Best Practice Guide for Timber Plantations in Tropical Cyclonic Areas of Queensland

June 2012

Project Partners

This guide has been prepared by Select Carbon for Timber Queensland

With help and support from:

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Disclaimer: *The Best Practice Guide for Timber Plantations in Tropical Cyclonic Areas* is based on background information that was made available, a Literature Review associated with this guide, and other reports produced by the Queensland Government and Select Carbon Pty Ltd. If you require further information or would like to see the reference list, please visit www.timberqueensland.com.au

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Introduction

Why a best practice guide?

Over the last decade severe tropical cyclones (TCs) Larry, Ului and Yasi have had devastating effects on timber plantations and plantation trial plots in the tropical Queensland region.

Climate change projections indicating that the average maximum wind speed of tropical cyclones will increase throughout the coming century in Queensland mean that there is a clear need to develop best practice guidelines to assist timber plantation investment and management decisions - particularly site and tree species selection, management (silvicultural) practices and target products.

This guide reviews the impacts of tropical cyclones on the timber growing sector of the tropical Queensland region. It aims to provide useful guidance to small and large growers on the factors that need to be considered when growing trees in this region.

The variables that have been explored in this guide include the following; tree species, plantation design, timber plantation age, location in the landscape and management (silvicultural) practices.

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Wind and Cyclones

What history tells us about tropical Queensland

To help understand how to manage timber plantations in tropical Queensland, it is important to first understand exactly what a tropical cyclone is, along with its frequency, wind speed and effects on the natural environment.

Definition of a Tropical Cyclone (TC):

The Bureau of Meteorology (BoM) defines a cyclone as a low-pressure system of tropical origin, in which ten minute mean winds of at least gale force (63 km/h) occur, the belt of maximum winds being in the vicinity of the system's centre.

In Australia, tropical cyclone intensity is described in terms of categories ranging from 1 (weakest) to 5 (strongest), and is related to the maximum mean wind speed. A severe tropical cyclone (Category 3 and above) is defined as a cyclone with maximum wind gusts of 164-225 km/hr with very destructive winds.

Bureau of Meteorology (BOM) Resources:

The Australian BoM has a wealth of resources available on the nature and history of tropical cyclones, including:

- Historical cyclone reports
- Maps and other resources

On average, the tropical cyclone season begins in late November and continues through to April, with the greatest activity usually occurring during the period of January to March.

Based on historical observation, the area between Cooktown and Mackay is the most cyclone prone stretch of the Queensland coast. Over the past 6 years, this stretch of coastline has been impacted by three severe tropical cyclones; TC Larry- 2006, TC Ului-2010, and TC Yasi-2011; with the latter being the main impetus for this Guide.

However the likelihood of cyclonic development, and the path the cyclone follows, is determined by ever-changing synoptic scale factors that cannot be predicted. The fact that two severe TCs crossed the coast within five years in the Innisfail - Mission Beach area has no bearing on where future severe tropical cyclones will cross.

Further Information:

Tropical Cyclone Information for the Australian Region

Cyclones Crossing the Queensland Coast From an Easterly Direction - By Region & Category (1970-2011)

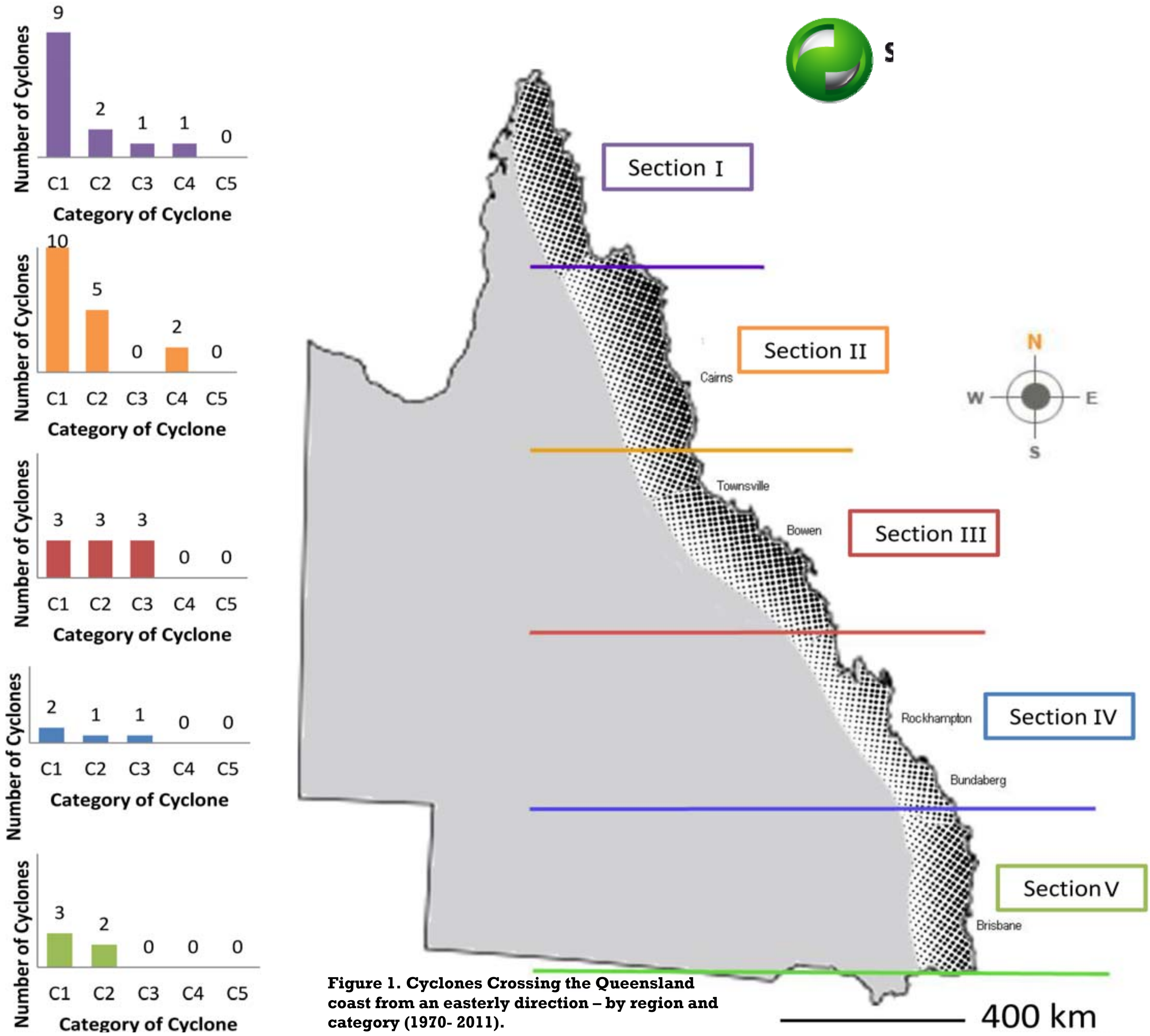


Figure 1. Cyclones Crossing the Queensland coast from an easterly direction – by region and category (1970- 2011).

The cyclone information displayed on this map is from January 1970 to December 2010 and only includes cyclones crossing the Queensland coast from an easterly direction (with the addition of Cyclone Yasi in February 2011). Being only a 40-year period, it does not represent the true long-term frequency of cyclones crossing the Queensland coast.

The number of cyclones and their category (as they crossed the Queensland coast) is based on cross-referencing historic cyclone information available from the Bureau of Meteorology & National Oceanic and Atmospheric Administration (NOAA) Historic Hurricane Tool. **Select Carbon** does not take any responsibility if this data is incorrect or if the data is misrepresented or misinterpreted for any purpose.

Historic Cyclone Paths for northeastern Australia 1970 - 2006

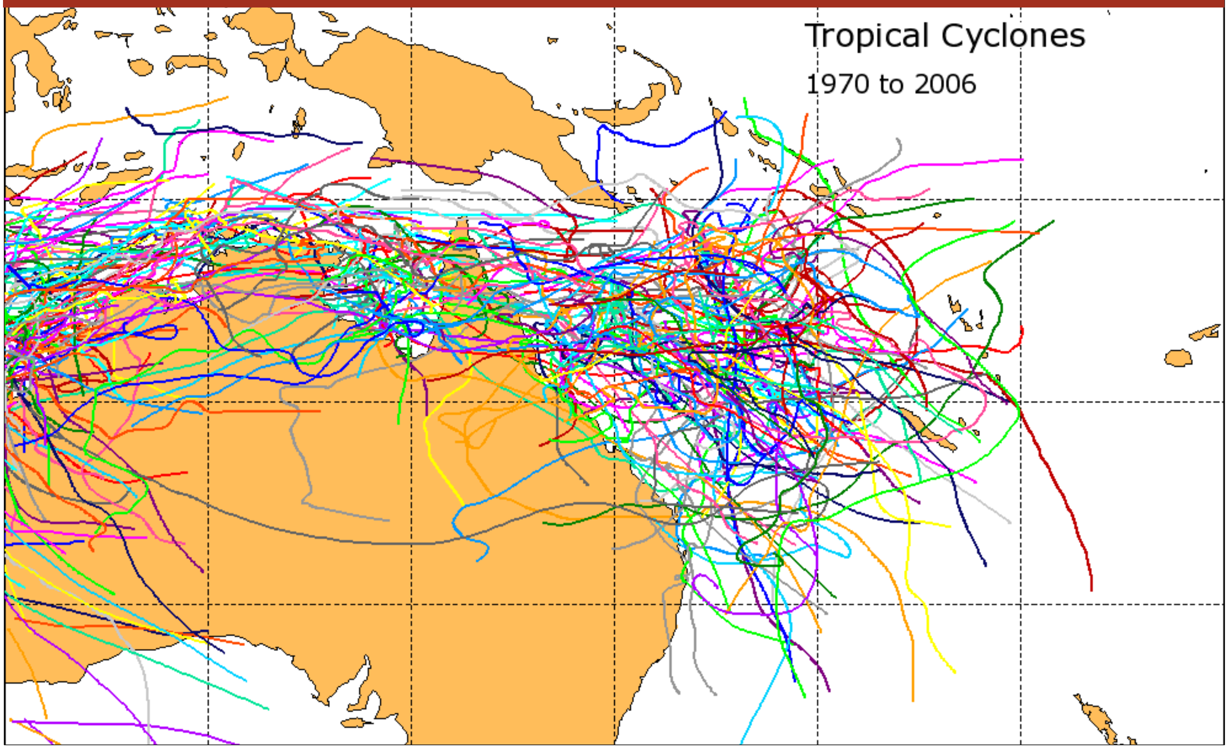


Figure 2. Historic tropical cyclone paths for northeastern Australia (1970-2006.). Note that colours DO NOT relate to cyclone intensity.(BoM, 2012)

Comparison of Cyclone Categories in Australia and the USA

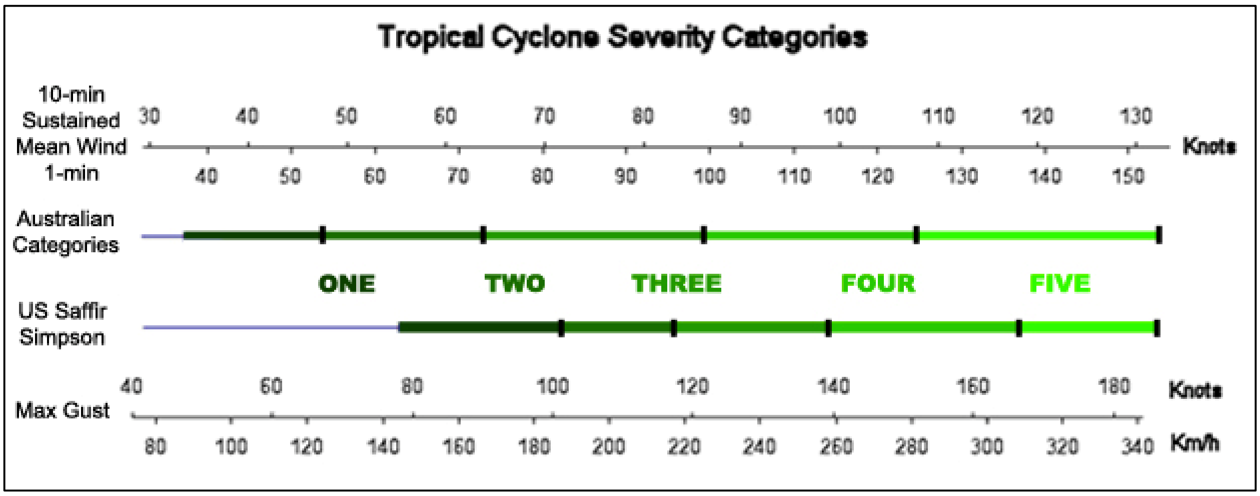


Figure 3. Comparison for tropical cyclone severity using the Australian Categories and the US-Saffir Simpson scale

Figure 4. National Oceanic Atmospheric Cyclone Tracking Tool

Cyclone Tracking Tool

National Oceanic Atmospheric Administration (NOAA)

The National Oceanic Atmospheric Administration (NOAA) Online Tool is a useful resource for people wanting to explore the history of cyclones anywhere around the world. The NOAA online tool uses the US Saffir Simpson scale and includes features and ways of interacting with the data to explore past TCs. The Saffir-Simpson hurricane intensity scale and the term 'Typhoon', which is a regionally specific name for a high intensity tropical cyclone (sustained winds of more than 118 km/hr or 64 knots), is used in the Northwest Pacific Ocean west of the dateline (See Figure 3 for comparison of the Australian and USA category system).

Incorporation of global data - More than 6,000 tropical cyclones records dating from 1842 and occurring in over seven major ocean basins around the world, are searchable thanks to the incorporation of NOAA's International Best Track Archive for Climate Stewardship (IBTrACS) dataset.

Easy way of changing your search parameters - Users can make quick and easy changes to their chosen search parameters without having to start over from scratch. As can be seen in the screenshot above, the NOAA Cyclone Tracking Tool has been refined to map Cyclone Ingrid in 2005. At any point along the cyclone track, all available meteorological data about the cyclone can be viewed by clicking on a point.

Further Information:

Visit NOAA online tool at:

http://www.csc.noaa.gov/hurricanes/#

Please also see a step-by-step screenshot tutorial at: http://www.timberqueensland.com.au

Climate Change: Future Predictions

Climate change presents a number of challenges to growing timber plantations in tropical cyclonic areas of Queensland.

As a result of climate change, the intensity of TCs is predicted to increase by between 2-11% by 2100. However, it is also predicted that there will be an overall decrease in the global average frequency of tropical cyclones by 6-34%. These predictions* confirm that:

- Category 1 TCs are likely to cross the tropical Queensland coast about 1 in 3 years
- Category 2 TCs 1 in 12 years
- Category 3 TCs 1 in 23 years
- Category 4, (eg. TC Yasi) about 1 in 67 years.
- The occurrence of catastrophic TCs (Category 5) such as the 1918 Innisfail cyclone, have a predicted return interval of one in 192 years.

**All likelihood statements follow conventions used by the Intergovernmental Panel on Climate Change (IPCC).*

Wind Speed Regions of Australia

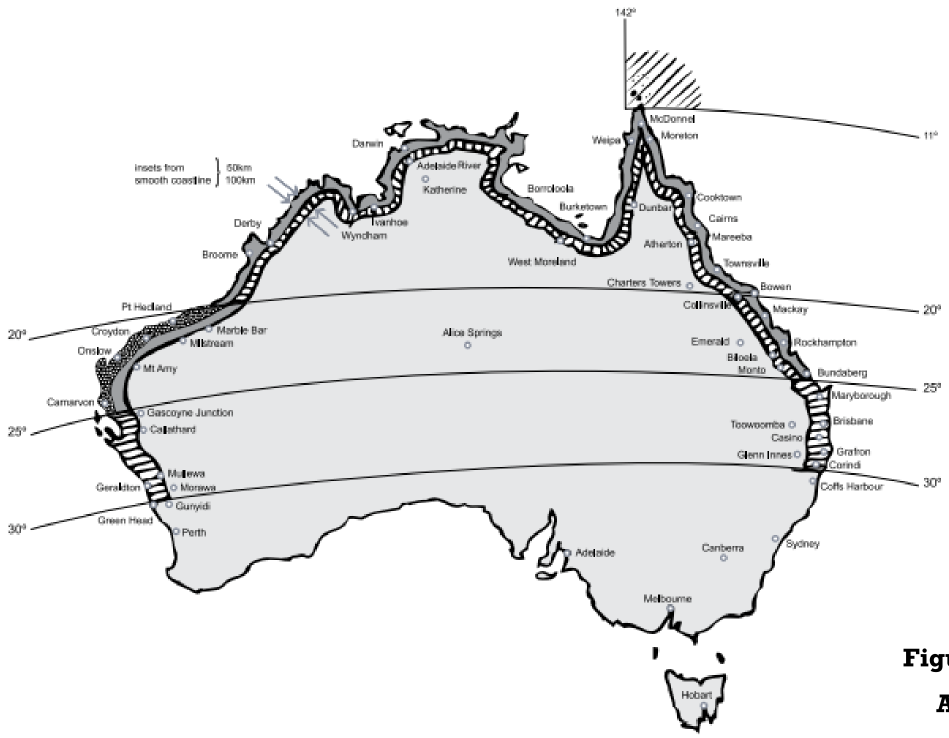
Australian Standards - Wind Speed Regions

The Australian Standards developed to address wind loads of buildings provide some useful insights into the factors influencing wind speeds, and the probability / relative frequency of TCs in various regions of Australia.

The wind region map from Australian Standard AS 4055-2006 shows the wind speed regions of Australia (Figure 5). The map is split into 4 Regions (A, B, C and D), with Region C having particular significance for timber plantations in tropical Queensland areas. Importantly, Region C only extends 50 km inland from the coast, in recognition of the very fast decay of cyclone intensity once TCs cross the coast. Cyclone decay is a result of the warm core being destroyed as the central pressure rises, and the belt of maximum wind expands away from near the centre. Decay may occur very rapidly if the system moves into an unfavourable atmospheric or geographic environment, but sometimes only the tropical characteristics and infilling occurs into the rapidly cooling core. Localised extreme wind columns may occur in rain bands to the south of decaying cyclones.

Further Information:

www.saiglobal.com



wind classification

AS4055-1992 is based on a ten-band wind classification system: N1 to N6 for non-cyclonic Regions A and B, and C1 to C4 for cyclonic Regions C and D.

location classification

Non-cyclonic Classification

REGION A

REGION B

Cyclonic Classification

REGION C

REGION D

Figure 5. Wind speed regions in Australia, according to the Australian Standard AS4055-2006 (Australian Standards, Wind Loads for Housing)

Other Factors Affecting Wind Speed

Wind classification systems for structural buildings use a combination of factors such as the location of the site, its location within different regions of Australia, the terrain category, the surrounding topography and any shielding offered by nearby buildings or other structures. The same factors can be considered when designing timber plantations in tropical Queensland.

Wind Shielding

The shielding classification system for wind loads on houses (AS4055) takes into account any localised shielding, which may be offered by surrounding buildings. As can be seen in Figure 6, the level of shielding for a typical house determines which shielding classification it receives, which ultimately has a bearing on the overall strength requirements of the building. For design cyclones (mid Category 4 in Region C), AS4055 does not allow shielding from trees, as their foliage is assumed to be stripped off.

As can be seen in Figure 6, the shielding classification is dependent on the protection provided by other structures. The shielding classification has a bearing on the overall strength requirements of the building.

The same general wind shielding principles can be applied to timber plantations for smaller wind speeds. The more shielding timber plantations have the greater protection that can be afforded to them during strong winds.

Some level of shielding can be afforded to plantations by local nearby features such as adjacent native forest, and maybe even by dense plantings of highly wind resistant species. Plantation managers have reported a distinct "*domino effect*" in exposed stands, which seemed to be less prevalent where there was shielding from adjacent native forest.

Although some shielding from local topography would be expected, observations of plantation damage from Cyclone Yasi were inconclusive about this factor.

Topographic Effects

Topographic effects cause the wind to speed up on the upper section of a hill, ridge or escarpment. For example in Figure 7, the house in T3 will be subject to higher wind speeds than the house at T1, because the T3 house is higher on the landscape and more exposed. The same topographic wind effects can be expected for trees and timber plantations when they are located at higher, more exposed, sites in the landscape.

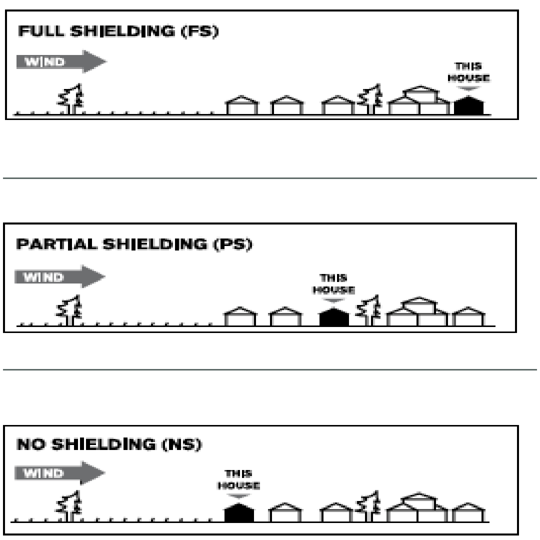


Figure 6. Wind shielding classification for wind loading on houses (AS4055)

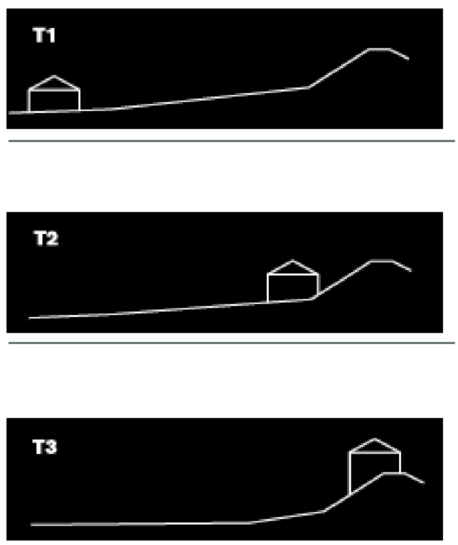


Figure 7. Topographic classification for wind loading on houses (AS4055)

Wind Multipliers for Hills

The Australian Standards recognise that the effect of topography on wind speed. According to the wind loading standard Australian Standard/New Zealand Standard AS/NZS1170.2-2011, shallow slopes less than a 1 in 20 rise do not have a wind speed-up effect. However, for a steeper slope with a rise of 1 in 10, the winds at the crest of this ridge or hill will be about 15% higher than the corresponding winds on flat terrain.

It should also be noted that the wind force on a building (or a tree/timber plantation) is proportional to the wind speed squared, so a 20% increase in wind speed will cause about a 44% (1.2^2) increase in wind force. This means that timber plantation trees planted on the tops of hills are likely to be exposed to higher wind speeds, and significantly greater wind forces.

Risk of Return Intervals

It is important to understand the risk of return intervals of various wind speeds when considering timber plantation investments in tropical cyclonic areas. The wind risk matrix model from AS/NZS1170.2-2011 can be used to estimate probability of occurrence of regional wind speeds, at any particular point in cyclone Region C. Table 1 has been calculated by the Cyclone Testing Station (CTS) and can be used to help consider relative risks of different timber plantation products and management regimes. By reducing the rotation age, the risk of exposure to higher wind speeds is significantly reduced.

It should be noted that as AS/NZS1170.2-2011 was developed for engineering purposes in the built environment and should only be used as a guide to the frequency of cyclones of different intensities.

Table 1. Regional Wind Speed Risk Matrix Model for any Point in Region C (Based on Table 3.1 AS/NZS 1170.2-2011)

Wind Risk Matrix Model for any Point in Region C (see Figure 5 for a Map of Wind Speed Regions)				
Maximum Regional Gust Wind Speed (at 10m height in open terrain km/hr)	**Probability of occurring in any one (single) year**	**Probability of occurring at least once in 10 years**	**Probability of occurring at least once in 25 years**	**Probability of occurring at least once in 50 years**
125	0.173	0.850	0.991	0.999925
170	0.0369	0.313	0.609	0.847
225	0.00613	0.060	0.142	0.265
280	0.000433	0.004	0.011	0.021

Tropical Cyclone Categories

Cyclone Yasi – A Case Study

Tropical cyclone Yasi crossed the north Queensland coast on 2nd February 2011 near Mission Beach as a Category 4 TC, and was one of the most powerful cyclones to have affected Queensland since records commenced. TC Yasi, although not a Category 5 cyclone, was an extremely wide system (several hundred kilometres across) that hit during a La Nina weather pattern when soils were heavily saturated.

Over 15,000 ha of timber plantations were severely affected (i.e. blown over completely or requiring salvage harvesting). Around half of these were young (<5 years old) plantations managed under Managed Investment Scheme (MIS) arrangements.

Prior to TC Yasi, there had already been major changes in the MIS industry. The Global Financial Crisis resulted in a number of MIS companies going into receivership, resulting in significant ownership changes.

TC Yasi caused all large-scale timber plantation growers to review their investments, and with a few exceptions, the owners of the MIS estates have decided to either clear their cyclone-damaged plantations and exit the region, or to cease funding new plantation development.

For more information go to:

www.bom.gov.au

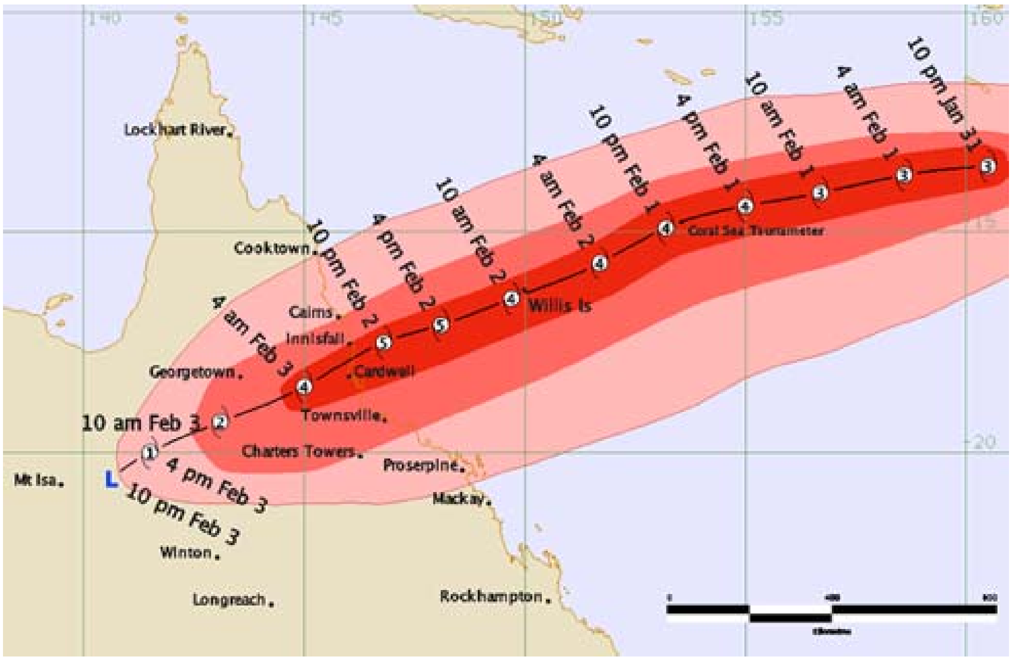


Figure 9. Cyclone Yasi Track Map (BoM, 2011).

Cyclone Yasi Field Photos

Being such a large system, TC Yasi maintained a strong core and damaging winds tracking westward across the state, eventually weakening to a tropical low over Mount Isa.

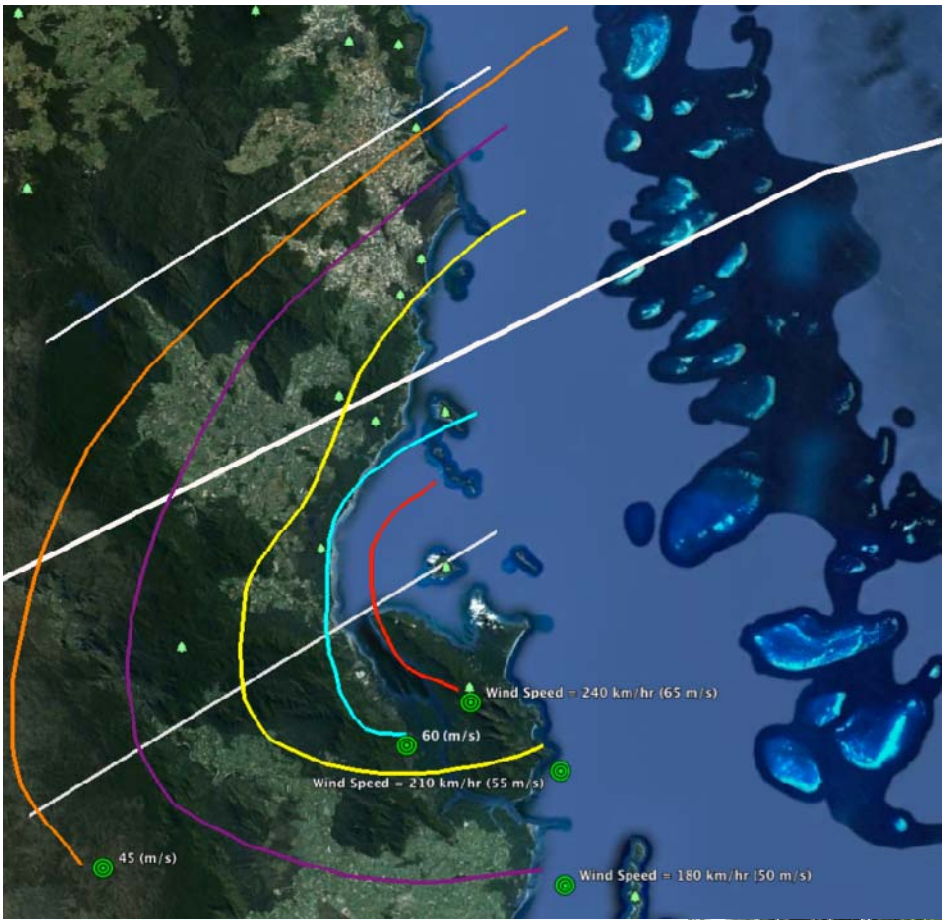
The estimated wind speeds and a series of field photos have been overlaid on a satellite image from Google Earth, so that viewers can see firsthand the damage and estimated wind speeds on certain sites that were assessed for this guide. As expected, much of the severe damage occurred south of the cyclone eye where the highest winds were recorded.

Existing and potential timber plantation growers can view these photos to help them make decisions about growing timber plantations in tropical Queensland cyclone-prone areas. To access to the Cyclone Yasi Wind Speed and Photo overlay, simply visit:

www.timberqueensland.com.au

The featured map above is based on Select Carbon's interpolation of data obtained from a combination of sources, including:

1. Holmes, JD. (2012) 'Cycloone Yasi' windfield revisted. 15th Australiasian wind engineering society workshop. Sydney 23-24th February, 2012.
2. Technical Report Number 57, Cyclone Testing Station.



Tree Performance in Cyclones

Trees are no different to other living organisms faced with the challenges of surviving in a natural environment. In tropical cyclonic areas where there have been regular extreme wind events, the role of evolution, natural selection and genetics has ensured local species have developed mechanisms to not only survive cyclones of varying intensities, but also regenerate and thrive in such environments.

Provenance Selection

Timber tree species with seed sourced from localities (or provenances) that have evolved in environments where cyclones don't occur, or occur less often, are likely to be more vulnerable to wind damage during a tropical cyclone. Recent tropical cyclones in north Queensland have demonstrated this point.

When TC Yasi hit in February 2011, the damage caused to exotic pine plantations owned by Forestry Plantations Queensland varied with different provenances. The mountainous Honduras provenance of exotic pine was affected much worse than its Cuban relative, which is subject to strong coastal winds regularly.

Forest Structure & Tree Architecture

The dynamic response of trees to wind is largely determined by the structure of forests, their growing conditions and whether or not they are subjected to frequent windy environments.

In many forest ecosystems, including timber plantations, trees grow very close together and compete for both nutrients and sunlight. The desired end result in timber plantations is a tendency towards tall and slender trees with little side-branch development. An important factor influencing the damage caused by wind is the size and shape of the trees.

Some native tropical Queensland species, such as *Elaeocarpus grandis* (Silver Quandong) have evolved to adapt to cyclones by investing in the development of spreading buttress roots.

Tree Age

Young trees, especially those less than 10 years old, appear to be particularly vulnerable to wind damage. Older trees are likely to have established root systems and a wider diameter stem. Research carried out by the Queensland government in association with this guide found that older trees of *Eucalytpus pellita* were damaged less than young trees, which were largely destroyed completely by TC Yasi. This was observed for a number of species in a timber plantation setting.

Contrasting this finding, literature and other observations in different settings found that older trees are more likely to have suffered termite damage, increased biomass above-ground with a lower percentage allocated to roots, leading to increased wind damage. Following TC Tracey, 43% of trees had increased rate of windthrow with increased tree height.

Further Information:

www.timberqueensland.com.au

Tree Performance in Cyclones

Tree Species Slenderness Ratios

The ability of a tree to withstand wind is sometimes correlated to its slenderness. Slenderness is defined as the ratio between the height (h) and the trunk diameter at breast height (DBH), with the ratio of height to diameter (h/DBH) giving a measure of slenderness.

A tree that is shorter and thicker with a low slenderness ratio tends to be more stable and better able to withstand higher wind loads than a higher slenderness ratio tree which can become too slender and can break due to having less structural capacity to respond to the forces generated by the wind. A graphic illustration of different slenderness ratios is provided in Figure 8 below.

An extreme example of high slenderness ratio observed is a particular stand of *Pinus contorta* in Alberta, Canada, with a height range of 9.4 to 15.3m and a slenderness ratio of 160 (Figure 8), which means these trees are highly susceptible to wind damage.

As can be seen in Figure 8, Australian native conifers (hoop/kauri pine) have relatively low slenderness ratios and are more likely to be wind firm. There is little research information available about the slenderness ratios of other tropical Queensland plantation species.

Slenderness coefficients of above 100 generally indicate low stability, with such trees likely to be severely affected by strong winds.

Insurance companies use this ratio to assist them when determining their level of cover. Forest trees with a slenderness ratio below 80 are generally considered as having excellent stability.

The tallest tree in the world, Californian Redwood *(Sequoiadendron sempervirens)*, has a slenderness ratio of just 10.5, which is testament to its survival over many centuries. The slenderness ratio of a tree will depend on a combination of natural characteristics and the management of the stand.

Further Information:

www.timberqueensland.com.au

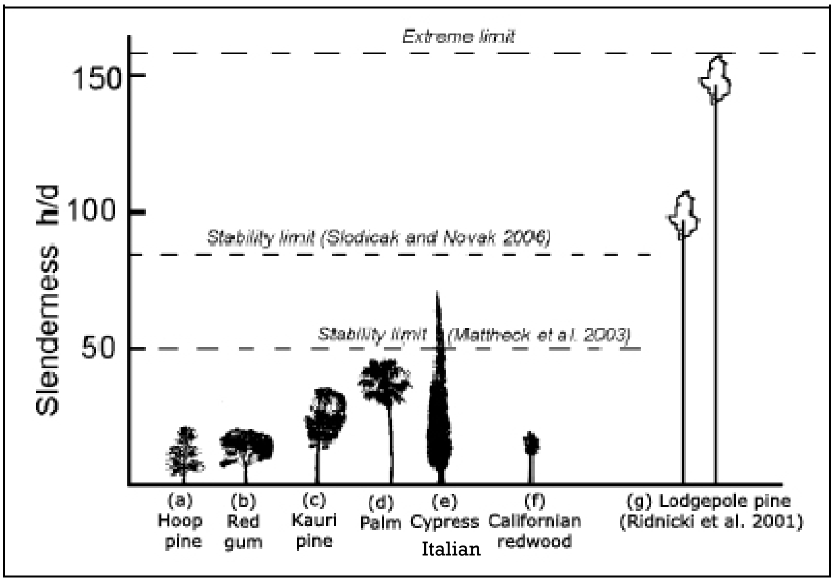


Figure 8 - Slenderness ratios for a range of tree species

Tree Performance in Cyclones

Wood Density

Wood density may contribute to the overall strength of a tree and therefore its ability to resist damage from tropical cyclones. Following TC Larry, a positive correlation was found in native forest tree species between their wood density, ability to withstand disturbance (resistance), and a negative correlation with their ability to recover biomass following disturbance (resilience). Tree species that experienced minor damage were likely to have a higher wood density, supporting the long-held association by many between resistance and mechanical strength. Tree species with lower wood density were more likely to suffer stem and branch damage due to tropical cyclones, however they also tend to be the first tree species to re-sprout and re-develop biomass.

Defoliation & Branch Loss

Leaf defoliation usually starts to occur during a high Category 2 tropical cyclone, with complete defoliation likely after high Category 3 wind speeds. Leaf traits can have a significant bearing on tropical cyclone resistance and the level of damage. Leaf size (area, length and width) and the petiole length influences the drag forces experienced during strong winds. Species with a large and persistent "sail area" are likely to be the first to experience damage during a TC. Leaf strength and retention is also important, and varies between species. For example it has been shown that leaves of eucalypts in a savannah environment resisted defoliation for longer than rainforest trees during TC Monica, in addition to harder wood resisting breakage.

Matching Species to Sites

Given that a typical timber plantation in tropical Queensland is likely to be subject to cyclones during its rotation, matching species to sites is an important factor to consider. Observations after Cyclone Yasi indicated that trees that were growing poorly were more susceptible to wind damage.

Poorly drained sites can be particularly susceptible to cyclones due to root development and soil stability when saturated.. In general, such sites should be avoided unless the species selected occurs naturally in the area on similar sites or has a proven resilience in a waterlogged environment.

Plantation Operations & Silviculture: Points to Consider

Silvicultural Regime in Tropical Cyclonic Areas

The silvicultural regime applied to plantations throughout their rotation will impact their susceptibility to strong winds. As well as selecting species that are naturally wind resistant, decisions are required on the stocking and silvicultural treatments, such as thinning and pruning, that are conducted throughout the rotation.

Some literature has recommended stocking plantations at higher rates while also reducing the traditional silvicultural management regime, including thinning and pruning, effectively increasing stand density and reducing wind penetration. The trade-off for this is reduced stem diameter leading to a higher slenderness ratio and smaller diameter products.

The Queensland government forestry research group observed timber plantation stands planted at low initial stocking rates (around 650 stems per hectare) had less damage than denser stands. It is thought that these trees were potentially less prone to wind damage when more open-grown and having a lower slenderness ratio. This theory is also supported in much of the literature.

The forestry research group also observed that stands with relatively even crowns performed better than stands with a variable height. In mixed height stands, larger trees tended to suffer direct wind damage, and falling trees and branches tended to damage the smaller trees.

Timber plantations that have been recently thinned are generally more susceptible to wind damage for several years following the operation due to increased wind penetration resulting from opening up the crown. However over time, thinned timber plantations become more wind firm. A forestry research experiment that was planted in 1991 and thinned in 1994 grew for twelve years before experiencing extreme winds during Severe TC Larry.

The unthinned Queensland maple trees in the experiment (planted at 2222 stems per hectare) showed evidence of rubbing against each other in the cyclone (upper stem break), which produced higher mortality and smaller diameters than the maple trees in the thinned plots (planted at 1111 and 833 stems per hectare).

Low initial tree stocking when establishing a timber plantation is likely to result in increased weed growth in the early years until the site has tree crown canopy cover. Weed control is important throughout the rotation, especially in areas where vines grow into the tree canopy, increasing the weight and wind resistance of the canopy and increasing the likelihood of wind damage. Hence, well-maintained timber plantations may suffer less damage than weed-infested sites. One of the challenges faced by timber plantation growers after a cyclone is the relatively quick infestation of weeds in cyclone-damaged areas. Weeds grow quickly and produce seeds which are then dispersed further, requiring expensive weed control operations.

It is unclear whether differences in timber plantation site preparation have an impact on tropical cyclone resistance. At one timber plantation site affected by TC Yasi, the majority of trees planted on mounded sites blew over, while only metres away trees planted without mounding remained standing. However, mounding was only used on the wetter sites while the un-mounded areas were on the well-drained foothill soils. The soil moisture and inherent stability of the soils are more likely to explain the differences. Trees on the exposed windward side of plantations tend to show greater mechanical strength due to the 'adaptive growth hypothesis', and when these trees are harvested it exposes trees lacking that exposure history and strength.

Plantation Operations & Silviculture: Further Points to Consider

Forest Products and Markets

Undertaking any successful forestry plantation venture requires the forest grower to understand the intended markets for the end product. The 3 scenarios featured in Table 1 of the Wind Risk Matrix relate to approximations of possible rotation lengths associated with various products. The 10 year scenario refers to producing a short-rotation fibre crop, such as pulp, biomass for energy or biochar (charcoal). The 25 year scenario refers to traditional softwood or hardwood sawlog regimes typically targeted by the industrial growers, and the 50 year rotation refers to growing long-rotation native rainforest species.

It is also important that there will be a market for the species grown. Simply growing a species due to its wind firmness may not be the best way to ensure a commercial return.

Management Planning

It is highly recommended that all forest growers, be they large or small, adopt a professional approach to risk management regarding cyclones in tropical Queensland. Good planning is essential and should include the following as a minimum:

- Target Market for Products
- Tree Species Selection
- Site Selection
- Tree Seed Sources
- Silvicultural Regime (including site preparation, weed control, pruning and thinning if required)
- Cyclone risk assessment and mitigation strategies
- Roads and Tracks
- Workplace Health & Safety
- Harvesting Operations
- Cyclone Salvage Plan

Salvage Logging Operations

In the event of cyclone damage to a plantation a salvage logging operation needs to consider a range of factors. The following points were recommended by operational foresters with salvage experience after Cyclones Larry, Ului and Yasi:

- Ensure that safety is considered first for you and any workers in any operations.
- Getting access to the plantation is critical, so clear access roads as a priority.
- Be aware that damage will often be highly variable across the estate..
- Logs deteriorate very quickly in tropical climates, so commence salvage operations as soon as possible. Watch out for rot which will start to appear after a number of months when the temperature and humidity begin to rise again ahead of the following wet season.
- Harvest green plantation stands while they remain green and reduce the acceleration of rot by removing trees without bark first if possible.

Trees and Carbon Sequestration

Establishing tree plantations for carbon sequestration is becoming more common around the world in response to global action on climate change.

In Australia the Carbon Farming Initiative (CFI) allows landholders to store carbon in trees and participate in the new carbon market creating an ongoing revenue stream.

Growing timber plantations for carbon sequestration in the tropical cyclone risk areas of north Queensland will have to address the requirement that the planted trees are to be maintained for a minimum period of 100 years to be considered permanent under regulations announced in the Carbon Farming Initiative (CFI).

Therefore, choosing a tree species that is less likely to be damaged by tropical cyclones is just as important as choosing a tree species based on its potential to sequester carbon.

For further information about the Carbon Farming Initiative, please visit www.cfi.gov.au

Queensland Government (DAFF) Forestry Research Cyclone Assessment

Influence of cyclonic winds on the performance of hardwood plantations in tropical north Queensland.

The Queensland Government Forest Research unit were contracted to review the impacts of TC Yasi on the performance of key hardwood timber plantation tree species in tropical Queensland. The assessment examined the influence of species, genetics, plantation design, management and age on plantation resilience during cyclones. A total of 2200 trees were assessed, comprising 44 species at 32 localities located from Daintree to Townsville. Key findings from the report include:

Plantation Age – Most species were observed to be more resilient to tropical cyclone damage as they approached maturity. Young plantations (particularly *E. pellita*) were found to be less resilient than older plantations.

Wind Damage- Established plantations showed high resilience (>80%) for Category 1 strength winds. Plantation resilience was variable for Category 2 strength winds. Plantation resilience was low (<40%) for Category 3 strength winds. Tree species with identified high cyclone resilience included: *Elaeocarpus grandis* and *Flindersia brayleana, E.cloeziana, E.grandis* and *E.pellita* (specifically older *E. pellita* trees), *Agathis robusta,* and *Araucaria cunninghamii,* although they are prone to minor breakage high in the stem.

Genetic variation - Provenance and clonal variation was observed in trials of *Eucalyptus pellita, Khaya senegalensis* and *Tectona grandis*. *Eucalyptus pellita* provenances from north Queensland appear to have greater tropical cyclone resilience than Papua New Guinea and Irian Jaya provenances, but they also grew more slowly. The largest trees in the stand were ones most likely to be damaged.

Plantation Design – The report found greater damage was associated with plantation zones of variable canopy architecture (height, density). These include plantation boundaries and within polycultures where there were large differences between tree species.

Plantation Management - Low initial tree stockings (e.g. 650 trees/ha) were more resilient to tropical cyclone damage. Plantations that were thinned a short time before cyclone impact (< 2 years) were less resilient to cyclone damage.

A full version of the report 'Influence of cyclonic winds on the performance of hardwood plantations in tropical north Queensland' can be found here.

Relative Tree Species Performance

The information contained in this guide is based on published literature, field observations made by project partners (namely Select Carbon Pty Ltd and the Queensland Government), and a series of small and large timber plantation grower surveys that were conducted as part of the project. The general experience from all of these sources indicates that timber plantation trees start to experience defoliation and broken branches during a high Category 2 TC or low Category 3 TC (around 150 – 160 km/hr appears to be a threshold for trees), and anything beyond a high category 3 TC (200-220 km/hr), usually results in severe damage regardless of their location in the landscape or management regime. The damage levels observed in tree species varies significantly and it must be stated that the following discussion regards observed trends rather than absolute findings.

Field Observations post Tropical Cyclone Yasi

Eucalyptus pellita

Large-scale commercial plantings of young (<8 years old) *Eucalyptus pellita* (red mahogany) planted on relatively low lying sites suffered severe damage in tropical cyclone Larry and tropical cyclone Yasi. Damage was extensive across the estate, with various sites factors appearing to have little impact on survival. These young plantations were of Papua New Guinea (PNG) provenance that does not naturally experience cyclones. However, older small research plantings of Queensland provenances (as opposed to PNG provenances) of red mahogany showed better tropical cyclone resistance, particularly when planted on well drained soils. It is unclear what role age, provenance and site played in these different observations.

Exotic Pine

Although overall there was a very high level of damage to both mature and young *Pinus caribea* variety *hondurensis* (PCH), there was some significant variation in damage, most likely related to wind speed and local site conditions. *Pinus caribea* variety *caribea* (PCC). fared much better than PCH, with mostly moderate levels of wind damage observed. However PCC is not as widely planted due to its lower productivity.

Teak

Young (<8 years old) *Tectona grandis* (teak) timber plantations performed better than expected, with relatively low levels of damage. However at least one of the mature teak timber plantation sites was severely impacted by cyclone Yasi.

African Mahogany

Grower reports regarding *Khaya senegalensis* (African mahogany) near Townsville indicated that this species stood up well to Category 3 wind speeds. This contrasts with reports of severe damage in urban areas in northern Australia and Queensland from Category 1-3 wind speeds. It is likely that the use of mature planting stock and regular watering impacts wind resilience of this species in urban settings.

Other native species

Native tree species appear to have the greatest resilience to cyclone damage in their native habitat. For example, *Melaleuca leucadendra* (tea tree) occurs in low-lying areas that are often not well drained; areas where damage to timber plantations was particularly high. However, this particular tree species shows a high resilience to tropical cyclone damage. Another native species, *Nauclea orientalis* (Leichhardt tree), also occurs in low-lying (wet) areas.

Other strong performing native species that are well-known to farm foresters in the region include *Agathis robusta* (kauri pine), *Flindersia* spp (native maple and ash species) and *Eleaocarpus grandis* (silver quandong). The relative performance of some key timber tree species should be considered by any potential timber plantation grower and these are outlined on the next page.

Table 2. Species Performance Summary Assuming a Category 2 Cyclone

Indicative Species Performance Summary

(assuming a Category 2 cyclone, see Key & Note on following page for definitions)

Scientific name	Common Name	Typical cyclone damage	Select Carbon Field Observations (Post TC Yasi)	DAFF Field Observations (Post TC Yasi)	Literature
Acacia mangium	Brown salwood	Stem break and/or lean (damages neighbours)	**-**	**Very Poor**	**Poor**
Agathis robusta	Kauri Pine	Stem break (characteristically a few metres from top)	**Very Good**	**Average**	**Very Good**
Araucaria cunninghamii	Hoop Pine	Stem break (characteristically a few metres from top)	**Good**	**Average**	**Average**
Blepharocarya involucrigera	Rose butternut	Stem break	**-**	**Average**	**-**
Castanospermum australe	Black Bean	Stem break. Many forks.	**-**	**Poor**	**Average**
Cedrela odorata	West Indian cedar	Stem break low to ground.	**-**	**Poor**	**-**
Corymbia torelliana	Cadaga	Crown thinning (branches break)	**Good**	**Average**	**Good**
Elaeocarpus angustifolius/grandis	Silver quandong	Minor branches break, some stem break. Some trees die after the cyclone, standing upright	**Very Good**	**Very Good**	**Very Good**
Eucalyptus acmenoides	White mahogany	Stem break and/or crown thinning	**-**	**Average**	**-**
Eucalyptus cloeziana	Gympie messmate	Crown thinning or minor stem break	**Very Good**	**Good**	**Very Good**
Eucalyptus grandis	Rose gum (flooded gum)	Crown thinning or minor stem break	**Very Good**	**Good**	**Good**
Eucalyptus pellita (young trees < 8 yo)	Red mahogany (pellita)	Stem break, crown thinning.	**Very Poor**	**Good**	**-**
Eucalyptus pellita (older trees > 8 yo)	Red mahogany (pellita)	Stem break, crown thinning.	**Good**	**Good**	**-**
Eucalyptus resinifera	Red mahogany (resinifera)	Stem break and/or crown thinning	**Average**	**Average**	
Eucalyptus tereticornis	Forest red gum	Crown thinning. Little damage observed – usually suppressed.	**Good**	**Average**	**Poor**
Flindersia brayleyana	Queensland maple	Leaning (large trees), Stem break (rare). Some trees die after the cyclone, standing upright.	**Very Good**	**Good**	**Good**

Grevillea robusta	Southern silky oak	Stem break	**-**	**Average**	**Poor**
Khaya anthotheca	African mahogany wet zone KNY	Stem break and/or lean (large trees)	**-**	**Average** (trees < 8 yo)	**-**
Khaya senegalensis	African Mahogany	Leaning (largest trees in stand). Species suited to drier areas	**Average**	**Average** (trees < 8 yo)	**Average**
Melia azedarach	White cedar	Stem break	**-**	**Poor**	**Poor**
Nauclea orientalis	Cheesewood (Leichardt)	Stem break – near top of tree	**Very Good**	**Average**	**Very Good**
Periserianthes toona	Red siris	Stem break (rare). Mid-storey tree	**-**	**Average**	**-**
Pinus caribea var. caribea (PCC)	Exotic Pine (Cuba)	Stands located adjacent to PCH suffered much less damage	**Good**	**-**	**Poor**
Pinus caribea var. hondurensis (PCH)	Exotic Pine (Honduras)	Widespread damage to entire estate	**Poor**	**-**	**-**
Tectona grandis (young trees < 8 yo)	Teak	Stem break and/or lean. Young plantations hardly damaged	**Good**	**Very Good**	**-**
Tectona grandis (old trees > 8 yo)	Teak	Stem break and/or lean. Young plantations hardly damaged	**Good**	**Poor**	**-**

+ Key for Species Performance Summary

Very Poor: Extensive tree damage and / or death. Very few remaining trees of long-term commercial value (DAFF Observations < 25% commercial)

Poor: Extensive tree damage and some tree death. Some remaining trees of long-term commercial value but significant defect (DAFF Observations 25% - 45% commercial).

Average: Significant stem and / or crown damage and limited tree death. Some trees retain long-term commercial value but generally of variable quality (DAFF Observations 45% - 55% commercial).

Good: Some stem and / or crown damage and occasional tree death. Most trees should retain long term commercial value but may be susceptible to increased incidence of defect (DAFF Observations 55% - 75% commercial).

Very Good: Limited stem and crown damage and occasional tree death. Majority of trees should retain their full long term commercial value (DAFF Observations > 75% commercial).

Note:

Ratings are indicative of the relative performance of these species, as observed after TC Yasi and from the available literature. The field performance of any tree / species will depend on a range of factors, including: provenance, site conditions, stand management, age, wind speeds etc.

Table 2 has been prepared assuming a category 2 tropical cyclone. Once category 3 wind speeds are reached, relative species performance may vary considerably from table 2.

For more information go to:

Queensland Government (DAFF) Report

Greening Australia Report

Summary of Best Practice Tips

1. Understand WHY you are planting trees. Develop a sound understanding of the very real risk of cyclones from information in this guide and elsewhere, and use the available tools and techniques to minimise the potential impacts on your plantation. Plantation planning needs to consider the intended market for your end product, the risk of cyclones to your target crop, and opportunities to mitigate the risk of cyclone damage throughout the rotation.

2. Rotation length is always a trade-off between risk and economic value. Fast-growing, short-rotation plantations for products such as fibre (pulpwood), biochar and/or energy will have less chance of cyclone damage than long rotation crops for products such as sawlogs.

3. Consider species and provenances that are considered to be wind resistant and will also meet your intended market. Wind resistant species tend to come from cyclonic areas, and will often include those native to the region. The species list on page 18 gives an indication of relative performance in a Category 3 cyclone for a range of potential plantation species.

4. Focus very carefully on matching tree species to site. Trees that are growing poorly tend to be more prone to wind damage.

5. Some sites are particularly vulnerable to cyclones. Poorly drained low-lying floodplains tend to be prone to wind damage, and exposed hilltops and ridgelines are subject to higher wind speeds. These sites need particular attention to species selection and plantation management.

6. For longer rotation plantations, manage them to maximise tree diameter growth rather than height growth to improve their performance in strong winds. Consider using a "direct regime" with a low initial stocking and no thinnings to avoid opening up the crown during the rotation. Improved seed sources may be required to deliver adequate log quality. If thinning is undertaken, ensure it is done early and not delayed.

7. Avoid delaying final harvest. This will limit the exposure of the highest value crop to the risk of destructive cyclones.

8. Plantation stands with uniform height and crown cover appeared to experience reduced damage levels in cyclone Yasi. This can be achieved by planting monoculture plantations or by ensuring that selected tree species have similar growth rates in terms of height development.

9. Cyclones tend to be more intense near the coast and decay as they move across the land. Consider planting further inland at least 50km from the east coast of tropical Queensland.

10. To reduce the risk of total failure in larger plantation operations, spread your plantation estate geographically and seek to establish a broad age class distribution.

11. Prepare and maintain a salvage plan. Fallen material deteriorates very quickly in the tropical climate so time is of the essence for salvage operations. The salvage plan should identify market options for lower-grade material that could be generated throughout the rotation, as well as key operational aspects of undertaking a salvage operation.

Further Information and Supporting Resources

All supporting information to the *Best Practice Guide for Timber Plantations in Tropical Cyclonic Areas* can be found on the Timber Queensland website, URL www.timberqueensland.com.au.

Information available on the website includes the following:

- Literature Review
- Queensland Government Field Report
- NOAA Screenshot Tutorial
- A selection of photos during field assessments conducted after Tropical Cyclone Yasi

Other useful resources include:

- NOAA Cyclone Tracking Tool – www.noaa.gov.us
- Bureau of Meteorology – www.bom.gov.au
- Greening Australia Tree Susceptibility to Cyclones Report – http://www.greeningaustralia.org.au/uploads/Our Solutions - Toolkit pdfs/QLD_2011_Cylone_Yasi_tree_assessment_report.pdf
- Cyclone Testing Station - http://www.jcu.edu.au/cts

DISCLAIMER

The Best Practice Guide for Timber Plantation in Tropical Cyclonic Areas of Queensland outlines some practical and useful information that can help forest growers reduce the risk of wind damage. Even though there are ways to help reduce the risk of wind damage to timber plantations, it is important to remember that there are also some common trade-offs that need to be considered by forest growers, all of which come with their own risks and benefits. There is inherent risk when growing timber plantations in cyclone-prone areas that a tropical cyclone of Category 3 or above may occur and cause severe damage and potentially compromise its commerciality. Timber plantation growers need to consider associated risks and how they can be reduced if commercially feasible.

The information in this guide has been prepared with due diligence and in good faith by the project partners. The guide is intended to assist forest growers in tropical Queensland better understand and prepare for cyclones, however it should not be used as the sole basis for decision making and no responsibility will be taken by the authors for decisions taken by individuals or companies as a result of reading this guide. Further research is required into the relative wind resistance of various species.

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