

TEMPORAL EFFECTS OF HURRICANES AND PRESCRIBED FIRE ON FUEL LOADING AND PINE REPRODUCTION IN THE SOUTHEASTERN UNITED STATES

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ABSTRACT

The frequency and severity of extreme weather events, including hurricanes, are expected to increase in response to global change. Concurrently, southern U.S. forests will experience droughts that may facilitate a rise in wildfire. Wind damage can alter fuel dynamics and forest structure increasing susceptibility to wildfire, especially with drought. To mitigate fuel loads, managers commonly use salvage logging and prescribed fire. Time since disturbance may further reduce loading. To understand the effect of hurricanes on fuel loading, and the impact of time since disturbance and management action, we compared fuel loads and pine reproduction across four hurricanes spanning 24 years. Highly impacted stands were paired with less severely impacted control stands at each site. Fuel accumulations initially increased with hurricane disturbance but stabilized with time. With prescribed fire, coarse woody debris decreased more rapidly than without fire. Without prescribed fire, damaged stands had greater fuel loads than control stands, even after 24 years. Although overstory mortality can provide growing space for regeneration, effects from heavy woody fuel loads and frequent prescribed fire can override opportunities for establishment and recruitment.

INTRODUCTION

Hurricanes are an important component of the natural disturbance regime of coastal forested ecosystems in the Southeastern United States (Lugo and others 1983, Walker 1991). Coupled with other disturbance agents, such as prescribed burns, wildfire, and ice storms, hurricanes help shape the structure, composition, and function of the predominate vegetation within this region (Conner and Day, Jr. 1989; Lu and others 2020; Pile and others 2017). Typically, many hurricanes result in abundant precipitation without making severe impacts to coastal areas. Further, they are an important process to both short- and long-term increases in productivity for coastal estuaries. However, catastrophic hurricanes can bring powerful wind gusts, causing devastating impacts to forest trees across broad swaths of the landscape.

Forest recovery following hurricane damage is influenced by hurricane severity, ranging from defoliation and debranching to single tree or larger gap openings and removals that emulate uniform thinning or clearcuts (Everham and Brokaw 1996, Merrens and Peart 1992, Spurr 1956). Further, forest recovery following a hurricane can be altered by other compounding and interacting disturbance events, including fire, insect outbreaks, anthropogenic activities, and

subsequent wind events (Everham and Brokaw 1996). Because hurricanes create large fuel loads, with increased susceptibility to pest and disease for residual trees, wildfire is commonly predicted as the next substantive disturbance event (Gardner and others 1991, Glitzenstein and Harcombe 1988, Hook and others 1991, Putz and Sharitz 1991). Additionally, open stand conditions created by extreme wind can accelerate local airflow and expose down woody debris to solar radiation. This increased mid-flame windspeed and dried fuel make hurricane-impacted stands susceptible to fires with extreme behaviors. As a result, it has been hypothesized that the probability of a major wildfire increases significantly after a severe hurricane (Myers and van Lear 1998). Further, based on a 1,200-year proxy record of hurricanes and fires from the coastal region of the Gulf of Mexico, Liu and others (2008) reported that the likelihood and intensity of fire increased significantly following major hurricanes, resulting in high tree mortality and the impairment of recruitment and recovery. However, this hypothesis, also known as the hypothesis of hurricane-fire interaction, has not been supported by recent data (i.e., the lack of a major fire outbreak after a recent hurricane) likely because of active fire suppression and post-hurricane mitigation efforts, including salvage logging and prescribed burning.

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In the Southeastern United States, periodic prescribed burns are one of the most used practices for managing the composition and structure of coastal pine forests and is an important mitigant in the reduction of fuel loading following extreme disturbance events. However, few studies have examined stand recovery following hurricanes and prescribed burning. In a study by Smith and others (1997), hurricanes and prescribed burning were unfavorable for loblolly pine (*Pinus taeda* L.) regeneration. A few studies have reported fuel characteristics in hurricane damaged stands (Cooke and others 2007, Wade 1993), but how post-hurricane fuel complexes and tree reproduction change with time and prescribed burning remains largely unknown.

The objective of this study was to examine the temporal effects of hurricanes on stand structure, fuel dynamics, and tree reproduction in southeastern coastal pine forests of the United States. To conduct this study, we examined forest stands that had suffered hurricane damage to neighboring, minimally damaged (“Control”) stands with similar management including prescribed burning. In situations where it allowed, we also compared Damaged and Control stands to salvage logging and damaged but without prescribed fire. Specifically, the study was designed to address the following questions: (1) What are the residual effects of hurricanes on forest stand structure? (2) How quickly do fuels recover to control levels following hurricanes? (3) How does increased fuel loading from hurricanes coupled with prescribed burning influence understory vegetation and tree reproduction? This

retrospective study was developed from a chronosequence of hurricanes over two decades from 1989 through 2008.

MATERIALS AND METHODS

Hurricane and Study Site Descriptions

We selected the most catastrophic hurricanes in recent history, including hurricanes Hugo, Opal, Katrina, and Ike and identified hurricane damaged pine stands on public lands within the impact zone with the aid of local land managers (fig. 1, table 1).

For Hurricane Hugo, we had two study locations, the Hobcaw Barony Wildlife Refuge (HBWR) and the Francis Marion National Forest (FMNF). HBWR (33°24'N, 79°15'W) is 6475 hectares of predominantly loblolly and longleaf pine (*P. palustris* Mill.) occupying the southern tip of the Waccamaw Peninsula in Georgetown County, South Carolina. Soils at HBWR are sandy, excessively to moderately drained on the western side, and moderately to poorly drained on the eastern side. The mean temperatures range from 8 °C in January to 23 °C in August with mean annual precipitation of approximately 1422 mm/year (NOAA National Centers for Environmental Information 2022). The FMNF, (33°9'N, 79°42'W) is 104 759 hectares of predominantly loblolly and longleaf pine located on the lower Coastal Plain of South Carolina, within Berkeley and Charleston counties. Soils in FMNF are sandy and moderately drained in pine stands with temperatures and precipitation

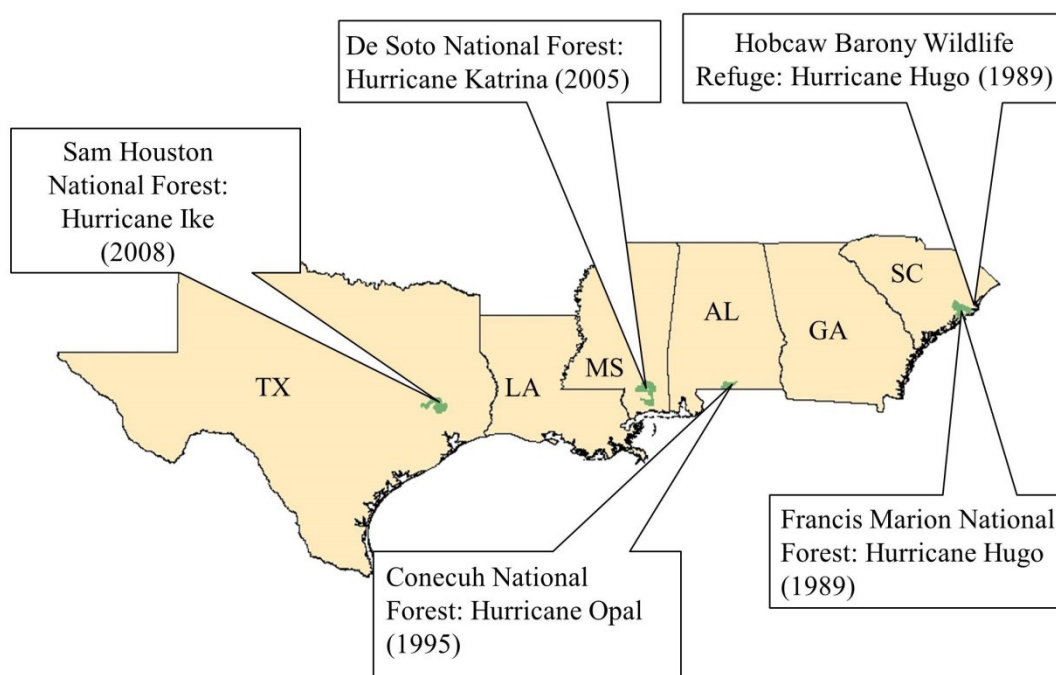


Figure 1—Location of study sites and associated hurricanes.

Table 1—Hurricane landfall date, location, Saffir/Simpson hurricane category and corresponding study site location and sampling design

		Hurricane category			
		Hugo	Opal	Katrina	Ike
	Date	September 21, 1989	October 4, 1995	August 29, 2005	September 13, 2008
Landfall	Location	Sullivan's Island, SC	Pensacola, FL Navarre Beach, FL	Buras-Triumph, LA	Galveston, TX
	Category	4	3	3	4
Study site	Location(s)	Francis Marion National Forest (FMNF) and Hobcaw Barony Wildlife Refuge (HBWR)	Conecuh National Forest (CNF)	Desoto National Forest (DNF)	Sam Houston National Forest (SHNF)
	Sampled stands	12 Total Damaged Stands (8 Damaged and Unburned, 4 Damaged and Burned); 10 Control Stands	10 Damaged Stands; 10 Control Stands	10 Damaged Stands; 10 Damaged and Salvaged Stands; 10 Control Stands	10 Damaged Stands; 10 Control Stands

amounts similar to HBWR. For Hurricane Opal, our study location was the Conecuh National Forest (CNF) 31°7'N, 86°45'W. The CNF is the southern-most national forest in Alabama occupying 33 949 hectares of predominate longleaf and slash pine. Soil types are marked by deep sandy soils predominantly of the Troup and Fuquay series. The mean temperatures range from 10 °C in January to 28 °C in July with mean annual precipitation of approximately 1524 mm/year (National Climatic Data Center). Our study location for Hurricane Katrina was the De Soto National Forest (DSNF) 31°4'N, 88°59'W occupying 209 865 hectares of predominately longleaf and slash (*P. elliottii* Engelm.) pines spreads across six counties in Mississippi. Soil types are mainly sandy loams. The monthly mean temperature ranges from 9 °C in January to 27 °C in July with mean annual precipitation of approximately 1651 mm/year (National Climatic Data Center). Our study location for Hurricane Ike was the Sam Houston National Forest (SHNF) 30°32'N, 95°21'W occupying 65 979 hectares of predominate loblolly and shortleaf (*P. echinata* Mill.) pines across the counties of Montgomery, Walker, and San Jacinto in eastern Texas. Soil types are primarily characterized as loamy and sandy. The monthly mean temperature ranges from 12 °C in January to 28 °C in July with mean annual precipitation of approximately 1397 mm/year (National Climatic Data Center).

Experimental Design and Sampling

This retrospective study was conducted as a completely randomized design comparing upland pine stands damaged by hurricanes to similar, neighboring, less damaged stands across the chronosequence of hurricane events. For each hurricane, 10-12 severely damaged upland pine stands ("Damaged") were identified based on existing records, aerial photos, and with the assistance of the local U.S. Department of Agriculture (USDA), Forest Service, Ranger District office (table 1). Damaged stands had observable overstory canopy mortality, primarily described as a majority of stems snapped or bent from wind damage. For comparison, 10 less

damaged pine stands, with similar stand and site conditions as those Damaged stands, were identified as ("Control") stands. These stands formed a chronosequence consisting of four distinct times since hurricane disturbance classes, ranging from 6 years (Hurricane Ike in 2008, sampled in 2014) to 8 years (Hurricane Katrina in 2005, sampled in 2013) to 18 years (Hurricane Opal in 1995, sampled in 2013) to 24 years (Hurricane Hugo in 1989, sampled in 2013). With the exception of Hurricane Hugo, prescribed burns were applied within the management plan for each location, typically within 2- to 5-year return intervals. For Hurricane Hugo, due to lack of representation of Damaged stands that included prescribed fire, we were able to sample four hurricane damaged and burned stands, similar to the other hurricanes, but we were also able to sample eight "Damaged and Unburned" (D+ UnB) stands for within hurricane comparison. Further, to determine the role of salvage logging on fuel loading and tree reproduction, we sampled an additional 10 hurricane Damaged stands on the Desoto National Forest that were salvage logged ("Salvaged").

In each identified stand, 1-3 plots were located at 30 m intervals along randomly established transects using ArcGIS. For the stands associated with Hurricane Hugo on the HBWR and FMNF, four of the Damaged stands had three plots, one had two plots, and three had one plot. Further, for the Control stands, six had one plot, and six had two plots. For stands sampled in the other hurricane areas, all stands had two plots each. To determine residual overstory stand structure and composition, the diameter at breast height (DBH) and species of all saplings (2.5 < DBH < 10.2 cm) were measured within 5.6 m radius from plot center and the DBH and species of all trees (DBH > 10.2 cm) were measured within 11.3 m radius of plot center.

To determine differences in woody fuel loading between Damaged and Control stands, a modified version (see Coates and others 2019, Hahn and others 2021) of Brown's (1974) planar intercept method was used to measure fuel loading by

size class. At the plot center, three 15 m sampling transects were established from the plot center. The orientation of the center transect was established in a random direction, and the other two transects were placed at +120° and -120° from the initial transect. Measurements along two of the fuel transects began at the plot center, and the third transect worked backward from the end point at 15 m. Down woody fuels of 0.00–0.64 cm, 0.64–2.54 cm, 2.54–7.62 cm in diameter, and over 7.62 cm in diameter that intersected the sampling plane were tallied as 1-, 10-, 100-, and 1,000-hour fuel classes, respectively. For 1- and 10-hour fuels, intercepts were counted along the first 1.8 m of the transect. For 100-hour fuels, intercepts were counted along the first 3.6 m of the transect. The 1,000-hour fuel was recorded as either pine or hardwood and decay class (sound or decayed) and measured for diameter along the entire 15 m transect (Lutes and Keane 2006, Maser and others 1979). Counts of 1-, 10-, 100- and 1,000-hour fuels obtained from transect sampling in the field were converted to weights using equations given by Brown (1974). Depths of downed woody debris were measured to the nearest 0.3 cm at sections of 3.66 to 3.96 m, 7.62 to 7.92 m, and 12.19 to 12.50 m. Woody fuel depth was measured from the surface of mineral soil to the highest dead and down woody fuel particle (<1.83 m), which intersected the transect. Litter (Oi horizon) and duff (Oe + Oa horizon) depths were measured to the nearest 0.3 cm along the same transect intervals.

To assess differences in ground cover and tree reproduction between Damaged and Control stands, we recorded the coverage of ground flora (classified as forbs or graminoids) and woody plants (shrubs and vines) in 4 m² quadrats centered at 1.5, 4.6, 7.6, 10.7, and 13.7 m along each transect. Further, within each quadrat, we tallied small (<0.3 m tall) and large (>0.3 m tall but DBH <2.5 cm) tree reproduction by species.

For statistical analyses, we limited our comparison to within hurricane assessments of overstory structure, fuel loading, vegetation, and tree reproduction. For each hurricane, we compared stand level averages by condition type (Damaged, Salvaged, or Damaged and Unburned stands compared to Control stands) using general linear mixed models (GLIMMIX) with condition type as a fixed effect. The distribution of dependent variables was assessed prior to analysis and fit within the model. Analyses were conducted in SAS 9.4 with significance determined at an alpha of 0.05. Means are reported as the treatment means $\pm$ the standard deviation.

RESULTS AND DISCUSSION

The effects of increased fuel loads following hurricanes can have long lasting residual effects on fuel, and forest structure and management can influence outcomes. Our results

indicate that (1) prescribed burns are effective at reducing fine fuels, even after short time periods, with 1-hour fuels similar to Controls within 6 years and 10-hour fuels after 8 years; (2) salvage logging reduces fine and coarse fuels more effectively than prescribed burning alone and is the only treatment where 1,000-hour fuels were comparable to Controls; (3) without burning, fuel loads remained higher even 24 years following disturbance; and (4) higher fuel loadings and prescribed burning can alter the composition of the forest understory, promoting forbs and graminoids and reducing woody stems including tree reproduction.

Residual Stand Structure

As expected, relative to the Control, hurricanes significantly reduced overstory basal area (BA) m²/ha and density [trees per hectare (TPH)] in Damaged stands following 6 (BA: $F = 30.7$; $p < 0.001$; TPH: $F = 22.9$; $p < 0.001$), 8 (BA: $F = 17.8$; $p < 0.001$; TPH: $F = 9.7$; $p = 0.001$) and 18 (BA: $F = 14.2$; $p = 0.001$; TPH: $F = 8.9$; $p = 0.008$) years post-hurricane (fig. 2). However, 24 years following a hurricane, tree recruitment is likely reducing differences between Damaged and Control stands, and especially in the absence of prescribed burns in Damaged and Unburned stands for hardwood and pine regeneration. There were no differences in BA between stand conditions for Hurricane Hugo ($F = 1.9$; $p = 0.18$), although there were differences in stem densities ($F = 19.6$; $p < 0.001$). Damaged and Unburned (1466 ± 516 TPH) stands had more stems than either Damaged (576 ± 237 TPH) or Control (470 ± 246) stands, which were similar. The differences in stem densities between stand condition type were particularly apparent in the smaller size classes of the Damaged and Unburned stands (fig. 3)

Fuel Loading and Depth

Prescribed fire was effective at reducing fine woody fuels, but 1,000-hour fuels were more recalcitrant even following a quarter century. There were no differences between stand condition in litter or duff for Hurricane Ike (litter: $F = 0.0$; $p = 0.88$; duff: $F = 0.1$; $p = 0.79$) or Hurricane Katrina (litter: $F = 0.9$; $p = 0.39$; duff: $F = 2.0$; $p = 0.15$). However, litter accumulations were greater in Control (0.83 ± 0.25 tons/ha) stands than Damaged (0.49 ± 0.26 tons/ha) stands for Hurricane Opal ($F = 9.2$; $p = 0.007$). But there were no differences in duff accumulations ($F = 0.5$; $p = 0.48$). Differences in litter accumulation were also recorded for Hurricane Hugo ($F = 6.9$; $p = 0.005$). Litter accumulations were significantly higher in Damaged and Unburned (6.48 ± 2.36 tons/ha) stands than either Damaged (2.07 ± 0.88 tons/ha) or Control (3.81 ± 2.15 tons/ha) stands, which were similar. Differences were also recorded for duff accumulation ($F = 19.3$; $p < 0.001$). Stands impacted by Hurricane Hugo that were Damaged and Unburned ($D + UnB$, 5.51 ± 1.94 tons/ha) and those that were Damaged (4.93 ± 1.35 tons/ha)

had significantly greater duff accumulations than Controls (1.69 ± 1.03 tons/ha). The differences in litter and duff depths for Hurricane Hugo are likely attributed to the lack of fine fuel consumption by prescribed fire in the Damaged and Unburned stands.

For 1-hour fuels, significant differences were recorded 24 years following a hurricane but not at sites with a more recent hurricane disturbance history ($F = 12.3$, $p < 0.001$), however, this reflected differences in the use of prescribed burning following a hurricane (fig. 4). The Damaged and Unburned (D+ UnB) stands assessed from Hurricane Hugo had higher 1-hour fuel loads than either the Damaged or Control stands but Damaged and Control stands were similar in their 1-hour loads. Differences in 10-hour fuels were recorded 6- and 8-years following hurricane disturbance (Hurricane Ike: $F = 26.8$; $p < 0.001$ and Hurricane Katrina: $F = 5.2$; $p = 0.013$, respectfully) (fig. 4). Six years following a hurricane, 10-hour fuels were nearly four times as high in Damaged (2.28 ± 0.91 tons/ha) stands than Control (0.60 ± 0.48 tons/ha) stands for

Hurricane Ike. Ten-hour fuels in Damaged stands (0.79 ± 0.67 tons/ha) remained higher 8 years following a hurricane, but Salvaged (0.28 ± 0.21 tons/ha) stands had similar loading as Control (0.24 ± 0.21 tons/ha) stands. Twenty-four years following a hurricane, Damaged and Unburned (4.12 ± 1.67 tons/ha) stands remained higher than the Control (1.13 ± 0.96 tons/ha). However, stands Damaged (2.56 ± 1.55 tons/ha) and treated with prescribed burning had 10-hour fuel loads similar to both Control and the Damaged and Unburned stands.

For 100-hour fuels, differences were recorded 6 years following hurricane disturbance, but not thereafter, except for the Damaged and Unburned stands from Hurricane Hugo (fig. 5). In Damaged (4.98 ± 3.95 tons/ha) stands, 100-hour fuels were nearly five times higher than Control (1.08 ± 0.85 tons/ha) stands in the 6 years following Hurricane Ike ($F = 9.3$; $p = 0.007$). After 24 years without prescribed burns, 100-hour fuels were significantly higher in the Damaged and Unburned (4.48 ± 2.46 tons/ha) stands than the Damaged

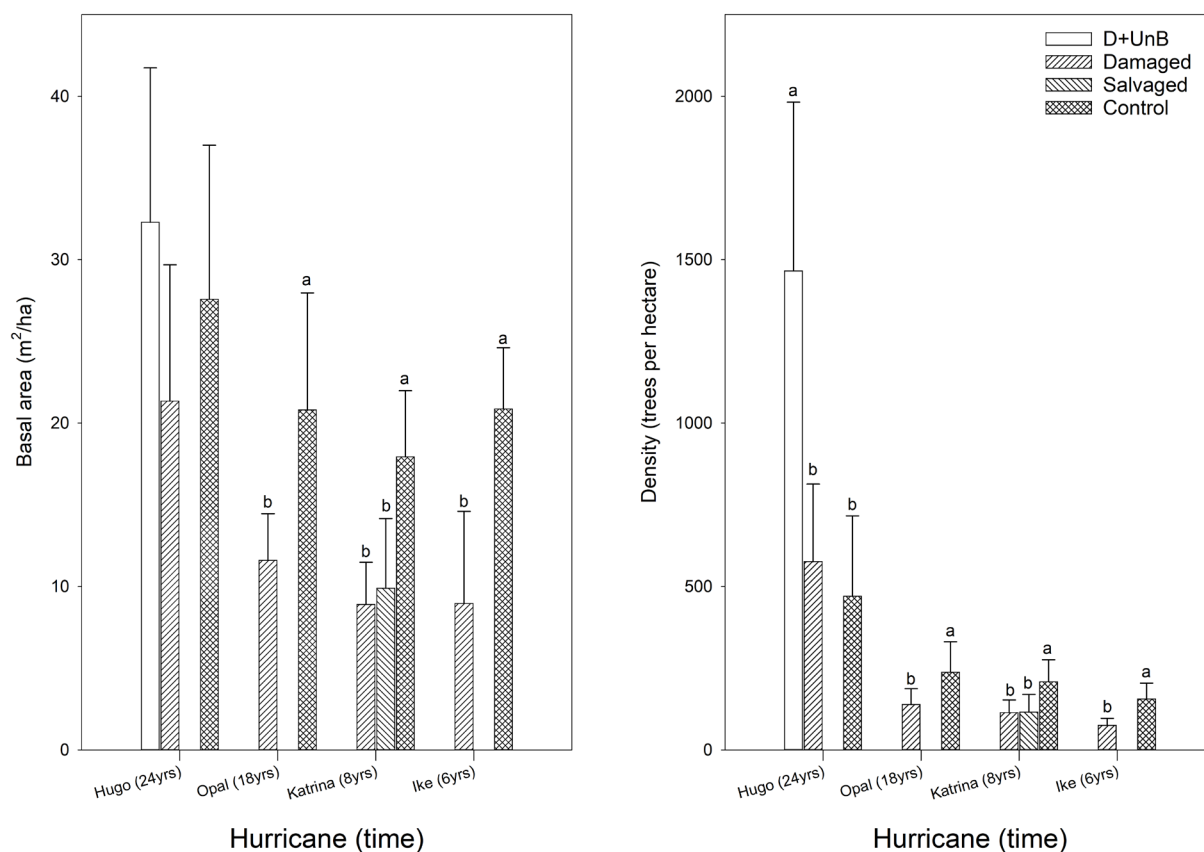


Figure 2—Basal area (m²/ha) and density by stand condition [Damaged and Unburned (D+UnB), Damaged, Salvaged, and Control] for each of the four hurricane events. Differences in letters indicates a significant difference between stand condition within hurricane.

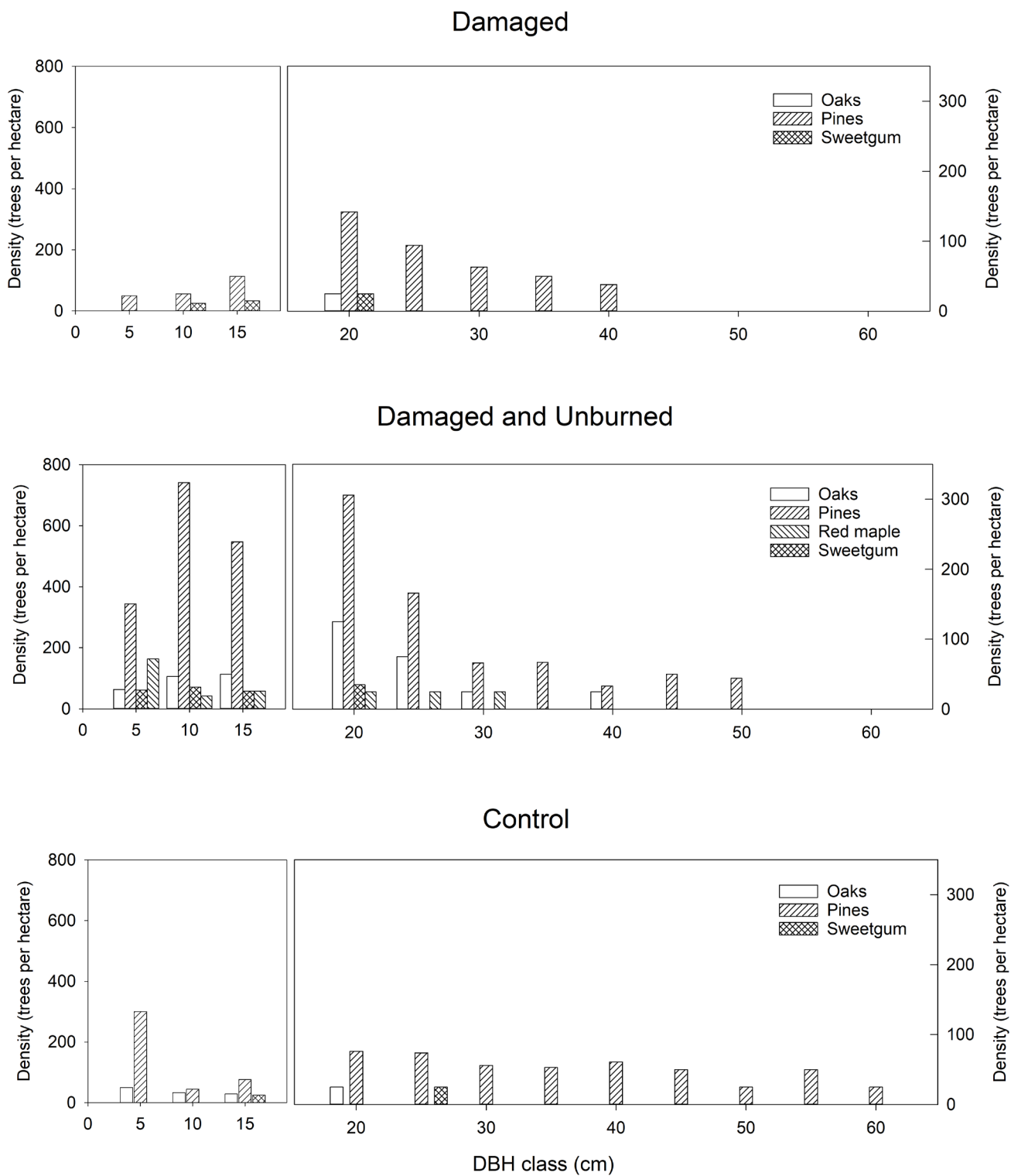


Figure 3—Diameter at breast height (DBH) distribution by species (oaks, pines, red maple, and sweetgum) of Damaged, Damaged and Unburned, and Control stands for Hurricane Hugo, 24 years post hurricane.

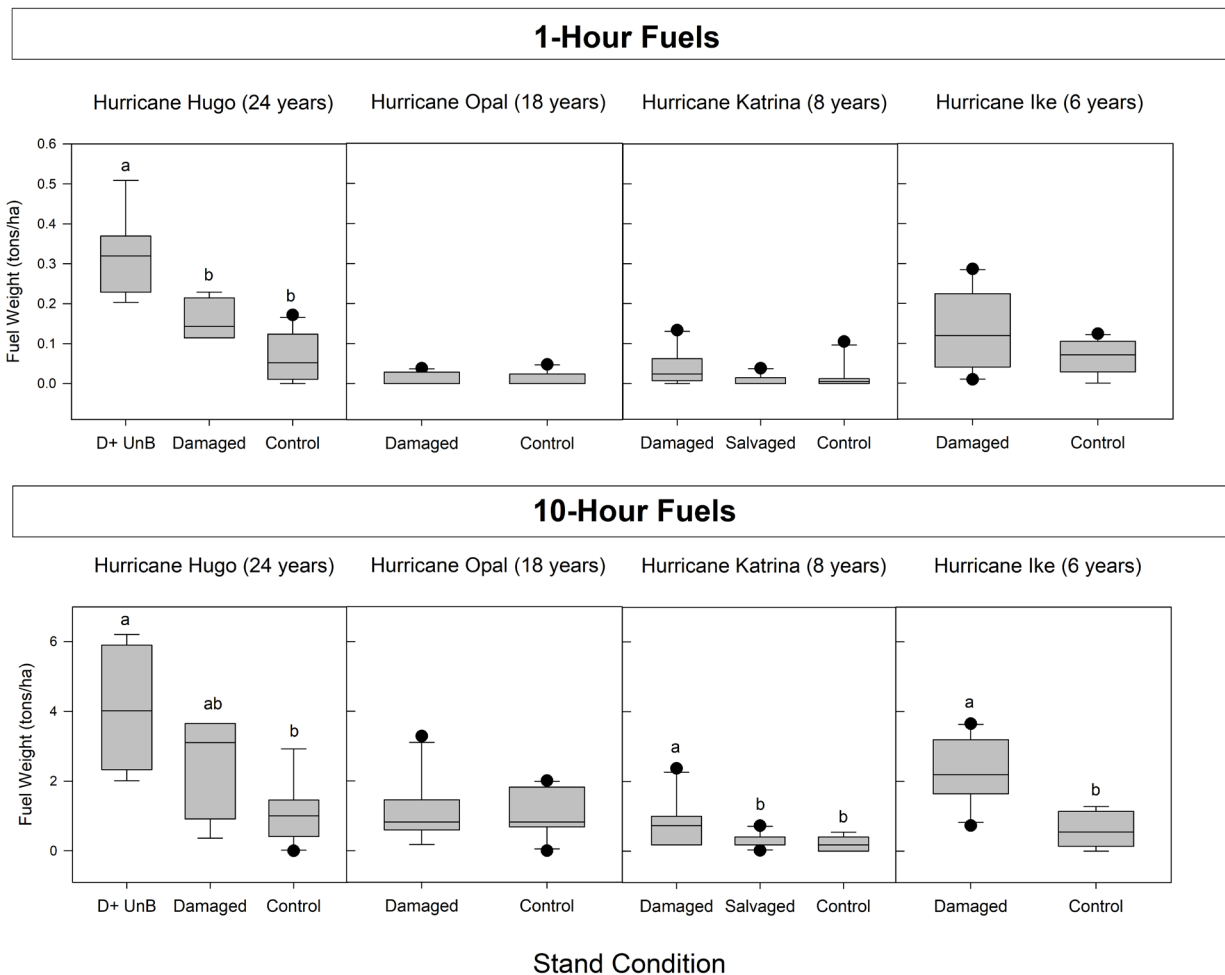


Figure 4—Fuel loading of 1- and 10-hour fuels by stand condition [Damaged, Salvaged, Damaged and Unburned (D+UnB) or Control] by hurricane representing a time-since-disturbance chronosequence. Means are compared within a hurricane. Different lowercase letters above a boxplot indicate significant disturbance effects between stand conditions. Boundaries of the box plot are represented by the 25th- and 75th-percentiles, the median line within the plot, whiskers represent the 10th- and 90th-percentiles, and points indicate outliers.

(1.81 ± 1.38 tons/ha) or Control (1.02 ± 1.49 tons/ha) stands. Differences in 1,000-hour fuels were still apparent from 6 to 24 years following a hurricane (fig. 5). Damaged (25.60 ± 14.74 tons/ha) stands from Hurricane Ike had more than four times the amount of 1,000-hour fuels than the Control (6.45 ± 6.75 tons/ha; $F = 13.9$; $p = 0.002$) stands. For Hurricane Katrina, Damaged (15.03 ± 8.46 tons/ha) stands had nearly twice the amount of 1,000-hour fuel loading as Salvaged (8.37 ± 6.25 tons/ha) stands, and five times the amount of Control (3.46 ± 2.71 tons/ha) stands ($F = 8.6$; $p = 0.001$) however, salvage logging did reduce 1,000-hour fuel loads within the range of the Control. One-thousand-hour fuel loads for Hurricane Opal, 18 years following a hurricane, were generally lower than hurricanes Katrina or Ike, but Damaged (5.50 ± 3.50 tons/ha) stands had significantly greater 1,000-hour fuels than Control (1.67 ± 2.91 tons/ha) stands ($F = 7.0$; $p = 0.016$). In our study, stands Damaged and Unburned (27.23 ± 18.09 tons/ha) had similar, but higher 1,000-hour fuels than

Damaged (12.35 ± 13.29 tons/ha) stands for Hurricane Hugo ($F = 11.2$; $p = 0.001$). Control (1.91 ± 2.50 tons/ha) stands had 1,000-hour fuel loads that approximated Damaged stands. The high variation and non-significance of our results are likely from our unbalanced sampling design for Hurricane Hugo, however, the large amount of residual 1,000-hour fuels in Damaged and Unburned stands is quite notable.

Understory Vegetation and Tree Reproduction

The differences in coverage of shrubs and vines, forbs, and graminoids between stand conditions were not consistent across hurricanes. For Hurricane Ike, shrubs and vines ($F = 5.7$; $p = 0.028$) were higher in Control stands but forbs ($F = 7.1$; $p = 0.016$) and graminoids ($F = 5.8$; $p = 0.027$) coverage was greater in the Damaged stands (fig. 6). For Hurricane Katrina, forb and graminoid coverage were greatest in Salvaged stands and comparable between Damaged and Control Stands (forbs: $F = 5.0$; $p = 0.014$; graminoids: $F = 6.4$; $p = 0.005$).

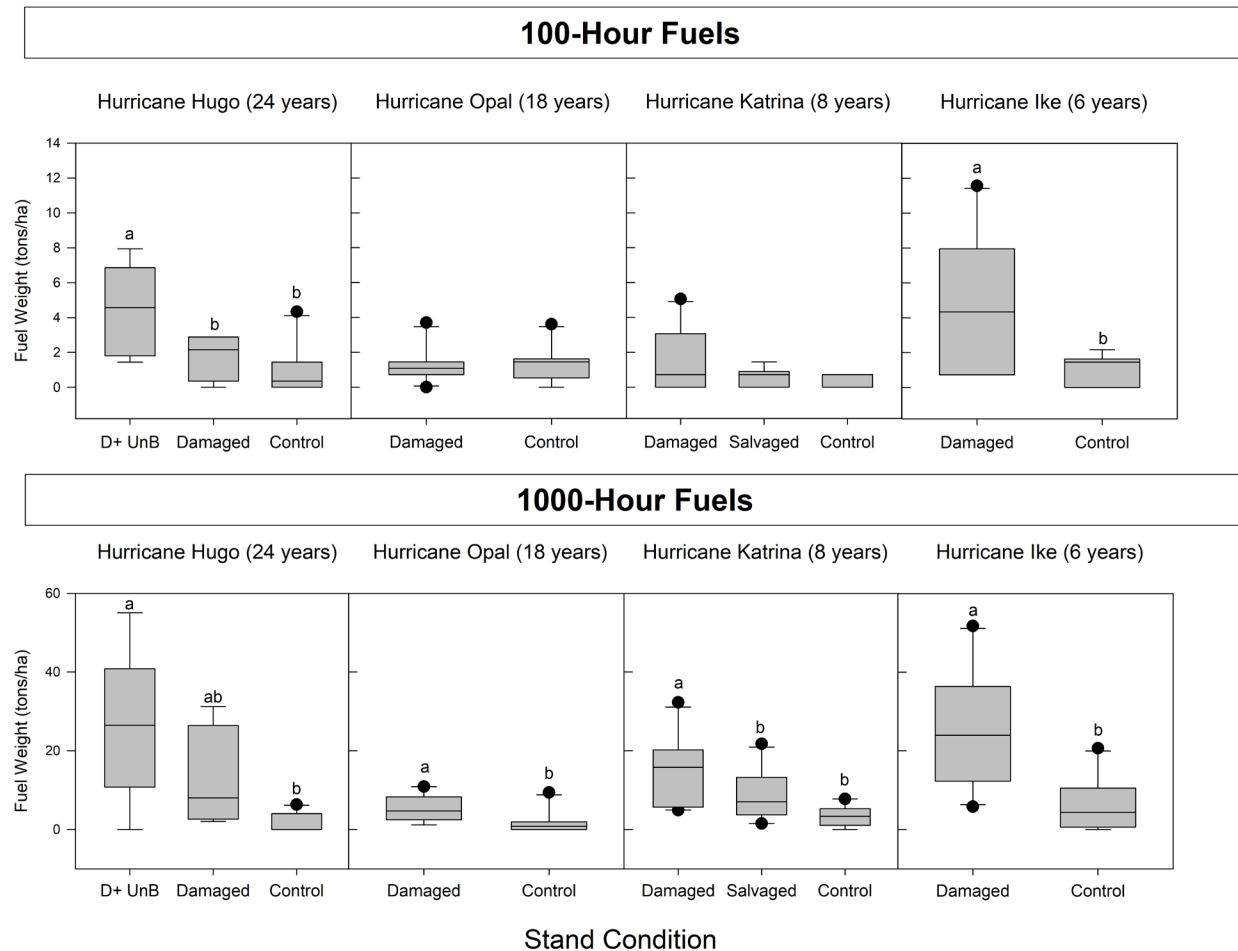


Figure 5—Fuel loading of 100- and 1,000-hour fuels by stand condition [Damaged, Salvaged, Damaged and Unburned (D+UnB) or Control] by hurricane representing a time-since-disturbance chronosequence. Means are compared within a hurricane. Different lowercase letters above a boxplot indicate significant disturbance effects between stand conditions. Boundaries of the box plot are represented by the 25th- and 75th-percentiles, the median line within the plot, whiskers represent the 10th- and 90th-percentiles, and points indicate outliers.

For Hurricane Opal, forb coverage was greater in Damaged stands than Control stands ($F = 6.8$; $p = 0.018$). The coverage of shrubs and vines differed for Hurricane Hugo, with coverage greatest in Damaged and Control stands and lowest in Damaged and Unburned stands ($F = 13.6$; $p < 0.001$).

After catastrophic wind damage, forest recovery follows one or more paths: regrowth, release, recruitment, or repression (Everham and Brokaw 1996). The path of recovery of a given site is greatly determined by both the severity of the disturbance and by the environmental dynamics of resources. Severe hurricane damage will create gaps in the canopy, which will provide light and space for new regeneration and other understory vegetation. These gaps favor shade intolerant species such as pines, and pioneer and sprouting hardwoods. Many studies have reported that gaps resulting from hurricanes have the appropriate gap size for the growth of longleaf pine and loblolly pine seedlings (Brockway and Outcalt 1998, McGuire and others 2001). Mitigations, such

as salvage logging, may change the ecosystem processes and population of species (Lindenmayer and Noss 2006). Further, periodic fire in hurricane damaged stands may impair regeneration processes. In our study, the density of total and pine reproduction was greatest in stands that were Damaged and Unburned for Hurricane Hugo (total: $F = 13.9$; $p < 0.001$; pine: $F = 21.8$; $p < 0.001$). However, pine reproduction was greatest in Salvaged stands for Hurricane Katrina ($F = 3.8$; $p = 0.034$) when compared to Damaged and Control stands (fig. 7). This is in contrast to Greene and others (2006) who reported that salvage logging reduced reproduction density due to limited seed source availability.

Although limited by our sample size and unbalanced experimental design for Hurricane Hugo, we were able to compare management with prescribed fire to that without 24 years following hurricane disturbance. Pine and total reproduction were greatest in Damaged and Unburned stands for Hurricane Hugo when compared to Damaged and

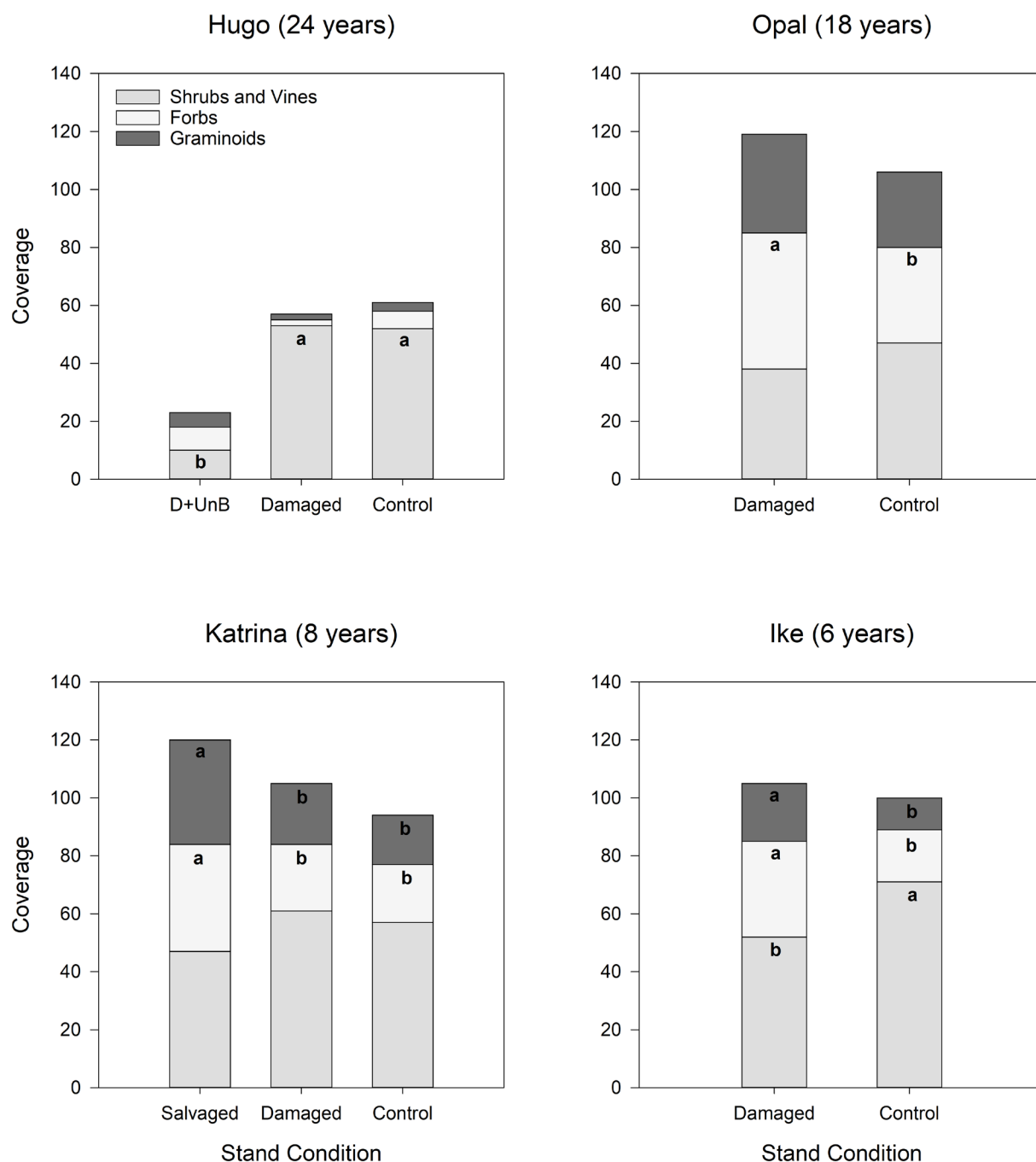


Figure 6—Coverage of shrubs and vines, forbs, and graminoids by hurricane and stand condition. Lower case letters indicate a significant difference between understory vegetation type within a hurricane based on an alpha of 0.05.

Control stands. The Damaged and Unburned stands also had lower coverage of shrubs and vines when compared to the other stand condition types where prescribed burns is a management practice. Over 50 percent of the reproduction in the Damaged and Unburned stands was pine, with loblolly pine the primary pine species. Its sensitivity to fire and ability to dominate a site following disturbance likely contributes to the increase in reproduction densities in the Damaged and Unburned stands. This contrasts with Hurricane Katrina, where salvage logging with prescribed fire reduced fuel

loading, increased forb and graminoid coverage, and resulted in more pine reproduction, specifically longleaf pine.

CONCLUSIONS

Frequent prescribed fire can reduce fine and coarse woody fuels in hurricane damaged stands. However, although beneficial for mitigating catastrophic events like drought-induced wildfire, frequent burning in hurricane impacted stands with high fuel loads can alter understory plant

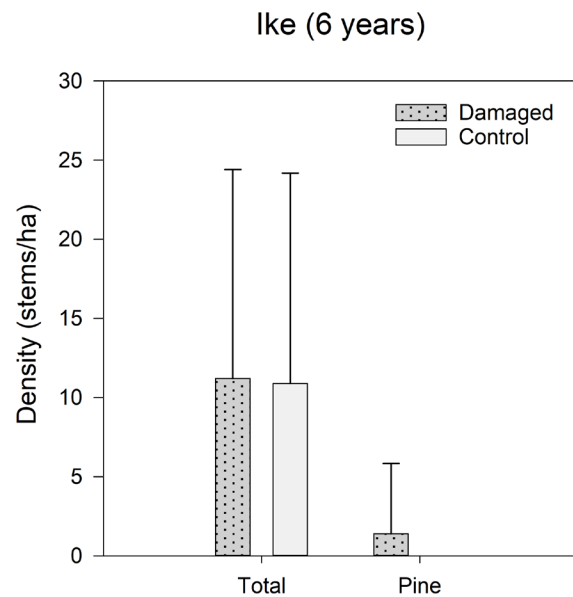
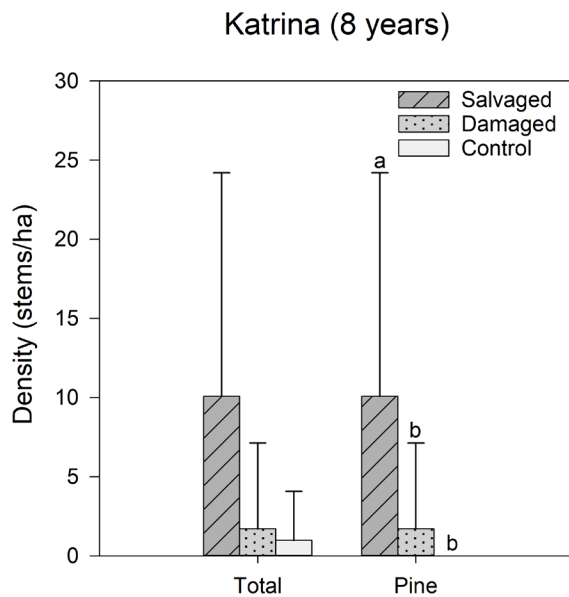
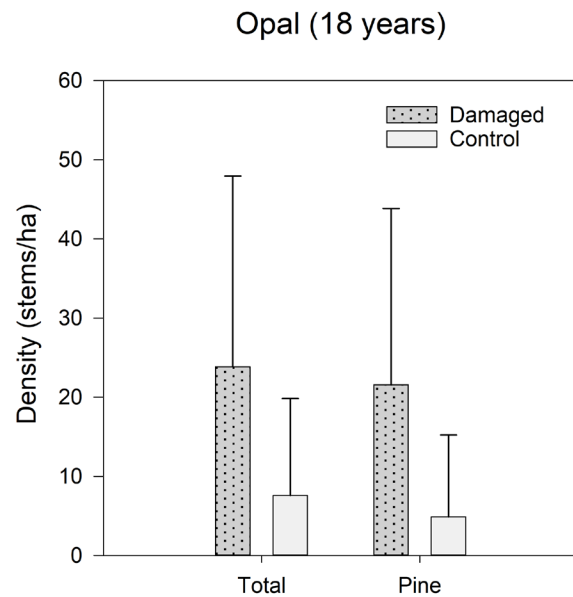
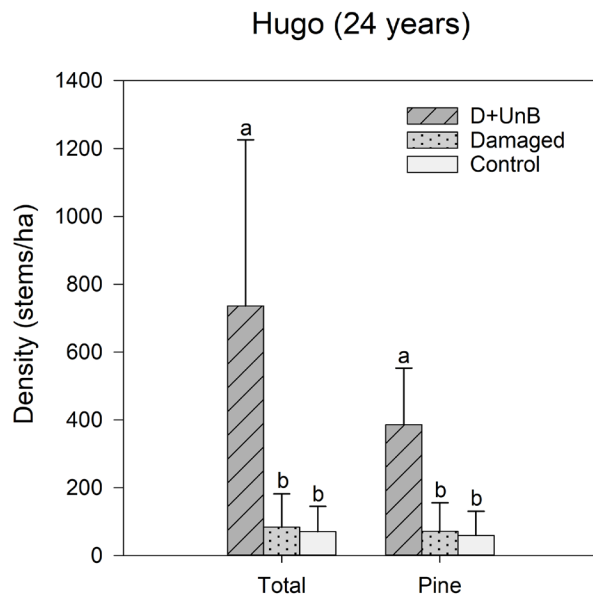


Figure 7—Total and pine reproduction densities by hurricane. Lower case letters indicate a significant difference between stand condition for either total or pine reproduction based on an alpha of 0.05.

communities and limit the establishment and recruitment of tree reproduction for some species. Nevertheless, if woodland structures with open canopies and increased coverage of grass and forb-dominated ground flora are desired, management including prescribed fire and salvage logging may accelerate meeting restoration objectives following hurricane damage.

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