STUMP SPROUT DOMINANCE PROBABILITIES OF FIVE OAK SPECIES IN SOUTHERN INDIANA 15 YEARS AFTER CLEARCUT HARVESTING

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Abstract—Oak stump sprouts are vital to sustaining oak's presence and long-term dominance when regenerating oak-, mixed-hardwood forests. A study was initiated on the Hoosier National Forest in southern Indiana in 1987 to predict the sprouting potential and dominance probability of oaks. Before clearcutting, we sampled 2,188 trees of 5 oak species: white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), and northern red oak (*Q. rubra* L.). Measurements were taken during 15 years to develop sprouting and dominance probability models. A dominant oak was one that had 1 or more sprouts per stump in the dominant or codominant crown class 15 years after clearcutting. We used logistic regression to develop models for estimating dominance probabilities of the five species. Two models were developed that predict future sprout dominance based on a preharvest stand inventory, and six models were developed based on postharvest measurements of stump sprouts and competing vegetation.

INTRODUCTION

Oaks are important for timber, wildlife food, and stand biodiversity. Oak regeneration continues to be a problem (Lorimer 1983, 1989). Oak advanced reproduction has been considered the main source of stems for the future forest (Sander and others 1984, Sander and others 1976). One component of the future stand is oak stump sprouts, often-overlooked because of the limited information about the percent of oak stumps that sprout and produce competitively successful oak stump sprouts. Thus, predicting the success or dominance of stump sprouts following overstory removal is important for understanding the role of stump sprouts for regenerating oaks.

Early research showed that parent tree age, diameter, and site quality were significant predictors of stump sprouting (Roth and Hepting 1943). In Missouri, parent tree age, stump diameter, and site index were important predictors of oak stump sprouting (Dey and others 1996, Johnson 1977). In northern lower Michigan, parent tree age and stump diameter were important predictors of stump sprouting for white oak (*Quercus alba* L.) and black oak (*Q. velutina* Lam.) (Bruggink 1988). Diameter breast height (d.b.h.) was a significant predictor for white, black, northern red (*Q. rubra* L.), and chestnut oak (*Q. prinus* L.) in Tennessee (Mann 1984).

Our objectives were to determine significant predictors of oak stump sprouting in southern Indiana and to develop dominance probability models for oaks that permit the forest manager to predict the amount of dominant or codominant oak stump sprouts in future stands. Two different types of models were developed to provide the forest manager the ability to predict dominance probability when either preharvest or postharvest data are available.

METHODS

Study Sites

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 3 stands in each of 3 age classes: 71-90, 91-110, and 110+. Harvesting was done between October 1987 and May 1989. In any given year, it was not possible to determine what season (growing or dormant) 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).

Measurements

Prior to harvest, 0.04-ha plots were established along transects in the nine stands. We inventoried and tagged 1,371 white oak, 180 chestnut oak, 399 black oak, 130 scarlet oak (*Q. coccinea* Muenchh.), and 108 northern red oak > 4.0 cms d.b.h. on the plots. Measurements included d.b.h. on all trees and heights and ages of selected trees used for site index determination. Postharvest measurements were completed 1, 5, 10, and 15 years after clearcutting. First-year measurements included aging the parent tree by counting rings on the stump surface and noting if any sprouts were present. Fifth- and 10th-year measurements included recording the number of sprouts and the height of tallest sprout. Tenth-year measurements also included recording the crown class. At year 15, we remeasured surviving oak stump sprouts and recorded the number of sprouts and the height, crown class, and d.b.h. of the tallest sprout.

Each stand was subdivided into smaller units that were uniform in aspect (north, 315°-135°; south, 136°-314°) and slope (ridge, upper slope, lower slope, and bottom). The mean height of the competition was computed for each of these units by averaging the heights of measured dominant or codominant competition within 1 m of selected stumps. The mean height of competition was used to determine if a stump sprout at years 5 and 10 was competitively successful, which it was if its height equaled or exceeded 80 percent of the mean height of the competition for the individual unit. This was done because stand crown closure does not happen in the first 10 years, so the traditional concept of crown class (Smith and others 1997) is not useful in determining the social position, or competitiveness, of tree reproduction. At age 15, oak sprout success was determined by its crown class position. This measure of sprout potential, success, or competitiveness

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is embodied in the concept of dominance probability (Spetich and others 2002). By year 15, crown closure had occurred, and the use of crown class would provide meaningful success rates.

Data Analysis

We used logistic regression for modeling the dominance probability of oak stump sprouts based on the above definition of a successful, competitive, or dominant sprout, i.e., that the main sprout was at least 80 percent of the mean competition height at stand ages 5 and 10; or that the oak sprout was in the dominant or codominant crown class at age 15.

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

Two different types of models were developed. The first type of model used preharvest measurements and therefore was not dependent on sprouting success at years 1, 5, or 10. The second type of model did not use preharvest data and consequently was dependent on sprouting success at years 1, 5, or 10.

Because the first type of model is not conditioned on stump sprouting status at years 1, 5, or 10, the model is useful when preharvest measurements can be made. Thus probability estimates for year 15 can be obtained for the stand before harvest. The same dependent variable and independent variables for year 15 were used as in the 1, 5, or 10 year models (Weigel and Peng 2002). The dependent variable was presence of a dominant or codominant stump sprout 15 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, and interactions between two or more of these independent variables.

Previous research emphasized developing preharvest models, which are not useful for evaluating regeneration after harvesting. To accommodate the need for predicting oak stump sprout performance after harvest, the postharvest models were developed. Postharvest models estimate dominance probabilities of stems at age 15 from stumps that had at least 1 live sprout at age 1, 5, or 10. These models used the same dependent variable as in the preharvest models, but the number of independent variables was reduced so that only stump diameter, species, and site index were required. These models were developed with the understanding that foresters would be examining the harvested stands at 1, 5, or 10 years after harvest, and thus they would not have preharvest tree age or d.b.h. information.

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

RESULTS

Preharvest to Age 15-Year Models

White oak group—The best model (model 1 in table 1) included four predictors: species, the interaction of parent tree age with d.b.h., site index, and the natural log of site index.

The overall significance of model 1 reached a Likelihood Ratio chi-square value of 453.0505 which was significant at $p < 0.0001$ with 4 degrees of freedom. The four predictors were each significant at $p < 0.05$. The goodness-of-fit of model 1 was confirmed by the insignificant Hosmer-Lemeshow (H-L) test (chi-square =8.1702, p =0.4170) (table 1) (Hosmer and Lemeshow 2000).

The overall correct classification rate based on model 1 was 84.0 percent which was an improvement over the chance level. Model 1 was more successful in classifying stumps that did not produce a dominant or codominant stump sprout than those that did. This observation was supported by the magnitude of specificity (94.9 percent), compared with that of sensitivity (34.9 percent). False positive and false negative rates were 39.9 percent and 13.2 percent, respectively.

Chestnut oak had higher dominance probabilities than white oak for a given tree age, d.b.h., and site quality (fig. 1). For example, when age, d.b.h., and site index were held constant at 50 years, 10 cms, and 18 m, respectively, 93 percent of chestnut oak stumps are expected to produce a dominant sprout compared to only 59 percent of white oak stumps at stand age 15 years. Also, lower quality sites (site index 18 m) had higher dominance probabilities than higher quality sites. For instance, the dominance probability for white oak was 59 percent at site index 18 m compared to 52 percent at site index 22 m. This influence of site quality on sprout dominance has been reported for 10-year-old stands (Weigel and Peng 2002). As in previous years, dominance probabilities decreased as oak trees became older and larger in diameter.

Table 1—Preharvest models: logistic regression models for estimating the probability that an oak stump sprout will be dominant or codominant at year 15

Model number	Species	Parameter estimates[a, b] b_0	b_1	b_2	b_3	Model evaluation statistics χ^2	H-L[c]
1	White oak	-77.8896	-0.00148	-2.0931	40.3664	453.0505	8.1702
	Chestnut oak	-75.6726	-0.00148	-2.0931	40.3664	($p < 0.0001$)	(p=0.4170)
2	Red and black oaks	0.3237	-0.00060			122.4697	10.3071
	Scarlet oak	1.7248	-0.00060			($p < 0.0001$)	(p=0.2441)

[a] Regression models are of the form $P = [1+e^{-(b0+b1X1+b2X2+b3X3)}]^{-1}$, where P is the estimated probability that a cut tree will produce a successful (dominant or codominant) stump sprout at age 15: $X1$ = (d.b.h. in cms x tree age); $X2$ is black oak site index in m (where site index is derived from Carmean and others (1989)); $X3$ is the natural log of site index.
[b] All parameter estimates differ significantly from zero at $p < 0.05$.
[c] Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000).

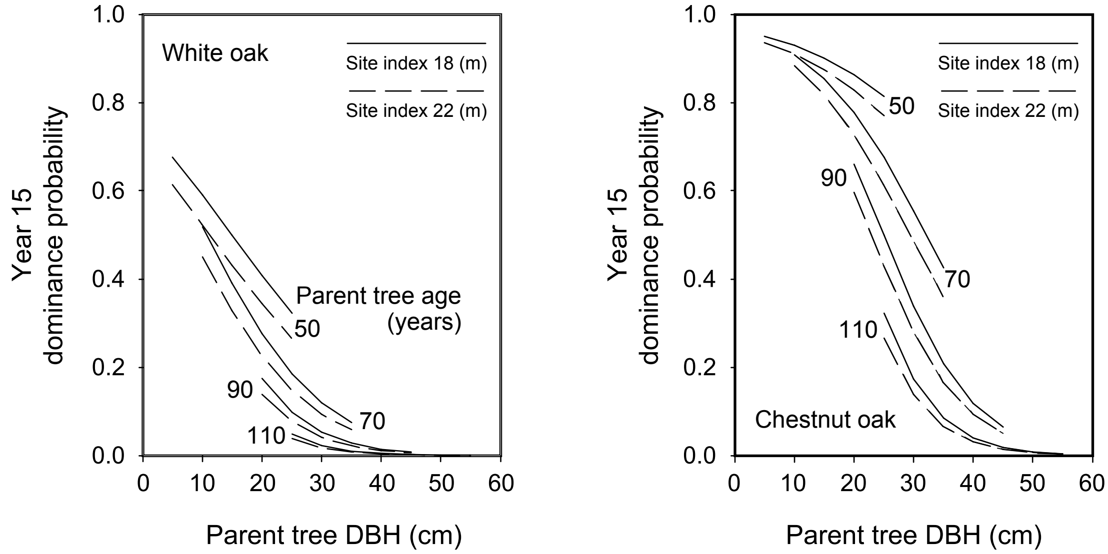


Figure 1—Estimated dominance probability that a white oak or chestnut oak stump will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent age, d.b.h., and black oak site index (model 1, table 1).

Red oak group—The dominance probabilities for northern red oak and black oak did not differ significantly ($p > 0.05$) at year 15. They did, however, differ significantly from scarlet oak ($p < 0.05$). Therefore, the two species were combined in subsequent analysis. Similar to the white oak model, the best red oak year-15 model (model 2 in table 1) included similar variables that were in the year-10 dominance probability model presented by Weigel and Peng (2002). Species and the interaction of parent tree age with d.b.h. were significantly related to future dominance probability in red oak stump sprouts.

The overall significance of model 2 reached a Likelihood Ratio chi-square value of 122.4697 which is significant at $p < 0.0001$ with 2 degrees of freedom. The two predictors were each significant at $p < 0.05$. The goodness-of-fit of model 2 was confirmed by the insignificant H-L test (chi-square = 10.3071, $p = 0.2441$) (table 1).

The overall correct classification rate based on model 2 was 71.6 percent which was an improvement over the chance level. Model 2 correctly classified stumps that did not produce a dominant or codominant stump sprout more frequently than those that did. This observation was supported by the magnitude of specificity (88.9 percent), compared with that of sensitivity (33.0 percent). False positive and false negative rates were 43.0 percent and 25.2 percent, respectively.

In general, scarlet oak trees had higher stump sprout dominance probabilities than northern red oak and black oak combined (fig. 2). Overall dominance probabilities continued to decline from year 1 (Weigel and Peng 2002) to year 15 since harvest. The continued decline in dominance probability indicated that the three species were not able to compete with the surrounding vegetation. Scarlet oak had higher sprouting probabilities at smaller d.b.h.s and younger ages

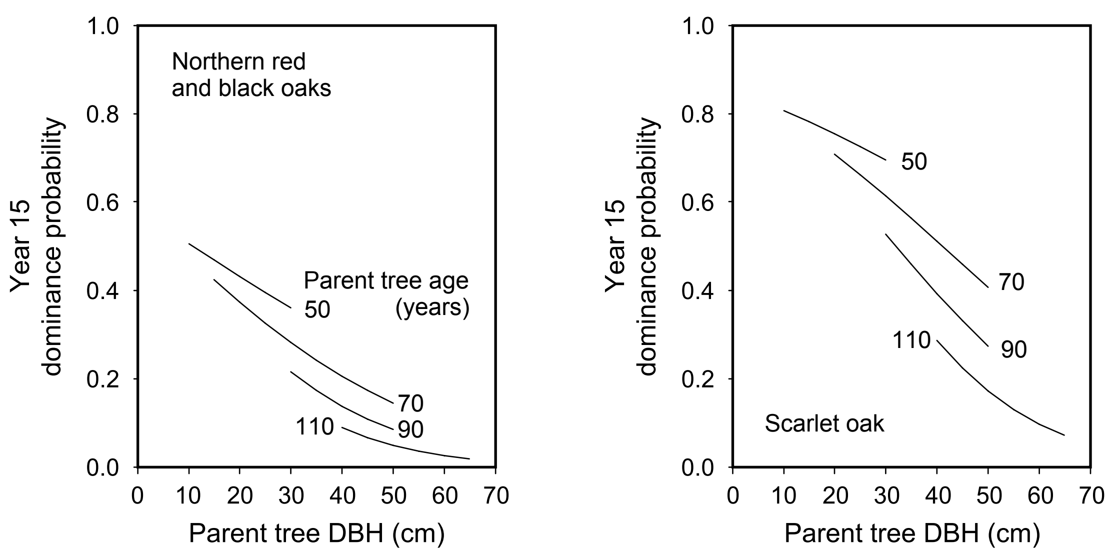


Figure 2—Estimated dominance probability that either a black oak or northern red oak (combined species model 2, table 1), or scarlet oak (model 2, table 1) stump will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent tree age and d.b.h.

than northern red and black oak (81 percent at age 50 and 10 cms d.b.h. versus 51 percent at age 50 and 10 cms d.b.h., respectively).

Postharvest to Age 15 Models

The after harvest models allow foresters to enter a harvested stand 1, 5, or 10 years after harvest to determine the dominance probability at year 15 for those stumps that have sprouts at 1, 5, or 10 years.

White Oak Group

Year 1—At year 1, the success probabilities for white and chestnut oak were not statistically different so they were combined ($p > 0.05$). The significant predictors were diameter at stump height and the interaction of site index with the natural log of site index (model 3 in table 2).

The overall significance of model 3 reached a Likelihood Ratio chi-square value of 103.1926, which is significant at $p < 0.0001$ with 2 degrees of freedom. The two predictors each were significant at $p < 0.05$. The insignificant H-L test (chi-square = 5.2709, $p = 0.7283$) confirmed the goodness-of-fit of model 3 (table 2).

The overall correct classification rate based on model 3 was 69.4 percent, which was an improvement over the chance level. Model 3 more correctly classified stump sprouts whose sprouts were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (77.3 percent), compared with that of specificity (60.1 percent). False positive and false negative rates were 30.6 percent and 30.7 percent, respectively.

On lower-quality sites, oaks were more likely to produce dominant or codominant stems at year 15 than on higher quality sites (fig. 3A). Dominance and codominance probabilities also were greater for smaller diameter stumps. The best results were for 10 cm diameter stumps with site index of 18 m (85 percent), while the lowest dominance probability was for sprouts on 60 cm diameter stumps with site index of 22 m (6 percent). The higher quality sites most likely had more and faster growing competition. Consequently, the oaks were unable to compete as well on higher quality sites, compared to lower quality sites.

Year 5—Three predictors for model 4 were significant ($p < 0.05$): species, diameter at stump height, and the interaction of site index with the natural log of site index (model 4 in table 2).

The overall significance of model 4 reached a Likelihood Ratio chi-square value of 70.6896, which is significant at $p < 0.0001$ with 3 degrees of freedom. The goodness-of-fit of model 4 was confirmed by the insignificant H-L test (chi-square = 8.2287, $p = 0.4115$) (table 2).

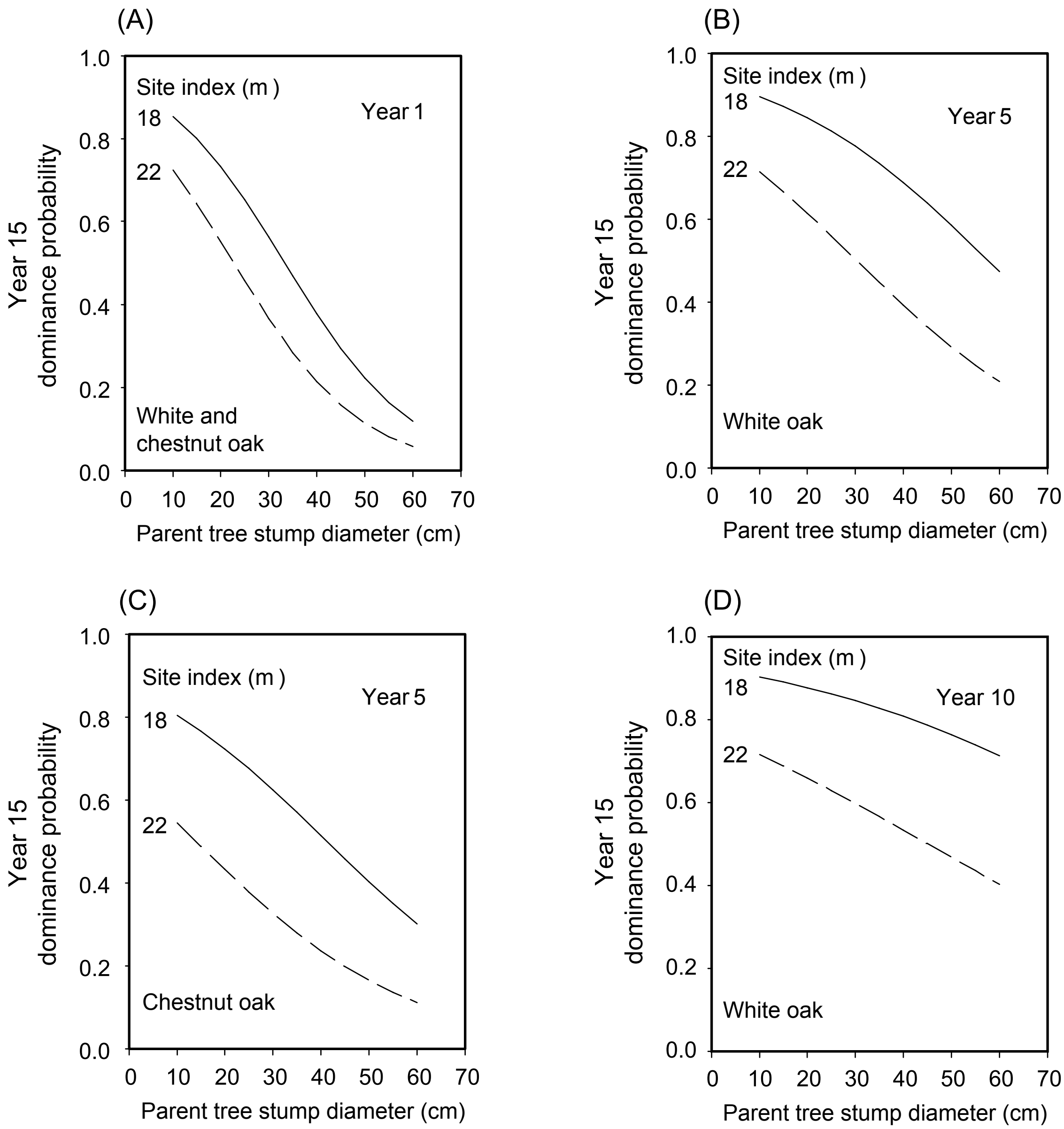
The overall correct classification rate based on model 4 was 70.4 percent, which was an improvement over the chance level. Model 4 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (83.6 percent) compared with that of specificity (44.4 percent). False positive and false negative rates were 25.2 percent and 42.2 percent, respectively.

White oak stump sprouts present at year 5 had higher dominance probabilities at year 15 than corresponding chestnut oak stump sprouts (fig. 3B, 3C). While chestnut oak stumps were more likely to sprout, white oak stumps that did sprout were more successful in becoming dominant or codominant at year 15. As in the year 1 model, the smallest stumps on lower quality sites had the highest dominance rates. The dominance probabilities decreased with increasing parent tree stump diameter and increasing site index.

Table 2—Postharvest models: logistic regression models for estimating the dominance probability that an oak stump sprout will be in either the dominant or codominant crown class at year 15 when sprouts were present at year 1, 5, or 10 after clearcutting

Model number	Species and year	Parameter estimates[a, b] b_0	b_1	b_2	b_3	Model evaluation statistics χ^2	H-L[c]
3	White and chestnut oaks, 1	5.1261	-0.0755	-0.0501		103.1926 ($p < 0.0001$)	5.2709 (p=0.7283)
4	White oak, 5	6.6136	-0.0451	-0.0772		70.6896	8.2287
	Chestnut oak, 5	5.8780	-0.0451	-0.0772		($p < 0.0001$)	(p=0.4115)
5	White oak, 10	6.7320	-0.0263	-0.0816		55.3027	6.1702
	Chestnut oak, 10	5.8194	-0.0263	-0.0816		($p < 0.0001$)	(p=0.6282)
6	Black and red oaks, 1	12.4027	-0.0310		-3.7613	54.4996	6.6816
	Scarlet oak, 1	14.1682	-0.0310		-3.7613	($p < 0.0001$)	(p=0.5713)
7	Black and red oaks, 5	4.9552		-0.0704		50.3936	12.0004
	Scarlet oak, 5	6.2045		-0.0704		($p < 0.0001$)	(p=0.1005)
8	Black and red oaks, 10	4.8243		-0.0649		40.3735	2.5005
	Scarlet oak, 10	6.1680		-0.0649		($p < 0.0001$)	(p=0.9271)

[a] Regression models are of the form $P = [1+e^{-(b0+b1X1+b2X2+b3X3)}]^{-1}$, where P is the estimated dominance probability that a cut tree will produce a stump sprout that is successful (dominant or codominant crown class) at age 15: $X1$ = stump diameter (cms) 15 cms above ground level; $X2$ is black oak site index in m x natural log of site index (where site index is derived from Carmean and others (1989)); $X3$ is the natural log of site index.
[b] All parameter estimates differ significantly from zero at $p < 0.05$.
[c] Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000).



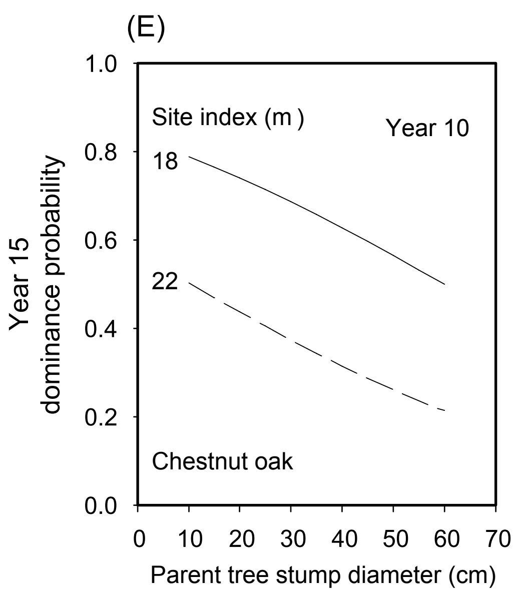


Figure 3—Estimated dominance probability that a white or chestnut oak stump sprout that is present at year 1, 5, or 10 will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent tree stump diameter and site index.

Year 10—Once again as in the year 5 model, chestnut oak differed significantly ($p < 0.05$) from white oak. The same additional predictors were also significant ($p < 0.05$): diameter at stump height and the interaction of site index with the natural log of site index (model 5 in table 2).

The overall significance of model 5 reached a Likelihood Ratio chi-square value of 55.3027, which is significant at $p < 0.0001$ with 3 degrees of freedom. The goodness-of-fit of model 5 was confirmed by the insignificant H-L test (chi-square = 6.1702, $p = 0.6282$) (table 2).

The overall correct classification rate based on model 5 was 72.9 percent, which was an improvement over the chance level. Model 5 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (92.9 percent), compared with that of specificity (20.6 percent). False positive and false negative rates were 24.6 percent and 47.6 percent, respectively.

For white oak, the dominance or codominance probabilities at year 15 were best predicted by the presence of a stump sprout at year 10 (fig. 3D), followed by that at year 5 (fig. 3B), then year 1 (fig. 3A). The trend was more complex for chestnut oak (fig. 3E). At smaller diameters (< 20 cms), the dominance or codominance probabilities at year 15 were best predicted by the presence of a stump sprout at year 1 (fig. 3A), followed by that at year 5 (fig. 3C), then year 10 (fig. 3E). For larger diameters (> 20 cms), the order reversed. The dominance or codominance probability at year 15 was best predicted by the presence of a stump sprout at year 10 (fig. 3E), followed by that at year 5 (fig. 3C), then year 1 (fig. 3A). Sprouts on smaller stumps were unable to compete as well as sprouts on larger diameter stumps.

Red Oak Group

Year 1—Scarlet oak was significantly different ($p < 0.05$) from black and northern red oak and thus modeled separately. The significant predictors ($p < 0.05$) beside species were: diameter at stump height and the natural log of site index (model 6 in table 2).

The overall significance of model 6 reached a Likelihood Ratio chi-square value of 59.4996, which is significant at $p < 0.0001$ with 3 degrees of freedom. The goodness-of-fit of model 6 was confirmed by the insignificant H-L test (chi-square = 6.6816, $p = 0.5713$) (table 2).

The overall correct classification rate based on model 6 was 68.7 percent, which was an improvement over the chance level. Model 6 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (73.2 percent), compared with that of specificity (62.7 percent). False positive and false negative rates were 27.6 percent and 36.4 percent, respectively.

Scarlet oak stump sprouts present at year 1 had much higher probabilities that they would be dominant or codominant at year 15 than did northern red or black oak (fig. 4). Scarlet oak's probabilities ranged from 95 percent (10 cms stump diameter, 18 m site index) to 59 percent (70 cms stump diameter, 22 m site index) compared to 77 percent and 20 percent for the combined northern red and black oak over the same range. Stump sprouts on lower quality sites had higher probabilities for dominance or codominance than those on higher quality sites. As with the white oak group (fig. 3A), red oak group stump sprouts (fig. 4) were able to better compete on the lower quality sites than on the higher quality sites.

Year 5—Scarlet oak differed significantly ($p < 0.05$) from black and northern red oaks. The other significant predictor ($p < 0.05$) was the interaction of site index with the natural log of site index (model 7 in table 2).

The overall significance of model 7 reached a Likelihood Ratio chi-square value of 50.3936, which is significant at $p < 0.0001$ with 2 degrees of freedom. The goodness-of-fit of model 7 was

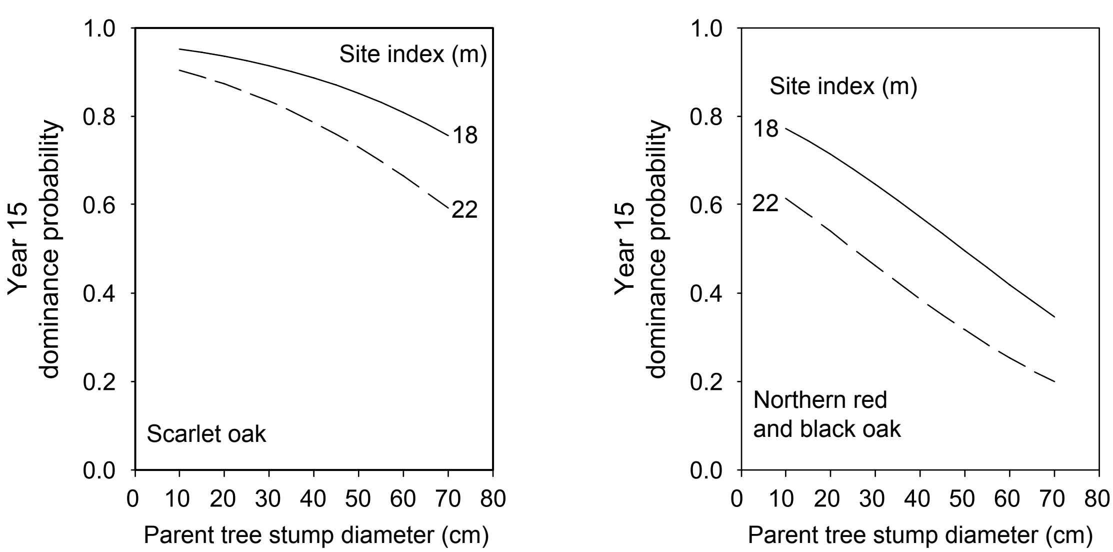


Figure 4—Estimated dominance probability that either a northern red oak or black oak stump sprout, or a scarlet oak stump sprout that is present at year 1 will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent tree stump diameter and site index.

confirmed by the insignificant H-L test (chi-square = 12.0004, $p = 0.1005$) (table 2).

The overall correct classification rate based on model 7 was 74.4 percent, which was an improvement over the chance level. Model 7 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (87.3 percent), compared with that of specificity (46.7 percent). False positive and false negative rates were 22.2 percent and 36.8 percent, respectively.

With diameter at stump height no longer a significant predictor, the simplified model 7 predicted higher probabilities for scarlet oak than northern red or black oaks combined (table 3). Again, lower quality sites resulted in higher probabilities than higher quality sites.

Year 10—As in year 1 and year 5, scarlet oak differed ($p < 0.05$) from black and northern red oak. The other significant predictor ($p < 0.05$) was the interaction of site index with the natural log of site index (model 8 in table 2).

The overall significance of model 8 reached a Likelihood Ratio chi-square value of 40.3735, which is significant at $p < 0.0001$ with 2 degrees of freedom. The goodness-of-fit of model 8 was confirmed by the insignificant H-L test (chi-square = 2.5005, $p = 0.9271$) (table 2).

The overall correct classification rate based on model 8 was 76.2 percent, which was an improvement over the chance level. Model 8 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (87.3 percent), compared with that of specificity (45.8 percent). False positive and false negative rates were 18.5 percent and 43.1 percent, respectively.

Similar to model 7, model 8 was very simple, predicting higher probabilities for scarlet oak than northern red or black oaks combined (table 3). Stump sprouts on lower quality sites performed better than those on higher quality sites. The probabilities for dominance or codominance increased in model 8 from model 7 for any given species and site index. This is a reasonable finding because model 8 was based on a shorter time span than model 7, until year 15. Consequently, the predicted probability that stump sprouts would survive was higher.

Table 3—The estimated dominance probability that a black, red, or scarlet oak stump sprout present at year 5 or 10 will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut

	Site index	
Initial year and species	18	22
Year 5		
scarlet oak	0.927	0.805
northern red & black oaks	0.785	0.542
Year 10		
scarlet oak	0.942	0.853
northern red & black oaks	0.810	0.601

DISCUSSION

The eight models presented in this paper are valuable for predicting the contribution of stump sprouts to forest regeneration. The models allow forest managers to predict the percent of competitive oak stump sprouts 15 years after an even-aged timber harvest. Models 1 and 2 can be used to predict the likelihood of dominant and codominant stump sprouts 15 years after clearcut harvest based on preharvest information. This also permits forest managers to assess the contribution of stump sprouts to the desired stocking of oak advanced reproduction and to adjust stand prescriptions to promote oak advance reproduction by reducing the vigor and abundance of major woody competitors. This analysis highlights the need for developing a prescription for oak underplanting to supplement natural oak advance reproduction where needed (Johnson and others 1986; Weigel and Johnson 1998a, 1998b, 2000).

The remaining six models, models 3 to 8, predict the likelihood of dominant and codominant stump sprouts at year 15 based on their presence at year 1, 5, or 10. Forest managers are then able to assess the need for crop tree release or another type of precommercial thinning to maintain desired stocking of oak. Forest modelers can use these models to better predict and describe the influence of oak stump sprouts on future stands and stand stocking.

Our study differs from many other stump sprout studies by using logistic regression to predict the contribution of stump sprouts to the future stand and hence the sustainability of oak in that stand. This integrates 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 understanding of stump sprouts. Many other reports are for the first 5 to 10 years. Here we examined the fate of oak stump sprouts at age 15, when crown closure and differentiation are occurring, providing a better indication of the reproduction assuming dominance.

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