

# From Detection Monitoring to Evaluation Monitoring—A Case Study Involving Crown Dieback in Northern White-Cedar

KaDonna Randolph<sup>1</sup>  
William A. Bechtold<sup>2</sup>  
Randall S. Morin<sup>3</sup>  
Stanley J. Zarnoch<sup>4</sup>

**Abstract:** *The Forest Inventory and Analysis (FIA) Phase 3 plot network is a crucial part of the U.S. Forest Health Monitoring program's detection monitoring system, where select indicators are monitored for signals that may indicate deteriorating forest health. When a negative signal is identified, evaluation monitoring provides a mechanism whereby a potential problem can be further investigated. Elevated crown dieback was observed among northern white-cedar (*Thuja occidentalis* L.) trees in Maine and Michigan on FIA Phase 3 plots measured between 2000 and 2004. We present results of this potential problem through the detection and evaluation monitoring process. We discuss the advantages and disadvantages of using FIA data to frame the problem, and share lessons learned from all phases of the project—including problem identification, project implementation, and results presentation.*

**Keywords:** Crown condition, FHM, FIA, forest health, Maine, Michigan, *Thuja occidentalis*.

## Introduction

The U.S. Forest Service, Forest Health Monitoring (FHM) program institutes a tiered strategy to monitor the status, changes, and trends in forest health across the United States (Riitters and Tkacz 2004). The first tier, known as detection monitoring, evaluates the status and change in the condition of forested ecosystems through analysis of data collected from nationally standardized aerial and ground surveys. The second tier, known as evaluation monitoring (EM), seeks to determine the extent, severity, and cause of any deteriorating forest conditions observed through detection monitoring. A third tier, intensive site monitoring,

---

<sup>1</sup> United States Forest Service; Southern Research Station; Forest Inventory and Analysis; 4700 Old Kingston Pike; Knoxville, TN 37919 USA; krandolph@fs.fed.us

<sup>2</sup> United States Forest Service; Southern Research Station; 200 Weaver Blvd; Asheville, NC 28804 USA; wabechtold@fs.fed.us

<sup>3</sup> United States Forest Service; Northern Research Station; Forest Inventory and Analysis; 11 Campus Drive, Suite 200; Newtown Square, PA 19073 USA; rsmorin@fs.fed.us

<sup>4</sup> United States Forest Service; Southern Research Station; 200 Weaver Blvd; Asheville, NC 28804 USA; szarnoch@fs.fed.us

investigates cause-effect relationships by linking detection monitoring to ecosystem process studies (U.S. Department of Agriculture 2003). Detection monitoring activities were begun in 1990 by FHM. In 2000, the network of FHM detection monitoring plots was integrated into the U.S. Forest Service, Forest Inventory and Analysis (FIA) program. Now known as Phase 3 plots, the detection monitoring plots are a subset of FIA's total network of Phase 2 ground plots (McRoberts 2005). In addition to these plots, the U.S. Forest Service, Forest Health Protection (FHP) unit also participates in detection monitoring by conducting annual aerial and ground-based surveys for forest insects, disease, and invasive plants.

Our objectives for this study were to describe the EM process, describe the role of FIA in EM, and review our experience with an EM project that originated from an unexpected trend observed in FIA Phase 3 data.

## **FHM Evaluation Monitoring Process**

The FHM program funds EM projects under two broad categories: base and fire plan. The purpose of base EM projects is to investigate any issues or concerns identified during detection monitoring. The purpose of fire plan EM projects is to investigate and explain the extent, severity, and/or cause of a fire-related phenomenon observed during detection monitoring. EM proposals are first screened by regional FHM managers and then forwarded to a national selection committee, which includes the FHM Program Manager and representatives from the Forest Service's National Forest System, State and Private Forestry, and Research and Development programs. Selection criteria include:

- linkage to detection monitoring,
- significance in terms of geographic scale,
- biological impact and/or political importance, and
- feasibility of successful project completion within 1 to 3 years.

Listings and descriptions of EM projects funded since 2004 are posted at [http://fhm.fs.fed.us/em/funded/proposals\\_base.shtm](http://fhm.fs.fed.us/em/funded/proposals_base.shtm).

## **Problem Identification and Presentation of Results**

National reports on forest health conditions are produced annually by the FHM program (e.g., Ambrose and Conkling 2007). State-level reports that include forest health indicators are produced by FIA on a 5-year basis (e.g. Turner and others 2008). Annual Forest Health Highlights (e.g., Washington State Department of Natural Resources 2007) are produced for each State by FHP staff and State partners. All of these reports are potential sources for identifying unusual or deteriorating forest health conditions that require further study.

Failure to identify a problem that truly exists has the potential for disaster. Thus, the EM process allows a wide range of potential forest health problems to be examined so that serious problems are not overlooked. Successful EM projects include not only those that confirm a significant forest health problem but those that nullify a suspected forest health problem as well. Both results improve knowledge of the resource in question and, in the case of confirmation, provide managers an opportunity to mitigate the threat.

Once an EM project is funded, the FHM management team requires annual progress reports. Results based on these reports are also presented in poster format at annual FHM working group meetings. Beginning with the 2008 report, summaries of recently completed EM projects will be included in the FHM national reports. This provides a structured forum for EM results and guarantees a published outlet to EM investigators. The format for these summaries is similar to an extended abstract, but it also allows one or two tables or figures per summary. This abbreviated format is not expected to interfere with other presentation and publication outlets, which are encouraged as well.

## **Role of FIA**

Using FIA data as the basis for EM projects has several benefits. First, researchers have access to a large, long-term, broad-scale dataset. FIA has been conducting inventories of the Nation's forest land for over 70 years. Up through the late 1990s, statewide inventories focused primarily on timber-based variables and were completed approximately once every 6 to 8 years in the South and 11 to 18 years in the rest of the country (Gillespie 1999). Since then FIA has switched to a panelized annual inventory system (Bechtold and Patterson 2005) and worked to reduce inventory cycles to 5 years in the East and 10 years in the West. Further, the integration of the FHM detection monitoring plots in 2000 broadened FIA's survey to include more nontimber variables. These FIA data, including the FHM detection monitoring data, are available to the public through FIA's Spatial Data Service (SDS) centers or online databases at <http://www.fia.fs.fed.us/tools-data/default.asp>.

All FHM data from 1990 to 1999 and FIA data from 2000 and beyond are available for analysis. One obstacle to integrating these data, however, is that even though FHM plots were merged into the FIA Phase 3 network, changes in protocols make it difficult to follow individual trees across the 2000 integration date. For many plots, algorithms must be used to match trees. Population inferences based on matched FHM-FIA detection monitoring data may be tenuous because there is a question about the extent to which the subsample of matched trees accurately represents the population due to the inability to match all trees.

A second benefit of using the FIA data is repeated measurements of permanent plots. These repeated measurements allow for longitudinal studies at the plot or

individual tree level. Though such studies may be complicated by missing or temporally irregular observations, most current statistical software packages can overcome this difficulty with careful model specifications. Almost all of the detection monitoring plots were measured more than once between 1990 and 1999, and since 2000 most of the FIA Phase 3 plots in the Eastern United States also have been remeasured. Within a few years, States in the Western United States will begin remeasurement as well.

A third benefit to using FIA data for detection monitoring and EM is that each plot is georeferenced with latitude and longitude coordinates. This allows researchers to look for changes and trends across space as well as over time. There are, however, strict regulations regarding the release of plot locations. Exact locations are protected as confidential information under the Food Security Act of 1986, Public Law 99-198 [H.R. 2100], so coordinates that accompany the publicly distributed plot data have been perturbed (McRoberts and others 2005). Researchers requiring exact plot locations should contact SDS for possible accommodation before submitting EM project proposals.

## **Experiences with EM Project NE-07-01**

### **Discovering Dieback among Northern White-Cedar**

As part of the 2006 national FHM report, spatial patterns of crown conditions by species group were evaluated to identify potential forest health problems within the coterminous United States (Randolph in press). Crown density, foliage transparency, and crown dieback averages were calculated by plot for individual species groups if the plot contained five or more trees (diameter  $\geq 5.0$  inches) in a given species group. All available data from FIA Phase 3 plots measured between 2000 and 2004 were included in the analyses. Spatial clusters of plots with high crown dieback, high foliage transparency, or low crown density averages relative to the other plots were identified as areas with potential forest health problems. Clusters of plots with northern white-cedar (*Thuja occidentalis* L.) crown dieback<sup>1</sup> averaging 10 percent or more were discovered in Maine and northern Michigan. Plot averages for northern white-cedar dieback met this threshold for 33 percent and 19 percent of the plots with at least five northern white-cedar trees in Maine and Michigan, respectively. Such elevated levels of dieback were of concern because unlike hardwood trees, conifers often do not exhibit crown dieback unless the tree is under serious stress (Millers and others 1992).

In general, northern white-cedar is a species resistant to serious injury from insects and disease, so reasons for the elevated levels of dieback were unclear. Local foresters, entomologists, and pathologists were questioned about potential

---

<sup>1</sup> Crown dieback is defined as “recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds toward the trunk” (Schomaker and others 2007).

causes. Most had not noticed a deterioration of northern white-cedar, though its general poor form and harsh growing conditions were often cited. Drought was mentioned as a suspected cause in Maine, where one of the worst droughts ever recorded there occurred between 1999 and 2002 (Lombard 2004). Dry conditions also occurred between 1998 and 2002 in the Upper Peninsula and northern Lower Peninsula of Michigan (Steinman 2004). Thus, drought was considered to be a potential explanation. Other suggested causes included unfavorable winter weather (Johnston 1990), other severe weather events, and silvicultural practices.

Stand-level condition data (e.g. disturbances, stand age, presence of water) were examined for correlations that might provide an explanation for the elevated levels of crown dieback. Residual stress from harvesting and wind disturbances explained the elevated dieback levels on two plots in Maine. However, harvesting and detrimental weather events did not seem broadly applicable reasons for the elevated levels of crown dieback.

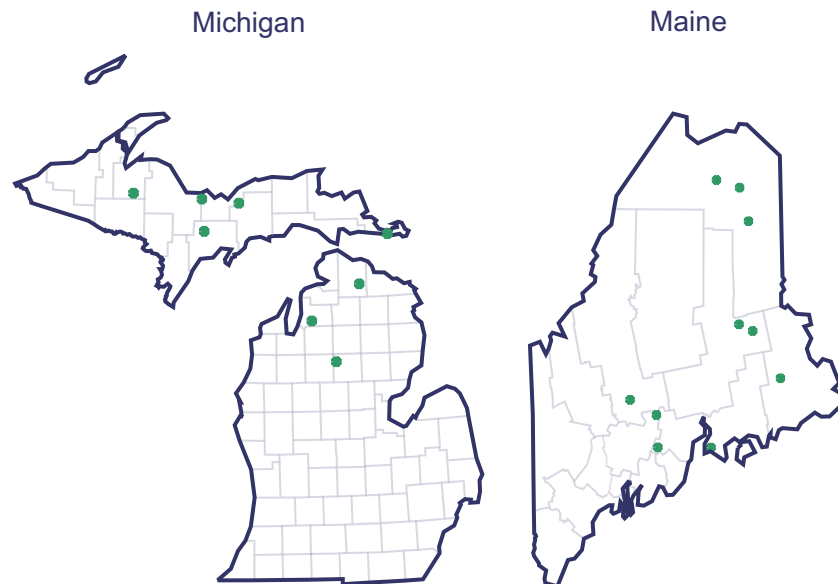
Continuing the investigation, we examined plot averages by broad species group to determine if the elevated levels of crown dieback were limited to the northern white-cedars. Crown dieback averages were calculated at plot-level for groupings of hardwoods and non-northern white-cedar softwoods (hereafter, “other softwoods”). We observed that high dieback averages for northern white-cedars were not necessarily accompanied by elevated averages among the hardwoods and other softwoods on the same plots. We therefore decided that additional ground work and more indepth data analyses warranted an EM project proposal.

We submitted a base EM project proposal that recommended additional field work to verify the original field crew assessments and to search for additional evidence of disturbances that may have been below the thresholds at which they are recorded by FIA field crews. We also proposed further analysis of the 2000-2004 FIA data and of FHM data collected during the 1990s. The proposal was accepted and funded for 2 years (Randolph 2008).

### **Field Verification and Data Analysis**

During the summer of 2007, we selected plots to revisit which had average northern white-cedar crown dieback > 10 percent (based on the 2000-2004 FIA surveys). Thereby, we identified 15 plots (6 in Michigan and 9 in Maine). To compare stand and tree conditions, we also revisited five additional plots with an average cedar crown dieback of 5 percent or less. Special approval was granted by FIA administrators to visit these plots. Working closely with the FIA crews in Maine and Michigan, visits were scheduled to coincide with their regularly planned visits as much as possible. This was done for three reasons. The experience and local knowledge of the field crews quickened our ability to find the plots. In addition, coincident visits limited the number of times the landowners were

contacted, and reduced the potential for plot degradation. Given the time allotted for field work we were able to visit 11 plots with the FIA field crews and 7 others independently, for a total 18 plot visits (figure 1).



**Figure 1:** Approximate locations of the plots visited in Michigan and Maine during the summer of 2007 for EM project NE-07-01.

These plot visits enabled us to verify the elevated levels of northern white-cedar crown dieback and to observe local growing conditions. Disturbances on two of the selected plots that previously had been identified by FIA field crews were validated also. In addition, on two other plots we found localized wind damage <1-acre in size and a combination of wind and flooding damage on still another. Besides the plot-level disturbances, many northern white-cedars were leaning, had exposed roots, or exhibited strips of dead cambium around the bole. These conditions gave insight into the distressed conditions of many trees. Readers are directed to Randolph and others (2008) for a detailed summary of the plot visits.

The plot visits did not identify any single cause for the high levels of crown dieback but did help identify variables to include in subsequent data analyses such as stand age, disturbance type, temperature, and precipitation. We began the data analysis by obtaining all detection monitoring plots measured in Maine and Michigan between 1990 and 2005 through the national SDS center. FHM data collection began in 1990 in Maine and in 1994 in Michigan; and it ended in both States in 1999. These timeframes are hereafter referred to as the “FHM time period.” A total of 259 plots (123 in Maine and 136 in Michigan) were obtained for this period of FHM data collection. Northern white-cedar was present on 37 percent of the plots in Maine and 18 percent of the plots in Michigan. All of the

plots in Maine and 122 plots in Michigan were measured at least twice during the FHM time period. Some plots were measured as many as nine times in Maine and four times in Michigan. FIA data collection began in both States in 2000. Data from a total of 417 plots (201 in Maine and 216 in Michigan) were obtained for the period of FIA data collection, 2000-2005 (“FIA time period”). Northern white-cedar was present on 34 percent of the plots in Maine and 22 percent of the plots in Michigan. Repeated measurements were made on 37 plots in Maine and 42 plots in Michigan. Of those remeasured plots, northern white-cedar was present on 11 in Maine and 10 in Michigan. Using a tree-matching algorithm, we confidently were able to match 495 northern white-cedar trees from 54 plots established in the FHM time period with their corresponding assessments from the FIA time period.

We then used the available data to determine (1) if the level of crown dieback in northern white-cedar was significantly higher than it was in other species, and (2) if there had been a change over time in the average level of northern white-cedar crown dieback. An analysis of variance model, with plot-level average crown dieback as the response variable and taxa (hardwoods, northern white-cedar, and other softwoods), measurement year, and the taxa \* measurement year interaction as the explanatory factors, was applied to answer question (1). This was done separately by State for each time period (FHM and FIA). Data from the two time periods were not combined due to complications from being unable to follow some FHM plots across the 2000 integration date. To accommodate the repeated measurements, we analyzed the data using the SAS® procedure MIXED (Littell and others 1996) with a REPEATED statement. Correlations between repeated measurements are typically larger for observations with shorter measurement intervals. To account for this, an autoregressive order 1 covariance structure was used to model the covariance structure within subjects for the FIA time period. Because of the unequally spaced time intervals between measurements, the spatial power law covariance structure was used for the FHM time period. Pairwise, least-squares mean difference comparisons between the taxa means were made with a Bonferroni adjusted comparisonwise alpha level of 0.0167 (overall familywise alpha = 0.05).

Preliminary analyses revealed that a number of plots were influencing the results. Weighting the plot observations by the number of trees sampled alleviated much of the undue influence. However, one plot in Michigan continued to have considerable influence. This plot (which we visited during our field work) was located in an area that experienced extreme flooding and wind damage (figure 2). We concluded that this plot was atypical of the other plots visited in Michigan and decided to drop it from the dataset. This case of one plot exerting great influence on the analyses highlights the need for researchers to be watchful for such possibilities.



**Figure 2:** Conditions of the atypical plot in Michigan with flooding and wind damage.

For question (2), the subset of individual northern white-cedar trees with matched observations spanning the FHM-FIA time periods were modeled as a linear function of measurement year, by State. Again, because of the unequally spaced time intervals between measurements, we used the spatial power law covariance structure to model the covariance structure within subjects.

### Conclusions about Northern White-Cedar Crown Dieback

We concluded for question (1) that when significant differences were present, northern white-cedar crown dieback levels were higher than the crown dieback levels of other softwood species and lower than the dieback levels of hardwood species, although such differences sometimes were dependent upon measurement year. In Maine, taxa, measurement year, and the taxa \* measurement year interaction were all significant at the alpha = 0.05 level during the FHM time period, but only taxa was significant during the FIA time period (table 1). During the FHM time period, average dieback for northern white-cedar was less than average dieback for the hardwoods and greater than average dieback for the other softwoods, but in most years was not significantly different from either group (figure 3). During the FIA time period, average northern white-cedar dieback was significantly higher than the average dieback of the other softwoods (figure 4). In Michigan, taxa was the only significant factor at the alpha = 0.05 level during the FHM time period, whereas all three factors were significant during the FIA time period (table 1). During the FHM time period, average northern white-cedar dieback

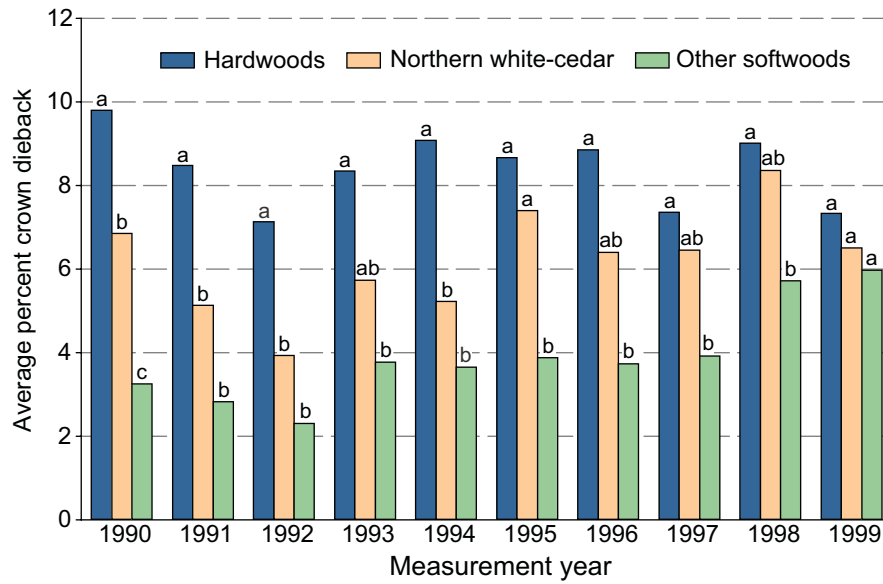
**Table 1:** Results (p-values) for the analysis of variance testing the effect of taxa and measurement year on average crown dieback in Maine and Michigan between 1990 and 2005

Factor	Maine		Michigan	
	1990-1999 <sup>a</sup>	2000-2005 <sup>b</sup>	1994-1999 <sup>a</sup>	2000-2005 <sup>b</sup>
Taxa	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Year	< 0.0001	0.0939	0.0754	0.0005
Taxa * year	0.0118	0.4335	0.1584	0.0015

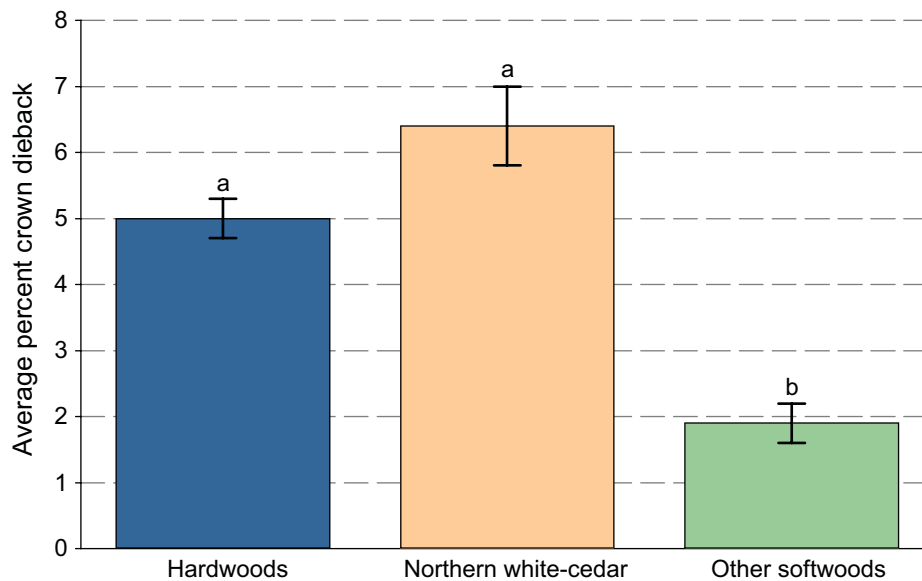
<sup>a</sup> FHM time period.

<sup>b</sup> FIA time period.



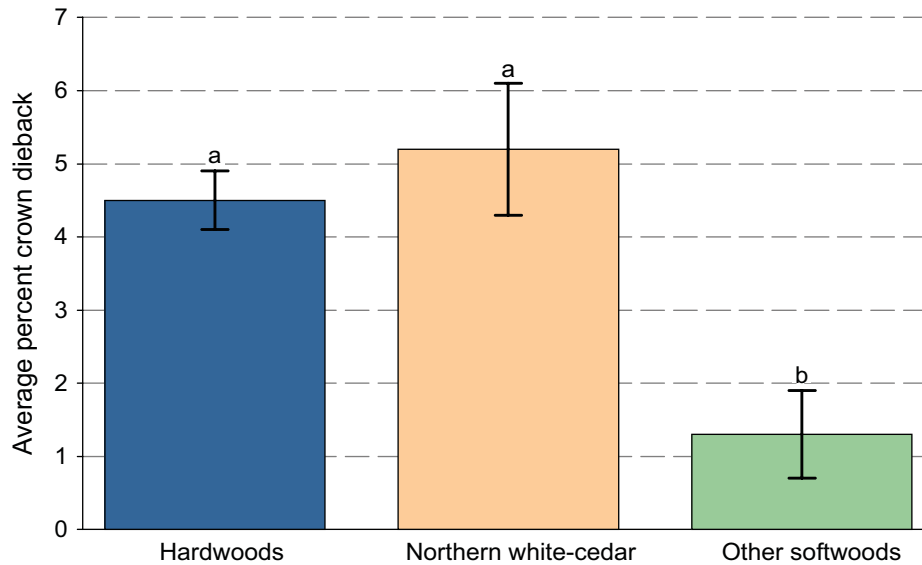


**Figure 3:** Least-squares mean estimates of average percent crown dieback by taxa and year in Maine. For each year, bars with different letters are significantly different at the Bonferroni comparison-wise alpha value of 0.0167.

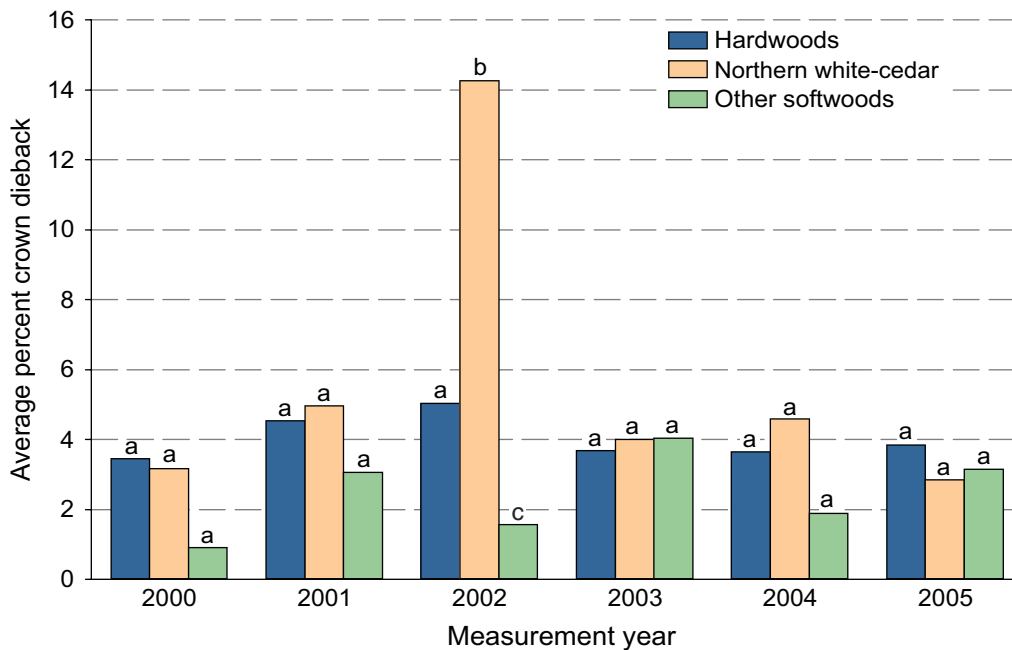


**Figure 4:** Least-squares mean estimates of average percent crown dieback in Maine during the FIA time period (2000–2005), by taxa, with standard error bars. Taxa means with different letters are significantly different at the Bonferroni comparison-wise alpha value of 0.0167.

was significantly higher than the average dieback of the other softwoods (figure 5). During the FIA time period, significant differences among the taxa occurred in 2002 only, when average dieback for northern white-cedar was significantly higher than the averages of the hardwoods and other softwoods (figure 6).



**Figure 5:** Least square mean estimates of average percent crown dieback in Michigan during the FHM time period (1994–1999), by taxa, with standard error bars. Taxa means with different letters are significantly different at the Bonferroni comparison-wise alpha value of 0.0167.



**Figure 6:** Least-squares mean estimates of average percent crown dieback by taxa and year in Michigan. For each year, bars with different letters are significantly different at the Bonferroni comparison-wise alpha value of 0.0167.

For question (2), we were not able to conclude from the available data that there was a significant increase in northern white-cedar crown dieback in either State during the timeframe we examined. Measurement year was nonsignificant in the model predicting crown dieback in both Maine (p-value = 0.5962) and Michigan (p-value = 0.1949). The answers to additional questions, e.g., about specific stand and weather conditions associated with high levels of northern white-cedar, will require additional research.

## Conclusion

Though we failed to reject the null hypothesis that northern white-cedar dieback was unchanged, we did verify that the species tends to have different average levels of dieback than other taxa. This finding supports the argument that average crown conditions tend to be species-specific, and that species differences should be taken into account when analyzing crown-condition data (Zarnoch and others 2004).

There are many advantages of using FIA data as the basis for EM projects. The broad scale, long-term data provide a wealth of information that can be analyzed to understand the past, present, and future ecological conditions of our forests. Because FIA has strict definitions and data collection protocols, researchers engaging in detection and EM activities are encouraged to collaborate or consult with FIA personnel throughout their projects' duration.

## Acknowledgments

Funding for this EM project (NE-EM-07-01) was provided in part by the U.S. Forest Service, Forest Health Monitoring Program. Appreciation is extended to the National FIA Spatial Data Service Center, everyone who assisted in the field work, and Jim Steinman and Manfred Mielke who provided helpful comments on an earlier draft of this manuscript.

## References

- Ambrose, M.J.; Conkling, B.L., eds. 2007. Forest health monitoring: 2005 national technical report. Gen. Tech. Rep. SRS-104. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 76 p.
- Bechtold, W.A.; Patterson, P.L., eds. 2005. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 85 p.
- Gillespie, A.J.R. 1999. Rationale for a national annual inventory program. *Journal of Forestry*. 97(12): 16-20.

- Johnston, W.F. 1990. Northern white-cedar. In: Burns, R.M.; Honkala, B.H., tech. coords. *Silvics of North America: 1. Conifers; 2. Hardwoods*. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service: 580-589.
- Littell, R.C.; Milliken, G.A.; Stroup, W.W.; Wolfinger, R.D. 1996. SAS® system for mixed models. Cary, NC: SAS Institute, Inc. 633 p.
- Lombard, P.J. 2004. Drought conditions in Maine, 1999-2002: a historical perspective. Water-Resources Investigations Report 03-4310. Augusta, ME: U.S. Department of the Interior, Geological Survey. 36 p.
- McRoberts, R.E. 2005. The enhanced Forest Inventory and Analysis program. In: The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures; Bechtold, William A.; Patterson, Paul L., eds. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 1-10.
- McRoberts, R.E.; Holden, G.R.; Nelson, M.D. [and others]. 2005. Estimating and circumventing the effects of perturbing and swapping inventory plot locations. *Journal of Forestry*. 103(6): 275-279.
- Millers, I.; Anderson, R.; Burkman, W.; Hoffard, W. 1992. Crown condition rating guide. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry; Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 37 p.
- Randolph, K. 2008. Evaluating elevated levels of crown dieback among northern white-cedar (*Thuja occidentalis*) trees in Maine and Michigan. [Online]. U.S. Forest Service Forest Health Monitoring Program evaluation monitoring project NE-EM-07-01. [http://fhm.fs.fed.us/em/funded/08/ne\\_em\\_07\\_01.pdf](http://fhm.fs.fed.us/em/funded/08/ne_em_07_01.pdf). [July 24, 2008].
- Randolph, K.; Ostrofsky, B.; Steinman, J. [and others]. 2008. Field observations of northern white-cedar (*Thuja occidentalis*) crown dieback in Maine and Michigan (NE-EM-07-01) [Online]. [http://fhm.fs.fed.us/posters/posters08/northern\\_white\\_cedar.pdf](http://fhm.fs.fed.us/posters/posters08/northern_white_cedar.pdf). [August 22, 2008].
- Randolph, K.C. [In press]. Crown condition. In: Ambrose, M.J.; Conkling, B.L (eds.). (in press). *Forest health monitoring 2006 national technical report*. Gen Tech. Rep. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station.
- Riitters, K.; Tkacz, B. 2004. The U.S. forest health monitoring program. In: *Environmental Monitoring*. Boca Raton, FL: CRC Press: 669-683.
- Schomaker, M.E.; Zarnoch, S.J.; Bechtold, W.A. [and others]. 2007. Crown-condition classification: a guide to data collection and analysis. Gen. Tech. Rep. SRS-102. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 78 p.

- Steinman, J. 2004. Forest health monitoring in the Northeastern United States: disturbances and conditions during 1993-2002. NA-TP-01-04. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry. 46 p.
- Turner, J.A.; Oswalt, C.M.; Chamberlain, J.L. [and others]. 2008. Kentucky's forests, 2004. Resour. Bull. SRS-129. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 101 p.
- U.S. Department of Agriculture Forest Service. 2003. Program description. Forest health monitoring factsheet series. [Online]. [http://www.fhm.fs.fed.us/fact/03/prog\\_desc.pdf](http://www.fhm.fs.fed.us/fact/03/prog_desc.pdf). [July 24, 2008].
- Washington State Department of Natural Resources. 2007. Forest health highlights in Washington—2007. [Online]. [http://fhm.fs.fed.us/fhh/fhh\\_07/wa\\_fhh\\_07.pdf](http://fhm.fs.fed.us/fhh/fhh_07/wa_fhh_07.pdf). [August 19, 2008].
- Zarnoch, S.J.; Bechtold, W.A.; Stolte, K.W. 2004. Using crown condition variables as indicators of forest health. Canadian Journal of Forest Research. 25: 462-469.