Plant strategies, dispersal and origins of flora at the northern Coral Sea Islands Territory, Australia

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***Abstract*:** A checklist of vascular plants of Coringa-Herald National Nature Reserve (CHNNR) (17º 11'S, 149º 00' E to 16º 23'S, 150º 30'E and Willis Island (16º 24'S, 149º 58'E) at the northern Coral Sea Islands Territory of Australia compiled during 2006/07 surveys, recorded 30 species including 18 species indigenous to the Coral Sea Islands (60%), 10 exotic species (33%) and two that were planted (7%). Plant life-forms included: 5 species of trees and tall shrubs (17%), 2 species of low shrubs (6.5%), 21 herbs (70%), and 2 vine/creepers (6.5%). Plant dispersal for the 30 species is predominantly by human activities (40%), ocean currents (33%) and seabirds (27%). The garden species and dispersal modes at Willis Island indicate that non-residential casual human visitation at CHNNR has at present had little effect on establishment of exotic weeds.

Resilience of leverage flora, floristic diversity and species origins of CHNNR are discussed in relation to its connectivity with the Melanesian region due to the South Equatorial Current operating in the region. *Colubrina asiatica* was recorded as a new record for oceanic islands in Australian territories. Previously recorded *Ximenia americana* and *Digitaria ctenantha* are considered locally extinct. Pattern analyses indicate that cays of similar size and vegetation structure are the most similar in floristic composition. Willis Island flora is relatively dissimilar to the CHNNR cays, due to the influence of anthropogenic activities associated with a staffed weather station.

Key words: coral cay, leverage flora, floristic diversity, species origins, naturalised species and similarity indices.

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Introduction

Relative to their isolated offshore location, Coringa-Herald National Nature Reserve (CHNNR)) and Willis Island are 'hot spots' of terrestrial and marine wildlife within the northern Coral Sea Islands Territory (Jaensch *et al*. 2002). These islands are considered some of the most significant nesting sites in Australia for 14 species of seabirds (Hicks 1985; Jaensch *et al*. 2002). These islands also provide critical breeding habitat for colonies of the green turtle (*Chelonia mydas*). The study area is an important stepping stone between the Great Barrier Reef and the broader Melanesian and Western Pacific regions. The drift seed flora of CHNNR and Willis Island is linked to the Melanesian region by the prevailing east–to–west South Equatorial Current and the predominant east to south-easterly trade winds (Farrow, 1984; Bureau of Meteorology, 2008).

The terrestrial vegetation of coral cays provides significant services for the physical and ecological balances of the islands. Plants trap moving sand particles and form relatively stable elevated surfaces, which are important for the development of coral cay landscapes (Batianoff 2001a). Plants also provide shade, shelter and breeding habitats for a variety of wildlife (Batianoff 2000). Hicks (1985) observed that cays with complex vegetation have a greater diversity of breeding seabirds and invertebrate fauna. At CHNNR, 70% of the seabird species may utilise forest vegetation for breeding (Batianoff *et al*. 2009).

The main objectives of this paper are to analyse the flora of the northern Coral Sea Islands, list leverage flora and discuss plant species strategies that assist resilience and survival. The floras of the CHNNR and Willis Island are compared with previous surveys to assess changes over time and implications for future management.

Methods

The Study Area

Coringa-Herald National Nature Reserve (CHNNR) and Willis Island are situated approximately 440km east of Cairns within the Queensland Plateau subregion of the Coral

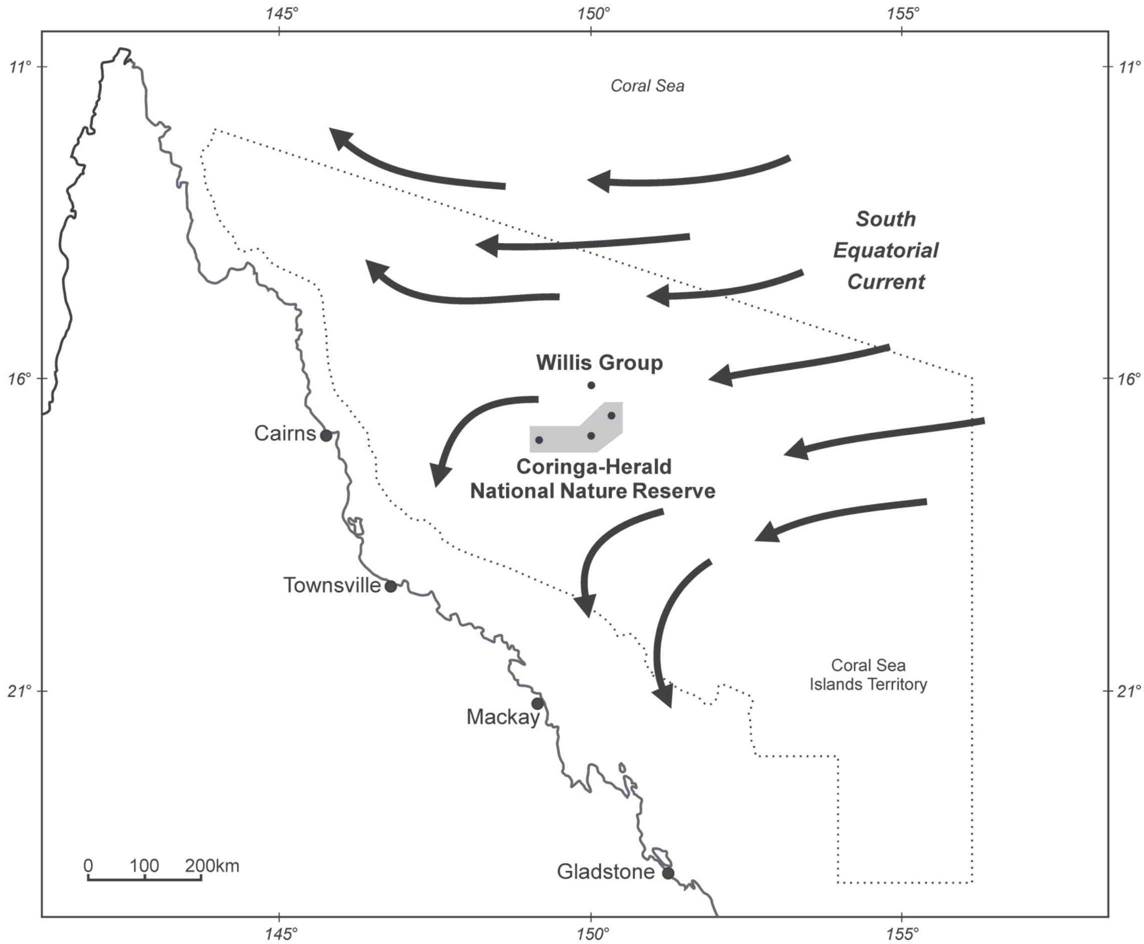

Fig. 1. Coringa-Herald National Nature Reserve and Willis Island in the northern Coral Sea Islands Territory.

Sea (Figure 1). The cays are considered 'low islands' with a maximum elevation of 5–6 m for the CHNNR islands (Heatwole 1979; ANPWS 1989), and 8–9 m for Willis Island (Farrow 1984). The CHNNR was proclaimed by the Commonwealth of Australia as part of the Coral Sea National Nature Reserves in 1982. The five permanently vegetated islands within the CHNNR are located between 17º 11'S, 149º 00'E to 16º 23'S, 150º 30'E. Willis Island (16º 24'S, 149º 58'E) to the north of the CHNNR islands is a relatively small cay and has had a manned Australian Bureau of Meteorology weather station since 1921. The total terrestrial island area is estimated at about 150ha, with North East Herald Cay the largest cay studied (52 ha), and Willis Island the smallest (7.7 ha). Area estimates for the other islands surveyed are: South West Herald Cay (18.8ha), Chilcott Islet (16.3 ha), South West Coringa Islet (17.3 ha) and South East Magdelaine Cay (37.0 ha).

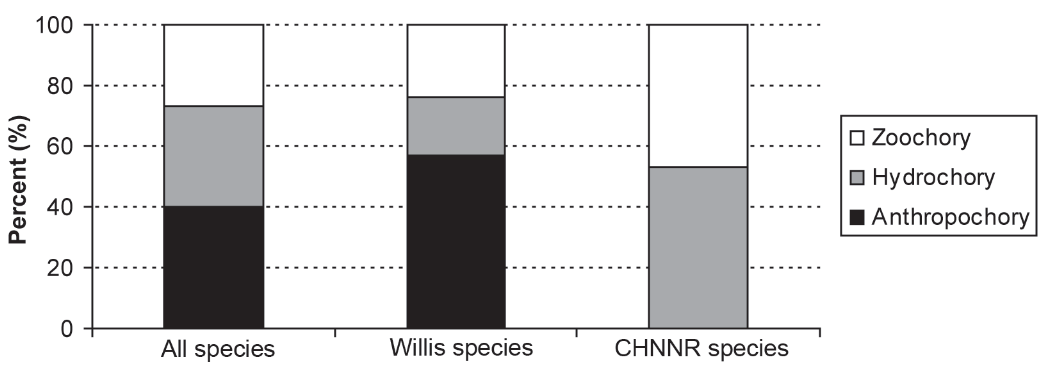

Fig. 2. Percentage of flora dispersed by each agent type, northern Coral Sea Islands (All species total 30, Willis total 21, CHNNR 17).

Table 1. Terrestrial plants species recorded (2006/07) at Coringa-Herald National Nature Reserve and Willis Island

Species: * naturalised species considered not native to Australia; # planted/not naturalised.

Life forms (LF): **Ha** annual herbs; **Hp** perennial herbs; **V** vines; **ST** tall shrubs/small trees (2–5m); **T** trees (>2m).

Dispersal DM): **A** human activity/anthropochory; **O** ocean currents/hydrochory; **V** vegetative; **W** wind/anemochory; **Z** animal/zoochory.

Islands: **1** NE Herald Cay; **2** SW Herald Cay; **3** Chilcott Islet; **4** SW Coringa Islet; **5** SE Magdelaine Cay; **6** Willis Island

Occurrence: **a** abundant (>30% cover/sites); **f** frequent (15–30% over/sites); **i** infrequent (<15% cover/sites); **r** rare (<1% cover/sites); ? possibly present; – not recorded during surveys.

			CHNNR Islands					**Willis**
Family/Species	**Lform**	**Disp**	**1**	**2**	**3**	**4**	**5**	**6**
AIZOACEAE								
**Trianthema portulacastrum*	Ha	AZ	–	–	–	–	–	r
AMARANTHACEAE								
Achyranthes aspera	Ha/p	Z	a	a	a	a	a	i
**Alternanthera pungens*	Ha	AZ	–	–	–	–	–	?
**Amaranthus viridis*	Ha	AZ	–	–	–	–	–	i
ARECACEAE								
@#*Cocos nucifera*	T	AO	–	–	–	–	–	r/i
ASTERACEAE								
**Tridax procumbens*	Ha	AW	–	–	–	–	–	r
BORAGINACEAE								
Argusia argentea	ST	O	f	f	f	f	f	f
Cordia subcordata	ST	OV	f	–	r	i	i	–
BRASSICACEAE								
Lepidium englerianum	Ha	O	i	i	i	i	i	?
CASUARINACEAE								
#*Casuarina equisetifolia* subsp. *equisetifolia*	T	AOW	–	–	–	–	–	r
CONVOLVULACEAE								
Ipomoea macrantha	Vp	OZ	f	f	a	a	f	–
Ipomoea pes–caprae subsp. *brasiliensis*	Hp	O	–	–	–	–	–	i
EUPHORBIACEAE								
**Chamaesyce prostrata*	Ha	AZ	–	–	–	–	–	i
#***Euphorbia cyathophora*	Ha/p	AZ	–	–	–	–	–	f
FABACEAE								
Canavalia rosea	V/Hp	O	–	–	–	–	i/f	–
MALVACEAE								
Abutilon albescens	S	ZWO	a	f	f	f	f	i
NYCTAGINACEAE								
Boerhavia albiflora	Hp	Z	f	a	f	f	f	a
Boerhavia mutabilis	Hp	Z	i	–	–	i/f	i	–
Pisonia grandis	T	ZV	a	–	–	–	f	–
PLUMBAGINACEAE								
Plumbago zeylanica	Hp	Z	–	i/f	i/f	f	i/f	–
POACEAE								
**Cenchrus echinatus*	Ha	AZ	–	–	–	–	–	i
#***Cynodon dactylon*	Hp	AVZ	–	–	–	–	–	i
**Dactyloctenium aegyptium*	Ha/p	AV	–	–	–	–	–	f
**Eleusine indica*	Ha	AZ	–	–	–	–	–	i
Lepturus repens	Ha/p	OZV	i/f	i	f	f	f	f
Sporobolus virginicus	Hp	OZV	f	f	i	–	f	f
Stenotaphrum micranthum	Ha/p	OV	i	i	i/f	–	i	?
PORTULACACEAE								
Portulaca oleracea	Ha/p	ZO	i/f	i/f	i	i	i	i
RHAMNACEAE								
Colubrina asiatica	S	O	–	–	–	–	r	–
ZYGOPHYLLACEAE								
Tribulus cistoides	Ha/p	ZO	f	f	f	f	f	i/f
TOTAL 17 families, 28 genera, 30 species	–	–	14	12	13	12	17	21 *10

The northern Coral Sea Islands Territory experiences a tropical, maritime climate with distinctly seasonal rainfall, stable annual temperatures and high evaporation rates (Farrow 1984; Neil & Jell 2001; Batianoff *et al*. 2009). Annual rainfall at Willis Island (1115 mm) occurs predominantly during the four ‘wet’ months of January to April with a ‘dry’ period lasting from May to November. Drought periods lasting between 1 and 5 years have also been recognised (Batianoff *et al*. 2009). The mean monthly ambient temperature ranges from a minimum of 21.9ºC in July to a maximum of 30.7ºC in January with little diurnal variation between day and night (Bureau of Meteorology 2008).

Data collection

Nineteen field days were undertaken over two ‘dry seasons’ on three separate trips. (November–December 2006, May 2007, October 2007). North East Herald Cay was the most comprehensively studied, with Willis Island receiving only two hours for sampling.

A list of plant species were compiled for each island together with floristic attributes such as genus, family, life-form and dispersal modes and abundance. Plants that provide major ecosystem services and determine island vegetation structure were listed under the terminology of coral cay ‘leverage’ species. Previous botanical reports for the Coral Sea Islands Territory (Heatwole 1979; Hicks & Hinchey 1984; Hicks 1985; Telford 1993a; Batianoff 2001a) were compared to assess floristic changes over time and to identify erroneous and anomalous recordings. Plant voucher specimens collected during surveys were incorporated into the Queensland Herbarium (BRI) collection. The BRI specimen database (HERBRECS 2008) was utilised extensively to verify dates and locations of previous botanical collections.

PATN analysis was used to determine dissimilarity between island floras based on the frequency of species found on each cay. The frequency data were classified using a hierarchical agglomerative polythetic clustering method based on flexible unweighted pair-group averages method (Belbin 2004).

Results

Floristic appraisal

The regional flora for CHNNR and Willis Island flora including exotic species comprises 30 species in 17 families and 28 genera (Table 1). The dominant group are the dicotyledons (72%), represented by 15 families, 20 genera and 22 species. The monocotyledons (28%) were represented by two families (8 genera and 8 species). The family Poaceae was represented by seven species (23%) including four exotics. Poaceae and Nyctaginaceae have the highest proportion of indigenous species with 3 species each.

Naturalised populations of exotic species were found only on Willis Island. There were 10 species (table 1), two of which (*Cynodon dactylon* and *Euphorbia cyathophora*) have been deliberately introduced and planted on Willis Island. *Alternanthera pungens* was recorded as a common weed at Willis Island in March 1995 (Donaldson 1995) and though it was not recorded during the October/November 2007 survey, it is a persistent annual herb and is most likely still present on this island. With the exception of *Cynodon dactylon* and *Dactyloctenium aegyptium*, which are perennial grass species, the remaining eight exotic species are all short-lived herbs that produce large amounts of viable seed.

Cocos nucifera and *Casuarina equisetifolia* subsp. *equisetifolia* are Australian tree species that have also been planted on Willis Island as part of a landscaping program but are not considered to be naturalised. During our October–November 2007 visit, three young individuals of *Cocos nucifera* were recorded establishing outside the landscape compounds of the meteorological station. No naturalised individuals of *Casuarina equisetifolia* were recorded away from the two patches of planted trees.

Apart from naturalisations, there is considerable evidence of turnover among the islands' floras. During the 2007 survey, *Colubrina asiatica,* a seashore shrub species widely distributed along Western Pacific seashores including Australia (Ridley 1930), was recorded for the first time in the northern Coral Sea Islands Territory (on SE Magdelaine Cay). Other new records for individual islands within CHNNR were *Cordia subcordata* (recorded on SW Coringa Islet), *Stenotaphrum micranthum* (at SW Herald Cay and Chilcott Islet), *Boerhavia mutabilis* (at Chilcott Islet and SE Magdelaine Cay), and *Sporobolus virginicus* (at SE Magdelaine Cay).

Two previously recorded plant species now considered locally extinct from CHNNR are.

- *Digitaria ctenantha*, a tropical annual grass has been previously collected at SE Magdelaine Cay (S. Hogg – May 1984, T. Scotney – October 1987, and I. Telford – 1989), Willis Island (S. Donaldson – March 1994) and NE Herald Cay (G. Batianoff – June 1997). It was not found on any island during the 2006 and 2007 surveys.
- *Ximenia americana* first recorded at NE Herald Cay by J. Hicks (December 1983) as a small tree (Du Puy & Telford, 1993c). In December 1991, I. Telford recorded *Ximenia americana* at the same location, describing one large shrub and several small shrubs. In June 1997, G. Batianoff recorded 10 individuals of different ages (Batianoff, 2001b). By the time the 2006 and 2007 surveys were undertaken, the entire *Ximenia americana* population had died, with only the dry stems remaining.

Recordings of species from previous surveys now considered erroneous are given in Table 2. For example the saltmarsh species *Suaeda australis* has been listed for Chilcott Island in the two Management Plans (ANPWS 1989; Environment Australia 2001), but is not recorded on any other Australian Oceanic Islands, and according to Telford (1993b) is erroneous.

Plant life-forms include trees, shrubs, vine/creepers and prostrate herbs. 21 species (70%) are herbaceous groundcover species, including 15 (50%) annuals and 12 (40%) with fleshy foliage. Five species (17%) are tall shrubs and/or trees, including the large *Pisonia grandis* tree; two are low shrubs, and two are creeper/vine species.

Table 1 lists the regional dispersal modes of the 30 species. Overall 40% are dispersed by human activities (anthropochory), 33% by ocean currents (hydrochory) and 27% by seabirds (zoochory). 21 species (70%) are adapted for more than one mode of dispersal (Figure 2). Of the 17 indigenous species found at CHNNR (Table 1), 9 species (53%) are primarily dispersed by ocean currents, and 8 (47%) by seabirds; no species are primarily dispersed by humans. Most of the Willis Island flora is dispersed by human activities (57%). Seabirds and ocean currents account for 24% and 19% respectively.

Individual island species composition and similarity

Indigenous plant species richness for CHNNR individual cays ranges from 12 species at SW Herald Cay and SW Coringa Islet, to 17 at SE Magdelaine Cay (Table 1). With the exception of *Ipomoea pes-caprae* subsp. *brasiliensis* (which occurs only on Willis Island), SE Magdelaine Cay has all of the native species currently recorded at CHNNR. SW Coringa Islet has the lowest species richness relative to its size. Although indigenous species richness compared to Australian mainland islands is low (Batianoff & Dillewaard 1997), the biodiversity at the generic and family levels is high, as indicated by the low species per genus and family ratios (1.1 spp./genus and 1.7 spp./family).

The floras on these cays constitute distinctive assemblages that share a close similarity (Figure 3). Chilcott Island and SW Herald Cay have the closest association with almost identical species compositions and abundances. *Cordia subcordata*, found on Chilcott Island is the only species that differentiates the species composition of Chilcott Island

Table 2. Erroneous recordings in previous reports of flora of Coringa-Herald National Nature Reserve

Species	Comments
Caesalpinia bonduc (Caesalpiniaceae)	Seedlings recorded at NE Herald (Telford, 1993a). Transient drift seed species, seedlings at NE Herald were removed by nesting green turtles.
Suaeda australis (Chenopodiaceae)	Listed for CHNNR – Chilcott?! (Environment Australia, 2001). According to Telford (1993a), the record is erroneous.
Calophyllum inophyllum (Clusiaceae)	Collected by Heatwole at the Herald Cays in September, 1967. Listed by Telford (1993a). Not reported in subsequent botanical surveys at NE Herald or SW Herald Cays. This transient drift seed species is now presumed locally extinct.
Terminalia spp. (Combretaceae)	Seedlings of drift seed plants recorded by Batianoff (2001a) on the shores of NE Herald. The seedlings were removed by nesting green turtles.
Ipomoea pes-caprae (Convolvulaceae)	Listed by Telford (1993a) for Turtle I., Lihou Reef. Listed by Environment Australia (2001) for CHNNR. Recorded as seedlings at NE Herald by Batianoff (2001a). Not recorded in subsequent surveys at NE Herald. *I. pes-caprae* is well established at Willis Island.
Erythrina spp. (Fabaceae)	Seedlings of drift seed plants were recorded by Batianoff (2001a) at NE Herald. However, seedlings were removed by nesting Green Turtles.
Scaevola taccada (Goodeniaceae)	Transient seashore shrub (Telford, 1993a). According to M. Hallam (1997, pers. comm.), *Scaevola taccada* had established at NE Herald in the mid-1990s but died out three years after its establishment.
Hibiscus tiliaceus (Malvaceae)	Listed by Batianoff (2001a) at NE Herald as a drift seed only.
Boerhavia diffusa (Nyctaginaceae)	Listed by Heatwole (1979). Misapplied name for *Boerhavia mutabilis*.
Boerhavia glabrata (Nyctaginaceae)	Listed by Telford (1993a). Misapplied name for *Boerhavia mutabilis*.
Boerhavia tetrandra (Nyctaginaceae)	Listed by ANPWS (1989) and Environment Australia (2001). Misapplied name for *B. albiflora* var. *albiflora*.
Commicarpus chinensis (Nyctaginaceae)	Listed by Heatwole (1979). This species not found in Queensland, its pink flowers are similar to *Boerhavia mutabilis*.
Commicarpus insularum (Nyctaginaceae)	Listed by Heatwole (1979) and Telford (1993a). Not reported in subsequent botanical surveys.
Thuarea involuta (Poaceae)	Listed in Environment Australia (2001) at CHNNR. Listed by Telford (1993a) as a doubtful record.

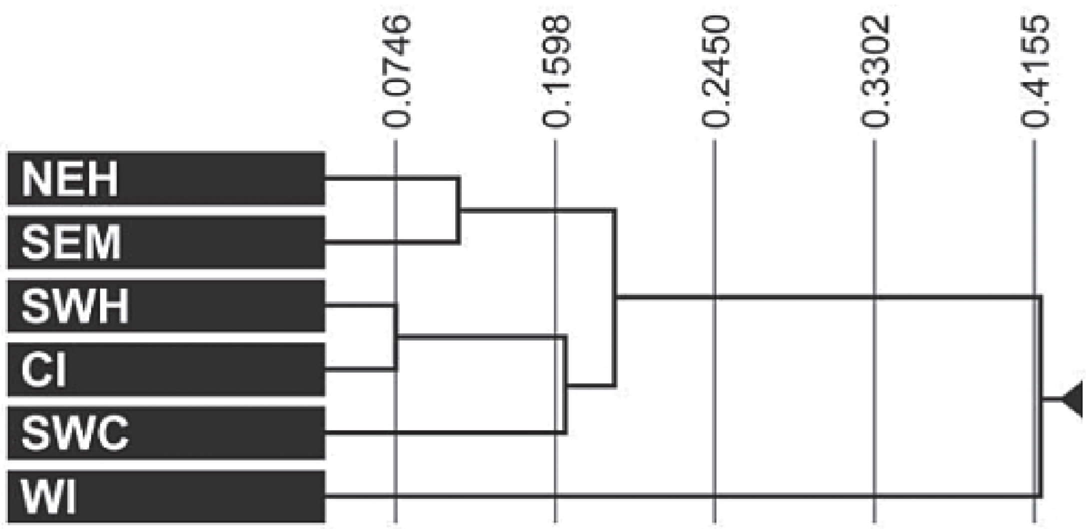

Fig. 3. Fusion dendrogram of Coringa-Herald National Nature Reserve and Willis Island flora associations based on PATN analysis (Belbin 2004). *Notes:* NEH, NE Herald Cay; SWH, SW Herald Cay; CI, Chilcott Islet; SWC, SW Coringa Islet; SEM, SE Magdelaine Cay; WI, Willis Island.

Table 3. Ecological notes on leverage coral cay species at Coringa-Herald National Nature Reserve and Willis Island

Species	Colonisation patterns
Ground layer *Lepturus repens* (beach lepturus)	Ocean dispersed tropical beach grass; widespread annual and/or short-lived grass; major component of littoral herbfields (Telford 1993b; Batianoff 2001b); persists in the interior with in *Abutilon* shrublands and herblands.
Boerhavia albiflora var. *albiflora* (white flowered tar vine)	Bird dispersed; widespread prostrate perennial herb; persists under cover of *Abutilon* and *Argusia* communities; occurs mainly in the interior herbfields (Telford 1993b; Batianoff 2001a).
Sporobolus virginicus (sand couch)	Ocean dispersed; widespread perennial grass of littoral margins and seepage areas, including brackish water; persists within interior communities (Telford 1993b; Batianoff 2001a).
Shrub layer *Abutilon albescens* (coastal lantern flower)	Possibly bird, wind and ocean dispersal; widespread shrub, 0.5– 2m tall; mainly in the interior of *Argusia* fringe; dominant heathlands/shrublands (Batianoff 2001a) common within *Pisonia* glades (Batianoff *et al*. 2009).
Tree layer *Argusia argentea* (octopus bush)	Ocean dispersed; widespread tree 2–6m; halophyte, tolerant of 80–90 % canopy inundation by beach sand; predominant as fringing scrub on seaward margins; prone to dieback along landward margins; rare in the interior beach ridges (Batianoff *et al*. 2009).
Cordia subcordata (sea trumpet)	Ocean dispersed common tree, 3–8m; forms closed-scrubs to low closed-forests from beach ridge to the *Pisonia* rainforest margins. Prone to dieback due to insect damage at CHNNR (moth larvae: *Armactica columbina* and *Ethmia* sp).; resistant to scale insect damage (Freebairn 2007). In mid to late 1800s, *C. subcordata* was almost exterminated by moth herbivory on the Hawaiian islands (Guppy 1906).
Pisonia grandis (grand Pisonia tree)	Bird dispersed; multi-stemmed; larges tree at the Reserve, up to 14m; soft spongy wood, able to hold reserves of water and nutrients (Du Puy & Telford 1993e); dormant during dry periods by shedding its leaves (Batianoff 1999); forms coral cay rainforests in the interior; persists along exposed shores as wind-shorn closed-scrubs.
Vines/twiners *Ipomoea macrantha* (coast moon flower)	Ocean dispersed; widespread perennial climber/vine; common species in the interior herbfields or canopy gap-filling role within woody vegetation (Telford 1993b; Batianoff 2001a).

from SW Herald Cay. NE Herald Cay and SE Magdelaine Cay also have similar floras. It is only the presence of a few distinct species, such as *Canavalia rosea* and *Colubrina asiatica* on SE Magdelaine Cay which provide any sort of dissimilarity between them. Willis Island tends to form a floristic entity unto itself. It does not have widespread species such as *Ipomoea macrantha, Lepidium englerianum, Plumbago zeylanica* and *Stenotaphrum micranthum* that tend to characterise the smaller CHNNR cays and has the only record of *Ipomoea pes-caprae* subsp. *brasiliensis*. The dissimilarity with other islands is evident when considering either the floristic composition based on natives only or, more predictably, when the occurrence of naturalised exotic species are included. When exotics are included in the analysis, the islands' dissimilarity index rises from 0.41 to 0.61 (Figure 3).

Leverage coral cay flora

'Leverage' or 'foundation' species are abundant and/or dominant plant taxa forming the main habitats that provide vegetative cover and reduce temperature, wind and moisture stress for other species (Krebs 2008). In CHNNR the key leverage species are *Abutilon albescens*, *Argusia argentea*, *Boerhavia albiflora* var. *albiflora*, *Cordia subcordata, Ipomoea macrantha*, *Lepturus repens*, *Pisonia grandis* and *Sporobolus virginicus* (Table 3). This leverage coral cay flora includes species that are easily integrated into Grime's classification of plant function (Grime 1979), *Ruderals,* adapted for high disturbance environments, e.g., *Lepturus repens, Sporobolus virginicus*; *Stress tolerator* species adapted to low moisture conditions, e.g., *Boerhavia albiflora* var. *albiflora*; and *Competitors* forming dominant populations under low-stress and low-disturbance conditions, e.g., *Abutilon albescens* and *Pisonia grandis*. Some species functions overlap. For example *Sporobolus virginicus* may function as ruderal on the seashore but inshore in salt affected areas it is a stress tolerant competitor.

Indigenous species that are common and widespread within CHNNR, but which were not included as coral cay key leverage flora include *Achyranthes aspera, Plumbago zeylanica, Portulaca oleracea* and *Tribulus cistoides* (Table 1). These herb/shrub species are widespread in disturbed areas of the Indian and West Pacific Islands due to human activities rather than natural processes (Guppy 1906; Ridley 1930; Barker & Telford 1993).

Discussion

The flora of the northern Coral Sea Islands Territory is a subset of the widely distributed Western Pacific low coral island flora (Heatwole 1979; ANPWS 1989; Batianoff *et al*. 2009). A high percentage of low-lying coral island floras are predominantly oceanic or seabird-dispersed littoral species, with life-forms ranging from grasses to trees (Whistler 1992).

Plant dispersal and establishment

Dispersal modes play an important role in species' geographic ranges and limits (Krebs 2008). Due to the strong influence of eastward winds (Bureau of Meteorology 2008) and the South Equatorial Current (Farrow 1984), the origins of ocean-dispersed species at CHNNR and Willis Island are most likely derived from Pacific Melanesian islands (Smith 1992; Smith 1994; Heyligers 2007). The indigenous coral cay species recorded from the northern Coral Sea Islands (Table 1) are all littoral seashore plants. The ubiquitous sea-dispersed Australian/Pacific *Colubrina asiatica* most likely established at CHNNR from seeds released from parent plants growing outside of Australian territorial waters.

Littoral plants are well-adapted for long distance oceanic dispersal, also referred to as 'island hopping' and/or 'jump' dispersal (Heatwole 1984; Hacker 1990; Batianoff 1999a; Batianoff 2001a; Krebs 2008). During high wave conditions, propagules of littoral and other ocean-dispersed species are deposited along seashores (Guppy, 1906; Smith *et al*., 1990; Smith, 1992; Batianoff *et al*., 1993; Smith, 1994; Heyligers, 2007). These species have buoyant propagules adapted for transport by ocean currents, or seeds that are 'sticky' or easily swallowed and adapted for dispersal by avifauna (Guppy 1906; Hacker 1990; Walker 1991; Batianoff 1999b; Card 2001; Turner & Batianoff 2007). Plants with 'sticky' seeds or hooking devices, are also often dispersed by human activities (Ridley 1930; Pijl 1972).

The modes of dispersal of some coral cay plants are difficult to categorize. The widespread coral cay shrub *Abutilon albescens* has dry seeds that are not buoyant or sticky and according to Card (2001), is dispersed by seabirds. Dry *Abutilon albescens* stems are used for nest-building and thereby many seeds are dispersed around individual islands. The 'green fruit' casings containing dry seeds are capable of floating for several hours (Batianoff, unpublished data). Furthermore, the individual seeds are enclosed in flat winged envelopes, capable of wind-dispersal (anemochory). The wind-dispersal syndrome is uncommon for coral cay plants (Batianoff 2001a). The poor representation of wind-dispersed flora is most likely a consequence of the vast areas of ocean separating these small islands.

Species' natural dispersal mechanisms together with human-assisted dispersal (anthropochory) frequently provide problems for understanding of species origins and/or their status. At Willis Island, most of the naturalised exotic weeds including garden plants were established after deliberate and/or accidental introduction associated with human activities. The absence of exotic species at CHNNR indicate that their low levels of human visitation have currently had little or no effect on establishment of exotic weeds.

Plant origins

Bean (2007) used the terms 'indigenous' and 'native' synonymously in his system of determining the origins of Australian plant species. However certain species may be indigenous to some eastern Australian islands due to their oceanic connectivity with the Melanesian region (Smith 1992; Smith 1994), though they may not be native to mainland Australia. In this study, plants with 'unknown' origins that are widely distributed in the Indo-Pacific region are assumed to be indigenous to the northern Coral Sea Islands. Compilers of lists of naturalised species need to recognise the role of 'natural' systems in continuing the incremental dispersal of plants around the world. This dispersal has occurred for millennia and is unlikely to have ceased in the current age.

Lepidium englerianum and *Portulaca oleracea* are ubiquitous in the study area and are considered as 'native' in the study although they are listed as naturalised exotics in mainland Queensland (Bostock & Holland 2007). Ridley (1930) considered the cosmopolitan *Portulaca oleracea* may have arrived relatively recently to the South Western Pacific region. Even if *Lepidium englerianum* and *Portulaca oleracea* are not indigenous as strictly considered by some botanists, our observations indicate that they do not pose a threat to any indigenous coral cay flora or fauna, and do not require active management.

The case of the coconut *Cocos nucifera* is particularly contentious. Bostock & Holland (2007) recognise *Cocos nucifera* as an introduced exotic to Queensland, but many botanists and biogeographers believe that it is indigenous to the Indo-Pacific Region, including Australia (Du Puy & Telford 1993a). (The questions and confusion about the geographical antiquity of *Cocos nucifera* can be followed through Corner (1966), Dennis & Gunn (1971), Buckley & Harries (1984) and Harries (1992)). Whilst this species has been cultivated at Willis Island, it is likely to be indigenous to coral cays in the region.

Plumbago zeylanica is recognised as native to Australia (Bostock & Holland 2007; Du Puy & Telford 1993d), has been in cultivation from ancient times by Chinese and Indian people for traditional medicine (Batianoff *et al*. 2009) and is currently widespread across subtropical Africa, southern Asia to northern Australia and some Pacific Islands (Du Puy & Telford 1993d). It is common in the study area. According to Ridley (1930), *Plumbago zeylanica* has an African/Asian origin and was introduced into Australia during the early 1800s in contaminated imports.

Species richness and island species composition

The indigenous plant species richness at CHNNR is comparable with the average of 18 indigenous species for atolls ranging in size from 4–70 ha within the Caroline Atoll Group (Kepler & Kepler 1994). The indigenous floras of 'younger' and/or less developed smaller cays such as SW Herald (12 spp.) and Willis Island (11 spp.) comprise a few herb species that are predominately ocean-dispersed (Table 1). These smaller cays frequently support only one or two woody plant species such as *Argusia argentea* and *Abutilon albescens*.

On more developed and/or larger cays, vegetation may include some trees and/or shrubby plant species, but the majority of species are herbaceous plants (Heatwole 1984;

Kepler & Kepler 1994). The number of indigenous woody species on atoll islands in the Caroline Islands remains relatively low and constant, as interior forests rapidly mature (Kepler & Kepler 1994). These forests form dense canopy layers of the predominant tree species, mainly from vegetative growth, and limit the establishment of other plant species. Similar growth patterns have been observed in forests in the interior of coral cays in Australia. For example, Elsol (1985) reported that after the removal of feral goats, most of the interior *Pisonia grandis* forest at Lady Musgrave Island re-established by means of rapid vegetative growth, thus excluding the establishment of other forest species. Likewise, at NE Herald Cay, virtually no plant species are found under the well-developed *Pisonia* littoral rainforest (Batianoff 2001a).

Plant survival and resilience

The long-term survival of a plant species on a coral cay island depends on its resilience to hostile conditions, and its ability to successfully reproduce under continually changing environmental conditions (Heatwole 1976; Batianoff 2001a). Newly dispersed plants that may initially germinate on the seashores of coral cays often fail to establish and/or reproduce due to desiccation, predation by foraging hermit crabs and/or removal through excavation by sea turtles during egg laying activities (Hacker 1990; Batianoff 2001a). Some transient species frequently survive for short periods of time (Heatwole 1984; Batianoff 2001a) but this short-lived establishment should not be interpreted as full-scale naturalisation.

Excessive insect predation on successfully established plant populations may result in mortality of individuals or localised extinction of the entire population. According to Smith *et al*. (2004), the entire *Pisonia grandis* littoral rainforest died out on SW Coringa Islet between 1993 and 2002 as a result of *Pulvinaria urbicola* (scale insect) outbreaks. *Pulvinaria urbicola* has also been responsible for significant declines of *Pisonia grandis* populations at Tryon Island (Capricorn-Bunker Region) and on Palmyra Atoll in the Line Islands of the northern equatorial Pacific (Kay *et al*. 2003; Handler *et al*. 2007). This decline of *Pisonia grandis* presents a potential long term conservation problem.

Regional vulnerability to naturalised flora

Most littoral and island floras including cays and atolls are prone to invasion by weedy exotic plant species (Heatwole 1984; Chaloupka & Domm 1986; Heatwole & Walker 1989; Kepler & Kepler 1994; Batianoff & Franks 1997). Humans and the types of activities they undertake are important factors influencing all island floras. On Willis Island 57% of the species are exotics, established as a result of human activities (Figure 2). Given the high levels of human disturbance and bird traffic (especially burrowing shearwaters), most naturalised weeds have established soil seed banks, meaning that weed control and/or eradication will be difficult and require long-term weed control management strategies. The susceptibility of most coral cays to invasion by exotic plants is an important consideration for wildlife management of islands in the CHNNR and on other Australian Oceanic Islands. Significantly, on some 'weedy' islands, zonation and succession patterns have been observed to change due to the displacement of indigenous plants by exotic species (Kay & Crocetti, 2004).

Unless strict quarantine and hygiene safeguards are in place, it will only be a matter of time before some of the exotic invasive flora from Willis Island spreads to other islands. According to Telford (1993b), all the exotic species on Willis Island (with the exception of **Trianthema portulacastrum*) are widespread weedy species of oceanic islands within Australian territories. *Euphorbia cyathophora* and *Tridax procumbens* were collected on Willis Island as early as December 1981 (by A. Skeat and J. Henry). The invasive weedy species that are widespread and/or highly competitive with the indigenous plants on the island are *Cenchrus echinatus, Dactyloctenium aegyptium*, *Eleusine indica* and *Euphorbia cyathophora* (Batianoff unpublished data).

Leverage coral cay species and management implications

The recognition of 'leverage coral cay species' within vegetation communities is considered important for plant conservation management (Given 1994; Krebs 2008). All coral cay key leverage species listed in Table 3 provide plant materials for seabirds in nest building and/or nesting and roosting habitats within plant canopies (Batianoff 2000; Batianoff 2001b; Batianoff & Cornelius 2005). For instance, the *Pisonia grandis* and *Argusia argentea* communities provide nesting sites for seven species (64%) of seabirds breeding at the Reserve (Batianoff *et. al*. 2009). The custodians of CHNNR have the potential to enhance resilience of coral cays ecosystem and/or vegetation recovery by encouraging the replanting of targeted species listed in the group of leverage coral cay flora (Table 3). The ability to repair habitats for wildlife communities after cyclone and/or exotic pest damage is an important consideration under current conditions of climate change (Batianoff *et al*. 2009).

Projected sea level rise may drown some current cay and reef areas by inundation, and result in the erosion of shorelines, and saltwater seeping into freshwater lenses (Burns 2000). The CHNNR cays are likely to undergo some decline in island area, with those of smaller size and without protective beach rock likely to be the most affected (Smithers *et al*. 2007; Batianoff 2009a). As shorelines erode and saltwater intrudes into freshwater lenses, it is likely that herbaceous plants will be favoured over deeper rooted woody species. This will impact on the ecology of the islands as it will decrease foraging, roosting and breeding opportunities for turtles and seabird species.

Conclusions

- The species found on the cays of the northern Coral Sea Islands Territory are a subset of the broader ubiquitous tropical Western Pacific oceanic flora, with a higher proportion of ocean and seabird-dispersed species.
- The CHNNR flora is subject to changes, particularly through the introduction of exotic (pest) species. However, the flora is resilient due to its plant strategies and ongoing adaptations to climatic conditions.
- A higher number of exotic species occur on Willis Island due to residential human activities; however, none of these exotics are currently in CHNNR.
- Exotic pest species such as invasive weeds are capable of establishment at CHNNR during favourable seasons. As a result, strict quarantine and biosecurity measures are recommended.

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