Effects of the 1956 Hurricane on Forests in Puerto Rico

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Tropical hurricanes, or cylonic storms revolving about a central "eye" and characterized by winds of 75 miles per hour or more and by heavy rainfall, frequently pass through the West Indies and occasionally strike Puerto Rico. These hurricanes normally originate either near the Cape Verde Islands or in the doldrums south of 10°N. latitude and between 40° and 55°W longitude[1]. They usually move westward into the Caribbean, then northwestward, becoming expended in the zone of the westerly winds north of the Tropic of Cancer. About 50 hurricanes have passed directly over Puerto Rico during the 450 years of recorded history[2].

Hurricane damage to exposed trees is generally spectacular. Breakage of branches and uprooting are important causes of failures in communications and electrical service and interruption of vehicular traffic. Damage of this character is deemed so serious by some that large and attractive trees along roadsides and near buildings sometimes are sacrificed to eliminate the hazard.

The effects of hurricanes on forests, many of which are in remote areas, are not well understood. Damage to forests, though less apparent to the layman, is nevertheless real, since the trees in the forest constitute a valuable crop which attains the proper size for harvesting only after years of exposure to hurricanes.

The prediction and prevention of hurricane damage are matters of interests to the entire population. In the forest, however, there is little evidence from past studies to determine whether or how hurricane damage might be minimized. The only attempt at a written description of the effects of hurricanes on trees in Puerto Rico concerns the hurricane of 1928[3]. It was observed that more trees were broken off than uprooted and that some trees escaped serious damage through loss of their leaves early in the storm. Some trees died without any apparent cause except defoliation. Dieback of limbs was caused by sun-scald on exposed branches. Dense forest was less damaged than open forest. This last observation appears to be corroborated by observers in Mauritius[4],/[5] who found indigenous forest relatively resistant to hurricane damage.

Forestry in Puerto Rico has made its most important advances during a period in which no hurricanes passed over the island, from 1932 to 1956. The land area under forest management doubled, and forests were established or improved on thousands of acres. Lands of all types and in all parts of the island were included. Measured plots have been established in areas representative of many of these conditions. This growing investment in forests and forestry makes it imperative that more be known about the nature of hurricane damage and any circumstances which tend to minimize it. Accordingly, a field survey of hurricane damage was made by the Tropical Forest Research Center with the cooperation of the Division of Forests, Fisheries and Wildlife of the Commonwealth

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1/ Tannehill, I. R. 1943. Hurricanes. Princeton University Press. pp. 265

2/ Fassig, O. L. 1929. On the frequency of hurricanes in the vicinity of Porto Rico. Porto Rico Jour. Pub. Health & Trp. Med. 5:106-113.

3/ Bates, Charles Z. 1929. Efectos del huracán del 13 de septiembre de 1928 en distintos árboles. Rev. de Agr. (Puerto Rico) 23:113-117.

4/ Vaughan, R. E. & Wiehe, P. O. 1937. Studies on the vegetation of Mauritius, Pt. 1. A preliminary survey of the plant communities.

5/ King, H. C. 1945. Notes on the three cyclones in Mauritius in 1945: their effect on exotic plantations, indigenous forest and on some timber buildings. Empire Forestry Rev. 24:192-195.

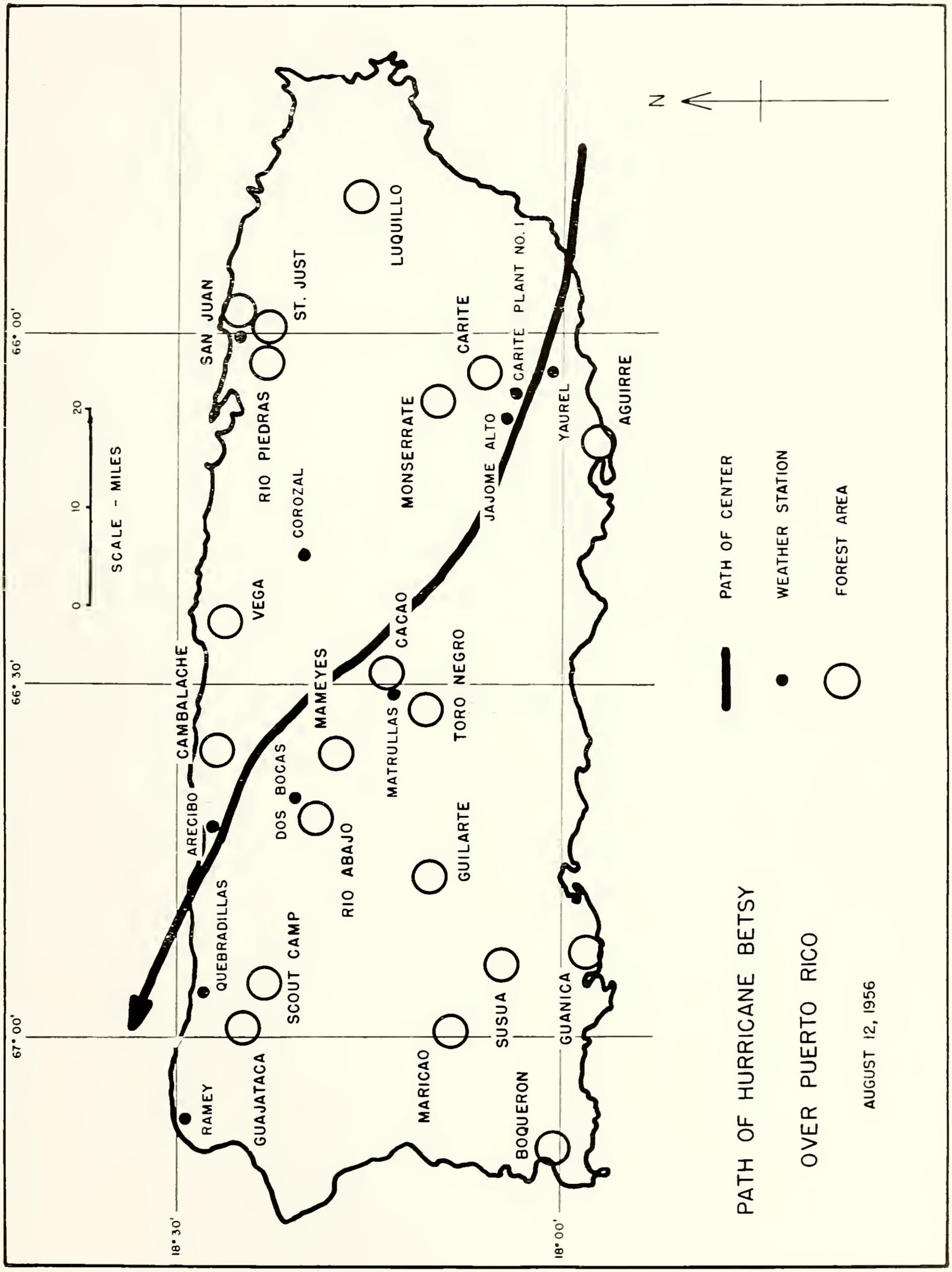
PATH OF HURRICANE BETSY
OVER PUERTO RICO
AUGUST 12, 1956
PATH OF CENTER
WEATHER STATION
FOREST AREA
SCALE - MILES
0
10
20
N
18° 30'
18° 00'
67° 00'
66° 30'
66° 00'
SAN JUAN
ST. JUST
LUQUILLO
RIO PIEDRAS
COROZAL
MONSERRATE
CARITE
CARITE PLANT NO. I
JAJOME ALTO
YAUREL
AGUIRRE
VEGA
CACAO
TORO NEGRO
MATRULLAS
MAMEYES
CAMBALACHE
DOS BOCAS
ARECIBO
RIO ABAJO
GUILARTE
QUEBRADILLAS
SCOUT CAMP
GUAJATACA
RAMEY
MARICAO
SUSUA
GUANICA
BOQUERON

Figure 1

Department of Agriculture and Commerce during the three months immediately following the hurricane of 1956.

THE 1956 HURRICANE

The 1956 hurricane, designated "Betsy" by the U. S. Weather Bureau, and locally called "Santa Clara", developed from an easterly barometric wave found in longitude 33°W. on August 6, reached hurricane intensity on August 10, and was centered over Puerto Rico from about noon to 3:15 p.m. on August 12[6]. The storm first hit Puerto Rico near Maunabo and left near Camuy. Its path, as plotted by radar, is shown in Fig. 1.

Recorded maximum wind velocities accompanying the hurricane were 92 miles per hour at San Juan, about 30 miles north of the path of the center, and 115 miles per hour at Ramey Air Force Base, 13 miles southwest of the path[6]. Unfortunately wind records were insufficient to show the pattern of extreme velocities over the island. However, all of Puerto Rico, according to the Weather Bureau,[6] received wind velocities of at least 50 miles per hour.

6/ U. S. Weather Bureau. 1956. Climatological Data, Puerto Rico and Virgin Islands. II, No. 8, GPO. Washington, D. C.

The maximum rainfall measured in Puerto Rico on August 12 was 8.7 inches at El Verde in the eastern mountains. The pattern of rainfall is shown for selected stations in Table 1. There it is seen that the tendency for rainfall to increase with proximity to the storm center, while generally apparent, is marred by a number of exceptions such as the heavy rainfall at Luquillo and the light rainfall at Aguirre. High rainfall appeared to extend farther in a northerly direction than to the south. A rather clear relationship with elevation is also apparent in Table 1. All but one of the stations receiving more than 5 inches of rainfall were above 1500 feet elevation. Moreover the least rainfall recorded at high elevation, 28 miles from the center, was equal to the rainfall much nearer the center at low elevations.

The rainfall immediately prior to Betsy might, by having already loosened the soil, contribute to the damage on the forest. However, an analysis of the August 9 to 11 rainfall on Puerto Rico indicates that it exceeded one inch for that period at only four of the selected stations. Such prior rain is believed to be too light to have contributed materially to the damage.

Table 1.—The relationship between location, elevation, and rainfall

Distance and Direction from storm center	Approximate Rainfall August 12[1]	Place of Observation
Miles	Inches	
	Elevation 0-1500 ft.	
37S	0.5	Guánica
33S	0.8	Boquerón
31N	3.2	San Juan
29S	1.2	Susúa
27N	2.7	St. Just
24N	2.3	Río Piedras
15S	4.6	Guajataca
13S	4.6	Scout camp
9S	4.1	Quebradillas
9NE	3.7	Vega
9N	2.4	Monserrate
7S	4.1	Río Abajo
6S	4.1	Dos Bocas
5S	1.6	Aguirre
4NE	6.2	Corozal
3N	2.4	Cambalache
3N	4.9	Carite Plant No. 1
1S	3.2	Yaurel
0	3.2	Arecibo
	Elevation 1500-3000 ft.	
28S	3.2	Maricao
25N	8.0	Luquillo
20SW	4.1	Guilarte
10SW	5.6	Toro Negro
7SW	8.6	Matrullas Dam
6N	4.2	Carite
4SW	6.3	Mameyes
3N	5.0	Jajome Alto
2SW	8.5	Cacao

1/ Based in some areas on interpolation from nearby station.

Hurricane Betsy was not as severe as many previous hurricanes. The storm was comparatively small in diameter (apparently little more than 100 miles), it progressed more rapidly across the island (about 20 miles per hour) than is usual, and the winds and rainfall which accompanied it both were considerably less than has been experienced in the past. Extremes for other hurricanes recorded in Puerto Rico are diameters in excess of 300 miles, forward velocity of less than 10 miles per hour, winds of 160 miles per hour, and rainfall up to 29 inches in 48 hours[1].

THE NATURE OF THE DAMAGE

Observations of the effects of the hurricane were made in 20 areas which contain natural or planted forests in Puerto Rico, the area surveyed totalling some 17,000 acres (See Fig. 1). These observations were based upon reconnaissance from the air and by counts on the ground within established plots or along transects[7]. In the selection of areas to be studied an effort was made to include a maximum range in the following factors: distance from the path of the center of the hurricane, elevation, topography, soil types, and stand structure and composition.

The most general type of damage to the forests was defoliation. In many areas the leaves of the exposed parts of tree crowns turned brown and dropped a few days after the storm passed. Elsewhere defoliation was immediate, apparently a direct result of the physical force of the wind.

Loosening and shredding of the bark of trees due to the whipping action of the winds was another form of damage. This effect was evident mostly in trees which had not been completely defoliated.

Breakage was another common effect of the hurricane on trees. At its least this form of damage affected only small limbs. At the other extreme trees were snapped off near the base. Such serious breakage resulted in damage to adjacent trees.

Uprooting was the usual effect of strong winds upon trees which were more resistant above than within the soil (See Fig. 2). At a minimum such trees were tipped and torn partially loose at the roots. However, uprooted trees were commonly blown to the ground, their root systems being pulled out of the soil, and neighboring trees often going down with them. In extreme conditions considerable areas of raw soil or rock were exposed beneath the upturned root systems.

Indirect effects of the hurricane on the forest are less spectacular but apparently serious. Defoliation apparently was followed by sun-scalding on the limbs and their subsequent death. Loosened bark, even where the tree is not killed, can adversely affect the quality of the tree. Insects and decay can enter where breakage has occurred. Trees which lean as a result of the wind tend thereafter to produce compression and tension wood which is of little value. Forest openings created by breakage and blowdown foster the development of vines which interfere with the re-establishment of the forest.

It was necessary for this study to define what constitutes the "loss" of a tree. Many of the trees damaged are neither dead nor will they die soon. Thus "loss" refers chiefly to the removal of a tree from the productive potential of the stand. Trees which suffered only defoliation and top breakage were not considered "lost". However, those with trunks snapped off, even where part of the tree could be salvaged, were considered "lost". Also trees with sufficient lean (15%+) to adversely affect future wood production, whatever their present salvage value, were considered "lost".

1/ Op. cit.

7/ Assistance is acknowledged for part of the field work by Benjamín Seda, Jorge Rivera, and forest ranger and guards of the Commonwealth Division of Forests, Fishieries & Wildlife; and by B. J. Huckenpahler, José Marrero, Raúl Ybarra Coronado, Ramiro Agosto Ruiz, and José Reyes Mateo of the Research Center.

THE RELATIONSHIP BETWEEN DAMAGE AND SITE

Observations made on the field were grouped on the basis of five factors of the physical environment: proximity to the path of the storm center, elevation, topographic exposure, aspect, and character of the soil. Site is not subject to much practical modification by man, but relationship to damage may show limitations on potential forest yields which need to be understood.

Proximity to the Path of the Center of the Hurricane

Hurricanes normally are most active near the center and are progressively weaker toward the periphery. Thus it might be expected that forests would be damaged by hurricanes roughly in proportion to their distance from the center.

Table 2 compares damage to proximity to the path of the storm center. It is seen that no appreciable damage was recorded beyond 15 miles to the south or 27 miles to the north of the storm center. Within this range the damage shows a general tendency to increase as the path of the center is approached.

Table 2 shows certain inconsistencies in this relationship between distance and damage. At Toro Negro, for example, the damage was less than at Guajataca, yet the distance from the storm path was only two-thirds as great. In addition to general variation there was evident in the field extreme local variation, making difficult the classification of damage as shown in Table 2. At Guajataca, Río Abajo, and Cambalache severe damage was mostly in small areas or strips, suggesting both a large local variation in the susceptibility of different forest areas and the probability that there were numerous small squalls of exceptionally high velocity.

Fig. 2.—Damage to 26-year old white mangrove stand at Aguirre by Hurricane Betsy. Fifty-nine of the trees were broken or uprooted by the storm as determined by a sample plot of 621 trees.

Table 2.—The relationship between location and hurricane damage

Distance and Direction From Storm Center	Degree of Damage: Negligible	Degree of Damage: Local or Slight	Degree of Damage: Extreme or Severe	Place of Observation
Miles				
37 to 20 S	x			Guánica, Boquerón, Susúa, Maricao and Guilarte
15 to 13 S		x		Guajataca and Scout camp
10 S	x			Toro Negro
7 SW		x		Río Abajo
5 S to 6 N			x	Aguirre, Mameyes, Cacao, Cambalache and Carite
9 to 27 N		x		Vega, Monserrate, Río Piedras, Luquillo, and St. Just
31 N	x			San Juan

The relationship between damage and distance from the center of Betsy would not necessarily be applicable to other hurricanes. The radius of the damaged area could vary greatly with the severity of the hurricane.

Elevation

Forest damage might be expected to show a relationship to elevation, yet the data do not bear this out. Although several areas at high elevation were severely damaged, such as Mameyes (1,600 ft.), Cacao (2,000 ft.), and Carite (1,800 ft.), others near sea level and no closer to the storm center, such as Aguirre (sea level) and Cambalache (100 ft.), were equally damaged. On each side of the path the most distant areas with reportable damage, Guajataca and St. Just, are both below 500 feet elevation. Within the Luquillo forest, where elevation ranges from 400 to 3,500 feet, damage did not increase with elevation.

Topographic Exposure

Most of the areas studied are rough in topography and afford within short distances an opportunity to compare the damage under different degrees of exposure and aspects.

On the limestone hills of the north coast damage was found both on the exposed hilltops and in the protected areas between the hills. A count of trees broken off or windthrown at Cambalache showed that of 834 trees on a hilltop 26 percent were lost, whereas of 1,445 trees on the adjacent slopes 21 percent were lost. Browned leaves and defoliation were chiefly confined to hilltops and exposed upper slopes, suggesting that the surviving trees there withstood more wind than those remaining in more protected areas. Nevertheless, on a few exposed slopes at Guajataca all vegetation was removed.

Evidence from other parts of the island supports the observation that trees on exposed hills and ridges withstood the winds at least as well as on slopes and in valleys. In the northern part of the Luquillo forest damage on the ridges was limited to defoliation, yet near the bottom of the deep Mameyes Valley windthrow was locally severe. At Mameyes, in the central mountains, damage was most severe on concave slopes protected from normal winds. At Cacao the most extensive damage seen in the mountains, about 300 acres with nearly every tree windthrown, was located in a deep valley.

Whereas the susceptibility of the forest to wind damage may not have been proven greater in the valleys than on the ridges, there can be no question but that the economic loss in the valleys is by far the most important. Lower slopes and valleys usually bear better stands than upper slopes and ridges, both as to quality of species, and tree form and height. The loss of these better trees may be in terms of sawtimber, either actual or potential, whereas on the ridges the trees generally contain only posts, poles, or short logs. This relationship is particularly sharp at Luquillo, St. Just, and Río Abajo, where potentially valuable plantations in the valleys suffered yet natural forests on the upper slopes, where little investment had been made, were much less affected.

Aspect

West Indian hurricanes are described as areas in which the general wind direction, as visualized on a map, forms a counterclockwise spiral about the center. Thus any area in the hurricane zone can be expected to experience, sooner or later, winds of hurricane force from all directions. An area directly in the path of the center should receive winds in one direction which gradually strenghten in violence and then a complete reversal of direction and gradual reduction in force. Areas affected but not in the path of the center experience winds which may gradually shift 90 degrees or more. Considering the direction of the drift of Betsy across the island, areas directly in the path of its center might be expected to receive north and south winds; areas to the north of the path, southeast to northeast winds, and areas to the south of the path northwest to southwest winds.

Observations in the field, which included the prevailing direction of windfallen trees, generally bear out this description. Areas lying in the path of the center were affected mostly by those winds which preceded the eye of the storm. Other areas were affected chiefly by winds from the direction to be expected when the storm center was closest. The significance of wind direction to damage was especially apparent on opposing slopes.

To the north of the path the damage was due mostly to easterly winds. At Luquillo defoliation was chiefly on east-facing slopes in watersheds draining north and east, with only the west-facing slopes entirely unaffected. At Vega defoliation was also apparent only on the east-facing upper slopes. At Carite damaging winds ranged from east to northwest. Defoliation at Cambalache was chiefly in areas exposed to the east and north, yet in number of trees destroyed the west slope suffered more heavily (30%) than the east (11%). From Cambalache to Arecibo the north-facing slopes showed most defoliation.

To the south of the path the damaging winds were mostly westerly. At Guajataca northwest winds damaged the north- and west-facing slopes, whereas those facing south were intact. At Toro Negro blowdown was caused by northwest winds also. At Aguirre windthrow was chiefly toward the east, indicating that the damaging winds were from the west. At Cacao, only 2 miles from the center, trees were blown down regardless of aspect, indicating destructive winds from several directions.

Soil

The forests in which hurricane damage was studied cover a wide range of soil conditions, some of which might well be significant to the resistance of trees to windthrow. In areas where windthrow was serious it is clear that anchorage of the trees in the soil was deficient. Where damage is due to breakage rather than windfall, anchorage might be considered adequate.

The soil characteristic most significant to damage might be expected to be soil depth, since trees with shallow roots could be expected to have less anchorage than those deeply rooted. However, the observations do not bear this out. At St. Just the forest on the shallow soils of the slopes was undamaged, yet serious uprooting took place in a comparable stand on the deep soils of the bottomland. In the Luquillo Forest damage on shallow soils was nearly all breakage. On the shallow soils on the limestone hills at Guajataca, Vega, Río Abajo, Cambalache, and the Scout Camp breakage was far more serious than uprooting, and in many places neither was important. Adjacent to these hills at Guajataca and Río Abajo the forests of deep soils suffered serious damage, chiefly due to uprooting. An exception was found at Cambalache where breakage was also most important on the deep soils of the bottomland. The factor responsible for this resistance to windthrow on shallow soils may well be anchorage of the roots in cracks and other openings in the upper layer of the parent rock.

Normal available moisture in the soil, unlike soil depth, appears to be very significant to tree anchorage. The most serious damage due to uprooting was on deep soils where moisture is normally abundant, and particularly where protection from the normal trade winds further favors moist conditions. Outstanding losses under these conditions, not shared by adjacent forests in less moist or protected locations were found at Luquillo, Carite, St. Just, Mameyes, Cacao, Guajataca, Río Abajo, Cambalache, and Aguirre.. The Luquillo forest, normally 50 percent more rainy than all other forests studied, suffered more damage than some other forests much closer to the path of the storm center. The relationship described here is further supported by the small root systems of the trees blown over. It would appear that under conditions of abundant moisture and protection from prevailing winds the top-root ratio of the trees increases to a point which reduces capacity to withstand exceptional winds.

THE RELATIONSHIP BETWEEN DAMAGE AND THE CONDITION OF THE FOREST

Observations on damaged forests were directed toward relationships with the structure and composition of the stands. Structure concerns the proportionate representation of different tree sizes and the density of the stand. Composition is concerned with the number and the identify of the species present. These conditions, unlike those of site, are subject to control and might be materially modified if suggested by differences in the susceptibility of different types of stands. The stands observed varied from those with all trees of the same young age and of only one or a few species to the very old uneven-aged forests with 30 or more species per acre such as originally covered most of Puerto Rico.

Structure and composition in Puerto Rican forests vary together to such a degree that it was not possible to isolate entirely either of them in order to relate damage to it. Stands which are even-aged in structure are almost everywhere pure in composition and stands which are all-aged are generally mixed. Thus comparisons could be made only among even-aged pure and all-aged mixed forests. Within these two conditions it was possible to make a few comparisons in young and old and in dense and open stands and to different individual tree species.

All-aged Mixed vs. Even-aged Pure Stands

There was a general difference in the character of the damage in all-aged mixed stands as compared with even-aged pure stands. In all-aged stands there was a range of susceptibility of individual trees within the stand, due apparently to inequalities in the degree of exposure of each tree and also, to a lesser degree, to species characteristics. Thus dominant, exposed trees generally suffered more than those subordinate in the canopy. This relationship was observed at Guajataca, Cambalache, Río Piedras, Luquillo, and St. Just.

In even-aged pure forests damage was far less selective than in all-aged mixed stands. Forests of this character, if damaged at all, generally suffered severely, apparently because all trees were so similar as to be about equally susceptible. Extensive damage of this type was suffered by even-aged pure forests at Guajataca, the Scout Camp, Río Abajo, Toro Negro, Aguirre, Mameyes, Cacao, Cambalache, Carite and Luquillo.

The extreme character of such damage to even-aged forests is apparent in a number of areas where data were taken. The most extensive devastation seen in even-aged pure stands was in coffee shade at Cacao. There in an area of 300 acres almost every tree was windthrown. At Aguirre a sample of 621 trees in an area of several hundred acres of 26-year-old (4 to 12 inches d.b.h.) natural forest showed 59 percent of the trees lost.

Pure forest plantations also suffered heavy losses in several areas. In the Luquillo forest one 19-year-old plantation (5 to 10 inches d.b.h.) was reduced from 600 to 12 trees per acre; another from 960 to 128. At Carite a 15 year-old plantation (6 to 15 inches d.b.h.) was reduced from 380 to 20 trees per acre, and an 18-year-old plantation (6 to12 inches d.b.h.) from 202 to 2 trees per acre. At Río Abajo an 18-year-old plantation (6 to 11 inches d.b.h.) was reduced from 293 to 30 trees per acre.

In a few areas it was possible to compare within close range the degree of damage suffered by all-aged and even-aged forests. Although it was frequently difficult to classify the severity of the damage, an attempt was made in Table 3. There it is seen that among the stands studied even-aged stands everywhere suffered as heavily as all-aged stands, and generally more so.

Age of Trees and Stands

Few direct comparisions were possible between old and young trees subject to similar exposure. It has already been pointed out that the larger (and presumably older) tress in all-aged forest are generally more affected than the subordinate trees. However, this appears to be due chiefly to greater exposure, rather than age. That advanced age is not alone an important factor in susceptibility is apparent in the many old trees on exposed ridges and slopes on the mountains, some of which must have survived dozens of hurricanes.

Table 3.—Comparative Damage in All-Aged and Even-aged Forests.

	Degree of Damage[1]		
	Negligible	Local or Slight	Extensive or Severe
Toro Negro	A	E	
Guajataca		A	E
Río Abajo		A	E
Carite		A	E
Cambalache			AE

1/ A - all-aged mixed stands; E - even-aged pure stands.

A contrast between damage to young and old forests was apparent at Aguirre. There, as has already been described, a 26 year-old even-aged forest suffered extensively, more than half of the trees being eliminated. In the midst of this area a 3-year-old stand of trees 12 feet tall was unharmed.

At Luquillo the greater resistance of young trees was also apparent in plantations of eucalyptus (*Eucaliptus* spp.) There 12 year-old plantations (4 to 10 inches d.b.h.) lost 15 to 40 percent of their trees, whereas 5-year-old plantations (1 to 3 inches d.b.h.) remained undamaged.

Stand Density

No observations were made in natural stands which were alike except for density. However, the effect of the hurricane in adjacent thinned and unthinned stands could be compared at Cambalache and at the Scout Camp. At Cambalache a 6-year-old plantation of teak (*Tectona grandis* L.) 3 to 4 inches d.b.h. had been thinned about 6 months before the hurricane. The results are shown in Table 4.

The greater hazard created by heavy thinning is apparent in Table 4. Of the trees lost, about 35 percent were broken off, 5 percent were uprooted, and 60 percent were tipped or bent permanently. Those left standing were not only defoliated but had been so whipped by the wind that much of their bark was stripped off or hanging in loose shreds. All tree areas have made a remarkable recovery. After cutting off the trees considered lost, the stumps have produced sprouts which in the larger openings provide a satisfactory replacement stand. Bark stripping on the trees left proved to be less serious than anticipated as new bark was formed over all wounds.

Another similar result from thinning was observed at the Scout Camp in an even-aged pure stand of guaraguao (*Guarea trichilioides* L.) averaging 6 to 10 inches d.b.h. A portion of this stand thinned from 100 to 80 square feet of basal area per acre 9 months earlier suffered crown breakage in more than 50 percent of the trees whereas nearby unthinned stands suffered only slightly.

The most seriously damaged plantation at Río Abajo had been heavily thinned only months before the hurricane. This plantation, 18 years of age and ranging from 6 to 11 inches in diameter, had been thinned from about 100 to 40 square feet of basal area.

Table 4.—Teak Losses at Cambalache

Basis of measurement	Number per acre by degree of thinning		
	Heavy	Light	None
Before Hurricane			
All trees	380	620	785
Crop trees	100	100	100
Basal area, sq. ft.	28	42	53
Losses			
All trees	180	65	45
Crop trees	60	35	25

The hurricane reduced it from 293 to 30 trees per acre. Damage in comparable adjacent plantations, while substantial, was less severe.

Tree Species

Observations already described have indicated variation in the susceptibility of forests to damage related to site and general stand conditions. Most of these observations are confounded in some degree with differences in the tree species present. Now, looking at it the other way, which tree species, other things being equal, showed the greatest susceptibility or resistance to the hurricane?

Variations in sites and stand conditions from place to place make difficult true comparisions of the susceptibility of different tree species to hurricane damage. However, it is apparent in Table 5, which presents data from a single location, that real differences do exist.

Indications of relative susceptibility were evident in other forests where individual species suffered either much more or much less than the general run of the forest. Where this relationship was observed under more than one condition the indication is especially strong. The results of these observations are summarized in Table 6. In this tabulation susceptible species are classified as subject primarily to windthrow (anchorage weaker than the stem) or to breakage (stem weaker than anchorage). Resistant species apparently have neither deficiency.

Table 5.—Damage to Different Tree Species on a West Slope at Cambalache

Trees Species	Percent Lost	Trees Examined
	%	No.
Sanguinaria (*Dipholis salicifolia* [L.] A.D.C.)	5	22
Uvilla (*Coccoloba diversifolia* Jacq.)	8	37
Almácigo (*Bursera simaruba* [L.] Sarg.)	18	17
San José (*Sabinea florida* [Vahl.] D.C.)	22	55
Verde seco (*Tetrazygia eleagnoides* [Sw.] D C.)	47	106
Mameyuelo (*Ardisia obovata* Desv.)	54	85
Laurel avispillo (*Nectandra coriacea* [Sw.] Griseb)	55	58

Table 6.—Especially Susceptible or Resistant Tree Species.

Species	Where Observed
Susceptible to Windthrow	
Caoba hondureña (*Swietenia macrophylla* King)	Luquillo, Carite, Río Abajo, St. Just
Ciprés (*Cupressus lusitanica* Miller)	Luquillo, Toro Negro
Cupey (*Clusia rosea* Jacq.)	Guajataca, Cambalache
Eucalyptus (*E. robusta* J. E. Smith & *alba* Reinw.)	St. Just
Jácana (*Pouteria multiflora* [A.DC] Eyma)	Guajataca
Laurel (*Nectandra* spp.)	Río Piedras, Cambalache, Río Abajo
Mangle blanco (*Laguncularia racemosa* [L.] Gaertn.)	Aguirre
Teca (*Tectona grandis* L.)	Luquillo, Carite
Susceptible to Breakage	
Algarrobo (*Hymenaea courbaril* L.)	Luquillo
Avelluelo (*Colubrina arborescens* [Mill.] Sarg.)	Río Abajo
Bucayo (*Erythrina poeppigiana* [Walp.] O.F. Cock)	Río Abajo
Casuarina (*Casuarina* spp.)	Luquillo, Cambalache, Scout Camp
Cedro Macho (*Hyeronima clusioides* [Tul.] Muell.)	Río Abajo
Eucalipto (*Eucaliptus* spp.)	Luquillo, Carite, St. Just, Cambalache
Guaba (*Inga vera* Willd.)	Luquillo, Carite, Mameyes, Cacao Guajataca
Guano (*Ochroma pyramidale* [Cav.] Urban)	Guajataca
Guaraguao (*Guarea trichilioides* L.)	Scout Camp
Mangle blanco	Aguirre
Mahoe (*Hibiscus elatus* Sw.)	Río Abajo
Teca	Carite, Cambalache

Wind Resistant

Almácigo (*Bursera simaruba* [L.] Sarg.)	Vega
Aquilón (*Laugeria racemosa* Vahl)	Guajataca
Ausubo (*Manilkara bidentata* [A. DC] Che.)	Monserrate
Caoba dominicana (*Swietenia mahagoni* Jacq.)	Guajataca, Río Abajo
Capá blanco (*Petitia domingensis* Jacq.)	Luquillo, Guajataca, Scout Camp, Río Abajo
Capá prieto (*Cordia alliodora* [R&p.] Cham.)	Guajataca, Monserrate
Hoja menuda (*Eugenia* sp.)	Cambalache
Maga (*Montezuma speciosissima* [Sesse & Moc.] Dubard)	Río Abajo
Mangle colorado (*Rhizophora mangle* L.)	Aguirre
María (*Calophyllum braziliense* Camb.)	Luquillo, Carite, Guajataca, Scout Camp, Río Abajo, St. Just
Moca (*Andira inermis* [W. Wright] H.B.K.)	Guajataca
Roble (*Tabebuia heterophylla* [DC] Britton)	Guajataca, Río Abajo, Luquillo, Carite

Table 6, in presenting exceptional species, undoubtedly includes only a few of those which might, with more observations or hurricane force, be so classified. Species found only near the path of the storm, located only on susceptible sites or in even-aged plantations probably showed failings which may be equally characteristic of but less evident in species not so located. Thus, although all-aged forests are much more extensive than even-aged, some 60 percent of the ratings were based upon even-aged forests.

Considering the proportion of native and exotic tree species exposed to the hurricane the number of susceptible exotics was high. Of those species susceptible to windthrow only cupey, laurel, and mangle blanco are native species in natural forests. Those susceptible to breakage include the following natives in natural environment: algarrobo, avelluelo, cedro macho, and guano. Nevertheless a few planted species, such as caoba dominicana, maría, and roble proved resistant.

CONCLUSIONS

1. Serious forest damage in Puerto Rico due to Hurricane Betsy was confined to an area within about 6 miles of the path of the center. Damage was negligible beyond 15 miles southwest and 27 miles northeast of the path.

2. Damage was as serious on sites protected from normal winds as on those exposed.
3. Forests on slopes are subject to the hazard of hurricane damage regardless of aspect.

4. Forests on shallow soils have not proven to be less windfirm than those on deep soils.
5. Uprooting of trees, indicating poor anchorage, is a common form of hurricane damage on soils which normally are very moist or wet.

6. All-aged mixed forest frequently suffer from slight and selective hurricane damage; even-aged pure forests generally suffer either no damage or very serious damage.
7. Heavy thinning of forests is conducive to susceptibility to wind damage.
8. Different tree species vary to a significant degree in their susceptibility to windthrow and breakage from hurricanes.