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Population structure of palms in rainforests frequently impacted by cyclones

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Abstract. *Latifah D, Congdon RA, Holtum JA. 2017. Population structure of palms in cyclone-dependent rainforests. Biodiversitas 18: 41-50.* Tropical cyclones may act as important ecological drivers in northern Australia including north Queensland, as several cyclones impact this region each year between November and May. Extensive research has been conducted to investigate how the population structure of rainforest species respond to cyclonic disturbances. However, there have been few such studies on palms although they are important components of rainforests. Therefore, these study aimed to investigate how the population structure of *Arenga australasica* (H. Wendl. & Drude) S. T. Blake *ex* H. E. Moore, *Calamus australis* Mart., *C. moti* F. M. Bailey, *Hydriastele wendlandiana* (F. Muell.) H. Wendl. & Drude and *Licuala ramsayi* var. *ramsayi* (F. Muell.) H. Wendl. & Drude responded to a cyclone, as shown by size class reflecting mass recruitment after a periodic major disturbance (case study: Cyclone Larry). The field research was carried out in three study sites: Tam OShanter/Djiru National Park, Clump Mountain National Park and Kurrimine Beach Conservation Park located near Mission Beach and Kurrimine Beach, in north Queensland. Observations were made of life stage distribution, height and dbh distribution and wind resistance. We found that responses of the population structures of these rainforest palms varied following cyclonic disturbance by demonstrating higher densities of seedlings and juveniles, suggesting populations would be retained. More seedlings of *C. australis* and *C. moti* were found in gaps with higher canopy openness; oppositely, less seedlings of *L. ramsayi* were encountered under sites with lower sunlight.

Keywords: disturbance, palms, population structure, northern Australia

INTRODUCTION

Natural disturbances that affect tropical forests may act as major ecological drivers in ecosystem dynamics. Various types of disturbance of intermediate intensity can maintain plant diversity in many tropical forests (Connell 1970; Franklin and Bowman 2003). More severe disturbances, such as catastrophic wind events, can lead to significant change in species composition and forest structure (de Gouvenain and Silander Jr 2003; Turton 2008). Many studies have analysed the influence of frequent natural disturbances on the structure of rainforests (Clarke and Kerrigan 2000; de Gouvenain and Silander Jr 2003; Foster and Boose 1992; Grove et al. 2000).Cyclones are catastrophic wind events that have influenced the dynamics of the vegetation of tropical lowland rainforests in north Queensland, Australia (de Gouvenain and Silander Jr 2003; Hopkins and Graham 1987; Webb 1958).

The influence of natural disturbances on species diversity is explained by the theory that various types of moderate disturbance can maintain plant diversity in many tropical forests (Connell 1970; Connell 1989; Franklin and Bowman 2003; Vandermeer 1994; Vandermeer et al. 1996). More severe disturbances, such as catastrophic wind events, can lead to significant change in species composition and forest structure (Bullock 2000; Connell 1989; Franklin and Bowman 2003; Vandermeer et al. 1996). The degree of forest disturbance caused by cyclones varies depending on the cyclone intensity combined with other factors. Boose et al. (1994) suggested that, at the landscape scale, the degree of forest damage induced by cyclones can be influenced by three main factors: (i) the wind velocity gradient resulting from cyclone size and intensity, and proximity to the storm track, complicated by local-convective scale effect; (ii) variations in site exposure and other effects of local topography; and (iii) differential response of individual ecosystems to wind disturbance as a function of species composition and forest structure. Natural disturbances that create canopy gaps increase the variety of regeneration niches (Bullock 2000). These niches can counteract species dominance through competition and allow persistence of populations of pioneers or shade-intolerant species (Bullock 2000; Connell 1989).

The responses of plants and forest structure to cyclones may vary. Webb (1958) observed that cyclones alter the composition of emergent trees and vines. Damage to emergent trees resulted in a lower and uneven canopy in tropical lowland rainforests in north Queensland, and promoted the growth of vines (Webb 1958). De Gouvenain and Silander (2003) also found that forest canopies of lowland tropical rainforests in Madagascar were also low, which was significantly correlated with the impact of tropical cyclones. Moreover, tropical cyclones increased tree population densities (de Gouvenain and Silander Jr 2003; Vandermeer 1994). However, Lugo (2008) found, in a long-term study (1943-2005), that species diversity of a tabonuco (*Dacryodes excelsa*) forest in Puerto Rico and Florida, first increased ten years after a major hurricane (San Cipriano, in 1932), but then gradually decreased. The species diversity increased nine years after Hurricane Hugo in 1989, then steadily declined after Hurricane Georges hit in 1998. It is clear that although species diversity decreased, these frequent hurricane disturbances between 1943 and 2005 resulted in an increase in the abundance of *D. excelsa* (the dominant species).

However, there have been few similar studies on palm population structure following cyclonic disturbances. For example, populations of some palms became dense following cyclonic disturbances. *C. australis* densely occupies the understorey following cyclones in north Queensland, as this climbing palm species is shade-intolerant (Webb 1958). This finding is consistent with recent studies that *C. australis* (Metcalfe et al. 2008) and *C. caryotoides* (Stork 2007) benefit from frequent cyclonic disturbances in north Queensland. *Prestoea montana* in the Caribbean also became dominant after Hurricane Hugo in Puerto Rico (Frangi and Lugo 1998).

The meteorological term “tropical cyclone” refers to severe storms with winds that circulate spirally inward and upward and then outward and upward around a storm axis, counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere. These storms produce wind velocities of 160 to 225 km per hour or greater and intense precipitation, depending upon the areas topography relative to the centre or eye (Cline 1926). Tropical cyclones occur regularly in seven areas worldwide, known as tropical cyclone basins (AOML 2011). North Queensland clearly lies within basin 7 under Nadis RSMC (Regional Specialised Meteorological Centres) with three centres involved: Nadi, Port Moresby and Brisbane (AOML 2007). Cyclones frequently impact on northeastern Queensland (Table S1). At the time of this study, the most recent devastating cyclone (Category 5; 290 kmh^{-1}) in northern Queensland was Cyclone Larry on 20 March 2006, which crossed the coast between Tully and Innisfail. Consequently, Mission Beach and Kurrimine Beach, part of the Wet Tropics World Heritage Area, were chosen for this study. Prior to Cyclone Larry, the last destructive cyclone in the Mission Beach-Tully area was Cyclone Winifred in February 1986 (Hopkins and Graham 1987). Previous cyclones that caused major damage in this region recorded by the Bureau of Meteorology, Australia, were in 1918 (no name), cyclones Joy in 1990 and Agnes in 1956 (JCU 1991; Hopkins and Graham 1987). Low-category Ex-Tropical Cyclone Ellie hit the Mission Beach region on 1 February 2009, causing a number of trees that had been damaged by Cyclone Larry to fall. Cyclone Yasi (Category 5) hit the Mission Beach-Tully region on 2 February 2011. This suggests that cyclonic disturbance of tropical lowland rainforests in north Queensland is significant and the structure of the rainforests within these regions may be determined by these cyclone events.

Therefore, the aim of this research was to investigate whether the population structure of palms [*Arenga australasica* (H. Wendl. & Drude) S.T. Blake ex H.E. Moore, *Hydriastele wendlandiana* (F. Muell.) H. Wendl. & Drude, *Licuala ramsayi* var. *ramsayi* (F. Muell.) Domin, *Calamus australis* Mart. and *C. moti* F.M. Bailey], as shown by size classes reflects mass recruitment after a periodic major disturbance in Mission Beach and Kurrimine Beach, north Queensland, Australia (case: Cyclone Larry).

MATERIALS AND METHODS

Study species

The five study species in this research were *A. australasica, C. australis, C. moti*, *H. wendlandiana* and *L. ramsayi* var *ramsayi* (Table 1).

Study site

Population structure was studied at Tam OShanter/ Djiru National Park (17º54 S 146º04 E: Site A-Licuala Walk area and B-river bank area) and Clump Mountain National Park (17º50 S 146º05 E: Site C- Bicton Hill) located in Mission Beach and Kurrimine Beach Conservation Park (17º47 S 146º03 E: Site D- Kurrimine Beach Conservation Park and Site E-Kurrimine Beach Esplanade) which is situated in Kurrimine Beach, north Queensland, Australia (Figure 1) using eighteen 10 m x 10 m study plots (See Table S2). The study site characteristics covering canopy openness and level of damage is presented in Table S2 (the assessment of the canopy openness and level of damage was also use in the regeneration strategies study and published in Latifah et al. 2016).

Survey methods

Life stage distribution

The sampling strategy using 10m x 10m study plots was chosen as larger plots or transects could not be used in cyclone-damaged forest. The composition of palm populations was determined for three life stages: seedlings, juveniles and mature plants. Palm densities were also determined. The immediate impact up to 1.5 years after the strike of Cyclone Larry (20 March 2006) on the population structures of Sites A1, C and D were assessed in July 2007; Sites A2 and B in August 2008 and Site E in May 2008. For the purposes of data collection of population structure, one cluster of palms was counted as one individual (Table 1). Data on the regeneration from the eighteen permanent plots (seedling recruitment and survivorship as part of a recovery) were published in Latifah et al. 2016.

Height distribution, distribution of height versus dbh and wind resistance of mature A. australasica, H. wendlandiana *and* L. ramsayi

Height and dbh distributions were examined from plots a-r. Heights of palms were measured using tape measures and a clinometer. When assessing damage and height and dbh distribution, stems of clustered palms were assessed individually and individuals were counted. Palm resistance to wind stress was assessed by recording the mortality and the extent of damage, i.e. damage category was also recorded if damaged palms were encountered. Surviving but damaged palms were monitored for their ability to recover by recording their capability to produce inflorescence/fruit in the eighteen permanent plots during the study course (2007-2009); the reproductive phenology records were published in Latifah et al. 2016. The level of damage to the palms, as shown by the different size classes, was categorized into four wind damage types by Dowe (2009): (1) crushed: impacted by falling debris; (2) uprooted: palm lying horizontal or nearly so, with root ball out of the ground; (3) trunk snapped near the middle; (4) trunk snapped at the apical meristem. However, as Dowes four damage types were based on one species with a solitary growth habit, *A. alexandrae*, in the current study the levels of damage were scored from 1 to 7, ranking from no damage (lowest) to uprooted (highest) (Table 2).

Data analyses

Population structure was surveyed by counting the number of individuals in each of the three life stages: seedling, juvenile and mature, for each species in each study plot. Analysis of variance (ANOVA) was used to determine the significance of the differences between the life stages and study sites. The relationships between height and dbh were determined using regression analysis, and the relationships between each of these and wind resistance were analysed using GLM in ordinal logistic form. The relationships between wind resistance (Table 2) and survivorship of damaged palm trees (Table 3) were analysed using Spearman Correlation. The recovery of the damaged palms was scored from 1 to 4 (Table 3). Values less than 1 were log-transformed, as log 10 (data + 1). All analyses were run utilizing SPSS for Windows version 19.0.

Table 1. Taxonomic affinities of the five palm study species and their growth habits (Uhl and Dransfield 2008)

Species	Taxonomic group	Growth habit
A. australasica	Subfamily: Arecoideae Tribe: Caryoteae	Clustering tree[1]
C. australis	Subfamily: Calamoideae Tribe: Calameae	Clumping[2], climbing plant
C. moti		clumping, climbing plant
H. wendlandiana	Subfamily: Arecoideae	Clustering tree or usually single-stemmed tree
L. ramsayi var. *ramsayi*	Subfamily: Coryphoideae Tribe: Corypheae	Solitary or rarely clustered tree

Notes: [1]Cluster means two to many stem coming out at the same point in the soil. [2]Clump is considered as a cluster too

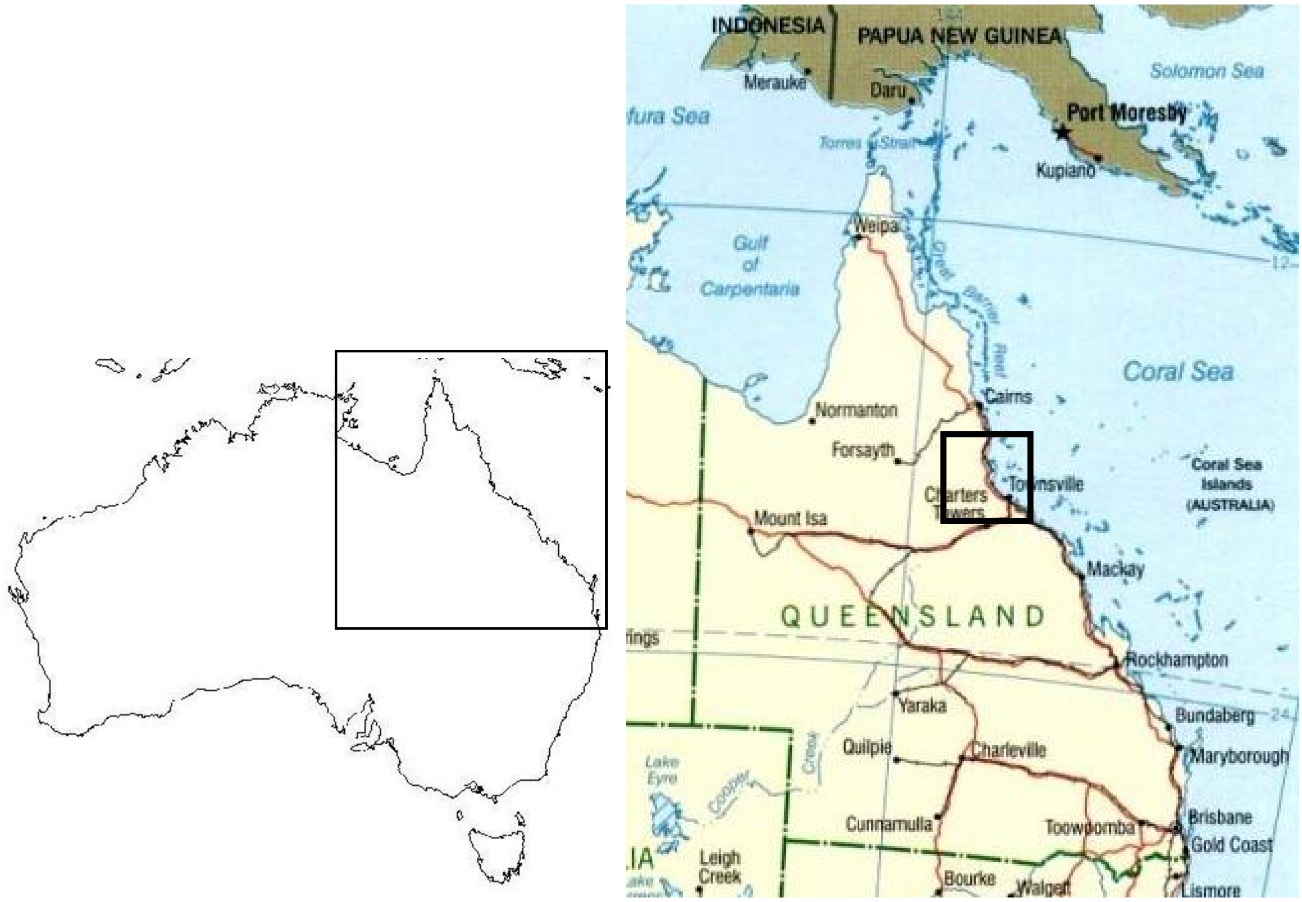


Figure 1. A map of Australia and an arrow showing the approximate location of Mission Beach, Queensland, Australia (Source: maps-oceania.com).

Table 2. Categories used to record wind resistance/damage of palm trees. The categories, ranked from 1 to 7, were only applied to mature palm trees and excluded palms with climbing growth habit, i.e. *C. australis* and *C. moti*. The description of wind resistance was modified from Dowe (2009). The damaged palms were categorised as recovered or did not survive based on Table 4

Category (rank)	Indicators of the level of wind resistance from 1 to 7
1	Palms survived without damage.
2	Palm tilted but survived.
3	Trunk was partially snapped in the middle causing wounding and tilting; palms may survive but the growth may be abnormal. Leaning palms whose fall was blocked by other standing trees, with their roots still in the ground, are included in this category.
4	Trunk was snapped at the apical meristem leaving abnormal shoot or crown growth; palms may survive but the growth may be abnormal.
5	Palms were partially uprooted causing palms to lie nearly horizontal but likely to survive and the growth may be abnormal.
6	Palms did not survive as the trunks were partially snapped and the upper parts had fallen but the lower parts were not uprooted.
7	Palms were uprooted, lying horizontal or nearly so, with root ball out of ground and palms did not survive.

Table 3. Survivorship of damaged palm trees following Cyclone Larry as recorded at the study sites. The scores, ranked from 1 to 4, were only applied to mature palm trees and excluded palms with climbing growth habit, i.e. *C. australis* and *C. moti*.

Descriptions of survivorship	Scores
Mature palms, wind resistance categories 1-5 (Table 2) were able to produce inflorescences/fruit (flowered/fruited) during the study course.	1
Vegetative regeneration (on palms with wind resistance categories 6-7).	2
No inflorescence produced (on palms with wind resistance categories 2-5).	3
Did not survive.	4

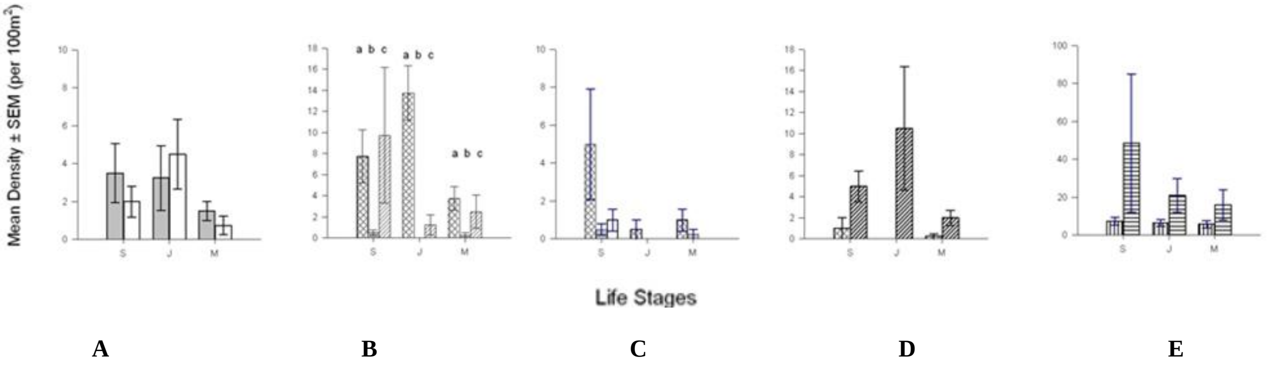


Figure 2. Life stage distribution of A. *A. australasica,* B. *C. australis,* C. *C. moti,* D. *H. Wendlandiana,* E. *L. ramsayi* at sites A1 (☒ 59%), A2 (▥, 62%), B (▤, 43%), C (■, 31%), D (□, 27%) and E (▨, 80%). Seedling (S), Juvenile (J), and Mature (M) samples with the same lower case letters are not significantly different ($p< 0.01$)

RESULTS AND DISCUSSION

There were fewer mature plants of *A. australasica* at sites C and D than juveniles and seedlings (Figure 2.A). However, statistically the difference was not significant due to the high variability between plots; the effects of sites and the interaction between life stages and sites was also not significant ($F_{2,18} = 0.61$, $p = 0.55$). The density of mature plants was 2 individuals/100 m^2 at site C (31% canopy openness, minor to moderate) and 1 individual/100 m^2 at site D (27% open, moderate to severe). The number of juveniles that survived Cyclone Larry was 3 individuals/100 m^2 at site C and 5 individuals/100 m^2 at site D. During the course of the study, fewer *A. australasica* seedlings were recruited at site D (2 individuals/100 m^2).

There were also fewer mature plants of *C. australis* at sites A1 and E than juveniles and seedlings (Figure 2.B), although the difference was not statistically significant. Densities of life stages were different among sites ($F_{2, 27} = 15.92$, $p < 0.01$, log-transformed). The density of mature plants was 4/100 m^2 at site A1 (59% open, moderate) and 3 individuals/100 m^2 at site E (80% open, severe). The density of juveniles which survived Cyclone Larry was 14 individuals/100 m^2 at site A1 and 1 individual/100 m^2 at site E. Fewer *C. australis* seedling were recruited in site A1 (8 seedlings/100 m^2); while only 1 mature plant and 2 seedlings were found at site C (31% open, minor to moderate).

Table 4. Density of the five study species per hectare for each life stage in July 2007 for Site A1, C and D, May 2008 for Site E and August 2008 for Site B

Species	**Site**	**Seedling**	**Juvenile**	**Mature**	**Total**
		individuals/ha			
A. australasica	C	350	325	150	825
	D	200	450	75	725
C. australis	A1	775	1375	375	2525
	C	50	0	25	75
	E	975	125	50	1150
C. moti	A1	500	50	100	650
	C	50	25	25	100
	D	50	0	0	50
	E	0	25	0	25
H. wendlandiana	A1	100	0	75	175
	E	525	275	75	875
L. ramsayi	A2	1950	600	850	3200
	B	6850	2150	1800	10750
	E	0	150	0	150

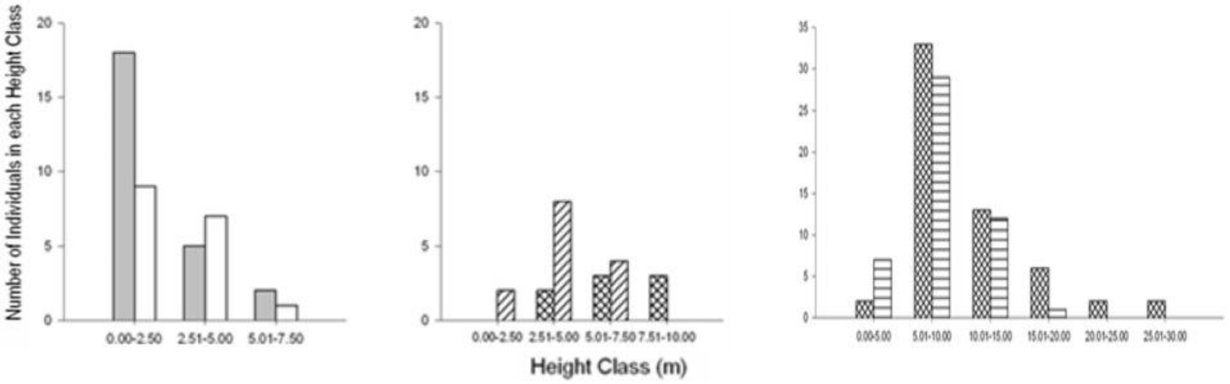
The population structure of *C. moti* at site A1 showed fewer mature and juveniles plants than seedlings (Figure 2.C). The densities of the three life stages were significantly different ($F_{2,27}$ = 3.26, p = 0.05, log-transformed); however, the effects of sites and the interaction between sites and life stages were not significant. The density of mature plants was 1/100 m^2 at site A1 (59% open, moderate). One juvenile/100 m^2 survived Cyclone Larry and 5 seedlings/100 m^2 were recruited at site A1. Only one mature plant occurred and 1 seedling/100 m^2 were recruited at site C (31% open, minor to moderate). Only one seedling per 100 m^2 was also recruited at site D (27% open, moderate to severe). The juveniles of *H. wendlandiana* were most abundant at site E (Figure 2.D), although the difference between the densities of life stages was not statistically significant. Fewer mature plants (2 individuals/100 m^2) were found at site E (80% open, severe, $F_{1,7}$ = 6.12, p = 0.06). The density of juveniles that survived Cyclone Larry was 11 individuals/100 m^2 at site E. More seedlings were recruited at site E ($F_{1,7}$ = 5.78, p = 0.05, log-transformed) than at site A1 (59% open, moderate). The population structure of *L. ramsayi* followed a nearly reverse-J-shaped curve, at site B but there was little difference at site A2 (Figure 2.E). There were more individuals of all life stages at site B (43% open, severe) compared to those at site A2 (62% open, moderate to severe, $F_{1,12}$ = 9.02, p = 0.01, log-transformed). The densities of the three life stages were presented in Table 4. *L. ramsayi* had the highest densities at the study sites.

All the palms studied in the current research exhibited a higher abundance of seedlings and juveniles compared to mature individuals suggesting a high probability of the populations maintaining themself as a part of a stable-climax plant community (Barbour et al. 1987). Dowe (2009) also reported that the population of *A.alexandrae* exhibited more seedlings and juveniles, a few days after Cyclone Larry in 2006; the seedlings and juveniles appeared to be less prone to be damaged by strong winds.. Conversely, Gorman (1996) found mature *L. ramsayi* were more abundant than juveniles and seedlings at Tam OShanter in 1996, 10 years after a major cyclone i.e. Cyclone Winifred in 1986 indicating the recruitment pattern of *L. ramsayi* was low. However, the recruitment of *L. ramsayi* in this study was more (Table 4).

Stands of mature *A. australasica* with a height of 3m or less (younger trees) were dominant following Cyclone Larry (Figure 3.A). Wind resistance was related to height (Figure 5.A). Ninety percent of 29 damaged mature trees (wind resistance ranks 2-5) did not produce flowers (survivorship score 3) (Figure 6.A). The height and diameter were not significantly correlated in *A. australasica*. Mean heights were similar at sites C and D (Table 5). *Hydriastele wendlandiana* stands with heights of 2.5-5 m were dominant in site E, while this height range was the least in site A1 (Figure 3.B). This species showed a positive correlation between height and dbh (Figure 4.A). Height and dbh of this species were not related to wind resistance. However, mature individuals with height more than 10 m were lost at site E (severe) suggesting those which their heights more than 10 m were more susceptible to wind (Figure 3.B). Damaged *H. wendlandiana* trees recovered well following the cyclone with their ability to resprout and the benefits of a clustered growth habit (Figure 6.B). Stems were taller at site A1 than site E (Table 5). Mature *L. ramsayi* trees with heights between 5 and 12 m were particularly abundant (Figure 3.C). This would indicate that individual which were taller than 12m were more susceptible to cyclones. Trees were taller at site A1 (Table 5), however, height and dbh were not significantly related.

In this study, the susceptibility of mature palms to Cyclone Larry varied and can be related to their height and/or dbh distribution (Figure 4); however, the cyclone caused trees to fall in many ways. In *A. australasica*, the results suggest that stands higher than 3 m were more susceptible to wind damage; the height was related to wind resistance. Among these stands, 10% of trees were damaged, 21% lost and 6% of the undamaged trees subsequently flowered. The usual height of mature plants is up to 20m (Jones 1996); however, the height is probably very variable, a few may make it up to 20 m, but the majority probably do not due to a wide range of factors. In *H. wendlandiana*, stands higher than 10 m and with dbh 5-8 cm were also more susceptible, with 30% of the trees damaged; although, height and dbh were correlated. In addition, the slopes of the regressions between stem diameter and height for *H. wendlandiana* suggest that this species was close to or exceeded the theoretical buckling limit i.e. the relative margin of safety against mechanical failure (Rich 1986) as palms do not have secondary growth from a vascular cambium, consequently the trees became less stable as they grow taller. However, 62% of the damaged trees re-grew vegetatively due to their clustering growth habit, and 25% of the damaged trees subsequently flowered. *L. ramsayi*, with heights of more than 12 m and dbh less than 16 cm, were more susceptible; although the height was not related to wind resistance, but dbh was correlated with wind resistance (Figure 5.B): 14% of mature trees were damaged, 20% lost and 63% of the damaged trees flowered, as the roots of the tilting and leaning damaged trees were still in the ground. Unwin *et al.*(1988) observed that trees of *L. ramsayi* were little damaged by Cyclone Winifred (1986). Moreover, 10 years after Cyclone Winifred, Gorman (1996) observed that 10-13-m tall *L. ramsayi* stands dominated in Tam OShanter National Park. In the current research, 7, 8 and 10-m tall *L. ramsayi* stands were most abundant in Tam OShanter National Park. These results suggest that cyclone susceptibility depends on the species and the age (Everham III and Brokaw 1996).

To conclude, the palm population data collected at Mission Beach and Kurrimine Beach indicated that the palms appear adapted to periodic cyclonic disturbance. The five palm species showed higher densities of seedlings and juveniles, suggesting populations would be maintained. The recruitment of the seedlings of *C. australis* and *C. moti* was higher in gaps with more light; however, the recruitment of *L. ramsayi* was higher in sites with lower canopy openness.

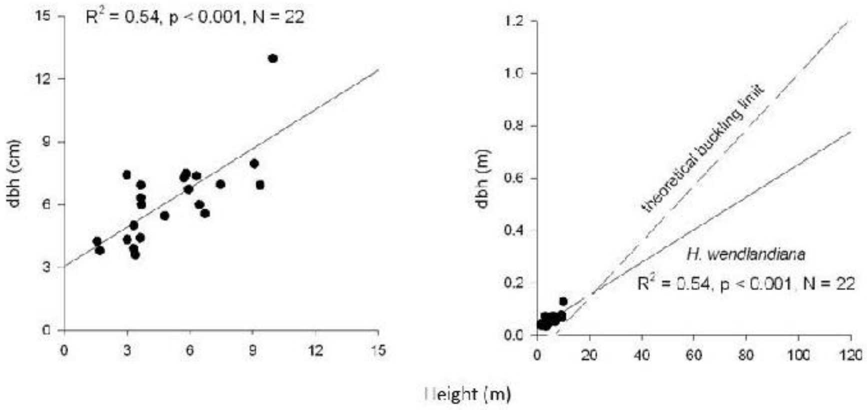


A B C

Figure 3. Height distributions of surviving mature individuals of A. *A. australasica*, B. *H. Wendlandiana*, C. *L. ramsayi* at sites A1 (▩ 59%), B (▤, 43%), C (■ , 31%), D (□, 27%) and E (▨, 80%)

Table 5. Heights of mature *A. australasica*, *H. wendlandiana* and *L. ramsayi* at sites A1, B, C, D and E

Species	Site	N (individuals/400m^2)	Height mean ± SEM (m)	Range (m)	Overall (mean ± SEM)
A. australasica	C	25	2.04 ± 0.32	0.50 -6.75	}C and D =
	D	17	2.68 ± 0.32	1.00 -5.50	}2.52 ± 0.16
H. wendlandiana	A1	8	6.73 ± 0.98	3.67 -9.95	}A1 and E =
	E	14	3.97 ± 0.02	1.56 -7.45	}5.35 ± 1.38
L. ramsayi	A1	58	10.56 ± 1.22	2.00 -25.72	}A1 and B =
	B	49	7.70 ± 0.41	0.70 -16.24	}9.13 ± 1.43



A B

Figure 4. Plots of dbh versus height for mature A. *H. wendlandiana* and B. The slope of the regression of *H. wendlandiana* exceeds the theoretical buckling limit.

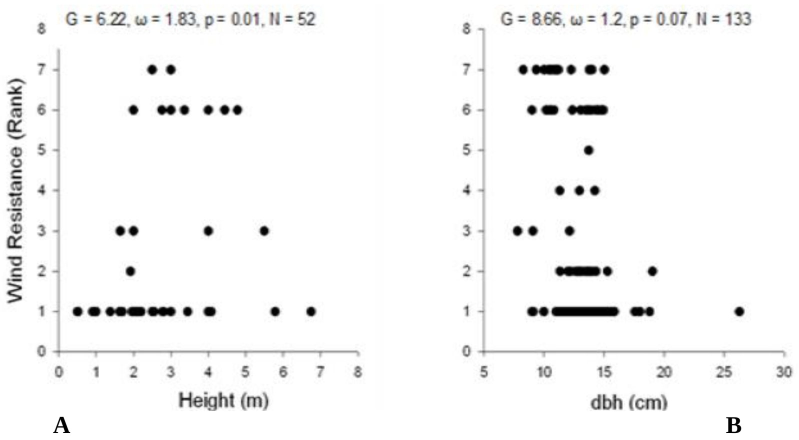


Figure 5. Wind resistance of mature A. *A. australasica;* height was correlated with wind resistance, and B. *L. ramsayi;* dbh was correlated with wind resistance. Wind resistance was recorded in July 2007 for sites A1, C, and D, May 2008 for Site E and August 2008 for Site B. Descriptions of wind resistance ranks are presented in Table 2.

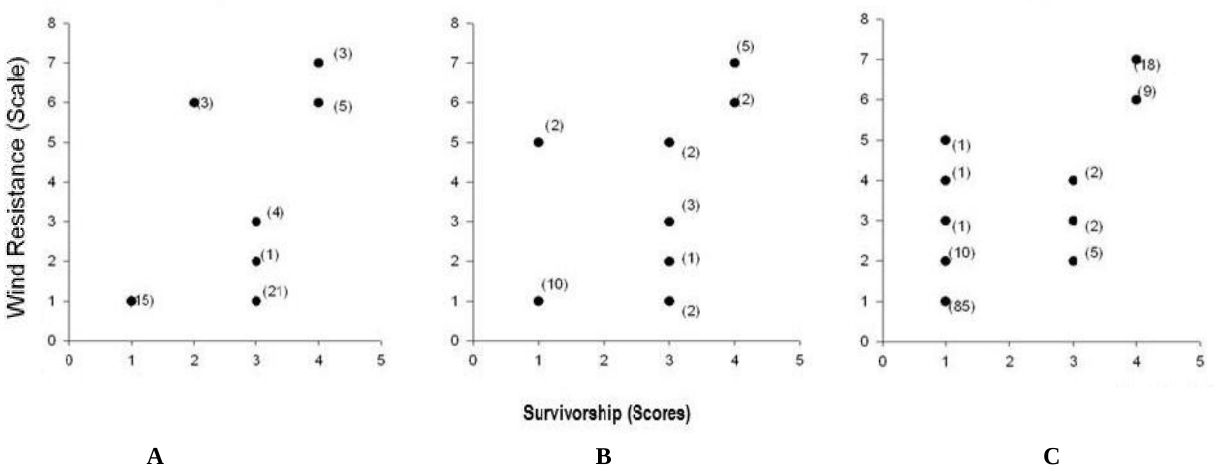


Figure 6. Recovery of mature A. *A. australasica,* B. *H. Wendlandiana,* and C. *L. Ramsayi* following the disturbance of Cyclone Larry. Wind resistance was rangked from 1 to 7 based on Table 2. Recovery was scored from 1 to 4 according to Table 3. Each point represents the number of individuals, which is indicated by figures in parentheses

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Table S1. Tropical cyclone events in north Queensland. References: 1 = BOM (2010a), 2 = Webb (1958), 3 = Hopkins and Graham (1987).

Date	Name	Areas impacted	Refs
1878, March 8	-	Cairns area	1
1882, February 2	-	Cardwell area	1
1884	-	n/a; noted as “particularly disastrous storms”	2
1890, March 24	-	Townsville-Ingham region	1
1896, January 26	Sigma	Townsville area	1,2
1899	-	n/a; noted as “particularly disastrous storms”	2
1903, March 9	Leonta	Townsville area	1,2
1906, January 28	-	Cairns area	1
1910, January 28	-	Cairns area	1
1911, January-March	-	Gulf of Carpentaria inland including Marburg in south-west Queensland (11 January); Port Douglas area (10 February); Mossman-Cairns area (16 March); Townsville area (23 March)	1,2
1912, April 7	-	Cairns-Innisfail region	1
1913, January 31	-	Cairns-Innisfail region	1
1918, March 10	-	Innisfail region including Mission Beach to Atherton Tableland	1.2
1920, February 3	-	Cairns region	1.2
1923	-	n/a; noted as “particularly disastrous storms”	2
1926, February 9	-	Townsville-Tully region	1
1927, February 9	-	Cairns area	1
1928	-	n/a; noted as “particularly disastrous storms”	2
1929, February	-	Townsville area (23 Feb) and Mossman-Cairns area (29 Feb)	
1932, January 19	-	Townsville area	1
1934, January 22	-	Cairns area	1
1940, February	-	Cardwell area (18 February); Townsville-Ayr area (7 April)	1
1946, March 2	-	Cairns-Townsville region	1
1954, February 7	-	Townsville area	1
1956, March 6	Agnes	Innisfail area or across Cairns-Townsville	2,1
1959, January 20	-	Cooktown-Cairns region	1
1964, December 6	Flora	Innisfail-Cardwell region	1
1965, January 30	Judy	Innisfail area	1
1971, February 16	Gertie	Cardwell area	1
1971, Dec 24	Althea	Townsville-Magnetic Island area	1
1973, Dec 19	Una	Townsville area	1
1977, January 31	Keith	Cairns first then Townsville	1
1979, January 1-2	Peter	Cairns area	1
1986, February 1	Winifred	Mission Beach-Tully area	
1990, Dec 22-25	Joy	Cairns first, weakening at Townsville, strengthening at Mackay	1
1997, March 22	Justin	Cairns-Atherton Tableland-Innisfail-Kurrimine Beach-Mission Beach-Tully-Townsville region	1
1998, Jan 10-11	Sid	Moved from Gulf across Cape York and intensified near Townsville	1
1999, February 11	Rona	Cairns-Mareeba region	1
2000, February 27	Steve	Cairns-Mareeba region	1
2000, April 2	Tessi	Townsville area	1
2001, Feb 23-27	Abigail	Cairns area including Green Island	1
2006, March 20	Larry	Cairns-Northern suburbs-Tablelands-Mareeba-Innisfail region	
2009, January 12	Charlotte	Townsville area	1
2009, February 1	Ellie	Mission Beach	1
2010, January 24	Olga	Innisfail area	1
2011, February 2	Yasi	Mission Beach-Tully region to Townsville area	1

Table S2. GPS readings for the 18 study plots distributed over five sites depending on the study species occurrence

Sites	**Species**	**Study plots**	**Canopy Oopenness (%Mean ±SEM)[1]**	**Level of Damage[1]**	**Location**
A1[2]	*C. australis* *C. moti* *H. wendlandiana* *L. ramsayi*	Plot a (17°54.739” S 146°04.191” E) Plot b (17°54.736” S 146°04.191” E) Plot c (17°54.734” S 146°04.189” E)[3] Plot d (17°54.637” S 146°04.123” E)[3]	59±6	Moderate	Tam OShanter National Park (Licuala Walk area)
B	*L. ramsayi*	Plot e (17º54.795” S 146º04.398” E) Plot f (17º54.710” S 146º04.547” E)	43±3	Severe	Tam OShanter National Park (river bank area)
C	*A. australasica* *C. australis* *C. moti*	Plot g (17°50.394” S 146°05.982” E) Plot h (17°50.348” S 146°05.902” E) Plot i (17°50.358” S 146°05.982” E) Plot j (17°50.370” S 146°05.994” E)	31±2	Minor to moderate	Clump Mountain National Park
D	*A. australasica* *C. australis* *C. moti*	Plot k (17°46.858” S 146°06.042” E) Plot l (17°46.853” S 146°06.041” E) Plot m (17°46.878” S 146°06.026” E) Plot n (17°46.872” S 146°06.025” E)	34±8	Moderate to severe	Kurrimine Beach National Park (Kurrimine Beach Conservation Park)
E	*C. australis* *C. moti* *H. wendlandiana*	Plot o (17°46.996” S 146°05.521” E) Plot p (17°46.980” S 146°05.547” E) Plot q (17°46.974” S 146°05572” E) Plot r (17°46.985” S 146°05.520” E)	50±4	Severe	Kurrimine Beach National Park (Kurrimine Beach Esplanade)

Note: [1]The assessment of canopy openness and level of damage were also used for regeneration strategies study and published in Latifah et al. 2016; [2]Site A1 was set up at the same site as previous study i.e.10 years after Cyclone Winifred in 1986 (Gorman 1996); [3]As *L. ramsayi* only occurred in Tam OShanter National Park so Sub site A2 (62±0.5% canopy openness, moderate to severe) consisting of plots c and d was used to permit comparison with *L. ramsayi* in Site B.