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Front Cover image: The Central Cordillera mountains of Puerto Rico encompass a wide range of more humid life zones and varying levels of forest land site productivity (USDA Forest Service photo by Thomas J. Brandeis).

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From left to right: Biological Scientist Luis O. Ortiz López (Southern Research Station), Forestry Technician Iván Vicéns Jiménez (International Institute of Tropical Forestry), and Biological Scientist Ixia Avilés Vázquez (Southern Research Station), standing in front of a large, 90-year old mahogany tree from a plantation established in 1937 at Camp Guajataka, San Sebastián, Puerto Rico (USDA Forest Service photo by Humfredo Marcano-Vega).

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Abstract

The Forest Inventory and Analysis (FIA) national forest inventory estimates site productivity for every forested plot. In the Puerto Rico and the U.S. Virgin Islands, the site class is not estimated because data are not collected on site trees due to the lack of both annual growth rings and growth and yield references, so default values are assigned. We calculated site productivity values by island, forest type and major soil taxon, stand characteristics by these same strata, and explore hurricane impacts. Generally, stand density measures decreased from drier to wetter forest types, while measures of basal, volume and growth increased. There was the suggestion that soils were correlated with volume and growth, with higher values observed on mollisols and vertisols. There were no statistically significant differences in trees per acre, stocking, basal area and volume levels between conditions undamaged and damaged by hurricanes. Gross growth, however, was lower on hurricane damaged plots. We determined that calculated values can be used to populate site class for many plots, and for those that have not reached full stocking, opportunities exist for the development of stand growth models, perhaps by forest type and not for individual islands.

KEYWORDS: Site productivity, Caribbean islands, wood volume, tree growth, tropical forests, hurricane.

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Introduction

The U.S. Department of Agriculture, Forest Service, Southern Research Station's (SRS) Forest Inventory and Analysis (FIA) research work unit implements the United States (U.S.) national forest inventory (NFI) in the 13 Southern States, the Commonwealth of Puerto Rico, and the U.S. Virgin Islands as mandated by law through the Agricultural Research Extension and Education Reform Act of 1998 (Farm Bill) (AREERA 1998) and updated in Title VIII of the 2014 U.S. Farm Bill (Agricultural Act of 2014).

The primary objective in conducting these inventories is to gather the multi-resource information needed to formulate sound forest policies, provide information for economic development, develop forest programs, and provide a scientific basis to monitor forest ecosystems. This is accomplished through the collection of authoritative data about forest carbon, forest products and services, biomass availability, economic development opportunities, land cover and land use change, weather effects on forests, incidence of nonnative invasive species, impacts of insects and diseases, and wildfire risk and impacts (Goeking 2025).

Estimates of forest productivity expressed in terms of tree growth are integral to achieving the objectives of forest inventories. These estimates tell us about the inherent capacity of a site to grow trees, defining the boundaries within which we can implement sustainable management and contributing to our understanding of the forest's overall health. This information is particularly valuable, and less well understood, in the forests of Puerto Rico and the U.S. Virgin Islands. This study improves that understanding by first explaining how the FIA program defines and measures site productivity in the NFI with particular focus on how this methodology has, and more importantly, has not, been applied to Caribbean island forests. We then explore the data collected over multiple permanent plot remeasurements, calculating a close approximation of the site productivity values used in the temperate forests of the conterminous U.S. (Fig. 1). We compare site productivity estimates and other forest characteristics across islands, forest types, major soil orders, and whether there has been significant hurricane disturbance. With these baselines established, we lay the groundwork for future analyses and modeling efforts.

Figure 1—Forestry Technician Ivan Vicéns, International Institute of Tropical Forestry (IITF), at the Luquillo Experimental Forest Arboretum, standing among 61-year old Eucalyptus grandis trees from a 1960 plantation where the growth potential of 68 timber species was tested. (USDA Forest Service photo by Humfredo Marcano-Vega).

Site Productivity Estimation in the National Forest Inventory

Indices of site quality or productivity estimate a site's capacity to grow wood and are used to guide forest management (Vissage et al. 2019). The FIA program's NFI estimates the site productivity class for each forested condition on a field-visited plot. This estimated value appears as the site class code (SITECLCD) in the Forest Inventory and Analysis Database (FIADB). FIA variable names as they appear in the FIADB will be included where relevant in this report. The SITECLCD classifies forest land in terms of "inherent capacity to grow crops of industrial wood" (Burrill et al. 2024). It identifies the potential growth in cubic feet per acre per year and is based on the culmination of mean annual increment (MAI) of well-stocked, even-aged natural stands of species suited to that site (Fig. 2). The FIA program uses seven possible site class categories ranging from site class 1 (+225 cubic feet per acre per year) to a site class 7 (0–19 cubic feet per acre per year) (Table 1; Burrill et al. 2024). Site classes 1 through 6 are considered potentially "productive" timberland while site class 7 is considered "unproductive" forest land, but not timberland.

Figure 2—The forests of Puerto Rico contain many species of high-quality tropical hardwoods that are used for artisanal woodworking (USDA Forest Service photo by Thomas J. Brandeis).

Table 1—Forest Inventory and Analysis site productivity class codes and the mean annual increment (MAI) range for each class in cubic feet per acre

Site class code (SITECLCD)	Maximum MAI range for the class (ft^3/acre · year)
1	225+
2	165–224
3	120–164
4	85–119
5	50–84
6	20–49
7	0–19

In CONUS, site productivity is determined by using data collected from site trees and comparing those data to published forest growth and yield references. At least one site tree that is considered by the field crew to be 1) between 20 and 70 years old in the Eastern U.S. 35 and 80 years old in the Western U.S., 2) not showing signs of damage, suppression, abnormalities at diameter at breast height (d.b.h.) or have rotten cores, 3) on the field guide's list of preferred species, and 4) are generally considered to be representative of the stand on that condition (see USDA Forest Service 2024, for details). Site tree data are collected on every accessible forested condition, with condition being an entire or part of a forested NFI plot that may have been subdivided according to forest type, stand characteristics or ownership following condition mapping rules presented in the NFI field guide (USDA Forest Service 2024). Site tree height and diameter are measured and tree age determined by taking a core with an increment borer and counting the annual rings between the outside edge of the core and the pith (USDA Forest Service 2024).

In the Southern U.S., the height and age of the site tree are compared to southern regional site curves developed for the preferred species to obtain the site index for the stand. Vissage et al. (2019) provides an overview of the yield tables, site index curves and equation references for the Southern U.S. and their use in estimating site productivity class for NFI plots. For example, a 60-year old, 110-foot-tall loblolly pine (*Pinus taeda*) would fall within the site class 3 on the site curve for that species, so the forested condition with that site tree would be assigned a maximum mean annual increment of 120–164 cubic feet per acre per year (Vissage et al. 2019). Burrill et al. (2024) state that "this attribute may be assigned based on the site trees available for the plot, or, if no valid site trees are available, this attribute is set equal to site productivity class code estimated, a default value that is either an estimated or predicted site productivity class".

Stocking Class Determination in the National Forest Inventory

The concept of forest stocking is integral to quantifying forest site productivity. Arner et al. (2001) define stocking as "an expression of stand density that may be expressed in absolute terms, such as basal area per acre, volume per acre, number of trees per acre, or in relative terms, as a percent of some previously defined standard". More simply, Avery and Burkhart (1994) define stocking as the "adequacy of a given stand density to meet some management objective". A site's maximum possible productivity in terms of tree growth would be achieved when it is fully stocked.

Arner et al. (2001) outline the procedures used by the NFI to determine a stand's stocking class and stocking relative to fully stocked. Stocking values (the tree-level variable STOCKING) are assigned to individual trees measured by the NFI using species or species group-specific functions developed from yield tables and stocking charts found in the forestry literature, as presented in Arner et al. (2001). These individual tree stocking values are then summed and expanded at the condition level (the condition-level variable ALSTK).

Additionally, the FIA variable TREECLCD classifies trees measured on permanent FIA inventory plots into three classes: growing stock, rough cull and rotten cull. Growing stock trees are "all live trees of commercial species that meet minimum merchantability standards. In general, these trees have at least one solid 8-foot section, are reasonably free of form defect on the merchantable bole, and at least 34 percent or more of the volume is merchantable" (USDA Forest Service 2024). Rough and rotten cull trees are excluded from growing stock due to their lack of sufficient utilizable volume in a merchantable bole. Stocking in terms of only growing stock trees is also estimated in the FIA data (the condition-level variable GSSTK).

Previous Studies of Tree Growth and Site Productivity Estimation in the Caribbean

In Puerto Rico and the U.S. Virgin Islands, a condition's SITECLCD is not estimated in the field because, unlike in the CONUS, data are not collected on site trees. Yield tables and site index curves have not been developed for these forests and tree species, and there are no Caribbean tree species on the field guide list of preferred site trees. This is partly because tree species growing on these islands may form growth rings, but they do not usually correspond to annual age due to irregularity in growth seasonality. Although there has been a history of forest management for wood products (e.g., plantation trials, selective harvest planning), there has been limited capacity for commercial logging, which has kept timber production small (Forero-Montaña et al. 2025) and the need for developing Caribbean forest yield tables and site index curves limited.

Studies of Caribbean tree growth rates have been conducted in relatively small, intensively monitored research areas, or in native and non-native species plantation trials. However, their results are not comparable to species growth rates in naturally regenerated stands of varying land use histories, ages, and species compositions found islandwide. Studies using FIA data have only looked at individual tree growth rates rather than growth rates covering entire stands (Adame et al. 2014, Brandeis 2009, Brandeis et al. 2005, Yang et al. 2025). Additional research is needed to establish maximum expected stand densities in natural stands across the entire range of conditions found in the islands.

Without site tree information, SITECLCD has been assigned according to the Caribbean forest type, which is based on the Holdridge life zone except for mangroves. Mangroves are considered a separate forest type due to their unique ecological function and because they are found in more than one life zone. See Holdridge (1967) for details on how climatic variables are used to delineate life zones and Ewel and Whitmore (1973) for life zone maps of the islands (Table 2). Currently, all humid Caribbean forest types, including moist, wet, rain and lower montane wet and rain forest life zones, are assigned a SITECLCD of 6. Dry forest is assigned a value of 7. This can be seen in a query of the FIA database (FIADB) which shows that 19.8 percent of forested conditions had a SITECLCD of 7 (0–19 cubic feet per acre per year) and 80.2 percent were SITECLCD 6 (20–49 cubic feet per acre per year) (Table 3).

Study Objectives

Based on growth estimated using NFI remeasurement data and stocking values, we assess whether these calculated values can be used to populate SITECLCD instead of the default values currently in use. To do so, we present calculated site productivity values (i.e., annual gross growth on all live trees) for each forested condition remeasured at least once by island, forest type and major soil taxon, and stand structural characteristics (trees per acre, all live tree basal area per acre, volume per acre, all live tree stocking percent). We test for correlation between these site characteristics and calculated site productivity by these same strata. For some conditions, there will be insufficient growth remeasurement data or stocking values, which indicate site productivity has not been fully expressed due to the stand being at an early stage of development or recovery from disturbance. Estimating SITECLCD for these conditions will require modeling. To help guide such future modeling, we conduct means comparison tests to explore whether there are statistically significant differences in the values of these parameters by forest type, island and major soil taxon (Fig. 3). Additionally, we explore the impacts of the 2017 hurricanes, Irma and Maria, on site productivity and the other forest stand characteristics mentioned above.

Table 2—Forest land area (acres) by island group, island and forest type, Puerto Rico and the U.S. Virgin Islands, 2024

Island group	Island	Forest type (Holdridge life zone)	Forest land area
Puerto Rico			
	Mainland Puerto Rico	Mangrove	10,311
		Dry forest	175,661
		Moist forest	629,172
		Wet and rain forest	362,288
		Lower montane wet and rain forest	10,985
		Nonstocked	4,398
		Total	**1,180,360**
	Vieques	Dry forest	15,015
		Moist forest	12,455
		Total	**27,470**
	Culebra	Dry forest	7,195
		Total	**7,195**
	Mona	Dry forest	12,861
		Total	**12,861**
U.S. Virgin Islands			
	St. Croix	Dry forest	26,296
		Moist forest	5,168
		Total	**31,464**
	St. John	Dry forest	5,728
		Moist forest	5,689
		Total	**11,417**
	St. Thomas	Dry forest	2,290
		Moist forest	5,368
		Total	**7,658**
		Total	**1,278,425**

Table 3—Forest land area (acres) by forest type and site productivity class, Puerto Rico and the U.S. Virgin Islands, 2024

Forest type (Holdridge life zone)	Site productivity class (ft^3/acre/year)		
	0–19	20–49	Total
Mangrove	4,819	5,493	10,311
Dry forest	245,046	–	245,046
Moist forest	–	645,397	645,397
Wet and rain forest	–	362,288	362,288
Lower montane wet and rain forest	–	10,985	10,985
Nonstocked	2,885	1,512	4,398
Total	**252,750**	**1,025,675**	**1,278,425**

– = No values recorded.

These data were obtained from the USDA Forest Service, Forest Inventory and Analysis Program, June 2025. Forest Inventory EVALIDator web-application Version 2.1.2. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. Available online: https://apps.fs.usda.gov/fiadb-api/evalidator

Figure 3—Cloud, or elfin, forests of reduced stature are found within the lower montane zones in Puerto Rico (USDA Forest Service photo by Thomas J. Brandeis).

Methods

National Forest Inventory Data in the Caribbean

Puerto Rico began collecting NFI data using the current annualized sampling design and plot layout, but on a periodic basis, in 2001. This was considered to be cycle 3 of the Puerto Rico NFI because it followed two prior periodic inventories in 1980 and 1990 (which are considered cycles 1 and 2). The U.S. Virgin Islands' first NFI measurements were taken in 2004 (cycle 1) and was also planned as a periodic inventory. Since then, remeasurements of permanent inventory plots in Puerto Rico have been completed in the years 2009 (cycle 4), 2014 (cycle 5), 2019 (cycle 6) and 2024 (cycle 7). Data from the Puerto Rico periodic inventories in 1980 and 1990 could not be used in this study, however, due to methodological changes. Plot remeasurements in the U.S. Virgin Islands have been completed in the years 2009 (cycle 2), 2014 (cycle 3), and 2024 (cycle 4). The planned U.S. Virgin Islands 2019 cycle was skipped due to the COVID-19 pandemic. In the NFI, all trees with a d.b.h. ≥5 inches previously located on a plot are relocated and remeasured. New trees are measured and added to the dataset as they grow to five inches (ingrowth). Therefore, there are some trees with five consecutive d.b.h. and height measurements in Puerto Rico and four consecutive d.b.h. measurements in the U.S. Virgin Islands spanning 20 years.

Tree d.b.h. measurements are used in equations that estimate cubic foot volume and include gross cubic-foot stem wood volume (the tree-level variable VOLCFGRS), which is the parameter we use to express site class productivity. It is estimated for all live and standing dead trees considered timber species that have a d.b.h. ≥5.0 inches. Tree species are considered timber species if their diameter is measured at breast height as opposed to at the root collar. The root collar is the measurement point for multi-stemmed woodland tree species. For timber species, VOLCFGRS is the total cubic-foot volume of wood in the central stem from a 1-foot stump to a minimum 4-inch top diameter, or to where the central stem breaks into limbs all of which are <4.0 inches in diameter (Burrill et al. 2024). This is a gross volume estimate, as loss due to rotten, missing, and form cull defect has not been deducted. The volume estimation methods used in the Caribbean are described in Woodall et al. (2011) and are not the more recently adopted National Scale Volume Biomass (NSVB) models (Westfall et al. 2024) used by the NFI in the CONUS.

Once individual tree cubic foot volumes are calculated, they are expanded using the condition-level expansion factor (the tree-level variable trees per acre unadjusted, TPA_UNADJ) to estimate what each tree represents at a per acre level. These individual tree per acre values are then summed to the condition/stand-level volume per acre. We use the volume of all live trees with d.b.h. ≥5.0 inches and the sum of their stocking values (the condition-level variable ALSTK) as the basis for calculating site productivity, rather than that of the subset of growing stock trees (GSTK), because volume growth on both growing stock and cull trees more completely represents the potential for tree growth on the site. Additionally, the percentage of total trees found on plots in the Caribbean that meet the standards for growing stock is often lower than that typically found on CONUS due to the wide variety of tropical tree growth forms and stems damaged by hurricanes which reduce their potential merchantability. An example of an extreme growth form can be seen with some individuals of the *Clusia* spp. whose "stem" consists of a mass of roots that encases the stem of the tree on which its seed sprouted.

The difference in volume per acre at each time period can be divided by the number of years between each measurement to estimate the change in cubic foot volume per acre per year which corresponds to the evaluation type EXPGROW for attribute 1201/574165 in the FIADB (Pugh et al. 2018). Toward the goal of characterizing maximum site productivity, we use differences in VOLCFGRS for each tree remeasurement as our expression of site productivity over time. The

FIA program defines mortality as the volume of trees that die from natural causes at the midpoint of each measurement interval. Therefore, when using VOLCFGRS, productivity estimates include the growth of mortality trees (volume growth between the previous interval and the midpoint of the measurement interval) as well as wood that is rotten, missing, or form cull. If we had used net cubic-foot stem wood volume (VOLCFNET), our productivity estimates would underestimate the total growth of that tree and exclude volume growth of mortality trees because VOLCFNET is not calculated for mortality trees. Estimates would also have excluded the volume growth of wood that is rotten, missing, or form cull, as VOLCFNET also excludes that wood.

With this estimate, we can directly calculate the stand's observed productivity. However, that estimate will not necessarily reflect the site's full productive capacity, the sum of maximum MAIs for the trees found there, because we do not know what full stocking would be for stands of Caribbean tree species. Previous NFI results in Puerto Rico indicate that many stands are still increasing in basal area over time as they naturally regenerate and grow after widespread deforestation in the mid-1900s and more recent hurricane disturbances (Brandeis et al. 2007; Brandeis and Oswalt 2007; Brandeis and Turner 2013a, 2013b; Marcano-Vega 2019).

Treatment of Data from Hurricane Disturbed Plots

Caribbean forests are frequently disturbed by hurricanes. Most recently, Hurricanes Irma (a Category 5 storm) and Maria (a Category 4 storm) passed the islands in 2017 and caused widespread forest damage (Fig. 4). We can expect these stands to be at varying stages of recovery, reaccumulating volume over time. The NFI data collection includes noting stand disturbances and human interventions like silvicultural treatments. Therefore, these plots identified as disturbed can be separated from those that were not notably disturbed.

To assess the impacts of hurricane disturbance on condition-level growth estimates, each condition was assigned a hurricane disturbance value for before and after 2017 (binary yes or no). In FIA, disturbances are recorded when the affected area is at least 1 acre in size and has resulted in the mortality and/or damage of 25 percent of all trees or 50 percent of the count of an individual species in a stand (USDA Forest Service 2024). If at no time did condition-level disturbance indicate hurricane damage, this condition was considered undamaged throughout its history of measurements. If the condition had hurricane disturbance even once after 2017, all measurements after 2017 were considered impacted even if hurricane disturbance was not indicated afterwards in 2024. We realize, however, that hurricane damage to trees before the start of annualized inventory in the islands will have affected site productivity, and that in some cases, hurricane damage might not have been sufficient to warrant being noted on the plot. While these factors introduce uncertainty to these analyses, they also reflect the natural cycle of disturbance in the islands.

Soils Data

Soil types and properties were extracted from the USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) (USDA NRCS 2026). These ancillary variables were appended to the dataset using ArcGIS Pro 3.3.4 (Esri 1995–2026).

Figure 4—Biological Science Technician (retired) Samuel Moya evaluates woody material collected after Hurricanes Irma and María in Puerto Rico. Hurricanes making landfall on the island can leave behind hundreds of thousands of downed logs, highlighting the need to explore wood salvage projects as part of future emergency response efforts (USDA Forest Service photo by Humfredo Marcano-Vega).

Data Compilation, Treatment of Outlier Values, and Analysis

The data were initially queried from the FIADB and subsequently organized and summarized using SAS/STAT software, Version 9.4 of the SAS System for Windows (SAS Institute 2023). We calculated annual change in VOLCFGRS per acre for each remeasured forested condition for each time interval between inventory cycles in Puerto Rico and the U.S. Virgin Islands. For example, a single-condition plot in the wet/rain forest of Puerto Rico showed an increase in VOLCFGRS of 60.48 cubic feet per acre per year from 2002 (when the plot was first installed) to 2007 (the year of its first remeasurement). Subsequently, VOLCFGRS increased by 52.30 cubic feet per acre per year from 2007 to 2012, 65.99 cubic feet per acre per year from 2012 to 2017, and 52.67 cubic feet per acre per year from 2017 to 2022. In addition, the plot showed hurricane damage from either or both Hurricanes Irma and Maria on its most recent remeasurement. These values for VOLCFGRS may indicate that hurricane damage reduced growth not only due to damaged crowns and branches but also due to delayed mortality of initially injured trees. Such damage was observed on most plots when remeasured in Puerto Rico in 2019. Considerable numbers of plots were still showing damage in 2024. Therefore, for this study of the maximum potential of a site to accumulate tree volume, we averaged gross growth rates on conditions that did not show hurricane damage. We also excluded conditions that were classified as unstocked or that had experienced other disturbances that would appreciably affect tree growth.

Figure 5—Agricultural lands naturally revert to forest when no longer managed, as seen here on St. Croix, U.S. Virgin Islands (USDA Forest Service photo by Thomas J. Brandeis).

The dataset began with 1,708 observations on 557 unique forested conditions, with an average of around three measurements per condition. This dropped to 1,680 observations once unstocked conditions were removed, then 1,103 observations once we removed conditions disturbed by landslides, fires, human activities, or hurricanes. Finally, removing outlier values left 842 observations on 706 unique forested conditions. We chose to exclude as outliers those conditions with negative gross growth values and one condition with extreme positive gross growth. These outliers all showed excessive or unexplained (no documentation of terminal leader damage or disturbances on the condition that would have caused tree breakage) changes in individual tree heights from one measurement period to the next. The impacts of tree height changes on condition-level gross growth were especially marked when it occurred on larger diameter (20–30 inch) trees.

Means comparisons were conducted for trees per acre (all live stems with d.b.h. ≥1 inch), all live stocking (all live stems with d.b.h. ≥1 inch), basal area (all live stems with d.b.h. ≥1 inch), gross volume (all live stems with d.b.h. ≥5 inches), and gross volume growth (all live stems with d.b.h. ≥5 inches) with the SAS software using PROC MIXED, a procedure for fitting mixed-effects models, which allows for blocking on random effects (for example, blocking on island when comparing mean values by forest type) and taking into account repeated measurements on individual conditions (Moser 2004). We chose the first-order autoregressive covariance structure for the repeated measures.

Results

Observed Site Productivity

The frequency distribution of average annual gross growth per acre for undamaged forested conditions (Fig. 6) shows that for undamaged stands, gross growth of <25 cubic feet per acre per year prevailed across the islands. When we group the frequency distribution of undamaged forested conditions into the seven FIA site productivity classes, and for the moment, disregard their degree of stocking, forested conditions with site classes of 6 and 7 (0–49 cubic feet per acre per year) were most frequent (69.25 percent of forested conditions) (Fig. 7).

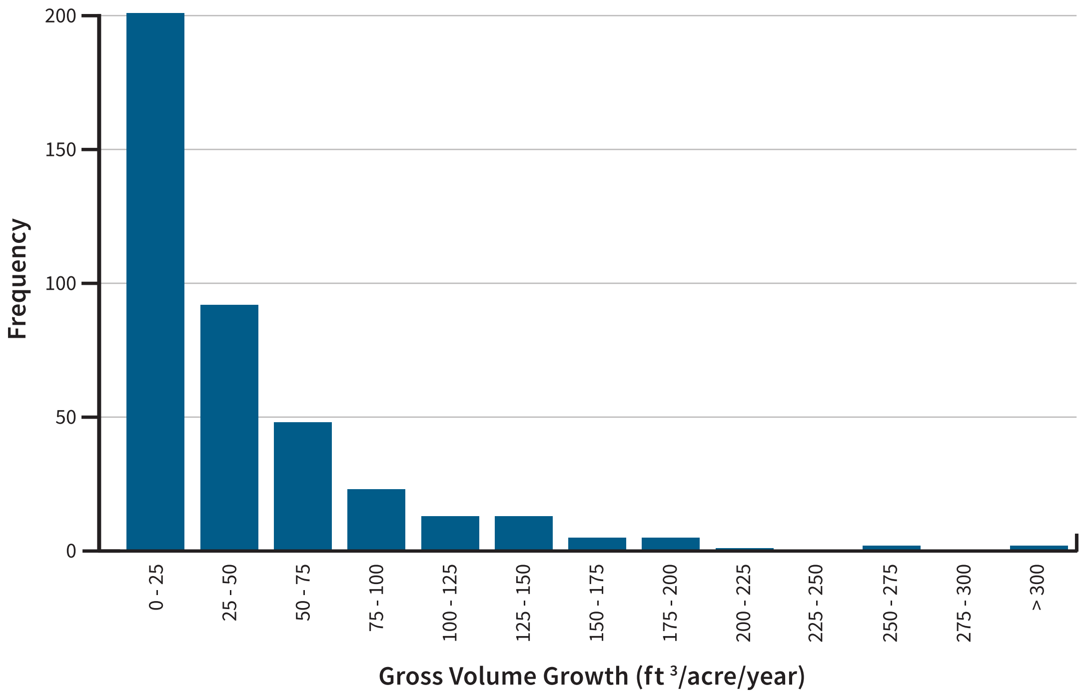

Figure 6—Forest Inventory and Analysis site productivity class codes and the mean annual increment range for each class in cubic feet per acre.

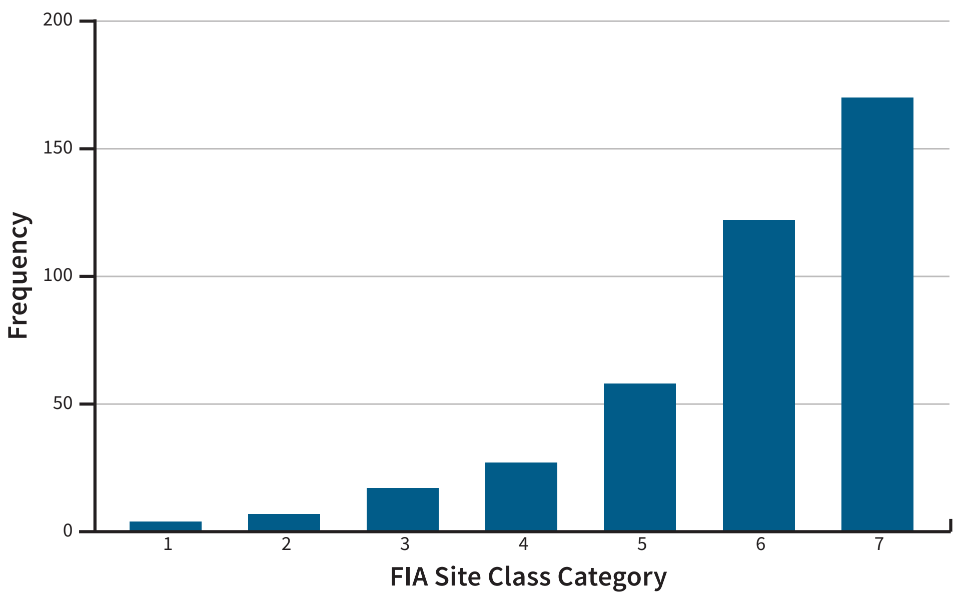

Figure 7—Forest land area (acres) by island group, island and forest type, Puerto Rico and the U.S. Virgin Islands, 2024.

Forest Parameters by Forest Type

Controlling for differences between islands, dry forests had significantly greater mean numbers of trees per acre than all other forest types except mangroves. There was the suggestion of differences with moist forest (p-value = 0.0878), and of higher stocking than other forest types (Figs. 8, 9, 10). In the box-and-whisker plots (Figs. 9–13 and 15), the box encompasses the upper and lower quartiles of the distribution of values for the forest parameters. The whiskers show 1.5 times the interquartile range, the diamond symbol represents the mean value, the line across the box the median value, and the circular symbols are the outlying maximum observations. Differing letters over each category represent statistically significant different group means at the $Pr > |t|$ of 0.05. Basal area and gross standing volume were significantly lower than in all other forest types except mangrove forest (Figs. 11, 12). Dry forest growth rates (averaging 18.96 cubic feet per acre per year) were significantly lower than those observed in moist, wet and rain forests (Table 5, Fig. 13).

The measures of stand density (trees per acre and all live stocking) in moist forest were significantly more than those observed in wet and rain forests (there was the suggestion of significant differences with dry forest) (Figs. 9, 10). Moist forest basal area was less than that in wet and rain forests. Moist forest growth was greater than that in dry forests but less than that in wet and rain forests (Figs. 11, 13). Similarly, moist forest volume was less than that observed in wet and rain and lower montane forests but greater than that in dry forests (Fig. 12). Neither trees per acre nor stocking differed between wet forests vs. rain plus lower montane forests. These forest types had the lowest trees per acre and highest values for basal area and volume. Lower montane forest showed the greatest mean growth rates at 62.77 cubic feet per acre per year, although they were not significantly greater than growth rates in mangrove and wet and rain forests. Mangrove forests were dense and showed low values of basal area (significantly lower than all other forest types as shown in Fig. 11), volume and growth (30.99 cubic feet per acre per year, Table 4).

Figure 8—Well-developed tropical wet forests demonstrate the productive potential of Puerto Rican forest lands (USDA Forest Service photo by Thomas J. Brandeis).

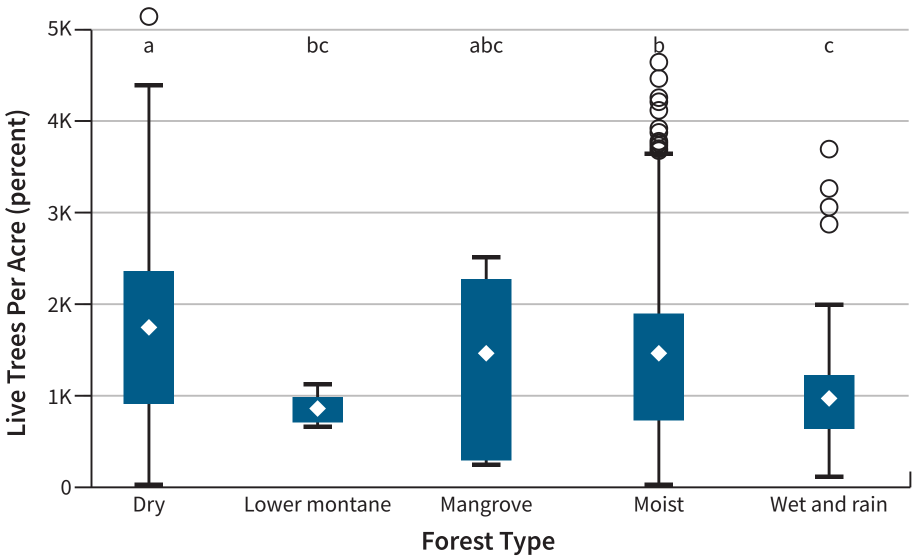

Figure 9—Mean, median, interquartile ranges, and outlying values for live trees (d.b.h. ≥1 inch) per acre by forest type, Puerto Rico, and the U.S. Virgin Islands, 2001–2024. Differing letters over each category represents statistically significant differences at the Pr > |t| of 0.05.

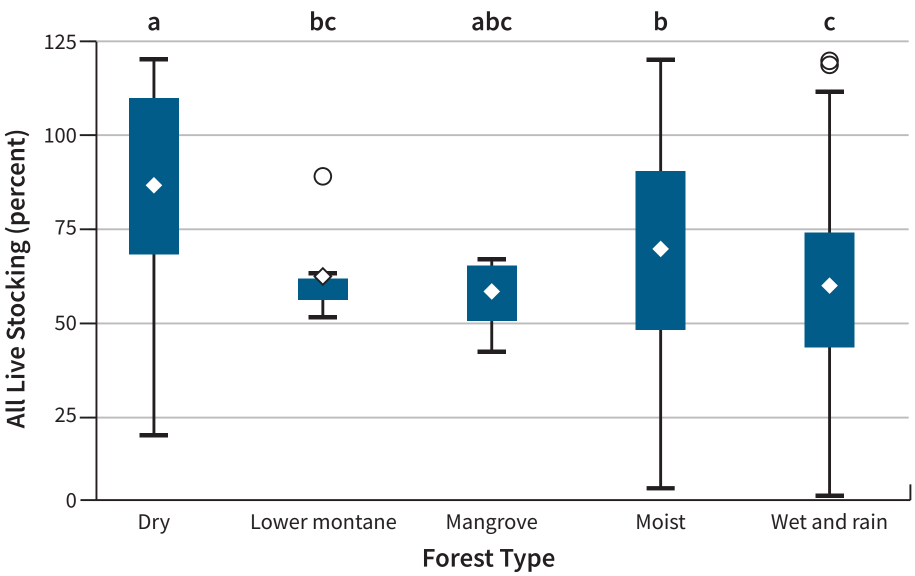

Figure 10—Mean, median, interquartile ranges, and outlying values for all live tree (d.b.h. ≥ 1 inch) stocking by forest type, Puerto Rico, and the U.S. Virgin Islands, 2001–2024. Differing letters over each category represents statistically significant differences at the Pr > |t| of 0.05.

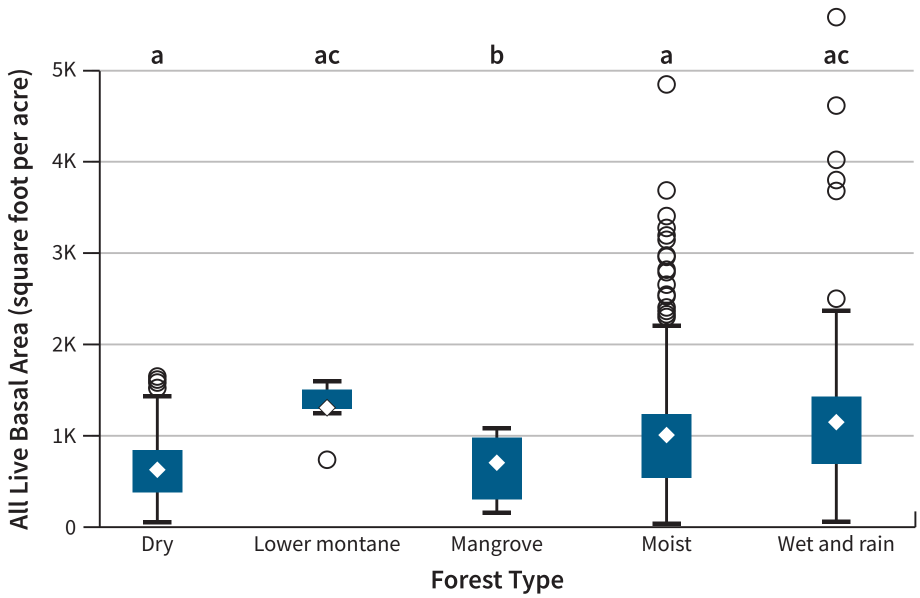

Figure 11—Mean, median, interquartile ranges, and outlying values for all live tree (d.b.h. ≥1 inch) basal area by forest type, Puerto Rico and the U.S. Virgin Islands, 2001–2024. Differing letters over each category represents statistically significant differences at the Pr > |t| of 0.05.

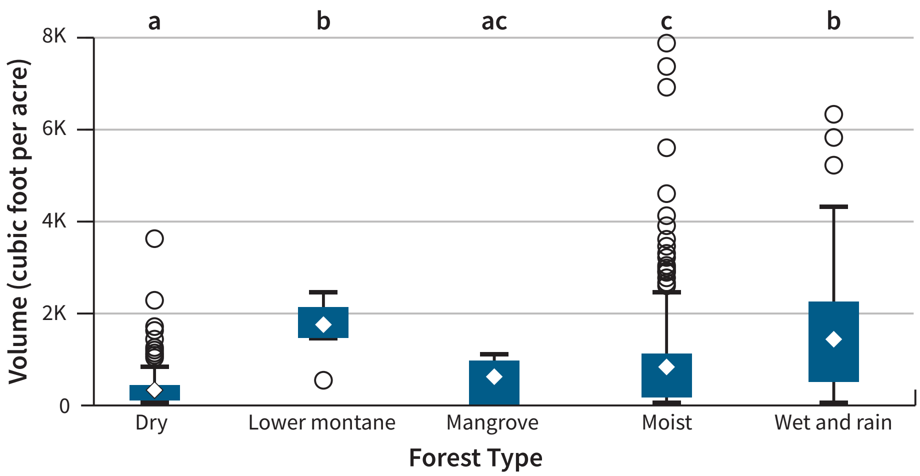

Figure 12—Mean, median, interquartile ranges, and outlying values for all live tree (d.b.h. ≥5 inches) gross volume by forest type, Puerto Rico and the U.S. Virgin Islands, 2001–2024. Differing letters over each category represents statistically significant differences at the Pr > |t| of 0.05.

Table 4a—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume and all live tree basal area by Holdridge life zone for Puerto Rico and the U.S. Virgin Islands

	Gross volume (ft^3/acre)					All live tree basal area (ft^2/acre)			
Life zone	N	Mean	SE	MIN	MAX	Mean	SE	MIN	MAX
Dry forest	172	317.72	26.10	4.82	2,197.91	63.09	2.59	3.14	164.63
Moist forest	351	809.73	52.86	7.09	7,876.43	99.71	3.68	2.51	483.74
Mangrove	6	610.78	201.29	6.24	1,134.91	70.31	15.80	14.08	109.74
Wet and rain forest	171	1,437.82	92.70	9.13	6,115.91	116.04	5.87	3.83	558.26
Lower montane wet and rain forest	6	2,015.23	131.89	1,508.02	2,483.51	146.34	3.72	137.37	160.18
All islands	**706**	**850.55**	**38.34**	**4.82**	**7,876.43**	**94.85**	**2.51**	**2.51**	**558.26**

Table 4b—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume growth and all live tree stocking by Holdridge life zone for Puerto Rico and the U.S. Virgin Islands

	Gross volume growth (ft^3/acre/year)					All live stocking (%)			
Life zone	N	Mean	SE	MIN	MAX	Mean	SE	MIN	MAX
Dry forest	172	18.96	2.52	0.13	342.33	87.02	2.05	19.50	120.00
Moist forest	351	45.49	2.96	0.08	452.79	69.70	1.46	5.16	120.00
Mangrove	6	30.99	12.00	1.52	74.13	57.99	4.01	41.74	67.02
Wet and rain forest	171	65.08	4.30	0.73	319.04	60.49	1.74	23.76	120.00
Lower montane wet and rain forest	6	62.77	13.39	27.10	114.86	64.65	4.84	56.66	88.52
All islands	**706**	**43.76**	**2.00**	**0.08**	**452.79**	**71.57**	**1.04**	**5.16**	**120.00**

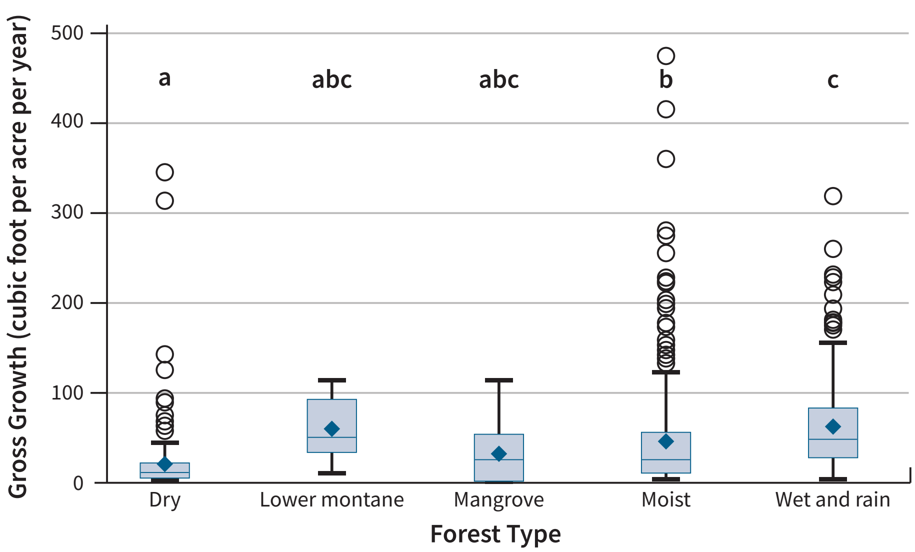

Figure 13—Mean, median, interquartile ranges, and outlying values for all live tree (d.b.h. ≥5 inches) gross volume growth by forest type, Puerto Rico and the U.S. Virgin Islands, 2001–2024. Differing letters over each category represents statistically significant differences at the Pr > |t| of 0.05.

Forest Parameters by Island, Forest Type, and Soils

The highest levels of gross volume growth were seen on the mainland of Puerto Rico (65.08 cubic feet per acre per year in wet and rain forests, with an island-wide average of 51.29 cubic feet per acre per year) (Table 5). Wet and rain forests and lower montane wet and rain forests were the most productive. The lowest observed productivity values were in the dry forest of Mona Island (5.00 cubic feet per acre per year) (Table 5). Stand productivity and characteristics also appeared to vary widely within forest types by major soil order (Tables 6, 7). Trees per acre and basal area in dry forests did not differ significantly by soil taxonomic order. There was a suggestion (p-values = 0.0595 and 0.0707, respectively) that soil taxonomic order was correlated with standing volume and growth, with higher values observed in stands growing on mollisols and vertisols.

Comparing dry forest parameters among islands, controlling for soils, there are significant differences for trees per acre, basal area and volume (p-values = 0.0012, <0.001, and 0.0134, respectively), but not for stocking or growth (main effects p-values = 0.3095 and 0.3757, respectively). The main difference in trees per acre was the higher values on St. Croix, which were significantly greater than those on mainland (Fig. 14) Puerto Rico, Culebra, Vieques, and Mona Island. St. Croix and St. John had the highest mean per acre values of basal area, which were significantly greater than all the other islands. Culebra, Mona, and St. Thomas showed lower volume per acre than the other islands, in some cases significantly so.

Trees per acre, basal area, volume and growth varied significantly by island (p-values of <0.0001, 0.0005, 0.0069, and 0.0271, respectively) in moist forest stands but stocking did not (p-values = 0.0987). As in the dry forests, St. Croix had the densest stands (2,466.41 trees per acre), which were significantly denser than all other islands except St. John. Vieques' moist forest basal area was notably and significantly lower than that on mainland Puerto Rico and St. Croix. Mean moist forest volume on St. John was the lowest measured across the islands (231.29 cubic feet per acre), significantly so when compared to mainland Puerto Rico and St. Croix.

After controlling for forest type and island, there were no statistically significant differences in trees per acre, stocking, basal area and volume levels between conditions undamaged and damaged by hurricanes (p-value = 0.1746, 0.3047, 0.2348 and 0.2612, respectively). Gross growth, however, was lower on hurricane damaged plots (p-value = 0.0024, Fig. 15).

Table 5a—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume and all live tree basal area by island and Holdridge life zone

		Gross volume (ft^3/acre)					All live tree basal area (ft^2/acre)			
Island	**Life zone**	**N**	**Mean**	**SE**	**MIN**	**MAX**	**Mean**	**SE**	**MIN**	**MAX**
Puerto Rico										
Mainland Puerto Rico	Subtropical dry	59	374.65	55.35	8.28	2,197.91	57.93	3.72	3.14	124.51
	Subtropical moist	291	865.30	60.82	7.09	7,876.43	103.51	4.20	2.51	483.74
	Mangrove	6	610.78	201.29	6.24	1,134.91	70.31	15.80	14.08	109.74
	Wet and rain forest	171	1,437.82	92.70	9.13	6,115.91	116.04	5.87	3.83	558.26
	Lower montane wet and rain forest	6	2,015.23	131.89	1,508.02	2,483.51	146.34	3.72	137.37	160.18
	Islandwide	**533**	**1,004.75**	**47.60**	**6.24**	**7,876.43**	**102.59**	**3.09**	**2.51**	**558.26**
Culebra	Subtropical dry	16	182.23	42.23	19.07	635.27	52.00	5.33	22.56	103.73
	Islandwide	**16**	**182.23**	**42.23**	**19.07**	**635.27**	**52.00**	**5.33**	**22.56**	**103.73**
Vieques	Subtropical dry	9	310.87	96.38	16.21	822.21	59.80	12.04	14.87	110.38
	Subtropical moist	23	405.91	70.99	16.96	1,353.41	54.08	8.79	2.61	195.76
	Islandwide	**32**	**379.18**	**57.48**	**16.21**	**1,353.41**	**55.69**	**7.08**	**2.61**	**195.76**
Mona	Subtropical dry	23	209.24	19.12	29.70	399.06	44.80	3.86	8.79	75.25
	Islandwide	**23**	**209.24**	**19.12**	**29.70**	**399.06**	**44.80**	**3.86**	**8.79**	**75.25**
U.S. Virgin Islands										
St. Croix	Subtropical dry	23	392.36	39.17	70.08	780.27	97.09	7.67	38.87	164.63
	Subtropical moist	16	1,022.49	252.50	131.35	3,222.62	123.19	8.54	54.10	191.40
	Islandwide	**39**	**650.88**	**115.66**	**70.08**	**3,222.62**	**107.80**	**6.02**	**38.87**	**191.40**
St. John	Subtropical dry	11	508.75	172.41	4.82	1,451.58	83.63	14.06	3.96	145.01
	Subtropical moist	15	231.29	54.35	9.44	637.41	80.45	11.53	15.81	190.19
	Islandwide	**26**	**348.68**	**82.08**	**4.82**	**1,451.58**	**81.86**	**8.78**	**3.96**	**190.19**
St. Thomas	Subtropical dry	31	238.61	54.36	5.01	1,277.48	60.01	5.53	7.89	119.75
	Subtropical moist	6	541.18	243.12	46.17	1,361.28	76.00	23.57	18.32	151.92
	Islandwide	**37**	**287.68**	**61.15**	**5.01**	**1,361.28**	**62.60**	**5.90**	**7.89**	**151.92**

Table 5b—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume growth and all live tree stocking by island and Holdridge life zone

		Gross volume growth (ft^3/acre/year)					All live stocking (%)			
Island	**Life zone**	**N**	**Mean**	**SE**	**MIN**	**MAX**	**Mean**	**SE**	**MIN**	**MAX**
Puerto Rico										
Mainland Puerto Rico	Subtropical dry	59	23.04	6.33	0.86	342.33	83.90	3.63	20.97	120.00
	Subtropical moist	291	49.09	3.43	0.08	452.79	69.69	1.59	5.16	120.00
	Mangrove	6	30.99	12.00	1.52	74.13	57.99	4.01	41.74	67.02
	Wet and rain forest	171	65.08	4.30	0.73	319.04	60.49	1.74	23.76	120.00
	Lower montane wet and rain forest	6	62.77	13.39	27.10	114.86	64.65	4.84	56.66	88.52
	Islandwide	**533**	**51.29**	**2.49**	**0.08**	**452.79**	**68.12**	**1.15**	**5.16**	**120.00**
Culebra	Subtropical dry	16	22.73	5.82	1.90	94.74	87.82	4.90	48.78	120.00
	Islandwide	**16**	**22.73**	**5.82**	**1.90**	**94.74**	**87.82**	**4.90**	**48.78**	**120.00**
Vieques	Subtropical dry	87.82	4.90	48.78	120.00	822.21	73.88	7.77	34.24	110.38
	Subtropical moist	87.82	4.90	48.78	120.00	1,353.41	56.15	5.35	11.77	105.81
	Islandwide	**32**	**379.18**	**57.48**	**16.21**	**1,353.41**	**61.14**	**4.59**	**11.77**	**110.38**
Mona	Subtropical dry	23	5.00	0.69	0.53	14.30	97.02	5.12	25.97	120.00
	Islandwide	**23**	**5.00**	**0.69**	**0.53**	**14.30**	**97.02**	**5.12**	**25.97**	**120.00**
U.S. Virgin Islands										
St. Croix	Subtropical dry	23	18.56	2.03	4.94	37.57	90.04	5.91	30.46	120.00
	Subtropical moist	16	40.97	12.45	7.89	207.84	75.86	4.99	31.51	120.00
	Islandwide	**39**	**27.76**	**5.45**	**4.94**	**207.84**	**84.22**	**4.15**	**30.46**	**120.00**
St. John	Subtropical dry	11	18.02	8.25	0.13	99.79	86.16	7.72	31.25	120.00
	Subtropical moist	15	18.56	6.03	0.17	92.76	83.04	8.49	14.37	120.00
	Islandwide	**26**	**18.32**	**4.87**	**0.13**	**99.79**	**84.43**	**5.73**	**14.37**	**120.00**
St. Thomas	Subtropical dry	31	15.78	3.00	0.22	81.96	87.04	5.28	19.50	120.00
	Subtropical moist	6	24.11	5.60	8.55	49.20	72.38	9.11	49.00	99.94
	Islandwide	**37**	**17.13**	**2.69**	**0.22**	**81.96**	**84.66**	**4.70**	**19.50**	**120.00**

Table 6a—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume and all live tree basal area by island and major soil order, Puerto Rico

				Gross volume (ft^3/acre)				All live tree basal area (ft^2/acre)			
Island	**Life zone**	**Major soil order**	**N**	**Mean**	**SE**	**MIN**	**MAX**	**Mean**	**SE**	**MIN**	**MAX**
Puerto Rico											
Mainland Puerto Rico	Subtropical dry	Missing	7	419.57	196.58	8.28	1,303.36	54.60	12.22	3.14	100.83
		Alfisols	1	27.25	0.00	27.25	27.25	3.74	0.00	3.74	3.74
		Aridisols	7	183.99	35.06	23.86	268.75	40.42	9.23	8.63	68.44
		Entisols	8	115.74	10.41	77.76	150.81	53.45	2.90	40.39	65.57
		Inceptisols	5	507.47	129.75	251.61	874.71	34.21	3.68	26.85	47.09
		Mollisols	18	510.02	142.51	28.58	2,197.91	72.48	8.08	14.83	124.51
		Ultisols	4	435.67	63.12	292.41	593.21	76.04	5.18	64.40	89.13
		Vertisols	9	385.09	108.40	25.36	1,016.05	60.17	6.71	29.37	86.52
	Subtropical moist	Missing	73	876.29	110.26	16.73	4,085.40	106.89	7.96	10.76	327.57
		Alfisols	19	788.78	144.39	60.31	1,957.58	95.08	15.94	8.10	237.72
		Aridisols	2	139.43	71.04	68.39	210.47	35.81	9.53	26.28	45.34
		Entisols	1	19.34	0.00	19.34	19.34	2.51	0.00	2.51	2.51
		Histosols	2	1,050.33	72.53	977.80	1,122.86	100.18	11.99	88.19	112.18
		Inceptisols	90	1,052.74	90.94	7.09	3,966.85	118.74	8.31	3.28	367.77
		Mollisols	54	774.11	218.88	7.36	7,876.43	86.17	10.33	11.12	483.74
		Oxisols	9	1,202.99	416.90	102.18	3,213.17	112.54	17.34	64.87	241.19
		Spodosols	3	684.98	241.23	311.26	1,136.08	217.44	37.62	151.52	281.81
		Ultisols	35	592.25	107.90	8.48	2,195.89	88.03	7.33	13.50	179.35
		Vertisols	3	96.55	21.05	58.76	131.50	50.32	4.87	42.77	59.44
	Mangrove	Entisols	4	910.04	108.29	614.40	1,134.91	94.13	6.68	77.14	109.74
		Mollisols	2	12.25	6.01	6.24	18.26	22.68	8.60	14.08	31.28
	Subtropical wet and rain forest	Missing	20	727.65	137.65	9.13	2,331.03	80.61	8.45	4.92	134.95
		Alfisols	4	3,726.82	106.39	3,426.63	3,920.43	205.84	5.46	190.95	217.24
		Inceptisols	35	1,105.15	168.93	52.79	4,181.00	116.47	18.77	23.96	558.26
		Mollisols	21	824.31	173.04	9.58	2,443.78	88.24	8.68	3.83	153.12
		Oxisols	30	2,276.33	286.20	47.27	6,115.91	158.76	17.79	21.38	402.26
		Ultisols	58	1,532.16	134.00	53.40	5,395.92	110.40	5.91	32.27	228.03
		Vertisols	3	1,086.79	295.79	532.55	1,543.04	103.99	6.78	90.58	112.47
	Lower montane wet and rain forest	Oxisols	3	1,793.51	148.92	1,508.02	2,009.77	149.19	5.52	142.88	160.18
		Ultisols	3	2,236.96	125.03	2,077.49	2,483.51	143.49	5.54	137.37	154.55
Culebra	Subtropical dry	Entisol	4	105.92	57.30	19.07	267.29	32.28	5.09	22.56	46.53
		Missing	2	91.81	35.45	56.36	127.25	50.91	3.27	47.64	54.19
Vieques	Subtropical dry	Entisols	2	219.29	0.74	218.55	220.03	91.83	2.13	89.69	93.96
		Inceptisols	1	62.12	0.00	62.12	62.12	33.90	0.00	33.90	33.90
		Mollisols	4	555.55	129.17	278.12	822.21	72.36	16.25	36.96	110.38
		Vertisols	2	37.45	21.24	16.21	58.68	15.58	0.72	14.87	16.30
	Subtropical moist	Missing	6	560.43	181.53	150.48	1.353.41	83.29	24.91	27.02	195.76
		Entisols	2	389.71	143.34	246.37	533.04	37.22	7.09	30.14	44.31
		Inceptisols	10	382.03	103.39	16.96	914.07	49.92	11.05	2.61	108.26
		Mollisols	5	274.76	127.07	41.02	657.25	34.10	8.90	10.64	56.51
Mona	Subtropical dry	Missing	22	211.65	19.85	29.70	399.06	45.73	3.92	8.79	75.25
		Entisols	1	156.26	0.00	156.26	156.26	24.34	0.00	24.34	24.34

Table 6b—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume growth and all live tree stocking by island and major soil order, Puerto Rico

				Gross volume growth (ft^3/acre/year)				All live stocking (%)			
Island	**Life zone**	**Major soil order**	**N**	**Mean**	**SE**	**MIN**	**MAX**	**Mean**	**SE**	**MIN**	**MAX**
Puerto Rico											
Mainland Puerto Rico	Subtropical dry	Missing	7	14.30	7.22	1.72	54.49	82.65	12.97	34.80	112.08
		Alfisols	1	5.45	0.00	5.45	5.45	38.35	0.00	38.35	38.35
		Aridisols	7	6.28	2.70	0.86	21.87	84.21	8.49	44.13	107.12
		Entisols	8	4.07	1.20	0.88	11.32	118.95	0.85	113.17	120.00
		Inceptisols	5	23.76	12.37	3.80	72.28	55.41	14.05	20.97	89.16
		Mollisols	18	39.68	19.15	3.30	342.33	84.04	5.30	38.26	113.87
		Ultisols	4	15.76	3.88	7.43	23.50	64.45	1.78	61.04	68.21
		Vertisols	9	31.27	10.40	2.63	78.99	82.71	8.32	53.50	120.00
	Subtropical moist	Missing	73	47.59	5.55	0.34	201.92	71.98	3.17	21.24	120.00
		Alfisols	19	43.85	10.30	1.03	141.97	71.04	6.15	31.23	120.00
		Aridisols	2	16.89	3.49	13.40	20.37	76.16	10.37	65.79	86.53
		Entisols	1	3.72	0.00	3.72	3.72	120.00	0.00	120.00	120.00
		Histosols	2	39.91	8.86	31.05	48.76	44.17	13.91	30.26	58.07
		Inceptisols	90	61.23	6.94	1.62	452.79	62.77	2.62	5.16	120.00
		Mollisols	54	38.05	9.40	0.08	359.49	77.00	4.32	22.36	120.00
		Oxisols	9	55.09	21.83	13.98	224.34	63.08	8.15	31.77	108.89
		Spodosols	3	92.36	17.50	58.84	117.84	94.53	8.57	83.95	111.50
		Ultisols	35	42.80	8.40	1.27	206.31	71.75	4.00	23.96	120.00
		Vertisols	3	7.88	0.81	6.76	9.46	48.12	7.75	36.65	62.88
	Mangrove	Entisols	4	45.52	12.21	17.56	74.13	55.98	6.01	41.74	67.02
		Mollisols	2	1.94	0.42	1.52	2.35	62.02	0.81	61.20	62.83
	Subtropical wet and rain forest	Missing	20	42.62	5.57	1.86	105.14	56.54	5.31	23.76	119.76
		Alfisols	4	40.07	4.38	32.93	52.28	70.83	4.74	61.92	80.98
		Inceptisols	35	56.62	7.94	3.97	223.65	55.19	4.33	24.13	120.00
		Mollisols	21	31.64	6.67	1.65	126.08	75.02	5.62	35.34	120.00
		Oxisols	30	72.26	10.18	4.28	228.97	68.35	4.15	26.52	111.33
		Ultisols	58	86.99	9.01	0.73	319.04	55.63	2.26	24.20	91.39
		Vertisols	3	85.77	22.77	47.61	126.39	48.76	5.58	37.61	54.73
	Lower montane wet and rain forest	Oxisols	3	53.04	18.67	27.10	89.28	70.41	9.10	59.73	88.52
		Ultisols	3	72.49	21.28	47.74	114.86	58.90	1.13	56.66	60.34
Culebra	Subtropical dry	Entisol	4	13.47	6.59	1.90	30.04	78.03	12.79	48.78	–
		Missing	2	12.92	1.87	11.05	14.79	78.57	11.98	66.60	–
Vieques	Subtropical dry	Entisols	2	13.47	2.89	10.58	16.36	96.52	2.38	94.14	98.90
		Inceptisols	1	9.63	0.00	9.63	9.63	110.38	0.00	110.38	110.38
		Mollisols	4	66.04	25.84	30.36	141.01	66.10	1.96	61.57	70.24
		Vertisols	2	4.59	3.11	1.48	7.69	48.53	14.29	34.24	62.82
	Subtropical moist	Missing	6	34.16	6.94	11.06	53.77	74.40	8.89	50.17	105.81
		Entisols	2	38.79	14.20	24.59	52.99	25.76	0.00	25.76	25.76
		Inceptisols	10	19.81	5.96	2.28	60.62	56.11	7.38	25.09	104.90
		Mollisols	5	24.30	12.26	1.52	67.61	46.48	12.00	11.77	81.36
Mona	Subtropical dry	Missing	22	4.94	0.72	0.53	14.30	97.33	5.35	25.97	–
		Entisols	1	6.39	0.00	6.39	6.39	90.16	0.00	90.16	–

– = No values recorded.

Table 7a—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume, and all live tree basal area by island and major soil order, U.S. Virgin Islands

				Gross volume (ft³/acre)				All live tree basal area (ft²/acre)			
Island	Life zone	Major soil order	N	Mean	SE	MIN	MAX	Mean	SE	MIN	MAX
U.S. Virgin Islands											
St. Croix	Subtropical dry	Missing	4	412.94	160.25	114.15	780.27	106.46	20.50	71.43	164.63
		Inceptisols	12	426.97	39.96	170.65	641.58	100.34	12.10	38.87	161.22
		Mollisols	7	321.27	70.03	70.08	541.60	86.14	9.88	56.56	121.42
	Subtropical moist	Inceptisols	5	550.17	57.38	367.88	711.05	109.39	5.03	95.45	122.19
		Mollisols	11	1,237.18	351.79	131.35	3,222.62	129.46	11.91	54.10	191.40
St. John	Subtropical dry	Missing	1	154.83	0.00	154.83	154.83	41.54	0.00	41.54	41.54
		Entisols	2	378.85	26.96	351.89	405.81	108.76	36.25	72.51	145.01
		Inceptisols	4	56.03	35.33	4.82	160.54	52.63	21.86	3.96	125.10
		Mollisols	4	1,114.90	258.99	352.08	1,451.58	120.34	7.48	100.26	133.09
	Subtropical moist	Missing	3	170.54	45.31	80.60	225.02	71.33	6.89	60.10	83.86
		Alfisols	4	323.18	139.86	37.29	637.41	112.27	36.23	15.81	190.19
		Entisols	2	376.10	64.78	311.32	440.87	90.78	19.50	71.28	110.29
		Inceptisols	1	107.13	0.00	107.13	107.13	29.21	0.00	29.21	29.21
		Mollisols	5	161.15	109.10	9.44	580.45	66.58	12.30	36.88	108.88
St. Thomas	Subtropical dry	Missing	2	47.61	29.46	18.15	77.07	78.59	8.90	69.69	87.49
		Entisols	2	20.82	4.33	16.49	25.15	66.26	6.80	59.47	73.06
		Inceptisols	4	318.64	182.21	5.01	693.73	79.43	21.77	30.36	119.75
		Mollisols	22	268.10	67.61	16.21	1,277.48	55.21	6.46	7.89	113.34
		Vertisols	1	87.52	0.00	87.52	87.52	38.39	0.00	38.39	38.39
	Subtropical moist	Mollisols	6	541.18	243.12	46.17	1,361.28	76.00	23.57	18.32	151.92

Table 7b—Mean value, number of sampled conditions (N), standard error of the mean (SE), minimum value (MIN) and maximum value (MAX) for gross volume growth and all live tree stocking by island and major soil order, U.S. Virgin Islands

				Gross volume growth (ft^3/acre/year)				All live stocking (%)			
Island	**Life zone**	**Major soil order**	**N**	**Mean**	**SE**	**MIN**	**MAX**	**Mean**	**SE**	**MIN**	**MAX**
U.S. Virgin Islands											
St. Croix	Subtropical dry	Missing	4	24.60	6.04	14.16	36.42	82.22	21.88	40.32	120.00
		Inceptisols	12	20.26	2.84	9.16	37.57	83.45	8.17	30.46	116.70
		Mollisols	7	12.21	1.68	4.94	17.04	105.80	3.88	91.83	119.56
	Subtropical moist	Inceptisols	5	26.86	4.64	15.31	42.36	68.21	4.51	58.28	80.91
		Mollisols	11	47.39	17.92	7.89	207.84	79.34	6.84	31.51	120.00
St. John	Subtropical dry	Missing	1	8.42	0.00	8.42	8.42	100.27	0.00	100.27	100.27
		Entisols	2	6.59	3.46	3.13	10.04	107.63	12.37	95.27	120.00
		Inceptisols	4	4.74	3.07	0.13	16.48	78.81	17.20	31.25	120.00
		Mollisols	4	42.73	20.61	6.96	99.79	81.08	3.47	74.67	88.60
	Subtropical moist	Missing	3	6.68	1.64	3.88	9.55	75.36	22.58	47.18	120.00
		Alfisols	4	37.48	19.33	7.31	92.76	57.09	14.51	14.37	78.61
		Entisols	2	23.35	2.18	21.17	25.53	100.90	15.23	85.67	116.14
		Inceptisols	1	8.43	0.00	8.43	8.43	118.90	0.00	118.90	118.90
		Mollisols	5	10.65	6.41	0.17	28.93	94.10	13.54	50.04	120.00
St. Thomas	Subtropical dry	Missing	2	7.88	4.64	3.24	12.52	53.24	8.17	45.07	61.41
		Entisols	2	1.65	0.11	1.54	1.75	118.41	1.59	116.82	120.00
		Inceptisols	4	17.78	10.83	0.46	45.85	114.86	2.45	109.45	120.00
		Mollisols	22	17.30	3.69	0.22	81.96	83.57	6.09	19.50	120.00
		Vertisols	1	18.30	0.00	18.30	18.30	56.88	0.00	56.88	56.88
	Subtropical moist	Mollisols	6	24.11	5.60	8.55	49.20	72.38	9.11	49.00	99.94

Figure 14—Tan-tan, or white lead tree (*Leucaena leucocephala*), an introduced nitrogen-fixing tree, often dominates former agricultural lands in the subtropical dry forests of the U.S. Virgin Islands, particularly in those areas frequently disturbed by hurricanes and fires (USDA Forest Service photo by Thomas J. Brandeis).

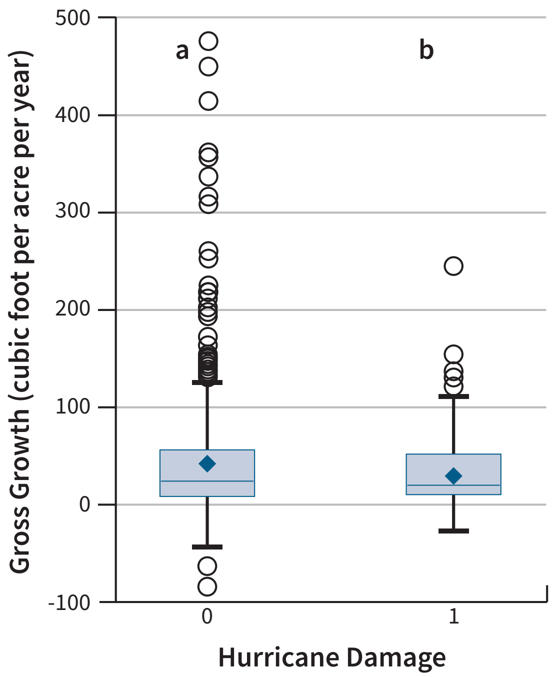

Figure 15—Mean, median, interquartile ranges, and outlying values for all live tree (d.b.h. ≥5 inches) gross volume growth by hurricane damage, Puerto Rico and the U.S. Virgin Islands, 2001–2024. Differing letters over each category represents statistically significant differences at the Pr > |t| of 0.05.

Discussion

Where applicable, the default SITECLCD of 6 or 7 currently being used in FIADB could be replaced with a calculated SITECLCD value if site productivity appears relatively stable over the remeasurement periods and the plot has not experienced significant disturbances or treatments that would negatively affect the accumulation of gross cubic foot volume. This would involve defining a metric that would be used to decide whether site productivity has been stable. Site productivity stability would imply that the stands are fully stocked and the culmination of MAI has been reached. Vissage et al. (2019) defines full stocking as all live tree stocking greater than or equal to 60 percent. We would recommend caution if considering using just stocking values as the sole metric for deciding when a condition has reached its maximum productivity. Dry forests have greater trees per acre than other forest types, and the FIA stocking algorithm appears to assign higher stocking values to those forests with dense stands of smaller stems. Further exploration of the FIA stocking algorithm and its use of default CONUS tree species in the Caribbean is needed, particularly if stocking percentage is being underestimated in stands consisting of fewer, larger diameter trees. Mean values for full stocking by forest type can be calculated from the plots exhibiting site productivity stability and could then be used to define full stocking for plots in sites without full stocking or that have been disturbed.

Another option to estimate full stocking for damaged plots, with low stocking, or without productivity stability would be a more complex modeling approach where variables drawn from stable plots and multiple ancillary site attributes (e.g., climate and soil maps) could be used to create models for assigning site productivity class to forested conditions. The results suggest that building individual gross growth models for the dry, moist and combined wet and rain and lower montane forest types might be warranted. These forest types—Holdridge life zones which are based on precipitation and biotemperature (Holdridge 1947)—integrate broad environmental factors affecting tree growth. A single model for both wet and rain forest and lower montane wet and rain forest is recommended due to the small sample size in the latter forest type and their proximity at higher elevations in the mountains. One forest type, mangroves, is an exception and is found on coastal and estuarine sites with specific geographic and hydrologic features, not being dependent on the life zone (Fig. 16). Either a mangrove-specific model for predicting site productivity can be fit to the data, or if the sample size proves too small, a generic model fit to the data from stands in all forest types.

Developing separate models by island or island groups for dry and moist forest types does not seem to be warranted based on the data. Additionally, we hypothesize that observed differences among the islands stem from differing land use histories rather than inherent site productivity characteristics. All of these islands except Mona were largely deforested beginning with European colonization, with forests replaced by export commodity-oriented agriculture of varying intensities (Wadsworth 1950). Capturing land use change, such as past crops, or time since agricultural abandonment and reversion to forest (a common historical occurrence on mainland Puerto Rico; see Grau et al. 2003 and Helmer 2004, for overviews), could be a valuable addition to site productivity modeling. But existing information has high uncertainty and is limited to mainland Puerto Rico from the 1950s. These aerial images have been challenging to georeference with sufficient accuracy to identify current plot locations. We don’t have this photography for the other islands and satellite imagery only goes back to the 1970s.

One exception where an island-specific model might be warranted is Mona Island. It had the lowest growth rates and is geographically and geologically distinct from the other islands (Frank et al. 1998) (Fig. 17). As an uplifted plateau bounded by vertical cliffs in the Mona Passage between the islands of Puerto Rico and Hispaniola, it is geographically isolated. Its dolomite core with thin soil atop the limestone plateau is geologically distinct. The island experienced guano mining in the past but not the same widespread deforestation of its relatively sparse forest cover as the other islands.

Figure 16—Complex tree growth forms complicate site productivity estimation in the mangrove forests of Puerto Rico (USDA Forest Service photo by Thomas J. Brandeis).

Figure 17—Thin, rocky soils and reduced rainfall limit the productivity of forest land on Mona Island, Puerto Rico (USDA Forest Service photo by Thomas J. Brandeis).

While we expect soil characteristics to significantly affect site productivity, the maps of major soil taxon may have too coarse of a spatial resolution, or the classes may be too generalized, for consistent results. More detailed soil properties will have to be tested when fitting models, such as depth to bedrock or parent materials (e.g., volcanic versus limestone-derived). As mentioned previously, Holdridge life zones integrate key climatic properties, but more detailed individual climatic properties should also be explored.

Another way of knowing if site productivity observed on the measured forest conditions is at its maximum would be to develop maximum stand density indices from the FIA data as done in Yang and Brandeis (2022) for mixed-hardwood forests across physiographic zones in the Eastern U.S. The modeling approach taken by that study did not require individual tree ages and only used data that is also collected on NFI plots in the Caribbean. Observed gross cubic foot volume or basal area levels on conditions could be compared to modeled maximum values. This approach would provide maximum stand density indices for Puerto Rico and the U.S. Virgin Islands forests but also for other islands of the Caribbean.

The lack of significant differences in all of the forest parameters we studied, except for growth, between conditions that were disturbed and undisturbed by hurricanes Irma and Maria, seems surprising at first. Across Puerto Rico, forests impacted by wind, heavy rain, flooding, or landslides, disturbances associated with hurricanes, show significantly increased mortality (Helmer et al. 2023, Vargas et al. 2025). Hurricanes Maria and Irma increased basal area mortality rates by 25 percent and reduced canopy height and cover by 45 percent and 21 percent, respectively (Vargas et al. 2025). However, trees that survive show considerable damage to the crowns and branches (Leitold et al. 2022, Marcano-Vega 2019, Uriarte et al. 2019). While tree stems might break, stem breakage is more frequent above where d.b.h. is measured, and effects on basal area measurements are minimal. Volume estimates, which are made with equations using d.b.h. and tree height, will be reduced by broken crowns and terminal leaders. But we can speculate that the rapid sprouting and foliage recovery of trees following hurricanes, in addition to the difficulty of making consistent tree height measurements in dense forests on rugged terrain, might be partially masking volume loss. For example, the biomass of fast growing introduced species like *Spathodea campanulata* increased across Puerto Rico by the time the post-hurricane measurement cycle ended in the year 2019 (Helmer et al. 2023), which would partially offset mortality and damage-related losses in site-level tree volume and productivity. The significantly decreased growth rates on hurricane-damaged plots, however, clearly reflect the negative impacts of mortality on plot-level changes in volume and likely also reflect reduced productivity of damaged survivor trees (Fig. 18).

Conclusions

This and other NFI datasets with repeated measurements on permanent plots offer opportunities and challenges for modeling site productivity, stand density, and individual tree growth. Here, with repeated NFI measurements, we estimate site productivity in terms of volume growth. The lack of basic forest mensuration information such as Caribbean-specific site index reference levels, stocking algorithms and stand density curves, complicates such efforts. Also, steadily increasing volume per acre over time—from an average of 10,660 board feet per acre in 2004 to 35,173 board feet per acre in 2019; Marcano-Vega 2019—would seem to indicate that a large percentage of the forest stands surveyed is still maturing after they naturally regenerated on deforested lands and have not yet reached full stocking and maximum site potential. We must also accept that a “stable” state in these dynamic forests includes periodic losses and recovery of productivity due to hurricane disturbance, making estimation inherently more uncertain.

Figure 18—Salvaged logs from hurricane events can provide valuable raw material for local sawmills, supporting the island's growing artisanal timber industry and promoting better use of wood resources that would otherwise go to waste (USDA Forest Service photo by Humfredo Marcano-Vega).

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Appendix—Additional documentation of Forest Inventory and Analysis methodology as applied in the Caribbean

Species assignments

The species reference table with stocking species group code (STOCKING_SPGRPCD) limited to just species found in the Caribbean can be accessed here:

```
select * from fs_fia_reference.ref_species where c_spgrpcd is not null
```

The vast majority of Caribbean species are assigned a STOCKING_SPGRPCD = 37. This code does not appear in Arner et al. 2001 but is actually the same coefficients used for STOCKING_SPGRPCD = 25, red maple. Additionally:

- One species (*Melaleuca quinquenervia*) was assigned to STOCKING_SPGRPCD = 1, spruce-fir
- One genus group (*Cupressus* spp.) was assigned to STOCKING_SPGRPCD = 10, Ponderosa pine
- One genus group (*Thuja* spp.) was assigned to STOCKING_SPGRPCD = 16, northern white cedar
- 14 conifer species are assigned to STOCKING_SPGRPCD = 20, red pine
- Three *Morus* spp. were assigned STOCKING_SPGRPCD = 25, red maple
- Three *Eucalyptus* spp. were assigned STOCKING_SPGRPCD = 26, red alder
- One genus group (*Catalpa* spp.) was assigned STOCKING_SPGRPCD = 27, maple, beech, birch
- One genus group (*Diospyros* spp.) was assigned STOCKING_SPGRPCD = 29, oak and hickory
- One genus group (*Juglans* spp.) was assigned STOCKING_SPGRPCD = 30, black walnut
- One species (*Taxodium mucronatum*) was assigned to STOCKING_SPGRPCD = 31, sweetgum
- Five species/genus groups (two *Magnolia* spp., *Fraxinus* spp. *Persea* spp. and *Melia azedarach*) were assigned STOCKING_SPGRPCD = 33, Cherry, ash, yellow poplar
- Three species/genus groups (*Prosopis* spp., *Acacia* spp. and *Acacia farnesiana*) were assigned STOCKING_SPGRPCD = 38/36, elm, ash, cottonwood. (Stocking code 38 does not appear in Arner et al. (2001) but the coefficients are the same as stocking group 36)

Stocking coefficients

Stocking equation coefficients (b_0 and b_1) are found here:

```
select * from fs_nims_srs.nims_coef_stocking
```

For example, for STOCKING_SPGRPCD = 37/25, the coefficients are $b_0 = 0.01105$ and $b_1 = 1.53$.

Brandeis, Thomas J.; Hartsell, Andy J.; Esham, Belinda D.; Marcano-Vega, Humfredo; Helmer, Eileen H. 2026. Estimating Caribbean forest site productivity from national forest inventory data. Gen. Tech. Rep. SRS-290. Asheville, NC: U.S. Department of Agriculture, Southern Research Station. 35 p. https://doi.org/10.2737/SRS-GTR-290.

The Forest Inventory and Analysis (FIA) national forest inventory estimates site productivity for every forested plot. In the Puerto Rico and the U.S. Virgin Islands, the site class is not estimated because data are not collected on site trees due to the lack of both annual growth rings and growth and yield references, so default values are assigned. We calculated site productivity values by island, forest type and major soil taxon, stand characteristics by these same strata, and explore hurricane impacts. Generally, stand density measures decreased from drier to wetter forest types, while measures of basal, volume and growth increased. There was the suggestion that soils were correlated with volume and growth, with higher values observed on mollisols and vertisols. There were no statistically significant differences in trees per acre, stocking, basal area and volume levels between conditions undamaged and damaged by hurricanes. Gross growth, however, was lower on hurricane damaged plots. We determined that calculated values can be used to populate site class for many plots, and for those that have not reached full stocking, opportunities exist for the development of stand growth models, perhaps by forest type and not for individual islands.

KEYWORDS: Site productivity, Caribbean islands, wood volume, tree growth, tropical forests, hurricane.

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