Tree Crown Condition in Virginia Before and After Hurricane Isabel (September 2003)

KaDonna Randolph[1]
Anita Rose[2]

***Abstract**: In September 2003, Hurricane Isabel made landfall in North Carolina as a Category 2 hurricane. As it moved inland, with sustained wind speeds of 37 to 69 miles per hour (59 to 111 km per hour) and gusts up to 91 miles per hour (146 km per hour), the hurricane caused widespread damage throughout Virginia and is a plausible explanation for adverse changes observed in tree crown condition since the hurricane. On average, trees measured before and after the hurricane showed a significant increase in foliage transparency. Increases in foliage transparency were greatest for loblolly pine, sweetgum, and the Coastal Plain region of the State. A significant correlation between tree size and increase in foliage transparency was not observed. This study highlighted the potential importance of foliage transparency as an indicator of tree damage from severe storms.*

Keywords: FIA, foliage transparency, forest health, hurricane damage.

Introduction

The U.S. Forest Service, Forest Inventory and Analysis (FIA) program has been conducting inventories of the Nation's forest land for 80 years. For most of this period, statewide inventories 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 the late 1990s, however, FIA has inventoried States on an annual basis, striving to complete an inventory cycle every 5 years in the East and every 10 years in the West.

The first set of such annual measurements began in Virginia in 1997 and concluded in 2001. This was the 7th statewide inventory of Virginia. The 8th statewide survey, also accomplished on an annual basis, was conducted during 2002 to 2007. As part of the 2001 (7th survey) report on the forests of Virginia, crown conditions were evaluated to identify potential forest health problems within the State (Rose 2007). Average crown density, foliage transparency, and

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

[2] United States Forest Service; Southern Research Station; Forest Inventory and Analysis; 4700 Old Kingston Pike; Knoxville, TN 37919 USA; anitarose@fs.fed.us

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crown dieback were calculated for the softwood and hardwood species groups, as well as for individual tree species. When crown conditions from the 7th survey were compared to the forthcoming 2007 (8th survey) report (Rose in preparation), several changes were noticed. As expected, average values fluctuated for all three crown variables; however, the change for foliage transparency, especially among the softwoods, seemed atypical. Across the State, average hardwood transparency increased from 20 percent to 23 percent and average softwood transparency increased from 22 percent to 29 percent. Several individual species also showed large increases in average foliage transparency between the two surveys. Loblolly pine (*Pinus taeda* L.) average foliage transparency increased from 19 percent to 30 percent and the average for sweetgum (*Liquidambar styraciflua* L.) increased from 17 percent to 25 percent. The levels of foliage transparency measured during the 8th survey appeared unusual because the majority of both hardwood and softwood trees in the Southern United States typically have foliage transparencies of 25 percent or less (Randolph 2006).

Because hurricanes can cause substantial damage to tree crowns (Putz and Sharitz 1991), we considered the hurricane that struck Virginia during the 8th survey as a likely explanation for the changes noticed in crown condition. In September 2003 Hurricane Isabel made landfall on the Outer Banks of North Carolina as a Category 2 hurricane (figure 1). The storm caused widespread wind and flood damage across eight States from North Carolina to New York. Isabel

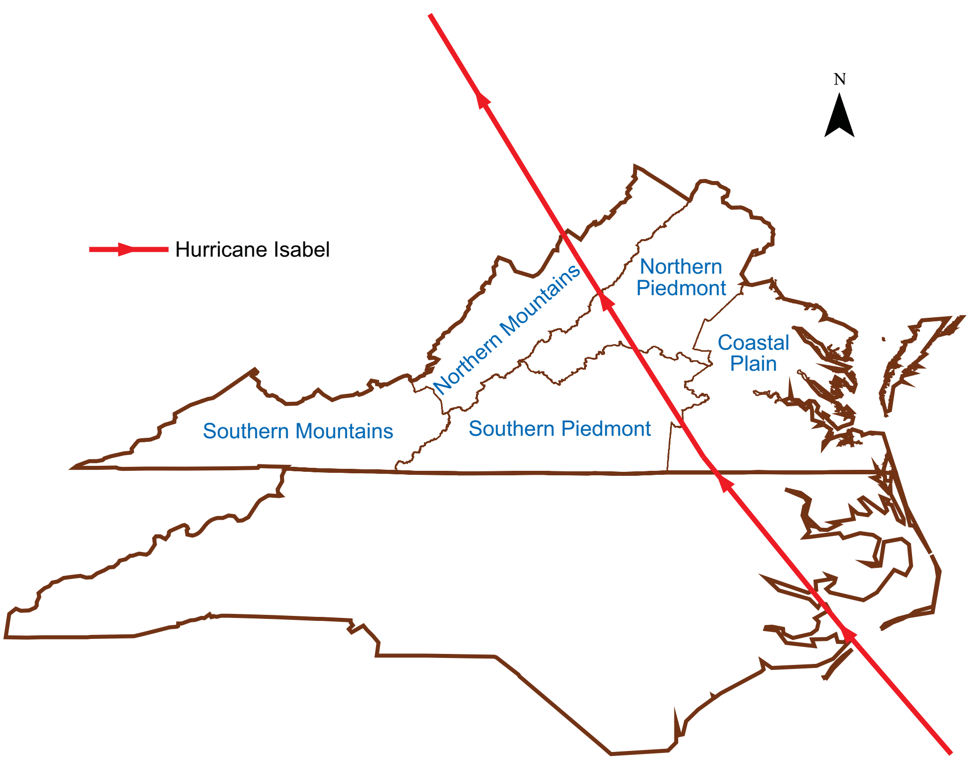

Figure 1: Path of Hurricane Isabel across North Carolina and Virginia, and the location of the five FIA units in Virginia.

passed through Virginia with sustained wind speeds ranging from 37 to 69 miles per hour (59 to 111 km per hour), with gusts up to 91 miles per hour (146 km per hour) (Beven and Cobb 2004). Rainfall from the hurricane averaged 4 to 7 inches (10 to 18 cm) over large portions of east-central Virginia, with the Shenandoah Valley in northern Virginia averaging 8 to 12 inches (20 to 30 cm) (Beven and Cobb 2004). A total of 77 counties and independent cities across Virginia were declared disaster zones, and the estimated economic loss was $925 million, greater than any of the other States through which Isabel passed (U.S. Department of Commerce 2004).

The purpose of this study was to examine trees that were measured both before and after the hurricane and explore the possibility that Hurricane Isabel was a contributing factor to the change in foliage transparency between the 7^{th} and 8^{th} surveys.

Methods

Data

Data for this study came from the FIA phase 3 plots measured in Virginia between 1997 and 2001 (7^{th} survey) and between 2002 and 2007 (8^{th} survey). FIA phase 3 plots are a cluster of four 1/24-acre (0.02 ha) circular subplots located across the landscape in a way such that each plot represents approximately 96,000 acres (38,850 ha) (McRoberts 2005). On each plot crown condition is assessed for every live tree ≥ 5.0 inches (12.7 cm) diameter at breast height (d.b.h.). Three crown condition variables are assessed: crown dieback, crown density, and foliage transparency. Crown dieback is the recent mortality of branches with fine twigs, whereas crown density and foliage transparency measure the amount of foliage and crown biomass on a tree (Schomaker and others 2007). Though foliage transparency and crown density are similar measures they cannot be interpreted as exact inverses. Crown density measures the amount of sunlight blocked by all biomass produced by the tree (both live and dead) in the crown, whereas foliage transparency measures the amount of sunlight penetrating only the live portion of the crown. Deductions are made from the maximum possible crown density for spaces between branches and other large openings in the crown. However, large gaps in the crown where foliage is not expected to occur are excluded from consideration when foliage transparency is rated.

Analysis

Individual trees from the 7^{th} and 8^{th} surveys were matched by plot and tree number and then divided into pre- and post-hurricane data sets. Trees measured before September 18, 2003 were assigned to the pre-hurricane data set and trees measured on or after September 18, 2003 were assigned to the post-hurricane data set. The mean, standard error, and 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles were calculated for both the pre- and post-hurricane data sets. Change in crown condition was calculated for survivor trees as the difference between the post- and pre-hurricane ratings. Trees that died between the first and second assessment were not included in this analysis. In this report we focus on the change in foliage transparency (δ_{ft}).

Paired t-tests were used to test the hypothesis that the mean of δ_{ft} equals zero at the State and FIA unit level for all trees combined, hardwood and softwood groups, and individual species groups. Scatter plots of δ_{ft} by d.b.h. and height, and average δ_{ft} ($\bar{\delta}_{ft}$) by crown position were produced to examine the relationship between δ_{ft} and tree dominance. In addition, $\bar{\delta}_{ft}$ based on only the remeasured trees was calculated for each plot with three or more live trees and mapped for visual inspection in relation to the path of Hurricane Isabel (U.S. Department of Commerce 2008).

Results

Pre- and post-hurricane assessments were matched for 1,492 live trees ≥ 5.0 inches (12.7 cm) d.b.h. on 74 plots. Hardwoods made up the majority of the trees assessed (67.9 percent). Chestnut oak (*Quercus prinus* L.), yellow-poplar (*Liriodendron tulipifera* L.), and red maple (*Acer rubrum* L.) were the most abundant hardwood species. Loblolly pine and Virginia pine (*Pinus virginiana* Mill.) were the most abundant softwood species. The time between the pre- and post-hurricane assessments was 4 years for one plot and 5 years for all other plots.

Across the State, there was a significant ($\alpha = 0.05$) increase in average foliage transparency pre- to post-hurricane for all trees combined, the hardwood and softwood groups, and several of the individual species groups (table 1). The increase in foliage transparency was greater among the softwoods ($\bar{\delta}_{ft} = 9.6$ percent) than among the hardwoods ($\bar{\delta}_{ft} = 5.7$ percent) and overall was greatest for sweetgum ($\bar{\delta}_{ft} = 14.4$ percent) and loblolly pine ($\bar{\delta}_{ft} = 12.0$ percent).

Changes in the percentiles of the foliage transparency frequency distributions followed the same general patterns as the changes in the average conditions. Statewide, median foliage transparency was 20 percent for all trees prior to the hurricane and 25 percent after the hurricane (table 2). Greater increases in the median were observed for loblolly pine and sweetgum (table 2). Since lower foliage transparency values typically indicate healthier trees, increases in the upper percentiles especially indicate that more trees had poorer conditions after the hurricane than before. Statewide, the 90^{th} percentile increased from 25 percent to 45 percent for all trees combined and from 30 percent to 50 percent and 25 percent to 35 percent for the softwood and hardwood groups, respectively (table 2).

The main path of Hurricane Isabel passed through four of the five FIA units in Virginia (figure 1). Therefore, it was useful to examine the changes in foliage transparency at the unit level to help determine the extent to which Hurricane Isabel may have been the cause of these changes. For all trees combined, the greatest increase in average foliage transparency was observed in the Coastal

Table 1: Mean foliage transparency and other statistics[a] for all live trees ≥ 5.0 inches d.b.h. measured in Virginia before and after Hurricane Isabel, by species group

Species group	Plots	Trees	Pre-hurricane Mean	Pre-hurricane SE	Post-hurricane Mean	Post-hurricane SE	t-test p-value[b]
	- - - number - - -		percent		percent		
Softwoods							
Virginia pine	16	135	25.7	1.55	34.9	3.95	0.0356
Loblolly pine	17	259	19.9	1.03	31.9	2.75	0.0005
Shortleaf pine	8	19	20.3	—	28.2	—	—
Eastern redcedar	7	14	18.6	—	27.9	—	—
Other softwoods	8	52	25.9	1.58	25.4	0.99	—
All softwoods	38	479	22.2	1.01	31.8	2.08	0.0002
Hardwoods							
Hickory	32	95	18.7	0.79	20.3	0.67	0.1792
Maple	37	156	19.4	0.70	27.5	1.83	0.0003
Tupelo	16	35	20.4	1.94	23.7	1.13	0.1540
Oak	53	386	19.9	0.44	23.3	0.89	0.0028
Sourwood	10	32	18.4	0.87	22.3	2.56	0.2344
Sweetgum	16	65	17.0	1.44	31.4	3.02	0.0001
Yellow-poplar	30	121	16.9	0.47	25.8	1.73	0.0001
Other hardwoods	37	123	19.4	0.76	26.2	1.82	0.0002
All hardwoods	69	1,013	19.1	0.36	24.8	0.98	0.0001
All trees	74	1,492	20.1	0.41	27.1	1.16	0.0001

SE = standard error; — = not presented due to insufficient sample.

[a] The mean and SE calculations consider the cluster of trees on plots. SE not presented for groups with < 20 trees.

[b] The probability of obtaining a large t-value under the null hypothesis that the difference between the two means equals 0. T-tests are not performed for species groups with < 10 plots.

Table 2: Foliage transparency frequency distribution percentiles for live trees ≥ 5.0 inches d.b.h. measured in Virginia before and after Hurricane Isabel, by species group

Species group	Pre-hurricane percentiles 25	50	75	90	Post-hurricane percentiles 25	50	75	90
				percent				
Softwoods								
Virginia pine	20	25	30	35	25	30	45	55
Loblolly pine	15	20	20	25	25	30	40	45
Shortleaf pine	20	20	20	25	20	25	30	40
Eastern redcedar	15	18	20	25	20	25	30	50
Other softwoods	20	25	30	35	20	25	30	30
All softwoods	20	20	25	30	25	25	40	50
Hardwoods								
Hickory	15	20	20	25	20	20	20	25
Maple	15	20	20	25	20	25	35	40
Tupelo	15	15	20	25	20	20	25	30
Oak	15	20	20	25	20	20	25	30
Sourwood	15	20	20	25	18	20	20	40
Sweetgum	15	15	20	20	20	30	35	45
Yellow-poplar	15	15	20	20	20	25	30	40
Other hardwoods	15	20	25	25	20	25	30	35
All hardwoods	15	20	20	25	20	20	25	35
All trees	15	20	20	25	20	25	30	45

Plain ($\bar{\delta}_{ft} = 15.8$ percent) followed by the Southern Piedmont ($\bar{\delta}_{ft} = 7.1$ percent), Southern Mountains ($\bar{\delta}_{ft} = 4.3$ percent), Northern Piedmont ($\bar{\delta}_{ft} = 3.6$ percent), and Northern Mountains ($\bar{\delta}_{ft} = 1.4$ percent) (table 3). The increase in foliage transparency was significant at the 95 percent confidence level in all units except the Northern Mountains and was marginally significant in the Southern Piedmont (p-value = 0.06). Increases in the 90th percentiles were observed in the Coastal Plain, Southern Piedmont, and Northern Mountains (table 4).

Scatter plots of δ_{ft} by pre-hurricane d.b.h. and height showed no systematic pattern (figures 2 and 3). That is, increased losses of foliage (higher δ_{ft}) were not associated with larger and taller trees. Likewise, there was not a significant

Table 3: Mean foliage transparency and other statistics[a] for live trees ≥ 5.0 inches d.b.h. measured in Virginia before and after Hurricane Isabel, by FIA unit and species group

Unit and species group	Plots	Trees	Pre-hurricane Mean	Pre-hurricane SE	Post-hurricane Mean	Post-hurricane SE	t-test p-value[b]
	- - - *number* - - -		*percent*		*percent*		
Coastal Plain							
Hardwoods	16	165	16.5	0.68	32.8	2.63	0.0001
Softwoods	13	199	19.0	0.88	34.4	3.27	0.0004
All trees	20	364	17.9	0.63	33.6	2.26	0.0001
Southern Piedmont							
Hardwoods	16	194	19.4	0.91	24.7	2.97	0.1053
Softwoods	9	145	22.8	1.57	32.4	5.07	—
All trees	16	339	20.9	0.80	28.0	3.67	0.0646
Northern Piedmont							
Hardwoods	11	204	19.1	0.76	23.1	1.10	0.0063
Softwoods	8	66	26.4	2.59	28.7	1.34	—
All trees	12	270	20.9	1.40	24.5	1.12	0.0122
Northern Mountains							
Hardwoods	16	280	20.4	0.62	22.1	0.85	0.1757
Softwoods	5	43	25.2	1.36	24.9	1.55	—
All trees	16	323	21.0	0.51	22.4	0.80	0.2200
Southern Mountains							
Hardwoods	10	170	19.1	0.53	23.9	1.13	0.0049
Softwoods	3	26	26.3	2.80	27.7	0.40	—
All trees	10	196	20.1	0.88	24.4	0.91	0.0096
Statewide							
Hardwoods	69	1,013	19.1	0.36	24.8	0.98	0.0001
Softwoods	38	479	22.2	1.01	31.8	2.08	0.0002
All trees	74	1,492	20.1	0.41	27.1	1.16	0.0001

SE = standard error; — = not presented due to insufficient sample.

[a] The mean and SE calculations consider the cluster of trees on plots.

[b] The probability of obtaining a larger t-value under the null hypothesis that the difference between the two means equals 0. T-tests are not performed for species groups with < 10 plots.

Table 4: Foliage transparency frequency distribution percentiles for live trees ≥ 5.0 inches d.b.h. measured in Virginia before and after Hurricane Isabel, by FIA unit

	Pre-hurricane percentiles				Post-hurricane percentiles			
Unit	**25**	**50**	**75**	**90**	**25**	**50**	**75**	**90**
				percent				
Coastal Plain	15	15	20	25	25	30	40	45
Southern Piedmont	15	20	25	30	20	20	35	55
Northern Piedmont	15	20	25	30	20	25	25	30
Northern Mountains	15	20	25	25	20	20	25	30
Southern Mountains	15	20	25	30	20	25	25	30

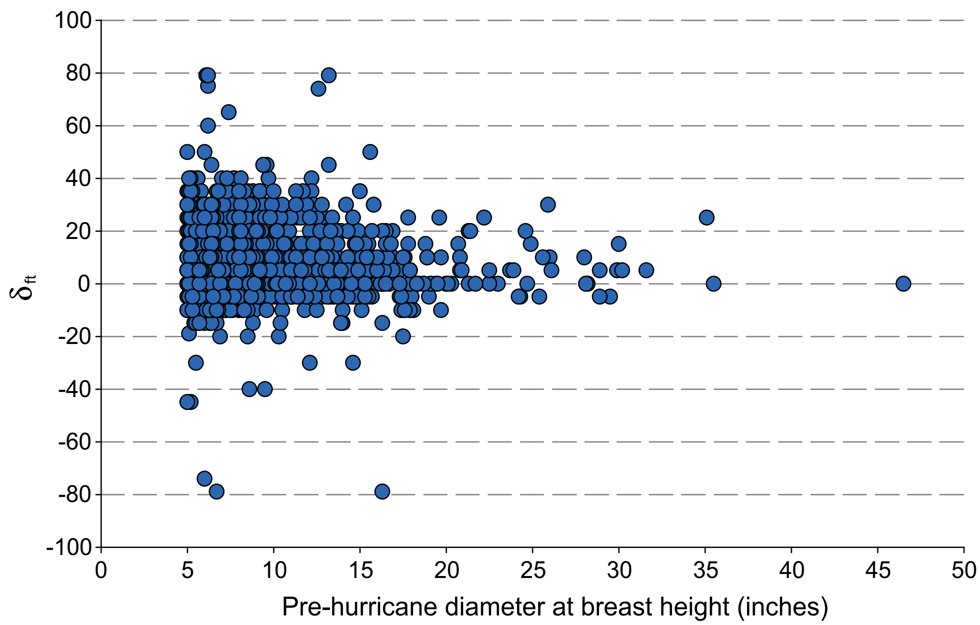

Figure 2: Change in foliage transparency for trees measured before and after Hurricane Isabel by pre-hurricane diameter at breast height.

difference in the average change in foliage transparency by crown position (figure 4). Across the State, $\bar{\delta}_{ft}$ ranged from -6.3 percent to 31.3 percent on individual plots, with the highest $\bar{\delta}_{ft}$ occurring on plots in the eastern half of the State (figure 5). In the Coastal Plain, $\bar{\delta}_{ft}$ was 10 percent or more on 70 percent of the plots. In the Piedmont units, $\bar{\delta}_{ft}$ was 10 percent or more on 18 percent of the plots. In the Mountain units only three plots (12 percent) had $\bar{\delta}_{ft}$ of 10 percent or more.

Discussion

Even in the absence of a stressor, small changes in crown condition over time generally are expected due to the natural year-to-year variability in tree crowns. The significant increase in average foliage transparency for almost all species groups, along with the sizeable shifts in the 90th percentiles suggest that more

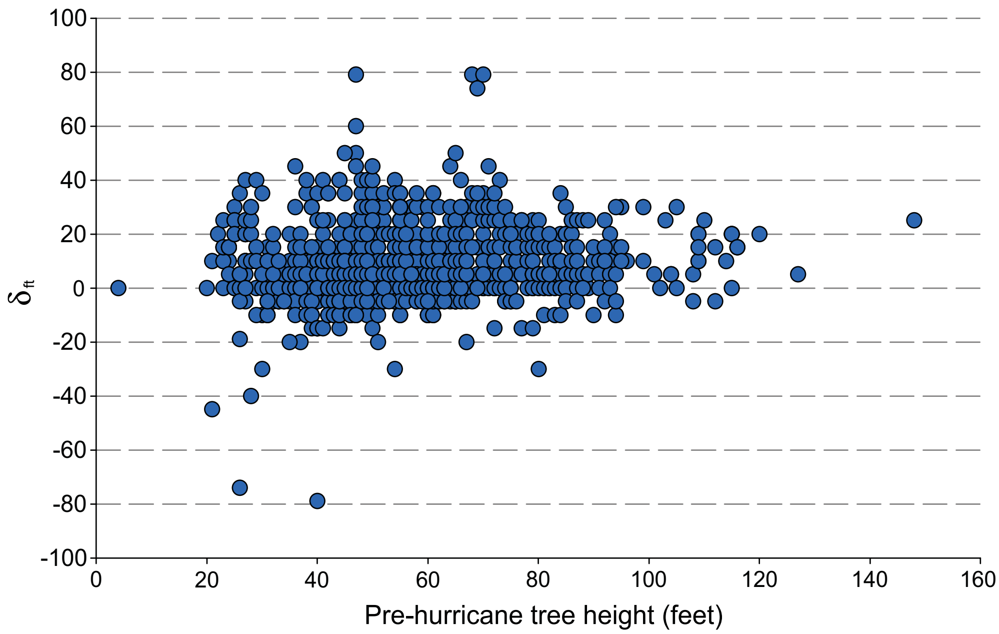

Figure 3: Change in foliage transparency for trees measured before and after Hurricane Isabel by pre-hurricane height.

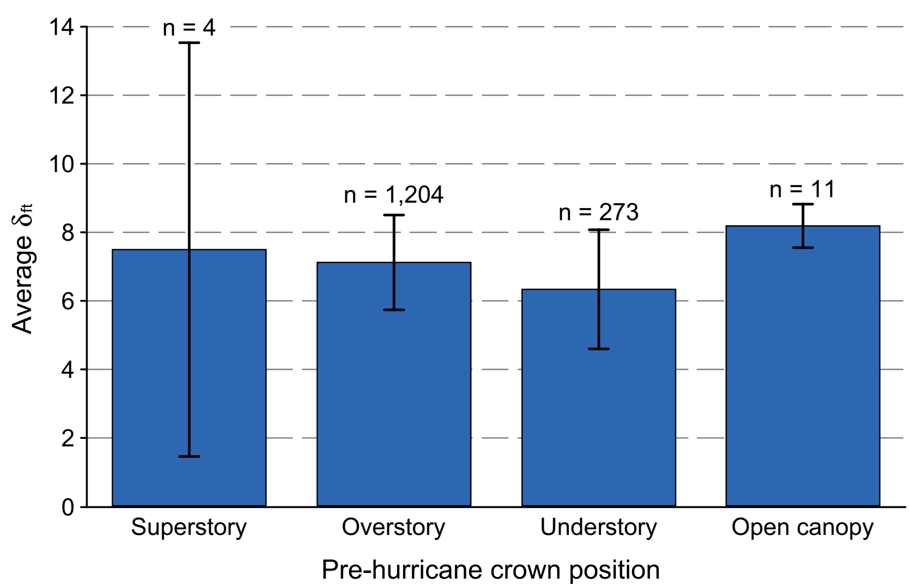

Figure 4: Average change in foliage transparency by pre-hurricane crown position, with standard error bars and sample size.

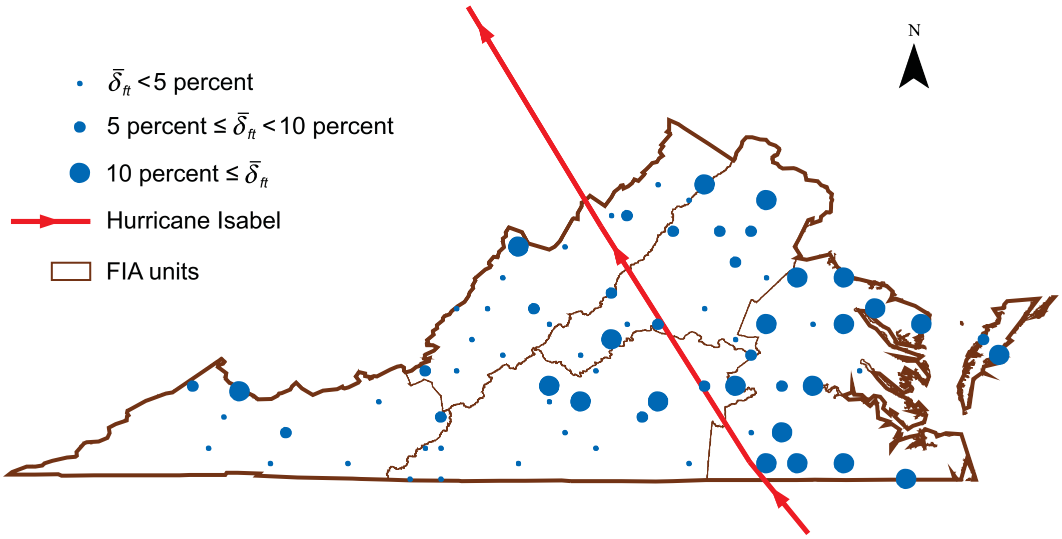

Figure 5: Change in percent foliage transparency for trees measured before and after Hurricane Isabel averaged at the plot level ($\bar{\delta}_{ft}$). Only plots with three or more live trees ≥ 5.0 inches (12.7 cm) d.b.h. are shown. Plot locations are approximate.

than just year-to-year variability was observed between the 7th and 8th surveys. Furthermore, the average change in crown density also indicated a significant loss in crown biomass at the State level as well as for most survey units and species groups (unpublished data). Thresholds for biologically significant changes have not been established for foliage transparency at this point in time. Therefore, changes in descriptive statistics highlight potential declining conditions.

The greatest changes in foliage transparency were observed in the eastern part of the State. Given the counter-clockwise rotation of hurricanes in the Northern Hemisphere and the north-westerly track of Hurricane Isabel, the greatest damage is expected on the northeast side of the hurricane's path. From the individual unit statistics and mapped plot averages, it is clear that this was the case in the Coastal Plain, though perhaps greater changes in foliage transparency were expected in the Northern Piedmont.

Boucher and others (2005) investigated the impact of Hurricane Isabel on a study site in Maryland, where individual trees on a 100 m by 100 m (328 ft by 328 ft) permanent plot were measured just prior to and again immediately after the hurricane passed through the area. After the hurricane they found a significant increase in the number of trees with severe damage. They also determined that trees with larger d.b.h. were more likely to suffer severe damage than smaller trees, and that for any given d.b.h., taller trees were more likely to be severely damaged than shorter trees. The present study did not find a significant correlation between d.b.h., height, crown position, and hurricane damage. However, Boucher and others (2005) considered damage as uprooting and leaning, and this study did not take those variables into account.

An increase in foliage transparency indicates a loss of foliage and hence, a loss of potential energy capture. The impact of foliage loss on tree growth in Virginia was not explored in this study; however, trees measured as late as 2006 still had elevated levels of transparency suggesting that trees experiencing foliage loss as a result of high winds and rain may take several years to recover. Despite the potential impact on growth, the loss of leaves may have prevented more serious damage by significantly reducing wind resistance (Putz and Sharitz 1991). Hedden and others (1995) reported that a 25 percent crown loss is more effective in preventing mortality than stem bending or branch streamlining at wind speeds below category 3 hurricanes, i.e., < 111 miles per hour (178 km per hour).

Conclusion

Quite often, studies of forest damage due to storms are limited in scale, with field measurements taken on subjectively and preferentially selected plots only after the storm has occurred. This preferential sampling typically emphasizes forest stands with unique characteristics, such as mature forests, or stands that have unusual features, such as rare species, making it problematic to determine the true scope of the damage across the landscape. In contrast, our approach utilized repeated measures on plots that were systematically distributed across Virginia. This allowed for the study of a wide range of stands across a variety of conditions before and after the hurricane.

The location of our study sites across the entire landscape and the observation that the greatest changes occurred in the Coastal Plain, lends support to the hypothesis that the changes in foliage transparency were due, at least in part, to the impacts of Hurricane Isabel. In addition to the crown condition indicators, a host of other individual-tree and plot-level variables are assessed on each plot. These include tree length, down woody material, and forest floor thickness. These data, along with auxiliary weather data (e.g. wind speeds and rainfall) are being explored to further understand and quantify the potential damage caused by Hurricane Isabel.

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