A Comparison of Tree Crown Condition in Areas With and Without Gypsy Moth Activity

KaDonna C. Randolph[1]

Abstract.—This study compared the crown condition of trees within and outside areas of gypsy moth defoliation in Virginia via hypothesis tests of mean differences for five U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis phase 3 crown condition indicators. Significant differences were found between the trees located within and outside gypsy moth activity, but no crown condition indicator was consistently different across the 4 years included in the study. Results suggest that the crown condition indicators may provide some benefit in pinpointing the presence of a known stressor and also may provide a starting point for identifying unknown stressors.

Objective

The U.S. Department of Agriculture (USDA) Forest Service, which is responsible for reporting the status of and trends in forest ecosystem health, has programs in Forest Inventory and Analysis (FIA), Forest Health Monitoring (FHM), and Forest Health Protection that cooperatively monitor forest health by means of aerial detection surveys and on-the-ground inventories. One of the ways in which changes in forest health are detected on the ground is through the measurement of a suite of ecological indicators on a network of plots known as FIA phase 3 plots (formerly FHM detection monitoring plots) (Riitters and Tkacz 2004).

Among the ecological indicators assessed on the FIA phase 3 plots is tree crown condition. Crown condition has long been recognized as a general gauge of forest health because healthy crowns are usually distributed symmetrically in a predictable manner along the stem and careful examinations for deviations from this pattern may indicate a tree undergoing stress (Waring 1987). Researchers have different conclusions about the relationship between crown condition and tree vigor (Anderson and Belanger 1987, Innes 1993, Kenk 1993, Solberg and Strand 1999), and even though crown condition indicators have been measured since the outset of the FHM program in 1990 few studies have sought to determine the usefulness of crown condition for evaluating forest health (e.g., Juknys and Augustaitis 1998, Steinman 2000). Thus, the purpose of this study was to assess the practicability of using the phase 3 crown condition indicators to detect forest health problems.

One way to gauge the usefulness of crown condition for monitoring forest health is to determine whether crown condition in areas with a known stress agent differs from that in areas without a known stress agent. If the impact of an obvious stressor cannot be observed, then the ability to detect the occurrence of subtler and unknown stressors is called into question. In this study, tree crown condition in areas of gypsy moth (*Lymantria dispar* Linnaeus) activity was compared to crown condition outside the areas of moth activity. Since the gypsy moth feeds directly on tree foliage, its impact on crown condition should be noticeable if the indicators are adequately sensitive.

Analysis Methods

The study area was confined to Virginia, which first showed evidence of gypsy moth defoliation in 1984. Collection of tree crown condition data began in Virginia in 1991 and continues through the present, but because of the pattern of gypsy moth activity and sample size concerns, only data from the 1992–95 period were utilized. For each year, all phase 3 plots in Virginia were assigned to one of five gypsy moth activity categories: present, likely present, possibly present, not currently present

[1] Mathematical Statistician, U.S. Department of Agriculture, Forest Service, Southern Research Station, 4700 Old Kingston Pike, Knoxville, TN 37919. E-mail: krandolph@fs.fed.us.

but present in past, or absent. Each plot was assigned to one of these categories based on conditions recorded on the plot (tree notes, tree damage codes, percent basal area in oak, plot disturbance codes) and proximity of the plot to aerially sketch mapped areas of gypsy moth defoliation. Plots were assigned to the present category if the tree or plot notes recorded by the field crews specifically indicated gypsy moth activity or if the plots were within 1 km (0.62 mi) of a mapped area of defoliation and had a disturbance code indicating the presence of damaging insects or oak trees with damaged foliage, buds, or shoots. Assignment of a plot to the likely present, possibly present, or present in past category was based on the amount of oak basal area on the plot, plot-level disturbance codes, tree-level damage codes, and past gypsy moth activity. Any plot failing to meet the requirements for the present, likely present, possibly present, or present in past categories was assigned to the absent category. Only two of the five categories, present and absent, were used for this particular study. Though the gypsy moth feeds on a variety of species, oaks (*Quercus* spp.) are the preferred host; therefore, only data for oak trees on plots with five or more living oaks with diameter at breast height (d.b.h.) > 12.6 cm were utilized in the analyses.

Two sets of crown condition indicators were included in the analyses: those recorded by the field crews (absolute indicators) and those calculated from the field data (composite indicators). The following were the absolute crown condition indicators (USDA Forest Service 2004):

1. Crown density—the amount of crown branches, foliage, and reproductive structures that blocks light visibility through the projected crown outline.
2. Crown dieback—recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds inward toward the trunk.
3. Foliage transparency—the amount of skylight visible through the live, normally foliated portion of the crown, excluding dieback, dead branches, and large gaps in the crown.

The absolute indicators are visually assessed by the field crews and are recorded in 5-percent increments from 0 to 100 percent. The composite crown indicators, composite crown volume (CCV) and composite crown surface area (CCSA), were calculated as

$$CCV = 0.5 \cdot \pi \cdot R^2 \cdot CL \cdot CD$$

and

$$CCSA = \frac{4\pi CL}{3R^2}\left[\left(R^2 + \frac{R^4}{4CL^2}\right)^{1.5} - \left(\frac{R^4}{4CL^2}\right)^{1.5}\right]CD$$

where:

R = crown diameter (meters)/2.

H = total tree height (meters).

CL = H*(live crown ratio)/100.

CD = crown density/100 (Zarnoch *et al.* 2004).

Crown diameter is the average of the greatest crown width and crown width measured along a line perpendicular to the axis of greatest crown width and live crown ratio is the percentage of the live tree height supporting live foliage. Crown diameter and live crown ratio were measured in the field; tree heights were not measured in the field and were predicted with FIA models. The use of predicted heights for calculating CCV and CCSA may mask some of the differences in crown size because trees undergoing stress would be expected to be shorter than trees free of stress. (Measurement of tree heights on the phase 3 plots began in 2000, but at the same time measurement of crown diameter was dropped. Hence, crown diameter is now predicted from models that have the potential to similarly mask tree crown condition. See Bechtold *et al.* [2002] for further discussion). Stem diameters, which were needed to predict tree height, were not measured between 1992 and 1994, and so CCV and CCSA were calculated for 1995 only.

To account for stem size, stand condition, and species impacts on crown condition, Zarnoch *et al.* (2004) recommend standardizing and residualizing the crown condition indicators so that trees may be combined or compared across species, or plots, or both. Their methods were employed in modeling CCV and CCSA for each year by species with the simple linear regression:

$$\beta_0 + \beta_1 \text{d.b.h.} + \beta_2 \text{ba}$$

where d.b.h. is diameter at breast height (cm) and ba is stand-level basal area (m^2) per hectare for all trees ≥ 2.5-cm d.b.h.

The residuals from the regression models were standardized by species. No single model form was found to be consistently adequate for predicting the absolute indicators across species and years; therefore, the absolute indicators were standardized by species only.

Means of the standardized and standardized-residualized crown condition indicators were calculated by year for the absent and present gypsy moth activity categories to test the hypothesis:

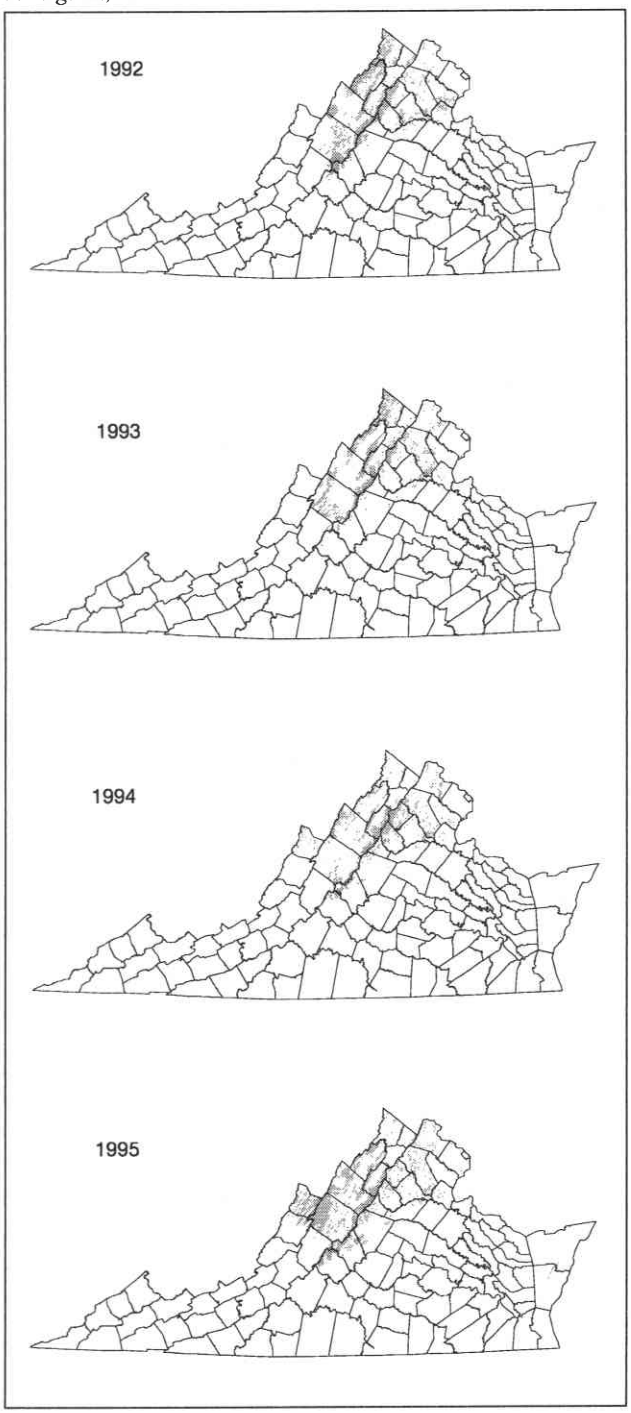
$$H_0: \mu_{absent} = \mu_{present}$$
$$H_1: \mu_{absent} \neq \mu_{present}.$$

Calculation of the standardized and standardized-residualized crown condition indicator means for both gypsy moth activity categories was performed with the SAS software procedure SURVEYMEANS (SAS 2001) because this procedure can make provision for the FIA sample survey design, which results in unequal-sized clusters of trees on the inventory plots. Given this survey design, it was simplest to test the null hypothesis given above via two-sided 95-percent confidence intervals for the difference (μ_{absent} - $\mu_{present}$). Two groups were declared significantly different at the 0.05 level of significance if the confidence interval for (μ_{absent} - $\mu_{present}$) did not include 0.

Results and Discussion

Gypsy moth defoliation in Virginia was most severe in 1992, when 748,100 acres were defoliated, and in 1995, when 849,584 acres were defoliated (fig. 1) (Virginia Department of Forestry 2005). In 1992 and 1994, six plots met the criteria for gypsy moth presence; five plots met the criteria in 1995 and three plots in 1993. The number of plots in the absent category ranged from 24 in 1992 to 37 in 1994 (table 1). Ten oak species were included in the analyses: *Quercus alba* L., *Q. coccinea* Muenchh., *Q. falcata* Michx. var *falcata*, *Q. marilandica* Muenchh., *Q. nigra* L., *Q. phellos* L., *Q. prinus* L., *Q. rubra* L., *Q. stellata* Wangenh., and *Q. velutina* Lam. Four of these species (*Q. marilandica*, *Q. nigra*, *Q. phellos*, and *Q. stellata*) had less than 30 observations each per year and were grouped together as one species for standardizing and standardizing-residualizing. The number of oak trees included in the analyses

Figure 1.—*Aerial sketch map areas of gypsy moth defoliation in Virginia, 1992–95.*



ranged from 73 to 103 for the present category and from 276 to 494 for the absent category (table 1).

Table 1.—*Number of plots and living oak trees in each gypsy moth activity category.*

Year	Gypsy moth		Gypsy moth	
	Absent	Present	Absent	Present
	(Number of plots)		(Number of oak)	
1992	24	6	276	90
1993	35	3	461	73
1994	37	6	494	103
1995	36	5	474	97

The standardized and standardized-residualized indicators describe deviation from the expected (average) crown conditions for a given population under typical conditions and are expressed in terms of standard deviation units from the mean. Trees with about average crown conditions will have standardized and standardized-residualized values near 0. Better or poorer than average crown conditions will be > or < 0, with the direction (positive or negative) depending on the nature of the crown condition indicator. For example, high crown dieback is indicative of poor crown condition and would correspond to positive standardized values. On the other hand, low crown density indicates poor crown condition and would correspond to negative standardized values. As expected, trees in the present category generally exhibited poorer than average crown conditions. Trees in the absent category generally exhibited average or better than average crown conditions; however, only a small number of the differences between the group means were significant: crown dieback in 1992, foliage transparency and crown dieback in 1994, and composite crown surface area in 1995 (table 2). Though significant differences were found between the crown conditions for trees on plots with and without the gypsy moth stress agent, no crown condition indicator was consistently different between the two groups.

Care was taken to assign plots to the present and absent categories correctly; thus, it was expected that the differences between the crown conditions in areas with and without gypsy moth activity would have been more extreme. Factors that may have impacted the hypothesis testing include the small sample size and inclusion of plots across the entire State. Given the sample survey design of the analysis, the confidence interval degrees of freedom were dependent on the number of plots in the gypsy moth activity categories. The small number of plots in the present category resulted in a larger t-value, and thus wider confidence intervals, which made it more difficult to declare differences significant than it would have been if the sample size had been larger. Plots from across the entire State, and not just in northern Virginia within the range of gypsy moth activity, were included in the absent category. Thus, the averages for the absent category may include some effects of geographic location.

The timing of plot assessment also may have contributed to the finding of only a few, small significant differences. Gypsy moth larvae typically feed from early May to late June (Coulson and Witter 1984), though the peak of defoliation may not occur until late July (Liebhold *et al.* 1997). Phase 3 plots are measured throughout the entire summer season (June through August), so some plots may be assessed before defoliation climaxes. This might have been the case with the three plots in the present category in 1993, because all of these plots were measured before June 18. For the other years, the plots in the present category were assessed as early as June 6 and as late as August 23: between July 22 and August 3 in 1992; between June 6 and June 29, and on August 23 in 1994; and between June 13 and July 28 in 1995. Even when measured late in the season, crown conditions may not show the effects of gypsy moth defoliation (or other defoliation events) because hardwood trees have the potential to produce a second flush of leaves if initial defoliation has been severe (USDA Forest Service 2005). Hence, the timing of plot assessment may affect the usefulness of the crown condition indicator for detecting forest health stressors, particularly if the impacts of the stressor are ephemeral or if they are manifested after the plot has been assessed.

Overall, success in detecting differences in this study was due in part to *a priori* knowledge of where gypsy moth defoliation occurred (fig. 1). Consider the map in figure 2, which shows the 1995 plot averages for oak standardized-residualized CCSA. The size of the dot indicates the magnitude of deviation from the expected species averages, with the larger dots indicating a

Table 2.—*Average absolute and composite crown condition indicators by year and gypsy moth activity category (Absent, Present), and 95-percent CIs for the difference of the means (Absent – Present).*

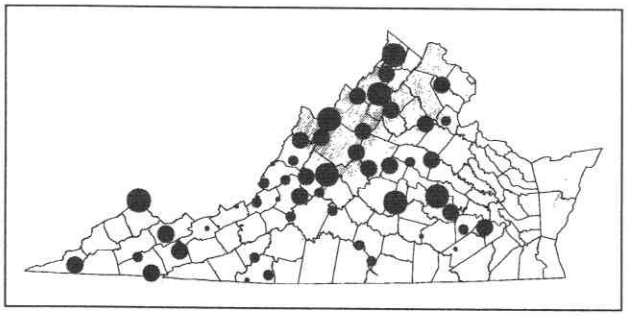
Indicator	Year			
	1992	1993	1994	1995
Standardized crown density				
Absent	0.15	0.03	0.00	0.15
Present	– 0.12	– 0.32	– 0.24	– 0.54
95-percent CI	– 0.16, 0.70	– 0.34, 1.04	– 0.31, 0.78	– 0.20, 1.57
Standardized crown dieback				
Absent	– 0.13	0.01	– 0.02	– 0.06
Present	0.21	– 0.12	0.24	0.32
95-percent CI	– 0.62, – 0.04[a]	– 0.21, 0.47	– 0.35, – 0.18[a]	– 0.83, 0.07
Standardized foliage transparency				
Absent	0.04	– 0.09	– 0.09	– 0.06
Present	0.33	0.47	0.52	0.55
95-percent CI	– 0.66, 0.09	– 1.53, 0.41	– 1.00, – 0.23[a]	– 2.34, 1.12
Composite crown volume standardized residual				
Absent	–[b]	–	–	0.10
Present	–	–	–	– 0.10
95-percent CI	–	–	–	– 0.15, 0.55
Composite crown surface area standardized residual				
Absent	–	–	–	0.15
Present	–	–	–	– 0.31
95-percent CI	–	–	–	0.11, 0.80[a]

CI = confidence interval.

[a] *Significant difference.*

[b] *Insufficient data to calculate the indicator for this year.*

Figure 2.—*Plot averages for oak standardized-residualized composite crown surface area overlying the area of gypsy moth defoliation in Virginia in 1995. The size of the dot indicates the magnitude of deviation from the expected species averages with the larger dots indicating a deviation toward smaller (poorer) composite crown surface areas.*



deviation toward smaller (poorer) CCSA. While the dots in the area of gypsy moth defoliation are large, they are not clearly distinguishable from dots in other parts of the State; e.g., southwestern and east central areas. Thus, unless one already knows where forests may be undergoing stress, comparing plot-level crown conditions may not pinpoint specific trouble spots, but may provide a starting point for further investigation.

Conclusions

The examination of crown conditions within and outside areas of known gypsy moth defoliation provided insight into

the practicability of using the crown condition indicators to identify trees undergoing stress. Trees on plots in two categories of gypsy moth activity had significant differences in crown condition, but the differences were neither extensive nor consistently significant for an indicator over the time period examined. When considered alone, the crown condition indicators may help us identify the presence of a known stressor, but perhaps only if the general area undergoing stress is known already. The crown condition indicators may also provide a starting point for identifying unknown stressors, though forest health problems may be difficult to distinguish if their manifestation in crown condition is subtle. Ongoing research continues to examine the usefulness of the crown condition indicators as early signals of declining forest health. Besides the annually collected phase 3 survey data, designed experiments and studies examining the effect of assessment timing will refine our expectations for the crown condition indicators.

Acknowledgments

The author thanks Ed Yockey, USDA Forest Service, Southern Region, State and Private Forestry, for providing the aerial sketch maps of gypsy moth defoliation and the following people from the USDA Forest Service for reviewing the project study plan, this manuscript, or both: Bill Bechtold (Southern Research Station), Jim Steinman (Northeastern Area State and Private Forestry), and Stan Zarnoch (Southern Research Station).

Literature Cited

Anderson, R.L.; Belanger, R.P. 1987. A crown rating method for assessing tree vigor of loblolly and shortleaf pines. In: Phillips, D., ed. Proceedings, 4th biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 538-543.

Bechtold, W.A.; Mielke, M.E.; Zarnoch, S.J. 2002. Comparison of field methods and models to estimate mean crown diameter. Northern Journal of Applied Forestry. 19(4): 177-182.

Coulson, R.N.; Witter, J.A. 1984. Forest entomology: ecology and management. New York: John Wiley. 669 p.

Innes, J.L. 1993. Forest health: its assessment and status. Oxon, UK: CAB International. 677 p.

Juknys, R.; Augustaitis, A. 1998. Indicators of crown and their application in forest health monitoring. Baltic Forestry. 2: 51-58.

Kenk, G. 1993. Growth in "declining" forests of Baden-Württemberg (Southwestern Germany). In: Huettl, R.F.; Mueller-Dombois, D., eds. Forest decline in the Atlantic and Pacific region. Berlin, NY: Springer-Verlag: 202-250.

Liebhold, A.M.; Gottschalk, K.W.; Luzader, E.R.; Mason, D.A.; Bush, R.; Twardus, D.B. 1997. Gypsy moth in the United States: an atlas. Gen. Tech. Rep. NE-233. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

Riitters, K.; Tkacz, B. 2004. The U.S. forest health monitoring program. In: Wiersma, B., ed. Environmental monitoring. Boca Raton, FL: CRC Press: 669-683.

SAS Institute, Inc. 2001. The SAS system: SAS OnlineDoc, Version 8.02, HTML format. Cary, NC: SAS Institute.

Solberg, S.; Strand, L. 1999. Crown density assessments, control surveys and reproducibility. Environmental Monitoring and Assessment. 56: 75-86.

Steinman, J. 2000. Tracking the health of trees over time on forest health monitoring plots. In: Hansen, M.; Burk, T., eds. Proceedings, IUFRO conference: integrated tools for natural resources inventories in the 21st century. Gen. Tech. Rep. NC-212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 334-339.

U.S. Department of Agriculture (USDA) Forest Service. 2004. Forest inventory and analysis field methods for phase 3 measurements, version 2.0, section 12.0 crowns: measurements and sampling. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/p3_2-0_sec12_3_04.pdf. (8 December 2005).

USDA Forest Service. 2005. Gypsy moth in North America: gypsy moth and forest relationships. http://www.fs.fed.us/ne/morgantown/4557/gmoth/forests/. (12 December 2005).

Virginia Department of Forestry. 2005. Gypsy moth defoliation in Virginia, 1984-2004. http://www.dof.virginia.gov/resinfo/gyp-moth-84-04.shtml. (May 2005).

Waring, R.H. 1987. Characteristics of trees predisposed to die: stress causes distinctive changes in photosynthate allocation. BioScience. 37(8): 569-574.

Zarnoch, S.J.; Bechtold, W.A.; Stolte, K.W. 2004. Using crown condition variables as indicators of forest health. Canadian Journal of Forest Research. 34: 1057-1070.