Model 2) and the third used the interaction of stump diameter and age of the parent tree as the predictor (Model 3). Model 3 was created after the model encompassing both stump diameter and age of the parent tree had been evaluated as being statistically insignificant. The resulting insignificance of the stump diameter and age model was due to multicollinearity, as a correlation index of $R = 0.689$ was determined between stump diameter and age of the parent tree. Table 2 lists the individual models with their respective parameters and AIC.

Model 1 used stump diameter independently. According to the results of the χ^2 test, it is statistically significant ($\chi^2 = 49.028$, $p < 0.00001$). Both its parameters are statistically significant (Wald statistic for parameter $a = 103.455$, $p < 0.00001$; for parameter $b_1 = 45.410$, $p < 0.00001$), and the AIC value is −1,372.66. The resulting probabilities are shown in Fig. 1, which depicts fitted values along a solid line and 95 % CI along dashed lines.

Model 2 used age of the parent tree independently. According to the results of the χ^2 test, it is statistically significant ($\chi^2 = 43.451$, $p < 0.00001$). Both of its parameters are statistically significant (Wald statistic for parameter $a = 113.365$, $p < 0.00001$; for parameter $b_2 = 40.545$, $p < 0.00001$). The AIC value is −1,367.44. The resulting probabilities are shown in Fig. 2, which depicts fitted values on an unbroken line and 95 % CI on dashed lines.

Model 3 used an interaction of the age of the parent tree and stump diameter. According to the results of the χ^2 test, it is statistically significant ($\chi^2 = 36.701$; $p < 0.00001$). Both model parameters are statistically significant (Wald statistic for parameter $a = 132.406$, $p < 0.00001$; for parameter $b_3 = 33.712$, $p < 0.00001$). The AIC value is −1,359.29. The resulting probabilities are shown in Fig. 3, where individual curves depict the probability in relation to the age of the parent tree.

The above-listed results indicate that Model 1 is the most suitable, followed by Models 2 and 3. In accordance with Burnham and Anderson (1998), comparison of the models using AIC reveals the identical statistical suitability of Models 1 and 2.

Table 3 lists the model parameters of all four compared oak species, including their AIC values. The AIC values reveal that none of the models for North American oak species are suitable for the possible modeling of the probability of sprout occurrence in sessile oak in the first year after harvest, as Fig. 4 clearly shows.

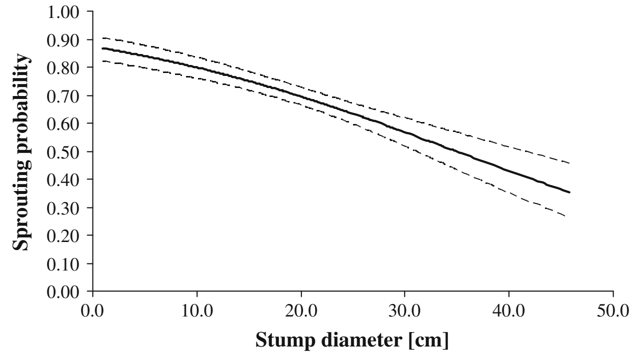

Fig. 1 Probability of sprout occurrence of sessile oak 1 year after harvest based on stump diameter

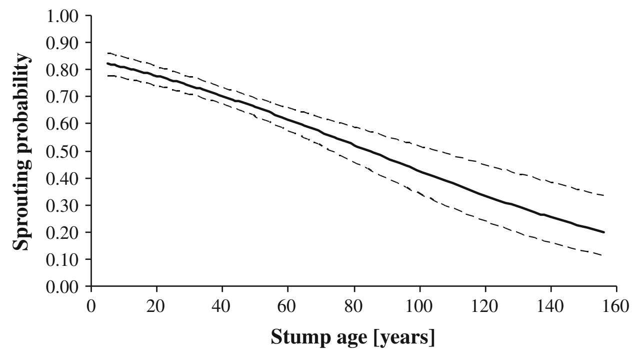

Fig. 2 Probability of sprout occurrence of sessile oak 1 year after harvest based on stump age

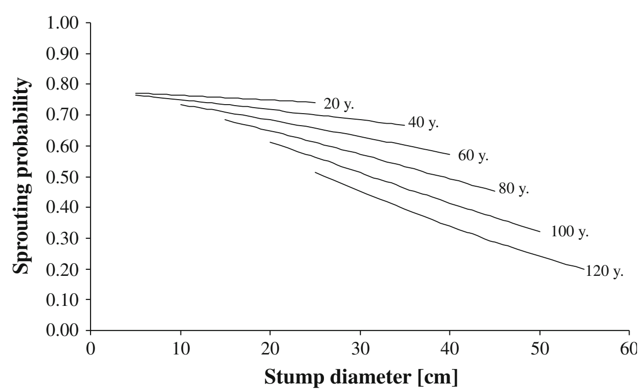

Fig. 3 Probability of sprout occurrence of sessile oak 1 year after harvest based on interaction of stump diameter and parent tree age

Table 2 Parameters of individual probability models of living sprout occurrence in sessile oak

Model no.	Predictor	a	b_1	b_2	b_3	AIC
1	Diameter	1.932	−0.055			−1,372.66
2	Age	1.632		−0.019		−1,367.44
3	Diameter × age	1.252			−0.0004	−1,359.29

a, b_1, b_2 and b_3 parameters of the models, *AIC* Akaike's information criterion

Table 3 Parameters of the sessile oak model and the compared models of selected North American oak species

Species	a	b_1	AIC
Quercus petraea	1.932	−0.055	−1,372.66
Quercus velutina	6.007	−0.078	−1,036.83
Quercus montana	6.421	−0.109	−1,056.13
Quercus alba	1.613	−0.018	−1,316.99

a, b_1 parameters of the models, *AIC* Akaike's information criterion

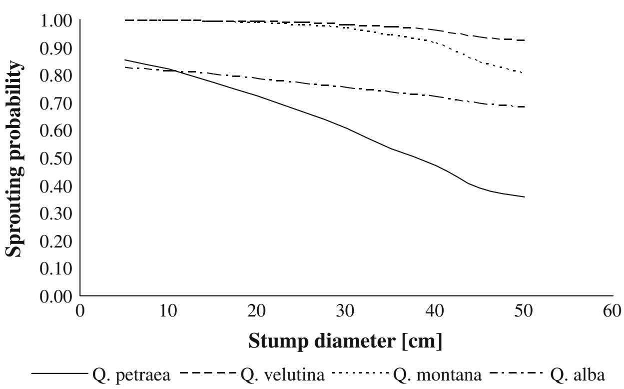

Fig. 4 Sprouting probability in the first year after harvest of the four compared oak species based on stump diameter

Discussion

As the obtained results reveal, the age and stump diameter of the parent tree are significant indicators of stump sprouting probability in sessile oak in the first year after harvest. The age of the parent tree, its stump diameter and site quality represent important factors for successful stump sprouting (Roth and Hepting 1943). According to Bruggink (1988), the age of the parent tree and the stump diameter are significant factors for stump sprouting in white oak and black oak in northern Michigan (USA). Studies indicate that the probability of stump sprouting is in inverse correlation to the age of the parent tree and breast height diameter and in direct proportion to site quality (Roth and Hepting 1943; Johnson 1977). According to Johnson (1977), significant factors for the successful stump sprouting of oaks in Missouri (USA) 1 year after stand harvest or after a forest fire include the age of the parent stand, stump diameter and stand quality indicators. Lynch and Bassett (1987) studied stump sprouting in oaks in northern Michigan (USA). For northern red oak and northern pin oak, they failed to find any impact of stump diameter on sprouting capacity, whereas for white oak, the impact was significant. Mann (1984) discovered in Tennessee (USA) that white oak, water oak and northern red oak produced fewer sprouts with increasing breast height diameter of the parent tree. *Quercus castanea* shows the highest sprouting probability for 15–30 cm breast height diameter of the parent tree. In California (USA), blue oak (*Quercus douglasii*) has more numerous stump sprouting with smaller parent tree diameters than with larger parent tree diameters (McCreary et al. 1991). High harvest intensity may prevent a decline in sprouting capacity (Johnson 1977; Weigel et al. 2006). Oak regeneration is a concern in many countries (Fischer et al. 1987; Lorimer 1989, 1993). Various forest management methods have been devised with oak regeneration as their objective (Hannah 1987), including shelterwood felling (Johnson 1993), controlled burning (Barnes and Van Lear 1998; Brose and Van Lear 1998) and planting (Weigel and Johnson 1998a, b, 2000). Planting represents one of the methods of enhancing the success rate of oak regeneration (Johnson et al. 2009). Multiple stump sprouts of northern red oak can survive in clusters for even longer than 50 years (Johnson 1975; Wendel 1975). Weigel et al. (2006) studied the probability of oak stump sprouting in Northern America and the probability of sprout dominance 15 years after harvest. Oaks producing one or more stump sprouts in the dominant or co-dominant crown classes were considered to be dominant. As their models indicate, the probability that a stump sprout will be dominant 15 years after harvest is conditioned primarily by the age of the parent tree and its diameter. For white oak, the probability of sprout dominance or co-dominance 15 years after harvest at an age of 50 years and a diameter of the parent tree of 10 cm is almost 70 %; at 70 years of age and a diameter of 10 cm, the probability is 50 %, and as the diameter increases, the probability declines rapidly, dropping below 20 % after 90 years. Out of all the studied oak species, chestnut oak (*Quercus prinus*) has the highest potential of sprout dominance 15 years after harvest. At the age of 50 years and a diameter of 10 cm, the probability exceeds 90 %; at the age of 70 years and a diameter of 10 cm, it reaches almost 90 %; at the age of 90 years and a 20 cm diameter, the probability is almost 70 %; and at an age of 110 years and a diameter of 25 cm, it amounts to 30 %. However, at every age, increasing breast height diameter decreases this probability. Black oak and northern red oak are species with the lowest potential to produce dominant or co-dominant sprouts 15 years after harvest. At the age of 50 years and a 10 cm diameter of the parent tree, they show only 50 % probability; at 70 years and a 15 cm diameter, it is only 40 %; at 90 years and a 30 cm diameter, they reach 20 % probability; and at 110 years and 40 cm diameter, the probability is as little as 10 %. According to the relevant model, scarlet oak (*Quercus coccinea*) reaches a probability of 80 % at the age of 50 years and a 10 cm diameter, whereas at 70 years and a 20 cm diameter, the probability decreases to 70 %; at 90 years and a 30 cm diameter, it exceeds 50 %; and at 110 years and a 40 cm diameter, the probability of stump sprout dominance or co-dominance falls to 30 % (Weigel et al. 2006).

Model 1 (logistic regression probability model of living sprout occurrence in the first year after harvest, based on stump diameter) reveals that the probability of stump sprout occurrence decreases with increasing stump diameter. The same conclusion has been reached by Johnson (1977); McCreary et al. (1991); Roth and Hepting (1943); and Weigel and Peng (2002), among others. If the stump diameter is less than 10 cm, the probability of at least one sprout's occurrence exceeds 80 %. As the stump diameter increases, the sprout capacity declines and, starting at a stump diameter of approximately 35 cm, it fails to reach 50 %. The optimum stump diameter for the production of sprouts is therefore up to 20 cm, which secures approximately a 70 % probability of living stump sprout occurrence. Model 2 represents a logistic regression probability model of a living sprout occurrence in the first year after harvest, based on the age of the parent tree. It clearly shows that the probability in the first year following the tree's felling decreases with the age of the parent tree. Among others, Roth and Hepting (1943); Bruggink (1988); Johnson (1977); and Weigel and Peng (2002) arrived at the same conclusion. The sprouting probability exceeds 70 % up to an age of approximately 40. Starting with 90 years, it fails to reach more than 50 %. Model 3 (logistic regression probability model of living sprout occurrence in the first year after harvest based on the interaction of stump diameter and age of the parent tree) managed to successfully remove the problem of the multicollinearity of the stump diameter and the age of the parent tree. A higher resulting product is associated with a lower probability of living sprouts in the first year after harvest. According to the obtained AIC values, Model 1, which is based on the stump diameter, appears to be the most suitable of the three.

Apart from the age of the parent tree and the stump diameter in our study, stump sprouting may also be affected by tree species, the site on which the tree is growing, its social status in the given stand and also the time that has elapsed since felling. Generally, trees growing on poorer quality stands tend to regenerate more effectively due to more pressing efforts to preserve their populations (Del Tredici 2001). Weigel and Peng (2002) studied stump sprouting probability in the first year after harvest in selected oak species (*Quercus* sp.) in Northern America. They also studied the successful sprout developments in the fifth and tenth year after harvest. Their models suggest that the most significant probability of sprout production occurs in the first year after harvest (nearly 100 % in chestnut oak at stump age of 50 years and 10 cm breast height diameter of the parent tree). According to their models, sprout capacity decreases as the age and breast height diameter of the parent tree increase (the sprouting probability in the first year after harvest in white oak of 110 years and parent tree breast height diameter exceeding 50 cm is only 5–10 %, falling to nearly zero in the fifth and tenth year after harvest). Their results also reveal that a higher site index is associated with a higher probability of living sprout occurrence after harvest and a higher probability of successful sprout development.

A comparison of the probability model of stump sprouting in sessile oak with models of selected North American oak species reveals that the latter models cannot be applied to sessile oak. The obtained result thus conflicts with the statement that compared with other deciduous tree species, the percentage of sprout occurrence in oaks in relation to the increasing stump diameter is relatively high (as stated, for example, by Cook and Sharik 1998; Johnson 1977; Sander 1971 and Wendel 1975). It is obvious that the sprouting probability in sessile oak decreases markedly with increasing stump diameter (the sprouting probability for stumps of 40 cm diameter falls below 50 %, unlike in all three North American oak species, whose sprouting probability for stumps of 40 cm diameter in the third year after harvest does not drop below 70 %).

Conclusion

The paper describes methods for evaluating stump sprouting probability in sessile oak in the first year after harvest in the Czech Republic (its Moravian part). The research plots were established in natural habitats of the species' occurrence, spanning the first to third forest vegetation zones on mesotrophic edaphic series. The plots were situated within stands of differing ages and with a certain percentage of sprout-origin specimens in areas managed by the "Masarykův les" Křtiny Training Forest Enterprise (a special-purpose facility of Mendel University in Brno). For the purposes of the study and with future monitoring of consequent probability of stump sprout survival in mind, the research plots were located in the S-JTSK (Křovák coordinate system). For each stump, the following parameters were measured: its position within the research plot, stump diameter, condition (successful or unsuccessful regeneration) and age. Sprout health condition was also determined.

The probability of a stump's sprouting in the first year following harvest was modeled using logistic regression. Three probability models of stump sprouting capacity in sessile oak were created, and the statistical significance of the individual models was evaluated. These models used different parameters as independent variables—stump diameter (Model 1), parent tree age (Model 2) and the interaction of parent tree age and stump diameter (Model

3). The obtained results revealed that based on AIC values, Model 1 is the most suitable, followed by Model 2 and Model 3. A larger stump diameter is associated with a lower probability of their sprout in the first year following harvest. Based on the obtained results, and in accord with authors such as Roth and Hepting (1943); Johnson (1977); Mann (1984); McCreary et al. (1991); Weigel and Peng (2002); or Weigel et al. (2006), it may be concluded that with increasing stump diameter and parent tree age sprouting probability declines. The results reveal that starting with approximately 35 cm stump diameters, the probability of stump sprouting fails to exceed 50 %. A stump diameter of up to 20 cm thus appears to be optimal for sprout production. This diameter still secures an approximately 70 % probability of a living sprout existing in the first year following harvest. Similarly, a probability above 70 % of a living sprout existing in the first year following harvest occurs in the analyzed stands at up to approximately 40 years of age.

A comparison of stump sprouting probability in sessile oak with similar models of selected North American oak species (*Quercus velutina, Quercus montana* and *Quercus alba*) reveals that the model for sessile oak differs significantly from the its North American counterparts. It is therefore evident that the North American models cannot be used for the potential modeling of sprouting probability and thus it was necessary to develop a new model whose parameters correspond to the conditions of sessile oak in its natural habitat in the Czech Republic.

The designed probability models of stump sprouting capacity (occurrence of at least one living sprout) in sessile oak in the first year following harvest may be considered unique, as models have not been created for this species or for the conditions of the Czech Republic. Another important fact that became apparent in the course of work is that the existing available probability models of selected North American oak species (Sands and Abrams 2009) could not be used for the given purpose. For these reasons, the creation of probability models of stump sprouting capacity in sessile oak in the Czech Republic appeared to be highly appropriate. The authors would like to express their hope that the results of their work may prove to be a valid argument in expert discussions, which are underway in the Czech Republic at present in relation to a possible reintroduction of coppicing as one of the traditional forest management methods used in Central Europe.

Acknowledgments This study was supported by the Czech National Agency of Agricultural Research, Grant No. QH71161, and by the Czech Ministry of Environment, Grant No. SP/2d4/59/07. We thank K. Drápela for his invaluable advice with the statistical analysis of the data. We also thank R. Knott, V. Hurt and M. Jun for their help in collecting field data.

References

Barnes TA, Van Lear DH (1998) Prescribed fire effects on advanced regeneration in mixed hardwood stands. South J Appl For 22(3):138–142

Bond WJ, Van Wilgen BW (1996) Fire and plants. Chapman & Hall, London

Brose PH, Van Lear DH (1998) Effects of seasonal prescribed fires on density of hardwood advanced regeneration in oak-dominated shelterwood stands. In: Waldrop TA (ed) Proceedings of the 9th Biennial southern silvilcultural research conference, 25–27 Feb 1997, Clemson, SC, pp 310–314

Bruggink JL (1988) Oak stump sprouting potential on outwash ecosystems of northern lower Michigan. M.S. thesis, Michigan State University

Burnham KP, Anderson DR (1998) Model selection and inference: a practical information-theoretic approach. Springer, New York

Burns RM, Honkala BH (1990) Silvics of North America: volume 2. Hardwoods. Agriculture Handbook, U.S. Dept. of Agriculture, Forest Service, Washington

Cook JE, Sharik TL (1998) Oak regeneration in the southern Appalachians: potential, problems, and possible solutions. South J Appl For 22:11–18

Del Tredici PD (2001) Sprouting in temperate trees: a morphological and ecological review. Bot Rev 2:121–140

Fischer BC, Kershaw JA Jr, George DW, George CA, Mills WL (1987) Tree regeneration response to clear-cutting on the USFS Brownstown Ranger District. Proc Indiana Acad Sci 96:231–242

Hamilton DA Jr (1986) A logistic model of mortality in thinned and unthinned mixed conifer stands of northern Idaho. For Sci 32:989–1000

Hannah PR (1987) Regeneration methods for oaks. North J Appl For 4:97–101

Johnson PS (1975) Growth and structural development of red oak sprout clumps. For Sci 21:413–418

Johnson PS (1977) Predicting oak stump sprouting and sprout development in the Missouri Ozarks. Res. Pap. NC-149. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul

Johnson PS (1993) Perspectives on the ecology and silviculture of oak-dominated forests in the central and eastern states. USDA For Serv Gen Tech Rep NC-153

Johnson PS, Shifley SR, Rogers R (2009) The ecology and silviculture of oaks. CABI International, New York

Loftsgaarden PO, Andrews, PL (1992) Constructing and testing logistic regression models for binary data: application to national fire danger rating system. USDA For. Serv Gen Tech Rep INT-286

Lorimer CG (1989) The oak regeneration problem: new evidence on causes and possible solutions. University of Wisconsin, Madison. Wis For Res Bull 8

Lorimer CG (1993) Causes of the oak regeneration problem. In: Loftis D, McGee D (eds) Proceedings, oak regeneration: serious problems, practical recommendations, 8–10 Sept 1992, Knoxville, Tenn. USDA For. Serv. Gen. Tech. Rep. SE-84, pp 14–39

Lynch AM, Bassett JR (1987) Oak stump sprouting on dry sites in northern lower Michigan. North J Appl For 4:142–145

Mann LK (1984) First-year regeneration in upland hardwoods after two levels of residue removal. Can J For Res 14:336–342

McCreary DD, Tietje WD, Schmidt RH, Gross R, Weitkamp WH, Willoughby BL, Bell F (1991) Stump sprouting of blue oaks in California. In: Standiford RB (ed) Proceedings, symposium on oak woodlands and hardwood rangeland management, 31 Oct–2 Nov 1990, Davis, Calif. USDA For. Serv. Gen. Tech. Rep. PSW-126, pp 64–69

McIntyre AC (1936) Sprout groups and their relations to the oak forests of Pennsylvania. J For 34:1054–1058

Polanský B et al. (1956) Silviculture. Part III. SZN Praha (in Czech)

Roth ER, Hepting GH (1943) Origin and development of oak stump sprouts as affecting their likelihood to decay. J For 41:27–36

Roth ER, Hepting GH (1969) Prediction of butt rot in newly regenerated sprout oak stands. J For 67:756–760

Sander IL (1971) Height growth of new oak sprouts depends on size of advance reproduction. J For 69:809–811

Sands BA, Abrams AD (2009) Effects of stump diameter on sprout number and size for three oak species in a Pennsylvania clearcut. North J Appl For 26:122–125

Viewegh J, Kusbach A, Mikeska M (2003) Czech forest ecosystem classification. J For Sci 49:74–82

Vyskot M (1958) Silviculture of oak. SZN, Praha (in Czech)

Weigel DR, Johnson PS (1998a) Planting white oak in the Ozark Highlands: a shelterwood prescription. USDA For. Serv. Tech. Brief NC-5, USDA Forest Service, North Central Forest Experiment Station, St. Paul

Weigel DR, Johnson PS (1998b) Planting red oak in the Ozark highlands: a shelterwood prescription. USDA For. Serv. Tech. Brief NC-6, USDA Forest Service, North Central Forest Experiment Station, St. Paul

Weigel DR, Johnson PS (2000) Planting red oak under oak/yellow-poplar shelterwoods: a provisional prescription. USDA For. Serv. Gen. Tech. Rep. NC-210, USDA Forest Service, North Central Forest Experiment Station, St. Paul

Weigel DR, Peng CJ (2002) Predicting stump sprouting and competitive success of five oak species in southern Indiana. Can J For Res 32:703–712

Weigel DR, Dey DC, Peng CJ (2006) Stump sprout dominance probabilities of five oak species in southern Indiana 15 years after clear-cut harvest. In: Connor KF (ed) Proceedings of the 13th biennial southern silvicultural research conference. US For. Serv. Gen. Tech. Rep. SRS-92, South. Res. Stn., Asheville, NC, pp 551–558

Wendel GW (1975) Stump sprout growth and quality of several Appalachian hardwood species after clearcutting. U.S. Forest Serv Res Pap NE-329, USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby (PA)