STUMP SPROUT DOMINANCE PROBABILITIES OF FIVE OAK SPECIES IN SOUTHERN INDIANA 25 YEARS AFTER CLEARCUT HARVESTING

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Abstract.—When regenerating oak or mixed-hardwood forests in southern Indiana, oak (*Quercus* spp.) stump sprouts are vital to sustaining their presence and long-term dominance. In 1987, a study began in the Hoosier National Forest in southern Indiana. The study goal was to predict the sprouting potential and dominance probability of oaks. Before clearcut harvesting, we sampled 2,188 trees of five oak species—white oak, chestnut oak, black oak, scarlet oak, and northern red oak. Measurements were taken before and 1, 5, and 25 years after clearcut harvesting. We used logistic regression to develop two preharvest predictive models and four postharvest models for dominance probabilities of the five species 25 years after harvest.

INTRODUCTION

Oaks (*Quercus* spp.) form a major component of the upland forests throughout the Central Hardwood region, and maintaining them on the regional landscape is important for wildlife, timber, and biodiversity. Regenerating oaks has been a problem in southern Indiana and surrounding regions (Fischer et al. 1987; Lorimer 1989, 1993) because of changes in forest management strategies and disturbance regimes, shifts in species composition, and unpredictable climatic influences.

Adequate oak reproduction in advance of the final harvest of even-aged stands is generally considered to be the key to ensuring oak in future stands (Dey 2014, Dey et al. 1996, Johnson et al. 2009, Sander et al. 1984). Stump sprouts that originate from harvested trees are, however, another potential source of oak reproduction. Because these sprouts are often the fastest-growing sources of oak reproduction, their contribution to future stocking is often important even when their numbers are relatively low. In fact, in many stands that originate from clearcutting, stump sprouts may comprise 50-75 percent of the basal area in oak that is free to grow or in dominant positions (Beck and Hooper 1986, Gould et al. 2002). In former oak forests in southern Indiana, Morrissey et al. (2008) found that 45 percent of dominant oak trees in 21- to 35-year-old clearcuts were from oak stump sprouts, and Swaim et al. (2016) reported that the few dominant oak trees in 23-year-old clearcuts were primarily of stump sprout origin.

Our objectives were to determine significant predictors of oak stump sprouting success in southern Indiana and to develop dominance probability models for oaks at year 25, which update previously developed models (Weigel and Peng 2002; Weigel et al. 2006, 2011). Dominance probability models permit the forest manager to make an informed prediction of the approximate number of dominant or codominant oak stump sprouts in future stands. Two model types were developed to enable the forest manager to predict dominance probability when either preharvest or postharvest data are available.

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METHODS

The study was conducted on the Hoosier National Forest in south-central Indiana. Nine stands scheduled to be clearcut were selected for measurement. There were three stands in each of three age classes: 71-90, 91-110, and 110+ years. Harvesting was done between October 1987 and May 1989. We could not determine the season (growing or dormant) during which individual stems were harvested because harvesting occurred over two seasons. For a complete discussion of the study sites, measurements, model building, and data analysis, see Weigel and Peng (2002).

Before harvest, 0.04-ha plots were established along transects in the nine stands. We inventoried and tagged 1,371 white oak (*Quercus alba* L.), 180 chestnut oak (*Q. prinus* L.), 399 black oak (*Q. velutina* Lam.), 130 scarlet oak *(Q. coccinea* Muenchh.), and 108 northern red oak (*Q. rubra* L.) >4 cm diameter at breast height (d.b.h.) on the plots. Measurements included d.b.h. on all trees and heights and ages of selected trees that were used to determine the site index. First-year measurements included determining parent-tree age by counting rings on the stump surface and noting whether any sprouts were present. Fifth-year measurements included recording the number of stump sprouts and measuring the height of the tallest sprout. At year 25, we remeasured surviving oak stump sprouts and recorded the number of sprouts, the height of the tallest sprout, and the crown class of the tallest sprout.

At age 25, oak sprout success was determined by its crown class position. By year 25 the crowns had closed; therefore, crown class provided a meaningful metric of sprout success. This measure of sprout potential, success, or competitiveness is embodied in the concept of dominance probability (Spetich et al. 2002). A successful sprout was characterized as a sprout in the dominant or codominant crown class at year 25.

We used the five-step model building approach suggested by Hosmer and Lemeshow (2000) to develop logistic regression models. We used the maximum likelihood method implemented in PROC LOGISTIC of SAS version 9.1 (SAS Institute Inc. 2004) to perform the logistic modeling.

The species were grouped into the white oak group and the red oak group for both model types. The white oak group consisted of white and chestnut oaks; the red oak group consisted of northern red, black, and scarlet oaks.

For the preharvest models the dependent variable was a dominant or codominant stump sprout 25 years after the parent stem was harvested. The independent variables were species, parent tree age, d.b.h., natural log of d.b.h., site index, natural log of site index, aspect, and interactions between two or more of these independent variables. According to Johnson et al. (2009), these are commonly the driving variables that affect sprouting and competitive relationships in regenerating oak forests.

The postharvest models used the same dependent variable as the preharvest models, but the number of independent variables was reduced so that only stump diameter, species, aspect, and site index were required.

Table 1.—Preharvest models: logistic regression models for estimating the probability that an oak stump sprout will be in either the dominant or codominant crown class at year 25

		Parameter estimates[a,b]			Model evaluation statistics	
Model No.	Species	b_0	b_1	b_2	X^2	H-L[c]
1	White oak	0.4168	2.4015	-0.1272	472.4107	12.8360
	Chestnut oak	1.8604	2.4015	-0.1272	(p<0.001)	(p=0.1176)
2	Red & black oak	0.0992	2.0586	-0.0637	200.7304	13.5027
	Scarlet oak	1.7435	2.0586	-0.0637	(p<0.0001)	(p=0.0957)

[a] Regression models are of the form $P = [1+e^{-(b_0+b_1X1+b_2X2)}]^{-1}$, where P is the estimated probability that a cut tree will produce a successful (dominant or codominant) stump sprout at age 25: $X1$ is aspect (north 315°-135° = 0, south 136°-314° = 1; Hannah 1968); $X2$ is d.b.h. in centimeters.

[b] All parameter estimates differ significantly from zero at $p < 0.01$.

[c] Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000).

RESULTS

Preharvest White Oak Group Model

At year 25, the best model developed from the preharvest variables included three of those variables: species, d.b.h., and aspect (model 1 in Table 1).

Preharvest Red Oak Group Model

Northern red oak and black oak were combined into a single group because in all previous models (Weigel and Peng 2002; Weigel et al. 2006, 2011) they did not differ significantly. This combined group did, however, differ significantly from scarlet oak.

The best model that predicted the dominance of the red oak group at year 25 (model 2 in Table 1) included species, d.b.h., and aspect.

Postharvest White Oak Group Models

Year 1: At year 1, white and chestnut oak did not differ significantly ($p > 0.05$) from each other, so they were combined. The significant predictors of stump sprout dominance at year 25 using data collected at year 1 were diameter at stump height, aspect, and site index (model 3 in Table 2).

Year 5: Using data at year 5 to predict dominance, we found that species, diameter at stump height, and site index were all significant predictors (model 4 in Table 2).

Postharvest Red Oak Group Models

As in the red oak preharvest models, northern red and black oaks were combined into a single group that differed significantly from scarlet oak.

Year 1: At year 1 the red oak group showed three significant predictors of dominance: species, diameter at stump height, and aspect (model 5 in Table 2).

Year 5: The only significant predictors from year 5 data for the red oak group were species and site index (model 6 in Table 2).

Table 2.—Postharvest models: logistic regression models for estimating the probability that an oak stump sprout will be in either the dominant or codominant crown class at year 25 when sprouts were present at year 1 or 5 after clearcutting

		Parameter estimates[a,b]				Model evaluation statistics	
Model	Species and year	b_0	b_1	b_2	b_3	X^2	H-L[c]
3	White and chestnut oaks, 1	4.4361	1.1263	-0.0594	-0.1770	110.8413 ($p<0.0001$)	13.0023 ($p=0.1118$)
4	White oak, 5	6.6776		-0.0314	-0.2821	61.5603	10.0860
	Chestnut oak, 5	6.0473		-0.0314	-0.2821	($p<0.0001$)	($p=0.2590$)
5	Black and red oaks, 1	0.2922	1.1033	-0.0294		69.8513	12.9706
	Scarlet oak, 1	2.2087	1.1033	-0.0294		($p<0.0001$)	($p=0.1129$)
6	Black and red oaks, 5	5.1520			-0.2450	52.0984	5.0943
	Scarlet oak, 5	6.5769			-0.2450	($p<0.0001$)	($p=0.6485$)

[a] Regression models are of the form $P = [1+e^{-(b_0+b_1X1+b_2X2+b_3X3)}]^{-1}$, where P is the estimated probability that a cut tree will produce a successful (dominant or codominant) stump sprout at age 25: *X*1 is aspect (north 315°-135° azimuth = 0, south 136°-314° azimuth = 1) (Hannah 1968); *X*2 is cut tree stump diameter in centimeters 15 centimeters above ground level; *X*3 = site index (where site index is derived from Carmean et al. 1989).

[b] All parameter estimates differ significantly from zero at $p < 0.01$ except for species in the white oak group year 1 model that differs significantly from zero at $p < 0.10$.

[c] Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000).

DISCUSSION

For all models, whether the prediction input variables were from preharvest data or postharvest data, and regardless of broad species grouping (red or white oak), dominance probabilities decreased with increasing diameters of cut trees.

Preharvest

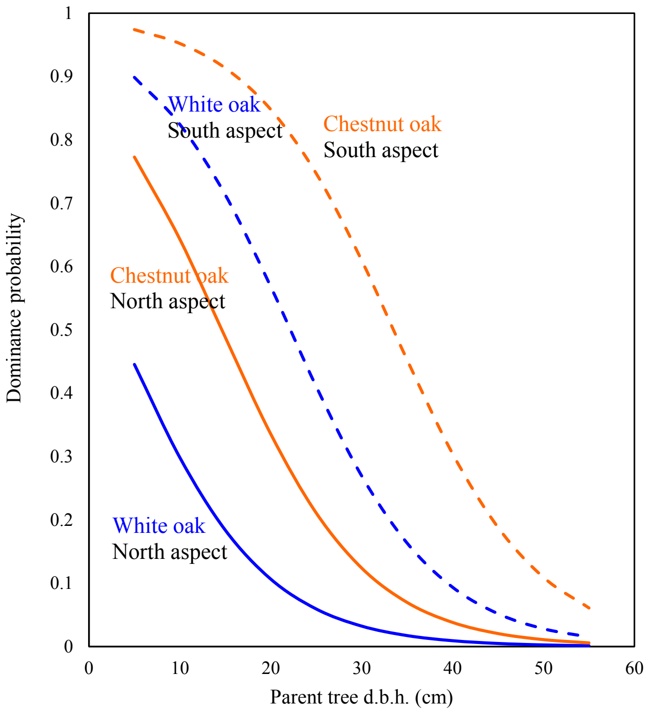

Figure 1.—Estimated probability (Table 1) that a white oak or chestnut oak stump will produce a sprout that is either dominant or codominant 25 years after the parent tree is cut in a clearcut regeneration harvest based on preharvest d.b.h. and aspect.

As in previous year models (Weigel and Peng 2002; Weigel et al. 2006, 2011), chestnut oak had higher dominance probabilities at year 25 than white oak (Fig. 1). Parent tree age and site index were, however, no longer significant variables in predicting dominance. A more general site quality variable, aspect, was significant (Hannah 1968). Aspect is one of several topographic factors that influences site index (Johnson et al. 2009), therefore, aspect and site index are correlated. The inclusion of one or both variables in the best model is likely influenced by sample size, data structure nuances, and artifacts of statistical analysis. The interpretation remains the same: oak dominance probabilities increase as site quality decreases, which is indicated by lower site index or hotter, drier, more exposed aspects. In general, oaks are more drought tolerant than many of their major competitors and are better able to persist on more xeric sites of lower productivity (Johnson et al. 2009). The diversity, abundance, and growth potential of oak competitors are also significantly less on the lower-quality sites (Kabrick et al. 2008, 2011, 2014). Parent trees for both species located on south aspects (136°-314°) had a higher probability of producing dominant or codominant sprouts than those found on a north aspect (315°-135°). Because southern aspects tend to have lower site indices (Johnson et al. 2009), this is similar to previous models where lower quality sites had higher dominance probabilities. Competition from faster growing species that are typically found on higher-quality sites limited the oaks' dominance probabilities on the better quality sites; however, on the lower-quality sites the oaks were able to successfully compete with the other species. Several studies in oak forests of the Central Hardwood region have shown increases in diversity, abundance, and competitiveness of oak competitors with increasing site quality, productivity, and index (Dey et al. 2009; Kabrick et al. 2008, 2011, 2014).

Chestnut oaks that are 10 cm d.b.h. and grow on a south aspect have a 95 percent probability of producing a dominant sprout 25 years after harvest; white oaks of a similar size have an 82 percent probability. The forest manager would know after inventorying the stand that 95 percent of all 10-cm chestnut oak on the south slopes would produce a dominant or codominant sprout 25 years after the harvest.

For the red oak group, data related to preharvest scarlet oak again resulted in higher dominance probabilities at age 25 than those of northern red or black oaks (Fig. 2), a result similar to previously published models (Weigel and Peng 2002; Weigel et al. 2006, 2011). For estimating dominance at age 25, parent tree age was no longer a significant predictor. The more general site quality variable, aspect, was significant; southern aspects have higher probabilities than northern aspects. As with the white oak group, the red oak group species were better able to compete on the lower-quality sites that tend to have less competition.

Postharvest

Year 1: Species was not a significant predictor of dominance at age 25 for the white oak group (Table 2). This is similar to previous models (Weigel and Peng 2002; Weigel et al. 2006, 2011). Site index remained a significant predictor as in these models; the more general variable, aspect, became significant. As in previous models, trees found on poorer-quality sites had higher dominance probabilities (Fig. 3).

The combined northern red and black oak grouping differed significantly from scarlet oak at year 1 (Table 2). By year 25, site index was no longer a significant predictive variable, but aspect was, a change from models developed for previous years. Scarlet oak had higher dominance probabilities than northern red or black oaks regardless of aspect, which was similar to previous models that indicated scarlet oak had higher dominance probabilities regardless of site index (Fig. 4).

Year 5: Aspect was no longer a significant predictor for the white oak group. Compared to year 1 results, white oak had higher dominance probabilities than chestnut oak (Fig. 5). Although aspect was no longer a significant predictor, site index did remain significant. As in previous models, trees on lower site index sites were predicted to have higher dominance probabilities.

Species for the white oak group became a significant predictor at year 25, which is different than in previous models (Weigel and Peng 2002; Weigel et al. 2006, 2011). A possible explanation was an increased mortality of chestnut oak sprouts from previous years. Field observations indicated that some large chestnut oak sprouts broke loose from the parent stump.

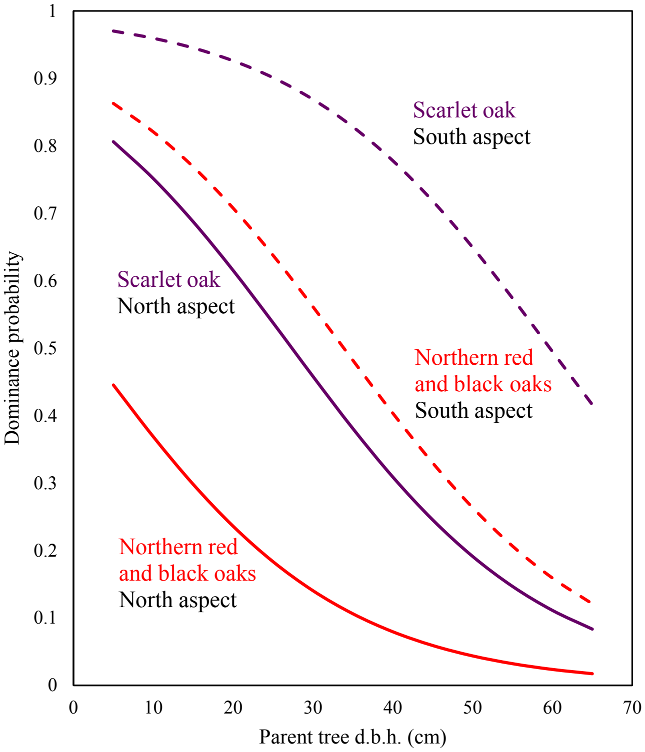

Figure 2.—Estimated probability (Table 1) that a black and northern red oak or scarlet oak stump will produce a sprout that is either dominant or codominant 25 years after the parent tree is cut in a clearcut regeneration harvest based on preharvest d.b.h. and aspect.

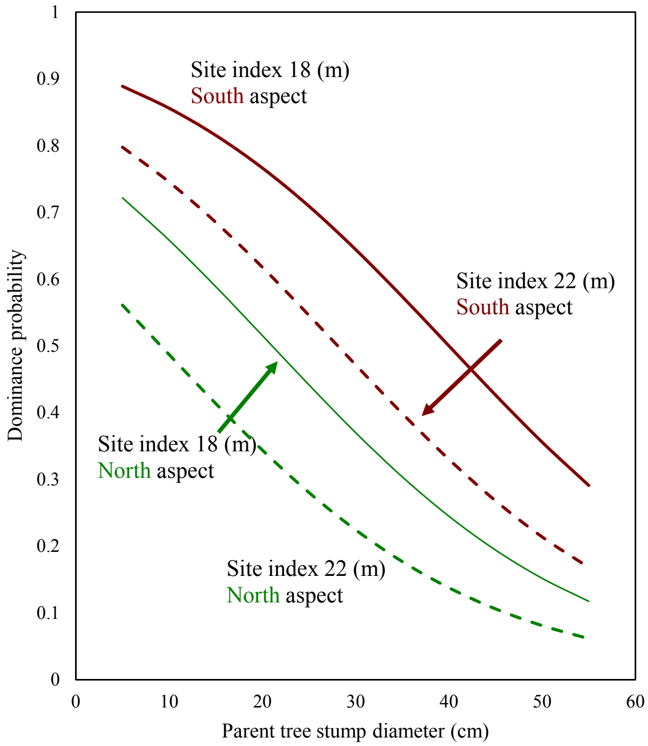

Figure 3.—Estimated probability (Table 2) that a white oak or chestnut oak stump sprout will be either dominant or codominant at year 25 when sprouts were present at year 1 after clearcutting based on aspect, stump diameter, and site index.

Species and site index were significant predictors for the red oak group; however, the dominance probabilities exceed 99 percent for both the combined northern red and black oak grouping and scarlet oak. This suggests very low mortality after year 5. If a sprout is present at year 5, it will be dominant or codominant at year 25. This is a higher dominance probability than reported by Weigel et al. (2011). Previous models included the interaction of site index with the natural log of site index. The present model does not contain this interaction, which may be related to the increased dominance probability.

CONCLUSION

The six models presented are valuable for predicting the contribution of stump sprouts to forest regeneration. The models allow forest managers to predict the percentage of oak stump sprouts that will be competitive 25 years after an even-age timber harvest. Models 1 and 2 can be used to predict the probability of dominant and codominant stump sprouts 25 years after a clearcut harvest based on preharvest information. These models also permit forest managers to assess the contribution of stump sprouts to the desired stocking of oak advanced reproduction. In addition, it allows them to adjust stand prescriptions to promote oak advance reproduction by reducing the vigor and abundance of major woody competitors.

Models 3 through 6 predict the probability of dominant and codominant stump sprouts at year 25 based on stumps sprouts being present at year 1 or year 5. Forest managers can then assess the need for crop tree release or another type of precommercial thinning to maintain the desired stocking of oak. Forest modelers can use these models to predict and describe the influence of oak stump sprouts on future stands and stand stocking.

Our analysis differs from many other stump sprout studies by predicting the contribution of stump sprouts to the future stand and hence the sustainability of oak in that stand. Our model incorporates data regarding whether a stump produces sprouts, whether those sprouts survive and grow, and how competitive these sprouts are relative to competing vegetation. Another unique quality of this study is that it provides a long-term evaluation of stump sprouts. We examined the fate of oak stump sprouts at age 25, when crowns close and differentiate; this gives forest managers a better understanding of stump sprout potential in the future stand.

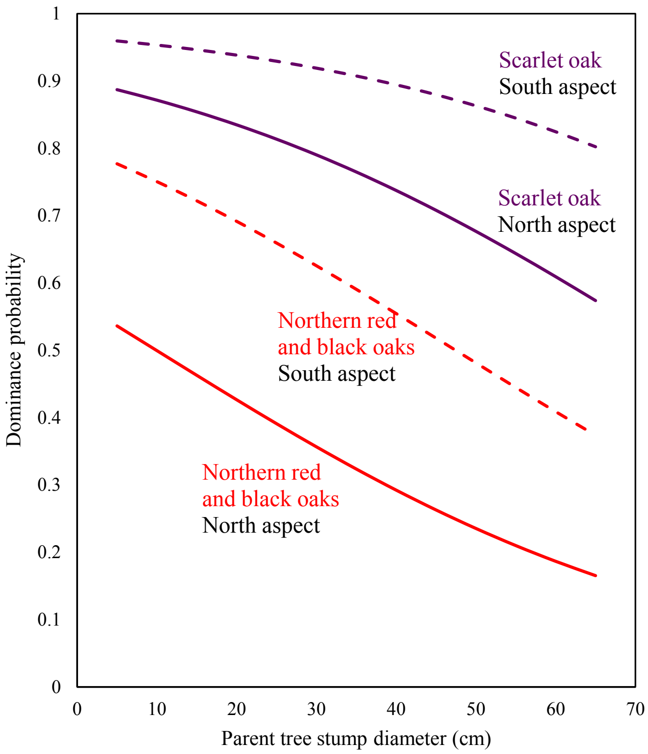

Figure 4.—Estimated probability (Table 2) that a black and northern red oak or scarlet oak stump sprout will be either dominant or codominant at year 25 when sprouts were present 1 year after clearcutting, based on stump diameter and aspect.

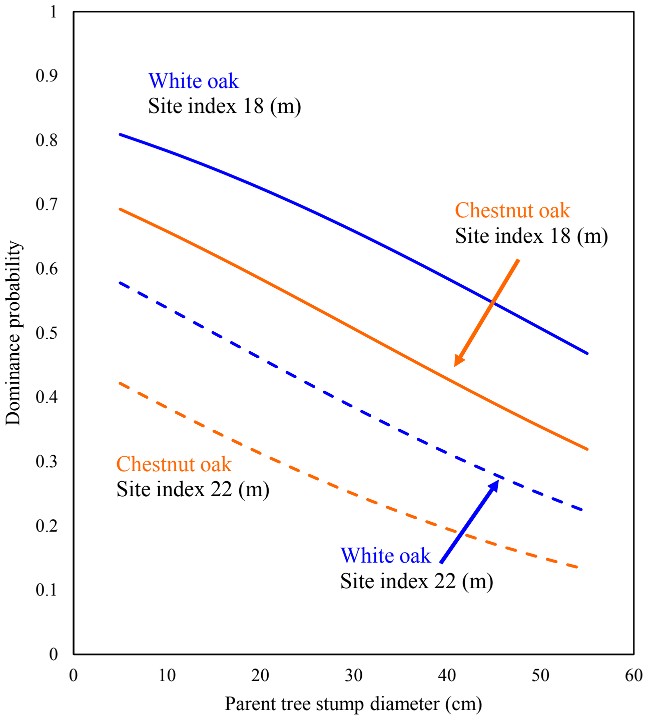

Figure 5.—Estimated probability (Table 2) that a white oak or chestnut oak stump sprout will be either dominant or codominant at year 25 when sprouts were present at year 5 after clearcutting, based on stump diameter and site index.

ACKNOWLEDGMENTS

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