Department of Agriculture, Fisheries and Forestry

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

A report prepared for the Timber Queensland project:
Best Practice Guide for Timber Plantations in Cyclonic Areas.

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EXECUTIVE SUMMARY

Severe Tropical Cyclone Yasi crossed the far north Queensland coast at Mission Beach on the morning of the 3rd February 2011, shattering the regions newly developing hardwood plantation forestry industry. The path of this cyclone precisely covered the primary areas of recent establishment, destroying thousands of hectares of young eucalyptus trees. The extent of cyclone damage, coupled with the weak domestic and international economy has resulted in a severe decline in industry confidence for the future of timber plantations in this region.

The purpose of this report was to review the impacts of Severe TC Yasi on the performance of key hardwood plantation species in north Queensland, summarising the influence of species, genetics, plantation design, management and age on plantation resilience. This data has been incorporated into a document "Best Practice Guide for Timber Plantations in Cyclonic Areas" which will assist companies with future plantation investment decisions in the tropical cyclone zone. For this project a total of 2200 trees were assessed, comprising 44 species at 32 localities located from Daintree to Balgal Beach, north of Townsville. Post-cyclone assessment data relating to 5900 African mahogany trees on four sites in the Ingham region is also presented. 21 hardwood species (17 native, four exotic) and two native conifers were assessed in sufficient numbers across multiple sites to make broad generalisations about their cyclone resilience.

A number of key outcomes were identified:

- Plantation age
    - Species morphology (crown: stem: root ratio) changes with age, making most species more resilient to cyclone damage as they approach maturity.
    - Young plantations (particularly *E. pellita*) were less resilient than older plantations.
    - *Tectona grandis* plantations became less resilient with increasing age.
- Wind speed effect on well-established (not young) plantations
    - Plantation resilience was high (>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.
- Species with identified high cyclone resilience
    - Rainforest species: *Elaeocarpus grandis* and *Flindersia brayleana* (although many stems died in the months after the cyclone, highlighting the difficulty of rating resilience).
    - Eucalypt species: *E. cloeziana*, *E. grandis* and older *E. pellita* (specifically > 8 years)
    - The native conifers *Agathis robusta* and *Araucaria cunninghamii* were prone to stem breakage high in the tree, but seemed able to recover from this minor setback.
- Genetic variation
    - Provenance and clonal variation was observed in trials of *Eucalyptus pellita, Khaya senegalensis* and *Tectona grandis*
    - *E. pellita* provenances from north Queensland appear to have greater cyclone resilience than New Guinea provenances, but they also grew more slowly.
    - The largest trees in the stand were the ones most likely to be damaged.

- Plantation design
    - 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 species.
    - Polycultures suffered more damage than monocultures.
- Plantation management
    - Plantations established at low initial stockings (eg. 650 trees/ha) were more resilient to cyclone damage.
    - Plantations that were thinned a short time before cyclone impact (< 2 years) were less resilient to cyclone damage.
- Site matching
    - The resilience of the species declined on sites where tree growth was poorer; for instance, silver quandong displayed less resilience on unsuitable sites near Ingham than on better sites nearer to Tully which experienced stronger winds.

The results presented in this report are based on a post-cyclone survey of a range of sites with diverse characteristics and management histories, rather than a comprehensive replicated scientific experiment. The observations reported should not be seen as a guarantee of future performance. Cyclonic winds are extremely variable and their behaviour is often highly unpredictable, not only between adjacent plantations, but also within the same plantation. Summarising this information has been a complex and painstaking task.

Never-the-less the information presented in this report provides valuable observations about the impact of cyclonic winds on the performance of hardwood plantations in tropical north Queensland, and will hopefully inform decision makers when considering options for the future development of the forest growing sector in this region.

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GLOSSARY – Species names and Codes

Code	Standard trade name (alternative)	Scientific name
BBN	black bean	*Castanospermum australe*
BSM	brown salwood (mangium)	*Acacia mangium*
CDG	cadaga (cadaghi)	*Corymbia torelliana*
CWD	cheesewood (Leichardt tree)	*Nauclea orientalis*
DMN	damson	*Terminalia sericocarpa*
FRG	forest red gum (Qld blue gum)	*Eucalyptus tereticornis*
GMS	Gympie messmate	*Eucalyptus cloeziana*
HP-	hoop pine	*Araucaria cunninghamii*
KNY	African mahogany, wet zone	*Khaya anthotheca*
KSE	African mahogany, dry zone	*Khaya senegalensis*
NKR	Queensland kauri pine	*Agathis robusta*
QMP	Queensland maple	*Flindersia brayleyana*
RBN	rose butternut	*Blepharocarya involucrigera*
RMM	red mahogany (pellita)	*Eucalyptus pellita*
RMY	red mahogany (resinifera)	*Eucalyptus resinifera*
RSG	rose gum (flooded gum)	*Eucalyptus grandis*
RSR	red siris	*Paraserianthes toona*
SLQ	silver quandong	*Elaeocarpus grandis*
SSO	southern silky oak	*Grevillea robusta*
TGT	teak	*Tectona grandis*
WCD	white cedar	*Melia azedarach*
WIC	West Indian cedar	*Cedrela odorata*
WMY	white mahogany	*Eucalyptus acmenoides*

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INTRODUCTION

The project "Best Practice Guide for Timber Plantations in Cyclonic Areas" was funded by an industry grant under the Queensland Government Rural Resilience Package program. The project was led and co-ordinated by Timber Queensland, with Select Carbon as the principal consultant and the Department of Agriculture, Fisheries and Forestry (DAFF, formerly the Department of Employment, Economic Development and Innovation, DEEDI) Horticulture and Forestry Science as collaborator, along with James Cook University Cyclone Testing Station (CTS) and numerous commercial plantation companies. This report, "Influence of cyclonic winds on the performance of hardwood plantations in tropical north Queensland" summarises the results of cyclone damage assessments of hardwood plantations and trials by DAFF, to provide technical information to inform the project report: "Best Practice Guide for Timber Plantations in Cyclonic Areas."

An interim report was produced by DAFF on 16 January 2012 which summarised the initial round of assessments, focussed on the area most affected by severe Tropical Cyclone (TC) Yasi, specifically the Cassowary Coast and Herbert Valley areas. A draft final report was released on 30 March 2012, incorporating cyclone-affected trials and growth plots further afield, as well as other trials in the severely-affected area that were not included in the interim report. Subsequent checking has revealed inaccuracies in the wind speed information used for that report ("the DEEDI report, March 2012"), rendering that report obsolete; this final report incorporates minor changes recommended by project collaborators, and corrects the previous errors. Species are referred to using either their scientific names or their standard common names, or related codes. The glossary lists the standard common name and abbreviation for the 23 species discussed in greatest detail.

Scope

This report is focussed on the performance of hardwood species planted for timber production in the high rainfall zone of north-east Queensland (Daintree to Townsville) since 1991. The results and observations relate to woodlot-style plantings of half a hectare or greater. The resilience of individual trees planted in the open, and wider-spaced park-style plantings may be very different to those of the same species planted in woodlots.

Tropical cyclone characteristics

Tropical cyclones are synoptic-scale low pressure systems having an organised convection with rotating winds of at least 34 knots for at least six hours (Bureau of Meteorology website). Cyclones typically reach maximum intensity over water, and rapidly degenerate as they pass over land. Cyclones vary considerably in their size, trajectory, speed and behaviour, each of which influences the damage caused. A severity category system is used to classify cyclone intensity, from 1 (least severe) to 5, shown in Table 1.

It should be noted that the maximum wind gusts estimated by the Bureau of Meteorology within a cyclone may occur high above ground level, and ground speeds may be significantly lower. In this report all references to wind speeds are maximum 3-second gusts at 10 metres height. It should also be noted that winds within a cyclone are notably capricious and unpredictably variable: one location may experience wind gusts vastly higher or lower than another location nearby.

Table 1. Tropical cyclone intensity categories (Source: BOM website)

Category	Maximum sustained wind speed	Strongest gust		Term used in report
	km/hr	km/hr	metres/second	
1	63 to 88	89 to 124	24.5 to 32.5	Gale Force
2	89 to 117	125 to 164	32.6 to 45	Storm Force
3	118 to 162	165 to 224	45.1 to 63	Hurricane Force
4	163 to 198	225 to 252	63.1 to 78	Very destructive*
5	Over 199	Over 280	Over 78	(Not referred to)**

Note: **Category 4 strength winds were not experienced in the locations assessed for this report*
*** Category 5 strength winds have not been experienced over land in this region during the study period*

Ten tropical cyclones have crossed the coastline in the study area since 1991 (Table 2). Two of these, Severe TC Larry (2006) and Severe TC Yasi (2011) passed over land as Category 3 or 4 systems, bringing wind gusts in excess of 163 km/hr, causing major damage to property, infrastructure, crops, native vegetation and tree plantations. The less intense cyclones have also caused moderate to major damage at specific sites, but the damage was more localised in extent. A notable exception was TC Justin (1997) which tracked west then south after crossing the coast near Cairns, and caused minor to moderate damage over inland areas south to Ingham. There have also been numerous occasions when gale force winds have been caused by cyclones located offshore in the Coral Sea, or in the Gulf of Carpentaria.

Table 2. Cyclones that have crossed the coast between Daintree and Townsville 1991 - 2011 (Source: BOM website)

Date	Name	Nearest Town	Intensity at landfall
March 1997	TC Justin	Cairns	Category 2
February 1998	TC Rona	Mossman	Category 2
February 1999	TC Steve	Cairns	Category 2
April 2000	TC Tessi	Ingham	Category 2
February 2001	TC Abigail	Cairns	Category 1
March 2006	Severe TC Larry	Innisfail	Category 3
February 2009	TC Ellie	Mission Beach	Category 1
January 2010	TC Olga	Innisfail	Low Pressure System
January 2011	TC Anthony	Cairns	Category 1
February 2011	Severe TC Yasi	Mission Beach	Category 4

Note: TC Olga approached the coast near Cooktown as a Category 2 system and generated gale-force winds in the Daintree - Mossman area, but degenerated and crossed the coast near Innisfail as a low pressure system

Severe Tropical Cyclone Yasi

Severe TC Yasi was the largest and most powerful cyclone to impact the eastern coast of Australia since 1918. The cyclone crossed land near Mission Beach, and produced hurricane-force winds to coastal areas between Innisfail and Ingham, including the Tully valley and upper Herbert valley around Abergowrie. Storm-force winds were experienced on the coast and ranges between

Babinda and Townsville, while gale-force winds caused extensive damage from Daintree to Sarina, and several hundred kilometres inland. Areas south of the cyclone experienced stronger winds for a longer period than areas a corresponding distance away on the northern side.

METHODS

Wind speed estimates

The project co-ordinator (Select Carbon Pty Ltd) provided DAFF with estimates of the maximum expected wind speed at the experimental sites and growth plots used for this study. The wind speed estimates were drawn from three different sources.

The highest degree of precision relates to the boundary between Category 3 and Category 2 winds (maximum 0.2 second gust of 45 m/sec ± 10% at 10 m height in open terrain, excluding local topographic effects), which was derived from Figure 5 in the research paper "'Cyclone Yasi' windfield re-visited" (Holmes 2012)[i]. This information was restricted to the area between Innisfail and Cardwell. A second source was used for the area between Cardwell and Ingham, that source being Figure 2.7 in James Cook University's Cyclone Testing Station Technical Report 57 (Boughton *et al* 2011)[ii]; the Category 3-Category 2 boundary was interpreted and interpolated using the maximum 3-second gust of 160 km/hr ± 10% at 10 m height over Terrain Category 2 (AS/NZS 1170.2)[iii]; with the caveat that the model used (Holland, 1980)[iv], excludes large-scale topographic effects (both amplification and shielding).

The approximate boundary between Category 2 and Category 1 was derived by Select Carbon using a range of data sources. Principally, the boundary was generated by GIS analysis of a map produced and displayed on the internet by the Bureau of Meteorology (BOM), which shows areas that received "gale force winds" (interpreted as Category 1), "destructive winds" (interpreted as Category 2) and "very destructive winds" (interpreted as Category 3 or greater). The BOM map was supplemented by field observations and local knowledge. The BOM map was based on broad-scale modelling of atmospheric conditions which may not or may not relate to on-ground wind speeds. Where there was disagreement between the BOM map and the other sources, the other sources were given primacy.

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[i] Holmes, JD (2012) 'Cyclone Yasi' windfield revisited. 15th Australasian wind engineering society workshop, Sydney, 23-24 February, 2012.

[ii] Boughton, GN, Henderson, DJ, Ginger, JD, Holmes, JD, Walker, GR, Leitch, CJ, Somerville, LR, Frye, U, Jayasinghe, NC, and Kim, PY (2011) Tropical Cyclone Yasi structural damage to buildings. Technical report 57. James Cook University School of Engineering and Physical Sciences Cyclone Testing Station, Townsville

[iii] Standards Australia (2002) AS/NZS 1170.2: 2002 Structural design actions Part 2: Wind actions. AS/NZS 1170.2: 2002, Standards Australia, Sydney, NSW, Australia

[iv] Holland, GJ (1981) An analytic model of the wind and pressure profiles in hurricanes, *Monthly Weather Review* 108 pp 1212 - 1218

Select Carbon also recommended a distinction be drawn between areas that received winds described as "High Category 2", as distinct from "Low Category 2". This divided areas around Mena Creek (High Category 2) from those north of South Johnstone and around Ravenshoe; and also divided the areas near to Ingham (High Category 2) from those south of Bambaroo (Low Category 2). The division was based on Select Carbon's field observations, and the closeness of the "High Category 2" areas to the boundary between Category 2 and Category 3.

Sampling locations

The sites inspected were of two broad types: either experiments which had been planted and maintained under DAFF supervision, or growth plots which were set up in woodlots that had already been established. The experimental stands were established and maintained to a very high standard, and detailed records were available regarding genetics, growth and maintenance operations. The growth plots varied considerably in quality of plantation establishment and maintenance, and stand history details were less well documented.

It was quite apparent that tree age played a significant role in cyclone resilience. Throughout this report the sampling locations are differentiated by tree age; eight years was arbitrarily chosen as a dividing point, which reflects the fact that most trees planted between 2003 and 2006 were destroyed by Severe TC Larry. It also forms a neat divide separating DAFF's older research trials (focussed on small-scale mixed species plantings of numerous Australian rainforest species), from trials established since 2006, focussed on species suited to broad scale plantation forestry: *Eucalyptus pellita, Khaya* species and *Tectona grandis*.

The sampling locations were distributed across the region, and experienced a range of wind speeds during Severe TC Yasi (Table 3). Further details are provided below, and summarised in Tables 4a - 4d. The location of the sites is shown in Appendix 1.

<u>Table 3.</u> Numbers of sites assessed for cyclone damage

Description	Maximum wind strength			
	Category 1	Category 2	Category 2 (high)	Category 3
DAFF experiments > 8 years	2	2		2
DAFF experiments < 8 years	1	2	5	4
Growth plots > 8 years	4	9	15	8
Growth plots < 8 years		4	3	
Total sites assessed	7	17	23	14

Details of species and planting pattern were analysed for difference in cyclone resilience. The sites were either planted with rainforest species, eucalypts or a mixture of the two. A variety of planting patterns were used in the experiments and growth plots. Common patterns included successive lines of species (often one line of eucalypt, one line of rainforest species), random patterns and monocultures. Some experiments (mono plots) were planted as small plots of monocultures, say six rows by eight trees, of different species.

DAFF experiments older than 8 years

Several trials were established in the early 1990s around Innisfail and Tully examining the growth rates, nutrition and silviculture of native rainforest trees believed to have potential for plantation forestry. The main species examined were black bean, hoop pine, kauri pine, Queensland maple and silver quandong. At each site a sample of trees were assessed. In 2002 new trials were planted near Mossman and Babinda examining monocultures and mixed-species stands of Queensland maple, red mahogany (*Eucalyptus pellita*), silver quandong and teak. The Babinda trials were destroyed by Severe TC Larry in 2006, and although the trials at Mossman were not exposed to cyclone-strength winds during Severe TC Yasi, they provided useful reference data for comparing with other sites.

Table 4a. Site details for older DAFF trials (maximum wind shows cyclone category)

Expt - plot	Year Planted	Locality	Species Type	Pattern	Main species	Max. wind
740-1B	1992	Jarra Creek	Rainforest	Monoculture	QMP	3
740-2C	1993	Feluga	Rainforest	Lines	HP-, NKR, BBN	3
740-3B	1994	South Johnstone	Rainforest	Mono Plots	QMP, NKR, BBN	2
743	1994	South Johnstone	Rainforest	Mono Plots	QMP	2
863-A	2002	North Mossman	Mixed	Mono Plots	RMM, QMP, SLQ	1
863-B	2002	Whyanbeel	Mixed	Lines	TGT	1

DAFF experiments younger than 5 years

Between 2006 and 2010 DAFF established trials in partnership with private forestry companies to evaluate germplasm of *Eucalyptus pellita* (Elders Forestry), *Khaya senegalensis* and *Tectona grandis* (Great Southern Ltd). DAFF also planted small areas intended for production of improved seed of *Acacia mangium, Eucalyptus grandis* and *E. pellita.* Two African mahogany trials (522-D and 766-D) were assessed in full at the time of scheduled inventory, soon after the cyclone (photo on page 2). For the other trials, a sample of trees was assessed for this report, or the trial was fully destroyed.

Table 4b. Site details for younger DAFF trials.

Expt - plot	Year Planted	Locality	Species Type	Pattern	Main species	Max wind
471*	2005	Tumoulin	Eucalypt	Monoculture	RSG	1
522-D	2006	Warrabullen	Rainforest	Lines	KNY, KSE	High 2
667-B	2008	Mena Creek	Rainforest	Monoculture	TGT	High 2
668-B	2008	Mena Creek	Rainforest	Monoculture	TGT	High 2
744-B*	2008	Abergowrie	Rainforest	Monoculture	KSE	3
745-B*	2007	South Johnstone	Eucalypt	Monoculture	RMM	2
746-B*	2007	Echo Creek	Eucalypt	Monoculture	RMM	3
746-C*	2010	Helens Hill	Eucalypt	Monoculture	RMM	High 2
746-D*	2010	Bilyana	Eucalypt	Monoculture	RMM	3
746-E*	2010	Daradgee	Eucalypt	Monoculture	RMM	2
766-D	2008	Abergowrie	Rainforest	Monoculture	KSE	3
862-C*	2007	Warrabullen	Rainforest	Monoculture	BSM	High 2

**Trial assessed but no data included in analysis*

Growth plots older than 8 years: Experiment 799ATH (CRRP growth plots)

During the 1990s several hundred small-scale woodlots were established on private land in north-east Queensland under the Community Rainforest Reforestation Program (CRRP). The woodlots were established by crews employed by the CRRP, using species selected by CRRP staff. From 1995, DAFF established a network of growth plots within the CRRP estate (experiment 799ATH), and measured the plots periodically until 2002. The distribution of the plots across the region, and the availability of pre-cyclone data made the plots highly suited for cyclone damage assessment.

Table 4c. Site details for the older growth plots (CRRP plots - Experiment 799).

Expt plot	Year Planted	Locality	Species Type	Pattern	Major species (by frequency)	Max wind
799-27	1993	Tumoulin	Eucalypt	Lines	RSG,RMY	1
799-28	1993	Tumoulin	Eucalypt	Lines	GMS,GIB	1
799-33	1993	Evelyn Central	Eucalypt	Lines	RSG,RRG	2
799-34	1993*	Evelyn Central	Mixed	Random	RSG, various	2
799-35	1993	Vine Creek	Rainforest	Monoculture	HP-	2
799-36	1993*	Vine Creek	Rainforest	Lines	NKR, various	2
799-37	1993*	Vine Creek	Mixed	Lines	RSG,NKR,GMS	2
799-44	1993*	Murray Upper	Mixed	Lines	FRG,RMM,QMP	3
799-45	1993	Murray Upper	Mixed	Lines	FRG,RMM,QMP	3
799-46	1993	Utchee Creek	Mixed	Random	RMM, various	2
799-51	1993*	Murray Upper	Rainforest	Random	various	3
799-52	1993*	Murray Upper	Rainforest	Random	various	3
799-53	1994*	Dingo Pocket	Mixed	Random	HP-,RMM,SLQ	3
799-54	1994*	Dingo Pocket	Mixed	Random	GMS,QMP,BBN	3
799-59	1996	Edmonton	Mixed	Lines	RMM,QMP	1
799-61	1996	Julatten	Mixed	Lines	RMM,QMP,BSM	1
799-62	1996	Julatten	Mixed	Lines	RMM,QMP	1
799-63	1993	Hawkins Creek	Rainforest	Random	QMP,SLQ,BBN	High 2
799-64	1995*	Abergowrie	Rainforest	Lines	BBN,BSM,QSA	3
799-65	1993	Abergowrie	Mixed	Random	NKR, various	3
799-66	1994	Ingham	Mixed	Random	various	High 2
799-67	1994	Ingham	Mixed	Random	various	High 2
799-68	1994*	Helens Hill	Eucalypt	Lines	FRG,GMS,RMM	High 2
799-69	1994	Helens Hill	Rainforest	Random	QMP,RBN,BBN	High 2
799-70	1994*	Yuruga	Eucalypt	Random	RMM,FRG,DMN	High 2
799-71	1994*	Yuruga	Eucalypt	Random	BSM,RMM,FRG	High 2
799-72	1994	Jourama	Mixed	Random	DMN,QMP,BBN	High 2
799-73	1994	Jourama	Mixed	Random	WMY,RMM,BKD	High 2
799-74	1994*	Bambaroo	Mixed	Random	FRG,CDG,GMS	High 2
799-75	1994*	Bambaroo	Mixed	Random	FRG,BSM,MLE	High 2
799-76	1995	Micheal's Creek	Eucalypt	Lines	GMS	High 2
799-77	1995	Micheal's Creek	Eucalypt	Lines	GMS, WMY	High 2
799-81	1994*	Upper Stone	Mixed	Random	RMM, various	High 2
799-82	1994*	Upper Stone	Mixed	Random	BSM, various	High 2
799-87	1996	Babinda	Rainforest	Lines	SLQ,WCD,QMP	2
799-104	1994	South Mossman	Mixed	Random	various	1

**Plot not measured*

Thirty-six of the CRRP growth plots were inspected and assessed, between Mossman and Bambaroo, inland to Julatten, Ravenshoe and Mount Fox. Thirteen extra plots located around Innisfail were inspected, but the stands had been effectively destroyed by Severe TC Larry. Re-locating the plots proved quite difficult in some cases, as plot pegs had deteriorated and been destroyed, particularly due to cyclone-related debris. Therefore not all of the 36 plots were re-measured.

Growth plots younger than 8 years: Experiment 867ATH (African mahogany growth plots)

Since the late 1990s there has been increasing interest amongst small-scale forest growers in *Khaya senegalensis,* particularly in the drier areas south of Ingham. DAFF have established a series of growth plots in young woodlot plantations of African mahogany; seven of these experienced storm-force winds during Severe TC Yasi, and the results of post-cyclone assessments have been summarised for this report.

Table 4d. Site details for the younger growth plots (Experiment 867).

Expt - plot	Year Planted	Locality	Species Type	Pattern	Main species	Max wind
867-25	2003	Rollingstone	Rainforest	Monoculture	KSE	2
867-26	2004	Rollingstone	Rainforest	Monoculture	KSE	2
867-32	2002	Balgal Beach	Rainforest	Monoculture	KSE	2
867-33	2002	Balgal Beach	Rainforest	Monoculture	KSE	2
867-36	2006	Helens Hill	Rainforest	Monoculture	KSE	High 2
867-37	2007	Helens Hill	Rainforest	Monoculture	KSE	High 2
867-38	2008	Helens Hill	Rainforest	Monoculture	KSE	High 2

Damage assessment

At each site individual trees were assessed for Lean, Stem Breakage and Crown Viability, ranked as negligible, minor or major, as defined in Table 5. This was used to calculate stand-level resilience, and then combined to determine species-specific resilience. Stand resilience was calculated as the percentage of undamaged trees plus half of the percentage of degraded trees. Species resilience was based solely on the percentage of undamaged trees. A tree was considered to be degraded if it had minor lean or stem breakage or major loss of crown viability. A tree was considered to be destroyed for the purpose of timber production if it had major lean or break damage, or minor damage for both lean and breakage.

Table 5. *Cyclone damage categories used in field assessment*

Factor	Negligible	Minor	Major
Lean	0 - 10%	10 - 30%	>30%
Breakage	No stem breakage	Broken above 6 metres	Broken below 6 metres
Crown viability	No obvious damage	Obvious damage, from which tree should recover within 12 months	Obvious damage from which tree is not likely to ever recover pre-cyclone productivity

Timing

The older experiments and growth plots were assessed between December 2011 and February 2012, approximately a year after Severe TC Yasi, as was experiment 522-D. Most of the younger trials were assessed in the weeks and months after the cyclone, and written off. Experiment 744-D and 766-D was measured in May 2011 as part of scheduled inventory. The younger growth plots were measured in July 2011.

In most cases it was reasonably easy to determine the damage related to Severe TC Yasi. However some of the deaths and leaning were probably caused by Severe TC Larry, or some other event, including periods of prolonged dry or wet soil. An effort was made to compensate for this, but it is probable that the figures reported will tend to over-estimate the damage due to Severe TC Yasi.

RESULTS

Cyclone damage types

Overview

Severe TC Yasi has caused major damage to small-scale woodlots in the Cassowary Coast and Herbert Valley regions. The damage has varied from place to place, but broadly in areas where the maximum wind gusts exceeded 163 km/hr (Category 3 strength), the woodlots have been essentially destroyed. Significantly, three woodlots in the Category 3 area suffered only modest damage, highlighting the erratic nature of cyclonic wind. In areas where the winds were less destructive, there has been variation in damage between sites, species and individual trees. The following discussion provides an outline of some of the variation that has been observed.

Lean

Lean is an objective measurement, which relies on subjective assessment of (a) the extent that it was caused by the cyclone; and (b) the extent that it will be a problem in the future. For the purpose of this project, a lean up to 10% off vertical was considered to be negligible, while more than 20% was considered unacceptable. However this was somewhat of a coarse measure, since small trees with a lean will most likely be able to grow straight in time. It was sometimes hard to tell if the lean was entirely due to the cyclone, or (often) due to the tree growing towards a gap in the canopy, or away from a dominant neighbour.

It was frequently observed that the tallest trees, or those with the largest crown, had more lean than others in the stand. In mixed species stands, this was often the Queensland Maple trees (Figure 1). In monocultures, it was generally the trees that had the best form as well as the largest volume. In many locations it was obvious that the main damage occurred at boundaries between tall and short trees, or where trees were growing beside gaps. A clear illustration of this was in the African Mahogany provenance trial at Abergowrie, where trees in the buffer rows of each plot suffered more damage than those in the plot proper. It is thought that the relatively uniform height of the trees in the plot made them less prone to damage, whereas the buffer trees were generally taller or shorter than those in the next plot.

Figure 1. *The Queensland maple at the front left had the largest diameter and crown area, and is now "degraded" due to lean; the smaller trees behind are not leaning. Murray Upper (Category 3 wind)*

Stem Breakage

Initially the criteria for judging the severity of stem breakage was based on the height of the tree, where a stem broken above half-height was only "degraded", but those broken below half-height were deemed to be destroyed. However this definition was not especially meaningful, given the varying heights of trees within the stand, and varying rates of growth between stands. It was therefore decided to judge whether a merchantable log (minimum length 6.0 metres) could be obtained below the break. If the break occurred above six metres the stem was degraded, below six metres the stem was destroyed.

It became apparent that several stands have had previous episodes of damage. For instance at Edmonton most of the eucalypts forked at around two to three metres, and the file notes showed that this was largely due to TC Justin (1997). In the Herbert Valley and Mount Fox, forking occurred on many stems at around five to eight metres; this may well have been due to damaged caused by TC Tessie in 2000. Severe TC Larry caused major damage to trees planted between Babinda and Murray Upper, including the Atherton Tablelands. Much of the damage caused in areas peripheral to Severe TC Yasi was actually due to re-breakage: the fork became the point of weakness in the height of the storm.

Stem breakage was not always due to the direct action of the wind. Smaller trees suffered breakage when stems and branches from taller trees fell on to them. On the whole however, the shorter trees had less breakage, because they were protected from the strongest winds. It is therefore difficult to compare the percent breakage between species. However some species such as kauri pine seemed to be predisposed to breaking (Figure 2).

<u>Figure 2.</u> *These kauri pines were broken by Severe TC Larry, and then re-broken by lower-strength winds from Severe TC Yasi. Babinda (Category 2 wind); photo taken 10 months post-Yasi.*

Eucalypt species varied in their incidence of breakage, however tallowwood (*Eucalyptus microcorys*) proved to be highly susceptible during Severe TC Larry, causing damage to horticultural crops on the Atherton Tablelands where it had been widely planted as a windbreak. No tallowwoods were seen alive during the field work for this report.

Crown Damage

One of the most dramatic signs of cyclone damage is the stripping of leaves from the forest canopy. It is reasonable to assume that this will result in a reduction in tree growth. In the field assessment of crown damage, an attempt was made to determine if the loss of growth would be short-term or long-term in nature. Minor crown damage was scored if there was evidence of small branches being stripped off, and the crown mainly comprising young leaves. Major crown damage usually involved a loss of large branches, generally with a profusion of epicormic shoots arising from the stem. Within a stand it was generally clear that some individuals had lost a greater proportion of the crown than others (Figure 3).

<u>Figure 3.</u> *Gympie messmate trees with minor crown damage (LHS) and major crown damage (RHS) Michael's Creek, Mount Fox (high Category 2 wind)*

Crown damage was the most difficult form of damage to assess objectively, since there was no pre-cyclone data about the crown to compare with. Species-specific leaf flush patterns, competition from neighbouring trees and the length of time since disturbance all affect the assessment of crown damage. For some species the ability to lose their leaves and re-shoot may be part of their adaptation to high wind: crown stripping was normally scored for eucalypts, especially those species that came through the cyclone with minimal lean or break. To avoid a negative bias against these species it was decided to ignore minor crown damage, and only regard a tree as degraded if it had major crown damage. Trees with very severe crown damage were generally dead or effectively destroyed due to major stem breakage.

Dead stems

The proportion of dead trees shown in the tables is almost certainly an over-estimate of the impact of Severe TC Yasi, since the deaths may have also been caused by Severe TC Larry or other, unrelated causes. For instance, drought killed most of the silver quandongs in the Herbert Valley in 2003-04. It was very notable that numerous individuals of some species died after the cyclone, standing upright, particularly Queensland maple (Figure 4) and silver quandong, and to some extent for Gympie messmate.

Figure 4. *A monoculture of Queensland maple showing numerous dead stems standing vertically. Jarra Creek (Category 3 wind). Photo taken twelve months after Severe TC Yasi.*

Stand resilience

Stand resilience of the twenty older growth plots were stratified according to the type of species planted (eucalypt, rainforest or mixed) and the pattern of planting (lines or random); only one monoculture growth plot was assessed, and this was combined with the linear - planted plots. The average stand resilience was calculated for each category within a modelled wind speed region (Table 6). Although there was quite a deal of variation between sites, the table shows that resilience is reasonably consistent in the lower wind categories, but the damage increases exponentially at the very highest wind speed.

Table 6. Average stand cyclone resilience (percent undamaged stems + 50% of degraded stems)

Description	Maximum wind strength			
	Category 1	Category 2	Category 2 (high)	Category 3
Species Type				
Eucalypt	81%	51%	53%	
Mixed	75%	43%*	61%	35%
Rainforest		85%	81%	
Planting pattern				
Lines	73%	74%	53%	37%
Random	95%	43%*	67%	34%
Overall	**77%**	**66%**	**64%**	**35%**

*Note: * This category contained only one plot, which had been badly damaged by Severe TC Larry, and much of the damage was believed to be due to re-break.*

Species resilience

A total of 8100 trees were assessed for cyclone damage, comprising 44 species in 36 localities. Assessment details are presented in Table 7 for trees older than 8 years (Table 7a) and for 4 species of trees younger than 8 years (Table 7b).

Table 7a. *Cyclone damage assessment (trees older than 8 years) showing percentage undamaged trees for each species in each wind speed category. Total number of trees assessed shown in brackets.*

Species Common name	CODE	Maximum wind strength Category 1	Category 2	Category 2 (high)	Category 3
Acacia aulacocarpa brown salwood	BSL				0% (1)
Acacia mangium brown salwood	BSM	100% (2)		54% (13)	0% (5)
Acacia melanoxylon blackwood	BKD			0% (3)	
Agathis robusta Queensland kauri pine	NKR	100% (3)	76% (33)	0% (1)	45% (42)
Alphitonia petriei pink ash	PKA		0% (1)		
Alstonia scholaris white cheesewood (Milky Pine)	WCW		100% (2)		
Araucaria cunninghamii hoop pine	HP-		91% (58)	50% (2)	11% (28)
Argyrodendron peralatum red tulip oak	RDT		75% (4)	100% (2)	
Blepharocarya involucrigera rose butternut	RBN		100% (1)	80% (10)	
Castanospermum australe black bean	BBN	100% (3)	50% (24)	87% (15)	62% (42)
Cedrela odorata West Indian cedar	WIC		100% (6)		0% (3)
Corymbia citriodora subsp. citriodora spotted gum	SGU			0% (6)	
Corymbia torelliana cadaga	CDG	100% (6)		83% (6)	
Elaeocarpus grandis silver quandong	SLQ	43% (105)	86% (21)	80% (5)	80% (10)
Eucalyptus acmenoides white mahogany	WMY	67% (3)		44% (27)	
Eucalyptus camaldulensis river red gum	RRG		40% (15)		
Eucalyptus cloeziana Gympie messmate	GMS	90% (30)		72% (54)	
Eucalyptus drepanophylla grey ironbark	GIB	73% (15)			
Eucalyptus grandis rose gum	RSG	87% (23)	62% (21)	50% (2)	0% (4)
Eucalyptus pellita red mahogany	RMM	68% (196)	41% (22)	81% (16)	40% (10)
Eucalyptus resinifera red mahogany	RMY	62% (13)		50% (2)	
Eucalyptus tereticornis forest red gum	FRG			100% (3)	13% (8)
Eucalyptus urophylla Timor white gum	EUT	100% (2)			

Species Common name	CODE	Maximum wind strength Category 1	 Category 2	 Category 2 (high)	 Category 3
Flindersia australis Crow's ash	CRA				0% (1)
Flindersia bourjotiana silver ash	QSA			0% (2)	
Flindersia brayleyana Queensland maple	QMP	61% (196)	76% (143)	50% (20)	64% (147)
Flindersia ifflaiana hickory ash	HKA	100% (1)			
Flindersia pimenteliana maple silkwood	MSW		0% (1)		
Flindersia schottiana silver ash	SSA	100% (2)			0% (3)
Grevillea robusta southern silky oak	SSO			67% (6)	75% (4)
Khaya nyasica African mahogany	KNY	100% (3)			
Khaya senegalensis African mahogany	KSE	100% (2)			
Lophostemon confertus brush box	BBX	80% (5)			
Melaleuca leucadendra broad-leaved tea-tree	MLE			0% (1)	
Melia azedarach white cedar	WCD		50% (6)		0% (1)
Miscellaneous spp. Unknown minor species	MIS	100% (5)	50% (3)		
Nauclea orientalis cheesewood	CWD		70% (10)		100% (1)
Neonauclea gordoniana hard leichhardt	HLH			71% (7)	
Paraserianthes toona red siris	RSR	75% (4)		75% (8)	
Syzygium australe creek satinash	CKS	88% (8)			
Syzygium tierneyanum Bamaga satinash	BMS	50% (4)			
Tectona grandis teak	TGT	95% (39)			0% (5)
Terminalia sericocarpa damson	DMN			68% (19)	14% (7)
Toona ciliata red cedar	RCD			100% (1)	

Table 7 shows the percentage of trees that were assessed as undamaged in each wind category and does not include degraded stems. The percentages are based on the pre-cyclone numbers: that is, the sum of those that are still alive and those that are dead. Some tree death is likely to have been caused by factors other than the cyclone, so the percentages shown are over-estimates of damage.

Gaps in the table indicate that no data was available for a particular species in a specific wind speed category.

Table 7b. *Cyclone damage assessment (trees younger than 8 years) showing percentage undamaged trees for each species in each wind speed category. Total number of trees assessed shown in brackets.*

	Maximum wind strength			
Species Common name	Category 1	Category 2	Category 2 (high)	Category 3
Eucalyptus pellita red mahogany (pellita) RMM				21% (112)
Khaya anthotheca African mahogany, wet zone KNY				25% (266)
Khaya senegalensis African mahogany, dry zone KSE		99% (217)	96% (158)	45% (5568)
Tectona grandis teak TGT			95% (227)	

DISCUSSION

Wind-speed

Severe tropical cyclones can generate wind speeds which are amongst the highest recorded anywhere in the world. Since the damage caused by wind increases exponentially as wind speed increases, forestry plantations located close to the path of a severe tropical cyclone are likely to be very badly damaged, as are horticultural crops, native vegetation and buildings. This was the case in Severe TC Yasi in 2011, as it was in Severe TC Larry in 2006. However the very destructive core of a cyclone is generally quite narrow, and degenerates rapidly after crossing land, so areas located inland and either side of the cyclone path receive much less powerful winds. To some extent there is an element of luck, since the likelihood of development, and the path the cyclone follows, seems to be mostly determined by ever-changing synoptic scale factors that cannot be planned for. The fact that two severe tropical cyclones crossed the coast within five years in the Innisfail - Mission Beach area has no influence on where future severe cyclones will cross. Similarly some sites located close to the path of the cyclone emerged relatively undamaged (Figure 5), presumably having been favoured by the aspect of the site they were planted on so they were sheltered by the surrounding hills; since winds rotate in a cyclone, it would be impossible to incorporate this good fortune into plantation design.

Since 1991 less than a third of the study area has experienced winds of category 3 strength, whereas most coastal areas have experienced winds equivalent to a category 2 cyclone at least twice, and category 1 winds several times. In the following discussion emphasis is placed on resilience observed in stands which experienced category 2 strength winds, which are demonstrably much more likely than category 3 strength winds.

Figure 5. This mixed-species stand at Abergowrie appears virtually undamaged, while areas nearby were devastated. This stand was modelled to have been within the Category 3 wind area

Species

Clear differences were observed in cyclone resilience between species. The performance of each species varied depending upon site factors, tree age, stand composition and wind speed, however five species were considered to have notably superior resilience to cyclones:

- Silver quandong (*Elaeocarpus grandis*)
- Queensland maple (*Flindersia brayleana*)
- Gympie messmate (*Eucalyptus cloeziana*)
- Rose gum (*Eucalyptus grandis*)
- Red mahogany (*Eucalyptus pellita*).

An attempt has been made to integrate the observed variation into a single, simple rating for each species which was observed on multiple sites and cyclone categories (Table 8). Also listed are relative tree form and relative growth rates, as these are related to cyclone resilience, and the combination of these factors are likely to affect the overall stand performance.

The following paragraphs emphasise key observations about the species made after Severe TC Yasi. It should be reiterated that the observations recorded here are not a guarantee of future performance, as site factors and management make each situation unique, and the dynamics of each cyclone are notoriously variable. It is also quite possible that a more detailed investigation would reveal patterns not observed or recorded in this study.

Elaeocarpus grandis (silver quandong) is a very fast-growing, very well-formed tree with an open-grown crown which was observed to have the least damage of all species assessed. The species is quite site-sensitive, intolerant of long dry spells, prolonged waterlogging, frost and infertile soils;

under these conditions, cyclone resilience is reduced. The species is also short-lived, with most stems showing signs of senescence by age 18.

Flindersia brayleana (Queensland Maple) typically has a much larger crown than silver quandong, which may explain why a proportion of trees develop a slight lean. In the areas hit by the strongest winds it was observed that many trees survived the cyclone but died in the following months, standing upright (as was also true of silver quandong). This may be advantageous in the event of salvage harvesting. There are several other *Flindersia* species that have been planted in the region, but none were represented in sufficiently large numbers to adequately assess resilience.

Eucalyptus pellita is a very fast-growing tree that was planted extensively in coastal areas subjected to the most destructive winds, and was generally the tallest tree planted in such stands. In numerous locations individual *E. pellita* were observed with little or no damage, standing tall above destroyed neighbours; this was especially true in several of the stands where the plot was unable to be located. The commonest form of breakage was a shattering stem break, usually in the upper half of the tree; adjacent mid-stratum trees would commonly also have a stem break, perhaps caused by the falling top of the *E. pellita.* Trees that broke in severe TC Larry appeared to reshoot at the height of the break and redevelop apical dominance, but this became a point of weakness during severe TC Yasi. It appeared that such stems were also prone to decay, so any salvage would need to occur reasonably soon after the cyclone. Young *E.pellita* trees have very poor resilience, as do older trees planted on poor sites, and stands that have been recently thinned.

Eucalyptus cloeziana and *Eucalyptus grandis* are very well-formed and fast grown trees that appeared to suffer minimal damage other than loss of crown and small branches. These species were typically planted on sites away from the coast, where the wind speeds were less extreme, and these factor should be considered in any interpretation of these observations. Other eucalypt species varied from site to site in their cyclone resilience and their overall health and vigour. A notable exception was *Eucalyptus microcorys* (tallowwood) which had a very high incidence of stem breakage during severe TC Larry; however no tallowwood trees were seen alive in the plots selected for this study.

Agathis robusta (kauri pine) and *Araucaria cunninghamii* (hoop pine) are native conifers characterised by slow early growth. Kauri pine was assessed at several sites during this study, and displayed a characteristic pattern of stem breakage within a few metres of the top, usually where the stem diameter was around 10 cm. Thus a tree that was 15 metres tall would break at say, 12 metres above the ground, whereas a tree that was 6 metres tall would break at 3 metres above the ground. The tree reacts to damage by sending multiple shoots from the height of the break, and these shoots are prone to breaking in subsequent cyclones. The same appeared true of hoop pine, although fewer trees were assessed. Unlike *E. pellita* there appeared little sign of decay in kauri pine trees that had been broken during severe TC Larry, suggesting a more effective internal wound response mechanism. If this was demonstrated to be the case, growers could consider retaining trees with broken stems for potential future harvest.

Table 8. Overall rating of cyclone response of main species assessed (trees older than 8 years)

Scientific name	Code	Indicative rating	Typical cyclone damage	Form	Growth
Elaeocarpus grandis	SLQ	Very Good	Minor branches break, some stem break. Some trees die after the cyclone, standing upright	Very Good	Fast
Tectona grandis (immature trees)	TGT	Very Good	Young trees had almost no damage, but mature plantations had very poor resilience - see comments below	Good	Moderate
Flindersia brayleyana	QMP	Good	Leaning (large trees), Stem break (rare). Some trees die after the cyclone, standing upright.	Good	Fast
Eucalyptus cloeziana	GMS	Good	Crown thinning or minor stem break	Very Good	Fast
Eucalyptus grandis	RSG	Good	Crown thinning or minor stem break	Very Good	Fast
Eucalyptus pellita (mature trees)	RMM	Good (mature)	Stem break, crown thinning. nb: young *E.pellita* trees have very poor resilience - see comments below	Very Good	Very Fast
Agathis robusta	NKR	Average +	Stem break (characteristically a few metres from top)	Very Good	Slow (early)
Araucaria cunninghamii	HP-	Average +	Stem break (characteristically a few metres from top)	Very Good	Moderate
Blepharocarya involucrigera	RBN	Average	Stem break	Average	Slow (early)
Corymbia torelliana	CDG	Average	Crown thinning (branches break)	Poor	Moderate
Eucalyptus acmenoides	WMY	Average	Stem break and/or crown thinning	Good	Moderate
Eucalyptus resinifera	RMY	Average	Stem break and crown thinning	Average	Moderate
Eucalyptus tereticornis	FRG	Average	Crown thinning. Little damage observed – usually suppressed.	Average	Slow (early)
Grevillea robusta	SSO	Average	Stem break	Good	Moderate
Nauclea orientalis	CWD	Average	Stem break – near top of tree	Average	Slow (early)
Periserianthes toona	RSR	Average	Stem break (rare). Mid-storey tree	Very poor	Very slow
Terminalia seriococarpa	DMN	Average	Stem break	Average	Slow
Khaya anthotheca (immature trees)	KNY	Average (immature)	Stem break and/or lean (large trees)	Very Good	Moderate
Khaya senegalensis (immature trees)	KSE	Average (immature)	Leaning (largest trees in stand). Sites observed probably wetter than ideal for this species suited to drier areas	Poor	Moderate
Castanospermum australe	BBN	Poor	Stem break. Many forks.	Poor	Slow
Cedrela odorata	WIC	Poor	Stem break low to ground.	Good	Fast
Melia azedarach	WCD	Poor	Stem break	Average	Moderate
Tectona grandis	TGT	Poor	Stem break and/or lean. Young plantations hardly damaged	Good	Moderate

Acacia mangium	BSM	Very Poor	Stem break and/or lean (damages neighbours)	Poor	Very Fast
Eucalyptus pellita (immature trees)	RMM	Very Poor (immature)	Leaning, crown stripping *E.pellita* less than 5 years suffered catastrophic damage levels (>75%)	Very Good	Very Fast

Key
Very Poor: Extensive tree damage and / or death. Very few remaining trees of long term commercial value (< 25% commercial)
Poor: Extensive tree damage and some tree death. Some remaining trees of long term commercial value but significant defect (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. (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 increased incidence of defect (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 (> 75% commercial).

Many of the other rainforest species assessed were mid-storey species, or very slow grown. These species suffered damage from falling limbs and stems from adjacent trees. It is unknown how such species may behave in stands where they are dominant or co-dominant. One species, *Castanospermum australe* (black bean) was planted in a monoculture at South Johnstone, but this appeared to be an unsuitable site, possibly due to grass competition and insect damage; the trees were poorly formed and prone to excessive forking.

Khaya anthotheca and *K. senegalensis* are moderately fast growing species which were not included in the early CRRP plantings, but which have been the subject of research interest in the past decade. The sites where the species were planted were subjected to very destructive winds (high Category 2 or Category 3), and many trees were damaged or destroyed. However differences were observed between different seed sources (details presented below), implying that cyclone resilience could be improved through breeding. In areas of moderate wind speed (Category 2) the mahogany trees in plantations suffered remarkably little damage, in contrast to open-grown trees that were reported to have caused major damage in parks and gardens around Townsville. Dr. Ross Coventry (Soil Horizons Pty Ltd) has noted that the *Khaya* trees in plantations at Balgal Beach have very shallow root systems, which appear to be grafted (evidenced by herbicide movement), and has hypothesised that the trees may have a mutual plate-like root network which confers a degree of stability during strong winds (Ross Coventry, pers. comm.)

The timber species found to be poorest for cyclone resilience were *Cedrela odorata* (West Indian cedar), *Melia azedarach* (white cedar) and *Tectona* grandis (Teak). These species were highly susceptible to breakage, and recovered poorly from damage. Young teak trees appeared to suffer almost no cyclone damage, but stands older than five years were decimated. This contrast may be partly due to clonal differences or site factors, but it also seems to correlate with tree architecture, which changes from narrow-crowned with few side branches when young to broad-crowned later when they mature.

Acacia mangium was the worst species for cyclone resilience. This species is grown extensively for wood production in south-east Asia, but in Australia it is more commonly planted to improve the availability of nitrogen, fixed by bacteria associated with the tree roots. The trees typically have very poor form, are prone to stem decay, and have large canopies making them prone to blowing over or breaking. This often results in damage to neighbouring trees. While there may be some value in having the acacias during the initial establishment phase, growers should remove the trees early (say four years after planting) to reduce the risk of major damage at a later date.

Genetics

Eucalyptus pellita

The source of the *E. pellita* used in the CRRP plantings was not always recorded, however it is believed that Australia provenances were used when available. Interestingly, the growth plot at Edmonton which suffered more substantial damage than expected, was planted with seed from a seed orchard of Irian Jayan origin. The field notes show that the site did suffer damage from TC Justin (1997), and is seasonally waterlogged and prone to insect attack, so genetics were not the only contributing factor.

Australian sources of *Eucalyptus pellita* were reported to have suffered less damage than PNG sources after a typhoon struck a CSIRO trial in southern China (Luo *et al*, 2006)[v]. A post-cyclone assessment of a thinned, four-year old DAFF genetic gains experiment (392cHWD) at Silkwood after severe TC Larry revealed a similar effect. Of the 286 trees in the trial, only five trees were undamaged; four of these (80%) came from Kuranda provenance (unpublished DAFF data). The difference between Kuranda and other provenances was not statistically significant, however it suggested that wind-firmness may be able to be improved through breeding.

After severe TC Larry DAFF established a number of new trials, comparing the growth of improved seed and clones of *Eucalyptus pellita* with unimproved wild seed from Australia and PNG (Table 9). Unfortunately the trees in these trials were too young to have revealed genetic differences in wind-firmness, and were either totally destroyed during the Severe TC Yasi (Figure 6) or were subsequently cleared by the commercial grower, Elders Forestry.

<u>Table 9:</u> Young trials of Eucalyptus pellita assessed for this report

Expt	Year	Location	Details	Status
745A	2007	Silkwood	Seed orchard (3rd gen)	Destroyed
745B	2007	Sth Johnstone	Seed orchard (2nd gen)	Destroyed
745C	2009	Sth Johnstone	Seedling seed orchard	Destroyed
746A	2007	Silkwood	Clone evaluation	Destroyed
746B	2007	Echo Creek	Clone evaluation	Destroyed
746C	2010	Ingham Sth	Genetic gains trial	Cleared for sale
746D	2010	Bilyana	Genetic gains trial	Destroyed
746E	2010	Daradgee	Genetic gains trial	Cattle grazing - trial abandoned

[v] J. Luo, R.J. Arnold, K. Aken (2006) Genetic variation in growth and typhoon resistance in *Eucalyptus pellita* in south-western China <u>Australian Forestry</u> **69** pp 32 - 47

Figure 6. *Eucalyptus pellita trees (age 3.75 years) within the DAFF 3rd generation seed orchard, destroyed. Elders' Taifalos Tree Farm, Silkwood. February 2011 (Category 3 wind)*

Khaya senegalensis and *Khaya anthotheca*

DAFF established a trial of dry zone African Mahogany (*Khaya senegalensis*) at Abergowrie in 2008 to evaluate variation between seed from 38 West African locations (five countries); the trial also included five sources of seed collected in Australia from trees of unknown African origin. There were statistically significant differences in cyclone damage between the African provenances, although the differences were not significant between countries (Figure 7). This may partly be due to an interaction with tree size: taller trees were statistically more likely to blow over (correlation co-efficient 0.27, $p<0.001$). It may also be partly due to the extreme strength of the wind at Abergowrie (Category 3 wind); it is possible that genetic differences may have emerged if the wind speed was less overwhelming.

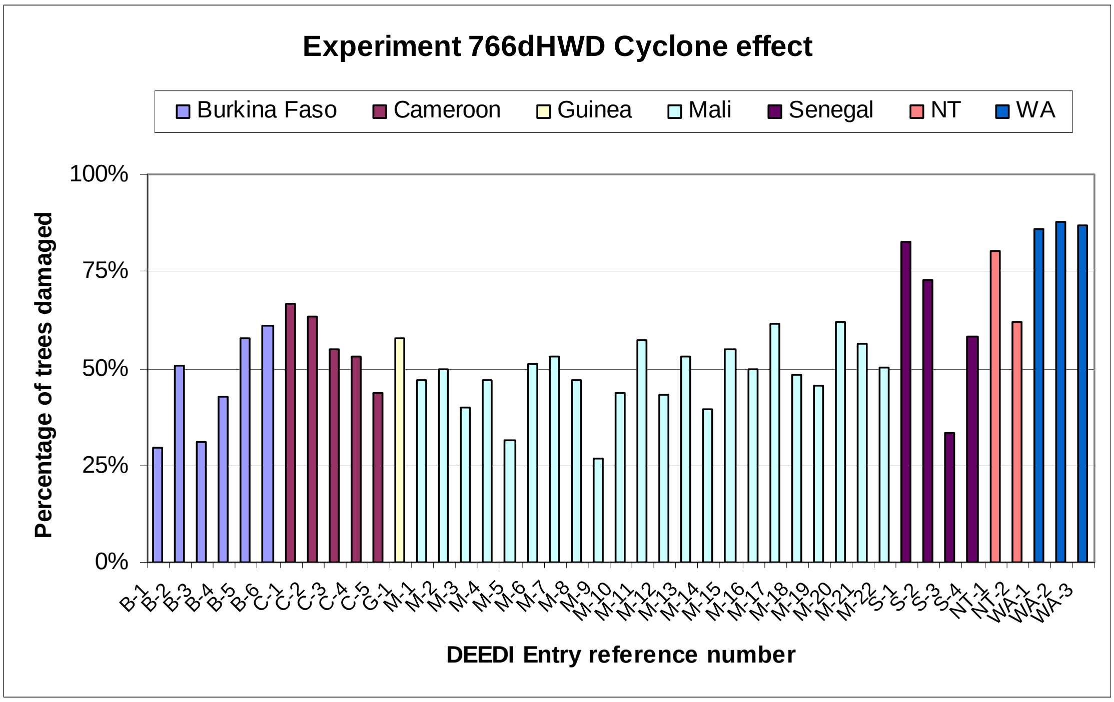

Figure 7: Variation in cyclone damage between Khaya senegalensis provenances at Abergowrie.

It is notable that the five Australian land race sources suffered more damage than most of the African provenances. It is possible that the seed was selected from trees with large crowns and seed crops, which may have been more prone to wind damage themselves. Alternatively it may reflect some inbreeding which would be expected from land race seed.

A similar result was observed at Silkwood in a trial of wet zone African Mahogany (*Khaya anthotheca*, formerly *Khaya nyasica*). Wild seed from Zimbabwe was compared with land race seed collected at Ingham, the parent seed of which came from Malawi. This trial was five years old when Severe TC Yasi struck, and also suffered very destructive winds (Category 3). Although the damage to the whole trial was massive, the land race seed suffered more damage than the wild seed. The land race seed also tended to break (63%), whereas the African seed were more prone to lean (47%). This pattern was correlated with differences in height and diameter (Table 10).

Table 10: *Variation in cyclone damage between Khaya anthotheca taxa at Silkwood*

	Wild seed Zimbabwe	Land race seed (Malawi)
Lean	47%	22%
Break	15%	63%
Pre-cyclone Height (m)	8.67	7.71
Pre-cyclone DBH (cm)	10.75	11.37

Tectona grandis
All of the teak plantations in the region were planted with clonal stock, from a variety of sources. After Severe TC Larry differences were apparent between clones planted in trials, however the identity of the clones was withheld by the company for intellectual property reasons (Figure 8). The company has since gone into receivership.

Figure 8. *Five-year old teak clone trial south of Tully damaged by Severe TC Larry (March 2006). The clone on the left was prone to breakage at approximately 4 - 5 m height, while the other clone was not. Wind speed believed to be Category 2. Photo taken August 2006.*

Severe TC Yasi decimated the oldest teak plantations in the region, which were located in the Tully valley. DAFF had collaborated with Great Southern to establish a trial evaluate teak clones at Mena Creek (Category 3 wind), but the trees were young and did not suffer obvious damage, so no differences were observed between clones.

Species mixtures and planting patterns

Monocultures appeared to suffer less cyclone damage than polycultures. It may be that in polycultures the largest trees are more prone to wind-throw because of their large surface area, whereas in monocultures the difference in tree size is less significant. It was notable that at the large *Khaya senegalensis* trial site at Abergowrie there was less damage observed in the provenance trial (planted in block plots of 6 rows by 10 trees) than in the adjacent clone trial, where there were large differences between neighbouring trees.

Although no difference was determined in average cyclone resilience between planting patterns, it would be expected that stands with species planted in lines would be more homogenous than those planted in random order, so more likely to withstand wind damage.

Amongst polycultures, there are several combinations of tree species which have comparable growth rates and therefore may be compatible. Successful combinations include SLQ-QMP, SLQ-RMM and RMM-QMP. Growers intending to plant slower-grown species should be mindful of the risk of cyclone damage, and avoid planting them with faster growing species. It is possible that rose butternut, southern silky oak and Leichhardt tree in particular would be more resilient if they were the tallest trees in a stand.

Tree age

Tree age appears to be a significant factor affecting cyclone resilience. Young teak trees have narrow canopies, and suffered minimal damage even in the most severe wind areas. However older teak trees (more than five years old) were blown over and had stems broken, in lower wind areas. By contrast young *Eucalyptus pellita* trees have large crowns relative to their height, and were highly prone to leaning over, even in a moderate wind. Older *E. pellita* trees in the growth plots however had a small crown : stem ratio, and mostly withstood extremely destructive winds.

In this report we have differentiated between trees younger and older than eight years, however the change in resilience is likely to be gradual as the trees age. Trees seem most vulnerable before they reach canopy-closure stage, which is usually between three to five years in this region.

The damage effects of cyclones seem to be cumulative, whereby trees that are damaged early appear prone to breaking at the same point in the future. Thus growers would be well-advised to remove any young trees damaged in a cyclone.

Stand Management

Stands planted at low initial stocking rates (around 650 stems per hectare) seemed to have less damage than those planted more densely. It may be that the trees have developed greater wind resistance from being somewhat open-grown, and that any trees that blow over have plenty of space to fall, so they are less likely to damage surrounding trees. Conversely stands that have been thinned are more susceptible to wind damage for several years; this applies whether the thinning was intentional or unintentional (caused by a cyclone). In time the thinned trees will become more wind firm. A DAFF experiment (743) that was planted in 1991 and thinned in 1994 grew for twelve years before being experiencing hurricane-force winds during Severe TC Larry. The unthinned Queensland maple trees in the experiment (2222 stems per hectare) showed evidence of rubbing against each other in the cyclone (upper stem break), higher mortality and smaller diameters than the maple trees in the thinned plots (1111 and 833 stems per hectare).

Low initial stocking is likely to result in increased weed growth, which would need to be offset by additional spraying of herbicide. Weed control is important throughout the rotation, especially in areas where vines grow into the tree crown, increasing the weight and wind resistance of the canopy and increasing the likelihood of damage. Well-maintained blocks suffered less damage than weed-infested blocks. One of the challenges faced by farmers with woodlots is the ability of light-loving weed species to proliferate in cyclone-damaged woodlots, producing seeds which then spread to neighbouring agricultural lands.

Tree form is also likely to be poorer if initial tree spacing is too wide, meaning extra cost will be required for pruning. High initial stocking followed by early thinning (say, around age four) may deliver the optimum result, albeit at greater expense, and with the knowledge that trees will be vulnerable to wind damage for several years after thinning. A better alternative may be to thin the stand regularly, removing a small proportion of trees (say 5%) per year. This would have the advantage of retaining sufficient stems to allow the stand to recover should some trees be damaged at a later date due to a moderately powerful cyclone.

Site factors

It was very obvious during the field inspections that many of the trees assessed were growing on sites for which they were unsuited. Often this was related to soil moisture or fertility, and sometimes temperature. Sometimes this was magnified by competition from neighbouring trees that were suited to the site. In general, the trees that were unsuited to the site were less resilient to cyclone damage than the other species.

Effect on productivity and potential returns

Tree growth rates recorded in north-east Queensland are amongst the highest anywhere in Australia, due to the high rainfall and warm temperatures of the region. In this study we observed an apparent correlation between tree size and cyclone damage, with a greater likelihood of leaning (and uprooting) affecting the largest trees in the stand. This means that the largest trees may not reach harvest age in cyclone-prone areas, and therefore growth models are likely to over-estimate stand yield. Growth models should also take account of the likely loss in increment in the year after a cyclone caused by crown-stripping, and loss of timber volume due to degrade related to stem breakage.

Post-cyclone clean-up is time-consuming and expensive, and adds significantly to the cost of growing trees in cyclone-prone areas. Financial models assessing likely returns should factor in the cost, which may be in the order of hundreds of dollars per hectare after a minor cyclone, and thousands of dollars per hectare after a severe cyclone. Tree age should also be incorporated into financial models, since young plantations (other than teak) are prone to more extensive damage, and it may be more cost-effective to clear and re-establish a severely damaged young stand. Based on the evidence of the last 20 years, it seems likely that trees planted in coastal areas of north-east Queensland will experience storm force winds at least twice, and the effects are likely to be less destructive in older stands.

PRIORITY AREAS FOR FURTHER INVESTIGATION

The results presented in this report were based on a post-cyclone survey of a range of sites with diverse characteristics and histories, rather than a comprehensive, replicated scientific experiment. Nonetheless, two rainforest species and three eucalypts have been seen to demonstrate high resilience to hurricane-force winds. The five most resilient species are silver quandong, Queensland maple, red mahogany (*E.pellita)*, rose gum and Gympie messmate. Another rainforest species (kauri pine) appears susceptible to stem breakage, but able to resist decay, suggesting it may be suitable for further afforestation efforts.

Despite the impact of two of the most severe tropical cyclones in living memory, there is still a sizeable resource of plantation-grown hardwood species in small scale woodlots on private land. Some of the faster-grown trees are approaching a size when they may be suitable for supplying the wood processing industry. To enhance the likelihood of that resource being utilised, it is recommended that more information should be gathered on the quality of the wood from plantation-grown trees that have been cyclone-damaged. Three questions identified in this report should be addressed:

1. Is there a difference in wood properties between trees that die in the months after a major cyclone, compared to adjacent trees that survive?
2. What differences exist between species in terms of excluding wood decay at the site of wounds (especially stem break), and how might these affect a grower's decision about post-cyclone removal of damaged trees?
3. How long is the window of opportunity to salvage harvest trees after a cyclone?

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This project is a scaled-down version of a proposal made to RIRDC, which was devised by the authors and Dr. David Lee (DAFF). Dr Kevin Harding (DAFF) made helpful suggestions on tailoring the project to suit TQ's needs. Nick Kelly (DAFF) provided very useful information about numerous cyclones that have affected the DAFF research plantings in the past 20 years, and also provided invaluable assistance making sense of file notes describing plot locations and layouts.

APPENDIX 1 - MAP OF SITES ASSESSED

The location of each of the sites is approximate only.

The following symbols are used on the maps

▲ Experimental plots planted and maintained by DAFF, older than 8 years
▲ Experimental plots planted and maintained by DAFF, younger than 8 years

★ Growth plots older than 8 years (experiment 799ATH)
★ Growth plots younger than 8 years (experiment 867ATH)

45 Plots in bold were measured
44 Plots in plain type were not measured

63 & 64 Two plots located on same property

Category 1 strength wind

Category 2 strength wind

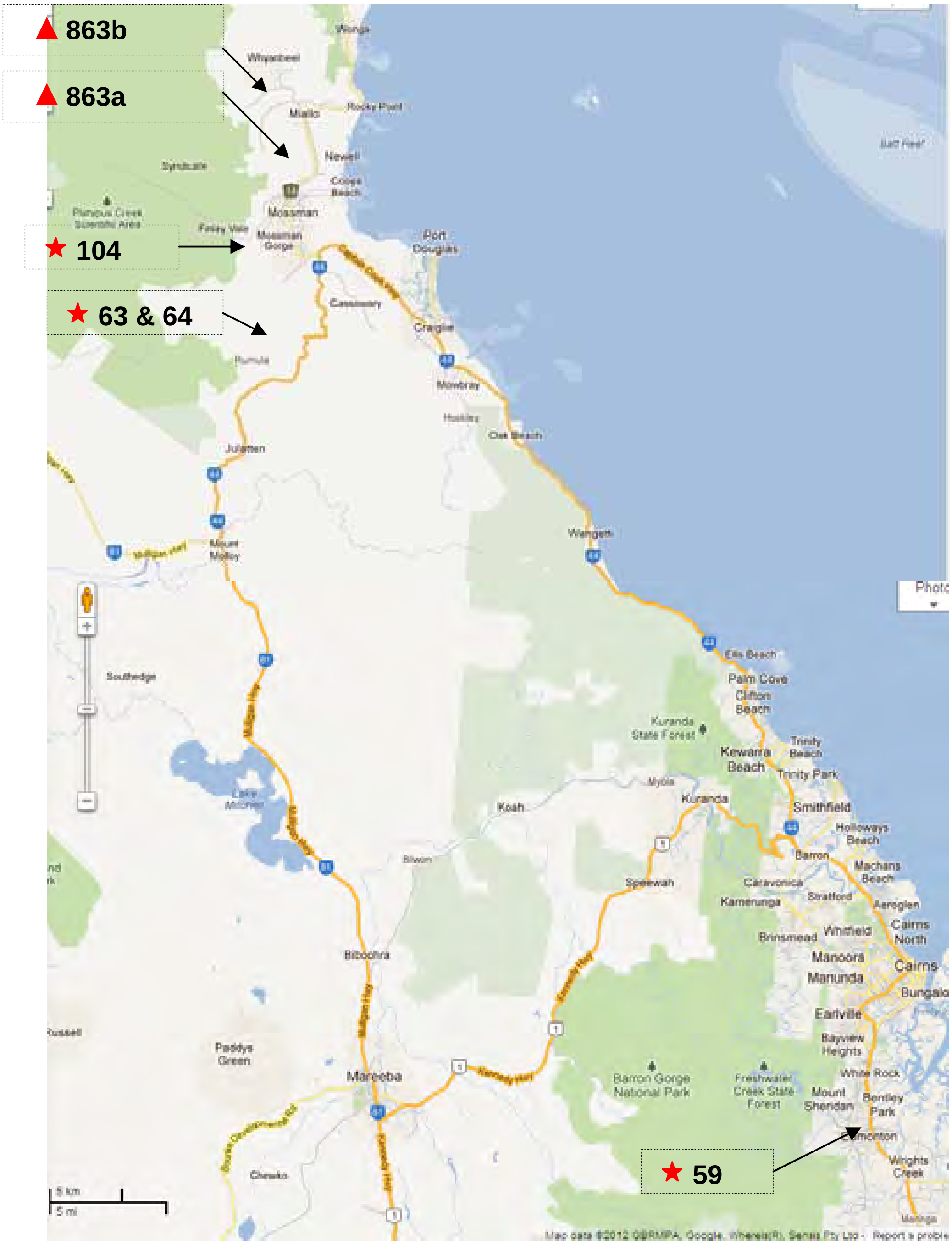
High category 2 strength wind

Category 3 strength wind

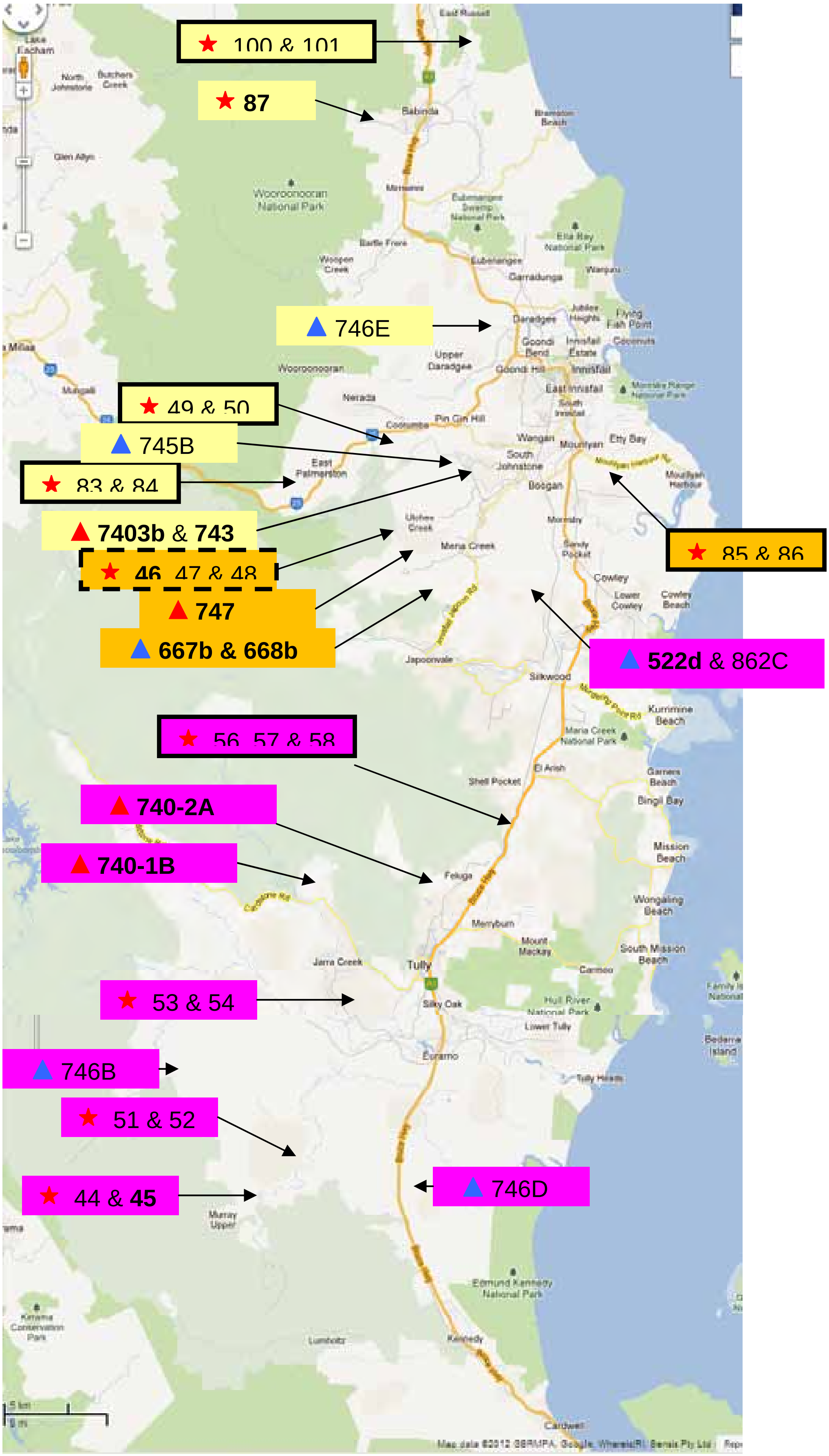
Growth plots effectively destroyed by Severe TC Larry (2006)

The maps were produced by the authors of the report using Google Maps.

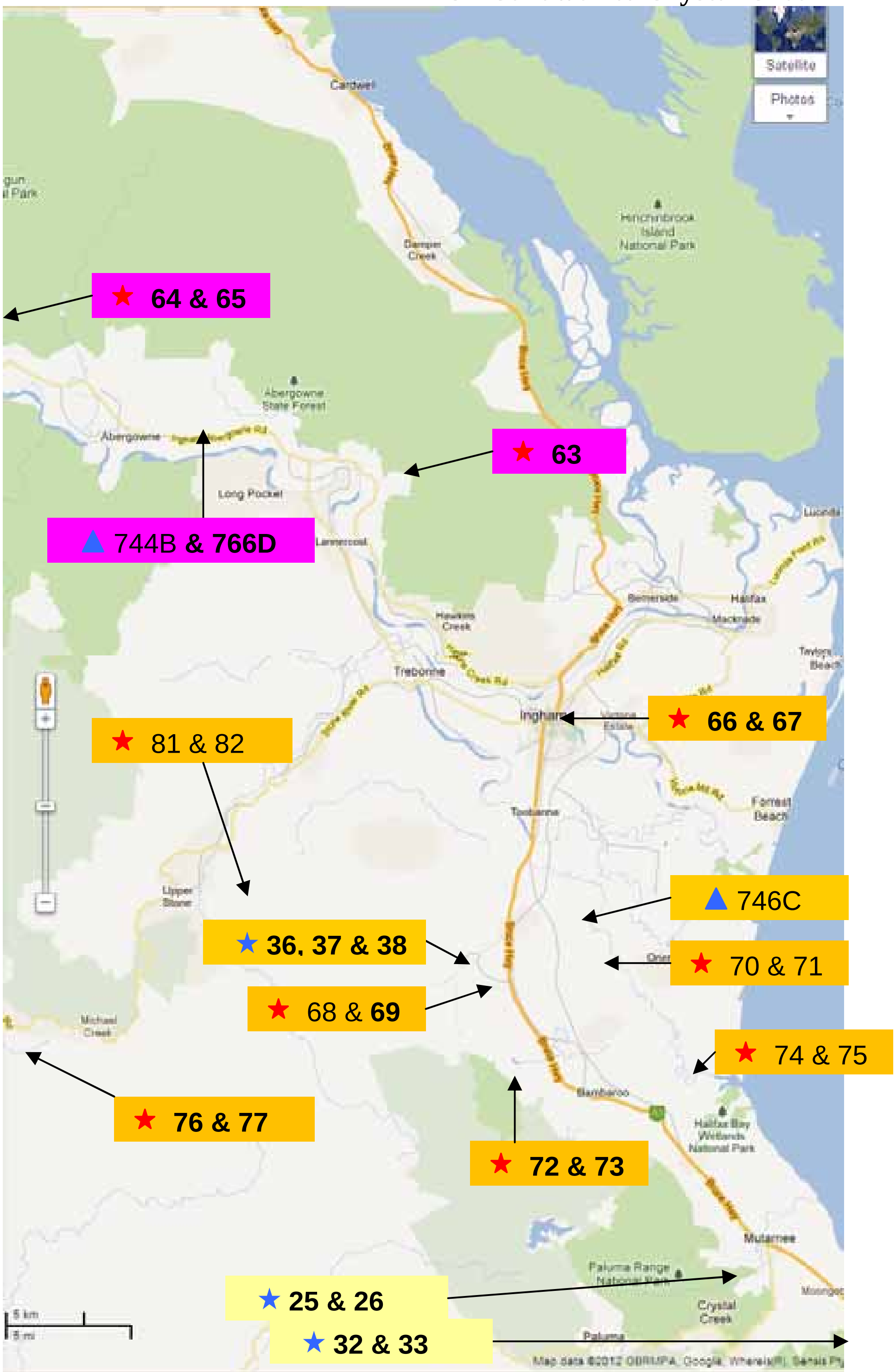
MAP 1 - Mossman to Cairns



MAP 2 - Babinda to Cardwell



MAP 3 - Cardwell to Crystal Creek



MAP 4 - Tablelands