Report

Vegetation Assessment and

Mapping of South Islet (Willis Islets), Coral Sea Marine Park

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For Parks Australia, the
Department of Agriculture,
Water and the Environment
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Organising and undertaking the vegetation survey field trip to Willis Island required the assistance of many people. The contribution of following people and organisations are acknowledged:

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SGS Cairns International analyses of the soil samples.

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Executive Summary

This document has been prepared for Parks Australia, Australian Department of Agriculture, Water and the Environment. A one and a half day field trip was undertaken on Willis Island, Coral Sea on 17th and 18th October, 2020 by two people with the following outcomes:

- A comprehensive species list of vascular plant species was compiled.
- A total of 16 plant species was recorded consisting of eight naturally occurring species native to Coral Sea cays, six naturalised exotic species not naturally occurring in Australia, one planted native species and one species considered to be exotic on the mainland but naturally occurring on the cays.
- Floristic composition at the time of the survey was compared to that of previous surveys of both Willis Island and other Coral Sea Marine Park cays.
- Digital site data and photographs recorded at 52 sites has been provided to Parks Australia.
- Incidental observations of species and abundance of nesting seabird species present as well as evidence of turtle nesting activity were also recorded at each of these sites.
- Twelve natural vegetation communities were identified and described.
- These vegetation communities were compared to those present on other Coral Sea cays and the Capricorn Bunker, Great Barrier Reef cays.
- A vegetation map was produced showing the location of each of these communities on the island. Parks Australia have been provided with rectified spatial files of the vegetation map polygons and associated data.
- Four permanent monitoring sites were established and surveyed, two representing natural marine couch grassland communities of the island, one representing a natural coastal *Argusia argentea* (octopus bush) community and one located in a herbland at the site of the sewage outlet.
- Nutrient analyses were undertaken on nine soil samples collected at the four permanent monitoring sites at different depths from 0m to 60 cm.
- Results of the soil analyses were compared to those obtained on previous occasions on other Coral Sea cays, and the Capricorn Bunker cays and Lady Elliot Island, Great Barrier Reef cays.
- Seventeen reference GPS coordinates were recorded to assist with future aerial image rectification.
- Recommendations are included in relation to weed control, other biosecurity management and suitable plant species for rehabilitation planting.

Limitations of the report include:

- extremely dry conditions on the island at the time of the survey;
- lack of a suitable rectified aerial image for delineation of vegetation communities;
- insufficient time on the cay to complete comprehensive surveys;
- difficulty accessing some sites due to the abundance of nesting seabirds; and
- lack of Coral Sea vegetation benchmark data for biocondition assessment.

While the October, 2020 survey provided good information on the vegetation of the island during dry conditions, it is recommended that a survey be undertaken immediately following a wetter period to provide better information on the vegetation diversity of the island.

1.0 Introduction

In October 2020, a survey of South Islet (Willis Islets), commonly referred to as Willis Island, was conducted to assess and map the vegetation. Willis Island is part of the Coral Sea Marine Park and has been the site of a Bureau of Meteorology weather station since 1921. The island was severely impacted by cyclone Yasi in 2011.

1.1 Objectives of the Willis Island Vegetation Survey

The objectives of the vegetation survey were to:

1. Establish and survey permanent monitoring sites (including *BioCondition reference sites if suitable) in as many vegetation communities as possible using the methodologies of Neldner *et al.* 2019 (secondary sites), Eyre *et al.*, 2017 and Eyre *et al.* 2015;
2. Traverse the island and record data at tertiary or quaternary site level (Neldner *et al.* 2019) to:
    - ground truth the vegetation map;
    - compile species lists;
    - determine presence, abundance and distribution of weeds;
    - identify other disturbance/threats to native cay vegetation; and
    - record presence and nesting of seabirds and evidence of turtle nesting on the island
3. Collect plant specimens as appropriate for identification and incorporation into the Queensland Herbarium and Australian National Herbarium collection as voucher records of species recorded on Willis Island; and
4. Collect soil samples for nutrient analyses.

*BioCondition is a site-based, quantitative, and repeatable, condition assessment methodology that provides a measure (expressed as a BioCondition score between 0 and maximum of 1 and BioCondition Class of 1, 2, 3 or 4 – one being the best) of how well a terrestrial ecosystem is functioning for biodiversity values. A suite of attributes (e.g. tree canopy cover, coarse woody debris, native plant species richness, litter cover) are assessed at a site and evaluated against benchmarks for those attributes. The benchmarks for attributes are derived from *a reference state* for the Regional Ecosystem – the latter being the natural variability in attributes of an ecosystem relatively unmodified since the time of European settlement (Eyre *et al.* 2015).

1.2 Limitations of the Vegetation Survey and Mapping

The prevailing and preceding very dry conditions on the island at the time of the survey made the vegetation survey challenging as many short-lived species, including annual invasive weed species, were not growing on the island at this time. Due to the dryness of the vegetation, the vegetation patterns on the drone image used to prepare the vegetation map did not accurately match the vegetation actually present on the ground. Photo 1 shows the state of the native marine couch

(*Sporobolus virginicus*) grassland at the time of the survey. The pattern on the 2019 aerial image indicates this area was a dense grassland at the time the image was taken.

Photo 1 Dry conditions at Willis Island during the October 2020 survey

The dry conditions also made collection of soil samples difficult and prevented sample collection from deeper in the soil profile.

The survey was undertaken during the peak seabird nesting season on the island. The presence of large numbers of nesting seabirds including shearwaters in burrows made traversing the Island during the survey both slow and difficult as care had to be taken not to disturb the nesting birds with some areas inaccessible. Comprehensive survey of one of the permanent monitoring sites would have dislodged red-footed booby chicks (*Sula sula*) from their nests in the native *Argusia argentea* (octopus bush) shrubs and therefore only limited data could be recorded at this site.

Early June, after the end of the wet season and shearwater nesting period, would be the most suitable time for vegetation survey with fewer ground and shrub nesting seabirds and moister conditions favouring germination and growth of herbaceous and small shrub species that were dormant in the seed bank at the time of the October 2020 survey.

A recent accurately rectified cloud free aerial image was not available prior to the field visit. There was some cloud cover in the only image available, making delineation of the vegetation patterns difficult and therefore limiting the accuracy of the vegetation map line work in parts of the island obscured by cloud.

The vegetation communities described and mapped on Willis Island in this report have been compared to Coral Cay vegetation communities identified and mapped by Batianoff *et.al*. (2008a) and Hemson and Melzer (2020) and Capricorn Bunker vegetation communities and regional ecosystems described and mapped by Batianoff *et al*. (2012). The Coral Sea cays do not occur within

a currently identified Bioregion of Queensland and have no regional ecosystem mapping. Whilst equivalent Capricorn Bunker regional ecosystems have been assigned to the vegetation communities identified during this survey, the ecosystems of the Coral Sea cays differ from those of the Capricorn Bunker cays in terms of both climate and available pathways for species recruitment. Although initial surveys have been undertaken to establish biocondition benchmarks for the Coral Sea cays (Hemson and Melzer, 2020), available benchmarks are currently restricted to *Pisonia grandis* (pisonia) communities and there are no biocondition benchmarks available for any of the vegetation communities present on Willis Island.

1.3 Nomenclature and Naturalised Status

Scientific plant species names used in this report are according to the *Census of the Queensland Flora 2019* (G.K.Brown & P.D.Bostock, 2019). Common names are included in brackets following the first use of each scientific name.

The term "non-native cay species" is used in this document to include exotic plant species not native to Australia and mainland native plant species that are not considered native to the Coral Sea cays. The term "weeds" is used to describe invasive herbaceous non-cay species that are self-propagating naturally on the island.

2.0 Background Information

2. 1 Location and Physical Environment

The location of Willis Island is shown in the map in Figure 1. The island is located at 16.2878^{0}S, 149.9652^{0}E, 450 kilometres east-north east of Cairns and 466 km north-east of Townsville, Queensland beyond the Great Barrier Reef. It is situated in the Coral Sea Marine Park approximately 50 km north-west of the Magdelaine Cays. Willis Island is located on the north-western side of the sunken Willis Reef atoll and is the southernmost and largest of three coral cays comprising the Willis Islets, which stretch in a NNE to SSW line for about 12 kilometres. It is protected on the eastern and southern sides by the fringing reef.

Willis Island is an oval shape and is aligned NW to SE with a vegetated area of approximately six hectares with a maximum length of 470 metres and a maximum width of 140 metres. The vegetated area is surrounded by a sandy beach which ranges from approximately 25m to 35 m wide. The exception to this is a 65m wide sandy spit at the north-western end. The island rises to a maximum elevation of 8-9 metres above sea level (Farrow, 1984). The cay has a relatively narrow, low beach rock platform that extends from the south-eastern tip to about three-quarters of the length along the north-eastern shore, seaward of the sandy beach.

The cay is derived almost entirely from coralline and algal limestone with some organic content derived from guano accumulation and decomposed plant material. The profile of the island is shown in Photo 2.

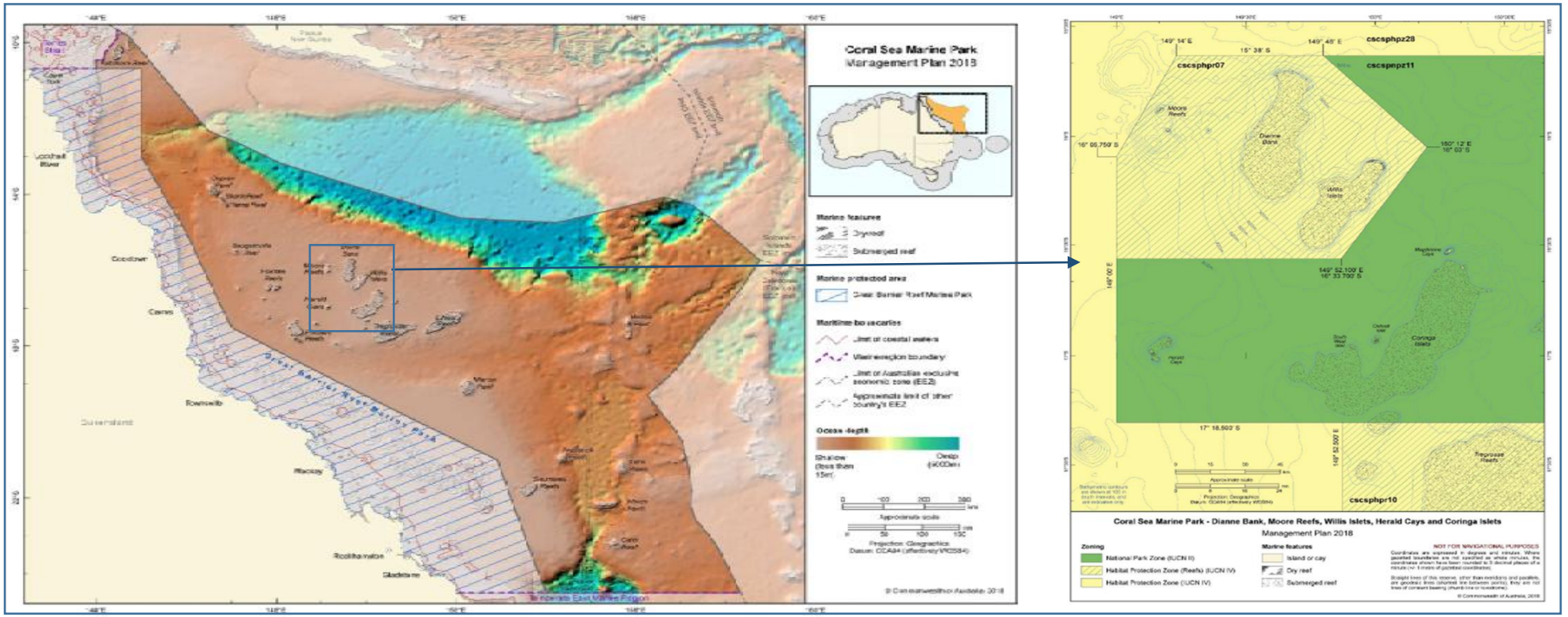

Figure 1 Location of Willis Island

Photo 2 Profile of Willis Island

2. 2 Climate

The climate of the area has been described as a dry, tropical maritime climate with seasonal rainfall, high and relatively stable temperatures throughout the year and high evaporation. Prevailing winds from May to November are the South East Trade Winds with northwest Monsoon winds prevailing during the wet season from December to April. An average of two to three cyclones affect the Coral Sea per year, mainly between December and April. Willis Island was severely impacted by Cyclone Yasi in 2011. Long term monthly and annual rainfall and temperature on Willis Island and monthly averages for the 12 months preceding the October 2020 field survey are listed in Table 1.

Comprehensive and detailed information on Willis Island climate can be found in Batianoff *et al*. 2008a.

Table 1 Current and long term temperature and rainfall records for Willis Island (Australian Bureau of Meteorology, 2020)

	Current year (Oct 19 to Oct 20)			Long Term Average (1921-2020)		
Monthly Total	**Minimum temperature (°C)**	**Maximum temperature (°C)**	**Rainfall (mm)**	**Minimum temperature (°C)**	**Maximum temperature (°C)**	**Rainfall (mm)**
21st to 31st Oct-19	24.2	28.6	4.4	23.7		
Nov-19	24.5	30.0	9.8	24.7	29.9	38.5
Dec-19	25.7	31.1	28.2	25.5	30.7	95.9
Jan-20	26.6	31.9	104.8	25.7	30.7	192
Feb-20	27.6	32.8	50.8	25.7	30.4	217
Mar-20	26.2	31.2	105.6	25.5	29.9	205.2
Apr-20	25.7	30.1	48.8	24.8	28.9	124.3
May-20	24.1	28.0	49.4	23.9	27.8	72.4
Jun-20	23.8	27.5	32.4	22.7	26.6	54.4
Jul-20	22.8	26.7	16.6	22	26	38.8
Aug-20	22.6	27.2	19.2	22	26.4	22.6
Sep-20	23.5	27.9	3	22.6	27.4	16
1st to 20th Oct	23.6	28.5	7.2			
Oct-20	24.2	29.1	7.4	23.7	28.7	20.8
Annual	24.8	29.5	480.2	24.1	28.6	1101.5
1st to 31st October 2020 temperatures were used to determine current year annual average temperatures						
1st to 20th October 2020 and 21st to 31st October 2019 were used to calculate the current year annual rainfall						

2. 3 Management Background

Willis Island is part of the Coral Sea Islands Territory which is an external territory of Australia and is also part of the Coral Sea Marine Park. Parks Australia is responsible for the management of Willis Island.

Willis Island and the surrounding waters are zoned Habitat Protection Zone (Reefs) (IUCN IV) under the *Coral Sea Marine Park Management Plan 2018*. This zone is managed to allow activities that do not harm or cause destruction to seafloor habitats while conserving ecosystems, habitats and native species in as natural a state as possible.

A Bureau of Meteorology weather station, established in 1921, is located in the central, highest part of the island. Currently the station and associated infrastructure are contained within an area of approximately 0.75 ha. The grounds within the operational area around the buildings and infrastructure are regularly mown.

2. 4 Ecological Values

The "dry" tropical vegetation of the Coral Sea cays including Willis Island are an important link with Indo-Pacific region and the Melanesian Islands with the assistance of seabirds and prevailing east-to-west South Equatorial Currents (Batianoff *et al.,2*008a and 2008b).

The vegetation communities on the Coral Sea cays, including Willis Island are unique, differing from those of both the Pacific/Melanesian cays and those of the Great Barrier Reef and provide important seabird habitat.

Willis Island is an important nesting site for a range of seabirds including *Sterna sumatrana* (black-naped tern), S*ula leucogaster* (brown booby), *Anous stolidus* (common noddy), *Anous minutus* (black noddy), *Sula sula* (red-footed booby), *Onychoprion fuscata* (sooty tern), and *Ardenna pacifica* (wedge-tailed shearwater) (Wilgar, 1994). The nesting seabirds are also important in supplying nutrient to the cay with nutrient leached into the water lens also being fed out to the sea and providing nutrient important to the ongoing health of the surrounding reef.

Pluvialis dominica (lesser golden plover), *Sterna bergii* (crested tern*), Pluvalis dominica* (lesser golden plover), and *Arenaria interpres* (ruddy turnstone) are permanent residents on the island (Wilgar, 1994).

Fregata ariel (least frigatebird), *Fregata minor* (great frigatebird), *Egretta sacra* (eastern reef egret), *Sula dactylatra* (masked booby) and *Phaethon rubricauda* (red-tailed tropicbird) are also regularly seen on the island (Shelley, 2019 and Wilgar, 1994).

Todiramphus sancta (sacred kingfisher) and a number of other land birds are also frequently seen on the island (Wilgar, 1994).

Willis is also a nesting site for the vulnerable *Chelonia mydas* (green turtle) and the vulnerable *Eretmochelys imbricata* (hawksbill turtle) is present in the waters of the surrounding reef (Wilgar, 1994).

2. 5 Existing Information

Previous reports on the vegetation of Willis Island include a report by S. Donaldson who visited and surveyed some northern Coral Sea Islands including Willis Island during 1994–95 (Donaldson, 1994) and a report on the 2006/2007 visit and survey of the then Coringa-Herald National Nature Reserve by George Batianoff and others (Batianoff *et al*. 2008a). The National Herbarium contains plant specimen records for plant specimens collected on Willis Island submitted in 1981 by A. Skeat. It is not known whether a report on this visit was prepared.

3.0 Methodologies

3.1 Vegetation Mapping

Prior to the field trip, a spatially rectified 2019 DigitalGlobe drone image was used to delineate patterns of vegetation on the island using the Quantum GIS program. Point coordinates of suitable locations for ground truthing of the vegetation polygons were created using the QGIS program and uploaded to a Garmin GPSMAP 66S Global Positioning System. Data was recorded in the vicinity of these locations and others during the field trip. The vegetation map polygons were attributed using the vegetation communities identified and described from data recorded at these sites.

3.2 Site Data Recorded

Two people spent one and a half days surveying and recording the vegetation on Willis Island on 18th and 19th October, 2020. As time on the island was limited, it was not possible to undertake comprehensive replicate site surveys in each vegetation community present on the island. To ensure sufficient data was obtained and the vegetation of the entire island was thoroughly assessed, a modified “quick” methodology was used with the following data recorded at each of 52 locations across the island:

- GPS coordinates
- vegetation structure (from estimated height and cover)
- all plant species present
- cover of each species at the site
- total weed cover
- slope
- surface soil description
- observations of nesting seabirds and other seabirds and evidence of turtle activity present

The number of square metres included in each site was not defined. The data recorded at each of the 52 sites represented an area surrounding the recorded GPS coordinates that was homogeneous in terms of vegetation community, soil, slope and aspect.

The location of these sites are shown in Figure 2.

The site data recorded was used to:

1. identify and describe all of the vegetation communities present on the island and the variation within each community;
2. obtain a complete floristic inventory for the island;
3. identify the spatial extent and abundance of all weed species present on the island;
4. attribute vegetation patterns on the drone imagery to create a vegetation map for the island;
5. determine habitat preferences of seabirds and turtles;
6. assess the recovery of the islands vegetation from the impact of Cyclone Yasi;
7. assess potential human impact on the island's vegetation; and
8. look for evidence of pests, diseases or any other issues affecting the vegetation of the island.

Heights and covers of total vegetation at each site were estimated to derive the structure class of the vegetation at each site as described in the methodology in Neldner *et al.* (2019). Structural classes derived from heights and covers are tabled in Appendix 1.

The cover of each species at each site was recorded as one of the following cover classes:

1. trace to 5%
2. 6% to 25%
3. 26% to 50 %
4. 51% to 75%
5. 75% to 95 %
6. 95% to 100%

This method provided a simple rapid method to document the relative dominance of each species at each site.

3.3 Permanent Vegetation Monitoring and Biocondition Assessment Sites

Four 50m x 20m permanent monitoring sites were established on the island to enable comparisons of the vegetation over time, monitor biocondition and to assess the impact of climate change and other disturbances on the vegetation of the island.

Sites were permanently marked with star pickets located at the 0m and 50m ends of the 50m transect in the centre of the plots.

Three of the permanent sites were surveyed using the secondary site survey methodology of Neldner *et al.* (2019). The fourth site, located in an *Argusia argentea* (octopus bush) community, could not be comprehensively surveyed during the October 2020 field trip as large numbers of red-footed boobies (*Sula sula*) including chicks were sitting on nests in the branches of the *Argusia* shrubs throughout the site and site survey would have caused unacceptable disturbance to these nesting birds. The permanent monitoring sites were located in a representative area within the selected vegetation communities and outside the boundaries of the operational area. As the sites are permanently marked with labelled star pickets, the sites can be re-monitored any time in the future. The marine couch (*Sporobolus virginicus)* grassland sites may be suitable reference sites to

obtain benchmarks for this community on other Coral Sea cays. To obtain benchmark data, the sites would have to be re-monitored at a wetter time of the year.

To ensure long term secure data storage and accessibility, data recorded at the permanent monitoring sites will be stored digitally by Parks Australia and also by the Queensland Herbarium in the CORVEG database and the Queensland Herbarium photo database.

No permanent monitoring sites were established in the herblands immediately adjacent to the shoreline as the vegetation in these areas is dynamic, constantly changing with wave accretion/ depositional processes and periodic inundation caused by cyclonic and storm surges.

Location of the permanent monitoring sites are shown in Figure 2. Plot orientation and a list of the data recorded at the permanent monitoring sites are contained in Appendix 2.

Figure 2 Location of vegetation data recording sites and permanent monitoring sites

3.4 Reference GPS Coordinates

Reference GPS coordinates were recorded using a Garmin GPSMAP 66S global positioning system at numerous fixed point locations such as corners of roofs and solar arrays, path intersections, anemometer antenna etc. for the purposes of image rectification. The accuracy of these positions as

recorded on the GPS was approximately 3m.The coordinates and locations of these are contained in Appendix 3.

3.5 Soil Analyses

Soil colour and texture were recorded at each of the 52 vegetation survey sites.

Soil samples were collected at various depths from each of the permanent monitoring sites for pH, conductivity and nutrient analyses.

Soils were analysed by SGS Cairns International. A summary of the methodologies used are contained in Appendix 5.

4.0 Results and Discussion

4.1 Prevailing Climatic Conditions

Prevailing conditions at the time of the October 2020 field survey were very dry. Comparison of rainfall records from Willis Island recorded in the 12 months preceding the survey with long term averages graphed in Figure 3 shows that all months in the preceding 12 months had been drier than average. The BoM recorded only 480.2mm of rain falling during this period compared with the long term annual average of 1101.5mm based on 95 years of records spanning 1921 to 2020 (Australian Bureau of Meteorology, viewed November 2020). Refer to Table 1 Current and long term temperature and rainfall records for Willis Island (Australian Bureau of Meteorology, 2020).

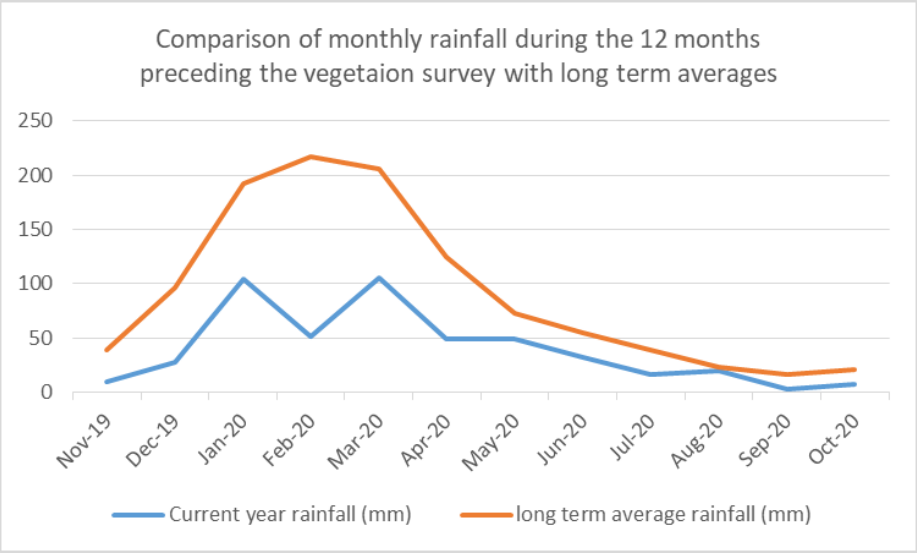

Figure 3 Comparison of monthly rainfall data for the preceding 12 months with long term averages (Australian Bureau of Meteorology, viewed November 2020)

4.2 Floristic Composition

Sixteen species were recorded on the island during the October 2020 field trip. These included all living plants and identifiable standing dead plants. No other species were identifiable in litter or from seeds on the ground. Of these sixteen species, eight were naturally occurring species native to Coral Sea cays, six were naturalised exotic species not naturally occurring in Australia, one was a planted native species and one was a species considered to be exotic on the mainland but naturally occurring on the cays. The vegetation was very dry at the time of the survey and had obviously died back during the preceding dry period. Many species previously recorded were not present in the above-ground vegetation during the October 2020 field survey. It is probable that most of these were present in the seedbank. A vegetation survey soon after the end of the wet season would provide the best opportunity to obtain a complete floristic inventory for the island. Table 2 includes a comparison of species recorded during the October 2020 survey with those recorded during previous surveys of Willis Island and also whether or not there are voucher pressed specimens in herbarium collections confirming the identification of these species at the Willis Island location.

The mature plants of the planted tree species, *Cocos nucifera and Casuarina equisetifolia* subsp. *equisetifolia* that were present on Willis Island prior to cyclone Yasi are no longer present on the island. One small plant of *Cocos nucifera* was observed during the survey.

The native grass *Stenotaphrum micranthum* (beach buffalo grass), positively identified during the October 2020 survey, had not previously been recorded on Willis Island. This species commonly occurs on cays throughout the Coral Sea and the Great Barrier Reef.

The vegetation of Willis Island is very similar to the vegetation present on other smaller Coral Sea cays with a small, limited number of species present compared to the vegetation of the mainland and continental islands. This is a consequence of limited mechanisms for recruitment. The Coral Sea cays also do not contain Ca*suarina equisetifolia, Pandanus tectorius* and several other species that characterise the vegetation of cays within the Great Barrier Reef. *Pisonia grandis* is present on some of the larger Coral Sea cays. According to historical records, however, *Pisonia grandis* has never been present on Willis Island.

Batianoff *et al (*2008a and 2008b) described the origins and dispersal mechanisms of the Coral Sea cays including Willis Island. According to Batianoff *et al.*, the species found on these cays are a subset of the broader ubiquitous tropical Indo-Pacific oceanic flora with the naturally occurring flora of the Coral Sea Marine Park Cays and Willis Island most likely derived from Pacific-Melanesian islands. Batianoff claimed that mechanisms of dispersal of naturally occurring species are via ocean currents and seabirds, and the establishment of naturalised exotic species on Willis Island was a consequence of human activity.

Batianoff *et al* also noted that due to isolation and prevailing westerly currents, the Coral Sea Marine Park cays and Willis Island have a unique species assemblage, and noted that the vegetation of Willis Island does not contain widespread native cay species such as *Ipomoea macrantha, Lepidium englerianum, and Plumbago zeylanica* (native plumbago) that tend to characterise the smaller cays of the Coral Sea Marine Park. It was also noted that Willis Island has the only *Ipomoea pes-caprae* subsp. *brasiliensis* (goats foot convolvulus) found in the area (Batianoff, 2008).

Table 2 contains a comparison of the species recorded on Willis Island with those recorded on the Coral Sea Marine Park and Willis Island cays by Donaldson (1994) and Batianoff et *al* (2008a) and in the Coral Sea Marine Park by Hemson and Melzer (2020). Willis Island was not visited in the 2019 survey by Hemson and Melzer.

The Willis Island Building Rectification Environmental Plan for Contractors (Bureau of Meteorology 2013) also lists the following weed species as present on Willis Island:

- *Argemone ochroleuca (*Mexican poppy*)*
- *Cleome gynandra* (cats whiskers)

These two species were not present on the island at the time of the October 2020 survey and there are no other records of their previous presence on Willis Island.

The native *Abutilon indicum* and *Abutilon albescens* were both listed in the Building Rectification Environmental Plan for Contractors. *Abutilon indicum* is a previously used synonym for *Abutilon albescens.* The current name for this species in Australia is *Abutilon albescens* (lantern bush). No plants of this species were growing on the island at the time of the survey and there was no evidence of fallen or dead standing plants. It is likely that viable *Abutilon albescens* seeds are still present on the island.

Most of the herbaceous sub-shrub, *Achyranthes aspera (*chaff flower*)* recorded were dead plants.

The native *Boerhavia albiflora* var *albiflora* has a large fleshy root enabling it to survive longer dry periods than most other herbaceous species and this species was alive and thriving at most sites. *Portulaca oleracea* (pigweed)*,* a native cay succulent, was also growing successfully in the dry conditions as were the native perennial native grasses, *Sporobolus virginicus (*marine couch*)* and *Lepturus repens* (stalky grass).

There were some invasive weeds present on the island at the time of the survey. *Cenchrus echinatus* (Mossman River grass) was present as dead standing plants and small infestations of *Euphorbia cyathophora* (dwarf poinsettia) were observed in four locations. These were marked with pink flagging tape and pointed out to BoM staff who agreed to remove them and monitor for regrowth. No evidence of the exotic grass, *Eleusine indica* (crows foot grass) was present which was unusual given this weed has previously been reported and is known to be a highly invasive species. It is likely that a seedbank of this, and other previously recorded weed species, are present and will re-establish in wetter conditions. The mown area consisted of an open grassland dominated by the exotic grass, *Dactyloctenium aegyptium* (coast button grass). A number of other exotic invasive herbaceous species were also present in the mown area. The locations of weed species recorded during the survey outside the mown area are shown in Figure 4.

Table 2 Comparison of species recorded on Willis Island with species records for Coral Sea Marine Park cays and previous records for Willis Island

1 = recorded by Donaldson, 1994; 2 =recorded by Batianoff *et al.* 2008a; 3 = recorded by Hemson and Melzer, 2019; 4 = recorded during October, 2020 by Brushe

A = abundant (present at 70–100% of sites with >30% cover per site); F = frequent (present at 30–70% of sites with 15–30% cover/site); I = infrequent (present at 10–30% of sites with <15% cover/site); R = rare (present at <10% of sites with <1% cover/site) (Note – abundance was not recorded by Donaldson or Hemson and Melzer.

* = exotic species not native to Australia, $ = Exotic species not native to the mainland but considered to be naturally occurring on cays, # = planted species

Note: Donaldson did not record species on South West Cay (Herald Cays), Chilcott Islet (Coringa Islets), South-West Islet (Coringa Islets). Donaldson (1994) also recorded plant species present on Coringa, Middle, Turtle and Anne Islands (Donaldson 1994)..

Scientific name	Common name	Family	North East Cay (Herald Cays)	South West Cay (Herald Cays)	Chilcott Islet (Coringa Islets)	South-West Islet (Coringa Islets)	South Magdelaine Island (Magdelaine Cays)	Willis Island	National Herbarium Specimen for Willis Island	Queensland Herbarium Specimen for Willis Island
Native Cay Species										
Abutilon albescens	lantern bush	Malvaceae	1, 2(A), 3	2(F), 3	2(F), 3	2(F), 3	1, 2(F), 3	1, 2(I)	Y	Y
Achyranthes aspera	chaff flower	Amaranthaceae	1, 2(A)	2(A), 3	2(A), 3	2(A), 3	1, 2(A), 3	1, 2(I), 4(I)	Y	Y
Argusia argentea	octopus bush	Boraginaceae	1, 2(F), 3	2(F), 3	2(F), 3	2(F), 3	1, 2(F), 3	1, 2(F), 4(F)	Y	Y
Boerhavia albiflora var. *albiflora*	boerhavia	Nyctaginaceae	1, 2(F)	2(A), 3	2(F), 3	2(F), 3	1, 2(F), 3	1, 2(A), 4(A)	Y	Y
Boerhavia mutabilis	pink flower boerhavia	Nyctaginaceae	?1, 2(I), 3	3		2(I/F), 3	1, 2(I), 3		N/A	N/A
Canavalia rosea	beach bean	Fabaceae					1, 2(I/F), 3		N/A	N/A
Colubrina asiatica	Asian naked wood	Rhamnaceae					2(R)		N/A	N/A
Cordia subcordata	sea trumpet	Boraginaceae	1, 2(F)		2(R)	2(I)	1, 2(I)		N/A	N/A
Digitaria bicornis	Asian crabgrass	Poaceae				3	3		N/A	N/A
Ipomoea pes-caprae subsp. *brasiliensis*	goats foot convolvulus	Convolvulaceae						1, 2(I), 4(I)	Y	Y
Ipomoea violacea	coast moon flower	Convolvulaceae	1, 2(F), 3	2(F), 3	2(I), 3	2(I), 3	1, 2(F), 3		N/A	N/A
Lepidium englerianum	beach peppercress	Brassicaceae	1, 2(I)	2(I)	2(I)	2(I)	1, 2(I)	2(?)	N/A	N/A
Lepturus repens	stalky grass	Poaceae	1, 2(I/F)	2(I), 3	2(F), 3	2(F), 3	1, 2(F), 3	1, 2(F), 4(F)	Y	Y
Pisonia grandis	Pisonia	Nyctaginaceae	1, 2(A), 3				1, 2(F), 3		N/A	N/A
Plumbago zeylanica	native plumbago	Plumbaginaceae		2(I/F), 3	2(I/F), 3	2(F), 3	1, 2(I/F), 3		N/A	N/A

Scientific name	Common name	Family	North East Cay (Herald Cays)	South West Cay (Herald Cays)	Chilcott Islet (Coringa Islets)	South-West Islet (Coringa Islets)	South Magdelaine Island (Magdelaine Cays)	Willis Island	National Herbarium Specimen for Willis Island	Queensland Herbarium Specimen for Willis Island
$*Portulaca oleracea*	pigweed	Portulacaceae	1, 2(I/F), 3	2(I/F), 3	2(I), 3	2(I), 3	1, 2(I), 3	1, 2(I), 4(F)	Y	Y
Sporobolus virginicus	sand couch	Poaceae	1, 2(F), 3	2(F), 3	2(I)		1, 2(F), 3	1, 2(F), 4(A)	Y	Y
Stenotaphrum micranthum	beach buffalo grass	Poaceae	1, 2(I)	2(I)	2(I/F), 3		1, 2(I), 3	2(?), 4(R)	N	N
Tribulus cistoides	Bulls head burr	Zygophyllaceae	1, 2(F), 3	2(F), 3	2(F), 3	2(F), 3	1, 2(F), 3	1, 2(I/F), 4(R)	Y	Y
Xirnenia americana		Olacaceae	1,							
Weed Species										
**Alternanthera pungens*	khaki weed	Amaranthaceae						1, 2(D)	Y	N
**Amaranthus viridis*	green amaranth	Amaranthaceae						1, 2(I), 4(I)	Y	Y
**Cenchrus echinatus*	Mossman River grass	Poaceae						1, 2(I), 4(I)	Y	Y
**Cynodon dactylon*	couch	Poaceae						2(I)	Y	Y
**Dactyloctenium aegyptium*	coast button grass	Poaceae						2(F), 4(F)	Y	Y
**Eleusine indica*	crows foot grass	Poaceae						1, 2(I)	Y	Y
**Euphorbia cyathophora*	dwarf poinsettia	Euphorbiaceae						2(F), 4(I)	Y	Y
**Euphorbia prostrata*	prostrate caustic creeper	Euphorbiaceae						1, 2(I), 4(R)	Y	Y
**Trianthema portulacastrum*	black pigweed	Aizoaceae						2(R), 4(R)	Y	Y
**Tridax procumbens*	tridax daisy	Asteraceae						1, 2(R)	Y	Y
Planted Species										
#*Casuarina equisetifolia* subsp. *equisetifolia*		Casuarinaceae						2(R)	N	Y
#*Cocos nucifera*	coconut	Arecaceae						2(R/I), (4R)	N	N

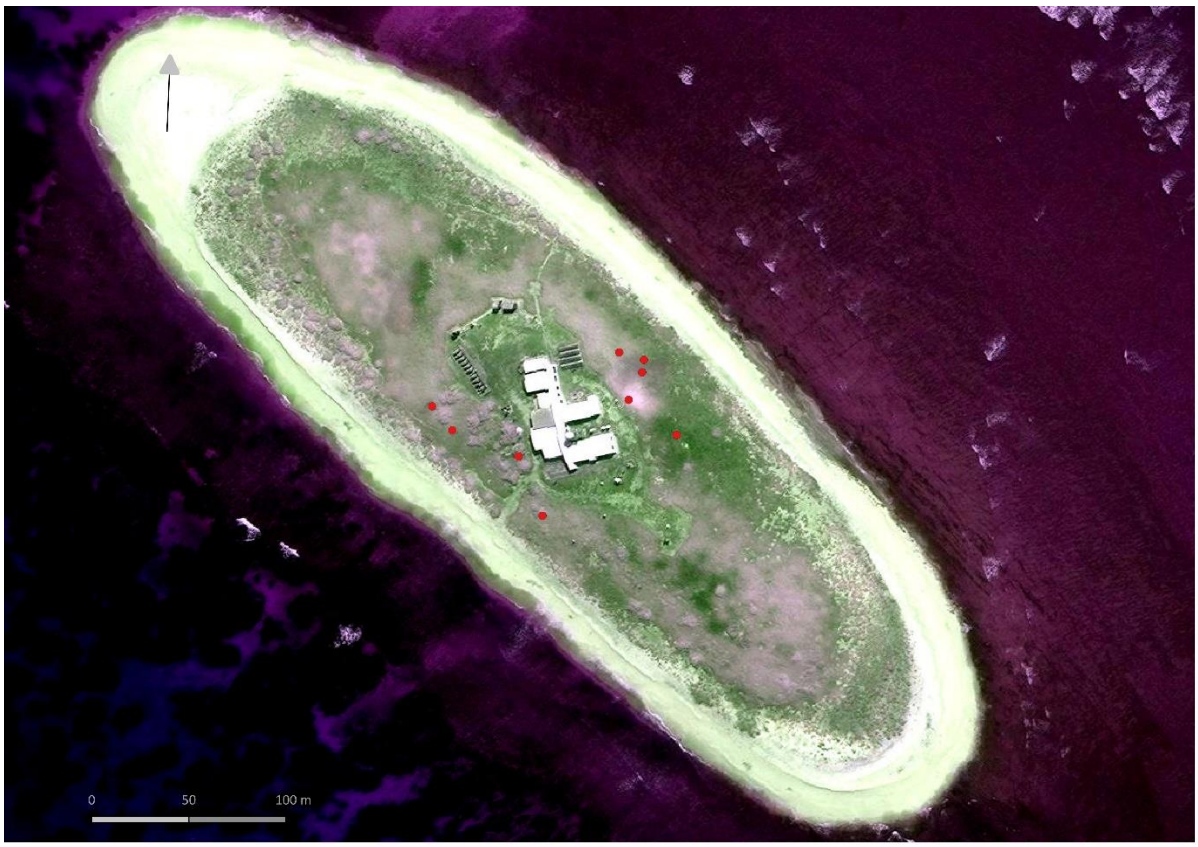

Figure 4 The red dots mark the location of weed species recorded outside the mown area during the October 2020 vegetation survey.

4.3 Vegetation Communities

The vegetation on Willis Island consisted predominantly of grasslands and herblands with low shrubs of *Argusia argentea* scattered along the coastline and also in other areas throughout the island. Vegetation communities identified, described and mapped in this section are very similar to communities present on the Coringa Islets, Herald Cays and Magdelaine Cays of the Coral Sea Marine Park mapped and described by Batianoff *et al.* (2008a) and Hemson and Melzer (2020).

The following native communities, present on the above cays were not present on Willis Island in October, 2020.

- *Ipomoea violacea* vineland
- *Abutilon albescens* open shrubland to shrubland communities
- *Plumbago zeylanica* shrubland to closed shrubland
- *Cordia subcordata* communities
- *Pisonia grandis* communities
- *Colubrina* open-heath

The *Ipomoea pes-caprae/Sporobolus virginicus* herbland community on Willis Island is not present on any of the Coringa, Herald or Magdelaine cays, although it does occur as a component of some vegetation communities on the Capricorn Bunker cays in the southern Great Barrier Reef.

It is likely that during wetter conditions, *Abutilon albescens* shrublands will re-establish from the seedbank on Willis Island. It is also likely that *Achyranthes aspera* herblands will be more extensive following rainfall events.

The *Argusia argentea* communities on the Willis Island were lower in height than those on the Coringa, Herald and Magdelaine cays with most less than one metre tall. The exception to this were a number of plants on the upper slope adjacent to the mown areas that reached a height of over 2m.

In 2006/2007 George Batianoff and others noted that there was an absence of *Argusia argentea* dieback at Willis Island, most likely due to the relatively recent establishment of *A. argentea* on the island as earlier reports and aerial photographs did not show its presence on Willis Island. The individuals that were present on the island at the time of their survey were younger than mature individuals in the Coringa, Herald and Magdelaine cays (Batianoff 2008a). There was some dieback of *A. argentea* on Willis Island in the October 2020 survey and the low height and extremely multi-branched growth form suggested that they had been buried (or partially buried) by sand deposits sand and had continued to grow through these sand deposits. Photo 3 shows the typical growth form of the Willis Island *Argusia argentea*.

Photo 3 Growth form and dieback of *Argusia argentea* on Willis Island

Figure 5 lists the vegetation communities present on Willis Island in October 2020 and shows their spatial distribution on the island.

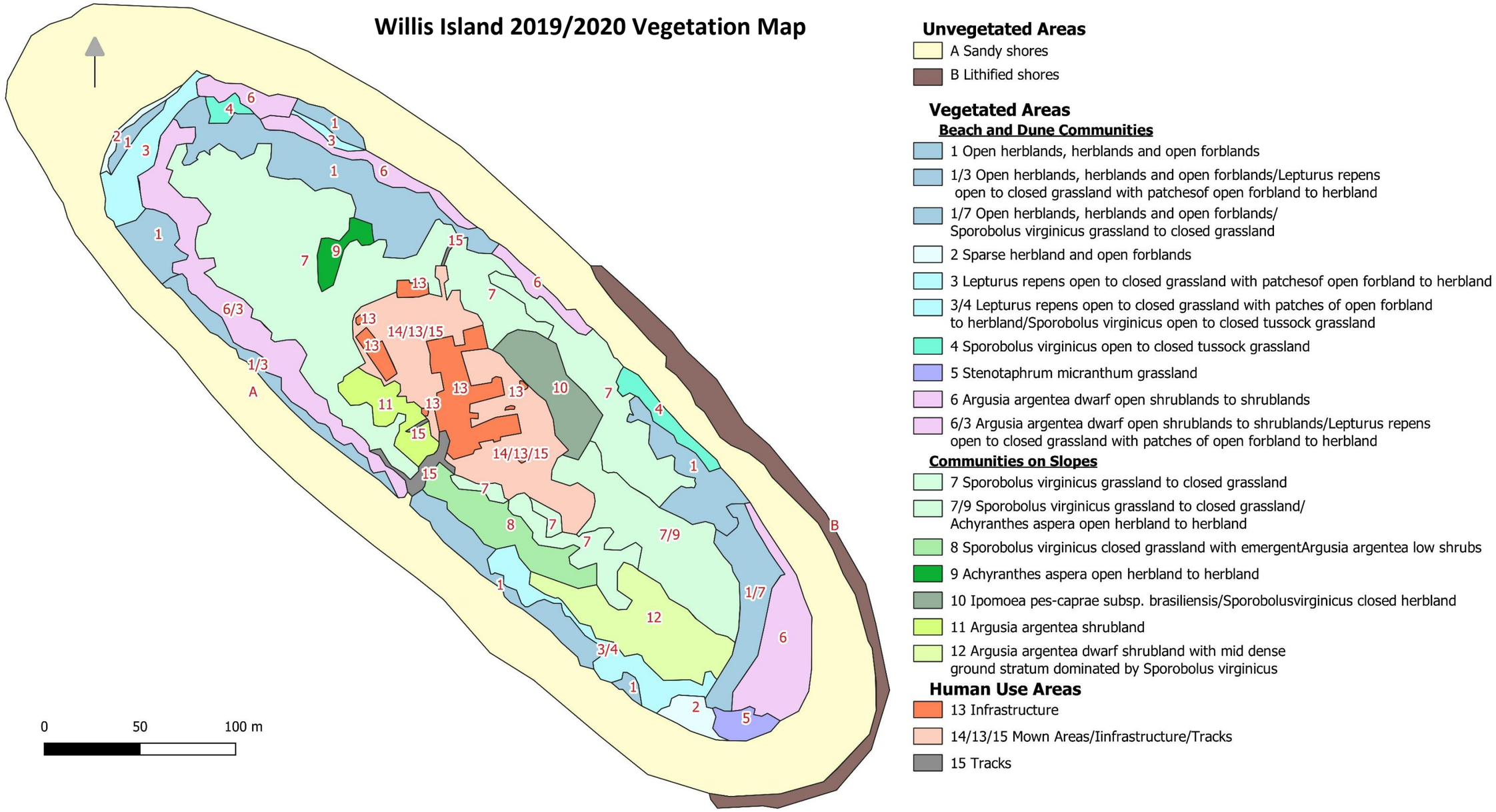

Figure 5 Vegetation map of Willis Island based on patterns visible on 2019 drone image and field data recorded in October 2020

The units shown in the map are described below. Equivalent or similar Coral Sea and Capricorn Bunker cays vegetation communities and Regional Ecosystems described and mapped by Batianoff et al., (2008a and 2012) and Hemson and Melzer (2020) are included for each of these communities where applicable. The vegetation and Regional Ecosystems of the Capricorn Bunker cays are listed as similar rather than equivalent to those of the Coral Sea as they differ floristically due to differences in both climate and available pathways for species recruitment.

Issues relating to large scale of cay vegetation mapping as a consequence of the small size of coral cays as well as the dynamic nature of some of the cay vegetation communities create difficulties in determining whether small areas dominated by particular species should be described and mapped as a component of surrounding communities or whether they should be identified and mapped as separate communities. Examples are the *Boerhavia albiflora, Achyranthes aspera, Ipomoea pes-caprae* herbland communities and *Abutilon albescens* shrublands, all of which can form patches large enough to map separately but which typically occur in small patches that mosaic with other vegetation types. Some of these are also quite short-lived (e.g. *Abutilon albescens* and *Achyranthes aspera* communities). Some cay communities can also vary between grasslands and forblands with changes in floristic dominance at different times. These issues have to be taken into account when comparing vegetation communities with those described and mapped in other cay vegetation reports.

Location of sites referred to in the vegetation community descriptions are shown on the map in Figure 2.

The following descriptions are based on data recorded during the October 2020 survey and reflect the prolonged extremely dry conditions at that time. Greater diversity is likely to be present during and following wetter seasons.

Unvegetated Units

A Sandy shores

Total area = 3.22 ha

Equivalent Capricorn Bunker Unit:	A - Sandy shores
Equivalent Coral Sea Unit (Batianoff *et al*., 2008a):	A - Sandy shores
Equivalent Coral Sea Unit (Hemson & Melzer, 2020):	Sandy shores

B Lithified shore

Total area = 0.33 ha

Equivalent Capricorn Bunker Unit:	B - Lithified shores
Equivalent Coral Sea Unit (Batianoff et al., 2008a):	B - Lithified shores
Equivalent Coral Sea Unit (Hemson & Melzer, 2020):	Lithified shores

Vegetated Units

Beach and Dune Communities

These communities are present on the foredune areas, swales and flats adjacent to the shoreline.

1 Open herblands, herblands and open forblands

Total area =0.97 ha

Sites: 1, 2, 3, 4, 10, 12, 17, 19, 26

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

1d - Seashore mixed herbland (Regional Ecosystem 12.2.14i)

Equivalent Coral Sea Vegetation Communities (Batianoff *et al*., 2008a):

1 - Littoral open-grassland/herbland; and 4 - *Boerhavia* herbland

Equivalent Coral Sea Vegetation Communities (Hemson & Melzer, 2020):

Littoral grassland/herbland; and *Boerhavia albiflora* herbland

Photo 4 Littoral open herbland

These communities are subjected to periodic inundation during storm surges and king tides. The vegetation is extremely dynamic and is constantly re-establishing with coastal erosion and accretion. Vegetation in the open forblands was dominated by *Boerhavia albiflora* var. *albiflora* (boerhavia). The herblands and open herblands were typically dominated by *Boerhavia albiflora* var. *albiflora*, *Lepturus repens* and *Portulaca oleracea*. Small patches of *Sporobolus virginicus* were present in some places. *Achyranthes aspera* was present at site 12 and occasional *Ipomoea pes-caprae subsp. brasiliensis* was present in the vicinity of site 1.

2 Sparse herbland and open forblands

Total area = 0.06 ha

Sites: 6, 21

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

1e - Very sparse herbland, mainly sand (North Reef) (Regional Ecosystem 12.2.14g)

Equivalent Coral Sea Vegetation Communities (Batianoff *et al*., 2008a):

1 - Littoral open-grassland/herbland; and 4 - *Boerhavia* herbland

Equivalent Coral Sea Vegetation Communities (Hemson & Melzer, 2020):

Littoral grassland/herbland; and *Boerhavia albiflora* herbland

Photo 5 Sparse herbland on accreting shoreline

These communities consisted of pioneer vegetation establishing on accreting shorelines. They were dominated by *Boerhavia albiflora* var. *albiflora* or *Portulaca oleracea*. Occasional plants of *Lepturus repens* and *Stenotaphrum micranthus* were also present, the latter only in the vicinity of site 6. *Argusia argentea* seedlings were establishing on the shoreline in this community on the northern spit.

3 *Lepturus repens* open grassland to grassland with patches of open forblands and herblands

Total area = 0.25 ha

Sites: 20, 22, 24, 25, 28, 33, 39

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

1d - Seashore mixed herbland (Regional Ecosystem 12.2.14i)

Equivalent Coral Sea Vegetation Community (Batianoff *et al*., 2008a):

2 - *Lepturus* open-grassland

Equivalent Coral Sea Vegetation Community (Hemson & Melzer, 2020):

Lepturus repens open to closed grassland

Photo 6 *Lepturus repens* grassland

The grass, *Lepturus repens* was the dominant species present. *Boerhavia albiflora* var. *albiflora* were present at all sites. At the time of the survey this community also had patches of open forblands and herblands variously dominated by *Boerhavia albiflora* var. *albiflora, Lepturus repens* and *Portulaca oleraceus*. *Sporobolus virginicus* and *Tribulus cistoides* (bulls head burr) were also present in the vicinity of site 39.

4 *Sporobolus virginicus* open to closed grassland

Total area = 0.12 ha

Sites: 5, 11, 45

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

1c - *Sporobolus virginicus* tussock grassland (Regional Ecosystem 12.2.14d)

Equivalent Coral Sea Vegetation Community (Batianoff *et al*., 2008a):

3 - *Sporobolus* open to closed-grassland

Equivalent Coral Sea Vegetation Community (Hemson & Melzer, 2020):

Sporobolus virginicus open to closed grassland

Photo 7 *Sporobolus virginicus* closed grassland

This community was present only in small patches on the frontal dune area. Other species in this community were *Boerhavia albiflora* var. *albiflora* and *Portulaca oleracea.*

5 *Stenotaphrum micranthum* grassland

Total area = 0.04 ha

Sites: 7

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

Component of 1d - Seashore mixed herbland (Regional Ecosystem 12.2.14i) and other foreshore beach vegetation communities

Equivalent Coral Sea Vegetation Communities (Batianoff *et al*., 2008a):

Component of Units 1 - Littoral open-grassland/herbland, 2 - *Lepturus* open-grassland and 3 - *Sporobolus* open to closed-grassland

Equivalent Coral Sea Vegetation Community (Hemson & Melzer, 2020):

Component of Littoral grassland/herbland and *Boerhavia albiflora* herbland.

Photo 8 *Stenotaphrum micranthum* grassland

Lepturus repens and occasional *Boerhavia albiflora* var. *albiflora, Portulaca oleracea* and *Sporobolus virginicus* were also present in this unit. *Stenotaphrum micranthum* is more abundant in the other Coral Sea cays and the Capricorn Bunker cays where it is a component of most seashore communities. This community was present only in one location on Willis Island in the SW coastline area and was mapped as a separate unit because its location and extent were accurately known. For consistency with mapping on the other cays it could be included as a component of shoreline grassland/ herbland communities 1 and 2.

6 Argusia argentea dwarf open shrublands to dwarf shrublands

Total area = 0.68 ha

Sites: 8, 9, 15, 16, 23, 27, 34, MO4

Similar Capricorn Bunker Vegetation Communities and Regional Ecosystems:

This community is similar to Capricorn Bunker Vegetation Community 2a - *Argusia argentea-Scaevola taccada* open-scrub (littoral scrub) +/- *Pandanus tectorius* emergents (Masthead) (Regional Ecosystem 12.2.19a) and 2b - *Argusia argentea* open-scrub with *Casuarina equisetifolia* subsp. *incana* emergents (Regional Ecosystem 12.2.19b). However, *Pandanus tectorius* and *Casuarina equisetifolia*, however, are not present on the Coral Sea cays.

Equivalent Coral Sea Vegetation Community (Batianoff *et al*., 2008a):

10a - *Argusia* open-shrubland to open-scrub

Equivalent Coral Sea Vegetation Community (Hemson & Melzer, 2020):

Argusia open shrubland to open scrub

This community is lower in height than on the other Coral Sea Cays and on the Capricorn Bunker cays.

Photo 9 *Argusia argentea* dwarf shrubland

Photo 10 Site 8 *Argusia argentea* dwarf open shrubland

The ground layer of this community was sparse and variously dominated by *Boerhavia albiflora* var. *albiflora*, *Lepturus repens* and *Portulaca oleracea.* The ground layer of site 34 was co-dominated by *Lepturus repens* and *Sporobolus virginicus*.

Communities on the slopes

These communities are located well above the highest astronomical tide level and rarely if ever experience sea water inundation and wave erosion.

7 Sporobolus virginicus grassland to closed grassland

Total area = 1.81 ha
Sites: 13, 14, 18, 29, 30, 31, 32, 35, 38, 40, 42, 44, 48, 49, 51, MO1, MO3

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:
4 - Mixed tussock grassland/herbland (Regional Ecosystem 12.2.17a)
Equivalent Coral Sea Vegetation Community (Batianoff *et al*., 2008a):
3 - *Sporobolus* open to closed-grassland
Equivalent Coral Sea Vegetation Community (Hemson & Melzer, 2020):
Sporobolus virginicus open to closed grassland

Photo 11 Site 13 *Sporobolus virginicus* closed grassland

Photo 12 Site 42 *Sporobolus virginicus* grassland

This was the dominant vegetation community on the island. *Boerhavia albiflora* var. *albiflora* was present at all sites. *Achyranthes aspera* was present at sites 31, 40, 42, 48, MO1 and MO3. *Ipomoea pes-caprae* subsp. *brasiliensis* was present in sites 13, 14 and 48. Occasional plants of *Lepturus repens* and *Tribulus cistoides and Portulaca oleracea* were present at sites 35, 48 and 31 respectively. Sites 31 and 32 had low numbers of the invasive exotic weed, *Euphorbia cyathophora*.

8 *Sporobolus virginicus* closed grassland with emergent *Argusia argentea* low shrubs

Total area = 0.16 ha

Site: 36

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

Nil

Similar Coral Sea Vegetation Community (Batianoff *et al*., 2008a):

3 - *Sporobolus* open to closed-grassland (NE Herald), 10b - *Argusia* tall open-shrubland (dieback) (NE Herald)

Similar Coral Sea Vegetation Community (Hemson & Melzer, 2020):

Sporobolus virginicus (sand couch) grasslands

The *Argusia argentea* is lower in height and has less dieback than reported on NE Herald by Batianoff et al., 2008a

Photo 13 Site 36 *Sporobolus virginicus* closed grassland with emergent *Argusia argentea* low shrubs

Occasional *Boerhavia albiflora* var. *albiflora* and *Ipomoea pes-caprae* subsp. *brasiliensis* were present in the vicinity of site 36. The invasive exotic weed, *Euphorbia cyathophora* was also present at this location.

9 *Achyranthes aspera* open herbland to herbland

Total area = 0.08 ha

Sites: 46, 50

Similar Capricorn Bunker Vegetation Communities and Regional Ecosystems:

Small patches of *Achyranthes aspera* are present within vegetation community 4 - Mixed tussock grassland/herbland (Regional Ecosystem 12.2.17a) and vegetation community 5c - *Abutilon albescens* shrubland (Regional Ecosystem 12.2.18c) as well as recently disturbed areas within other units.

Equivalent Coral Sea Vegetation Community (Batianoff *et al*., 2008a):

6 - *Achyranthes* mixed herbland

Equivalent Coral Sea Vegetation Community (Hemson & Melzer, 2020):

Achyranthes aspera herbland

Photo 14 Site 46 *Achyranthes aspera/Sporobolus virginicus* open herbland

Achyranthes aspera is a short-lived herbaceous sub-shrub that dies off in dry conditions as demonstrated in Photo 14. At the time of the October 2020 survey, this community was co-dominated by *Sporobolus virginicus. Boerhavia albiflora* var. *albiflora* are also present at these sites.

10 *Ipomoea pes-caprae* subsp. *brasiliensis/Sporobolus virginicus* closed herbland

Total area = 0.16 ha

Sites: 47, MO2

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

This vegetation community is a component of Vegetation Community 4 - Mixed tussock grassland/herbland (Regional Ecosystem 12.2.17a)

Equivalent Coral Sea Vegetation Community (Batianoff *et al*., 2008a):

Nil

Equivalent Coral Sea Vegetation Community (Hemson & Melzer, 2020):

Nil

Photo 15 Site 47 and MO2 *Ipomoea pes-caprae* subsp*. brasiliensis/Sporobolus virginicus* closed herbland

This community was located at only one location on the island (Site 47 is in site MO2.), in the vicinity of the treated sewage outflow. As would be expected the vegetation at this site was lush and green compared to the rest of the island and this feature can be seen on most recent aerial photographs of the island. *Achyranthes aspera* and occasional plants of *Boerhavia albiflora* var. *albiflora* were present in this unit. The invasive exotic weeds, *Euphorbia cyathophora* and *Cenchrus echinatus* were also present.

11 *Argusia argentea* shrubland

Total area = 0.1 ha

Site: 52

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:

Nil

Similar Coral Sea Vegetation Community (Batianoff *et al*., 2008a):

10b - *Argusia* tall open-shrubland (dieback)

Similar Coral Sea Vegetation Communities (Hemson & Melzer, 2020):

Argusia tall open shrubland to closed scrub; *Argusia* open to closed scrub

This community is lower in height than on the other Coral Sea Cays and has less dieback than that reported by Batianoff et al., 2008a.

Photo 16 Site 52 *Argusia argentea* shrubland

This community was located on the upper slope adjacent to the western boundary of the mown lawn of the operational areas. The ground layer was sparse and dominated by *Sporobolus virginicus* and *Boerhavia albiflora* var. *albiflora.* An occasional plant of *Achyranthes aspera* was present in this community as well as occasional plants of the invasive exotic weeds, *Amaranthus viridis* (green amaranth) and *Cenchrus echinatus.*

12 *Argusia argentea* dwarf shrubland with mid dense ground stratum dominated by *Sporobolus virginicus*

Total area = 0.29 ha

Sites: 41, 43

Similar Capricorn Bunker Vegetation Community and Regional Ecosystem:
Nil

Similar Coral Sea Vegetation Community (Batianoff *et al*., 2008a):
10b - *Argusia* tall open-shrubland (dieback)

Similar Coral Sea Vegetation Communities (Hemson & Melzer, 2020):
Argusia tall open shrubland to closed scrub; *Argusia* open to closed scrub

Photo 17 Site 43 *Argusia argentea* dwarf shrubland with mid dense ground stratum dominated by *Sporobolus virginicus*

Boerhavia albiflora var. *albiflora* was also present sites in this unit.

It is unusual for *Argusia argentea* to establish away from the shoreline at higher elevation as it does in vegetation communities 8, 11 and 12. Its presence in these locations may be an indication of the location of earlier shorelines or areas where *Argusia argentea* has established following seawater inundation events.

Human Use Areas

This area is the part of the BoM Operational Area containing infrastructure where the vegetation is regularly mown.

Similar Capricorn Bunker Unit:	C - Disturbed areas (high human impact)
Similar Coral Sea Unit (Batianoff *et al*., 2008a):	Nil
Similar Coral Sea Unit (Hemson & Melzer, 2020):	Nil

13 Infrastructure

Total area = 0.21 ha

Infrastructure on the island includes the BoM offices and living and recreational areas, workshop, store and power house, radar tower, hydrogen generating plant, balloon release site, other meteorological recording infrastructure, fuel storage area, gas storage, desalination plant, salt water pump, sewage treatment plant, water tanks, incinerator, satellite dishes, solar arrays, wind turbine, and well.

14 Mown Areas

Total area = 0.49 ha

Site: 37

Photo 18a and 18b Site37 Mown area of open grassland dominated by *the exotic grass, Dactyloctenium aegyptium*

The mown area consisted predominantly of an open grassland dominated by the exotic grass, *Dactyloctenium aegyptium*.

The native grasses, *Sporobolus virginicus* and *Lepturus repens*, the native forbs, *Boerhavia albiflora* var. *albiflora* (most abundant), *Achyranthes aspera* and the native vine, *Ipomoea pes-caprae* subsp. *brasiliensis Portulaca oleracea* and *Tribulus cistoides* were present in low abundance. *Sporobolus virginicus* was abundant at the boundary of the mown and unmown vegetation and was coping with the mowing and dry conditions better than the exotic *Dactyloctenium aegyptium*.

Other invasive exotic species present in the mown area were *Amaranthus viridis* (the most abundant), *Cenchrus echinatus*, *Euphorbia prostrata* (prostrate caustic creeper) and *Trianthema portulacastrum* (black pigweed).

According to the BoM staff the mown area had been recently weeded with non-grass plants removed (including the native *Boerhavia albiflora* var. *albiflora*).

15 Tracks
Total area = 0.05 ha

Photo 19 The access track used to ferry supplies and gear to and from transport boat to the BOM facility.

At the time of the survey the tracks were weed free. Invasive exotic weeds were present, however, in the vicinity of the tracks and likely to invade the bare ground when conditions are suitable.

4.4 Permanent Monitoring Sites

Four permanent monitoring sites, each 50m x20m were established on the island:

M01 Situated in a *Sporobolus virginicus* tussock grassland on the upper slope NW of the BOM operational area (vegetation map unit 9);

M02 *Ipomoea pes-caprae* subsp. *brasiliensis/ Sporobolus virginicus* herbland on an upper slope at the location of the sewage outlet (vegetation map unit 13);

M03 *Sporobolus virginicus* tussock grassland situated on a mid-slope, SE of the BOM operational area. (vegetation map unit 9); and

M04 A*rgusia argentea* dwarf shrubland located on the NW shoreline (vegetation map unit 8).

Recorded data and photographs from the permanent monitoring sites are held at Parks Australia and the Queensland Herbarium.

4.5 Seabirds

During the October 2020 visit, large numbers of seabirds were nesting over the entire island. The exception to this was the human use area. Abundance of seabird nesting in this area was low because of constant disturbance and the policy of nest relocation to prevent harm and disturbance to birds.

The most abundant of the nesting seabirds were sooty terns (*Onychoprion fuscata*) which were nesting on the ground all over the vegetated areas of the island with eggs and newly hatched to mature chicks on the nests. Ground nesting brown boobies (S*ula leucogaster***)** were also abundant throughout the island but fewer in numbers than the sooty terns. These also had eggs and young to mature chicks on the nests.

Red-footed boobies (*Sula sula*) were abundant on nests in the branches of the *Argusia argentea* shrubs with mostly mature chicks on the nests. Relatively smaller numbers of black noddies (*Anous minutus)* were also present on the branches of the *Argusia argentea* shrubs.

Shearwater (*Ardenna pacifica)* burrows were abundant on the slopes, favouring the upper slopes over the lower slopes. Small numbers of black–naped terns (*Sterna sumatrana*) were nesting on the shoreline of the beach on the northern spit with both eggs and chicks on the nests. Small numbers of red-tailed tropic birds (*Phaethon rubricauda*) were also present, under *Argusia argentea* shrubs.

According to the BoM staff, nesting common noddies (*Anous stolidus*) and crested terns (*Thalasseus bergii*) had been extremely abundant earlier in the season. Only small numbers of common noddies (*Anous stolidus*) were present at the time of the October 2020 field survey, although abundant unoccupied nests were still present throughout the island. Occasional frigate birds (*Fregata* sp.) were observed flying overhead and roosting on the *Argusia argentea* shrubs.

4.6 Turtles

Evidence of turtle nesting (body pits) was present in most sites in all of the beach and dune communities throughout the island. The first turtle nesting for the season was observed by the BoM staff during our visit.

4.7 Soils Analyses

Physical properties

The soil/substrate on Willis Island consisted of varying sized particles of coral rubble and coarse sand derived from coral and the profiles were uniform and without structure. Colour varied from white to pale greyish white on the beach and active dune area to greyish brown in more densely vegetated areas landward of the foredunes.

Chemical analyses

The results of the soils analyses are shown in Table 3.

Comparisons are made in this section with soil data obtained from soil analyses of samples from other Coral Sea cays sampled in 2006/2007, Capricorn Bunker cays (including Lady Elliot Island) sampled in 2007/2008 and Lady Elliot Island sampled in 2020. Data from these samples were reported by Batianoff *et al*., (2008 and 2010), Batianoff *et al*., (2012) and Brushe (in prep) respectively. Caution is needed when comparing and interpreting differences in the datasets obtained in different years as prevailing climatic conditions and fluctuations in numbers of nesting seabirds is likely to affect the levels of soil nutrients at the time of sampling.

Table 3 Results of Soils Analyses

Site	M01			M02		M03			M04
Depth	0-20cm	20-40cm	40-60cm	0-20cm	20-40cm	0-20cm	20-40cm	40-60cm	0-20
pH (ph Units)	8.3	8.7	8.7	8	8.4	8.1	8.3	8.5	8.4
Conductivity of Extract (1:5 dry sample basis)(MicroS/cm)	600	340	360	800	500	710	540	400	560
Nitrate Nitrogen and Nitrite Nitrogen (NOx) as N (mg/kg)	150	71	74	380	160	260	230	140	180
Total Kjeldahl Nitrogen (mg/kg)	1500	590	410	1600	850	2400	2600	1900	350
Total Nitrogen (mg/kg)	1600	660	490	2000	1000	2600	2800	2100	530
Total Phosphorus (Kjeldahl Digestion) (mg/kg)	14000	10000	7200	23000	18000	26000	37000	36000	3600
Colwell Phosphorus (mg/kg)	740	340	390	950	650	960	910	760	690
Aluminium, Al (mg/kg)	<50	<50	<50	170	140	<50	<50	54	<50
Copper, Cu (mg/kg)	23	13	16	47	29	13	23	19	18
Iron, Fe (mg/kg)	65	<50	<50	1800	1900	<50	68	72	320
Potassium, K (mg/kg)	230	100	150	330	150	150	130	130	120
Magnesium, Mg (mg/kg)	7400	8600	9400	6600	5900	7300	9600	8600	11000
Manganese, Mn (mg/kg)	7	4	5	52	41	6	7	7	4
Sodium, Na (mg/kg)	3300	3300	3300	3400	3300	3400	3200	3100	3500
Sulphur, S (mg/kg)	2000	1600	1800	2100	1600	1700	1900	1700	1700
Zinc, Zn (mg/kg)	62	24	35	210	160	57	79	73	14
Exchangeable Sodium, Na (mg/kg)	200	96	140	210	180	200	170	130	110
Exchangeable Potassium, K (mg/kg)	110	41	63	180	83	100	87	69	49
Exchangeable Calcium, Ca (mg/kg)	4500	4300	4400	4300	4200	4200	4500	4300	4500
Exchangeable Magnesium, Mg (mg/kg)	250	180	200	300	230	260	310	250	190
Exchangeable Sodium, Na (meq/100g)	0.88	0.42	0.59	0.92	0.77	0.88	0.76	0.56	0.46
Exchangeable Potassium, K (meq/100g)	0.29	0.11	0.16	0.45	0.21	0.27	0.22	0.18	0.13
Exchangeable Calcium, Ca (meq/100g)	23	21	22	22	21	21	23	22	22
Exchangeable Magnesium, Mg (meq/100g)	2.1	1.5	1.6	2.5	1.9	2.2	2.5	2.1	1.6
Exchangeable Sodium percentage (%)	3.4	1.8	2.4	3.6	3.3	3.6	2.9	2.3	1.9
Exchangeable Potassium percentage (%)	1.1	0.4	0.7	1.8	0.9	1.1	0.9	0.7	0.5
Exchangeable Calcium percentage (%)	87.5	91.6	90.2	84.8	88	86.3	86.5	88.4	91.1
Exchangeable Magnesium percentage (%)	8	6.2	6.7	9.8	7.9	8.9	9.7	8.6	6.5
Cation Exchange Capacity (meq/100g)	26	23	24	26	24	24	26	24	25
Carbon (%)	9.4	9.5	9.3	9.2	8.6	9.9	9.1	9.1	10
Total Organic Carbon (%)	0.51	0.21	0.32	0.7	0.48	0.88	0.63	0.42	0.25
Carbonate Carbon, CO3-C (%)	9.7	10	9.8	9.3	8.8	9.9	9.2	9.5	11

Soils at all Willis Island sites were alkaline with pH values ranging from 8.0 to 8.7, similar to values obtained in similar communities for the Coral Sea cays in 2006/2007, the Capricorn Bunker cays in 2007/2008 and Lady Elliot Island in 2007/2008 and 2019.

Electrical conductivity varied from 340 to 800 microS/cm with the highest value) recorded in the surface soil at the site of the sewage outlet. This value was higher than any obtained previously at the other cays. Values at the other Willis Island sites were comparable with previous values obtained at the other cays.

Total nitrogen levels at Willis Island were highest at site MO3, possibly due to the build-up of nutrient from the large number of birds nesting in the vicinity. Levels were slightly lower than those previously recorded on the other Coral Sea Cays in 2006/2007 and also with levels recorded in 2007/2008 at the Capricorn Bunker cays with the exception of the interior of Lady Elliot Island which had considerably higher total nitrogen levels in both 2007/2008 and 2019.

Nitrate Nitrogen and Nitrite Nitrogen were highest in the surface soils (o to 20 cm) at Willis Island. No comparative data is available for Nitrate Nitrogen and Nitrite Nitrogen for the other cays.

Levels of aluminium, copper, iron, manganese and zinc were considerably higher at MO2 that at the other Willis Island sites.

Other Willis Island sites had comparable levels of aluminium to the Capricorn Bunker Cays with the exception of Lady Elliot Island which had much higher aluminium levels in the interior of the island. No data is available for levels of aluminium in the soils of the Coral Sea cays.

Copper levels on grassland sites other than MO2 on Willis Island were comparable or slightly higher than those of similar communities on the other Coral Sea cays. Copper levels in the coastal site MO4 on Willis Island were higher than levels in all available datasets sets for the coastal areas of the other cays. The Capricorn Bunker cays except for the interior of Lady Elliot Island had lower copper levels than the Coral Sea cays.

Iron levels in the coastal site MO4 on Willis Island were also higher than levels in all available datasets sets for the coastal areas of the other cays but were considerably lower than the levels at site MO2. The interior areas of Lady Elliot Island also had high levels of iron, but not as high as the levels at Willis Island site MO2.

Levels of manganese on sites other than MO2 on Willis Island were comparable to or slightly lower than those of the Coral Sea cays and the Capricorn Bunker cays (excluding Lady Elliot). Lady Elliot Island internal soils also had high levels of manganese.

Zinc levels on sites other than MO2 on Willis Island had comparable zinc levels to the Coral Sea cays. Capricorn Bunker soils with the exception of Lady Elliot Island have lower levels of zinc. Zinc levels in soils in the interior of Lady Elliot Island had high zinc levels.

Cation exchange capacity data is not available for the Coral Sea cay soils. Cation exchange capacity on Willis Island was similar to or slightly lower than that of the Lady Elliot Island soils and higher than the average of the Capricorn Bunker samples.

Total carbon soil levels were similar at all the Willis Island sample sites and similar to those from similar vegetation communities on the Coral Sea cays. The 2019 Lady Elliot levels were higher, while the average 2007/2008 Capricorn Bunker (including Lady Elliot Island) sample levels were slightly lower.

Organic carbon levels were considerably lower than those obtained for all the previous samples for the Coral Sea Cays and the Capricorn Bunker Cays including Lady Elliot.

Colwell phosphorus levels for all sites were comparable to those in samples from similar communities in the other Coral Sea cays and Lady Elliot Island. Average levels in the other Capricorn Bunker cays were lower.

Total phosphorus data are not available for the Coral Sea or grassland/herbland communities of the Capricorn Bunker cays. Coastal communities of the Capricorn Bunker cays had comparable levels to the Willis Island coastal community at Site MO4. Interior of Lady Elliot Island had higher levels than Willis Island.

Potassium levels on Willis Island were similar to those of the Coral Sea and the Capricorn Bunker cays samples. Levels were higher than those of Willis Island in the interior of Lady Elliot Island in 2019.

Magnesium levels in the Willis Island samples were similar to those for similar vegetation communities in both the Coral Sea and Capricorn Bunker cays (including Lady Elliot Island). Magnesium levels on Willis Island were lower than those in the interior of Lady Elliot Island.

Sodium levels are similar in all the Willis Island sites and comparable with all of the previous data sets for similar communities in both the Coral Sea cays and the Capricorn Bunker cays including Lady Eliot Island.

Sulphur levels of the Willis Island soils were all fairly similar and only slightly higher than those obtained at for both the Coral Sea cays and those of the Capricorn Bunkers (including Lady Elliot Island) in 2007/2008.

Calcium levels were slightly higher than those of the Coral Sea soil samples. Capricorn Buner cays had lower calcium levels than Willis Island with the exception of Lady Elliot Island which had similar levels.

5.0 Recommendations

5.1 Weed Management

All plant species not native to the Coral Sea cays should be removed from the entire island.

Batianoff *et al*. (2008) recommended that current and emerging exotic weedy plants from Willis Island be removed.

Naturalised exotic weeds, are not only a threat to the natural ecosystem on Willis Island, they also represent a biosecurity threat to other Coral Sea Marine Park cays. No weed species have been recorded on any of the six other cays in the Coral Sea Marine Park that had been comprehensively surveyed (Batianoff et al. 2008; Hemson et al. 2020), so it is important to eradicate or control the weed species present on Willis Island and to develop and implement weed hygiene and biosecurity measures to prevent weed spread both on Willis Island and to other cays in the region. A Capricorn Bunker Biosecurity Plan (QPWS, *in prep*) is currently being developed. This document is also intended to serve as an example for development of biosecurity plans for other cays and will contain guidelines and templates for this purpose. (*Pers. comm.* John Olds, QPWS).

Weed eradication cannot be achieved until the seed bank of weed species is also eliminated from the entire island. Therefore it is not only important to remove existing weed plants in both the human use area and the natural areas, but also to undertake regular comprehensive inspections for regrowth and remove regrowth plants before they go to seed.

The current infestations of *Euphorbia cyathophora, Cenchrus echinatus* and *Amaranthus viridis* observed growing outside the mown area (location shown in Figure 4) should be removed as soon as

possible and the infestation sites regularly monitored so that regrowth can be removed before it seeds again. This also applies to any other non-cay species that may establish in the natural areas.

Weeds are currently more prevalent in the human use areas than the in the natural areas. When carrying out weed inspections or when entering the natural areas for any other reason, weed hygiene protocols need to be followed to prevent spread of weeds from the human use areas to the natural areas.

Amaranthus viridis, Cenchrus echinatus, *Eleusine indica, Alternanthera pungens* (khaki weed), *Trianthema portulacastrum* and *Euphorbia prostrata* have all been recorded on Willis Island and priority should be given to their eradication of from the entire island.

Weeds that are removed should be either incinerated or removed from the island as they are likely to regrow if left on the ground and may contain viable seeds. Even immature seeds can mature on dead plants or successfully germinate before they fully mature.

During the October 2020 survey it was observed that the mown native grass, *Sporobolus virginicus* at the edges of the mown areas was greener and coping with the dry conditions more successfully than the exotic grass, *Dactyloctenium aegyptium* that dominated most of the mown area. It is recommended that exotic grasses in the mown areas are gradually replaced with *Sporobolus virginicus* and other native species. This could be achieved by a combination of planting and removal of exotic plants to promote natural spread from the margins of the natural grassland. An appropriate approved herbicide could be used on strips of existing exotic species immediately adjacent to the mown edges adjoining the natural areas. Repeat herbicide treatment of one or two generations of regrowth will also be required before planting into patches away from the edge of the native grassland. The native grass, *Lepturus repens* and the native herb, *Boerhavia albiflora* var. *albiflora* should also be planted with the *Sporobolus virginicus*. Ongoing weed control will be necessary in the newly established areas until the seedbank of exotic species is depleted.

Tribulus cistoides seeds have large pungent thorns and therefore, even though this is a native cay plant species, its removal from tracks and the mown lawn within the human use areas is justified. It should not, however, be removed from the natural vegetation beyond the boundary of the mown area and tracks. No other native grasses or herbs should be removed from the mown area or tracks.

Keeping the mown area as short as practical and mowing in the direction that flicks the mown material back into the mown area rather than into the adjacent natural areas will help to minimise spread of non-cay species beyond the mown boundary.

Rehabilitation planting (if required) should be restricted to planting only those plant species that have previously been recorded as naturally occurring on Willis Island. These species are listed in Appendix 4.To ensure plants planted on Willis Island are well adapted to local environmental conditions, propagation material (seeds and cuttings) for vegetation rehabilitation should be sourced from local provenance i.e. from plants already growing on Willis Island or on nearby Coral Sea Cays and from a number of different individual plants from more than one location to maximise genetic diversity.

If food plants are grown on Willis Island, appropriate biosecurity measures need to be implemented to prevent them escaping and becoming naturalised on the island. An indoor hydroponic system is probably the best way of managing this biosecurity risk.

Ornamental plants and any other plant material (live or dead) should not be brought to the island.

5.2 Follow up Vegetation Assessment

The planted *Cocos nucifera* and *Casuarina equisetifolia* subsp. *equisetifolia* were lost during cyclone Yasi. The impact of cyclone Yasi or subsequent prolonged dry periods may also have resulted in the loss of some herbaceous and smaller shrub species. In order to determine if this was the case, it is recommended that the vegetation survey be repeated during a wetter period when all species present are more likely to be growing. The permeant monitoring sites should also be resurveyed when the vegetation is in better condition after the end of the wet season and after the shearwater nesting is finished.

A current rectified high resolution aerial image of the island, clear of cloud cover is required to improve the accuracy and reliability of the island's vegetation mapping. Again it would be preferable to obtain an image taken during moister conditions to detect image patterns representing vegetation diversity during a wetter period. This may also require additional ground truthing during a wetter period to better describe and attribute this diversity on the vegetation map.

Regular Health checks using the QPWS methodology (Melzer 2019) should also be done routinely on the Coral Sea Cays including Willis Island to monitor the condition of key values. These are currently being done routinely on the Capricorn Bunker Cays and were included in the 2019 vegetation surveys of the Coral Sea cays (Hemson and Melzer 2020).

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Appendix 1 Vegetation Structure

(from Neldner et al., 2019)

Proj. foliage cover	›70%	›30–70%	10–30%	‹10%
Crown class	Dense/closed	Mid-dense	Sparse	Very sparse
Crown cover %[1]	›80%	›50–80%	20–50%	‹20%
GROWTH FORM[2]	**Structural formation classes (qualified by height)**			
Trees ›30 m	tall closed forest TCF	tall open forest TOF	tall woodland TW	tall open woodland TOW
Trees 10–30 m	closed forest CF	open forest OF	woodland W	open woodland OW
Trees 2–10 m	low closed forest LCF	low open forest LOF	low woodland LW	low open woodland LOW
Shrubs 2– 8 m	closed scrub CSC	open scrub OSC	tall shrubland TS	tall open shrubland TOS
Shrubs 1–2 m	closed heath CHT or closed shrubland CS	open heath OHT or shrubland S	shrubland S	open shrubland OS
Shrubs ‹1 m	dwarf closed shrubland DCS	dwarf open heath DOHT	dwarf shrubland DS	dwarf open shrubland DOS
Succulent shrub	NA	succulent shrubland	succulent shrubland SS	open succulent shrubland OSS
Hummock grasses	NA	NA	hummock grassland HG	open hummock grassland
Tussock grasses	closed tussock grassland CTG	tussock grassland TG	open tussock grassland OTG	sparse tussock grassland STG
Herbs[3]	closed herbland CH	herbland H	open herbland OH	sparse herbland SH
Forbs	closed forbland CFB	forbland FB	open forbland OFB	sparse forbland SFB
Rush	closed rushland CR	rushland R	open rushland OR	sparse rushland SR
Vines	closed vineland CVI	vineland VI	open vineland OVI	sparse vineland SVI
Ferns	closed fernland CFN	fernland FN	open fernland OFN	sparse fernland SFN
Sedges	closed sedgeland CV	sedgeland V	open sedgeland OV	sparse sedgeland SV

1 In this table the crown cover classes listed are used to allocate the modified Specht (1970) structural formation labels (after Hnatiuk et al. 2009, Table 17, p81) and the relationship in Scarth et al. (2008) These approximate the Specht (1970) projective foliage cover (pfc) classes and derivation by converting crown cover to pfc using crown density types.

2 Growth form of the predominant layer (the ecologically dominant layer). See table 28 for definition of growth forms.

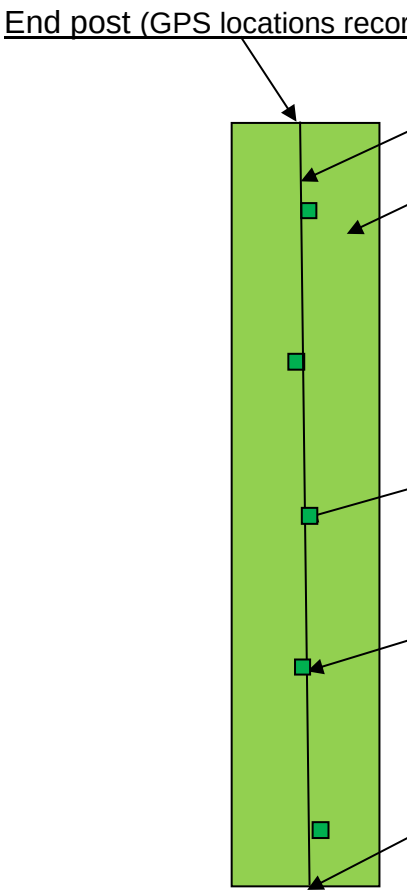
3 Herbland refers to associations in which species composition and abundance is dependent on seasonal conditions and at any one time grasses or forbs may predominate.

Source: after Specht (1970), Neldner (1984), Walker and Hopkins (1998) and Hnatiuk et al. 2009.

Appendix 2 Plot Orientation of the Permanent Monitoring Sites and List of the Data Recorded at these Sites

Plot diagram

Plots are located in representative areas within a vegetation community.



- canopy cover for each species in each emergent tree and shrub layer present

- species list
- median heights and height range for each layer
- stem counts (tree and shrub species) for each species in each emergent, tree and shrub layers
- stem diameters (to calculate basal areas for plot) for each species in each emergent tree and shrub layer
- recruitment
- coarse woody debris (logs)
- total pest plant cover

- GPS location
- basal area sweep
- plot photographs

- ground covers for each plant species present in ground layer
- per cent cover of rock, bare soil, coral rubble and cryptograms

Data recorded at each site (using methodology of Neldner *et al.* 2019 for secondary sites)

Site descriptions

- Site descriptions for each site are documented. These descriptions include all site attributes that do not change including bioregion, subregion, GPS and location description, area/width of the vegetation represented by the plot, a position in landscape diagram, landform element, landform pattern, slope, altitude, substrate, plot size and plot orientation including

Other data recorded

- site number, recorder names, date, start and finish time
  - GPS location of plot centre and end points (GDA 94 datum), location description, transect bearing
  - vegetation structural layers present, median height and height range of each layer
  - comprehensive species list for each layer
  - ground layer per cent foliage projected cover for each vascular plant species, litter, bare ground, rock outcrop and cryptograms
  - per cent crown cover by species for each layer for the emergent, tree and shrub layers (if present)
  - from the species list and cover measurements, the following can be derived:
    - total vegetation cover in each layer
    - native cover in each layer
    - non-native cay cover in each layer
    - species richness – total and differentiated by growth form
    - native species richness – total and differentiated by growth form
    - non-native cay species richness – total and differentiated by growth form
    - species richness in each layer present – total and differentiated by growth form
    - native species richness in each layer present – total and differentiated by growth form
    - non-native cay species richness in each layer present – total and differentiated by growth form
- estimate of overall non-native cay plant cover (including herbaceous and woody weeds and plantings)
- stem counts of woody species (if present) per species per layer in the tree and shrub layers; including standing dead plants (count per hectare can be calculated for each species, growth form and layer)
- basal area sweep measurements of woody species (if present) per species per layer
- girth measurements for woody species if present(basal area per hectare can be calculated for each species, growth form and layer)
- evidence of recruitment of woody species
- topsoil depth, colour and texture
- soil samples will be collected for full nutrient analysis
- total length of logs (coarse woody debris)
- presence of shearwater burrows or other evidence of bird nesting
- evidence of turtle nesting
- other disturbance type (e.g. evidence of wind damage to vegetation, wind erosion, saltwater inundation, fire, mowing/slashing, other human disturbance) and severity
- patch size
- community extent
- community area
- community context (extent of connectivity to other native vegetation communities)
- evidence of disease, death, dieback, presence of scale, insect attack and leaf drop

- mean monthly climatic data (since previous monitoring)
- eight site photographs from the plot centre – a landscape and portrait photo facing the direction of the bearing and at 90, 180 and 370 degrees from the direction of the bearing

Appendix 3 Location and Coordinates of Reference Points

The green dots are the locations on the image and the red dots are the locations where GPS coordinates were recorded for each of the locations. There appears to be a slight rectification error of approximately 3 to 5 m.

Coordinates recoded on GPS (GDA 94, MGA 55)

Site	Latitude	Longitude	y_proj	x_proj	Date
R01	-16.287614	149.964475	8196949.669	816836.0908	18/10/2020
R02	-16.287532	149.964453	8196958.784	816833.8696	18/10/2020
R03	-16.287473	149.964469	8196965.293	816835.6758	18/10/2020
R04	-16.287036	149.964335	8197013.896	816822.0462	18/10/2020
R05	-16.287014	149.964471	8197016.121	816836.628	18/10/2020
R06	-16.287231	149.964545	8196991.974	816844.1939	18/10/2020
R07	-16.287188	149.964697	8196996.5	816860.5209	18/10/2020
R08	-16.287299	149.964712	8196984.184	816861.9467	18/10/2020
R09	-16.287391	149.964783	8196973.886	816869.3928	18/10/2020
R10	-16.287486	149.964803	8196963.334	816871.3791	18/10/2020
R11	-16.287583	149.964624	8196952.87	816852.0775	18/10/2020
R12	-16.287601	149.964741	8196950.695	816864.5627	18/10/2020
R13	-16.287878	149.965052	8196919.536	816897.3812	18/10/2020
R14	-16.287215	149.96414	8196994.375	816800.9014	18/10/2020
R15	-16.287013	149.963989	8197016.98	816785.0754	18/10/2020
R16	-16.286763	149.964331	8197044.135	816822.0574	18/10/2020
R17	-16.287073	149.964627	8197009.344	816853.2187	18/10/2020

Appendix 4 List of Plant Species Recommended for Rehabilitation Planting on Willis Island

Scientific Name	**Common Name**	**Growth Form**	**Suitable for Planting in Human Use Areas**
Abutilon albescens	lantern bush	Shrub	Yes
Achyranthes aspera	chaff flower	Large "woody" herb	No – short lived and has irritating seeds
Argusia argentea	octopus bush	Shrub/Small tree	Yes
Boerhavia albiflora var. *albiflora*	boerhavia	Herb	Yes
Ipomoea pes-caprae subsp. *brasiliensis*	goats foot convolvulus	Ground cover vine	Yes
Lepturus repens	stalky grass	Grass	Yes
Portulaca oleracea	pigweed	Succulent herb	Yes
Sporobolus virginicus	sand couch	Grass	Yes
Stenotaphrum micranthum	beach buffalo grass	Grass	Yes
Tribulus cistoides *	Bulls head burr	Annual Herb	No – has large robust sharp seeds

Appendix 5 Soil Analyses Methods

SGS

METHOD SUMMARY

CE148893 R0

METHOD	METHODOLOGY SUMMARY
AN015	Soil sample is extracted in an end over end roller in 0.5 N sodium bicarbonate at pH 8.5 with the supernatant liquor analysed for Phosphorous. Orthophosphate anion (PO43-) is reacted with ammonium molybdate and potassium antimony tartrate in sulfuric acid solution. The resulting phospho-molybdate complex is reduced, using ascorbic acid, to an intense blue coloured complex Molybdenum Blue. The absorbance of this complex is measured at 880 nm by Discrete Analyser, and compared with calibration standards to obtain the concentration of orthophosphate in the sample. Based on Rayment & Higginson 9B1.
AN040/AN320	A portion of sample is digested with nitric acid to decompose organic matter and hydrochloric acid to complete the digestion of metals. The digest is then analysed by ICP OES with metals results reported on the dried sample basis. Based on USEPA method 200.8 and 6010C.
AN101	pH in Soil Sludge Sediment and Water: pH is measured electrometrically using a combination electrode and is calibrated against 3 buffers purchased commercially. For soils, sediments and sludges, an extract with water (or 0.01M CaCl2) is made at a ratio of 1:5 and the pH determined and reported on the extract. Reference APHA 4500-H+.
AN106	Conductivity and TDS by Calculation: Conductivity is measured by meter with temperature compensation and is calibrated against a standard solution of potassium chloride. Conductivity is generally reported as µmhos/cm or µS/cm @ 25°C. For soils, an extract of as received sample with water is made at a ratio of 1:5 and the EC determined and reported on the extract, or calculated back to the as-received sample. Salinity can be estimated from conductivity using a conversion factor, which for natural waters, is in the range 0.55 to 0.75. Reference APHA 2510 B.
AN122	Exchangeable Cations, CEC and ESP: Soil sample is extracted in 1 M Ammonium Acetate at pH=7 (or 1M Ammonium Chloride at pH=7) with cations (Na, K, Ca & Mg) then determined by ICP OES/ICP MS and reported as Exchangeable Cations. For saline soils, these results can be corrected for water soluble cations and reported as Exchangeable cations in meq/100g or soil can be pre-treated (aqueous ethanol/aqueous glycerol) prior to extraction. Cation Exchange Capacity (CEC) is the sum of the exchangeable cations in meq/100g.
AN122	The Exchangeable Sodium Percentage (ESP) is calculated as the exchangeable sodium divided by the CEC (all in meq/100g) times 100. ESP can be used to categorise the sodicity of the soil as below: ESP < 6% non-sodic ESP 6-15% sodic ESP >15% strongly sodic Method is referenced to Rayment and Lyons, 2011, sections 15D3 and 15N1.-
AN248	Nitrate / Nitrite in extract by Auto Analyser: In an acidic medium, nitrate is reduced quantitatively to nitrite by cadmium metal. This nitrite plus any original nitrite is determined as an intense red-pink azo dye at 540 nm following diazotisation with sulphanilamide and subsequent coupling with N-(1-naphthyl) ethylenediamine dihydrochloride. Reference APHA 4500-NO3- F.
AN281	The sample is heated in the presence of Sulphuric acid, K2SO4 and CuSO4 for two and half hours using a temperature controlled digestion block. Amino Nitrogen of many organic materials is converted to ammonium ion. Free ammonia also is converted to ammonium. The digest is cooled and placed on the Aquakem 250 discrete analyser for Ammonia determination.
CSA03V	This method involves the determination of total carbon which includes both organic and inorganic carbon. Carbon is determined via infra red absorption of the evolved CO2 gases after heating the sample in a carrier gas of oxygen. The IR cal output is calibrated against the value of the known standards to provide the total carbon value of the unknown sample.
CSA06V	The sulfur is oxidised to sulfur trioxide gas and carbon to carbon dioxde gas in a tube furnace using oxygen to aid the oxidation process. The evolved sulfur trioxide and carbon dioxide is measured by an infra red cell. The infra red cell output is calibrated against the value of a known standard sample to provide the total sulfur and total carbon value of the unknown sample.