A Spatial Cluster of Poor Crown Conditions:

Evaluating Results from Crown Indicators and Spatial Scan Statistics

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Abstract: *Spatial analyses of FIA Phase 3 data collected in 2000 and 2001 yielded statistically significant clusters of trees with relatively small crown volumes near Augusta, Georgia. An Evaluation-Monitoring Project was launched in 2004 to further investigate the finding. This poster describes the analytical techniques and data associated with that project. Additional testing to check individual crown dimensions for spatial patterns did not yield the consistent geographic clustering observed with crown volumes. Further evaluation of the crown volumes in the original clusters with t-tests failed to confirm the results of the spatial scan statistic, leading us to suspect that the latter was prone to Type 1 statistical error. A field trip to inspect some of the sampled trees in the suspect area revealed no visual evidence of a problem. The statistically significant clustering detected in the original analysis most likely resulted from the use of statistical thresholds to identify trees with poor crowns, estimation of crown diameters with models, and our adaptation of the spatial scan statistic. All of these issues require attention to improve the utility of the Crown Indicator.*

Potential Problem Identified by Detection Monitoring

FIA has recently published results from the latest inventory of South Carolina's forests (Conner and others, 2004). The Crown Indicator was one of six FHM detection-monitoring indicators featured in that report. Techniques developed by Zarnoch and others (2004) were used to calculate crown volumes for trees sampled on FIA Phase 3 (forest health) plots in 2000 and 2001. Regression models were used to adjust each crown volume for differences in stem size (dbh), by species. Residuals from these models were then re-scaled to a mean of 0 and standard deviation of 1, thereby enabling direct comparisons of deviations from expected crown volumes across species and tree sizes. Because biological thresholds have not yet been developed, statistical thresholds were used to identify potential problem trees. Trees below the 25th-percentile on these adjusted statistical distributions were assumed to have poor crown conditions. Below-threshold trees were then examined for spatial patterns. Because the 25th-percentile was arbitrarily chosen, trees below the 10th- and 5th-percentiles were similarly checked for spatial patterns to reduce the possibility of a false signal.

The spatial scan statistic developed by Kulldorff (1997) was utilized to search for potential clusters of trees with below-threshold crowns. The scanning proceeds by visiting every plot in the study area, and a series of circular windows of increasing size (up to 50 percent of the study area) is superimposed over each location. A test statistic is then calculated to determine if the ratio of "events" inside each window is statistically greater than the ratio of events outside that window. Plots up to 80 miles outside South Carolina were included in the analysis to avoid any edge effect caused by truncating the analysis at the border. Statistically significant clusters of trees with small crown volumes were detected near Augusta, Georgia for trees below the 25th-percentile threshold. Similar results were obtained when trees below the 10th- and 5th-percentiles were checked (figure 1). A detailed account of the Detection Monitoring analysis is available in Bechtold and Coulston (in press).

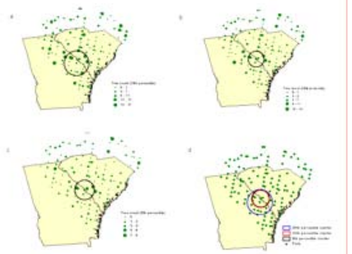

Figure 1. *The distribution of FIA plots measured within 80 miles of South Carolina (2000-2001), showing significant (p<0.01) spatial clusters of FIA plots containing sample trees with standardized-residualized crown volumes below the (a) 25th, (b) 10th, (c) 5th percentile, and (d) overlay of significant spatial clusters.*

Evaluation-Monitoring Project

Evaluation-Monitoring (EM) Project SO-EM-04-04 was funded in 2004 to further investigate the observed spatial clustering. Two approaches were taken. The first involved additional analysis of the original data. The second involved a field visit to the study area to search for visual evidence of a problem.

Additional Analysis of the Original Data

Improved adjustment model

The model originally used to adjust composite crown volumes (CCV's) for natural factors was improved by adding a quadratic term for dbh, and a term for stand basal area (ba):

$$CCV = b_o + b_1\,(dbh) + b_2\,(dbh)^2 + b_3\,(ba) \qquad (1)$$

Residuals from the improved model were again checked for spatial patterns with the Kulldorff scan statistic. Again, statistically significant clusters of trees with standardized-residualized CCV's below the 25th-, 10th-, and 5th-percentiles were detected near Augusta.

Spatial clusters checked with conventional t-tests

The Kulldorff statistic is designed to test counts of "events" and "non-events" for departures from randomness. Continuous crown data thus had to be transformed to binary counts in order to apply the Kulldorff scan statistic. The effect of this transformation on the Kulldorff application is unclear. This, uncertainty about the clustering effect of trees on plots, and uncertainty about whether tree-level or plot-level values were more appropriate, prompted us to examine trees in the spatial clusters with more conventional approaches that permitted crown variables to be treated as continuous variables. T-tests were thus used to determine if the mean residual values obtained from trees inside the Kulldorff clusters differed from the means of trees outside each cluster. To account for the covariance among trees on the same plots, the t-tests were designed so that trees were nested on plots.

Results from the t-tests were not consistent with the spatial scan results. Test 1 in table 1 shows that none of the spatial clusters identified as statistically significant by the Kulldorff method was significant (p=.05) when checked with t-tests, although the 25th-percentile was close (p=.08).

Subsets of trees evaluated with conventional t-tests

In addition to all trees combined, numerous subsets of trees in these clusters were checked (with t-tests) to determine if there might be a detectable problem in some particular subset of the data (table 1). This additional testing revealed weak evidence of a potential problem with softwoods (tests 2 and 3) in natural stands (tests 4 and 5), that appeared to affect loblolly as well as other softwood species (tests 6 and 7). Other softwoods seem to have been impacted more than loblolly, but the sample of these species within the clusters was relatively small, and there were too few samples of individual species to permit further testing.

Individual crown variables evaluated with conventional t-tests

Composite crown volume is computed as:

$$CCV = 0.5(\pi(\hat{C}D/2)^2(CL)(DEN)) \qquad (2)$$

where
CL = *H (UCR)* = crown length (ft),
UCR = uncompacted crown ratio (percent),
H = total tree length (ft),
DEN = crown density (percent), and
CD = crown diameter (ft), which was estimated from the model:

$$\hat{C}D = b_0 + b_1(dbh) + b_2(dbh)^2 + b_3(UCR) \qquad (3)$$

The three individual variables that comprise CCV (i.e., CD, CL, and DEN) were examined separately to determine if any specific crown parameter could be causing significant differences between trees inside and outside the Kulldorff clusters (tests 8-11 in table 1). No significant clusters were associated with any of these variables, although the results from crown density (test 8) were similar to those from CCV (test 1), in that the significance of the 25-percentile cluster was borderline.

Because CD is predicted from dbh, test 10 essentially checks whether there are any significant differences in mean dbh between trees inside and outside the Kulldorff clusters. Test 11 was conducted to remove the effect of estimated crown diameters from the expression of CCV by using a dependent variable that was the product of crown length and crown density. No significant clusters were associated with this term either.

Individual crown variables evaluated with Kulldorff scan statistic

Standardized residuals from the crown variables used in tests 8-11 were also analyzed with the Kulldorff scan statistic. Prior to this, only CCV had been evaluated, and the results were always consistent, with statistically significant spatial clusters of below-threshold values located near Augusta. However, when residuals from the individual crown attributes were checked, the results were much less consistent, with statistically significant clusters identified in a variety of locations around South Carolina and Georgia. At this point, we suspected that our use of the Kulldorff scan statistic on tree-level binary classifications derived from statistical thresholds was likely prone to Type 1 error (i.e., false positives).

Table 1. Mean standardized-residualized differences between trees inside and outside three significant spatial clusters near Augusta, GA for selected subsets of trees and several crown-indicator variables, 2000-2001.

Test	Trees	Crown Variable	25th-percentile Spatial Cluster	10th-percentile Spatial Cluster	5th-percentile Spatial Cluster
1	All Trees (n)	CCV	2470	2666	2850
	n inside		380	184	194
	n outside		1979	2388	2656
	mean inside		-.1770	-.1790	-.1318
	mean outside		.0886	.0680	.0664
	p-value		.0794	.1915	.2847
2	Softwoods (n)	CCV	1497	1497	1497
	n inside		140	64	68
	n outside		1357	1433	1429
	mean inside		-.5785	-1.0282	-.7954
	mean outside		.0655	.0398	.0360
	p-value		.0636	.0115*	.0387*
3	Hardwoods (n)	CCV	1353	1353	1353
	n inside		240	120	126
	n outside		1113	1233	1227
	mean inside		-.0209	.0937	.1128
	mean outside		.0912	.0727	.0707
	p-value		.5380	.9397	.8712
4	Natural Softwoods (n)	CCV	665	665	665
	n inside		81	58	62
	n outside		584	607	603
	mean inside		-.4388	-.7110	-.5492
	mean outside		.0359	.0167	.0155
	p-value		.0832	.0402*	.0902
5	Planted Softwoods (n)	CCV	823	823	823
	n inside		59	6	6
	n outside		764	817	817
	mean inside		-.0618	.3517	.3517
	mean outside		.0442	.0181	.0181
	p-value		.9265	.7962	.7962
6	Loblolly (n)	CCV	1113	1113	1113
	n inside		111	54	58
	n outside		1002	1059	1055
	mean inside		-.6302	-1.0201	-.7837
	mean outside		.2595	.2453	.2423
	p-value		.1437	.0408*	.0813
7	Softwoods except loblolly (n)	CCV	483	483	483
	n inside		29	10	10
	n outside		354	373	373
	mean inside		-.5122	-.8019	-.8019
	mean outside		.1784	.1410	.1410
	p-value		.0147*	.0315*	.0315*
8	All trees (n)	Crown Density	2850	2850	2850
	n inside		380	184	194
	n outside		2470	2666	2656
	mean inside		-.3083	-.0223	-.0458
	mean outside		.0347	-.0121	-.1010
	p-value		.0934	.9682	.8873
9	All trees (n)	Crown Length	2850	2850	2850
	n inside		380	184	194
	n outside		2470	2666	2656
	mean inside		-.0621	-.0078	.0051
	mean outside		.0702	.0561	.0557
	p-value		.4232	.7572	.8028
10	All Trees (n)	Estimated Crown Diameter	2850	2850	2850
	n inside		380	184	194
	n outside		2470	2666	2656
	mean inside		-.0096	.0220	.1470
	mean outside		.0727	.0642	.0549
	p-value		.6699	.8554	.6968
11	All trees (n)	(Crown Length) x (Density)	2850	2850	2850
	n inside		380	184	194
	n outside		2470	2666	2656
	mean inside		-.1681	.0005	-.0009
	mean outside		.0834	.0520	.0526
	p-value		.1380	.8086	.7972

Follow-up Field Visit

No visual evidence of a problem

Ten plots in the study area were identified for a follow-up field visit. Most of these plots were located within the 5th-percentile cluster near Augusta, and most exhibited a range of trees with above- and below-threshold standardized-residualized CCV's. Nine plots were subsequently visited by Mike Schomaker (Indicator Advisor), Bill Bechtold (Analyst), and Dale Starkey (Tree Pathologist) during the week of 8/16/04, yielding a total of 176 remeasured trees. The field trip had two main objectives:

(1) to scrutinize all trees on these plots for damage or other symptoms that might indicate a correlation between the calculated standardized-residualized CCV's and forest health.

(2) to remeasure all Phase 3 crown variables on these plots (as well as dbh, tree length, and crown diameters) in an attempt to evaluate the quality of the data and models used in the original analysis.

Concerning objective 1, no obvious visual correlation between poor tree health and low residualized CCV's was observed in the field. For the most part, trees with low residual CCV's appeared quite average. Some trees with low values exhibited damage (mostly minor) attributed to fusiform, Ips beetles, decay, and ice damage, but so did trees with relatively high indicator values. Overall, the trees and stands in this area seemed quite typical. No obvious evidence of clusters of trees with poor crowns was observed.

Data issues

Analysis of data from the return visit uncovered two potential issues related to data quality and model performance.

(1) Crown density was probably over-estimated by the crews in 2000-2001. Although it was not possible to conduct a rigorous QA analysis of the original data because crown architecture changed in the 3-4-year interval between measurements, the tree heights, crown ratios, and crown lengths from the original crews seemed reasonably accurate when compared with the follow-up data (table 2). However, the crown densities recorded by the original crews averaged two classes high when compared with the follow-up data—a statistically significant difference of about 27 percent (p< .0001). Measurement bias is suspected, but it should be noted that drought conditions could explain a reduction in crown density of this magnitude.

(2) Crown diameters are not measured on Phase 3 plots, so models had to be used for this attribute in the calculation of CCV. Based on comparisons between crown diameters measured in 2004 and respective predictions from model 3 (using independent variables from the 2004 data), the models were under-predicting crown diameters in the study area by a statistically significant (p<.0001) average of 1.6 ft, or 8 percent. Note that this bias is exaggerated by squaring the crown-diameter term in equation (2).

Table 2. Means and standard errors of tree and crown parameters, by time of visit, for 176 trees near Augusta, Ga.

Variable	Time of Visit[1]	Mean	Standard Error	Pr > |t|[3]
Crown Diameter	Follow-up (measured)	20.8	0.60	
	Follow-up (predicted)[2]	19.2	0.40	.0001*
Crown Density	Initial	45.5	0.63	
	Follow-up	35.8	0.58	.0001*
Crown Ratio	Initial	48.4	1.35	
	Follow-up	46.6	1.27	.0548
Tree Length	Initial	64.1	1.24	
	Follow-up	65.5	1.23	.0601
Crown Length	Initial	30.0	0.80	
	Follow-up	30.0	0.75	.6695
DBH	Initial	9.5	0.26	
	Follow-up	10.2	0.27	.0001*

[1] Follow-up visit in 2004, initial visit in 2000-2001.
[2] Crown diameter predicted with dbh and crown ratio data measured at follow-up visit.
[3] The probability that the difference between the two means is zero.

Conclusions

The initial consistency with which the Kulldorff scan statistic identified clusters of trees with below-threshold CCV's was misleading. It eventually became apparent that our adaptation of continuous tree-level crown data to this technique was prone to Type I error. The Kulldorff scan statistic might be used as a starting point for analyzing FHM data spatially, but until it can be satisfactorily adapted for the application described herein, the results should also be examined with statistical techniques designed for continuous data.

The field visit offered an opportunity to compare processed analytical results with visual inspection of the trees from which they were derived. No apparent correlation could be established between the standardized-residual CCV's calculated for individual trees and subsequent examination of these trees for physical problems. This is attributed to several factors:

(1) The signal was probably false. The use of statistical thresholds is disadvantaged in that it always assumes a meaningful signal exists. The percentiles used to identify "events" in this study were not low enough, because even trees in the 5th percentile appeared average. Difficulty identifying meaningful signals will persist until biological thresholds can be established.

(2) Contradictory biases associated with the crown-density variable and predicted crown diameters reduced the signal-to-noise ratio of the CCV variable.

(3) The analysis was handicapped by the use of models to predict crown diameters. **Failure to measure crown diameters in the field effectively precludes the use of composite crown indicators for forest health monitoring.** There is no guarantee that a model developed from one dataset will be unbiased for another, and the crown-diameter predictions were demonstrably biased for the trees in the study area.

(4) 3-4 years had passed since initial measurement. Although unlikely, it is possible that a real change in crown morphology could have occurred during that time. Ideally, the gap between Detection and Evaluation monitoring should not exceed two years.

Based on further examination of the original data, as well as a follow-up field investigation, we conclude that there is no obvious clustering of trees with low crown volumes in the vicinity of Augusta, GA.

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