<u>Hurricanes and the Forests Of Belize</u>

Forest Department

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Jon Friesner

1.0 Introduction

Belize is situated within the hurricane belt of the tropics. It is periodically subject to hurricanes and tropical storms, particularly during the period June to July (figure 1).

This report is presented in three sections.

- A list of hurricanes known to have struck Belize. Several lists documenting cyclones passing across Belize have been produced. These have been supplemented where possible from archive material, concentrating on the location and degree of damage as it relates to forestry.

- A map of hurricane paths across Belize. This has been produced on the GIS mapping system from data supplied by the National Climatic Data Centre, North Carolina, USA. Some additional sketch maps of hurricane paths were available from archive material.

- A general discussion of matters relating to a hurricane prone forest resource.

In order to most easily quote sources, and so as not to interfere with the flow of text, references are given as a number in brackets and expanded upon in the reference section.

Summary of Hurricanes in Belize

This report lists a total of 32 hurricanes.

1.1 On Hurricanes and Cyclones (from C.J.Neumann et al)

Any closed circulation, in which the winds rotate anticlockwise in the Northern Hemisphere or clockwise in the Southern Hemisphere, is called a cyclone. Tropical cyclones refer to those circulations which develop over tropical waters, the tropical cyclone basins. The Caribbean Sea is included in the Atlantic tropical cyclone basin, one of six such basins. The others in the Northern Hemisphere are the western North Pacific (where such storms are called Typhoons), the eastern North Pacific and the northern Indian Ocean. The Southern Hemisphere basins are the southern Indian Ocean and the southwest Pacific-Australian area.

Tropical cyclones differ in their characteristics from those forming outside the tropics known as extratropical cyclones. They derive their energy from the latent heat of condensation of water vapour not from large-scale horizontal contrasts of temperature and moisture, and are generally smaller in extent, typically ranging from 100 to 600 nautical miles in diameter at maturity. Winds normally increase towards the centre of the storm and rotate around the "eye", a unique feature of tropical cyclones, where winds are typically light and cloud cover and sea-level pressure minimal. The diameter of the eye usually averages 10 to 30 miles across. Tropical cyclones pass through three stages of development, intensification, maturity, and decay or modification. After formation dissipation occurs on average 7 to 8 days later, or when storms move overland and away from the sustaining marine environment.

During these final stages tropical cyclones take on extratropical cyclone characteristics. The size of the circulation usually expands, the speed of the maximum winds decreases, and the distribution of winds, rainfall, and temperatures around the centre become increasingly asymmetric. However some tropical characteristics such as a small area of strong, often hurricane-force, winds near the centre and heavy rainfall may be retained for a considerable time. Those cyclones which develop over sub-tropical waters and exhibit a hybrid of tropical and extratropical characteristics are classed as subtropical cyclones. Many of these develop further and become purely tropical systems.

Further classification of tropical cyclones depends upon the wind speeds near the centre of the system. Sustained surface winds of less than 34 knots define a tropical depression, those between 34 and 63 knots inclusive a tropical storm and those greater than 64 knots a hurricane. These refer to the average wind speed taken over a minute. Winds may drop below this figure, or gust above it. Storms are named if of tropical storm or hurricane strength. As winds of gale or even storm force only cause negligible damage to trees (11) this report was focused on the effects of hurricane force winds.

Information on hurricanes is anything but comprehensive. The earliest hurricanes were not fully reported or documented. The detection of early storms was dependent upon chance encounters with shipping or populated areas. While it is unlikely that major storms went undetected their exact locations or intensities cannot be fully specified while smaller sized storms could have been missed. Since the turn of the century there has been a steady advance in the techniques used to monitor hurricanes. For example the introduction of aircraft reconnaissance after 1944 and continuous weather satellite surveillance since the mid-sixties. Figure 2 summarises some important advances.

The wind speeds used to classify tropical cyclones can rarely be recorded precisely. Maximum wind speeds are often inferred from indirect evidence, and a final wind speed is assigned after considering all sources.

The that the hurricane tracks identified in this report represent estimates of the path of the eye across the earths surface. They represent the overall motion of the storm as best identified by the information available. The exact location of the path may have deviated considerably from this (between 5-20 nautical miles). An impression of the hurricane path is important. Damage is centred around this point. For example after hurricane Hattie it was found to be very severe within 10 to 15 miles of the centre line and severe between 15 and 30 miles of the centre line (3).

However despite these shortcomings it is possible to produce an approximate picture of historical hurricane damage.

2.0 Hurricanes in Belize

1785 (2).

1787 2nd September. Settlement of Belize completely destroyed (3,4). The sea level at the entrance to the Belize river was reported to have risen 7 or 8 feet, flooding the settlement. First major hurricane on record, compared in intensity to hurricane Hattie (1).

1805 (2).

1813 1st August. Hurricane struck belize city (1,2).

1813 25th August. No details (1,2).

1827 19th August. Hurricane at Belize; St.George's caye flooded on 20th August (1).

1831 Probably a minor hurricane, between Belize and Chetumal (1).

1864 31st August. Hurricane at Belize city. The eye passed over the town itself and the sea rose 5 feet causing widespread flooding (1).

1883 (4).

1893 6th June. Severe damage to Belize city (1) and in the southern districts great damage was inflicted on crops and forests (2).

1902 20th June. A minor hurricane in the Belize area (1).

1915 15th October (1).

1916 1st September. Minor hurricane in the Chetumal area (1).

1918 25th August. Minor hurricane in the Punta Gorda area (1).

1920 16th October. Hurricane struck the northern part of the colony. The sea at Corozal and Payo Obispo receded for several miles (1).

1931 10th september. This hurricane passed over Belize city but was reportedly not felt 18 miles south at gales point (4). Belize was flooded by a storm surge 5 to 15 feet high (1). Maximum wind speeds of 132 mph were recorded after which the wind gauge at Belize collapsed under strain (2). Average daily maximum wind speed near the storm centre was 100 mph, the storm crossing inland approximately 25 nautical miles to the northeast of Belize International Airport (18). It damaged the forests within a belt of about 50 miles (4). Pine forest near to Belize were practically destroyed and great damage was done to other pine areas within its path (6). Mahogany and other hardwood forests were also damaged, especially in the coastal areas. Further inland damage to mahogany was not severe (6). Considered to be a major hurricane.

1934 5th and 8th of June. Tropical storm passed the Belize coast north of Belize city, moved into Peten, swung south into the Montagu lowlands, out into the Gulf of Honduras near Puerto Barrios. It then travelled north along the barrier reef, again passing close to Belize city (1).

1941 28th September. Stann Creek District. Long criss-crossing swathes of damage to improved Mahogany forest in the Silk Grass reserve. Between these lay islands of comparatively little damage. The tops of the ridges in the most level portions of the reserve were the most badly hit. The forest on the south-east face of the hills lying to the northland west were very badly damaged. Many large trees and tall poles survived undamaged in otherwise badly damaged areas. About 10% of the larger pines in the Melinda area to the north of the Silk Grass forest reserve were blown down but the younger poles and regeneration were not badly damaged (6). In the Silkgrass reserve some damage was done to the Mahogany, about 15% of poles being blown down, with the major damage occuring in the 'improvement areas' where the natural regeneration of Mahogany was being promoted (6). Average daily maximum wind speed near the storm centre was 70 mph, the storm crossing inland approximately 68 nautical miles to the south of Belize International Airport (18).

1942 Summer. Toledo District. Destruction reached well into Guatemala to a point 85 miles inland from the coast. More than 75% of the large trees growing on the clay soils of the lowlands were overturned (including almost all the remaining mahogany). On the limestone soils most trees survived, including those in the main track of the storm (4).

1942 November. Struck the northern half of Belize. The hurricane track passed over Freshwater Creek Forest Reserve. Southern boundary of new damage overlapped the northern boundary of the damage from the 1931 storm (4). Corozal Town, Sarteneja, Caye Caulker and Ambergris Caye were hit (2). The centre of the storm appeared to have extended from Bomba, and Maskall on the Northern river, Shipyard (New River) and Los Bocas (River Hondo) on the south and Shipstern, New Home (freshwater Creek), San Estevan (New river) and Santa Cruz (River Hondo) on the north (6). The width of the storm damage apparently decreased as the hurricane advanced inland. A survey after the storm showed that more than 75% of the canopy species had been destroyed. The low bush was not badly damaged, but about 25% to 50% of the pine were blown. Damage on deep soils was largely from breakage while on shallow soils mostly from wind throw (6). Average daily maximum wind speed near the storm centre was 80 mph, the storm crossing inland approximately 25 nautical miles to the north of Belize International Airport (18).

1943 A storm during the early 1940's, possibly 1943. Affected the southern Maya Mountains and said to have created the broken ridge forest adjacent to the Machaca Pine plantation. It could however be the same as the 1942 summer storm (4).

1945 October 3 (18). Struck the southern part of half of the country from Monkey River southwards in a southwest direction (6). Crossed the coast between the mouths of the Temax and Sarstun rivers (4). Damage estimated to have been as great as that to the northern districts in the 1942 hurricane (6). Continued to cause forest damage until nearly 40 miles inside the Guatemalen border, in the basin of the Rio Machiquila (4). Average daily maximum wind speed near the storm centre was 70 mph, the storm crossing inland approximately 68 nautical miles south southeast of Belize International Airport (18).

1955 27th September. Hurricane 'Janet'. Struck the northern half of the Country, the winds mainly from the northwest (6). Corozal Town was hit squarely as the eye passed over it. Winds were recorded at over 175 mph (2). It was accompanied by torrential downpours and flooding of many northern districts, but there was little flooding from the sea except in Sarteneja where the water is reported to have risen by 8 feet (5). Caused serious and widespread damage to mahogany and chicle forest. The Freshwater Creek, Xcanha and Honey Jip Camp Forest Reserves were badly blown while the Maskalls Forest Reserve was slightly damaged (4). In Freshwater Creek all mahogany seedbearers which survived the 1942 hurricane were badly damaged and some blown down (4), while all small mahogany trees and about 1000 mature trees (20% of total) were blown down (5). Some 3000 Sapodilla trees (10% of total) in the reserve destroyed. The 80% of mature trees remaining although without leaves or fruit and having broken limbs were expected to recover (5). This latest damage compounded on damage from the 1942 hurricane and with the effects of accidental fires and over-exploitation of the forrest. Those forests owned by the Belize Estate and Produce

Company Limited in the south and south-western sector of the Orange Walk District were largely undamaged (4). Average daily maximum wind speed near the storm centre was 160 mph, the storm crossing inland approximately 61 nautical miles to the north of Belize International Airport (18).

1960 July 15 (18). Hurricane 'Abbie'. Small but intense. Crossed the coast between Stann Creek and Monkey River in the south. Damage to the forest was minimal (4). Average daily maximum wind speed near the storm centre was 70 mph, the storm crossing inland approximately 60 nautical miles to the south of Belize International Airport (18).

1961 July 24. Hurricane 'Anna'. Average daily maximum wind speed near the storm centre was 70 mph, the storm crossing inland approximately 44 nautical miles to the south southwest of Belize International Airport (18).

1961 31st October. Hurricane 'Hattie'. Struck at a time normally considered well past the hurricane season and was the severest storm in living memory. Estimated wind speeds of between 150 and 230 mph. Its centre affected the Belize District with gales extending 200 miles to the north and 140 miles to the south. Its path swept across the entire width of the country from the north-east into the Maya Mountains and on into Guatemala. The eye passed between St.Georges Caye and the Turneffe Islands striking the coast near Mullins River. It passed over Melinda, Silkgrass Grant's Works, Commerce Bight and Mango Creek Forest Reserves as well as the Cockscomb Basin in the Stann Creek District. In the Toledo District, the Swasey Bladen, Deep River and Columbia Forest Reserves were affected while the Mountain Pine Ridge and Chiquibul Forest Reserves in the Cayo Districts were hit (3). Severe damage extended along a belt 80 km wide and light damage a belt 100 km. Strong gales affected the whole country (4). The edge of the storm appeared to have passed along the Belize Cayo road in the north and on a line from Blair Atholl southwest to south of the Quartz ridge. There was a decreasing "fringe" area of about 10-15 miles both north and south (7).

Tides of some 10 to 11 feet were measured along the Belize water front, while storm tides of 14 to 15 feet around the storms centre. Total rainfall during the passing of the storm was 7.66ins (14). Average daily maximum wind speed near the storm centre was 120 mph, the storm crossing inland approximately 25 nautical miles to the south southeast of Belize International Airport (18).

It was estimated that of 4076 square miles (total forest area), 1350 square miles of forest was damaged and 1650 square miles of forest was severely damaged. A 30 mile wide strip of forest was severely damaged by the eye of the hurricane, and damaged forest lay along two bolts each 15 miles on either side of the path. In the severely damaged bolt about 60% of the trees had been blown down. Little but the trunks remained of the 40% which were left standing (8). It was most severe along the coastal plain, and very severe between Mullins River and Stann Creek where there was 90% wind throw of large trees. Further south the degree of damage lessened. In the Riversdale-Blair Athol area many of the susceptible trees had been felled by hurricane 'Abbie' the year before and the worst damage in the south was in the forests south of the Swasey Branch of Monkey River where there were pockets of 80% damage. The Mountain Pine Ridge Forest Reserve was largely protected behind the Cockscomb and Maya Mountains Ranges. The upper Sibun and Macal Valleys were severely damaged with whole hillsides suffering 90% windthrow (3).

1969 3rd September. Hurricane 'Francelia'. Average daily maximum wind speed near the storm centre was 95 mph, the storm crossing inland approximately 78 nautical miles to the south of Belize International Airport (18).

1971 10th September. Hurricane 'Edith'. Average daily maximum wind speed near the storm centre was 90 mph, the storm crossing inland approximately 25 nautical miles to the northeast of Belize International Airport (18).

1971 20th November (18). 'Laura'. In the Stann Creek Valley damaging the Melinda plantations (4). Average daily maximum wind speed near the storm centre was 60 mph, the storm crossing inland approximately 39 nautical miles to the southeast of Belize International Airport (18). Referred to as a hurricane by BTFAP (4) but a Tropical Storm by C.J.Neumann et al. (17).

1974 1st September. Hurricane 'Carmen'. Damage to the northern district of Corozal (2). Track passed just north of Belize (4). Average daily maximum wind speed near the storm centre was 110 mph, the storm crossing inland approximately 70 nautical miles to the north northeast of Belize International Airport (18).

1974 19th September. Hurricane 'Fifi'. Hit the Coast at Placencia Village affecting communities of Seine Bight, Big Creek, Mango Creek and Independence (2). Average daily maximum wind speed near the storm centre was 95 mph, the storm crossing inland approximately 61 nautical miles to the south southwest of Belize International Airport (18).

1978 18th September. Hurricane 'Greta'. Dangriga pounded by 120 mph winds (2). Centre passed slightly north of Dangriga and the main core of the hurricane entered the Stann Creek Valley which took it just south of Middlesex and across the Mountain Pine Ridge area, thence into Guatemala (9). Belize also buffeted by strong winds with water rushing over the sea walls at a hight of five feet (2). At Belize Weather Bureau the highest sustained winds were 55 mph. Dangriga was spared the associated hurricane tides. Belize suffered a tidal increase of 2 to 4 feet (9). Average daily maximum wind speed near the storm centre was 110 mph, the storm crossing inland approximately 27 nautical miles to the south of Belize International Airport (18).

3.0 Discussion - Hurricanes and Forestry

Hurricanes can impact on a forest system in several ways. Several factors can combine to influence the type and extent of storm damage. Factors relating to the storm, the soils and topography of the area and the forest vegetation itself.

3.1 Factors relating to the storm.

The wind speeds associated with a hurricane, often used as a measure of the storms intensity, can be used as a measure of the extent of the level of damage to the forest. However to consider the maximum wind speed alone can be misleading and it is useful to also include the average wind speed (usually measured as an hourly rate), often half this figure. Persistently strong winds weaken a tree to a point where a strong gust is then able to cause serious damage (11). The length of time over which such winds persist is therefore an important factor when considering the extent of damage. Longer storms cause greater damage.

Additionally the winds of a cyclone keep changing direction, especially either side of the eye where they may rotate through 180 degrees, whereas the winds of other storms may be strong but more constant in direction (11).

Local topography may also result in unpredictable and asymmetric wind patterns. Damage would be expected to be greatest on exposed ridges rather than sheltered valleys, although in some instances winds may be funnelled through valleys causing severe damage. Small 'off-shoot' cyclones or eddies could cause damage in what would otherwise be sheltered conditions (22).

3.2 Factors relating to the soil.

The depth and character of the soil can influences the type and extent of hurricane damage. After the 1942 november hurricane it was noted that in deep black soils the larger trees were broken off, damaging and smashing the small vegetation, while on the shallow red soils most of the trees were uprooted (6). The influence of soil depth was also noted by Neil and Barrance (22). This may influence the value of salvaged timber since a snapped or broken tree is generally of less commercial value than an uprooted tree, especially where markets for small piece sizes are limited. It is important to be able to process the small irregular inputs in the form of thinnings and larger pieces that can be salvaged from cyclone damaged forest.

Shallow rooting species appear to be more likely to be uprooted than deep rooting species, these species being more susceptible to wind break. Similarly in soils which allow for good roots to be established trees would more likely be snapped while in those that restrict root growth trees would be thrown (27).

King et al. (1993, unpublished, 19) produced a classification of rooting conditions for the soils of Belize (0 represents the most favourable rooting conditions while 7 the poorest).

0 - no impedance to rooting (deep soil), would tend to be a sandier soil.

1 - firm to compact soil.

2 - less than 50cm to berock (shallow soil).

3 - very stony.

4 - shallow and very stony or compact.

5 - 25 to 50cm to bedrock.

6 - 10 to 25cm to bedrock, or extremely compact soil for less than 60cm.

7 - surface gravel to bedrock or ferricrete at surface.

Using this system the rooting conditions across the country could be mapped (figure x).

High levels of rainfall will also act to increase the intensity of wind damage to make it higher than perhaps wind speeds alone might suggest. High soil moisture content has been linked to reduced root support with sites subject to high rainfall being susceptable to storm damage (25). Damage may be greater if a storm brings exceptionally heavy rains (25) or if soils are waterlogged (22). Rainfall figures of over 20" are frequently recorded during a wet cyclone (11).

Associated features of cyclones include torrential rains, storm tides and an increase in the hight of standing water (10). Reduced tranpiration rates following the loss of vegetation cover can increase the risk of flooding after heavy rains (20). The loss of forest cover increases the risk of land slide in steeply sloping areas after heavy rainfall and also the risk of flash floods. In 1962 aircraft were used to trace flood waters back to their source and a connection was shown to areas denuded by the 1961 hurricane (3). Erosion was noted on the steeper slopes of the Maya and Cockscomb ranges while the upper reaches of the Sibun River were especially bad (3). However in a letter to the Forestry Department in Trinidad in 1963 (13), A.L.Wolfsohn, the then Conservator of Forests, remarked that in Belize such erosion was not a significant problem. That within the Mountains erosion occurred only on very steep slopes (>60%), normally starting at places where trees had been uprooted or where the complete destruction of the canopy trees coincided with slopes exceeding 200%. This despite the sandy mountain soils and rainfall exceeding 150" per annum with showers frequently over 2" in any 12 hour period. He also noted that eroded areas were fairly rapidly colonised by bracken while heavy growth of coppice and vines occurred all over the devastated forest. Reforestation was not therefore attempted except for an unsuccessful attempt at seeding pine from the air in an area burned in 1962. Failure was believed to be due to the seed being too old (13).

3.3 Factors relating to the forest vegetation.

Abnormally high winds which may cause wind throw, wind break, defoliation or internal damage to a tree (3)

Rot often provides points of weakness which high winds can exploit (11,12,22,23). Rotten roots can promote windthrow while rotten stems or branches wind break. Many of the pine trees broken by Hattie were badly infested with cocayo (rot and termite),(12). Rot can be induced subsequent to branch breaks, weakening trees to have survived the hurricane. "Shaking" can cause dislocation of the cambium in either roots or stems resulting in death (11). Internal damage may also make the tree liable to fungus and termite attack later (3). Although often rotting trees are often of limited commercial value (12) the rotting of damaged but otherwise salvageable timber post hurricane could be a significant problem. Species differ in their susceptibility to rot and to insect and fungal attack (24). Increases in populations of Bark beetles in the pine plantations of Jamaica after hurricane Allen (23) promted the burning of windblown trees in an attempt to protect undamaged plantations. However beetle numbers were only reduced by an estimated 48%. Several reports document rises in beetle populations after storm damage and large numbers of broken stems and exposed stumps could promote the rapid spread of fungal infections (23).

When post hurricane damage has been more closely examined, damage has often been found to vary amongst individuals of different ages and sizes. At what stages of development a species proves vulnerable depends on the species in question. Records of the 1942 hurricane noted that where soils were shallow the mahogany trees left standing were mostly of medium to small size with comparatively thin crowns (6).

What would appears to be of over riding importance is that species vary in their resistance to hurricane damage. Studies of hurricane damaged forest have given some insight into the differing characteristics of several tree species, although comparisons are not definitive. Differences may have been masked or even exaggerated by additional factors such as uneven winds or differences in local topology, however they do provide useful information. In the case of the most severest cyclones however no species can be considered entirely immune to damage.

<u>Pine</u> - *Pinus caribaea*

Experience of the 1961 hurricane (summarised by Lindo) seemed to suggest that natural pine forests suffered less damage than hardwood forests. It is possible they offered less resistance to the wind and being more open the trees that broke or fell did not usually damage adjacent trees (12). Creeper growth in hardwood stands assisted in dragging trees down (8). Pine also greater recuperative ability (3).

A pattern of damage to pine was observed after Hattie where mature and overmature trees were uprooted, the crowns of timber and young sized trees were snapped off and large poles and smaller trees bent almost to ground level. These younger trees subsequently straightened up (3). Most damage was to medium sized trees ,those between 8" and 12" diameter, which were neither as supple as younger trees nor as strong as the older trees (12).

It was possible to salvage more fallen timber from pine forests then hardwood forests since there was not the same mat of vegetation to impede access (12). This also ment the risk of fire was not much greater than normal (12). Quick action is important because of the risk of blue stain and pinworm effecting pine logs on the ground after three months and further risk of rot which will render the sapwood unusable (8). Pawsey (1968) discuses the effects of these beetles in *P.Caribaea* (26).

Within pine plantations rehabilitaion involved salvaging fallen timber, clearing up the mess of fallen trees to improve access and where nescessary to straighten up trees bent over by the weight of other fallen trees (12).

The coniferous forests of Jamaica showed a similar pattern of damage (23). The mean diameter of snapped trees was less than that of windthrown trees.

<u>Hardwoods</u>

During Hattie, generally all natural hardwood forests suffered defoliation and the stripping of twigs. Close to the hurricane path only 20% of trees were left with more than half the crown intact, the remainder left with only a few if any branches. A large number of trees had broken boles or were uprooted. Larger trees were damaged but left standing while smaller trees were uprooted (3). A mass of fallen vegetation covered the forest floor making access extremely difficult.

<u>Mahogany</u> - *Swietenia macrophylla*

After the 1961 hurricane Mahogany appeared to fairly resistant to wind damage (8). Plantations included a mixture of wild species and most damage to Mahogany came from other trees falling amougst them. Otherwise trees were able to bend with the wind and partially spring back again. The most serious damage occured to the middle aged, larger trees of diameters between 9' and 15' (inches??) which were less windfirm and liable to break. Younger trees did better than other pioneer species around them (3). After just 2 weeks trees were seen to be putting on a flush of leaves.

Rehabilitation work involved the cleaning up of the fallen bush, freeing Mahogany saplings bent over by fallen trees. If a sapling was beyond saving it was possible to cut it back to a point at which it could coppice and grow into a straight tree again (12). It was also important not to fell mature trees which when recovered might again produce seed (6).

After hurricane Janet (1955) it was found in the northern hardwood forests that up to 5 years later it was still possible to exploit the blown Mahogany trees, providing they had maintained some roots in the soil. Deterioration of the timber was not excessive. It was hoped this may similarly allow for the forest to be worked for species such as Santa Maria (*Calophyllum brasiliense*), Nargusta (*Terminalia amazonia*) and Cortez. However after 5 years such timber may become increasingly vulnerable to factors such as bark beetle, pin hole borer and fungal or termite attack (7).

<u>Balsa</u> - *Ochroma limonensis.Lagopus*

Balsa was noted to have been very badly effected with almost 100% of trees suffering wind break. Its natural regeneration was poor, a point blamed on the decay of its seeds post hurricane and the lack of seed bearing trees. It appeared vulnerable at any stage of development (3).

<u>Eucalyptus spp</u>

Eucalyptus saligna plantations were effected much the same as Balsa with no trees left standing (12). Trees over 2 years old were all broken off near the ground, but they coppiced rapidly (3).

<u>*Gmelina arborea*</u>

One 7 acre plot of *Gmelina* existed at the time of the 1961 hurricane. All trees broke off at about 15 ft, the height of the surrounding bush. The timber could be easily salvaged and the stumps coppiced (3). It was thought that Gmelina would probably regenerate from seed (12).

<u>Mayflower</u> - *Tabebuia pentaphylla*

Mayflower saplings survived almost intact apart form suffering defoliation. Older trees survived moderately well (3). Resistance to fungal and insect attack moderately high and not susceptible to sap stain or pinworm (24). Rehabilitation measures were similar to those for Mahogany (12).

Teak - *Tectona grandis*

Young Teak survived well despite loosing its leaves (3) while older Teak (over 5 years) suffered badly from broken crowns and stems and some uprooting (12), breaking off rather easily (3). Young Teak needed no rehabilition while clearfelling and coppicing would appear appropriate for older Teak (12).

Langly (1963) attempted to classify the effects of hurricane Hattie on individual indigenous hardwood species in the Stann Creek District (21). The following classifications were arrived at:-

CLASS I - Spp suffering heavy damage (trees uprooted, boles broken, 50% or more of crown damaged, complete defoliation)

* Santa Maria (*Colophyllum brasiliense*)
Negrito (*Simaruba glauca*)
Yemeri (*Vochysia hondurensis*)
Waika Chewstick (*Symphonia globulifera*)

CLASS II - Spp suffering moderate damage (standing trees with less than 50% crown damaged and complete defoliation)

* Mahogany (*Swistenia macrophylla*)
Carbon (*Tetragastris stevensonii*)
* Nargusta (*Terminalia amazonia*)
Gumgolimbo (*Bursera simaruba*)
Prickly Yellow (*Zanihoxylum* spp)

CLASS III - Spp suffering light damage (trees intact or only part of crowns missing, but only effect will be slight increment loss)

* Billy Webb (*Sweetia panamensia*)
Cortez (*Tabebuia chrysantha*)
* Quamwood (*Schizolobium parahybum*)
Banak (*Virola koschnyi*)

Neil and Barrance used the experiences of cyclone damage in Vanuatu (22) to classify species in terms of their resistance to hurricane force winds:-

species	windfirmness	tendancy to snap	leaf loss
Agathis macrophylla	***	***	***

Anthocephalus chinensis	**	*	*
Cassia siamea	**	***	***
Castanospermum australe	***	**	***
Cordia alliodora	**	**	***
Eucalyptus camaldulensis	*	*	
E.deglupta	*	*	
E.torelliana	**	***	
Gmelina arborea	**	**	*
Intsia bijuga	***	**	***
Khaya invorensis	*	**	
Nauclea diderichii	***	**	**
Pinus caribaea	***	***	**
Swietenia macrophylla	***	**	**
Terminalia calamansanii	**	*	
T.ivorensis	**	*	

Experiences of tropical cyclones in Mauritius suggest wind resistant timber species include the Araucarias, *Cryptomeria japonica* and some sub-tropical Pines, such as *P.elliotii* and *P.taeda*; also *Eucalyptus tereticornis* and *Casuarina equisetifolia* (11).

3.4 Factors relating to forest management.

There would also appear from experiences of tropical cyclones in Mauritius that there is no apparent benefit in close spacing, dense stocking, mixtures and so called wind breaks. Although they may be effective when it comes to the prevailing winds they may be less so when it comes to those of hurricane force (11). Falling trees may damage those adjacent to them, a point exaggerated by dense packing. Mixtures of species are rarely equally resistant to cyclones. Hurricane damage may simply result in the removal of less resistant species and effective stocking is seriously affected (11). As was noted after hurricane Hattie the largely pure stands of Pine suffered less than the more mixed hardwood forests (3), although this was not shown to be necessarily due to the lack of mixing.

After 'Hattie' damage was found to be greater in pine plantations than in natural pine forests where trees were more closely spaced (12). This supports the conventional wisdom that thinning is detrimental to stability. Experience of hurricane damage in Jamaica (23) also suggested that within conifer plantations the number of trees snapped in the bole appeared to be inversely proportional to stocking levels except where extremes of damage occured. However fairly wide initial spacings and some degree of thinning may help to improve tree vigour. Tree vigour is essential for wind resistance (11). In the Jamaican forests where damage was extensive the trees left standing were of of lower than average diameter, but where damage was less extensive, the remaining trees had larger than average diameters (23). Heavy thinning which could provide a focus for severe damage should be avoided (11).

Much effort must also be concentrated on the need to limit the risk of fires post-hurricane. Fire appears to be the most serious post-hurricane threat due to the mass of vegetation left on the forest floor. Fires that spark up amongst the mass of fallen vegetation during a dry period will be very difficult to control, and the heat generated by such a fire could destroy the litter and humus of the forest floor thereby causing forest site deterioration (20).

Until recently damage reports have relied on site visits (often hampered by impenetrable fallen vegetation) and aerial overviews. Aerial surveys may give an exagerated estimate of damage but are useful in establishing the scale of loss ((22). Landsat TM satellite data can also be used to make a quick quantitative assesment of the degree of hurricane damage. Imagery generated from bands of the electromagnetic spectrum reflected and emitted from the Earths surface allow areas of defoliation in pine forest to be identified. Assessments of deciduous forests are more complicated as it is necessary to distinguish between natural leaf senescence and defoliation by storm force winds (16). Such a technique does not remove the need or undermine the value of site visits and detailed aerial photography, but is certainly a useful tool allowing speedy damage assessments to be made.

3.5 Conclusions

To distribute the risk of hurricane damage as widely as possible the building up of high concentrations of hurricane susceptible stands in any one area should be avoided. Also since hurricanes usually track in a generally east to west pattern, cover-types and age-classes should be distributed as evenly as practicable along a north-south axis. High concentrations of mature timber or of one or two species along the path of a hurricane would result in much more damage to the economy than the loss of a swathe representing an 'average' component of the entire spectrum of forest growth (15). Where possible rotation lengths should be short (22) and management flexable (11).(expand?)

The total loss of forest depends not only on the damaged caused by strong winds but also the speed of harvesting and the number of standing trees removed as part of the clean up excercise for silvicultural or management reasons (22).

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