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Assessment of Forest Fuel Loadings in Puerto Rico and the US Virgin Islands

Quantification of the downed woody materials that comprise forest fuels has gained importance in Caribbean forest ecosystems due to the increasing incidence and severity of wildfires on island ecosystems. Because large-scale assessments of forest fuels have rarely been conducted for these ecosystems, forest fuels were assessed at 121 US Department of Agriculture forest service inventory plots on Puerto Rico, Vieques, and the US Virgin Islands. Results indicated that fuel loadings averaged 24.05 Mg ha^{-1} in 2004–2006. Forest litter decreased from wetter to drier forest life zones. These island forests showed a paucity of coarse woody fuels (CWD) (2.91 Mg ha^{-1}) and relatively greater quantities of smaller-sized fine woody fuels (FWD) (10.18 Mg ha^{-1} for FWD and 10.82 Mg ha^{-1} for duff/litter) when compared to continental tropical forests. Between 2001 and 2006, CWD fuel loads decreased, while fine fuels and litter increased, such that total fuel loads remained constant on a subset of plots on Puerto Rico. This trend indicates that continued decomposition of CWD deposited by the last severe hurricane is balanced by increasing inputs of FWD from recovering and maturing secondary forests. Forest disturbance cycles and successional development must be taken into account by agencies charged with fire protection and risk assessment.

INTRODUCTION

In the absence of human activities, wildfires are an infrequent event in Caribbean forests (1). The increasing frequency of wildfires related to agricultural burning, arson, and human carelessness has increased concern about these effects on forest tree species composition and structure, particularly the islands' subtropical dry forests (1, 2). Wildfires can heavily impact island ecosystems, sometimes maintaining extensive areas of young forest in a suspended successional state, impairing the delivery of ecosystem services, and slowing forest recovery processes. Forested watersheds retain more freshwater and stabilize soils, and so maintain the health of tightly linked Caribbean terrestrial and marine ecosystems. Island economies benefit from recreational and ecotourism benefits created by these uniquely biodiverse Caribbean forests.

Although Caribbean island forest ecosystems are influenced by hurricane disturbances (3–9), the additional anthropogenic disturbance of wildfires may represent a tipping point in some indigenous forest ecosystems. Chronically burned Caribbean forests may no longer support their notably high levels of biodiversity and endemism (10), an ecosystem attribute that may never be attained again. For example, fires favor tree species that have adapted to survive them, such as *Leucaena leucocephala* (Lam.) De Wit. (11). These trees often survive fires by resprouting, similar to what occurs after cutting (12) or hurricane damage (13). Some tree species' seeds survive in the soil seed bank until competing vegetation is killed, after which they create dense stands of small, multistemmed trees and shrubs.

Fire is also of growing concern in Caribbean ecosystems due to increased economic losses and risks to local populations. As island human population densities increase, it is likely that losses from uncontrolled wildfires will increase. Firefighting public agencies will be hard-pressed to meet the demand for fire suppression and structure protection activities as wildfires occur more frequently in the growing, increasingly complex, wildland-urban interface.

The situation in the Caribbean is a microcosm of the continental United States, where increasing fire frequency, severity, greater economic losses, and firefighting costs have created a demand for better wildfire fuel load estimates, fuel models, and risk assessments. Because downed woody materials (DWM) such as coarse and fine woody debris (CWD and FWD, respectively) are a major determinant of wildfire behavior, quantification of these fuels in a spatially explicit manner allows land managers to properly assess fire hazards. To inform such decision-making processes, forest fuels that increase wildfire risks must be assessed. However, obtaining the data necessary to estimate fuel loads and fire behavior requires extensive ground-based sampling across the landscape (14).

The need for fuel loading information across the United States guided the incorporation of DWM measurement protocols into the US Forest Service's Forest Inventory and Analysis (FIA) program in the United States beginning in 2001 (Puerto Rico in 2000–2001, US Virgin Islands in 2004). Estimates of downed woody fuels, combined with standing-tree fuel information from the standard forest inventory, recently presented for Puerto Rico in Brandeis, Helmer, and Oswalt (15) and for the US Virgin Islands presented in Brandeis and Oswalt (16), can provide much of the information needed for wildfire risk assessment.

The main objective of this study was to estimate mean fuel loadings (biomass) for forests in Puerto Rico and the US Virgin Islands according to fuel size classes: FWD (1 hr, 10 hr, 100 hr time lags), CWD (1000+ hr time lag), duff, and litter (17). Additionally, mean fuel loadings by forested life zones were compared to further identify areas of higher risk. Changes in fuel loadings in relation to forest maturation and disturbance events were assessed using estimates of fuel loading over a 5 y period on mainland Puerto Rico. Finally, study results were examined in a regional and global context using published literature for comparable DWM studies in tropical and temperate forests.

MATERIALS AND METHODS

Study Area and Sampling Design

Data used in this study were derived from FIA inventories from Puerto Rico (including Vieques) and the US Virgin Islands. These data were collected at sampling points along a computer-generated hexagonal grid spread evenly across the islands, providing an unbiased, systematic DWM sampling framework (18). Initially, 25 plots were installed systematically in 2001 on mainland Puerto Rico. The inventory was extended to include Vieques and the US Virgin Islands in 2004. In 2006, sampling intensity was increased on mainland Puerto Rico to increase

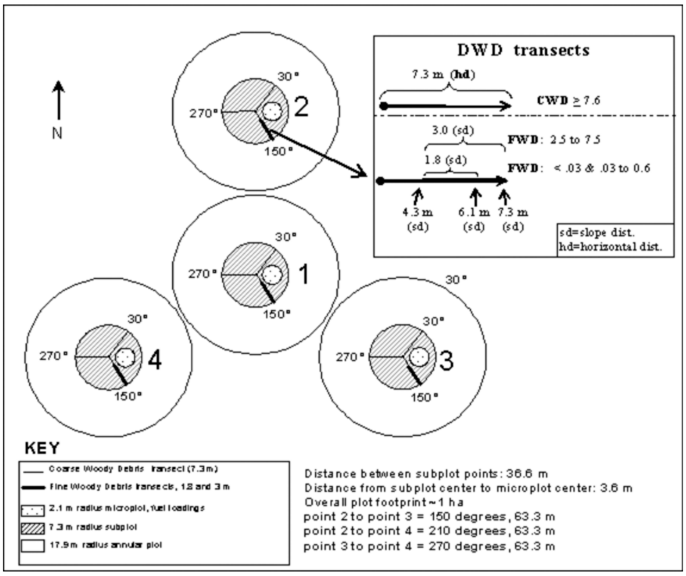

Figure 1. US Forest Inventory and Analysis plot layout. (Adapted from Woodall and Williams [24].)

precision and include lower montane forest (19, 20). Data from a total of 121 plots were used for this study, 93 in Puerto Rico (90 mainland, 3 Vieques) and 28 in the Virgin Islands (7 on St. Croix, 20 on St. John, and 1 on St. Thomas). The initial 25 plots on mainland Puerto Rico were measured twice (2001 and 2006). Plots were stratified by island and Holdridge life zone according to a digitized version of the life zone map published by Ewel and Whitmore (21).

Fuel Categories and Measurements

FIA inventory plots consist of a cluster of four subplots (Fig. 1). Detailed information on plot location, installation, marking, site descriptions, tree measurement, tree damage description, and other data collected at each forested plot can be found in Bechtold and Scott (22) and the US Department of Agriculture (USDA) Forest Service (23). Forest fuels are the organic matter available for fire ignition and combustion (14), and they are commonly quantified by size/hour classes that reflect the time required for their moisture content to change significantly (24). For the purposes of this study, CWD was defined as dead and downed (greater than 45° lean from vertical) woody material with a diameter of at least 8 cm at its point of intersection with a sampling transect and at least 1 m in length. CWD (Table 1) was sampled on three 7.3-m-long transects radiating from each FIA subplot center at 30°, 150°, and 270° (24). Several attributes were measured for each CWD piece: transect diameter (diameter of piece where it crosses the transect), total length, small-end diameter, large-end diameter, decay class, species, evidence of fire, and presence of cavities. This study defined FWD as downed and dead woody material below 8 cm in size at its point of intersection with a sampling transect. FWD was sampled only along the 150° transect on each subplot in three size classes (Table 1). One (transect diameter less than 0.6 cm) and 10 hr fuels (transect diameter between 0.6 and 2.4 cm) were sampled along 1.8 m of the 150° transect, and 100 hr fuels (transect diameter between 2.5 and 7.6 cm) were sampled along 3 m of the 150° transect (Table 1). Duff (defined as decomposing leaves and other organic material containing no recognizable plant parts) and litter (loose plant material found on the duff surface, not including bark or elements that meet the definitions of FWD or CWD) depths were measured within a 30-cm-diameter sampling frame at the ends of each 7.3 m transect.

Table 1. Downed woody material (DWM) classes, fuel-hour classes, diameter classes (cm), and sampling transect slope lengths (m). (Adapted from Woodall and Williams [24].)

DWM class	Fuel-hour	Diameter	Transect length
Small fine	1	0.03–0.6	1.8
Medium fine	10	0.6–2.4	1.8
Large fine	100	2.5–7.6	3
Coarse	1000+	7.6+	7.3

Estimation and Analysis

Fuel loadings per plot (totals and by fuel category subsets) were estimated using line intersect models (24–26). For further information regarding the FIA sample protocol and estimation procedures for DWM, see Woodall and Williams (24). Comparisons of mean fuel values between life zones were made for the two measurement periods (2001 and 2004–2006) separately in order not to confound difference between life zones with change over time. The plots measured in 2001 were located only on mainland Puerto Rico. The plots measured in 2004–2006 were on Vieques (2004), the US Virgin Islands (2004), and mainland Puerto Rico (2006). The reasons for this division were: *i*) to have two measurement periods for estimating fuel loading changes on mainland Puerto Rico; and *ii*) to assess the current fuel loadings across all the islands.

Mean life zone values were compared for statistically significant differences ($\alpha \leq 0.05$) using the SAS Version 8.0 PROC GLM procedure of analysis of variance with a model of less than full rank and least-squares means comparisons (27). Analyses of change in fuel loadings on mainland Puerto Rico were made using only the data collected in 2001 and 2006. All data collected in 2006 were used, even from plots that were not measured in 2001, because the extra data provided superior estimates of DWM and fuels at the second measurement period. Change estimates were made using the PROC MIXED procedures for repeated measures, where the autoregressive covariance structure was chosen after examination of the REML log likelihood, Akaike Information Criterion, and Schwarz Bayesian Criteria statistics (28). For all means comparisons, an alpha level of 0.05 was used for establishing statistical significance.

One plot measured in 2006 in the subtropical dry forest had CWD biomass (88.79 Mg ha^{-1}) that was much higher than any other plot due to four large fallen logs, one with transect diameter of 70 cm. Trees with a diameter at breast height (d.b.h.) >60 cm are uncommon in the forests of Puerto Rico (15). The data point from this single plot was strongly influential in increasing the mean value for that life zone and the entire measurement year. While the data point from this plot can be seen as representing the high variability of DWM across the forest landscape, it was excluded from further analysis.

Conversely, one of the two plots in the mangrove forest showed the highest observed amounts of duff (46.97 Mg ha^{-1}), but those data were retained. This was done for two reasons. First, plots in other life zones had duff amounts that approached this high value. Second, there were only two plots in mangrove forest, and dropping the data from one would have further weakened estimates for that forest type. The reader should keep in mind the small sample sizes for mangrove and lower montane forest when interpreting the following results.

RESULTS

Fuel Loadings

Some mean CWD, FWD, duff, and litter fuel loads varied significantly from one measurement period to the next (Table

Table 2. Mean values for woody and forest floor fuels (in Mg ha^{-1}, with standard errors of the mean) for Puerto Rico and the US Virgin Islands. Results are presented for measurement periods 2001, 2004–2006, and both measurement periods combined. The p values are from means comparisons tests between the two measurement periods.

Fuel class	Mean 2001 (N = 25)	Mean 2004–2006 (N = 121)	p	Mean all years (N = 146)
1 hr	0.70 (0.11)	1.30 (0.12)	0.0019	1.20 (0.093)
10 hr	4.98 (0.49)	3.73 (0.34)	0.2341	3.94 (0.30)
100 hr	6.45 (1.112)	5.15 (0.58)	0.5796	5.37 (0.52)
Subtotal fine woody fuels	*12.13 (1.35)*	*10.18 (0.85)*	*0.6419*	*10.51 (0.74)*
1000+ hr	11.17 (2.71)	2.91 (1.28)	0.0431	4.33 (1.18)
Subtotal all woody fuels	*23.29 (3.17)*	*13.10 (1.63)*	*0.1196*	*14.84 (1.48)*
Duff	8.07 (1.51)	3.82 (0.86)	0.1367	4.55 (0.77)
Litter	4.57 (6.53)	7.00 (0.67)	0.0458	6.58 (0.77)
Subtotal forest floor fuels	*12.63 (1.83)*	*10.82 (12.4)*	*0.8928*	*11.13 (1.08)*
Total fuels	**34.17 (3.54)**	**24.05 (2.28)**	**0.3909**	**25.78 (2.00)**

2), and these differences varied by life zone. There were no differences in quantities of fuel loadings between life zones in the data collected only in 2001 on mainland Puerto Rico. (Note that the lower montane life zone was not sampled in 2001.) However, in the second measurement period, there were differences in the total fuels ($p = 0.0014$) (Fig. 2), duff ($p < 0.0001$), and litter ($p < 0.0001$) between life zones. Subtropical dry (14.92 Mg ha^{-1}) and moist (22.13 Mg ha^{-1}) forests had fewer tons of fuels than values found in subtropical wet (36.95 Mg ha^{-1}) and mangrove (63.85 Mg ha^{-1}) forests (Fig. 2). Neither CWD nor FWD differed significantly between life zones for this measurement period (Fig. 3).

The differences between life zones were due to the organic material found on the forest floor (Fig. 4). The amount of duff found in the two mangrove forest plots was striking and significantly greater (38.28 Mg ha^{-1}, all $p < 0.05$) than values found in any other life zone. Otherwise, duff amounts did not vary greatly by life zone except for subtropical wet forest (6.35 Mg ha^{-1}), which had greater amounts of duff than values found in subtropical dry forest (1.41 Mg ha^{-1}, $p = 0.0251$). Litter amounts, however, clearly decreased as the life zones became drier. Subtropical dry forests had less litter (3.54 Mg ha^{-1}) than lower montane (19.24 Mg ha^{-1}, $p = 0.0013$) and subtropical wet (12.76 Mg ha^{-1}, $p < 0.0001$) forests, and somewhat less than subtropical moist forests (6.27 Mg ha^{-1}, $p = 0.0551$). Mangrove forest litter amounts were relatively low (2.72 Mg ha^{-1})—significantly lower than values found in lower montane ($p = 0.0128$) and subtropical wet forests ($p = 0.0386$). Again, the very small lower montane and mangrove forest sample sizes must be taken into consideration when interpreting these results.

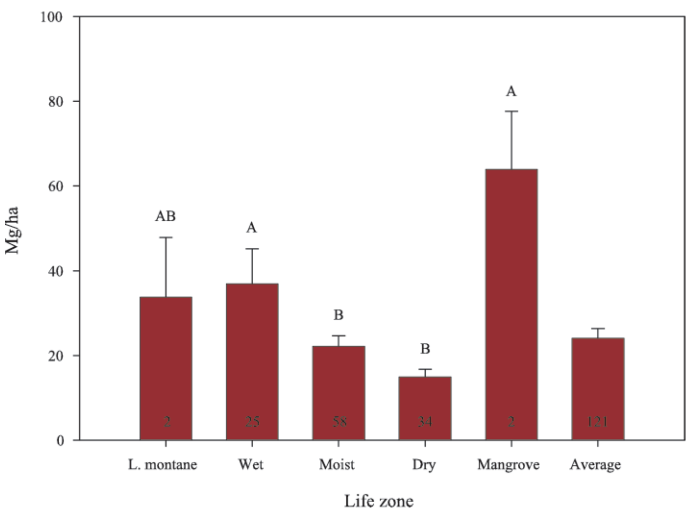

Figure 2. Total amounts of potential forest fire fuels (sum of all 1000+ hr, 100 hr, 10 hr, and 1 hr fuels, plus forest floor litter and duff in Mg ha^{-1}) for Puerto Rico and the US Virgin Islands as measured in 2004–2006, by forest life zone and average value across all life zones, with standard error of the mean. Note that the number of plots in each life zone is indicated at the base of each bar.

Change in Fuel Loadings Over Time

FWD, CWD, and the forest floor fuel loads changed significantly over the 5 y measurement period on mainland Puerto Rico (Table 2). There were increases in the smallest category of FWD, the 1 hr fuels ($p = 0.0019$), and in amounts of litter ($p = 0.0458$). Conversely, CWD, the largest-sized fuel category, decreased ($p = 0.0431$). Despite these changes, total fuels per hectare did not change significantly, and levels of the other individual fuel categories remained relatively steady.

DISCUSSION

Fuel Loadings in a Regional and Global Context

The regional context for these baseline measurements is made difficult by the differences in sampling protocols and definitions used in other published studies. As such, for valid comparisons, this study's results have been summarized by varying detrital categories utilized in a diversity of other studies in Puerto Rico and other tropical/temperate forests (Table 3). In Puerto Rico, Li et al. (29) found 5.9 Mg ha^{-1} of total forest floor mass, which is described as both litter and downed wood, in secondary forest in the Luquillo Mountains. This amount of fuels is much lower than the 36.95 Mg ha^{-1} for subtropical wet forest and 33.7 Mg

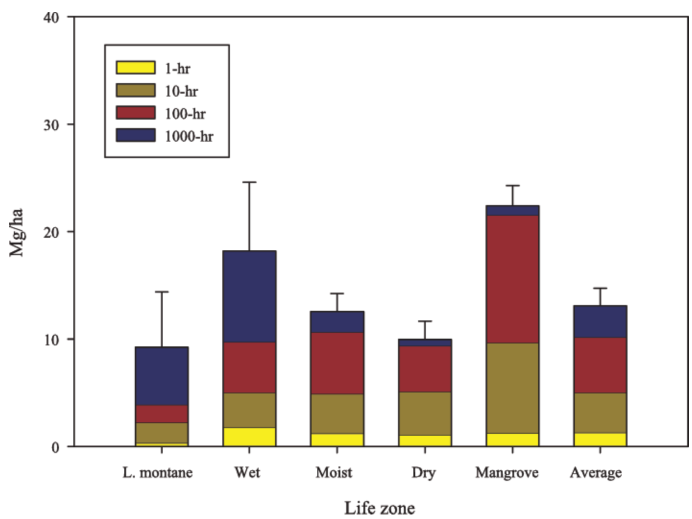

Figure 3. Forest fire fuels (Mg ha^{-1}) by piece size category for Puerto Rico and the US Virgin Islands by forest life zone and averaged across all life zones, with standard error of the total mean value.

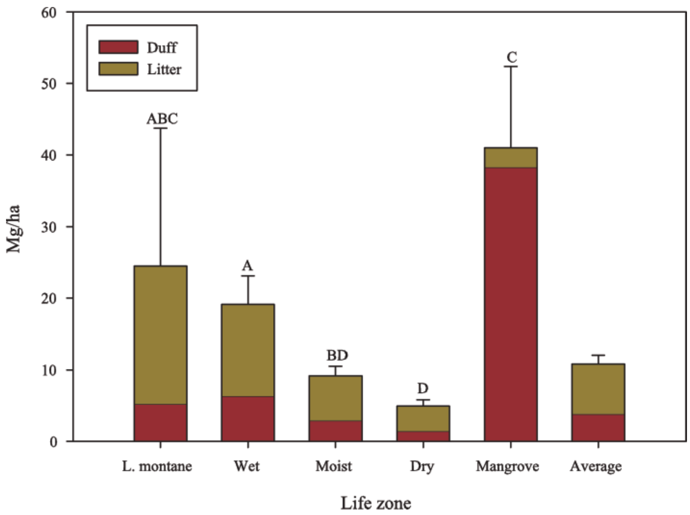

Figure 4. Forest floor litter and duff (Mg ha^{-1}) for Puerto Rico and the US Virgin Islands by forest life zone and averaged across all life zones, with standard error of the total mean value. Letters indicate significant differences between mean total values.

ha^{-1} for lower montane forest found by this study in the two forest types that would occur in that area. Similarly, the subtropical wet forest mean litter and FWD mean value of 22.51 Mg ha^{-1} found by the current study is much higher than the 13.3 Mg ha^{-1} of litter and FWD estimated by Lugo et al. (30) for secondary forest in Barranquitas, Puerto Rico. Murphy and Lugo (31) found 2.7 Mg ha^{-1} of FWM and CWM, and 12.3 Mg ha^{-1} of leaf litter in the Guánica Commonwealth forest in Puerto Rico. The current study found 9.39 Mg ha^{-1} of FWM and CWD in subtropical dry forest and only 3.54 Mg ha^{-1} in leaf litter.

On a regional and global scale, it appears that the amounts of fuels, particularly CWD, in forests of Puerto Rico and the US Virgin Islands fall at the lower end of observed values for other tropical and temperate forests. Average CWD values for tropical wet and moist forests in South and Central American tropical forests range from 16.7 Mg ha^{-1} (32, for Venezuelan moist forest) to 46.3 Mg ha^{-1} (33, for La Selva, Costa Rica) (Table 3), which are well above even the higher averages from the Puerto Rico measurements taken in 2001 of 12.16 Mg ha^{-1} for subtropical moist forest and 12.18 Mg ha^{-1} for subtropical wet forests. The current study's CWD results fell within, but at the low end, of the widely varying range of values observed in temperate hardwood forests. Although there were fewer studies with comparable forest floor measurements, litter and duff amounts found here were also lower, but similar, to other tropical forests (Table 3).

The smaller-sized FWD fuels, however, appear to be present in greater quantities on Puerto Rico and the US Virgin Islands (Table 3), and the difference between the island forests and continental tropical forests increases with increasing moisture and potentially greater site productivity. Delaney et al. (32) found 2.4 Mg ha^{-1} of CWD and 5.2 Mg ha^{-1} of FWD in Venezuelan dry forest, values that are similar to the 0.57–1.21 Mg ha^{-1} of CWD and 7.04–9.40 Mg ha^{-1} of FWD found in subtropical dry forest by the current study for the two measurement periods. However, the Venezuelan lower montane moist and wet forest held 17.2–21.2 Mg ha^{-1} of CWD and 2.7–3.1 Mg ha^{-1} of FWD, while Puerto Rican lower montane forest held only 5.33 Mg ha^{-1} of CWD and 3.92 Mg ha^{-1} of FWD. We cannot yet make any assertions regarding fuel loading trends until sample sizes are increased along with more comparable studies from other regions.

Forest Fuel Dynamics, Disturbance, and Forest Maturation

The rather static value of total tons of fuels per hectare over the past 5 y is due to increases in FWD and decreases in CWD. Lugo and Scatena (45) noted that leaf fall and litter production remained very constant over a 25 y observation period, but they attributed this stability to the age of the relatively mature tabonuco forest they studied. Secondary forests and plantations within the same experimental forest showed much more variation, and tendencies toward increasing leaf fall with age (45). Increasing litterfall, and with it increasing FWD, would seem to be a logical phenomenon in stands in early stages of stand development, where crown development, branch shedding, and canopy closure occur at a relatively rapid rate compared to latter stages of stand development (46). Forest age and structural development might also help explain the relative paucity of larger-sized fuels found in Puerto Rico and the US Virgin Islands. Almost all of the islands' forests and the sites sampled, except possibly in the lower montane life zone, are still

Table 3. Values (Mg ha^{-1}) of coarse woody debris (CWD), fine woody debris (FWD), forest floor (sum of litter and duff), and total downed woody materials (DWM) observed in this study and comparable published studies. Note that total DWM from this study does not sum exactly due to rounding.

Location	CWD	FWD	CWD and FWD	Forest floor	Total DWM	Source
Puerto Rico, wet forest	–	–	–	–	5.9	Li et al. 2005 (29)
Puerto Rico, wet forest	–	–	–	–	11.0–16.0	Lugo et al. 1999 (30)
Puerto Rico, dry forest	–	–	2.7	12.3	–	Murphy and Lugo 1986 (31)
Venezuela, dry forest	2.4	5.2	7.6	–	–	Delaney et al. 1997 (32)
Venezuela, dry/moist transition	3.3	2.7	6.0	–	–	Delaney et al. 1997 (32)
Venezuela, lower montane moist	21.2	3.1	24.3	–	–	Delaney et al. 1997 (32)
Venezuela, lower montane wet	17.2	2.7	19.9	–	–	Delaney et al. 1997 (32)
Venezuela, moist forest	16.7	2.4	19.1	–	–	Delaney et al. 1997 (32)
Costa Rica, La Selva	46.3	–	–	–	–	Clark et al. 2002 (33)
Mexico, moist forest	–	–	0–14	2.1–7.7	–	Hughes, Kauffman, and Jaramillo 1999 (34)
Mexico, dry forest	5.3–31.5	3.5–6.0	–	–	–	Eaton and Lawrence 2006 (35)
Brazil, Amazon	28.9	9.6	38.5	–	–	Cummings et al. 2002 (36)
Brazil, Amazon	24.7	3.2	27.9	7.6	63.4	Nascimento and Laurance 2002 (37)
Guyana, rain forest	21.5–22.6	2.9	–	–	–	ter Steege 2001 (38)
Slovenia, temperate forest	40.0–179.3	–	–	–	–	Debeljak 2006 (39)
US, temperate forest	4.4	7.3	11.7	17.9	32.0	Chojnacky and Schuler 2004 (40)
US, temperate forest	39.8–137.2	–	–	–	–	Idol et al. 2001 (41)
US, temperate forest	2.2–158.4	–	–	–	–	Rubino and McCarthy 2003 (42)
US, all forest	–	–	–	–	10.2–88.8	Birdsey 1992 (43)
Ecuador, montane forest	–	–	–	–	11.0–12.7	Fehse et al. 2002 (44)
Puerto Rico and US Virgin Islands	**4.3**	**10.5**	**14.8**	**11.1**	**25.8**	**This study**

at a young, vigorously growing developmental stage (15), so there is little natural mortality that would leave large logs on the ground. Most of the published studies cited here were in more mature forest. Hughes, Kauffman, and Jaramillo (34) and Eaton and Lawrence (35) studied secondary forest in Mexico and found very similar FWD amounts, but still higher CWD amounts, than the values observed in this study (Table 3). Perhaps over time and with continued monitoring, we will see a shift in the distribution of fuels as the larger trees produce more, larger pieces of CWD, and the amount of FWD will decrease.

Another consideration is the timing of these first DWM measurements in relation to the last occurrence of a damaging hurricane in the islands. Hurricanes Georges (1998) and Lenny (1999) were the most recent severe hurricanes to pass over Puerto Rico and the US Virgin Islands, respectively. These hurricanes left in their wake large amounts of DWM and potential forest fuels, as was the case after Hurricane Hugo. Frangi and Lugo (47) estimated that 10% of aboveground biomass in the floodplain forest of the Luquillo Mountains was deposited onto the forest floor by Hurricane Hugo, and Vogt et al. (48) estimated that the hurricane deposited 2.6–9.8 Mg ha^{-1} of woody materials with a diameter >1 cm in the Luquillo Experimental Forest. This study's measurements in Puerto Rico and the US Virgin Islands were taken subsequent to hurricane damage (3–8 y and 5 y, respectively). Five years after the passage of Hurricane Hugo, Vogt et al. (48) observed that fine litterfall had still not recovered to predisturbance levels. Further, based on their observed rates of decomposition and the large amount of material, they postulated that it would require 10 y or more for the woody material deposited by the hurricane to be completely decomposed (48). Vogt et al. (48) expanded on the idea put forth by Lugo and Scatena (45), stating that some forests in Puerto Rico might be in a continuous state of recovery from hurricanes.

However, it is surprising to consider that these islandwide estimates of fuels would be so impacted by the disturbance of Hurricane Georges for so long a time afterward. The damage caused by this hurricane, while widespread and severe, was not consistent across the entire island (49). The long-term effects of hurricanes on fuels cited here occurred entirely within the Luquillo Experimental Forest in the northeastern portion of the island, an area that was heavily impacted by both Hurricane Hugo (1989) and Hurricane Georges (1998). We have to consider that hurricane effects on fuels were more widespread, and that perhaps some other factors are contributing to the increase in FWD and decrease in CWD over time. It seems reasonable that in areas impacted by Hurricane Georges, hurricane-deposited CWD continues to decompose and is almost exhausted and FWD has yet to reach prehurricane levels. However, in areas that were not impacted by the hurricane, perhaps FWD accumulation is related to forest maturation.

CONCLUSIONS

Trends in Caribbean island forest fuel loadings appear to be dynamic and episodic, changing with both natural and anthropogenic disturbance as well as with forest succession. Although total amounts of forest fuels did not change over time, their distribution amongst the size classes is dynamic. One can expect to see periods of high CWD fuel loads subsequent to hurricanes that slowly decrease over the course of several years. Initially, hurricanes will create high FWD fuel loads, but these will decrease quickly and take many years to reach predisturbance levels as stand development slowly progresses. These changes, however, will be additionally affected by an overall increase in downed woody piece size and increased amounts of FWD and forest floor material from normal mortality and leaf fall in maturing forests with increasingly large average tree diameters. Future monitoring will quantify these posthurricane pulses of fuels and subsequent reincorporation into living forest biomass. These pulses of downed fuels drive fuel dynamics and attendant wildfire risks that resource managers and agencies charged with fire protection will have to continually assess and plan for accordingly in tropical island ecosystems such as those found on Puerto Rico.

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