CHAPTER 13

Tree Crown Condition

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The crown-condition indicator was originally developed in 1990 to monitor tree crown health. The indicator presently consists of seven "absolute" variables recorded in the field (sapling vigor class, uncompacted live crown ratio, crown light exposure, crown position, crown density, foliage transparency, and crown dieback), and four "composite" variables formulated from multiple crown dimensions (crown volume, crown surface area, crown shape, and crown efficiency). Detailed descriptions of the crown-condition indicator are available in Schomaker and others (2007) and on the Web at http://srsfia2.fs.fed.us/crowns/. Between 1990 and 1999, the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, collected crown data as part of the FHM Detection Monitoring (DM) system (Riitters and Tkacz 2004). In 2000, upon integration of the FHM plot system with the phase 3 plot network (Bechtold and Patterson 2005) of the Forest Inventory and Analysis (FIA) Program of the Forest Service, FIA assumed responsibility for collecting crown data.

The FHM program funded four Evaluation Monitoring (EM) projects associated with the crown-condition indicator. All of these projects originated from potential problems noticed during analysis of DM plot data.

Project NE-EM-98-02: Evaluation of Unexplained Defoliation of Ash and Other Hardwoods

The 1997 FHM aerial detection survey in Vermont identified more than 20 sites (totaling about 17,000 acres) with trees exhibiting thin crowns, brown foliage, and leaf cast. White ash (*Fraxinus americana*) was the most severely affected species, but similar symptoms also were observed for white birch (*Betula papyrifera*), beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), striped maple (*Acer pennsylvanicum*), red oak (*Quercus rubra*), and ironwood (*Ostrya virginiana*).

EM Project NE-EM-98-02 was funded to monitor the situation more closely during the next 3 years. Seven of the problem areas identified in 1997 were reexamined by ground crews in 1998, 1999, and 2000. The follow-up checks revealed that white ash crown dieback and foliage transparency levels were higher than average on these sites, but the foliage browning and defoliation observed in 1997 did not recur. No significant causal agents were detected on symptomatic tissue examined in the laboratory. In addition to improvements on sites defoliated in 1997, statewide aerial surveys conducted during the follow-up period did not detect defoliation at any new locations.

This project concluded that the symptoms observed in 1997 were likely related to poor water availability caused by dry weather, shallow soils, exposed sites, and tree wounding. White ash was affected more severely than other species because the sites exhibiting symptoms were located at the edge of its natural range, where the species is more vulnerable to stress.

Project NC-EM-03-01: Evaluation of Increased Crown Dieback and Reduced Foliage Transparency within the Laurentian Mixed Forest

Detection Monitoring plots were first established in the three Upper Great Lake (UGL) States of Michigan, Minnesota, and Wisconsin in 1994. Ambrose (2001) observed that foliage transparency and crown dieback data in northern Minnesota and Wisconsin were relatively high and became progressively worse between 1994 and 1998. He concluded that the observed changes were attributable to chronic stressors.

FHM aerial detection surveys identified 125,000 acres of mapped jack pine defoliation and 210,000 acres of spruce budworm defoliation in the UGL region in 1997. Because the crown analysis by Ambrose (2001) coincided with known episodes of insect defoliation, Project NC-EM-03-01 was launched to examine the conclusion that deteriorating crown conditions in UGL forests were attributable to chronic stressors rather than single insect or disease episodes. A Before-After-Control-Impact (BACI) analysis was conducted to identify effects associated with the two insect outbreaks.

The BACI design used for this study required measurements from before and after the time of impact on a set of impacted

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sites, as well as a set of non-impacted (control) sites. Because the study was intended to evaluate the effect of single-event episodes, the analysis was restricted to plots that experienced low levels of insect defoliation before and after the defoliation event in 1997. FHM plots located in or near the mapped defoliation areas were used to represent impact sites. Each impacted plot was then paired with a similar plot from outside the impact zones; plot cohorts selected from beyond the impact zone thus represented control plots. The year of outbreak (1997) was used to split the available data into before- and after-impact groups: 1994-96 versus 1997-99.

After the plot selection criteria were applied to the dataset, only two plots met the selection criteria. Because so few DM plots occurred in the defoliated areas, the BACI analysis was halted and the project concluded that the defoliation events mapped in 1997 were not responsible for any crown deterioration observed in DM plots in UGL forests between 1994 and 1999.

Project SO-EM-04-04: A Spatial Cluster of Poor Crown Conditions: Evaluating Results from Crown Indicators and Spatial Scan Statistics

The Kulldorff scan statistic (Kulldorff 1997) was originally developed to test for randomness of human disease occurrence in the spatial and temporal domains. When applied to FIA phase 3 crown data collected in 2000 and 2001, statistically significant clusters of trees with relatively small crown volumes were identified near Augusta, GA (Bechtold and Coulston 2005, Conner and others 2004). Project SO-EM-04-04 was funded to further investigate the situation through additional analysis of the plot data, combined with a field visit to search for physical evidence of a problem.

Additional testing to check individual crown dimensions (e.g., crown density, crown diameter, and crown length) for spatial patterns did not yield the consistent geographic clustering observed with crown volumes (Bechtold and others 2005). Further evaluation of the crown volumes in the original clusters with more conventional t-tests failed to confirm the results of the spatial scan statistic. The subsequent field inspection of sampled trees in the suspect area revealed no visual evidence of a problem.

The EM study concluded that statistically significant clustering detected in the original analysis most likely resulted from:

- the use of statistical thresholds (as opposed to biological thresholds) to identify trees with poor crowns. Trees with crown volumes in the bottom 5th percentile (after adjustment for species and diameter at breast height) were assumed to have a problem. Field inspection of these trees revealed no visual evidence of a problem.
- adaptation of the Kulldorff scan statistic to a forest health application. In particular, the data had to be transformed from continuous measurements to binary counts, and it was not clear whether tree-level or plot-level observations should be used. These modifications may have rendered the scan statistic prone to Type 1 error (i.e., false positives).
- the estimation of crown diameters with models. Crown diameters, which are needed to compute composite crown volumes, are not measured in the field. There is no guarantee that a model developed from one dataset will be unbiased for another, and the crown-diameter predictions used for this analysis were demonstrably biased for the trees in the study area. The lack of measured crown diameters hampers the use of composite crown variables.

Project Number NE-EM-07-01: Evaluating Elevated Levels of Crown Dieback Among Northern White-Cedar (*Thuja occidentalis*) Trees in Maine and Michigan

Spatial clusters of plots where the crown dieback of northern white cedars (*Thuja occidentalis*) averaged 10 percent or more were discovered in Maine and northern Michigan when analyzing FIA phase 3 crown data for the FHM 2006 national technical report (Randolph 2009). High averages for northern white cedar (NWC) were not necessarily accompanied by elevated averages among the hardwoods and other softwoods on the same plots.

The first stage of this EM study was accomplished during the summer of 2007, when some of the plots with elevated levels of NWC dieback were revisited and inspected for additional evidence of a problem (Randolph and others 2008). The field visits were successful in verifying elevated levels of NWC dieback, but no single cause was apparent. A variety of factors had contributed to elevated dieback including tree age, weather (e.g., wind, flooding), soil conditions, and past harvesting practices.

The second stage of this project involved the statistical analysis of NWC data collected by the FIA and FHM programs, ranging as far back as 1990. Analyses are ongoing at the time of this writing, but preliminary results (Randolph and others 2009) indicate that:

- when significant differences were found among species groups, NWC crown dieback was higher than dieback levels of other softwood species, and lower than the dieback levels of hardwood species.
- there has been no statistically significant increase in NWC crown dieback in either State during the timeframe examined in the study.

Additional questions about correlations between NWC dieback and stand and weather conditions continue to be investigated.

During this analysis, opportunities to improve the crown-condition indicator were noted. Many leaning trees were encountered during the field visit, but lean angle is not currently recorded on FIA plots. This metric could be used to identify stressed trees, especially with respect to damage after harvesting, hurricanes, tornados, floods, or ice storms. The measure of dieback is not cumulative, which could have a confounding effect on the analysis of temporal trends. As dead leaves, twigs, and branches disintegrate, they are no longer classified as dieback, and therefore, the measure of dieback on a given tree may actually improve as its crown deteriorates. Also, as trees with excessive dieback die and drop out of the inventory, average plot-level estimates of dieback could improve.

Utilization of Project Results

The EM projects discussed here found no unexplained or unusual problems affecting tree crown condition. Detection Monitoring identified phenomena deemed worthy of further evaluation, and these projects were in response to those detections. Had any of these phenomena been new or important issues, these evaluations would have provided confirmation and triggered further necessary actions. In addition, these investigations suggested where the sampling and analysis methodology associated with the crown-condition indicator might be improved. These suggestions, some of which can be applied to other DM indicators, are discussed in the next section.

Suggestions for Further Investigation

The primary research need for the crown-condition indicator is the establishment of biological thresholds. All the crown-related projects discussed above would have greatly benefited from this information, and at least some may not have been necessary. Unfortunately, the point at which a tree begins to decline is difficult to pinpoint. The task is further complicated because the thresholds are expected to vary by species. Schomaker and others (2007) have given some consideration as to how such research might proceed. This task will become more feasible as individual trees are tracked further through time, and the crown conditions preceding their eventual decline and death are better known.

The further development of spatial scan tools is another fruitful area of research that would not only improve analyses of the crown-condition indicator, but most other FIA phase 3 indicators as well. Problems encountered with the Kulldorff scan statistic used in Project SO-EM-04-04 need to be rectified. Work in this area is currently proceeding with funding designated for FHM analysis and reporting (Coulston and others 2008). This line of research should be supported until suitable geographic surveillance tools are developed and transferred to FHM analysts.

Care must be exercised when using the DM plot network for EM studies involving small areas, such as those sometimes mapped during aerial detection surveys. At the base sampling intensity, each phase 3 FIA DM plot represents approximately 96,000 acres. It is therefore not surprising that only 2 plots were located in the 335,000 defoliated acres examined under Project NC-EM-03-01. As pointed out by the investigators, the coarseness of the aerial maps and the perturbation of plot coordinates (McRoberts and others 2005) also create uncertainty about whether or not a plot is actually located in an impact area. Investigators should plan on using auxiliary data and/or supplementary sampling (as was done for Project NE-EM-98-02) when focusing on small areas. Rough guidelines from statistical power analyses conducted by Bechtold and others (2009) suggest that crown studies depending on statistical analyses involving less than 100 plots (or 50 paired plots) should be scrutinized to ensure there are enough samples to conduct the analysis.

Finally, crown-condition data issues that have become apparent during analysis deserve further attention. Failure to measure crown diameters essentially precludes the use of composite crown indicators. As such, there is currently no reliable way to monitor changes in tree crown volumes. Bechtold and others (2002) discuss several techniques that yield acceptable crown-diameter data, including ocular estimation. The utility of a lean-angle variable, as suggested in Project NE-EM-07-01, deserves further investigation. Research into methods that yield cumulative measures of crown dieback, up to (and possibly including) the point of tree mortality, would also be worthwhile.

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