UTILITY OF TREE CROWN CONDITION INDICATORS TO PREDICT TREE SURVIVAL USING REMEASURED FOREST INVENTORY AND ANALYSIS DATA

Randall S. Morin, Jim Steinman, and KaDonna C. Randolph[1]

Abstract.—The condition of tree crowns is an important indicator of tree and forest health. Crown conditions have been evaluated during surveys of Forest Inventory and Analysis (FIA) Phase 3 (P3) plots since 1999. In this study, remeasured data from 39,357 trees in the northern United States were used to assess the probability of survival among various tree species using the suite of crown condition variables. Logistic regression procedures were employed to assess the importance of individual crown condition variables alone and in combination for predicting tree survival. Results of the regression analyses indicated that crown dieback was the most important crown condition variable for predicting tree survival for all species combined and for the 10 individual species in the study. Additionally, one-way analysis of variance (ANOVA) results identified differences among the ability of different tree species to survive varying levels of crown dieback. The results provide statistical evidence for selecting crown dieback as one of the crown condition variables to be collected on a subset of Phase 2 plots (P2+) starting in 2012.

INTRODUCTION

An important indicator of the health of a tree is the condition of its crown. The U.S. Forest Service Forest Inventory and Analysis (FIA) Program uses visual assessments of tree crown condition to monitor trends in forest health. Trees with vigorous, healthy crowns tend to have higher growth rates. By contrast, trees with damaged or degraded crowns have a reduced capacity for photosynthesis and slower growth rates. Many stressors can cause crown degradation including insects, disease, weather events, senescence, and competition or other stand conditions (Kenk 1993). Additionally, trees with unhealthy crowns are more susceptible to mortality (Kulman 1971, Lawrence et al. 2002).

Assessments of tree crown conditions have been conducted as part of the U.S. Forest Service Forest Health Monitoring (FHM) Program since 1990 and as a part of FIA since 1999 (Riiters and Tkacz 2004). Preliminary analyses of crown condition data through the FHM program demonstrated the data's utility in classifying tree health and likelihood of survivorship, with crown dieback as the best indicator of crown condition (Steinman 2000). The crown health indicators for live overstory trees (d.b.h. ≥ 5.0 in) that have been consistently collected since 2001 are uncompacted live crown ratio (UNCR), crown light exposure (CL), crown density (CDEN), crown dieback (CDBK), and foliage transparency (TRANS) (Schomaker et al. 2007). Results from crown condition data have been presented as frequency statistics for individual crown indicators (e.g., Randolph et al. 2010), summaries of tree health by species in FIA

[1] Research Forester (RSM), Northern Research Station, 11 Campus Blvd., Suite 200, Newtown Square, PA 19073; Forest Health Coordinator (JS), U.S. Forest Service, Northeastern Area State & Private Forestry; Mathematical Statistician (KCR), U.S. Forest Service, Southern Research Station. RSM is corresponding author: to contact, call 610-557-4054 or email at rsmorin@fs.fed.us.

5-year reports (e.g., Widmann et al. 2012), and more specific analyses investigating changes in forest health (e.g., Morin et al. 2004, Will-Wolf and Jovan 2009).

To increase the efficiency of field data collection, FIA is evaluating the analytical utility of numerous variables such as collected as indicators of forest health. Here, we assess the importance of crown indicators individually and in combination for predicting tree survival; the study objective is to provide statistical evidence for choosing crown condition indicators for continued inclusion in FIA data collection. This study focuses only on the utility of the crown condition variables for predicting tree survival and does not explore other applications.

METHODS

A three-phase forest inventory and monitoring effort is implemented by the FIA program within the U.S. Forest Service (Bechtold and Patterson 2005). Phase 1 (P1) is the development of a post-stratification scheme using remotely-sensed data. The second phase (P2) entails measuring sample plots on the ground for the usual suite of forest mensuration variables such as tree species, d.b.h., height, forest type, stand age, etc. Overstory trees (d.b.h. $\geq$ 5.0 in.) are measured on four 24-ft radius subplots; saplings (1.0 $\leq$ d.b.h. < 5.0 in.) are recorded on four microplots of 6.8-ft radius each. Phase three (P3) occurs on a 1/16th subset of the P2 plots, where additional data are collected on forest health indicators, including the crown condition variables.

In this study, remeasured data from 39,357 trees in the northern United States (2001-2005 to 2006-2010) were used to assess the probability of survival among various tree species using the suite of crown condition variables. Tree species with at least 1,000 remeasured trees were included in the individual species models. Survival of an individual tree is a discrete event where each remeasured tree can only have the value of 1 (live) or 2 (dead); removed trees were not included.

The probability of survival was modeled using the logistic equation:

$$P(1) = 1 / (1 + e(b'x))$$

where $b'x$ is a linear combination of parameters b and independent variables x, and e is the base of the natural logarithm. The PROC LOGISTIC procedure (SAS Institute 2009) was used to estimate the parameters of the logistic regression using maximum likelihood methods. Additionally, one-way analysis of variance (ANOVA) tests were used to test the effect of CDBK on tree survival. Tests were conducted for all trees combined and for five the most abundant species individually: red maple, sugar maple, northern white-cedar, balsam fir, and quaking aspen. The Student-Newman-Kuels test was employed to determine significant differences in survivorship among CDBK classes.

RESULTS

All parameters listed in Table 1 are significant (α=0.05) and many are highly significant (p-value <0.0001 indicated by an *). For all species combined, we found all crown variables to be highly significant in predicting survival; for each species individually, we found CDBK to be highly significant. The area under the receiver operating characteristic (ROC) curve is provided for the classification models as an indicator of classification accuracy (Table 2). To judge the relative importance of the variables, standard errors are listed in Table 1 and Chi-square values are given in Table 2.

Parameter estimates conform to expectations in nearly all cases. The coefficient of CDBK is negative in all cases (Table 1), indicating decreasing survival with increasing CDBK. Similarly, the coefficient of TRANS is negative in the most significant cases, indicating decreasing survival with increasing TRANS. The coefficients of the other variables are all positive, except for CL in the models for balsam fir and eastern hemlock (Table 1), which indicates increasing survival with increases in those variables.

Table 1.—Estimated parameters for survival models. All parameters are significant at the 95 percent level of confidence (α = 0.05)

Species	Sample Size (n)	Variable				
		CDBK	UNCR	CDEN	CL	TRANS
All species	39,357	-0.0371 (0.00185)*	0.0165 (0.00113)*	0.0290 (0.00168)*	0.0821 (0.0180)*	-0.0118 (0.00183)*
Red maple	4,459	-0.0464 (0.00672)*	0.0340 (0.00486)*	0.0356 (0.00582)*	0.5933 (0.0978)*	0.0221 (0.00985)
Sugar maple	3,003	-0.0423 (0.00945)*	0.0219 (0.00651)	0.0525 (0.00900)*	0.4488 (0.1291)	0.0308 (0.0153)
Northern white-cedar	1,962	-0.0436 (0.00594)*			0.3484 (0.1054)	
Balsam fir	1,603	-0.1127 (0.0166)*	0.0260 (0.00361)*	0.0264 (0.00560)*	-0.1965(0.0483)*	
Quaking aspen	1,536	-0.0622 (0.0109)*	0.0233 (0.00585)*	0.0320 (0.00556)*		
White oak	1,336	-0.0775 (0.0124)*			0.4609 (0.1686)	
Paper birch	1,290	-0.0265 (0.00754)		0.0268 (0.00613)*	0.2979 (0.0725)*	
Northern red oak	1,092	-0.0655 (0.0150)*			0.5081 (0.1727)	-0.0474 (0.00779)*
Eastern white pine	1,027	0.0661 (0.0149)*	0.0275 (0.00748)		0.4159 (0.1391)	
Eastern hemlock	1,009	-0.0908 (0.0178)*				

CDBK is crown dieback, UNCR is uncompacted live crown ratio, CDEN is crown density, CL is crown light exposure, and TRANS is foliage transparency.
Standard errors are given in parentheses.
* indicates significance (p <0.0001).

Table 2.—Receiver operating characteristic (ROC) curve area and Chi-square values for the parameter estimates in Table 1

Species	ROC Curve Area	Chi-Square Statistic Variable				
		CDBK	UNCR	CDEN	CL	TRANS
All species	0.7176	403	215	298	21	42
Red maple	0.8059	48	49	37	37	5
Sugar maple	0.8015	20	11	34	12	4
Northern white-cedar	0.7200	54			11	
Balsam fir	0.7557	46	52	22	17	
Quaking aspen	0.7075	32	16	33		
White oak	0.7532	39			7	
Paper birch	0.7015	12		19	17	
Northern red oak	0.7805	19			9	37
Eastern white pine	0.7699	20	14		9	
Eastern hemlock	0.7340	26				

CDBK is crown dieback, UNCR is uncompacted live crown ratio, CDEN is crown density, CL is crown light exposure, and TRANS is foliage transparency.

The Chi-square statistics in Table 2 reveal that the most important variable for all species combined and most species individually is CDBK. The second most important variable for all species combined is CDEN, and it is also the most important for sugar maple, quaking aspen, and paper birch. Among individual species the rankings of importance of the variables is inconsistent except that CDBK is the most important in most models.

One-way ANOVA analyses indicate that the proportion of trees that survived until remeasurement decreased as CDBK increased (Figs. 1 and 2). For all species combined, the proportion of surviving trees for each CDBK class is significantly different from all others. For most individual species, the proportion of survivors in the greater than 50 percent CDBK class is significantly different from all other classes, but for balsam fir and quaking aspen, proportion of surviving trees in the 26 to 50 CDBK class is similar to the greater than 50 percent CDBK class. Based on the proportion of surviving trees in the 26 to 50 and greater than 50 CDBK classes, sugar maple and northern white-cedar appear to be able to tolerate high levels of CDK better than red maple, balsam fir, and quaking aspen (Fig. 2).

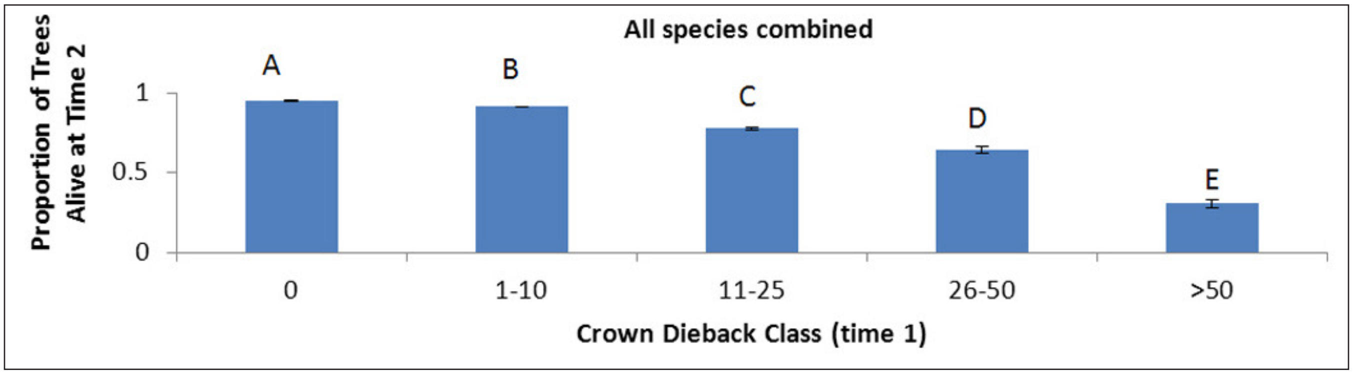

Figure 1.—Proportion of trees that were alive at remeasurement in crown dieback classes from time 1 measurement. Bars labeled with the same letter (A-E) are not significantly different (ANOVA, Student-Newman-Keuls test, a = 0.05).

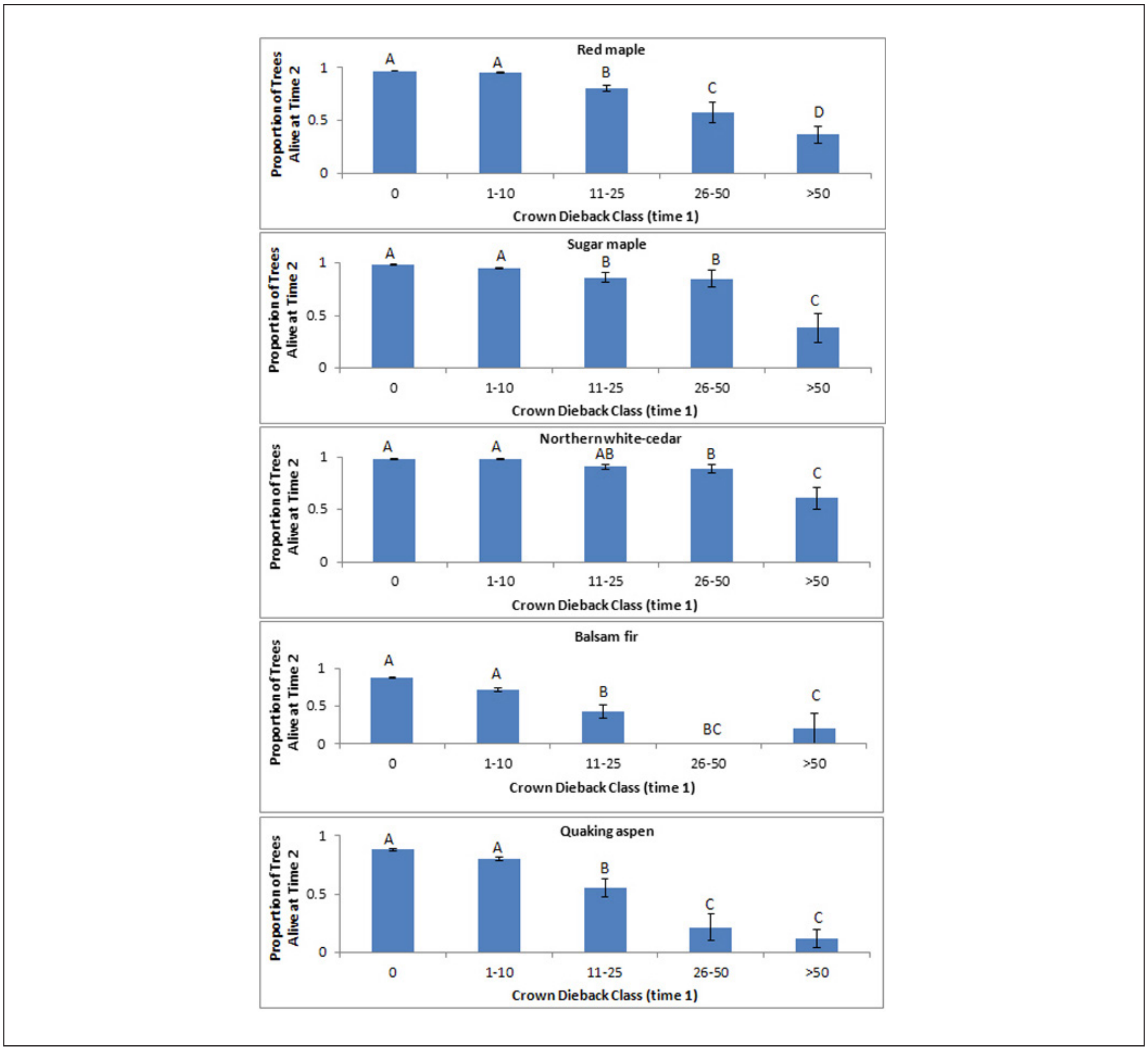

Figure 2.—Proportion of trees that were alive at remeasurement in crown dieback classes from time 1 measurement, by species. Bars labeled with the same letter (A-E) are not significantly different (ANOVA, Student-Newman-Keuls test, a = 0.05).

DISCUSSION

Results of the logistic regression analysis for all species combined indicate that the crown condition variables are all significant predictors of survival, but CDBK was the most important variable. It should be noted, however, that even though UNCR was not a significant predictor of survivability for all species, by way of establishing the base of the live crown UNCR forms the basis for assessing all of the other crown condition variables and therefore must always be assessed. Additionally, results of the logistic regression analyses for individual species indicate that CDBK is the only crown condition variable that is a significant predictor of survival for all 10 species in this study. Based on differences in the proportion of survivors among individual species, CDBK is also a useful metric for assessing the ability of different species to tolerate and survive varying levels of crown health.

The results of this study provide statistical evidence for selecting CDBK as one of the crown condition variables to be collected on a subset of Phase 2 plots (termed P2+) beginning in 2012. The P2+ sample will be larger than the P3 sample. Therefore, moving the CDBK indicator from P3 to P2+ will increase statistical power for this line of research. Additional research that is suggested by the results of this study include looking at successive measures of CDBK on surviving trees to determine whether crown health recovery has occurred and predicting future mortality based on CDBK values. There is also great potential in using crown dieback as a means to parse FIA reporting attributes (e.g., volume) of live trees into healthy and unhealthy categories.

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