HURRICANE ISABEL AND THE FORESTS OF THE MID-ATLANTIC PIEDMONT AND BLUE RIDGE: SHORT-TERM IMPACTS AND LONG-TERM IMPLICATIONS

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ABSTRACT

Hurricane Isabel caused large forest blowdowns over a wide area of the Mid-Atlantic, including the Piedmont and Blue Ridge in Maryland, Virginia, and West Virginia. This damage occurred despite these regions being well inland from the coast and maximum wind gust speeds of only about 50 mph (23 $m \cdot s^{-1}$). Forest damage was intensively sampled in a 1-ha plot in the Piedmont of Maryland that had been delimited and tagged five years prior to Hurricane Isabel, and thus can be considered a random sample with respect to storm impact. Additionally, blowdown and control transects were compared at six other locations in the region.

The intensive study site (West Woods Permanent Plot) had 23.5% of its trees showing "severe damage" (uprooting or snapping of the trunk) and destruction of the canopy over 21% of its area. Damage was patchy, with some large gaps of up to 1500 m^2, but with other parts of the plot showing little or no damage. Tree fall was overwhelmingly toward the west. Uprooting—total or partial—was the predominant form of damage (over 19% of trees). The storm contributed an estimated 78 $Mg \cdot ha^{-1}$ of coarse woody debris to the forest floor, over five times the amount previously present and comparable to levels typically found in old-growth forests.

At the intensive study site and in all six blowdown-control pairs, areas of forest with larger trees had the highest probabilities of uprooting. Tuliptree and black cherry were especially likely to be uprooted. These patterns imply that as the secondary forests of the inland Mid-Atlantic grow older and their trees become larger, they will be increasingly vulnerable to damage, even from relatively weak storms. This prediction has implications for a variety of policy questions, including suburban sprawl, land use planning, risk estimation, burial of utility lines, and forest management, as well as for greenhouse warming, nitrogen inputs to the Chesapeake Bay, and the ecology of disturbance.

INTRODUCTION

Most of the articles in this volume concern estuarine ecosystems, particularly those of the Chesapeake Bay. Here the focus shifts to terrestrial, upland ecosystems, in particular, the forests of the Piedmont and Blue Ridge in the Mid-Atlantic region. In this landscape, the predominant impact of Hurricane Isabel resulted from wind damage.

At first glance, one would not have expected Hurricane Isabel to have had much impact on the forests of this region. Its intensity at landfall was only Category 2. By the time it reached the Piedmont of central Maryland, it had traveled across several hundred kilometers of Coastal Plain and the storm had diminished to tropical storm intensity with wind speeds comparable to those of thunderstorms, winter nor'easters, and other storms typical of the region that may occur annually or more frequently.

Several of the initial descriptions of Isabel's impact on the Piedmont matched the expectation of little impact on the inland areas. Some officials did describe the storm's impact in dire terms, but other coverage emphasized that damage appeared to be less than expected—at least in inland areas.

The headline in the Frederick News-Post on the day after the storm was “Isabel Not So Bad,” and climatologist Patrick Michaels, in an op-ed a week later, said simply: “As windbags go, Isabel was a weenie” [1, 2].

In this paper, the authors show that although such statements accurately describe wind speeds, the damage to inland forests was considerably greater than expected. Furthermore, the factors that led to the forests’ vulnerability, such as large tree size, particularly in species such as *Liriodendron tulipifera* (tuliptree or yellow-poplar), are likely to become more important in coming decades. This prediction has implications for several issues of ecology and policy.

METHODS

Wind Gust Estimation

Standard NOAA estimates of sustained winds associated with Hurricane Isabel in our region were used. However, since damage to trees may be more closely associated with wind gusts than with sustained wind speeds, estimates of maximum wind gust intensities at a finer resolution than is possible with official weather station data were also sought.

For this purpose, the authors used the records of maximum wind gusts recorded at the stations of the NBC-4 WeatherNet, affiliated with television station WRC-TV in Washington, D.C. [3]. These stations are located at schools, colleges, federal agencies, and other institutions, and provide daily measurements of basic weather data (including maximum wind gust) available through the television station’s website.

On 29 September 2003, the data for all WeatherNet stations between Manassas, Virginia in the south and Ijamsville, Maryland in the north and from Washington, D.C. in the east to Martinsburg, West Virginia in the west were downloaded. After discarding stations lacking data for 18 and 19 September and excluding one station with anomalously low values as an outlier (NIST, Gaithersburg, Maryland; maximum gusts recorded as 27.8 mph ($km \cdot hr^{-1}$) or 18 September and 4.6 mph ($km \cdot hr^{-1}$) for 19 September), 25 stations contained valid data. The larger of the 18 September and the 19 September “maximum wind gust” values was taken as the estimate. To check for latitudinal and longitudinal trends, the maximum wind gust estimates were regressed against each station’s latitude and longitude.

Study Sites: West Woods Permanent Plot

Site Description

In studies of forest damage by storms, study sites are usually chosen and plots laid out only after storm damage has occurred. This situation creates problems in estimating forest damage, since the exact location of the plot boundaries can have major effects on estimates. Thus, the subjectivity involved in locating study plots makes it difficult to assess whether the forest damage measured is truly representative of the overall landscape.

Serendipitously, a study site in the Piedmont of Maryland had been established 5 years before Isabel with all trees in a 1-ha forest plot at this site identified, tagged, and annually measured from summer 1998 through 2003. Thus, this site provides both long-term background data in addition to detailed estimates of forest damage due to Isabel at a location independent of damage by the hurricane. These estimates can, therefore, be considered as a random sample of the damage to the forests in this region.

The West Woods study site is located in Dickerson, Maryland (39.21º N, 77.42º W) at 100 m elevation in the Piedmont of Maryland, about 50 km northwest of Washington, D.C., 5 km from Sugarloaf Mountain and well inland from the Atlantic coast (220 km). It is located on Penn sandy loam soils over bedrock of New Oxford Triassic sandstone. The site slopes gently to the west (1–5%) down to the floodplain of the Little Monocacy River. The approximately 4 ha of forest is estimated to be 80–100 years old.

A 100 x 100 m Permanent Plot was established within the 4 ha of forest in the summer of 1998; all trees 10 cm DBH (diameter at breast height) and up were tagged, identified, measured, and mapped on a 10 x 10 m grid. As of September

2003, the Permanent Plot had 23 tree species and was dominated by tuliptree (*Liriodendron tulipifera*) and black cherry (*Prunus serotina*). Other important trees were: oaks (*Quercus*, 4 spp.), hickories (*Carya*, 4 spp.), ashes (*Fraxinus*, 2 spp.), maples (*Acer*, 2 spp.), beech (*Fagus grandifolia*), and elm (*Ulmus rubra*). No conifers were present. Tree density was 425 trees·ha^{-1} and the total basal area was 36.32 m^2·ha^{-1} Canopy height, estimated with an electronic clinometer, averaged 33.8 m (SD = 0.6 m, range = 29.4–42.7 m), and was less than 5 m at only 1.7% of the 121 grid points.

Damage Estimation

The annual measurements of the Permanent Plot for summer 2003 had been taken from 22–24 June. These data were updated on the morning of 18 September, just before the hurricane passed over the region. All trees in the plot were checked to see whether they had died since June with their damage status classified on a 7-point scale: 1 = Standing erect ("OK"), 2 = Leaning by 1–15 º, 3 = Leaning 16–30 º, 4 = Leaning 31–45 º, 5 = Leaning more than 45º, 6 = Trunk snapped, and 7 = Uprooted. The direction of leaning or fall was also noted.

Immediately after the hurricane's passage (19–21 September), this damage assessment was repeated for all trees. Trees in category 5 (Leaning by more than 45º) were kept from falling because their crowns were ensnared in neighboring trees and would otherwise have been classified as Uprooted.

Coarse Woody Debris

Coarse Woody Debris (CWD) input to the forest floor of the Permanent Plot by Isabel was estimated using the line transect method [4]. Since the direction of fall was clearly non-random, perpendicular transects in cardinal directions (N-S, E-W) [5] were used. Each piece of CWD was measured, identified, and assigned a decay class using a modified Adams and Owens' classification [6]. Total CWD volume was determined using the standard formula for line-transect sampling; biomass was calculated by multiplying volume by density separately for each species and decay class [5, 6].

Study Sites: Blowdown and Control Paired Transects

To verify conclusions from the West Woods site with replicates at other sites in the region, paired transects were established at six other forest sites in September and October 2003. Each pair consisted of a 0.2-ha transect through a blowdown caused by Isabel and a 0.2-ha transect through adjacent forest that had suffered little or no damage, as a control.

The transect pairs were located at sites in the Piedmont and Blue Ridge within 60 km of the West Woods. From east to west, their locations were: Schaeffer Farms area, Seneca Creek State Park, Maryland (2 sites), Sugarloaf Mountain, Maryland (1 site), Turner's Gap, Maryland (2 sites), and Keyes' Gap, on the Virginia/West Virginia border (1 site). At three sites, the forest is dominated by oaks and hickories, while tuliptree is the dominant at the other three (Table 1). Stand density does not vary greatly among these sites.

Locating these transects involved a certain amount of subjectivity, as discussed above. To minimize this, pre-existing trails were used as the centers of 20-m-wide (10 m on each side of the trail) x 100-m-long transects for both blowdowns and control. After locating the blowdown transect so that its center was within the heavily damaged area, the control transect was placed along the nearest part of the trail that matched the blowdown transect in slope and aspect. In three of the six cases, the control was immediately adjacent to the blowdown; the largest distance between the two transects in a pair was less than 100 m.

In each blowdown and control transect, the DBH of all trees were identified and measured and assigned to damage categories using the same scale as the West Woods site.

Growth Trends of Mid-Atlantic Forests

The findings at the West Woods site and the six blowdown-control transect pairs (see Results) indicated that future growth trends of the region's forests will have a major influence on their vulnerability to damage by storms. To evaluate growth trends, data from the U.S. Forest Service's

Table 1. Mean DBH (mm) of trees in paired 0.2-ha transects in blowdowns caused by Hurricane Isabel and in nearby less-damaged control forest and percent of trees with severe damage (Leaning > 45º, Snapped, or Uprooted) at six sites in the Piedmont and Blue Ridge of Maryland, Virginia, and West Virginia. For paired t-test of difference in mean DBH between blowdowns and controls: Mean difference = 60 mm, t = 5.89, n = 6, P (two-tailed) = 0.002.

Site	Forest type	Blowdown mean DBH (mm; trees·ha^{-1} in parentheses)	Control mean DBH (mm; trees·ha^{-1} in parentheses)	Percent of trees w/ severe damage in blowdown
Sugarloaf E, MD	Tuliptree	380 (305)	284 (405)	28.7
Keyes' Gap, WV-VA	Oak-hickory	312 (330)	248 (570)	9.2
Turner's Gap N1, MD	Tuliptree	355 (260)	283 (355)	13.5
Turner's Gap N2, MD	Oak-hickory	270 (385)	249 (450)	15.6
Schaeffer Farms S Seneca Creek State Park, MD	Tuliptree	395 (390)	349 (435)	14.1
Schaeffer Farms N Seneca Creek State Park, MD	Oak-hickory	332 (415)	268 (500)	6.0

Forest Inventory and Analysis (FIA) project were used. These data are part of a standardized nationwide inventory of forest growth and composition available in tabulated form on the Internet [7] and also summarized in various forms [8, 9]. The data for the state of Maryland, where most of the study sites are located, were used in the study. The most recent FIA data for Maryland are from 1999.

RESULTS

Storm Track and Wind Speeds

Hurricane Isabel's center passed approximately 110 km to the west of the West Woods site between 02:00 and 05:00 on 19 September 2003. The maximum sustained 1-min wind speed in the vicinity of the West Woods Permanent Plot, based on the NOAA Tropical Storm Surface Wind Field Analysis contour map [10], was about 37 mph (16.5 m·s^{-1}). The maximum wind gust for the 25 NBC-4 WeatherNet stations in the study region averaged 50.5 mph (22.6 m·s^{-1}) with a standard deviation of 6.9 mph (3.1 m·s^{-1}). The maximum value recorded among the 25 stations was 62.9 mph (28.1 m·s^{-1}) at Reston, Virginia while the minimum was 36.0 mph (16.1 m·s^{-1}) at Leesburg, Virginia. There was no significant trend in either direction in the regression of maximum wind gust versus latitude and longitude.

Forest Damage: Permanent Plot

Despite these relatively low wind speeds, damage to the Permanent Plot was high (Figure 1). Overall, 15.5% of the trees were uprooted, 4.2% were snapped, and 3.8% were left leaning by more than 45º. These results compare to none uprooted, 0.2% snapped, and 0.7% leaning by more than 45º just before Isabel. Combining these three highest damage categories as "Severe Damage" gives a value of 23.5% after the storm versus just 0.7% beforehand.

Other measures of forest damage yield similar values. Using basal area instead of density to calculate the percentages gives a Severe Damage value of 25.1%. Canopy gap area (points where the canopy height was less than 5 m) was 21.5% of the plot post-Isabel compared to 1.7% prior to the storm.

The direction of fall of the severely damaged trees was overwhelmingly toward the west (mode = 270º), with the large majority falling between 225º and 315º. The spatial pattern of tree fall was quite clumped, with large gaps in some parts of the plot and practically no damage in others. The largest gap was about 1500 m^2, extending from the central part of the plot to the southeast corner; a second gap along the south border of the plot covered about 600 m^2 within the plot and about an equal area outside of it.

Logistic regressions of the probability of severe damage versus DBH and tree species showed significant effects of both. Larger DBH trees were considerably more likely to suffer severe damage ($P < 0.001$). A separate analysis showed that for a given DBH, trees with greater heights were more likely to be severely damaged. While levels of severe damage varied considerably among species, only black cherry was significantly more likely to suffer severe damage after controlling for DBH ($P = 0.004$).

Coarse woody debris input to the forest floor in the Permanent Plot was very large, with an estimated 78 $Mg \cdot ha^{-1}$ being added by the hurricane. This compares to 15 $Mg \cdot ha^{-1}$ present before Isabel. The CWD input was about equally divided between trunks (53%) and branches (47%). An estimated 77.5% of the CWD biomass was from tuliptree, the site's dominant species.

Forest Damage: Blowdown-Control Pairs

The relationship between tree size and severe damage was reinforced by the comparison of the blowdown and control transects at the six other sites. In every case, trees in the blowdown area had a larger mean DBH than trees in the control transects (Table 1), a difference that is highly significant (mean difference = 60 mm, $t = 5.89$, $n = 6$, P (two-tailed) = 0.002). Forest stands dominated by tuliptree had consistently greater levels of severe damage in their blowdown transects (mean of 18.8%), than did forests dominated by oak and hickory (10.3%).

Logistic regression of the probability of severe damage versus DBH and species, taking the trees from the six blowdown-control transect pairs as a

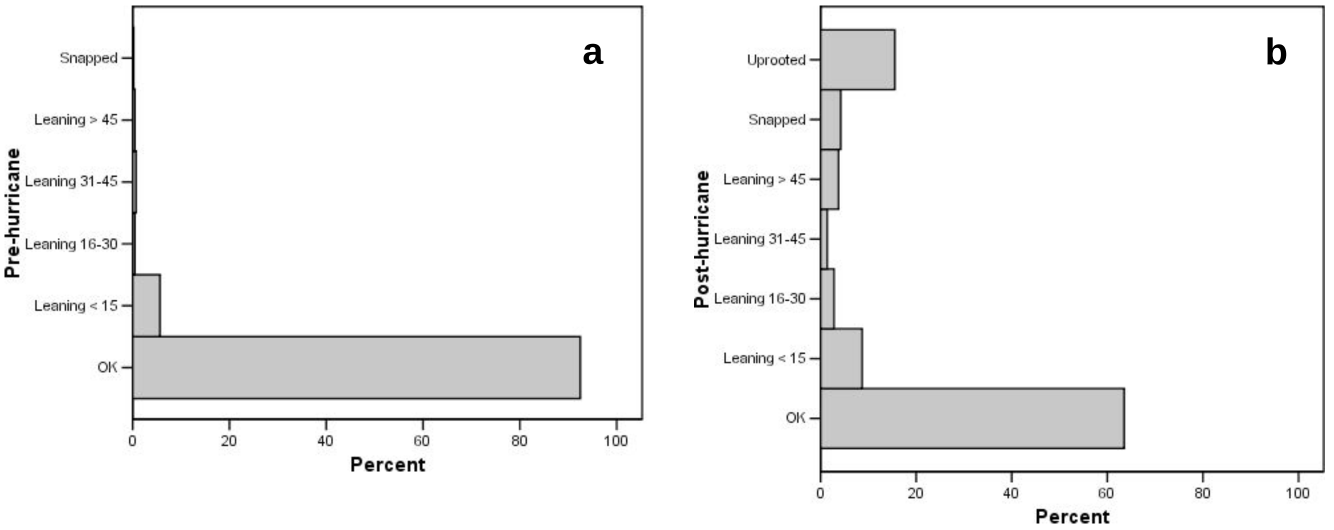

Figure 1. Damage status of trees before (a) and after (b) the passage of Hurricane Isabel at the West Woods Permanent Plot, Dickerson, Maryland. Damage categories were: Standing erect ("OK"); Leaning by 1–15º; Leaning by 16–30º; Leaning by 31–45º; Leaning by more than 45º; and Trunk snapped and uprooted.

whole, shows the same patterns as the paired comparisons. Probability of severe damage is significantly increased by increasing DBH (P = 0.001) and controlling for DBH if the species is tuliptree (P = 0.012) or black cherry (P = 0.016).

Forest Growth Trends in the Mid-Atlantic

The FIA inventories indicate clearly that tree DBHs and timber volumes in Maryland forests have increased substantially in recent decades, and that this trend is continuing. Average timber volume per acre in Maryland forests has grown from 2274 bd-ft·acre^{-1} in 1950 to 6814 bd-ft·acre^{-1} in 1999 [8]. The diameter distribution of tree sizes shifted towards larger trees between 1986 and 1999, with more individuals having diameters above 400 mm (16 in) and fewer with diameters below that size [9].

Tuliptree was already the most abundant tree in the state in 1999 [8]. In coming decades, its relative abundance should increase even more, based on the annual rates of change calculated from the 1999 inventory. That inventory showed that annual net change in sawtimber volume on Maryland timberlands was 155,901 Mbd-ft·yr^{-1}, of which 125,707 Mbd-ft·yr^{-1} was tuliptree (80.6%). The percentage is even higher for growing-stock volume (21,082 M cu-ft·yr^{-1} out of a total 24,137 M cu-ft·yr^{-1}, or 87.3%) [7].

DISCUSSION

Vulnerability of the Region's Forests to Damage by Weak Storms

Taken together, our results indicate that the forests of the Mid-Atlantic Piedmont and Blue Ridge are vulnerable to substantial damage, even from weak storms. Hurricane Isabel had diminished substantially in intensity by the time it reached this region, with maximum wind gusts estimated at only 50.5 mph (22.6 m·s^{-1}). Nevertheless, it severely damaged high percentages of trees at seven forest sites, ranging up to 28.6%. The percentage for the Permanent Plot (23.5%) is especially notable, since this plot was established five years before the hurricane and thus was located without the possible subjective bias in the other samples.

This plot had no true pioneer species, in the sense of species that dominate the early years of succession and then disappear as the canopy closes (e.g., red cedar - *Juniperus virginiana* or Virginia pine - *Pinus virginiana*). Like many century-old forest stands in the Mid-Atlantic, however, it was dominated by fast-growing, shade-intolerant species (tuliptree and black cherry) that persist for centuries during succession, but do not successfully reproduce in their own shade. Such species appear to be particularly vulnerable to damage from wind storms such as Isabel.

Vulnerability to wind damage was clearly related to tree DBH in both the Permanent Plot dataset and the six blowdown-control transects. Furthermore, dominance of forest stands by tuliptree and black cherry further increased vulnerability, compared with oak-hickory stands. Since trends in the region indicate that future forests will have larger DBH trees and will be more and more dominated by tuliptree, vulnerability to windstorms will only increase in decades to come. This prediction is independent of the still-debated idea that hurricane frequency and intensity will increase with global warming [11]

These results reinforce the findings of other researchers studying hurricane impacts in the North Carolina mountains [12, 13, 14, 15]. It is becoming increasingly evident that temperate forest landscapes, as well as tropical ones, can be significantly impacted by disturbances such as hurricanes [16].

Long-term Implications

Over the long term, these results raise questions about our current patterns of land use in the Mid-Atlantic. A major concern in this region is the issue of suburban sprawl, particularly the tendency to develop subdivisions in areas of older forest. This pattern of land use can be expected to produce increasingly severe problems as windstorms occur in coming decades, even if wind velocities are low. If the frequency and/or intensity of future hurricanes increase due to global warming, as has been predicted [11], it will further accentuate these difficulties.

Rather than look upon hurricanes such as Isabel as unforeseeable "acts of God," it is reasonable to take their expected impacts into account in land use planning. These impacts are relevant to such concerns as:

- The debate about the burial of utility lines, which reduces the danger of outages due to trees falling on above-ground lines.
- Calculations of insurance risk based on past history of storm damage, without accounting for the effects of changing size and composition of forests.
- Trends in forest management, including harvest and land-use policies, which have tended to decrease the proportion of oaks.
- The growing threat of invasive exotic species, perhaps further aggravated by high white-tailed deer densities [17].

These findings also have implications for important ecological questions. McNulty [18] has made the case that because of their substantial CWD input, "hurricanes are a significant factor in reducing short-term carbon storage in U.S. forests." His regional analysis showed that hurricanes can be expected to lower the amount of carbon sequestered by eastern forests by about 10%. This study complements McNulty's findings: CWD levels after a single weak hurricane that were comparable to those typical of old-growth forests [4]. Lowered estimates of carbon sequestration by forests imply that greenhouse warming may be a more serious problem than previously thought.

Such major impacts on biomass also affect the forest's role in storing other elements, such as nitrogen. This storage role is an important link between the terrestrial ecosystems of the Chesapeake watershed and the dynamics of the Bay's aquatic ecosystems. While the data necessary to estimate release of N or other nutrients from forests due to Isabel are not currently available, this link between land and water deserves increased scrutiny from both terrestrial and aquatic scientists.

Finally, these findings can alter our view of the role of disturbance in structuring ecological communities. They indicate that disturbance impact is a function not only of the physical characteristics of the disturbance but also of the community's composition, which depends on its land use history. Land use decisions being made today, interacting with future disturbances similar to Isabel, will produce the forest landscape of the Mid-Atlantic in the 21st century.

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