USDA FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

Southern Research Station | Research Paper SRS-65 | March 2022

Assessing Forest Resource Damage Following Natural Disasters Using National Forest Inventory Plots: A Case Study of Hurricane Michael

Thomas Brandeis, Jeffery Turner, Andrés Baeza Castro, Mark Brown, and Samuel Lambert

Author Information:

Thomas Brandeis, Supervisory Research Forester, U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis, Knoxville, TN 37934.

Jeffery Turner, Supervisory Biological Scientist, U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis, Knoxville, TN 37934.

Andrés Baeza Castro, Biological Scientist, U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis, Knoxville, TN 37934.

Mark Brown, Forester, U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis, Knoxville, TN 37934.

Samuel Lambert, Forester, U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis, Knoxville, TN 37934.

PHOTO CREDITS: USDA Forest Service photos by Jason Cooper, unless otherwise noted.

ERRATA (August 2022): Four minor corrections were made to tables 4, 8, 11, and 13—the State names "Georgia" and "Florida" were switched. The States should have been listed in alphabetical order.

March 2022
https://doi.org/10.2737/SRS-RP-65

Forest Service
Research & Development
Southern Research Station
Research Paper SRS-65

Southern Research Station
200 W.T. Weaver Blvd.
Asheville, NC 28804
www.srs.fs.usda.gov

Contents

Assessing Forest Resource Damage Following Natural Disasters Using National Forest Inventory Plots: A Case Study of Hurricane Michael

Thomas Brandeis, Jeffery Turner, Andrés Baeza Castro, Mark Brown, and Samuel Lambert

Broken tree stems and large amounts of down woody materials can be seen in this badly damaged mixed pine-hardwood forest.

Abstract

Hurricane Michael, a Category 5 storm that made landfall on October 10, 2018, caused considerable damage in the States of Alabama, Florida, and Georgia. We assessed forest resource damages using the U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program's permanent forest inventory plot network and the National Oceanic and Atmospheric Administration's defined storm damage severity zones. This assessment showed there had been 6.17 million acres of forest land with 10.01 billion cubic feet of timber within the damage zones. Of that total, 6.81 billion cubic feet remained alive after the hurricane, 1.54 billion cubic feet were standing dead, and 1.66 billion cubic feet were utilized. This represents a total of 68.0 percent of live tree volume surviving across the entire damage zone, with survival decreasing from 74.5 percent in moderately damaged areas to 36.6 percent in the catastrophically damaged areas. The percentage of utilized tree volume across all damage severity zones averaged 16.6 percent, with higher utilization rates in the catastrophic zone (39.4 percent). Over the entire damaged area, more volume per acre was left alive (1,103.50 cubic feet per acre) than left standing dead (248.97 cubic feet per acre) or utilized (269.67 cubic feet per acre). But this varied by State, damage severity zone, and major species group. Pines (*Pinus* spp.) showed decreasing amounts of live volume remaining in the forest with increasing damage severity, ranging from 70.0 percent in the moderately damaged zone to 22.7 percent in the catastrophically damaged zone. Other softwoods and both hardwood groups were less impacted than pines. The percentage of volume utilized after the hurricane was highest for the pines, with 50.5 percent of the pre-hurricane live volume utilized in the catastrophically damaged zone. The amounts of down woody materials found on the forest floor on plots remeasured after the passage of Hurricane Michael were considerably (over four times) higher than those found prior to the hurricane, most notably for coarse woody materials and piles.

KEYWORDS: Damage assessment, down woody materials, forest inventory, hurricane, natural disaster, tree mortality, wood volume.

Introduction

On October 10, 2018 near 1330 Eastern Daylight Time (EDT), the eye of Hurricane Michael made landfall in the Florida Panhandle near the city of Mexico Beach and Tyndall Air Force Base as a Category 5 (on the Saffir-Simpson Hurricane Wind Scale) hurricane (Beven and others 2019). Some 4 hours later (1730 EDT), the eye had crossed into southwestern Georgia; by 2000 EDT, it was another 50 miles into Georgia, passing west of Albany, further weakening from a Category 3 to a Category 1 hurricane. By 0200 on October 11, it was 170 miles into Georgia and had deteriorated to a tropical storm, reaching South Carolina by 0900 EDT, passing through North Carolina and Virginia, and then heading out to sea by 0200 EDT on October 12.

The storm's intense winds and storm surge caused 16 deaths in the United States and an estimated $25 billion in damages, some of the worst of which were in Bay County, FL, where 1,584 buildings out of 1,692 were damaged (Beven and others 2019). In addition to the loss of life and structural damage, Michael passed through a region of economically important timberlands, causing considerable damage to productive pine (*Pinus* spp.) plantations and naturally regenerated hardwood and mixed pine-hardwood forests (see Brandeis and others 2016, Brown and others 2017, and Hartsell 2018 for more information on the forest resources like forest land area and tree volume for Georgia, Florida, and Alabama, respectively). Assessing the degree of damage was a priority for State and Federal natural resource agencies.

The U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis (SRS FIA) program is responsible for inventorying the forest resources of the Southern United States and produces annually updated estimates of forest land, available wood volume, forest health, and many other parameters using

data collected from a permanent plot network spread across the region (Bechtold and Patterson 2005). The SRS FIA program made an initial rapid assessment of forest resource losses from Hurricane Michael based on forest land plots measured in the years prior to the hurricane's passage in 2018. This rapid assessment for the States of Alabama, Florida, and Georgia estimated that 5.30 million acres of forest land owned by 91,000 owners were damaged and 2.55 billion cubic feet of volume lost, with a potential total loss of 3.19 billion cubic feet if future tree form and canopy damage were considered (USDA Forest Service 2018a). These losses were expected to affect the flow of timber to 23 wood processing facilities within Michael's damage zone, and potentially to 154 facilities within 150 miles of the outside edge of the severe and catastrophic damage zones (USDA Forest Service 2018b).

The Georgia Forestry Commission used aerial surveys to assess and quantify the damage to their timber resources, estimating 2.37 million acres of forest land were impacted within the State (Georgia Forestry Commission 2018). Using pre-hurricane FIA data from within affected Georgia counties, they further estimated wood volume losses of 20.31 million green tons of pine and 17.18 million tons of hardwood with an approximate value of $276.68 million (Georgia Forestry Commission 2018). The Florida Forest Service also conducted a damage assessment within their State, with initial estimates of >2.81 million acres of forest altered, damaged, or destroyed with a value loss of $1.29 billion, based on aerial surveys and queries of the FIA data similar to those used in Georgia (Florida Forest Service 2018). The State of Alabama did not produce its own damage assessments because the area of forest land affected there was comparatively small.

Starting in the spring of 2019, the SRS FIA program began plans to revisit and remeasure a subset of its permanent forest inventory plots within the Hurricane Michael damage zone (fig. 1). This study's objectives were to provide information on the extent of the damage to the timber resource (expressed in terms of the numbers of trees and their wood volume) in this damaged area based on post-hurricane field measurements, as well as how those impacts varied according to the National Oceanic

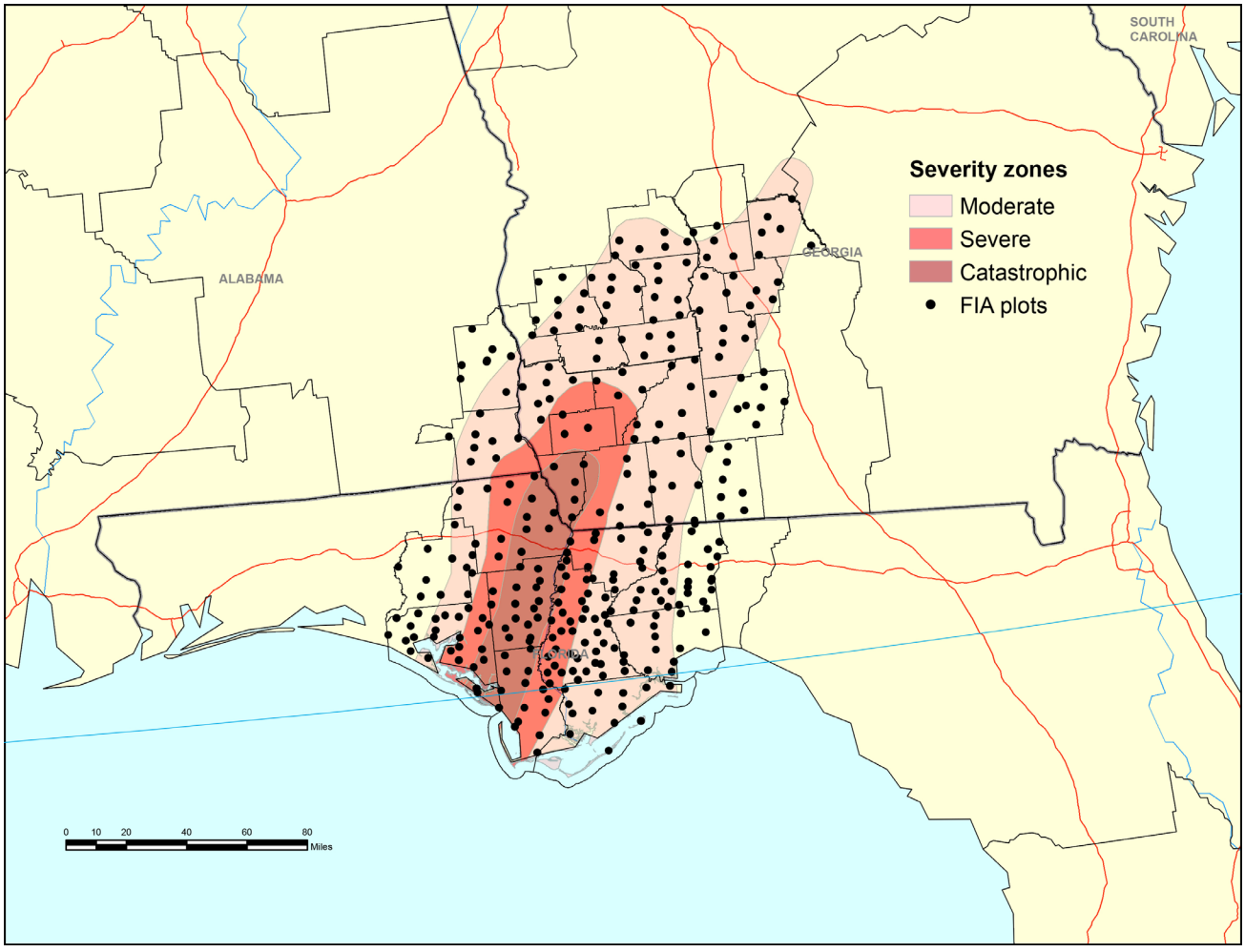

Figure 1—National Oceanic and Atmospheric Administration's (NOAA) Hurricane Michael damage severity zones in the States of Alabama, Georgia, and Florida and the Forest Inventory and Analysis (FIA) plots measured as part of the damage assessment.

and Atmospheric Administration's (NOAA) damage severity zones and major tree species group, with summaries for the entire area and by State. Additionally, we took the opportunity to assess the efficacy of this assessment data collection effort in meeting those objectives and suggest future improvements where needed.

Methods

Impacted Area and Damage Severity Zone Delineation

Three zones of forest damage severity (light to moderate, severe, and catastrophic) were delineated by NOAA in Alabama, Florida, and Georgia (fig. 1). Forests with light to moderate damage (which will simply be referred to as moderate) were those determined to have experienced winds up to 110 miles per hour (mph) (which includes Saffir-Simpson Category 1 and 2 hurricanes) and potentially heavy rains. Damage was described as mainly occurring in small to large size tree limbs, downed trees, and an increase in litter with the canopy slightly broken. Approximately 15 percent of the trees were in the range of light damage. On moderately damaged sites, there were numerous small-, medium-, and large-diameter limbs on the ground, a significant number of trees on the ground, treetops broken out, and fragmented forest canopy, and some type of disturbance was expected over approximately 45 percent of the trees or area. Severely damaged forests were characterized by hurricane winds in the range of 111–129 mph (Saffir-Simpson Category 3), very large rainfall amounts, and areas of widespread destruction of forest stands. On these sites, around 25–40 percent of the trees have been laid on the ground by the storms or all the tops have been broken. The trees in these forests could be considered "jack-strawed." In general, some type of disturbance could be expected over approximately 60 percent of the trees or area. Catastrophically damaged forests experienced winds 130–156 mph and above (Saffir-Simpson Category 4). Later reassessments of Michael recategorized the hurricane as having made landfall as a Category 5 with wind speeds exceeding 157 mph. Most trees were snapped or uprooted, and damages were expected to reach 95 percent or more. Scattered forest damage exists outside of these zones due to gale force winds but was considered indeterminate and not included in this study. The total impacted area (the sum of all three damage severity zones in both forest and nonforest lands) was 8,254,404.76 acres. There were 6,168,313 acres of forest land within the damaged zone, with the most forest acreage in Florida (table 1).

Table 1—Area of forest land by State within the NOAA-defined damage severity zones for Hurricane Michael

State	Damage severity zone			State total
	Moderate	Severe	Catastrophic	
	thousands of acres			
Alabama	117.46	0	0	117.46
Florida	1,925.29	1,119.22	738.27	3,782.78
Georgia	2,043.45	135.20	89.43	2,268.07
Zone total	4,086.19	1,254.42	827.70	6,168.31

NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

A network of access roads and skid trails are needed for a salvage logging operation.

Hurricane Michael left forest stands within the impacted areas with a mix of live, standing dead, broken, and windthrown trees.

Plot Sampling

The SRS FIA plots that were not measured after the damage from Michael (those from inventory years 2020 in Alabama, 2019 in Georgia, and 2017 and 2018 in Florida) were revisited before their normally scheduled remeasurement. We took a reduced suite of FIA plot measurements based on the version 9.0 SRS FIA field manual (USDA Forest Service 2020). This gave a total of 331 existing FIA plots, with 265 within the NOAA-defined damage severity zones (177 plots within the moderate damage zone, 44 in the severe damage zone, and 44 in the catastrophic damage zone) and 66 outside these damage zones but within affected counties (table 2, fig. 2). The intent with remeasuring FIA plots outside the damage zones was to allow for complete county-level summaries for those counties not entirely within the damage zones (see app. A for the complete list of counties by State and damage severity zone). We chose not to make county-level summaries for this report and therefore did not include these data in this study.

In many of the damaged plantations, all trees were harvested to prepare the site for replanting.

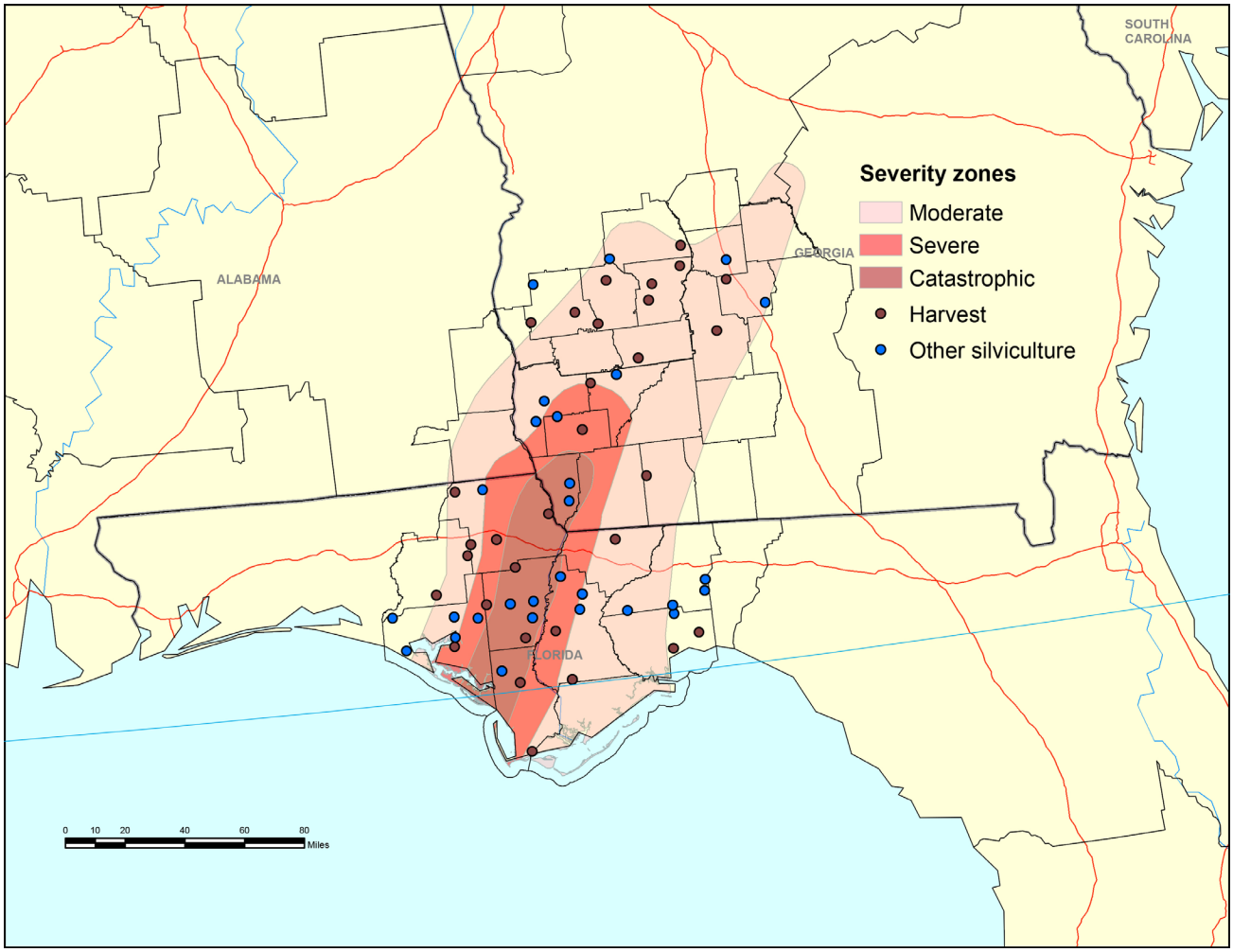

Figure 2—Forest Inventory and Analysis plots remeasured that had harvesting or other silvicultural activity post-hurricane as part of the Hurricane Michael damage assessment in the States of Alabama, Florida, and Georgia within National Oceanic and Atmospheric Administration's (NOAA) damage severity zones.

Table 2—Numbers of Forest Inventory and Analysis plots by State sampled within and adjacent to the NOAA-defined damage severity zones for Hurricane Michael

State	Plot status	Damage severity zone	Number of plots
Alabama	Forest	Moderate	4
		Outside of damage zone	5
	Nonforest	Moderate	4
		Outside of damage zone	3
		State subtotal	16
Florida	Forest	Moderate	75
		Severe	34
		Catastrophic	33
		Outside of damage zones	31
	Nonforest	Moderate	7
		Severe	3
		Catastrophic	5
		Outside of damage zones	2
	Missing[a]	Moderate	1
		Severe	1
		Catastrophic	1
		Outside of damage zones	1
		State subtotal	194
Georgia	Forest	Moderate	70
		Severe	4
		Catastrophic	4
		Outside of damage zones	21
	Nonforest	Moderate	16
		Severe	2
		Catastrophic	1
		Outside of damage zones	3
		State subtotal	121
	Total		331

NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

[a] Not sampled because the plot could not be located and the field crew did not put in a replacement plot.

Much of the area damaged by the passage of Hurricane Michael held managed southern yellow pine stands.

This pine forest was almost completely destroyed by the passage of Hurricane Michael. Courtesy photo by Jarek Nowak, Florida Forest Service.

Field Plot Measurement and Data Processing

Not all variables normally collected on an FIA Phase 2 national forest inventory permanent plot were collected on the plots revisited for the Hurricane Michael damage assessment. The standard field data collection protocols can be found in USDA Forest Service (2020). Appendix B summarizes the variables collected, and appendix C has the full text of the FIA Mobile Integrated Data Acquisition System (MIDAS) PROMPT file that indicates which variables are to be completed by field crew and which were excluded. A key feature of the damage assessment was the exclusion of current diameter at breast height (d.b.h.) and tree height from the remeasurement. All trees (live, standing dead, and utilized) on all four subplots (fig. 3) were accounted for, and for those left alive, damages were described using standard procedures.

Specific damages of interest for this study were:

◊ Abiotic (i.e., not caused by other organisms), which could include:

- Any damage to the terminal leader
- Damage ≥20 percent of the roots or boles 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

◊ Human (signs of open wounds or embedded foreign objects caused by a variety of activities [e.g., poor pruning, vandalism, logging injury]), which could include:

- Any damage to the terminal leader
- Damage ≥20 percent of the roots or boles 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.

◊ Harvest

- Removal of ≥10 percent of a tree's total cubic volume

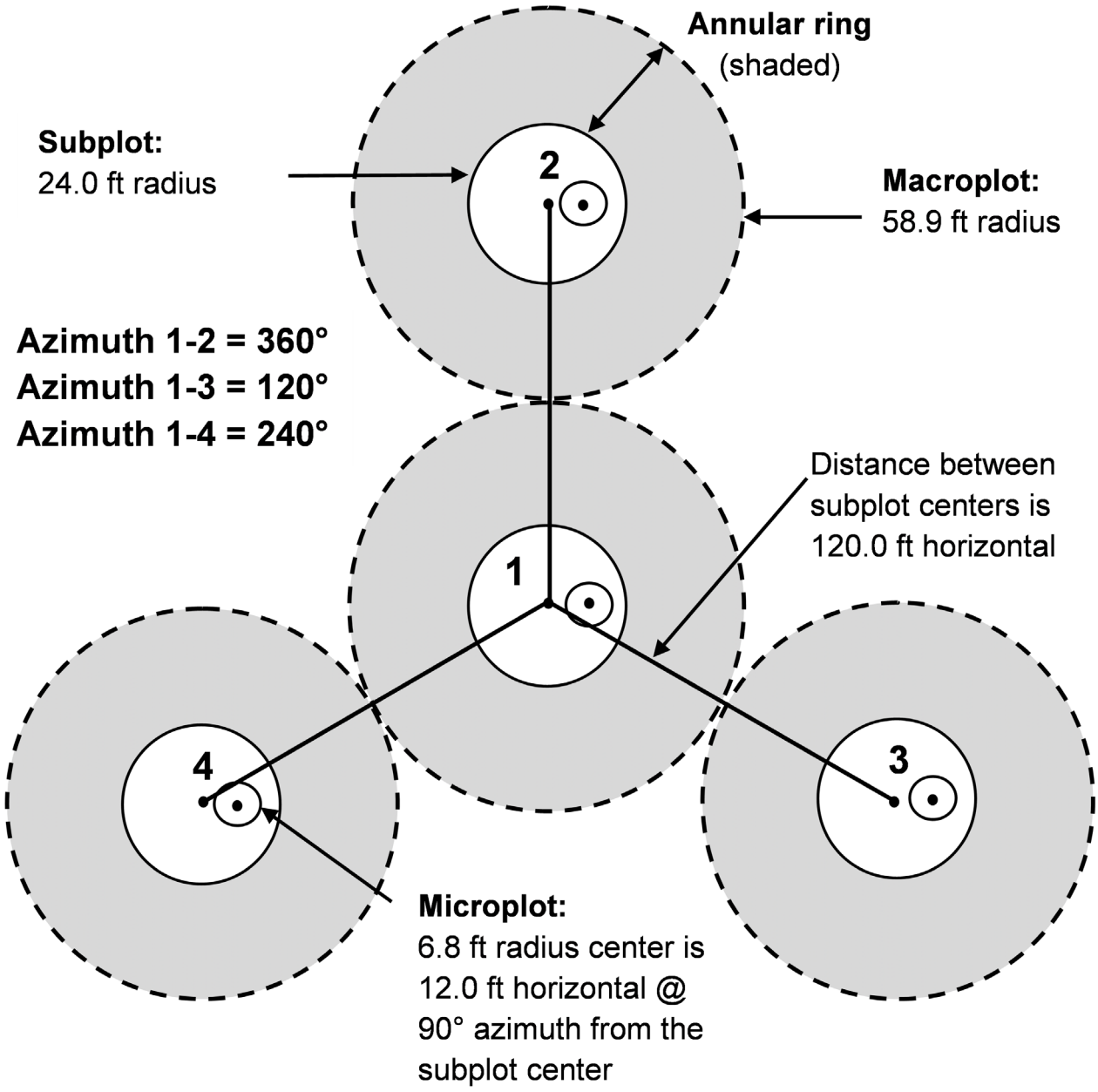

Figure 3—Forest Inventory and Analysis Phase 2 plot diagram.

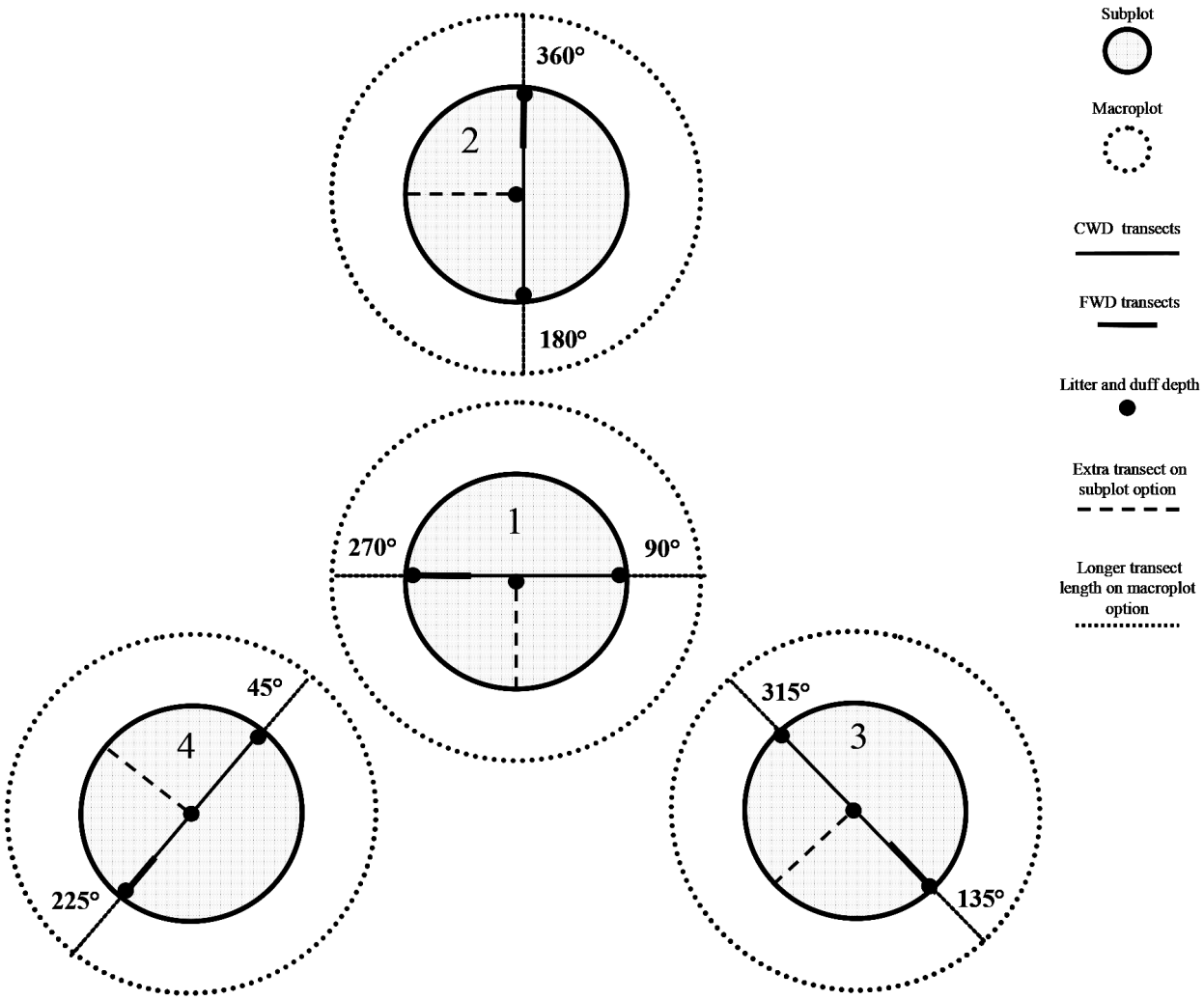

Figure 4—Plot layout for sampling coarse woody debris (CWD), fine woody debris (FWD), and litter and duff depth. The CWD transects include two 24-foot transects per subplot (starting at subplot center designated by its azimuth as labeled).

The nested microplots (fig. 3) used to measure trees with d.b.h. 1–4.9 inches were also remeasured. No attempt was made to account for ingrowth trees, nor to differentiate between mortality or harvesting that occurred in the time since their last measurement and before the hurricane and that which occurred due to the hurricane. This differs from the standard FIA methodology in the National Information Management System (NIMS) where a tree that died or was removed would be "grown" to the midpoint of the remeasurement period using annual radial increment models (Pugh and others 2018). Trees were categorized as utilized after the hurricane if there was a cut stump in their former location on the plot, and no attempt was made to differentiate between those that were alive when cut and those that were standing dead, or the degree to which they had been damaged before being harvested.

Down woody materials (DWM) data were collected on all plots using the standard base (known in FIA as option 1 [fig. 4]) protocols (USDA Forest Service 2020). Fine woody debris (FWD) included downed, dead branches, twigs, and small tree or shrub boles <3 inches in diameter that are not attached to a living or standing dead source. Coarse woody debris (CWD) included downed, dead tree and shrub boles, large limbs, and other woody pieces that are ≥3 inches in diameter and severed from their original source of growth. A pile was defined as an accumulation of large woody material in which individual pieces are impossible to tally separately. Piles may have been created by human activity or natural causes.

All of these field data were collected on plots starting in July of 2019 through October of 2020 on a customized configuration of the MIDAS that allowed for nonstandard inputs (see app. C for the configuration PROMPT file).

These data were then transmitted to the FIA NIMS for editing and processing. Strata areas and accompanying expansion factors for NOAA damage severity zone and State combinations had to be generated with customized programming in the R programming language for subsequent partial processing within NIMS. The only processes that could be run in NIMS were area calculations (condition proportion, condition change matrix, and population expansion factors), and FIA evaluations were only created for the remeasurement plot sample and the DWM sample. As mentioned previously, the pre-hurricane individual tree volume and biomass estimates had to be used to represent the post-hurricane values as well.

Pre-hurricane Values

Estimates of pre-hurricane forest parameters (forest land area, total numbers of trees, numbers of trees per acre, total volume, volume per acre, merchantable biomass, merchantable biomass per acre) and DWM in affected counties of Alabama, Georgia, and Florida were run in the EVALIDator (version 1.8.0.01) online tool using the most current datasets available (USDA Forest Service 2021). These estimates were used for comparison and validation of the post-hurricane estimates; however, we don't present all of those values in this report. These values can be replicated by using the EVALIDator tool and limiting the queries to the affected counties using the script included in appendix A. Pre-hurricane forest parameter estimates from 2017 generated in EVALIDator using all the plots within a county will include data from FIA plots that did not fall within a NOAA damage severity zone, potentially affecting the comparability to post-hurricane estimates.

Results

A total of 5,367 trees were sampled on the plots remeasured within the NOAA-defined damage severity zones. The remeasurement only collected information on those trees that were present on the plots when most recently measured before Hurricane Michael. Table 3 shows the numbers of sampled trees by their status before and after the hurricane. On forest land within the damage zones, we estimate there to have been a total population of 2.4 billion trees with d.b.h. ≥1 inch (table 4).

Table 3—Numbers of sampled trees (d.b.h. ≥1 inch) by pre- and post-hurricane status and NOAA-defined damage severity zones for Hurricane Michael in Alabama, Florida, and Georgia

		Post-hurricane status		
Damage severity zone	Pre-hurricane status	Live	Standing dead	Utilized
Moderate	Live (n = 3,486)	2,613	405	468
	Standing dead (n = 148)	2[a]	146	0
	Zone subtotal (n = 3,634)	2,615	551	468
Severe	Live (n = 849)	496	215	138
	Standing dead (n = 43)	0	43	0
	Zone subtotal (n = 892)	496	258	138
Catastrophic	Live (n = 822)	444	200	178
	Standing dead (n = 19)	0	19	0
	Zone subtotal (n = 841)	444	219	178
	Total (n = 5,367)	3,555	1,028	784

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

[a] Trees appeared to be dead when observed pre-hurricane but showed signs of life when observed post-hurricane.

Table 4—Numbers of trees (d.b.h. ≥1 inch) left alive, standing dead, and utilized by State and NOAA-defined damage severity zones for Hurricane Michael

Damage severity zone	State	Post-hurricane status			Total
		Live	Standing dead	Utilized	
		millions of trees			
Moderate	Alabama	30.49	9.12	9.35	48.96
	Florida	503.47	118.65	45.12	667.24
	Georgia	616.34	251.15	52.30	919.80
	Zone subtotal	1,150.31	378.92	106.78	1,636.00
Severe	Florida	227.14	107.00	33.33	367.46
	Georgia	3.83	24.58	12.07	40.47
	Zone subtotal	230.96	131.58	45.40	407.94
Catastrophic	Florida	196.29	81.34	48.47	326.11
	Georgia	10.28	5.11	0.75	16.14
	Zone subtotal	206.58	86.45	49.23	342.25
	Total	1,587.85	596.94	201.40	2,386.19

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

This equates to an average of 386.85 live, standing dead, and utilized trees per acre within the damage zones (table 5). Average post-hurricane tree density in Alabama and Georgia (416.84 and 430.50, respectively) is very similar, while that in Florida is slightly lower (359.74) in comparison. These post-hurricane averages compare reasonably well with the pre-hurricane live tree estimates for the affected counties in Florida (421.17 live trees per acre) and Georgia (387.68 live trees per acre) (USDA Forest Service 2021). Alabama, however, had notably higher tree densities pre-hurricane (646.81), although we must be mindful of the small sample size (two counties) in that State (USDA Forest Service 2021). Table 6 breaks down the numbers of trees left alive, standing dead, and utilized after Michael by their pre-hurricane diameter class.

Post-hurricane harvesting operations recovered a considerable amount of usable timber, as evidenced by these pine logs ready for loading and transport to a mill.

Table 5—Stem density of trees (d.b.h. ≥1 inch) left alive, standing dead, and utilized by State and NOAA-defined damage severity zones for Hurricane Michael

		Post-hurricane status			
	Damage severity zone	Live	Standing dead	Utilized	Zone subtotal
		trees per acre			
Alabama[a]	Moderate	259.60	77.61	79.62	416.84
	State average	259.60	77.61	79.62	416.84
Florida	Moderate	261.51	61.63	23.44	346.57
	Severe	202.94	95.60	29.78	328.32
	Catastrophic	265.88	110.18	65.66	441.72
	State average	245.03	81.15	33.55	359.74
Georgia	Moderate	301.62	122.91	25.59	450.12
	Severe	28.30	181.81	89.26	299.37
	Catastrophic	114.97	57.10	8.42	180.48
	State average	277.97	123.82	28.71	430.50
	Average	257.42	96.78	32.65	386.85

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

[a] In Alabama, forest land was only moderately damaged.

In the more severely impacted areas, pine plantations were heavily damaged with high percentages of trees killed, many of which were snapped off in the direction of the hurricane-force winds.

Table 6—Numbers of trees (d.b.h. ≥1 inch) left alive, standing dead, and utilized after Hurricane Michael in Alabama, Florida, and Georgia, based on pre-hurricane diameter class

Pre-hurricane status	Diameter class	Post-hurricane status			
		Live	Standing dead	Utilized	Total
		millions of trees			
Live	2	687.44	321.99	27.44	1,036.88
	4	358.44	85.49	16.84	460.77
	6	187.19	52.48	53.60	293.28
	8	139.28	33.96	51.22	224.45
	10	87.07	18.99	27.79	133.85
	12	55.10	8.03	13.05	76.19
	14	31.30	4.27	7.28	42.86
	16	19.28	3.17	1.72	24.17
	18	7.76	1.44	1.79	10.99
	20	5.55	0.95	0.30	6.80
	22	2.96	0.90	0.37	4.22
	24	2.48	0.37	0	2.85
	26	1.71	0.45	0	2.15
	28	0.45	0	0	0.45
	30	0.82	0	0	0.82
	32	0	0.22	0	0.22
	34	0.37	0	0	0.37
	36	0	0.22	0	0.22
	44	0	0.23	0	0.23
	50	0.22	0	0	0.22
	Subtotal	1,587.41	533.17	201.40	2,321.98
Standing dead	2	0	11.48	0	11.48
	4	0	14.86	0	14.86
	6	0	14.93	0	14.93
	8	0.44[a]	8.46	0	8.90
	10	0	5.91	0	5.91
	12	0	2.72	0	2.72
	14	0	2.72	0	2.72
	16	0	1.13	0	1.13
	18	0	0.68	0	0.68
	20	0	0.44	0	0.44
	22	0	0.22	0	0.22
	24	0	0.23	0	0.23
	Subtotal	0.44	63.77	0	64.21
	Total	1,587.85	596.94	201.40	2,386.19

d.b.h. = diameter at breast height.

[a] Trees appeared to be dead when observed pre-hurricane but showed signs of life when observed post-hurricane.

Table 7—Percentages of trees (d.b.h. ≥1 inch) by pre- and post-hurricane status, by NOAA-defined damage severity zones for Hurricane Michael in Alabama, Florida, and Georgia

Damage severity zone	Pre-hurricane status	Post-hurricane status			Total
		Live	Standing dead	Utilized	
		percent			
Moderate	Live	72.1	21.2	6.7	100.0
	Standing dead	1.1[a]	98.9	0.0	100.0
	Zone subtotal	70.3	23.2	6.5	100.0
Severe	Live	59.1	29.3	11.6	100.0
	Standing dead	0.0	100.0	0.0	100.0
	Zone subtotal	56.6	32.3	11.1	100.0
Catastrophic	Live	61.5	23.9	14.7	100.0
	Standing dead	0.0	100.0	0.0	100.0
	Zone subtotal	60.4	25.3	14.4	100.0
	Total	66.5	25.0	8.4	100.0

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

[a] Trees appeared to be dead when observed pre-hurricane but showed signs of life when observed post-hurricane.

Table 8—Volume in trees (d.b.h. ≥5 inches) left alive, standing dead, and utilized by State and NOAA-defined damage severity zones for Hurricane Michael

Damage severity zone	State	Post-hurricane status			Total
		Live	Standing dead	Utilized	
		millions of cubic feet			
Moderate	Alabama	104.47	51.12	23.63	179.22
	Florida	2,458.29	276.21	347.56	3,082.05
	Georgia	2,404.09	488.07	512.68	3,404.84
	Zone subtotal	4,966.85	815.39	883.87	6,666.11
Severe	Florida	1,415.45	443.13	255.53	2,114.11
	Georgia	19.14	10.91	88.13	118.17
	Zone subtotal	1,434.59	454.04	343.66	2,232.29
Catastrophic	Florida	376.47	261.67	385.22	1,023.36
	Georgia	28.82	4.60	50.64	84.05
	Zone subtotal	405.29	266.27	435.85	1,107.41
	Total	6,806.73	1,535.70	1,663.39	10,005.81

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

From these population estimates, we can calculate the percentages of trees that survived the hurricane and those that died, remained standing dead, and were utilized (table 7). Note the increasing percentages of trees that were utilized as the hurricane damage severity zone increased.

In terms of volume (and therefore limited to trees with d.b.h. ≥5.0 inches), 10.01 billion cubic feet of timber were within the damage zones, of which 6.81 billion cubic feet remained alive after the hurricane, 1.54 billion cubic feet were standing dead, and 1.66 billion cubic feet were utilized (table 8). This represents a total of 68.0 percent of live tree volume surviving across the entire damage zone, with survival decreasing from 74.5 percent in moderate damage zones to 36.6 percent in the catastrophic damage zones (table 9). The percentage of utilized tree volume (percentage of pre-hurricane live volume that was utilized post-hurricane) across all damage severity zones was 16.6 percent, with considerably higher utilization rates in the catastrophic zone (39.4 percent).

Volume per acre on forest land in the damaged zones averaged 1,622.13 cubic feet, with Florida showing the highest volume density at 1,644.17 cubic feet per acre (table 10). Queries of the pre-hurricane volume-per-acre estimates for the affected counties agreed well with our study's findings (a pre-hurricane average of 1,645.97 cubic feet per acre: Alabama with 1,564.46 cubic feet per acre, Florida with 1,640.62 cubic feet per acre, and Georgia with 1,665.32 cubic feet per acre) (USDA Forest Service 2021).

Table 9—Percentage of volume in trees (d.b.h. ≥5 inches) by pre- and post-hurricane status within NOAA-defined damage severity zones for Hurricane Michael in Alabama, Florida, and Georgia

Damage severity zone		Pre-hurricane status	Post-hurricane status		
			Live	Standing dead	Utilized
		percent			
Moderate	Live	98.6	74.5	10.5	13.3
	Standing dead	1.4	0.0	1.7	0.0
	Zone subtotal	100.0	74.5	12.2	13.3
Severe	Live	98.7	64.3	19.0	15.4
	Standing dead	1.3	0.0	1.4	0.0
	Zone subtotal	100.0	64.3	20.3	15.4
Catastrophic	Live	98.2	36.6	22.7	39.4
	Standing dead	1.8	0.0	1.3	0.0
	Zone subtotal	100.0	36.6	24.0	39.4
	Total	100.0	68.0	15.3	16.6

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Dead and damaged pine and hardwood trees are seen in this naturally regenerated forest. Note that many of the deciduous trees are still alive but lacking leaves in this picture taken in the winter.

Table 10—Average volume per acre in trees (d.b.h. ≥5 inches) left alive, standing dead, and utilized by State within NOAA-defined damage severity zones for Hurricane Michael

		Post-hurricane status			
	Damage severity zone	Live	Standing dead	Utilized	Zone subtotal
		cubic feet per acre			
Alabama[a]	Moderate	889.42	435.20	201.14	1,525.77
	State average	889.42	435.20	201.14	1,525.77
Florida	Moderate	1,276.84	143.46	180.52	1,600.83
	Severe	1,264.67	395.92	228.31	1,888.91
	Catastrophic	509.93	354.44	521.79	1,386.16
	State average	1,123.57	259.33	261.27	1,644.17
Georgia	Moderate	1,176.49	238.85	250.89	1,666.22
	Severe	141.55	80.69	651.85	874.08
	Catastrophic	322.31	51.39	566.22	939.92
	State average	1,081.12	222.03	287.23	1,590.37
	Average	1,103.50	248.97	269.67	1,622.13

d.b.h. = diameter at breast heigh; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.
[a] In Alabama, forest land was only moderately damaged.

Forest land volume was subdivided into four major species groups (pine, other softwood, hard hardwood, and soft hardwood) (see Burrill and others 2021 for details on which species fall within these major species groups). Table 11 presents the total cubic foot volume in each State by major species group and post-hurricane status, while table 12 shows these values in terms of volume per acre. Tree volume can also be expressed in terms of tons of biomass, units often used by the wood products industry. These values by State and major species group are presented in table 13.

Examining the post-hurricane volume by damage severity zone and major species group, we see that pines were the species group with the greatest volumes per acre (table 14). Pines showed decreasing amounts of live volume remaining in the forest with increasing damage severity, ranging from 70.0 percent in the moderate damage zone to 22.7 percent in the catastrophic damage zone (table 15). Other softwoods did not appear to be as negatively affected as pines, but their sampling in this study was relatively small. Both hardwood groups were less impacted than the pines, showing higher percentages of live volume after the hurricane. The percentage of volume utilized after the hurricane was highest for the pine species group, with 50.5 percent of the pre-hurricane live volume utilized in the catastrophic damage zone. The percentages of trees cut from damaged hardwood stands were overall low, ranging from 0.7–10.6 percent. The distribution of harvesting and other silvicultural activity across the damage severity zones is shown in figure 2.

Table 11—Volume in trees (d.b.h. ≥5 inches) left alive, standing dead, and utilized after Hurricane Michael by State and major species group

State	Major species group	Post-hurricane status			Species group subtotal
		Live	Standing dead	Utilized	
		millions of cubic feet			
Alabama	Pine	22.13	24.57	23.63	70.32
	Hard hardwood	63.90	17.55	0	81.46
	Soft hardwood	18.44	9.00	0	27.44
	State subtotal	104.47	51.12	23.63	179.22
Florida	Pine	1,818.30	601.50	933.23	3,353.03
	Other softwood	421.51	34.47	0	455.98
	Hard hardwood	1,433.23	149.39	12.01	1,.63
	Soft hardwood	577.16	195.65	43.07	815.88
	State subtotal	4,250.21	981.00	988.31	6,219.52
Georgia	Pine	1,270.17	189.20	509.83	1,969.20
	Other softwood	287.09	5.02	0	292.11
	Hard hardwood	415.56	136.15	125.79	677.51
	Soft hardwood	479.22	173.20	15.83	668.25
	State subtotal	2,452.05	503.57	651.45	3,607.07
	Total	6,806.73	1,535.70	1,663.39	10,005.81

d.b.h. = diameter at breast height.

Table 12—Volume per acre in trees (d.b.h. ≥5 inches) left alive, standing dead, and utilized after Hurricane Michael by State and major species group

State	Major species group	Post-hurricane status			Species group subtotal
		Live	Standing dead	Utilized	
		cubic feet per acre			
Alabama	Pine	188.38	209.17	201.14	598.70
	Other softwood	0	0	0	0
	Hard hardwood	544.03	149.44	0	693.47
	Soft hardwood	157.01	76.59	0	233.60
	State subtotal	889.42	435.20	201.14	1,525.77
Florida	Pine	480.68	159.01	246.71	886.39
	Other softwood	111.43	9.11	0	120.54
	Hard hardwood	378.88	39.49	3.17	421.55
	Soft hardwood	152.58	51.72	11.39	215.68
	State subtotal	1,123.57	259.33	261.27	1,644.17
Georgia	Pine	560.02	83.42	224.78	868.22
	Other softwood	126.58	2.22	0	128.79
	Hard hardwood	183.22	60.03	55.46	298.72
	Soft hardwood	211.29	76.36	6.98	294.63
	State subtotal	1,081.12	222.03	287.23	1,590.37
	Total	1,103.50	248.97	269.67	1,622.13

d.b.h. = diameter at breast height.

Table 13—Aboveground dry biomass in trees (d.b.h. ≥5 inches) left alive, standing dead, and utilized after Hurricane Michael by State and major species group

State	Major species group	Post-hurricane status			Species group subtotal
		Live	Standing dead	Utilized	
		short tons			
Alabama	Pine	11,063.72	12,284.92	11,813.35	35,161.99
	Hard hardwood	31,951.18	8,776.67	0	40,727.85
	Soft hardwood	9,221.35	4,497.90	0	13,719.24
	State subtotal	52,236.24	25,559.49	11,813.35	89,609.08
Florida	Pine	909,150.09	300,749.45	466,616.82	1,676,516.37
	Other softwood	210,755.59	17,233.10	0	227,988.69
	Hard hardwood	716,617.14	74,694.06	6,005.11	797,316.30
	Soft hardwood	288,581.72	97,825.71	21,533.53	407,940.96
	State subtotal	2,125,104.54	490,502.32	494,155.46	3,109,762.32
Georgia	Pine	635,085.73	94,598.85	254,913.16	984,597.74
	Other softwood	143,544.57	2,512.27	0	146,056.85
	Hard hardwood	207,781.92	68,076.57	62,897.10	338,755.58
	Soft hardwood	239,612.03	86,599.53	7,914.06	334,125.62
	State subtotal	1,226,024.25	251,787.22	325,724.32	1,803,535.79
	Total	3,403,365.03	767,849.03	831,693.12	5,002,907.18

d.b.h. = diameter at breast height.

Table 14—Volume per acre in trees (d.b.h. ≥5 inches) left alive, standing dead, and utilized by NOAA-defined damage severity zones for Hurricane Michael and major species group in Alabama, Florida, and Georgia

Damage severity zone	Major species group	Post-hurricane status			Species group subtotal
		Live	Standing dead	Utilized	
		cubic feet per acre			
Moderate	Pine	639.56	89.97	184.18	913.70
	Other softwood	126.16	6.04	0	132.20
	Hard hardwood	267.01	49.85	29.42	346.28
	Soft hardwood	182.79	53.69	2.71	239.19
	Zone subtotal	1,215.52	199.55	216.31	1,631.38
Severe	Pine	245.33	179.26	233.40	657.99
	Other softwood	131.17	6.24	0	137.41
	Hard hardwood	578.15	61.22	4.45	643.83
	Soft hardwood	188.97	115.22	36.11	340.30
	Zone subtotal	1,143.62	361.95	273.96	1,779.53
Catastrophic	Pine	228.93	269.15	509.04	1,007.12
	Other softwood	34.48	8.45	0	42.92
	Hard hardwood	116.46	27.30	14.51	158.26
	Soft hardwood	109.79	16.81	3.04	129.64
	Zone subtotal	489.66	321.70	526.59	1,337.95
	Total	1,103.50	248.97	269.67	1,622.13

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Table 15—Percentage of volume in trees (d.b.h. ≥5 inches) by pre- and post-hurricane status and major species group within NOAA-defined damage severity zones for Hurricane Michael in Alabama, Florida, and Georgia

Damage severity zone	Major species group	Pre-hurricane status		Post-hurricane status		
				Live	Standing dead	Utilized
			percent			
Moderate	Pine	Live	98.6	70.0	8.5	20.2
		Standing dead	1.4	0.0	1.4	0.0
		Subtotal	100.0	70.0	9.9	20.2
	Other softwood	Live	96.7	95.1	1.6	0.0
		Standing dead	3.3	0.3	3.0	0.0
		Subtotal	100.0	95.4	4.6	0.0
	Hard hardwood	Live	98.4	77.0	12.9	8.5
		Standing dead	1.6	0.1	1.5	0.0
		Subtotal	100.0	77.1	14.4	8.5
	Soft hardwood	Live	97.3	76.4	19.8	1.1
		Standing dead	2.7	0.0	2.7	0.0
		Subtotal	100.0	76.4	22.4	1.1
Severe	Pine	Live	99.1	37.3	26.4	35.5
		Standing dead	0.9	0.0	0.9	0.0
		Subtotal	100.0	37.3	27.2	35.5
	Other softwood	Live	96.5	95.5	1.1	0.0
		Standing dead	3.5	0.0	3.5	0.0
		Subtotal	100.0	95.5	4.5	0.0
	Hard hardwood	Live	98.1	89.8	7.6	0.7
		Standing dead	1.9	0.0	1.9	0.0
		Subtotal	100.0	89.8	9.5	0.7
	Soft hardwood	Live	99.6	55.5	33.4	10.6
		Standing dead	0.4	0.0	0.4	0.0
		Subtotal	100.0	55.5	33.9	10.6
Catastrophic	Pine	Live	98.6	22.7	25.3	50.5
		Standing dead	1.4	0.0	1.4	0.0
		Subtotal	100.0	22.7	26.7	50.5
	Other softwood	Live	98.1	80.3	17.8	0.0
		Standing dead	1.9	0.0	1.9	0.0
		Subtotal	100.0	80.3	19.7	0.0
	Hard hardwood	Live	99.1	73.6	16.4	9.2
		Standing dead	0.9	0.0	0.9	0.0
		Subtotal	100.0	73.6	17.2	9.2
	Soft hardwood	Live	98.9	84.7	11.9	2.3
		Standing dead	1.1	0.0	1.1	0.0
		Subtotal	100.0	84.7	13.0	2.3
		Total	100.0	68.0	15.3	16.6

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Table 16—Volume per acre in trees (d.b.h. ≥5 inches) left alive, standing dead, and utilized by State and NOAA-defined damage severity zones for Hurricane Michael

State	Damage severity zone	Major species group	Post-hurricane status			Species group subtotal
			Live	Standing dead	Utilized	
			cubic feet per acre			
Alabama[a]	Moderate	Pine	188.38	209.17	201.14	598.70
		Other softwood	0	0	0	0
		Hard hardwood	544.03	149.44	0	693.47
		Soft hardwood	157.01	76.59	0	233.60
		Zone subtotal	889.42	435.20	201.14	1,525.77
		State subtotal	889.42	435.20	201.14	1,525.77
Florida	Moderate	Pine	695.56	83.25	179.74	958.56
		Other softwood	118.65	10.20	0	128.85
		Hard hardwood	319.39	27.86	0	347.25
		Soft hardwood	143.24	22.15	0.78	166.17
		Zone subtotal	1,276.84	143.46	180.52	1,600.83
	Severe	Pine	258.80	195.17	193.42	647.39
		Other softwood	147.02	7.00	0	154.01
		Hard hardwood	647.78	68.61	0	716.39
		Soft hardwood	211.07	125.14	34.89	371.11
		Zone subtotal	1,264.67	395.92	228.31	1,888.91
	Catastrophic	Pine	256.67	301.75	502.11	1,060.52
		Other softwood	38.65	9.47	0	48.12
		Hard hardwood	126.38	25.68	16.27	168.33
		Soft hardwood	88.23	17.54	3.41	109.19
		Zone subtotal	509.93	354.44	521.79	1,386.16
		State subtotal	1,123.57	259.33	261.27	1,644.17
Georgia	Moderate	Pine	612.73	89.44	187.38	889.55
		Other softwood	140.49	2.46	0	142.95
		Hard hardwood	201.74	64.85	58.83	325.41
		Soft hardwood	221.53	82.10	4.69	308.32
		Zone subtotal	1,176.49	238.85	250.89	1,666.22
	Severe	Pine	133.80	47.58	564.34	745.72
		Other softwood	0	0	0	0
		Hard hardwood	1.76	0	41.33	43.09
		Soft hardwood	5.99	33.11	46.18	85.28
		Zone subtotal	141.55	80.69	651.85	874.08
	Catastrophic	Pine	0	0	566.22	566.22
		Other softwood	0	0	0	0
		Hard hardwood	34.53	40.67	0	75.20
		Soft hardwood	287.78	10.72	0	298.50
		Zone subtotal	322.31	51.39	566.22	939.92
		State subtotal	1,081.12	222.03	287.23	1,590.37
		Total	1,103.50	248.97	269.67	1,622.13

d.b.h. = diameter at breast height; NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

[a] In Alabama, forest land was only moderately damaged.

In Alabama, forest land was only moderately damaged, and damage was entirely within the pine species group where there was more volume in the standing dead and utilized categories than left alive post-hurricane (table 16). The moderately damaged zones in Florida and Georgia had more pine volume left alive after the hurricane than was found to be standing dead or utilized. Georgia, on the other hand, had more volume per acre utilized in the severely damaged zone than was left alive or standing dead.

Individual Tree Damages

A total of 893 instances of damages to survivor trees were recorded. It is not possible to say what percentage of the damages recorded post-hurricane was new or pre-existing (table 17). We can assume with some degree of safety that most instances of wind damage were caused by Hurricane Michael, while others like the occurrences of pests and diseases (which include cankers and fungal fruiting bodies) may have been present before. Be mindful while summing these damage occurrences that up to three damages can be tallied on a single tree. Interestingly, there was a higher frequency of abiotic damage (which includes wind) in the moderate damage severity zone than in the severe and catastrophic damage zones. We can postulate, though, that this was due to a higher percentage of trees being killed and/or salvage logged in these zones of higher wind speeds, leaving fewer live damaged trees.

Table 17—Survivor tree damage occurrences by damaging agent and percentages of those occurrences in each NOAA-defined damage severity zone for Hurricane Michael in Alabama, Florida, and Georgia

		Damage severity zone		
Damage agent	**Number of occurrences (n = 893)**	**Moderate**	**Severe**	**Catastrophic**
Abiotic (n = 237)		---------- *percent* ----------		
General	19	84.2	5.3	10.5
Lightning	1	100.0	0.0	0.0
Wind	217	46.5	24.0	29.5
Damage agent average		49.8	22.4	27.8
Human activities (n = 13)				
General	5	60.0	20.0	20.0
Embedded objects	4	100.0	0.0	0.0
Logging damage	4	75.0	25.0	0.0
Damage agent average		76.9	7.7	15.4
Pests and diseases	610	89.8	4.1	6.1
Domestic animals	15	86.7	13.3	0.0
Fire	18	94.4	5.6	0.0
Average		79.1	9.2	11.8

NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Hurricane Michael left many down and standing dead trees in this naturally regenerated, mixed pine-hardwood forest. Note that many of the deciduous trees are still alive but lacking leaves in this picture taken in the winter.

A large portion of the woody debris on the forest floor in the aftermath of Hurricane Michael was found in slash piles left after salvage logging operations.

Down Woody Materials

We estimate that there were 83.63 million short tons of DWM deposited within the Hurricane Michael-damaged forest lands (table 18), which was an average of 13.56 tons per acre across all damage severity zones (table 19) and over four times the pre-hurricane amounts (1.56 tons per acre for FWD, 0.91 tons per acre for CWD, and 0.75 tons per acre for piles—a total of 3.22 tons per acre [USDA Forest Service 2021]). The amount of DWM per acre found on the forest floor increased with increasing severity, going from 9.14 tons per acre in the moderate damage zone to 39.51 tons per acre in the catastrophic damage zone (table 19). The increase in DWM in the catastrophic damage severity zone was due to CWD and DWM piles in particular.

Table 18—Dry weight of down woody materials (DWM) (including fine woody debris [FWD], coarse woody debris [CWD], and piles) by NOAA-defined damage severity zones for Hurricane Michael in Alabama, Florida, and Georgia

Damage severity zone	DWM class	Dry weight
		short tons
Moderate	FWD	9,884,709.53
	CWD	11,543,668.13
	Piles	15,911,497.33
Subtotal		37,339,874.99
Severe	FWD	3,556,074.75
	CWD	6,518,699.86
	Piles	3,515,148.91
Subtotal		13,589,923.52
Catastrophic	FWD	2,056,300.75
	CWD	6,708,435.92
	Piles	23,935,099.24
Subtotal		32,699,835.92
Total		83,629,634.43

NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

A salvage logging operation nears completion in the Hurricane Michael impact area.

Table 19—Average dry weight per acre of down woody materials (DWM) (including fine woody debris [FWD], coarse woody debris [CWD], and piles) by NOAA-defined damage severity zones for Hurricane Michael in Alabama, Florida, and Georgia

Damage severity zone	DWM class	Dry weight
		short tons per acre
Moderate	FWD	2.42
	CWD	2.83
	Piles	3.89
Subtotal		9.14
Severe	FWD	2.83
	CWD	5.20
	Piles	2.80
Subtotal		10.83
Catastrophic	FWD	2.48
	CWD	8.10
	Piles	28.92
Subtotal		39.51
Average across all zones		13.56

NOAA = National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Discussion and Conclusions

Initial estimates by SRS FIA based on early NOAA-defined damage severity zones indicated that 5.30 million acres of forest land were affected by Hurricane Michael. Subsequent analyses refined the damage severity zones, increasing the total acres affected and changing slightly the distribution of those acres across the severity zones. Our analyses represent the final, definitive estimates of acres affected (6.17 million acres) and shows the initial acreage estimate to be an underestimation. The State of Florida's study was based on damage to 2.81 million acres, while our study used the later NOAA estimate of 3.78 million acres (table 1). Georgia's estimates are based on 2.37 million acres, while our study used 2.27 million acres (table 1). Understandably then, the estimates of tree numbers, volume, and biomass damaged found by this study are higher than the initial estimates. In addition, the comparability of initial estimates and our results is limited because the initial estimates are in terms of volume of trees damaged (3.19 billion cubic feet), while we present live volume, standing dead, and utilized trees as found on plots when they were remeasured post-hurricane.

Estimates of trees and volume density generated using the 2017, pre-hurricane data in the FIA database showed overall good agreement with our reconstruction of what was on the plots. We found notable the contrast between the percentage of trees that survived, were left standing dead, and were utilized when expressed in terms of numbers of trees or in terms of volume. There was no clear pattern of increasing mortality with increasing damage severity in numbers of trees. Large numbers of 2- and 4-inch class trees were killed or utilized post-hurricane across all severity zones, perhaps muting trend. We can speculate that the utilized saplings were cut as part of site clearing in preparation for replanting.

But there was indication of increasing mortality and utilization in terms of volume with increasing damage severity. Less live volume was left, and the percentages of trees utilized increased markedly. When volume is broken down into major species groups, pine was the most utilized in all three States, with no other softwood being salvaged (at least not on the remeasured plots) and much less hardwood volume being salvaged. Georgia showed the highest amount of utilization (988.41 million cubic feet), the vast majority of it pine (933.23 million cubic feet). We can only speculate as to how much of the volume recorded as utilized was in fact cut down and piled for burning or disposal later.

The amounts of DWM found on the forest floor on plots remeasured after the passage of Hurricane Michael were considerably (over four times) higher than those found prior to the hurricane, most notably for CWD and piles. It is probable that the large numbers of trees broken or uprooted by the storm plus post-hurricane salvage logging and site cleanup, which created numerous piles of logs and branches, is at least part of the reason for our study's findings of much higher amounts of DWM. Tracking this hurricane-deposited DWM into the future will give us insights into the cycle of disturbance and dead wood deposition and decomposition in these Southern U.S. forest ecosystems.

Lessons Learned

Despite the nearly annual passage of damaging hurricanes along the Southeastern U.S. coast, there were lessons to be learned from this most recent effort to assess their impact of the region's forests. We are fortunate to have a network of permanent forest inventory and monitoring plots in place upon which future assessments of the impacts of natural disasters like Hurricane Michael can be conducted, particularly in the Southern States where forest resources are a vital part of the region's economy. Studies on the impact of hurricanes on forest resources should be done in as timely a manner as possible. Although initial estimates of the damage caused to the timber resources of Alabama, Florida, and Georgia were released within weeks of Hurrican Michael's passing, field data collection for this study was not completed until 2 years after the

event. This study's implementation could not begin until funding was obtained more than 1 year after the hurricane. Staffing shortages meant that a new field crew had to be trained on FIA data collection methods. Finally, the latter stages of the study corresponded with the beginning of the COVID-19 pandemic, further delaying completion. This said, the delayed response allowed for salvage logging to be completed before the plot remeasurement began, giving a more complete picture of how much of the damaged timber was utilized than we would have had if we had begun immediately after the hurricane's passage.

Two important factors in the speed at which a rapid assessment can be completed are, of course, the numbers of plots visited and what data are collected on them. The selection of plots to be remeasured rapidly requires careful consideration. This study also collected data on plots outside the NOAA-defined damage severity zones with the intention of providing the opportunity for subsequent county-level summaries that would include impacted and nonimpacted forest land. We chose not to use these data and focused only on forests within the hurricane damage zone. The other important factor that contributes to the speed of the assessment using FIA plots is deciding whether to collect the full suite of variables or a reduced number. Care must be taken, however, to not exclude variables that are needed to process these data using standard estimation procedures. This also applies to the pre-field work. Time needs to be taken to create the strata of the special study area required to afterward apply the correct expansion factors to plot data that are needed to correctly make per-acre estimates with NIMS.

All of the above decisions and implementation steps need to be fully documented. The FIA program has extensive documentation on all of its standard field plot measurement protocols, data processing methods, and estimation procedures. Supplemental documentation is critical when the program deviates from its standard procedures in situations like a rapid assessment. Only through full documentation can we make subsequent use of data and learn from these experiences so that we are better prepared for the next rapid assessment.

An aerial view shows a salvage-logged pine plantation ready for replanting.

Acknowledgments

We would like to thank the following people for their work collecting these data in the field: Shannon Anderson and William Webb of the Alabama Forestry Commission; Ian Ford, Bryant Jernigan, Christopher Jones, Jordan Kimball, Richard Larsen, Chris McGarvey, Matthew Pegram, Chris Schmiege, Lindsey Soto, and Cara Specht of the Florida Forest Service; Mark Barrett, David Dickinson, Mark Freeman, Tim Karchner, and Chad Northcutt of the Georgia Forestry Commission; and Jay Frost, Justin Medley, Donovan Stone, Edd Watson, and Eric Winters of the Forest Service, U.S. Department of Agriculture. We also thank Robert Lee and Angie Rowe of the Forest Service, Southern Research Station Forest Inventory and Analysis (SRS FIA) for coordinating the field data collection; Jason McHan and David Watkins of SRS FIA for their assistance with processing these data; William Burkman for securing the funding and initiating this effort; and Jarek Nowak and Chris Schmiege of the Florida Forest Service and David Dickinson of the Georgia Forestry Commission for their reviews of the draft manuscript.

References

Bechtold, W.A.; Patterson, P.L., eds. 2005. The enhanced Forest Inventory and Analysis program - national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 85 p. **https://doi.org/10.2737/SRS-GTR-80.**

Beven, J.L., II; Berg, R.; Hagen, A. 2019. Hurricane Michael (AL142018). National Hurricane Center tropical cyclone report. [Place of publication unknown]: U.S. Department of Commerce National Oceanic and Atmospheric Administration, National Weather Service. 86 p. **https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf.** [Date accessed: September 8, 2021].

Brandeis, T.J.; McCollum, J.M.; Hartsell, A.J. [and others]. 2016. Georgia's forests, 2014. Resour. Bull. SRS-209. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 78 p. **https://doi.org/10.2737/SRS-RB-209.**

Brown, M.J.; Nowak, J.; Vogt, J.T. 2017. Florida's forests, 2013. Resour. Bull. SRS-213. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 94 p. **https://doi.org/10.2737/SRS-RB-213.**

Burrill, E.A.; DiTommaso, A.M.; Turner, J.A. [and others]. 2021. The Forest Inventory and Analysis Database: database description and user guide version 9.0.1 for Phase 2. [Place of publication unknown]: U.S. Department of Agriculture Forest Service. 1,026 p. **https://www.fia.fs.fed.us/library/database-documentation/.** [Date accessed: September 7, 2021].

Florida Forest Service. 2018. Hurricane Michael initial value estimate of altered, damaged or destroyed timber in Florida. Unpublished report. [Place of publication unknown]. 18 p. **https://www.fdacs.gov/content/download/82204/file/hurricanemichaelinitialtimberdamageestimate_lite.pdf.** [Date accessed: September 7, 2021].

Georgia Forestry Commission. 2018. Timber impact assessment. Hurricane Michael, October 10–11, 2018. Rev. October 29, 2018. [Place of publication unknown]: Georgia Forestry Commission Forest Health Management Group. 12 p. **https://gatrees.org/wp-content/uploads/2020/01/Hurricane-MichaelTimber-Impact-Assessment-Georgia-October-10-11-2018-2.pdf.** [Date accessed: September 7, 2021].

Hartsell, A.J. 2018. Alabama's forests, 2015. Resour. Bull. SRS-220. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 73 p. **https://doi.org/10.2737/SRS-RB-220.**

Pugh, S.A.; Turner, J.A.; Burrill, E.A.; David, W. 2018. The Forest Inventory and Analysis Database: population estimation user guide (edition: November 2018). [Place of publication unknown]: U.S. Department of Agriculture Forest Service. 166 p. **https://www.fia.fs.fed.us/library/database-documentation/.** [Date last accessed: December 14, 2021].

U.S. Department of Agriculture (USDA) Forest Service. 2018a. Hurricane Michael (October 10–12, 2018) forest damage assessment [October 30, 2018]. 8 p. Unpublished report. On file with: U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37934.

U.S. Department of Agriculture (USDA) Forest Service. 2018b. Impact of Hurricane Michael on primary forest industries in Florida, Georgia, Alabama [October 30, 2018]. 5 p. Unpublished report. On file with: U.S. Department of Agriculture Forest Service, Southern Research Station, Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37934.

U.S. Department of Agriculture (USDA) Forest Service. 2020. Forest Inventory and Analysis national core field guide. Vol. 1: field data collection procedures for Phase 2 plots, version 9.0. Washington, DC. 435 p. **www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2019/core_ver9-0_10_2019_final_rev_2_10_2020.pdf.** [Date accessed: September 7, 2021].

U.S. Department of Agriculture (USDA) Forest Service. 2021. EVALIDator version 1.8.0.01. St. Paul, MN: U.S. Department of Agriculture Forest Service, Northern Research Station. **https://apps.fs.usda.gov/Evalidator/evalidator.jsp.** [Date last accessed: December 14, 2021].

Appendix A

Names of counties (Federal Information Processing Standards [FIPS] codes) included in the study area, by State and National Oceanic and Atmospheric Administration's (NOAA) Hurricane Michael damage severity zones. County names are repeated when they fall within multiple severity zones. Also included is the SQL query selection statement that can be used in EVALIDator to replicate our estimates of pre-hurricane conditions.

Alabama

Moderate

Henry (10067)
Houston (10069)

Florida

Moderate

Bay (12005)
Franklin (12037)
Gadsden (12039)
Gulf (12045)
Jackson (12063)
Leon (12073)
Liberty (12077)
Wakulla (12129)
Washington (12133)

Severe

Bay (12005)
Calhoun (12013)
Gadsden (12039)
Gulf (12045)
Jackson (12063)
Liberty (12077)

Catastrophic

Bay (12005)
Calhoun (12013)
Gadsden (12039)
Gulf (12045)
Jackson (12063)
Liberty (12077)

Georgia

Moderate

Baker (13007)
Calhoun (13037)
Clay (13061)
Colquitt (13071)
Crisp (13081)
Decatur (13087)
Dougherty (13095)
Early (13099)
Grady (13131)
Lee (12177)
Mitchell (13205)
Randolph (13243)
Sumter (13261)
Terrell (13273)
Thomas (13275)
Turner (13287)
Wilcox (13315)
Worth (13321)

Severe

Baker (13007)
Decatur (13087)
Early (13099)
Miller (13201)

Catastrophic

Decatur (13087)
Seminole (13253)

EVALIDator (available at **https://apps.fs.usda.gov/Evalidator/evalidator.jsp**) filter statement to limit the query to the study area State and county list above while selecting the data for Alabama, Florida, and Georgia from the 2017 inventory year.

```
and ((plot.statecd = 1 and plot.countycd in (067, 69))
or
(plot.statecd = 12 and plot.countycd in (05, 37, 39, 45, 63, 73, 77, 129, 133, 13, 45))
or
(plot.statecd = 13 and plot.countycd in (07, 37, 61, 71, 81, 87, 95, 99, 131, 177, 205, 243, 261, 273, 275, 287, 315, 321, 201, 253)))
```

Appendix B

Hurricane assessment protocol details, including modifications to the standard Forest Inventory and Analysis version 9.0 Phase 2 field guide (USDA 2020) and Mobile Integrated Data Acquisition System (MIDAS) for plot, condition, subplot, boundary, tree, and down woody materials data.

PLOT:

All plot-level variables were collected as normal.

CONDITON:

Condition variables collected were reduced to the following:

CN
PLT_CN
CONDID
LAND_USE_SRS
COND_NONSAMPLE_REASN_CD
COND_STATUS_CD
DSTRBCD1
DSTRBYR1
DSTRBCD2
DSTRBYR2
DSTRBCD3
DSTRBYR3
TRTCD1
HARVEST_TYPE1_SRS
TRTYR1
TRTCD2
HARVEST_TYPE2_SRS
TRTYR2
TRTCD3
HARVEST_TYPE3_SRS
TRTYR3

SUBPLOT:

The following subplot columns were not collected:

ASPECT
SLOPE
WATERDEP
MACRCOND

BOUNDARY:

Boundary-defining variables were collected normally.

TREE:

The focus was if the tree survived and was standing or not as a rapid assessment to determine the amount of damage that occurred. Tree variables collected were reduced to the following variables:

CN
PLT_CN
CONDID
SPCD
SPCD_SRS
STATUSCD
PREV_STATUS_CD
RECONCILECD
STANDING_DEAD_CD
AZIMUTH
DIST
TREE
PREVDIA
DAMAGE_AGENT_CD1
DAMAGE_AGENT_CD2
DAMAGE_AGENT_CD3
AGENTCD
MORTYR
UTILCD_SRS

DOWN WOODY MATERIALS:

Option 1 (base) variables for coarse woody debris, fine woody debris, piles, and duff/litter depth were collected on all study plots. The down woody materials variables collected were:

SEGMENT CONDITION CLASS
SEGMENT BEGINNING DISTANCE
SEGMENT ENDING DISTANCE
DWM TRANSECT SEGMENT SAMPLE STATUS
DWM TRANSECT SEGMENT NONSAMPLED REASON
SUBPLOT NUMBER
TRANSECT
CWD CONDITION CLASS
PIECE ON SUBPLOT OR ANNULAR PLOT?
CWD DECAY CLASS
SPECIES
DIAMETER AT POINT OF INTERSECTION
DIAMETER AT HOLLOW AT POINT OF INTERSECTION
CWD LENGTH ≥3 FEET
PILE SUBPLOT NUMBER
PILE TRANSECT
PILE CONDITION CLASS
PILE BEGINNING DISTANCE
PILE ENDING DISTANCE
COMPACTED HEIGHT OF CWD IN PILE
PILE DECAY CLASS
PILE SPECIES
FWD TRANSECT
FWD CONDITION CLASS
FWD TRANSECT SEGMENT SAMPLE STATUS
FWD TRANSECT SEGMENT NONSAMPLED REASON
SMALL FWD COUNT
MEDIUM FWD COUNT
LARGE FWD COUNT
HIGH COUNT REASON
DUFF/LITTER SUBPLOT NUMBER
DUFF/LITTER TRANSECT
DUFF/LITTER CONDITION CLASS
DUFF/LITTER SAMPLE STATUS
DUFF/LITTER NONSAMPLED REASON
DUFF DEPTH
LITTER DEPTH
DUFF AND LITTER METHOD

Appendix C

Mobile Integrated Data Acquisition System (MIDAS) configuration PROMPT file used for the Hurricane Michael damage assessment. This file summarizes which Forest Inventory and Analysis Phase 2 variables were collected and which were not.

plot STATE State number 2 0 0 PLOT STATECD NA NA 153
plot UNIT Unit number 1 0 0 PLOT UNITCD NA NA 173
plot CNTY County number 3 0 0 PLOT COUNTYCD NA NA 11
plot PLOT Plot number 5 0 0 PLOT PLOT NA NA 97
plot CYCLE Cycle number 2 0 0 PLOT CYCLE NA NA 19
plot SUBCY Subcycle number 2 0 0 PLOT SUBCYCLE NA NA 158
plot CCor? CountyCorrect_SRS number 1 0 0 PLOT PLT_IN_CORR_COUNTY_SRS NA NA 12
plot NewCo CorrectCounty_SRS number 3 0 0 PLOT CORR_COUNTYCD_SRS NA NA 10
plot SK SampleKind number 1 0 0 PLOT KINDCD NA NA 142
plot PrPl# PreviousPlotNumber number 5 0 0 PLOT REPLACED_PLOT_NBR NA NA 127
plot PltSt PlotStatus number 1 0 0 PLOT PLOT_STATUS_CD NA NA 104
plot PNSR PlotNonsampledReason number 2 0 0 PLOT PLOT_NONSAMPLE_REASN_CD NA NA 101
plot Auth# Authorization_SRS number 5 0 0 PLOT AUTHORIZATION_SRS NA NA 4
plot Year Year number 4 0 0 PLOT MEASYEAR NA NA 178
plot Month Month number 2 0 0 PLOT MEASMON NA NA 73
plot Day Day number 2 0 0 PLOT MEASDAY NA NA 21
plot PYear PastYear_SRS number 4 0 0 PLOT PAST_YEAR_SRS NA NA 94
plot PMon PastMonth_SRS number 2 0 0 PLOT PAST_MONTH_SRS NA NA 93
plot PDay PastDay_SRS number 2 0 0 PLOT PAST_DAY_SRS NA NA 92
plot QASt QAStatus number 1 0 0 PLOT QA_STATUS NA NA 134
plot Crew1 CrewNumber1 number 6 0 0 PLOT CREWNBR1 NA NA 13
plot Crew2 CrewNumber2 number 6 0 0 PLOT CREWNBR2 NA NA 14
plot Crew3 CrewNumber3 number 6 0 0 PLOT CREWNBR3 NA NA 15
plot Crew4 CrewNumber4 number 6 0 0 PLOT CREWNBR4 NA NA 16
plot Crew5 CrewNumber5 number 6 0 0 PLOT CREWNBR5 NA NA 17
plot NFSam NonforestSamplingStatus number 1 0 0 PLOT NF_SAMPLING_STATUS_CD NA NA 83
plot InvSt InvasiveSamplingStatus number 1 0 0 PLOT INVASIVE_SAMPLING_STATUS_CD NA NA 61
plot VegSt P2vegSamplingStatus number 1 0 0 PLOT P2VEG_SAMPLING_STATUS_CD NA NA 89
plot Level P2vegSamplingLevelOfDetail number 1 0 0 PLOT P2VEG_SAMPLING_LEVEL_DETAIL_CD NA NA 88
plot DWMSt P2dwmSamplingStatus number 1 0 0 PLOT P2DWM_SAMPLING_STATUS_CD NA NA 179
plot DWM#S P2dwmNumberSubplot number 1 0 0 PLOT P2DWM_NBR_SUBP NA NA 180
plot DWM#T P2dwmNumberSubplotTransect number 1 0 0 PLOT P2DWM_NBR_SUBP_TRANSECT NA NA 181
plot DWMSL P2dwmSubplotList number 4 0 0 PLOT P2DWM_SUBPLIST NA NA 184
plot DWMLN P2dwmTransectLength number 3 1 0 PLOT P2DWM_TRANSECT_LENGTH NA NA 182

plot Empt InvasiveSpecimenRule number 1 0 0 PLOT INVASIVE_SPECIMEN_RULE_CD NA NA 62
plot Empt HistPreviousReserveStatus number 1 0 0 PLOT HIST_PREV_RESERVE_STATUS_CD NA NA 51
plot Empt HistPreviousMonth number 2 0 0 PLOT HIST_PREV_MONTH NA NA 49
plot Empt HistPreviousYear number 4 0 0 PLOT HIST_PREV_YEAR NA NA 52
plot Empt SubplotsExam number 1 0 0 PLOT SUBP_EXAMINE_CD NA NA 163
plot Empt HistPreviousPlotStatus number 1 0 0 PLOT HIST_PREV_PLOT_STATUS_CD NA NA 50
plot Empt Subplot4NextConsec number 9 0 0 PLOT HIST_SUBP4_NEXT_TREE NA NA 162
plot Empt Subplot3NextConsec number 9 0 0 PLOT HIST_SUBP3_NEXT_TREE NA NA 161
plot Empt Subplot2NextConsec number 9 0 0 PLOT HIST_SUBP2_NEXT_TREE NA NA 160
plot Empt Subplot1NextConsec number 9 0 0 PLOT HIST_SUBP1_NEXT_TREE NA NA 159
plot Empt HistState number 2 0 0 PLOT HIST_STATECD NA NA 55
plot Empt HistUnit number 1 0 0 PLOT HIST_UNITCD NA NA 57

plot Empt HistCounty number 3 0 0 PLOT HIST_COUNTYCD NA NA 44
plot Empt HistPlot number 5 0 0 PLOT HIST_PLOT NA NA 47
plot Empt HistCycle number 2 0 0 PLOT HIST_CYCLE NA NA 45
plot Empt HistSubcycle number 1 0 0 PLOT HIST_SUBCYCLE NA NA 56
plot Empt HistSampleKind number 1 0 0 PLOT HIST_KINDCD NA NA 54
plot Empt JavaEditWarning number 4 0 0 PLOT JAVAEDITWARNING NA NA 66
plot Empt JavaEditFix number 4 0 0 PLOT JAVAEDITFIX NA NA 65
plot Empt JavaLoadWarning number 4 0 0 PLOT JAVALOADWARNING NA NA 68
plot Empt JavaLoadFix number 4 0 0 PLOT JAVALOADFIX NA NA 67
plot Empt HistAllowDelete number 1 0 0 PLOT HIST_ALLOW_DELETE NA NA
plot Empt RegionFlag text 12 0 0 PLOT RGN_FLG NA NA
plot Empt RegionType text 40 0 0 PLOT RGN_TYP NA NA
plot Empt StartVersionControlNum text 30 0 0 PLOT PDR_START_VERSION NA NA
plot Empt EndVersionControlNum text 30 0 0 PLOT PDR_END_VERSION NA NA

condition Cond# Condition number 1 0 0 COND CONDID NA NA 7
condition LUse LandUse_SRS number 2 0 0 COND LAND_USE_SRS NA NA 73
condition CNSR NonSampledReason number 2 0 0 COND COND_NONSAMPLE_REASN_CD NA NA 80
condition CndSt ConditionStatus number 1 0 0 COND COND_STATUS_CD NA NA 8
condition Dist1 Disturbance1 number 2 0 0 COND DSTRBCD1 NA NA 13
condition DYr1 DisturbanceYear1 number 4 0 0 COND DSTRBYR1 NA NA 22
condition Dist2 Disturbance2 number 2 0 0 COND DSTRBCD2 NA NA 16
condition DYr2 DisturbanceYear2 number 4 0 0 COND DSTRBYR2 NA NA 25
condition Dist3 Disturbance3 number 2 0 0 COND DSTRBCD3 NA NA 19
condition DYr3 DisturbanceYear3 number 4 0 0 COND DSTRBYR3 NA NA 28
condition Trmt1 Treatment1 number 2 0 0 COND TRTCD1 NA NA 133
condition Cut1 HarvestType1_SRS number 2 0 0 COND HARVEST_TYPE1_SRS NA NA 47
condition TYr1 TreatmentYear1 number 4 0 0 COND TRTYR1 NA NA 142
condition Trmt2 Treatment2 number 2 0 0 COND TRTCD2 NA NA 136
condition Cut2 HarvestType2_SRS number 2 0 0 COND HARVEST_TYPE2_SRS NA NA 48
condition TYr2 TreatmentYear2 number 4 0 0 COND TRTYR2 NA NA 145
condition Trmt3 Treatment3 number 2 0 0 COND TRTCD3 NA NA 139
condition Cut3 HarvestType3_SRS number 2 0 0 COND HARVEST_TYPE3_SRS NA NA 49
condition TYr3 TreatmentYear3 number 4 0 0 COND TRTYR3 NA NA 148

condition Empt HistAllowDelete number 1 0 0 COND HIST_ALLOW_DELETE NA NA
condition Empt RegionFlag text 12 0 0 COND RGN_FLG NA NA
condition Empt RegionType text 40 0 0 COND RGN_TYP NA NA

tree Cond# Condition number 1 0 0 TREE CONDID NA NA 29
tree SPP Species number 4 0 0 TREE SPCD NA NA 193
tree SpSRS Species_SRS number 2 0 0 TREE SPCD_SRS NA NA 194
tree TStat TreeStatus number 1 0 0 TREE STATUSCD NA NA 213
tree PStat PreviousStatus number 1 0 0 TREE PREV_STATUS_CD NA NA 159
tree Reco Reconcile number 1 0 0 TREE RECONCILECD NA NA 171
tree Dead? StandingDead number 1 0 0 TREE STANDING_DEAD_CD NA NA 195
tree Azi Azimuth number 3 0 0 TREE AZIMUTH NA NA 4
tree Dist Distance number 3 1 0 TREE DIST NA NA 84
tree Tree# Tree number 3 0 0 TREE TREE NA NA 202
tree PrDia PreviousDiameter number 3 1 0 TREE PREVDIA NA NA 150
tree Dmg1 DamageAgent1 number 5 0 0 TREE DAMAGE_AGENT_CD1 NA NA 244
tree Dmg2 DamageAgent2 number 5 0 0 TREE DAMAGE_AGENT_CD2 NA NA 245
tree Dmg3 DamageAgent3 number 5 0 0 TREE DAMAGE_AGENT_CD3 NA NA 246
tree Cause CauseOfDeath number 2 0 0 TREE AGENTCD NA NA 23

tree MorYr MortalityYear number 4 0 0 TREE MORTYR NA NA 128
tree Util UtilClass_SRS number 1 0 0 TREE UTILCD_SRS NA NA 234

tree Empt HistPreviousLengthToDiameter number 3 1 0 TREE HIST_PREV_HTDMP NA NA 104
tree Empt HistPreviousTree number 9 0 0 TREE HIST_PREV_TREE NA NA 108
tree Empt HistPreviousSpecies number 4 0 0 TREE HIST_PREV_SPCD NA NA 105
tree Empt HistPreviousStatus number 1 0 0 TREE HIST_PREV_STATUS_CD NA NA 106
tree Empt HistPreviousDistance number 4 1 0 TREE HIST_PREV_DIST NA NA 103
tree Empt HistPreviousDiameter number 4 1 0 TREE HIST_PREV_DIA NA NA 102
tree Empt HistPreviousAzimuth number 3 0 0 TREE HIST_PREV_AZIMUTH NA NA 99

tree Empt HistAllowDelete number 1 0 0 TREE HIST_ALLOW_DELETE NA NA
tree Empt RegionFlag text 12 0 0 TREE RGN_FLG NA NA
tree Empt RegionType text 40 0 0 TREE RGN_TYP NA NA

boundary PType PlotType number 1 0 0 BOUNDARY SUBPTYP NA NA 17
boundary BChg BoundaryChange number 1 0 0 BOUNDARY BNDCHG NA NA 1
boundary CCond ContrastingCond number 1 0 0 BOUNDARY CONTRAST NA NA 4
boundary LAzi LeftAzimuth number 3 0 0 BOUNDARY AZMLEFT NA NA 14
boundary CAzi CornerAzimuth number 3 0 0 BOUNDARY AZMCORN NA NA 5
boundary CDis CornerDistance number 2 0 0 BOUNDARY DISTCORN NA NA 6
boundary RAzi RightAzimuth number 3 0 0 BOUNDARY AZMRIGHT NA NA 21
boundary %Are PercentArea number 3 0 0 BOUNDARY PERCENT_AREA NA NA 16

boundary Empt HistPreviousLeftAzi number 3 0 0 BOUNDARY HIST_PREV_AZMLEFT NA NA 11
boundary Empt HistPreviousCornerAzi number 3 0 0 BOUNDARY HIST_PREV_AZMCORN NA NA 9
boundary Empt HistPreviousCornerDist number 3 0 0 BOUNDARY HIST_PREV_DISTCORN NA NA 10
boundary Empt HistPreviousRightAzi number 3 0 0 BOUNDARY HIST_PREV_AZMRIGHT NA NA 13

boundary Empt HistAllowDelete number 1 0 0 BOUNDARY HIST_ALLOW_DELETE NA NA
boundary Empt RegionFlag text 12 0 0 BOUNDARY RGN_FLG NA NA
boundary Empt RegionType text 40 0 0 BOUNDARY RGN_TYP NA NA

subplot SubSt SubplotStatus number 1 0 0 SUBPLOT STATUSCD NA NA 83
subplot SNSR SubplotNonsampledReason number 2 0 0 SUBPLOT POINT_NONSAMPLE_REASN_CD NA NA 81
subplot SubCt SubplotCenterCond number 1 0 0 SUBPLOT SUBPCOND NA NA 80
subplot MicCt MicroplotCenterCond number 1 0 0 SUBPLOT MICRCOND NA NA 23
subplot CList ConditionList number 4 0 0 SUBPLOT CONDLIST NA NA 5

subplot Empt HistAllowDelete number 1 0 0 SUBPLOT HIST_ALLOW_DELETE NA NA
subplot Empt RegionFlag text 12 0 0 SUBPLOT RGN_FLG NA NA
subplot Empt RegionType text 40 0 0 SUBPLOT RGN_TYP NA NA

p2dwmTransectSegment Cond Condition number 1 0 0 P2DWM_TRANSECT_SEGMENT CONDID NA NA 3
p2dwmTransectSegment SegSt SegmentStatus number 1 0 0 P2DWM_TRANSECT_SEGMENT SEGMNT_STATUS_CD A NA 6
p2dwmTransectSegment SegNS SegmentNonSampledReason number 2 0 0 P2DWM_TRANSECT_SEGMENT SEGMNT_NONSAMPLE_REASN_CD NA NA 7
p2dwmTransectSegment BegHD BeginningHorizontalDistance number 3 1 0 P2DWM_TRANSECT_SEGMENT BEGINHORIZDIST NA NA 4
p2dwmTransectSegment EndHD EndingHorizontalDistance number 3 1 0 P2DWM_TRANSECT_SEGMENT ENDHORIZDIST NA NA 5

p2dwmTransectSegment Empt HistAllowDelete number 1 0 0 P2DWM_TRANSECT_SEGMENT HIST_ALLOW_DELETE NA NA
p2dwmTransectSegment Empt RegionFlag text 12 0 0 P2DWM_TRANSECT_SEGMENT RGN_FLG NA NA
p2dwmTransectSegment Empt RegionType text 40 0 0 P2DWM_TRANSECT_SEGMENT RGN_TYP NA NA

p2dwmCWD Cond Condition number 1 0 0 P2DWM_CWD CONDID NA NA 3
p2dwmCWD SubAn OnSubplotAnnularplot number 1 0 0 P2DWM_CWD ONSUBP_ANNPCD NA NA 4
p2dwmCWD HDist HorizontalDistance number 3 1 0 P2DWM_CWD HORIZDIST NA NA 5
p2dwmCWD Decay DecayClass number 1 0 0 P2DWM_CWD DECAYCD NA NA 6
p2dwmCWD Spp Species number 4 0 0 P2DWM_CWD SPCD NA NA 7
p2dwmCWD TrDia TransectDiameter number 3 0 0 P2DWM_CWD TRANSECT_DIA NA NA 8
p2dwmCWD HoDia HollowDiameter number 3 0 0 P2DWM_CWD HOLLOW_DIA NA NA 9
p2dwmCWD Len3 Length3Ft number 1 0 0 P2DWM_CWD LENGTH_3FTCD NA NA 12

p2dwmCWD Empt HistAllowDelete number 1 0 0 P2DWM_CWD HIST_ALLOW_DELETE NA NA
p2dwmCWD Empt RegionFlag text 12 0 0 P2DWM_CWD RGN_FLG NA NA
p2dwmCWD Empt RegionType text 40 0 0 P2DWM_CWD RGN_TYP NA NA

p2dwmResidue Cond Condition number 1 0 0 P2DWM_RESIDUE_PILE CONDID NA NA 3
p2dwmResidue BegHD BeginningHorizontalDistance number 3 1 0 P2DWM_RESIDUE_PILE BEGINHORIZDIST NA NA 4
p2dwmResidue EndHD EndingHorizontalDistance number 3 1 0 P2DWM_RESIDUE_PILE ENDHORIZDIST NA NA 5
p2dwmResidue PileH PileHeight1 number 2 0 0 P2DWM_RESIDUE_PILE COMP_HT NA NA 6
p2dwmResidue Decay DecayClass number 1 0 0 P2DWM_RESIDUE_PILE DECAYCD NA NA 7
p2dwmResidue Spp Species number 4 0 0 P2DWM_RESIDUE_PILE SPCD NA NA 8

p2dwmResidue Empt HistAllowDelete number 1 0 0 P2DWM_RESIDUE_PILE HIST_ALLOW_DELETE NA NA
p2dwmResidue Empt RegionFlag text 12 0 0 P2DWM_RESIDUE_PILE RGN_FLG NA NA
p2dwmResidue Empt RegionType text 40 0 0 P2DWM_RESIDUE_PILE RGN_TYP NA NA

p2dwmFWD Cond Condition number 1 0 0 P2DWM_FWD CONDID NA NA 2
p2dwmFWD FWDSt FWDStatus number 1 0 0 P2DWM_FWD FWD_STATUS_CD NA NA 3
p2dwmFWD FWDNS FWDNonSampledReason number 2 0 0 P2DWM_FWD FWD_NONSAMPLE_REASN_CD NA NA 4
p2dwmFWD SmCnt SmallCount number 3 0 0 P2DWM_FWD SMALLCT NA NA 5
p2dwmFWD MdCnt MediumCount number 3 0 0 P2DWM_FWD MEDIUMCT NA NA 6
p2dwmFWD LgCnt LargeCount number 3 0 0 P2DWM_FWD LARGECT NA NA 7
p2dwmFWD HiRea HighCountReason number 1 0 0 P2DWM_FWD REASNCTCD NA NA 8

p2dwmFWD Empt HistAllowDelete number 1 0 0 P2DWM_FWD HIST_ALLOW_DELETE NA NA
p2dwmFWD Empt RegionFlag text 12 0 0 P2DWM_FWD RGN_FLG NA NA
p2dwmFWD Empt RegionType text 40 0 0 P2DWM_FWD RGN_TYP NA NA

p2dwmDuff Cond Condition number 1 0 0 P2DWM_DUFF_LITTER CONDID NA NA 2
p2dwmDuff DLSt DuffLitterStatus number 1 0 0 P2DWM_DUFF_LITTER DL_STATUS_CD NA NA 3
p2dwmDuff DLNS DuffLitterNonSampledReason number 2 0 0 P2DWM_DUFF_LITTER DL_NONSAMPLE_REASN_CD NA NA 4
p2dwmDuff DuDep DuffDepth number 3 1 0 P2DWM_DUFF_LITTER DUFFDEP NA NA 5
p2dwmDuff LiDep LitterDepth number 3 1 0 P2DWM_DUFF_LITTER LITTERDEP NA NA 6
p2dwmDuff Meth DuffLitterMethod number 1 0 0 P2DWM_DUFF_LITTER DL_METHODCD NA NA 7

p2dwmDuff Empt HistAllowDelete number 1 0 0 P2DWM_DUFF_LITTER HIST_ALLOW_DELETE NA NA
p2dwmDuff Empt RegionFlag text 12 0 0 P2DWM_DUFF_LITTER RGN_FLG NA NA
p2dwmDuff Empt RegionType text 40 0 0 P2DWM_DUFF_LITTER RGN_TYP NA NA

EOF

2020-03-09 11:02:27.0

Brandeis, Thomas; Turner, Jeffery; Baeza Castro, Andrés; Brown, Mark; Lambert, Samuel. 2022. Assessing forest resource damage following natural disasters using national forest inventory plots: a case study of Hurricane Michael. Res. Pap. SRS-65. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 30 p. **https://doi.org/10.2737/SRS-RP-65**.

Hurricane Michael, a Category 5 storm that made landfall on October 10, 2018, caused considerable damage in the States of Alabama, Florida, and Georgia. We assessed forest resource damages using the U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program's permanent forest inventory plot network and the National Oceanic and Atmospheric Administration's defined storm damage severity zones. This assessment showed there had been 6.17 million acres of forest land with 10.01 billion cubic feet of timber within the damage zones. Of that total, 6.81 billion cubic feet remained alive after the hurricane, 1.54 billion cubic feet were standing dead, and 1.66 billion cubic feet were utilized. This represents a total of 68.0 percent of live tree volume surviving across the entire damage zone, with survival decreasing from 74.5 percent in moderately damaged areas to 36.6 percent in the catastrophically damaged areas. The percentage of utilized tree volume across all damage severity zones averaged 16.6 percent, with higher utilization rates in the catastrophic zone (39.4 percent). Over the entire damaged area, more volume per acre was left alive (1,103.50 cubic feet per acre) than left standing dead (248.97 cubic feet per acre) or utilized (269.67 cubic feet per acre). But this varied by State, damage severity zone, and major species group. Pines (*Pinus* spp.) showed decreasing amounts of live volume remaining in the forest with increasing damage severity, ranging from 70.0 percent in the moderately damaged zone to 22.7 percent in the catastrophically damaged zone. Other softwoods and both hardwood groups were less impacted than pines. The percentage of volume utilized after the hurricane was highest for the pines, with 50.5 percent of the pre-hurricane live volume utilized in the catastrophically damaged zone. The amounts of down woody materials found on the forest floor on plots remeasured after the passage of Hurricane Michael were considerably (over four times) higher than those found prior to the hurricane, most notably for coarse woody materials and piles.

Keywords: Damage assessment, down woody materials, forest inventory, hurricane, natural disaster, tree mortality, wood volume.