HURRICANE IMPACTS ON FOREST RESOURCES IN THE EASTERN UNITED STATES: A POST-SANDY ASSESSMENT

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Abstract—Extreme weather events play a role in shaping the composition and structure of forests. Responding to and mitigating a storm event in a forested environment requires information about the location and severity of tree damage. However, this information can be difficult to obtain immediately following an event. Post-storm assessments using regularly collected forest information from the Forest Inventory and Analysis (FIA) program of the USDA Forest Service can help inform response to future storm events. We analyzed data from the FIA program for an area along the Atlantic Coast directly in the path of Hurricane Sandy in October 2012 as well as an area in West Virginia that received heavy snowfall coincident with the hurricane. The ratio of damaged trees to all live trees was not substantially different between the pre- and post-storm observations at field sites. However, the ratio of trees with broken tops to all live trees increased in the path of the storm from 0.025 to 0.041 and from 0.019 to 0.040 in the heavy snowfall area. Hardwoods experienced an increase in broken tops in both areas, while for softwoods, an increase occurred only in the heavy snowfall area.

Extreme weather events act upon forests with outcomes ranging from minor changes in forest structure to major compositional shifts with long-term ecological consequences. Impacts on forests have been documented using diverse methodologies, including satellite remote sensing and field studies, for multiple types of severe weather such as ice storms (Bragg et al. 2003, Irland 2000), wind storms (Everham and Brokaw 1996, Nelson et al. 2009, Stueve et al. 2010), tornadoes (Peterson 2000), and hurricanes (Boose et al. 1994, Boutet and Weishampel 2003). Because of the sudden and dramatic implications of these major disturbance events, land managers and policy makers need rapid assessments of the impacts to forests. Gathering this type of information using remote sensing is often complicated by cloud cover that accompanies weather events, and logistical and safety challenges can impede immediate in situ data collection. As such, each new weather event is an opportunity to inform responses to future events. The Forest Inventory and Analysis (FIA) program of the USDA Forest Service collects forest data on a network of field plots across the United States on a recurring basis. Our objective was to use FIA data to assess changes in the condition of forest resources following a major hurricane which made landfall in the eastern United States.

Hurricane Sandy battered the Atlantic Coast of the United States in late October 2012, resulting in saltwater inundation from storm surges, rain-induced flooding, property damage estimated in the billions of dollars, and loss of life. Farther inland, a co-occurring cold weather system deposited nearly 1 meter of snow in the mountains of West Virginia and Maryland as well as heavy snow in five other states over the course of 2 days.

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METHODS

We identified FIA plots for two storm-damaged areas: the Atlantic Coast, which experienced high winds in the direct path of the storm in parts of several states (for this analysis, Connecticut, Delaware, Maryland, New Jersey, New York, Pennsylvania, and Rhode Island); and the Appalachian Mountains of West Virginia, which received heavy snowfall (Fig. 1).

In the Atlantic region, areas of probable high winds (25.7 – 32.9 m sec-1) were identified using wind swath data from the National Hurricane Center. Areas of high snowfall (≥50 mm snow water equivalent) in the West Virginia Appalachians were identified using data from the National Operational Hydrologic Remote Sensing Center Snow Data Assimilation System (NOAA 2004). For both regions, we selected FIA plots that were visited after the storm in either 2012 or 2013 and compared them to their previous plot visit, which occurred 5 to 7 years earlier (Atlantic Coast: n=195; West Virginia: n=193). Using standard FIA estimation procedures (Bechtold and Patterson 2005), we examined the ratio of trees damaged by weather events to all live trees for trees greater than 12.7 cm d.b.h. for both the pre- and post-storm conditions. Damage was assessed with regard to both damage agent codes recorded by field staff as well as those trees for which a broken top was recorded. This ratio was estimated for all trees as well as separately for select hardwoods and softwoods common in each area, and also by genus.

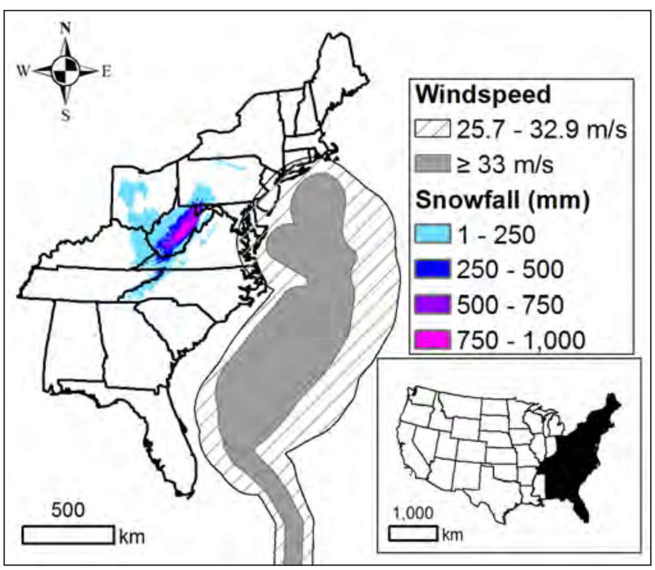

Figure 1.— Areas impacted by Hurricane Sandy in 2012. Both areas of high snowfall in the mid-Atlantic states and areas of probable high winds in the direct path of the storm are shown.

We note that for a damage code to be recorded for an individual tree, a threshold must be met. For example, the threshold for wind damage is as follows:

Any damage to the terminal leader; damage = 20 percent of the roots or boles with >20 percent of the circumference affected; damage >20 percent of the multiple-stems (on multi-stemmed woodland species) with >20 percent of the circumference affected; >20 percent of the branches affected; damage = 20 percent of the foliage with > 50 percent of the leaf/needle affected (USDA Forest Service 2010).

Broken tops are recorded for live trees if completely detached from the bole.

RESULTS

The ratio of weather-damaged trees to all trees was very low in both the path of the hurricane and in the heavy snowfall area in West Virginia and was not substantially different prior to Hurricane Sandy (Table 1). There is some variation between hardwoods and softwoods and by genus, although we note that high standard errors limit interpretation at the genus level. The impact is more apparent with regard to broken tops. In the coastal area, the broken top ratio increased from 0.025 to 0.041. The West Virginia snowfall area experienced a similar increase from 0.019 to 0.040. The ratio of broken tops for softwoods increased tenfold in the heavy snowfall area with most of the change occurring in eastern hemlock (Tsuga canadensis). Broken tops nearly doubled in hardwoods for the West Virginia study area with most tree species experiencing some increase.

In the coastal hurricane path, softwoods showed a slight, but unsubstantial decrease (Table 1). The hardwood broken top ratio increased from 0.033 to 0.057 with every genus experiencing some increase (although changes for some species are not substantial). Both Nyssa and Liquidambar (primarily tupelo and sweetgum species) had broken tops on more than 11 percent of all live trees after the storm.

Table 1—Ratio of trees damaged by weather to all trees and ratio of trees with broken tops to all trees. The sample size of live trees used in each ratio estimate is provided, as well as the lower and upper bounds of the 95 percent confidence interval (95% C.I.). Estimates are provided for all species combined, for common hardwoods/softwoods, and by genus for common species. Estimates are provided for an area affected by high winds in the path of Hurricane Sandy and for an area in West Virginia that received more than 50 mm snow water equivalent in a single storm event.

	Ratio of weather damage		Ratio of broken tree tops		n (live trees)	
	Pre-storm (95% C.I.)	Post-storm (95% C.I.)	Pre-storm (95% C.I.)	Post-storm (95% C.I.)	Pre-storm	Post-storm
Hurricane Path						
Overall (Total)	0.005 (0.0004, 0.0096)	0.008 (0.0034, 0.0126)	0.025 (0.0181, 0.0319)	0.041 (0.0320, 0.0500)	4236	4888
Common Softwoods	0.001 (0.00, 0.0031)	0.002 (0.00, 0.0047)	0.010 (0.0034, 0.0166)	0.008 (0.0022, 0.0138)	1197	1379
Chamaecyparis	0.000 (N/A)	0.016 (0.0013, 0.0307)	0.030 (0.0109, 0.0491)	0.017 (0.00, 0.0354)	70	64
Pinus	0.001 (0.00, 0.0031)	0.001 (0.00, 0.0029)	0.006 (0.0013, 0.0107)	0.005 (0.0004, 0.0096)	1127	1315
Common Hardwoods	0.007 (0.0003, 0.0137)	0.011 (0.0044, 0.0176)	0.033 (0.0237, 0.0423)	0.057 (0.0449, 0.0691)	2611	2970
Acer	0.005 (0.00, 0.0106)	0.017 (0.0019, 0.0321)	0.028 (0.0115, 0.0445)	0.051 (0.0330, 0.0690)	804	958
Fagus	0.000 (N/A)	0.020 (0.00, 0.0609)	0.027 (0.00, 0.0791)	0.032 (0.00, 0.0757)	58	69
Ilex	0.000 (N/A)	0.006 (0.00, 0.0185)	0.013 (0.00, 0.0419)	0.074 (0.0122, 0.1358)	136	185
Liquidambar	0.027 (0.00, 0.0797)	0.009 (0.00, 0.0212)	0.073 (0.0288, 0.1172)	0.114 (0.0598, 0.1682)	354	391
Liriodendron	0.017 (0.00, 0.0437)	0.000 (N/A)	0.029 (0.00, 0.0617)	0.065 (0.00, 0.1348)	108	111
Nyssa	0.000 (N/A)	0.013 (0.00, 0.0321)	0.082 (0.0371, 0.1269)	0.113 (0.0711, 0.1549)	200	228
Prunus	0.014 (0.00, 0.0428)	0.007 (0.00, 0.0209)	0.031 (0.00, 0.0677)	0.064 (0.0094, 0.1186)	116	123
Quercus	0.000 (N/A)	0.009 (0.0008, 0.0172)	0.019 (0.0084, 0.0296)	0.025 (0.0088, 0.0412)	768	833
Sassafras	0.027 (0.00, 0.0826)	0.000 (N/A)	0.050 (0.00, 0.1176)	0.083 (0.00, 0.1687)	67	72

Table 1—Ratio of trees damaged by weather to all trees and ratio of trees with broken tops to all trees. The sample size of live trees used in each ratio estimate is provided, as well as the lower and upper bounds of the 95 percent confidence interval (95% C.I.). Estimates are provided for all species combined, for common hardwoods/softwoods, and by genus for common species. Estimates are provided for an area affected by high winds in the path of Hurricane Sandy and for an area in West Virginia that received more than 50 mm snow water equivalent in a single storm event. (continued)

	Ratio of weather damage		Ratio of broken tree tops		n (live trees)	
	Pre-storm (95% C.I.)	Post-storm (95% C.I.)	Pre-storm (95% C.I.)	Post-storm (95% C.I.)	Pre-storm	Post-storm
Snowfall (WV)						
Overall (Total)	0.013 (0.0082, 0.0178)	0.012 (0.0070, 0.0170)	0.019 (0.0134, 0.0246)	0.040 (0.0300, 0.0500)	5360	4778
Common Softwoods	0.002 (0.00, 0.0057)	0.017 (0.0024, 0.0316)	0.005 (0.00, 0.0115)	0.050 (0.0145, 0.0855)	392	376
Picea	0.000 (N/A)	0.025 (0.00, 0.0647)	0.00 (N/A)	0.0 (N/A)	158	160
Tsuga	0.003 (0.00, 0.0087)	0.018 (0.00,0.0369)	0.00 (N/A)	0.067 (0.0183, 0.1157)	234	216
Common Hardwoods	0.014 (0.0087, 0.0193)	0.012 (0.0066, 0.0174)	0.021 (0.0147, 0.0273)	0.039 (0.0290, 0.0490)	3770	3358
Acer	0.017 (0.0080, 0.0260)	0.008 (0.0023, 0.0137)	0.017 (0.0090, 0.0250)	0.036 (0.0209, 0.0511)	1627	1412
Betula	0.004 (0.00, 0.0096)	0.009 (0.00, 0.0194)	0.009 (0.00, 0.0202)	0.017 (0.0032, 0.0308)	544	493
Fagus	0.013 (0.0001, 0.0259)	0.012 (0.00, 0.0242)	0.041 (0.0025, 0.0795)	0.090 (0.0379, 0.1421)	333	329
Fraxinus	0.026 (0.00, 0.0572)	0.033 (0.00, 0.0787)	0.000 (N/A)	0.089 (0.0055, 0.1725)	85	75
Oxydendrum	0.010 (0.00, 0.0288)	0.010 (0.00, 0.0296)	0.046 (0.0125, 0.0795)	0.052 (0.0126, 0.0914)	133	123
Prunus	0.006 (0.00, 0.0175)	0.019 (0.00, 0.0440)	0.027 (0.0031, 0.0509)	0.023 (0.00, 0.0509)	243	249
Quercus	0.006 (0.0000, 0.0120)	0.006 (0.00, 0.0128)	0.015 (0.0050, 0.0250)	0.012 (0.0039, 0.0201)	673	567
Tilia	0.026 (0.00, 0.0766)	0.012 (0.00, 0.0349)	0.035 (0.00, 0.0870)	0.064 (0.0128, 0.1152)	132	110

DISCUSSION

While overall reported estimates of damage were relatively low, this assessment provides an initial indication of the impacts of Hurricane Sandy on forests in the eastern United States. Analysis was influenced by several factors. First, a large-scale, long-lived wind storm (i.e., a derecho) swept through West Virginia on June 29, 2012, just 4 months before the snowfall associated with Hurricane Sandy. Anecdotal reports indicated many trees in the state experienced weather-related damage due to wind gusts up to 44 m sec^{-1}, and it is difficult to separate trees damaged by wind in June and those damaged in the snowstorm in late October when damage observations occurred after both events. In addition, the FIA damage codes used in the region through 2012 were generic and included a single code for weather. As a result, wind damage and heavy snowfall damage could both be labeled as "weather" damage. Beginning with the 2013 inventory year, more detailed codes were implemented. Finally, the amount of FIA data available for the post-storm period was limited at the time of this analysis. Damage appears to be sporadic and patchy with some plots having up to 25 percent of all trees impacted by weather. Yet, a large number of plots in the storm areas had little or no weather-related damage that rose to the threshold described previously. As additional FIA observations become available, we will also examine mortality and down woody materials and should be better able to fully assess the impact on forest resources, in both the direct path of Hurricane Sandy and the associated snowstorm.

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