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Christmas Island National Park

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Annual Report for the Christmas Island Minesite to Forest Rehabilitation (CIMFR) Program

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July 2015 - June 2016

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1. Executive Summary

The Christmas Island Minesite to Forest Rehabilitation (CIMFR) program operates under a Memorandum of Understanding (MoU) between the Department of Infrastructure and Regional Development (DIRD) and the Director of National Parks (DNP/Parks Australia). The purpose of the CIMFR program is to conduct ecological restoration on old, relinquished phosphate minefields adjacent to forest areas of high conservation value. The program is funded by a conservation levy paid by Christmas Island Phosphates (CIP) to the Australian Government as a condition of its mining lease. Under the 2012-2020 MoU, DIRD engages Parks Australia to conduct forest rehabilitation works. Works are carried out in accordance with the CIMFR Program 2012-2020 Plan; the Christmas Island National Park Management Plan 2014-2024; threatened species recovery plans (prepared in accordance with the *Environment Protection and Biodiversity Conservation Act 1999*); and other relevant guiding documents and research reports produced between 1981 and 2014.

During the period covered by this annual report (1 July 2015 to 30 June 2016) the CIMFR program carried out earthworks and new plantings on an area of 2 hectares, and secondary plantings across 20 hectares of already established fields. A total of ~14,500 trees were planted, of which ~4,900 were employed in the new field, Blowholes 107 (previously known as ML 107). This field was almost entirely surrounded by high-quality forest on all sides, so offered good conditions for establishment. A total of 25 native tree species were used, predominantly being primary 'pioneer' species. A further ~9,600 trees (mainly secondary/forest mix species) were planted across ~20 hectares of established fields (including 21W, 21ESP, 22C, 22CE, 22CW and 23N, 23E and 23 Upper) to increase species richness and promote ecosystem succession. These follow up plantings incorporate an extra 10 species that are slower-growing, longer-lived and better suited to partly shaded conditions when young.

Field maintenance, including physical and chemical control of weeds, fertiliser additions and track management were ongoing. Throughout 2015-16, field maintenance was conducted over 110 hectares. Approximately 15 hectares of fields >10 years old were relinquished from management activities such as weed control and fertiliser applications. Since the CIMFR program began in 2004, approximately 300,000 native trees have been planted in relinquished old mine fields across Christmas Island. Biophysical monitoring of fields up to ten-years-old indicated that most fields were performing well.

In the 2015-16 financial year, the CIMFR program expended $1.3 million, which covered all costs associated with the program (e.g. up to 12 local staff, earthworks, nursery operation and production, infrastructure and vehicle depreciation and running costs, rates, and supplies such as herbicide and fertiliser). In accordance with the MoU, a schedule of works was submitted to DIRD in May 2016 outlining the plan and budget, with projected cost estimated at $1.45 million for next financial year (2016-17). It takes 12-24 months from the time seed is collected and germinated to the time when saplings have grown sufficiently to be planted. Early indication of funding for future years greatly improves planning effectiveness, efficiencies in costs and will maximise the conservation outcomes of the CIMFR program.

2. Introduction and background

Since the 1890s, phosphate mining has been a major part of Christmas Island's history. Approximately 3300 hectares of forest has been cleared on Christmas Island for phosphate mining and associated infrastructure. The majority of mine fields are located on the plateau >150m above sea level. Tall, evergreen rainforest is the vegetation community and ecosystem most severely impacted by this clearing. Due to a range of threats, particularly introduced species and habitat loss and decline, populations of several native species have decreased severely, some to the point of extinction (e.g. native mammals such as Maclear's rat and the bulldog rat). Under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) three flora species and fifteen fauna species are listed as threatened (critically endangered, endangered or vulnerable), with ten of these having existing national recovery plans. The EPBC Act obliges the Commonwealth to implement recovery plans to the extent to which they apply to Commonwealth areas. Protection of existing rainforest, as well as rehabilitation of areas with high conservation value potential, are actions stipulated in a number of threatened species recovery plans (e.g. those for Abbott's booby (*Papasula abbotti*), Christmas Island goshawk (*Accipiter hiogaster natalis*) and Christmas Island hawk-owl (*Ninox natalis*).

Approximately 338 hectares of relinquished mine lease have undergone rehabilitation work, achieving a range of vegetation types (e.g. evergreen plateau forest, semi-deciduous terrace forest, deciduous scrub forest) with varying stages of development. Parks Australia and its predecessors (e.g. the Australian National Parks and Wildlife Service - ANPWS) have been conducting rehabilitation works since 1989, with funding provided by the conservation levy paid by Christmas Island Phosphates (CIP). In 2004, the Christmas Island Minesite to Forest Rehabilitation (CIMFR) program began, and is distinguished from earlier programs by its foundation on research conducted by the Centre for Mined Land Rehabilitation at the University of Queensland (2000).

Based on evidence and comparisons of rehabilitation with varying degrees of success, the UQ research advised that the best outcomes are likely achieved when soil depth is at least 1.5 m, regular weed control is conducted and sufficient fertiliser is provided to the establishing plants. These conditions are the minimum requirements if the aim is to establish regrowth rainforest that may eventually attain levels of diversity, density and structure approaching that of the original rainforest community. Providing the right soil depth is fundamental to success, as it must hold enough moisture to support plant survival throughout years when rainfall is less than average, or dry spells that persist longer than normal. Deeper soils permit greater root development than shallow soils, and increase the potential for a broader range of plateau rainforest tree species to inhabit the area.

The aim of the CIMFR program is: *to revegetate abandoned minefields with rainforest tree species, and create biodiverse, resilient, self-sustaining ecosystems that provide or enhance habitat for native flora and fauna, especially land crabs, endemic forest birds and in the long term, the Abbott's Bobby*. Priority areas for rehabilitation are those that provide the greatest benefit to these species, especially sites adjacent to forest areas of high conservation value, as rehabilitation of these sites improves ecosystem connectivity. The CIMFR program is conducted by the Director of National Parks (DNP) in accordance with the CIMFR program (2012-2020) Plan. Funding is provided from a conservation levy paid by CIP to the Department of Infrastructure and Regional Development (DIRD) and its predecessor departments and then provided to the DNP via a Memorandum of Understanding (MoU). The current MoU (2012-2020) was finalised and signed on 4 October 2012, supporting continuation of the program until 2020.

3. Year in review

3.1 Weather

In the calendar year of 2015, Christmas Island received 1722 mm of rain: approximately 19% below the long term average of 2117 mm (Bureau of Meteorology 2016). Eleven out of twelve months were considerably drier than usual, yet this was partly offset by an extremely wet March 2015 when more than double the long term average for that month was received (Figure 1). By contrast, September and October 2015 brought only 1% of the average rainfall for both of those months.

The wet season started with only modest rainfall in December 2015 (13% below average) and January 2016 (16% below average), but picked up strongly in February. Every month from February to June 2016 was well above average (12% to 173%) – a trend that continued until the time of writing. April, May and June were especially wet, receiving 411 mm, 489 mm and 367 mm respectively. Amazingly, the sum total rainfall in the first six months of 2016 was 2248 mm; thus surpassing the long term average for an entire year (2117 mm) (Bureau of Meteorology 2016).

The coldest temperature recorded on Christmas Island during the 12 months covered by this annual report was 20.2 °C (7th August 2015); the hottest was 30.7 °C (26th January 2016) (Bureau of Meteorology 2016).

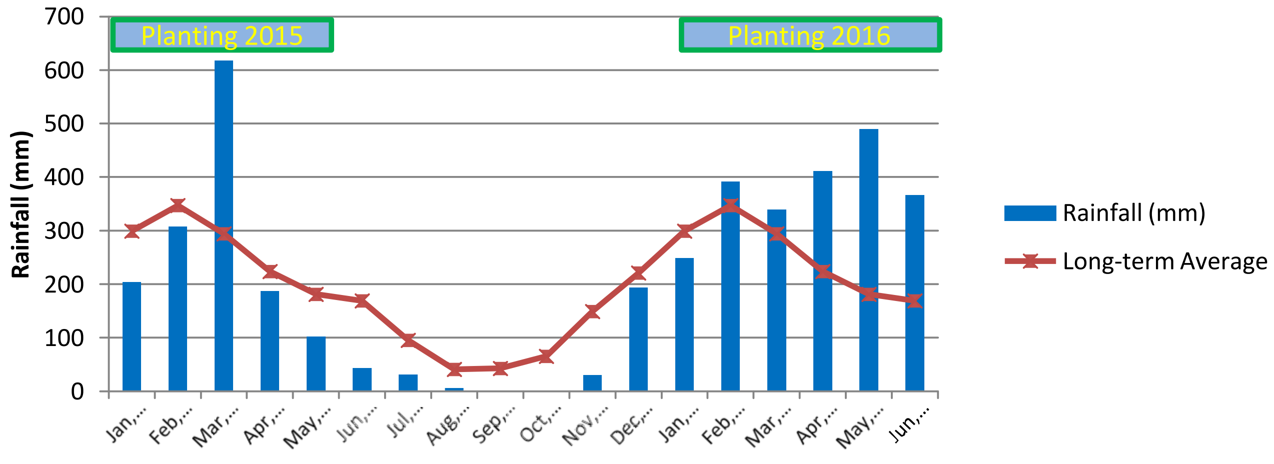

Figure 1: Monthly rainfall (bars) and long-term average rainfall (line) on Christmas Island from 1 January 2015 through to 30-June 2016. Data sourced from Bureau of Meteorology 2016.

3.2 Preparation of the new field: Earthworks and weed removal

Earthworks were conducted at 'Blowholes Field 107' during the dry-season months of August and September 2015 in preparation for planting in early 2016. The site has an area of 2 hectares and is located approximately 750 m past the junction of the Blowholes road and the mining quarries in ML 106; and is approximately 250 m along the track from the boundary with the National Park (Figure 2). It has an elevation of 170 m ASL and numerous Abbott's Booby nesting trees in the vicinity. Previously the field was known as Mine Lease (ML) 107. Incorporating the historically disturbed edge that extends into National Park, but excluding the Blowholes Road that bisects it, approximately two hectares of land required earth moving and weed removal. It was heavily infested with woody weeds such as *Leucaena leucocephala, Psidium guajava, Cordia curassavica,* and *Aleurites moluccanus,* many of which were >4 m tall. Some native trees (mainly *Macaranga tanarius*) were interspersed amongst the weeds. Heavy machinery was used to clear weedy vegetation from approximately 1.5 hectares. The remaining 0.5 hectares of weed removal was selectively done by hand in order to keep remnant native trees around them. The site is predominantly Vacant/Unallocated Crown Land (VCL/UCL). A clearing permit application was submitted to the Department of Environment and Regulation (WA) to remove low quality vegetation in order to allow rehabilitation to take place. The clearing permit was granted in July 2014 (permit number 6124/1). Several good-sized *Ficus macrocarpa* trees and other native trees were retained in a patch of vegetation on a remnant soil mound just off the road. This patch was identified as important to keep in the supporting documentation for the permit application so was not requested in the clearing permit area. Manual woody-weed removal and maintenance of this patch and its surrounds will occur during the maintenance life of this field.

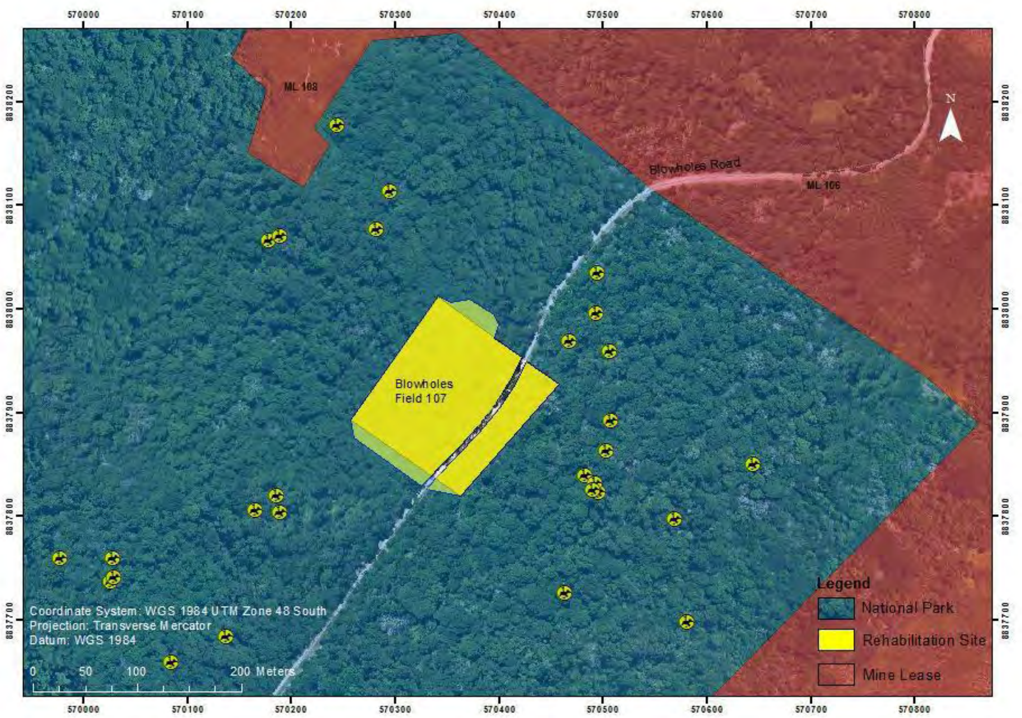

Figure 2: Location of Blowholes Field 107, land tenure and known Abbott's booby nesting trees

Figure 3: Earthworks at Blowholes Field 107

There was some variability in soil depth across the field; in many places there was less than 10 cm of soil overlying limestone; in other places there was close to 1 m. The intended depth of cover was aimed at between 1.0 and 1.5m. About 75% of the 2 hectare area actually required earthmoving and soil application. This area was ripped by a dozer to the maximum depth of the ripping tine (1m), or until rock was hit, with rip lines spaced ~1.5 m apart. Soil was sourced from stockpile 107C on the eastern side of the Blowholes Road- approximately ~15,000 tonnes was extracted (Figure 3). Possibly due to the fact this stockpile was immediately adjacent to the road, it was densely covered in weeds and ferns. Two other stockpiles of equivalent size on the western side of the field were also assessed, but were found to have very good quality regrowth of advanced succession native trees and deemed too good to clear. Their boundary to primary rainforest in the National Park, and separation from the road by ~100m likely resulted in the greater success of native vegetation recolonisation on these stockpiles.

3.3 Planting and Nursery

The planting season of 2016 started on 13th January. A total of ~14,500 trees were planted across all sites (Table 1). Early plantings began with secondary 'forest mix' species in established fields. Once rainfall was considered reliable enough in February, plantings at the new Blowholes 107 field began (11/2/16). Due to the importance of planting only when rain is present or expected, planting was conducted usually 2-3 days per week on average. Dry days in between were used to carry out weed control elsewhere in established fields to make way for secondary plantings later on. After the Blowholes 107 field was completed in early March 2016, secondary plantings were recommenced.

Table 1: Number of trees planting in the 2016 wet season (January to May)

Planting type	Area	Number
New field Primaries	2.1 ha	4,900
Established field Secondaries	20 ha	9,600
Total		14,500

Around 4,900 trees were planted at Blowholes Field 107 (Figure 4). Valuable native trees and patches of mature, regrowth vegetation were retained inside the 2 hectare area, thus reducing the number of seedlings required for planting out. Overall, we aimed to achieve a plant density across the field of approximately 3200 stems per hectare. Plant spacing was 1.5 - 2 m in rows to allow for efficient management and a suitable plant density. It should be noted that of the 2 hectares prepared for rehabilitation, ~1.5 hectares was open, exposed soil requiring mainly primary 'pioneer' species; the remaining ~0.5 hectares that received manual weed removal in remnant patches was planted with secondary 'forest mix' species at a lower density (because established trees were already present). Twenty eight native tree species were employed across the site; 'primary 'pioneer' species accounted for approximately 85% of the total; the rest being secondary species such as *Syzygium nervosum, Planchonella nitida, Inocarpus fagifer*, and *Celtis timorensis.* Because the site is small and surrounded by forest, good conditions are present in terms of wind protection, humidity, shade, bird and crab visitation. The roadway, however, does open up the area to incursion by weeds so may require special attention in the next few years. Survivorship in the first six months after planting was over 95% - any mortalities were replaced when rain permitted.

Secondary 'forest mix' and infill plantings were conducted in fields 21 West, 21 East stockpile, 22 Central, 22 Central East, 22 Central West stockpile, 22 West, 23 North, 23 East and 23 Upper. The area of these fields is approximately 20 hectares. Plantings occurred on rainy days up until the 9th June- a longer than usual planting period thanks to an extended wet season. A total of 9,600 trees were planted in these established fields, including mostly secondary 'forest mix' species planted under dappled shade conditions.

For the tree planting, holes were dug using mechanical augers (usually) or with matics/hoes by hand to a depth of 200-300 mm, water holding crystals were added (fully hydrated) and mixed with soft soil backfilled to within ~150 mm of the surface, and a 40g fertiliser tablet (Native Plant Pill) placed in the hole before the plant was put in. After returning soil around it matching the existing soil level, a sprinkling of 'Tristar' granular fertiliser was added around the base. Soil nutrient analysis conducted in previous years, along with complementary fertiliser trials done by CIMFR and the Mintope program indicate that Potassium and Nitrogen are the key nutrients limiting growth in these soils. Baileys Tristar fertiliser contains high potassium, high sulphate, moderate nitrogen, and some micronutrients and is applied to feed the plants early on in the wet season to provide for good growth at the outset. The Native Plant Pill (Baileys Fertiliser) is a large, 40 g tablet designed to slowly release nutrients when water is available for up to twelve months. It contains moderate to high levels levels of nitrogen and potassium, a modest amount of sulphur as sulphate, several important trace elements and is low in phosphate (Table 2). The combination of these two fertilisers satisfies the immediate and sustained needs of the plants to give the best-possible health and growth for the first year or more.

Table 2: Composition of the two main fertilisers used during tree planting

Fertiliser	Native Plant Pill (w/w%)	Tristar (w/w%)
Total Nitrogen	20.7	8.3
Total Phosphorus	1.2	0
Total Potassium	10.5	14.8
Sulphur as Sulphate	4.6	18.7
Magnesium	0.45	2.1
Iron	0.36	1
Zinc	0.08	negligible
Copper	0.05	negligible
Manganese	0.08	negligible
Boron	0.01	negligible
Calcium	negligible	1.8

Figure 4: Planting at Blowholes Field 107

3.4. Rehabilitation Field Maintenance

Approximately 200 hectares of previously mined land has been subject to rehabilitation works by on the central plateau over the past ~25 years. In 2014-15, about 125 hectares were actively managed conducting tasks such as weed control, track maintenance and fertiliser applications. This year, 15 hectares of fields >10 years old were relinquished from regular management activities. These include fields 20 Central, 20 West, 22 South, 22 East, 22 North East, 22 North West and 24 East. In general, trees in these areas are sufficiently established and big enough to survive competition from weeds, recruitment is taking place to ensure natural succession and replacement occurs, and the areas are providing habitat and resources for native forest birds and land crabs. With these areas now off the weed control and fertiliser application schedule, approximately 110 hectares remain for regular field maintenance.

As in previous years, the worst weeds requiring the most effort still include the vine species *Mikania micrantha* (mile-a-minute vine), *Macroptilium atropurpureum* (siratro), *Centrosema pubescens* (centro) and *Mucuna albertsii*, as well as the woody weeds *Cordia curassavica* and *Leucaena leucocephala.* Whilst these problem species do persist in some areas, ongoing management is successfully bringing about noticeable declines in many places. In general, with each round of weed removal and subsequent fertiliser application, native trees grow taller and increase canopy cover. These improvements gradually make it harder for weeds to compete for light and resources, leading to their decline. For instance, a field that may have taken eight people, ten days to weed and spray when it was three- years-old, may take the same number of people only five days to weed when it is six-years-old.

Fertiliser additions continued in sites showing nutrient deficiency, usually up to eight years of age. This was applied by hand to ensure targeted applications to native plants. As with plantings, two types of fertiliser were used- granular 'Tristar' and 'Native Plant Pills'. The granular Tristar was cast on the soil surface beneath the canopy of target trees and only after weed control had been conducted recently so there was little to no competition with green weeds. For small trees (usually <1.5m tall) such as secondary/forest mix species, Native Plant Pills were sometimes applied, and only ever subsurface (~25-50 mm). Subsurface application is favourable as it provides a more concentrated location of fertiliser available to the native tree and some separation from germinating weed seed on the surface in an effort to reduce weed growth. Fields older than seven years generally appear to be moving towards self sufficiency in nutrient cycling, so inputs were typically less than for younger fields.

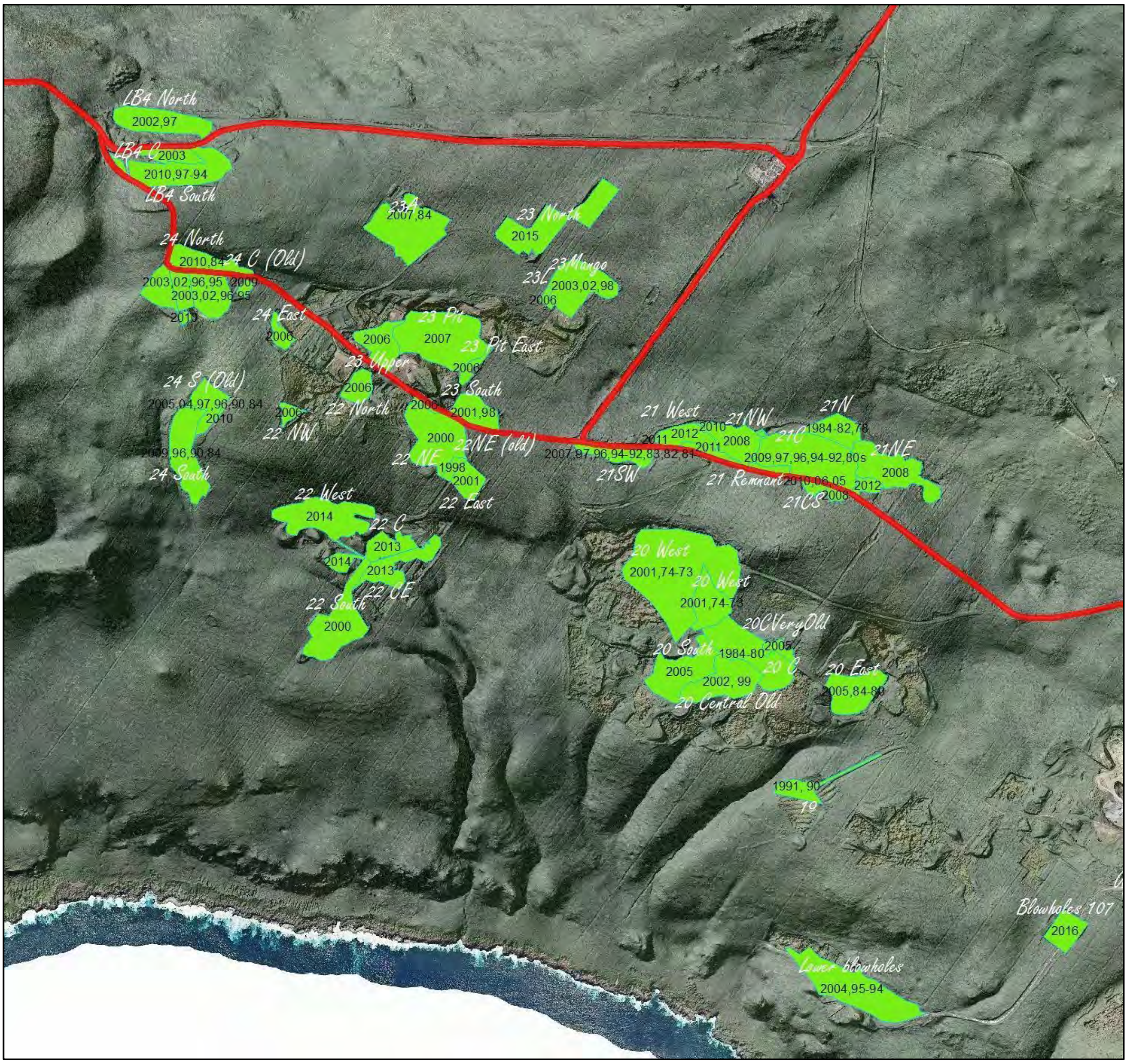

Figure 5: Rehabilitated areas on the central plateau.

Figure 6: Manual and chemical weed control in rehabilitation fields

3.5. Staffing

Staff numbers ranged from a minimum of 9 to a maximum of 12, with an average full time equivalent (FTE) of ~10 staff throughout the 2015-16 financial year. Highest staff numbers were required during the first half of the year to carry out the tree planting program and to address heavy weed loads following the rains. The average length of time staff have been working in the rehabilitation team is just over 5 years. Of the 10 people, five are local residents who have spent most, if not all their lives on Christmas Island. Of the remaining five, most have been on island for between 2 and 6 years.

A gazette advertised recruitment process for APS1-2 Field Officers was conducted at the start of 2016; 49 people applied. Five people have been employed from this process. Two are life-long local residents, and a third had been on CI for more than 2 years – all three were incumbent. The other two successful candidates were from the mainland and have proven to be hard working, knowledgeable, competent, of excellent character, and fit in well with the team. One position was approved as ongoing (permanent); this was awarded to Shairazi Razak (a Christmas Island local).

A gazette-advertised process was also conducted for the APS3 Field Supervisor in the latter half of 2015. Six people applied, but only two positions were available. An ongoing position was awarded to Roslan Sani - a Christmas Island local for most of his life (over 30 years). The non-ongoing position was won by an employee who had been working with us for more than two years and demonstrated outstanding capability for all selection criteria.

The CIMFR team displays a good balance of well-trained young staff that bring fresh perspectives, as well as long term staff who provide valuable skills, experience and historical knowledge.

3.6. Knowledge Building and Collaborative Work

The Australian National Botanic Gardens (ANBG) has continued to provide excellent technical support, in-kind, to the CIMFR program. Throughout the year, staff at the ANBG nursery, seed-bank and herbarium were always helpful in providing advice and discussion about a range of issues including horticultural practices (e.g. plant pathogen and pest management), seed storage techniques, and plant species verifications, especially of introduced weeds. In addition to the remote support they provide, they were kind enough to fund a visit by the National Seed Bank curator (Dr Tom North) and horticulturalist (Heather Sweet) in May 2016 for just over one week.

Figure 7: Seed collection work with Dr Tom North from the Australian National Seed Bank

In addition to providing training and tips to our staff on state-of-the-art industry practices, they were also here to carry out seed collections of key native species for incorporation in to the Australian National Seed Bank. Some collections were also destined for the Millennium Seed Bank at Kew Gardens, London.

All CIMFR staff benefited from this experience and have continued to put into practice the skills they learn from these visits. Such exposure to some of Australia's most respected and knowledgeable people in the field of conservation horticulture, advances staff knowledge and skills to the forefront of industry-best practice standards.

In terms of nationally recognised training accredit-tations, the CIMFR program supported five of its staff to undertake their Certificate IV in Conservation and Land Management (Roslan Sani, Adijah Bingham, Jason turl), or Certificate IV in Horticulture (Muhammad Jafni Jamil, Shairazi Abdul Razak). Of these staff, four are life-long local residents, and one has been working with CIMFR for more than two years already. Christmas Island National Park is working alongside Indian Ocean Group Training Association (IOGTA) with the Great Southern Institute of Technology (GSIT) to provide local employees with the professional development opportunities they need to effectively carry out their duties and enhance their career aspirations.

In the CIMFR Nursery during January 2016, staff members discovered three larval stage specimens of the rare and endemic Christmas Island Emperor butterfly (*Polyura andrewsi*). This was the first time it had ever appeared in the nursery (the newly setup Territory Day Park side) so a remarkable occurrence. This was the wet season and significant rains had occurred in the weeks preceding the discovery. Two of the specimens were left to naturally develop and fly away, the third was monitored closely. The caterpillar was found on 14th January, feeding on the branch of a 40cm tall seedling of the species *Celtis timorensis*. The caterpillar was green in colour, its head looks like a triceratops, with two main horns, and two side horns (Figure 8). By the following day, it had formed its chrysalis. It emerged as a butterfly on 28th January 2016. This specimen was preserved and sent to the CSIRO Australian National Insect Collection. It is only the second specimen of the species in the collection; the last was apparently collected in 1965.

Figure 8: Various life stages of Christmas Island Emperor butterfly discovered in the CIMFR Nursery

3.7 Fertiliser trials

To further improve the cost effectiveness of fertiliser additions, identify which nutrients were most limiting and get the best growth possible, a trial was started in March 2015 at the open field 23 North. As noted in last year's annual report, this is a two year study to be completed in March/April 2017.

The experimental design for this trial (a statistically valid, randomised block design) was developed in consultation with CSIRO. A total of eight fertiliser treatments were applied, including control plants which received no fertiliser, and seven different products (see those listed in Table 3). The products chosen were all identified as potentially offering benefits following consideration of soil nutrient data collected previously.

Table 3: Fertiliser treatments in experimental plots at Field 23 North

Treatment #	Treatment nutrient
1	No Fertiliser- control
2	Iron sulphate
3	Urea Nitrogen (Apex Polyon)
4	Trace Elements
5	General NPK+trace Tablets
6	Potassium Sulphate (Pot Ash)
7	Liquid fish emulsion+ fulvic acid
8	NPK granules

Six plant species were tested, each from a different plant family and with different ecological or functional traits (Table 4). For example, this included leguminous/nitrogen-fixing species (e.g. *Inocarpus fagifer*) and non-leguminous/non-nitrogen fixing species (e.g. *Calophyllum inophyllum* and others); fast-growing species (e.g. *Macaranga tanarius*) and relatively slow-growing (e.g. *Ochrosia ackeringae*) species, as well as others that are all important in the current species planting mix.

Replication was achieved by having seven separate plots throughout the 7 hectare field, and blocks were randomised within plots. Two plants of each species were used in each treatment block to provide some redundancy. As such, the total number of plants used may be calculated as follows:

Total number of plants = 8 (treatments) x 6 (species) x 7 (plots) x 2 (individuals) = 672

Table 4: List of species used in fertiliser trials at Field 23 North

Species #	Species	Family
1	*Barringtonia racemosa*	Lecythidaceae
2	*Calophyllum inophyllum*	Clusiaceae
3	*Gyrocarpus americanus*	Hernandiaceae
4	*Inocarpus fagifer*	Fabaceae
5	*Macaranga tanarius*	Euphorbiaceae
6	*Ochrosia ackeringae*	Apocynaceae

To quantify the effectiveness of each fertiliser treatment, the following parameters were measured on each of the 672 trees planted:

1. Tree height (cm) to the apical meristem
2. Stem diameter @ 10 cm above ground (important when they are less than 1.0 m)
3. Stem diameter @ 100 cm above ground (where applicable)
4. Leaf count
5. Leaf length. Using allometric relationship between length and leaf area, determine average leaf size. With leaf count, determine total leaf area of the plant
6. Leaf greenness (colourmetric determination of digital images)
7. Crown diameter on two axes
8. Pest infection type (e.g. scale, caterpillars, leaf minor, borers etc)
9. Pest infection severity (0=none, 1=insignificant effect on growth, 2=significantly effecting plant growth; 3=severely affecting plant growth)
10. Herbivory extent (percentage of leaves eaten/missing
11. Overall appearance of nutrition and health (5=excellent, 4=good, 3=fair, 2=poor, 1=very poor, 0=dead or apparently dead)

The first assessments were conducted shortly after planting in March 2015 and before any fertiliser was applied, making this is the 'time zero' start point. In April 2015, fertilisers were applied. Fertilisers are re-applied periodically, as per label instructions. Monitoring assessments were conducted every 4 months up until being one-year old, then every six months up until two-year old (April 2017). All monitoring times have been conducted as planned so far.

Preliminary analysis of the results thus far highlight the importance of Potassium and Nitrogen in providing for good growth and plant health. Final statistical analysis will be conducted after all field monitoring surveys are completed and conclusions will be reported next year.

3.8 Biophysical Monitoring 2016

In 2016, biophysical monitoring of planted fields was conducted in sites of varying ages from newly planted 'zero-year-old' (field 107 at the Blowholes); 'one-year-old' (field 23 North); 'three-years-old' (fields 22 Central and Central East); 'five-years-old' (field 21 West Roadside), and 'ten-years-old' (fields 22 North, 22 North West, 23 Upper, 23 Pit East and 24 East).

This year, biophysical monitoring surveys were undertaken from June to September. Parameters measured were in three main categories:

1) *Vegetation assessments*: plant species abundance and diversity, tree heights and diameters, plant health, canopy cover, ground cover, recruitment of native species
2) *Fauna assessments*: presence of birds, crabs and other invertebrates
3) *Soil assessments*: soil bulk density, water-holding capacity, pH, electrical conductivity (EC)

Each of these categories is discussed below in context of field age (see Appendix 1 for methods).

In general, most fields are doing well and show progress in line with expectation since planting. The new field, (Blowholes 107), and the one-year-old field (23 North), are doing extremely well in terms of plant survivorship, species diversity, growth, canopy cover and other parameters, presumably largely because the field is surrounded by high-quality primary forest on all sides. The three-year-old, five-year-old and ten-year-old fields demonstrate good health, species diversity, canopy development and recruitment.

Vegetation Assessments

New/ zero-year-old fields

Planted in early 2016 (February-March), field 107 at the Blowholes was only 4 months old when monitoring was conducted . For the sake of consistency with older fields and keeping the naming pattern to annual increments, this field will be referred to as '0-years-old' in figures throughout the document. Two monitoring transects were established at this field.

Field Blowholes

Figure 9: Photographs of monitoring transects at the newly planted zero-year-old site Blowholes 107

A total of 27 native species were detected in these transects- close to the 28 species produced by the nursery that year. New recruits from the surrounding forest were already appearing in the field, with over 875 recruits per hectare. Around 425 of these were already over 20 cm tall, which is better than usual but not surprising given the above average rainfall every month between planting and monitoring. The abundance of recruits can be explained by the fields' relatively small size and close proximity to the forest on all sides.

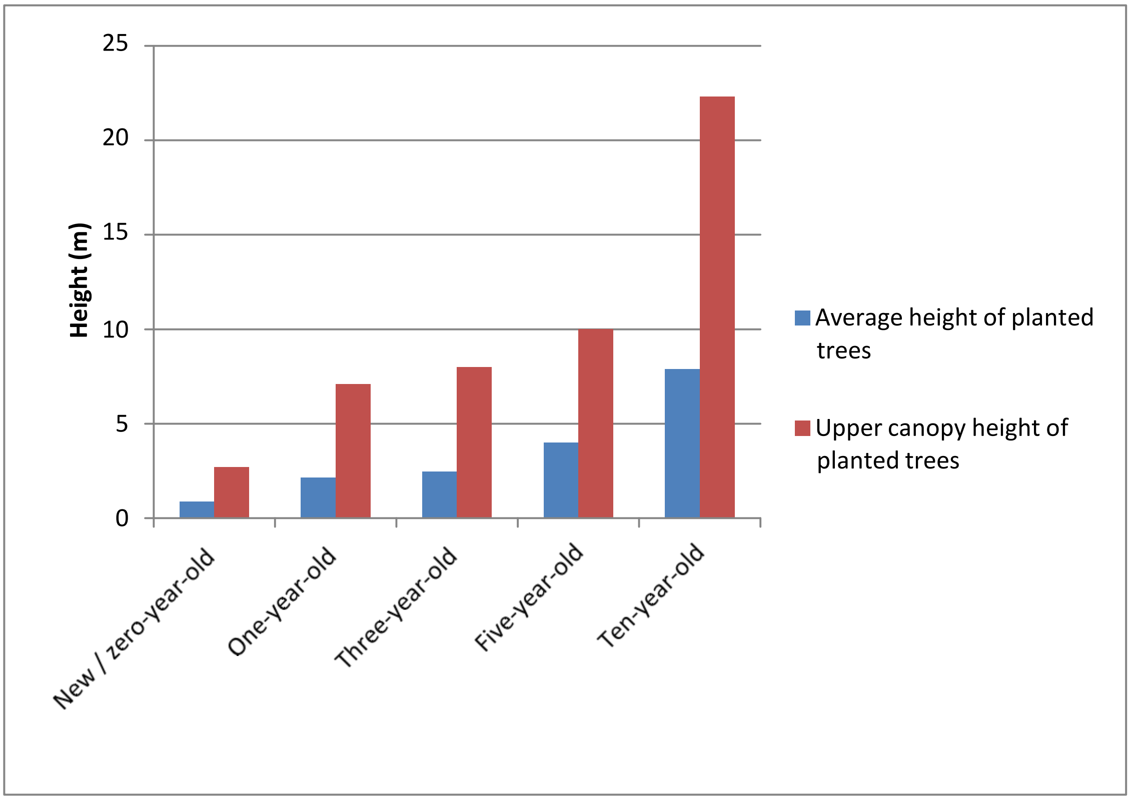

Figure 10: Average and upper canopy heights of planted trees in fields of various ages

Plant density along the transect was close to what was intended (~3,225 trees per hectare - Table 5). It should be noted that open, exposed soil accounted for ~ 1.5 hectares, whilst 0.5 hectares just required manual weed control and infill plantings. Shannon's Diversity Index (*H)* for this site was high (2.79 out of 3.33 (H_{max})) giving a Shannon/Pielou value of 85%. This diversity index '*H'* is a mathematical measure to quantify species diversity in a community. It takes into account the relative abundances of each species, the total number of individuals and number of species (for further information on how this is calculated, please refer to section A.1.1 of Appendix 1). Simpson's *D*, representing the statistical probability that any two species would be the same, equals 9.7%. Values close to zero approach infinite diversity and values approaching 100 means no diversity (i.e. a monoculture). Expressed as a 1-*D*, and therefore the statistical likelihood that any two plants will be *different* species, the value is thus 90.3% (where values approaching 100% indicate very high diversity). Such values are well above expectation and indicate that, in terms of biodiversity, the field is off to an excellent start.

Equitability (Simpson's E_d), which is also constrained between 0 and 1, was 0.38, which indicates stronger representation of some species than others. This is an expected outcome given that pioneer species like *Macaranga tanarius* were a significant part of the planting mix (~25%).

In terms of growth, average height of these newly planted trees is 0.89m and maximum height 2.7m (see Table 5 and Figure 10). Not surprisingly, almost 98% of the trees encountered in these transects were less than 2 m tall, with only a few taller than this (Figure 11).

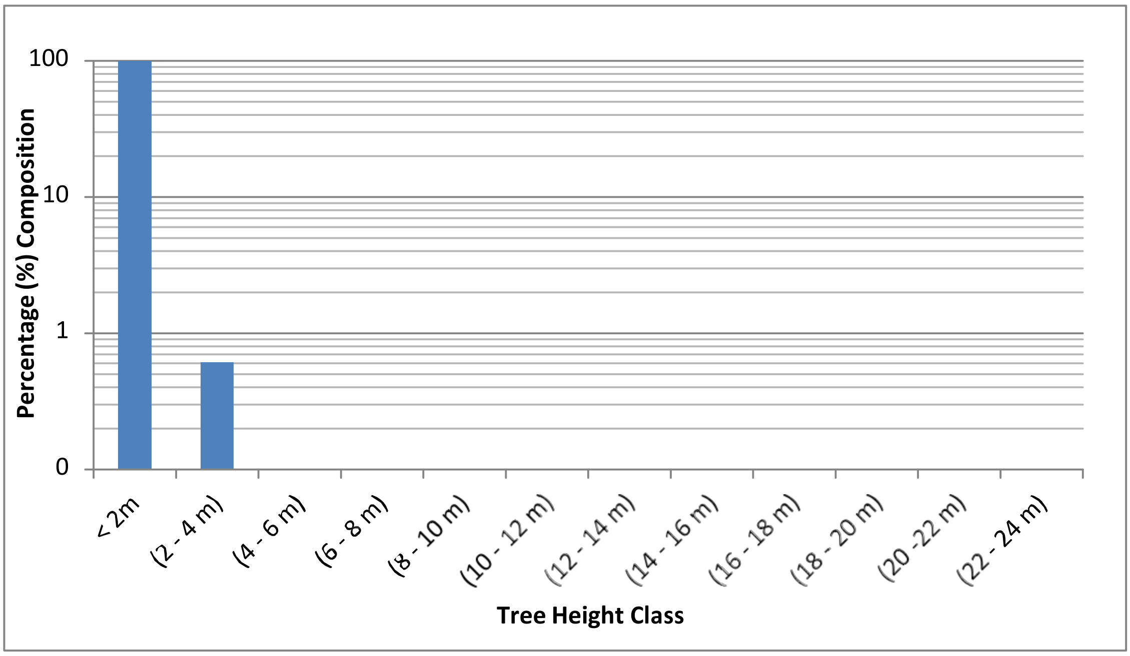

Figure 11: Height frequency distribution of trees in the new/zero-year-old field (Blowholes)

The percentage composition of tree heights is represented in Figure 11: height frequency distribution of trees in the new/zero-year-old field (Blowholes). Note that Figure 11 displays a logarithmic scale (base 10) on the vertical axis to represent the percentage composition. This gives more appropriate acknowledgement of tree size in the chart, as one large mature tree (e.g. with a height of say 23 m) will provide considerably more ecosystem value (e.g. roosting habitat for birds, leaf litter production) than one small recruit standing 0.3 m tall. Secondly, in terms of shade, one such large tree may well give more ground surface shade than 100 small saplings. This is an important consideration for the habitability of sites to red crabs. Remnant native trees are important as they provide patches of shade, seed, and leaf litter. Furthermore they provide bird-roosting habitat which also brings in seed of other species from adjacent forest, thus improving recruitment rates.

Another important measure of growth is trunk/stem diameter (at 10cm above ground level), or, the subsequent calculation of stem cross-sectional area. Of these 164 stems measured in the new field, average cross-sectional area was 3 cm^2 (see Table 5 and Figure 12). This is seemingly small, but perfectly normal for trees with an average height of 89 cm tall.

Canopy cover, as determined by hemispherical photography (with a fish-eye lens) and image analysis (Gap Light Analyser), was 17%, which is normal for a field of this age (see Figure 13).

Leaf litter projected area on the ground was 21%, which is good for such a young field. Ferns were largely absent from most areas with only 2% of ground area covered by fronds. Low to moderate abundance of ferns (<30% projected cover) may be slightly beneficial for holding surface soils together and limiting weed growth, but high levels (>50%) can be problematic as they can take over and inhibit the recruitment of native species (Table 5).

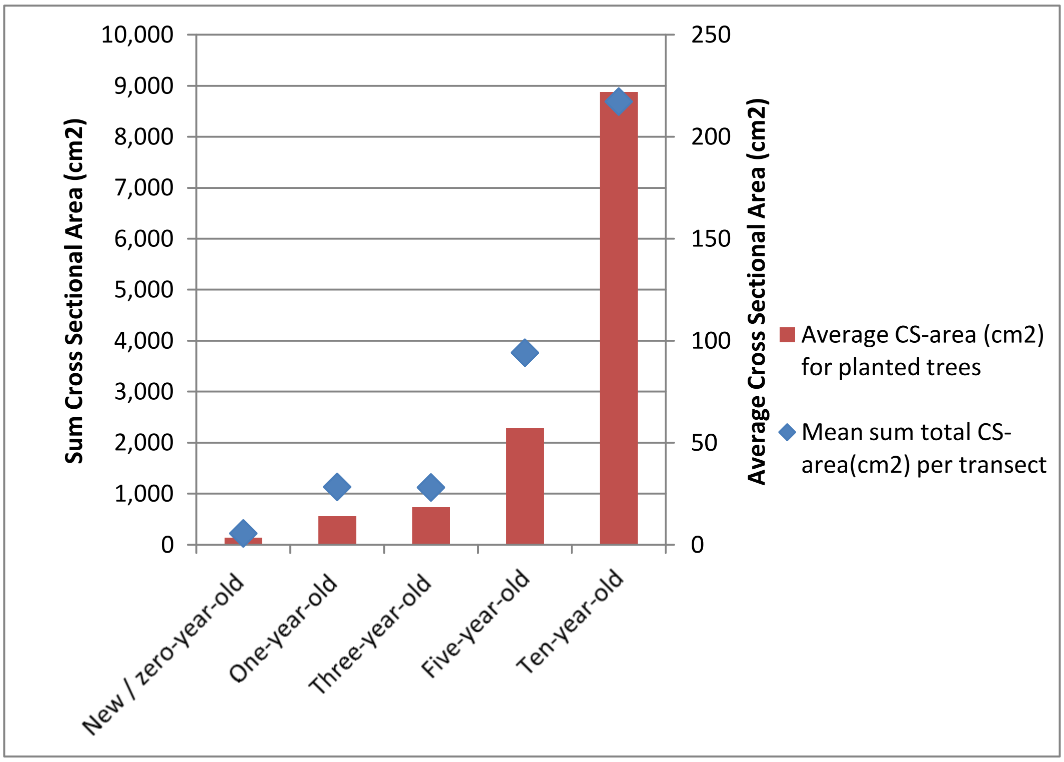

Figure 12: Average cross-sectional area (cm2) and the average sum total cross-sectional area (cm2) of planted trees measured at 10cm above ground level for fields of different ages.

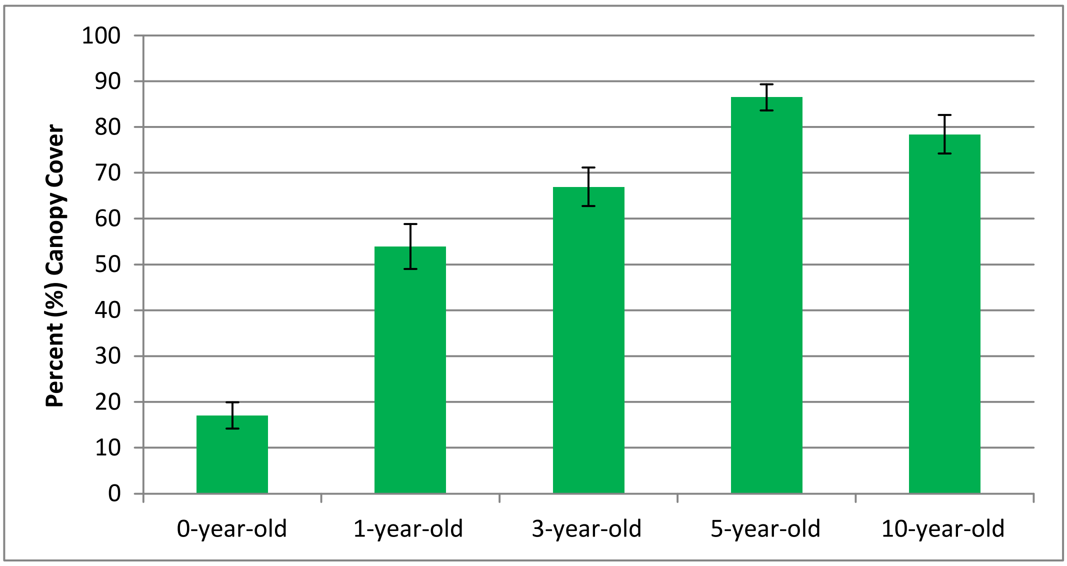

Figure 13: Percentage canopy cover for fields of different ages. Error bars are standard errors of the mean.

One-year-old fields

The one-year-old field, site 23 North, formerly ML 115, is located on the central plateau in forest bounded by Murray Road, East-West baseline and North-West Point Road on all three sides. It can be accessed from Murray Road. The turnoff is 1.1 km south of Central Area Workshop, and the field is 850 m down the track on the right-hand-side (north). Four monitoring transects were established throughout 23 North. (see Figure 14).

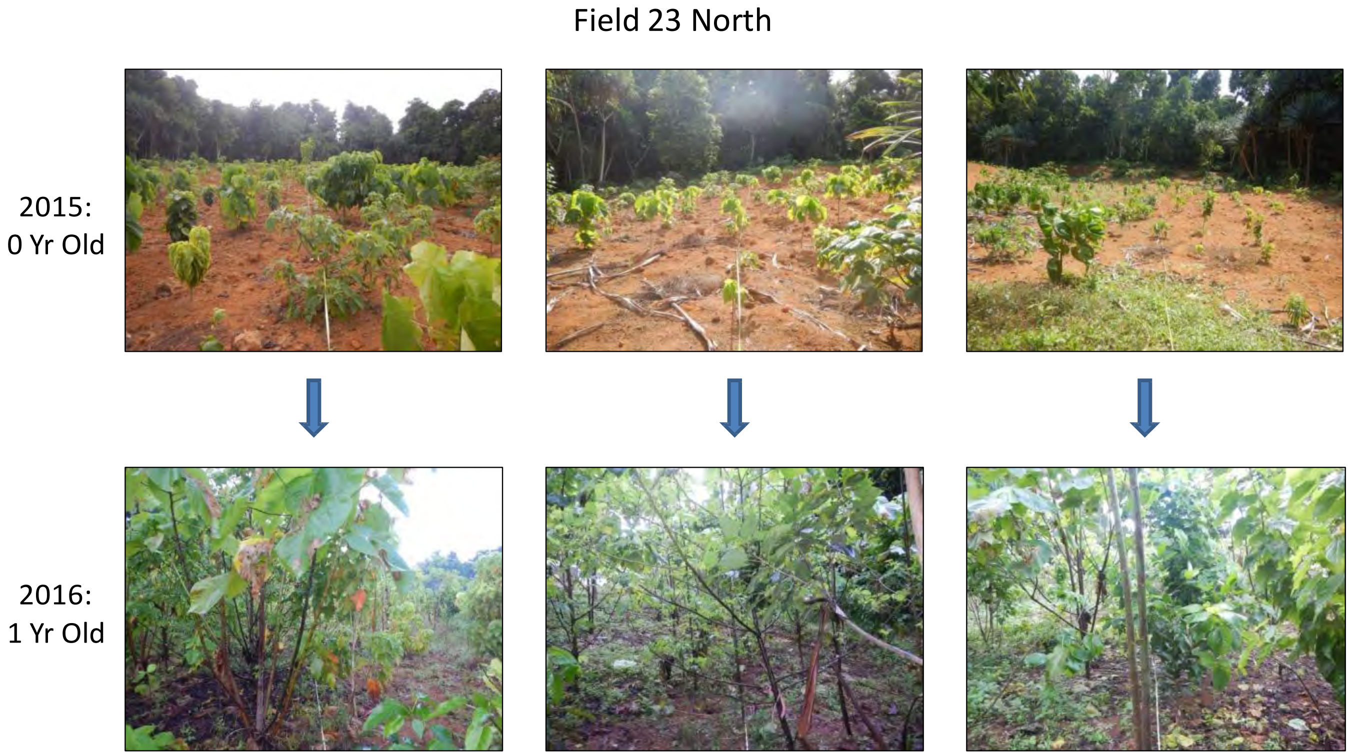

Figure 14: Photographs of monitoring transects at the one-year-old site 23 North

A total of 28 species were found in the four transects across this site, which is high for a field of this age. The species representation composed primarily of pioneer species, however, good representation of secondary 'forest mix' species is present with addition of some recruit species not planted within the CIMFR program. Vegetation diversity measures were encouraging, with Shannon's Diversity Index (H^1=2.82) representing 85% of maximum possible diversity for the given composition (H_{max}=3.33) (see Table 5). The statistical likelihood of two species in the population being the same (Simpson's Index *D*) was 10.5%. Evenness of the sample population was slightly more uniform than the new field- hence slightly less dominance of any particular species (Simpson's Equitability E_d=0.33).

Density of plants was around 3,413 per hectare, which is very good. Natural recruitment was also very good in these transects, with 638 individuals per hectare observed to date. This is likely due to the close proximity of tall, high quality forest completely surrounding the site and the retention of remnant trees within the rehabilitation field. It provides ideal conditions for recruitment such as favourable microclimate, shade around edges, faunal seed dispersal mechanisms, minimal encroachment of weeds and maximum edge contact for seed dispersal from the surrounding forest. No fern cover was detected in these transects and leaf litter cover was 30% (Table 5), both being perfectly acceptable for a one-year-old field.

Average height of planted trees in field 23 North was 2.2m and the upper canopy height of planted trees was 7.1m (Table 5). Approximately 44% of planted trees were above 2 m in height (Figure 15). Average stem-cross-sectional area (measured at 10 cm above ground) was 14 cm^2. This represents excellent growth for a one-year-old field.

Percentage canopy cover was 54% which is also excellent for a 1-year-old field (Figure 13).

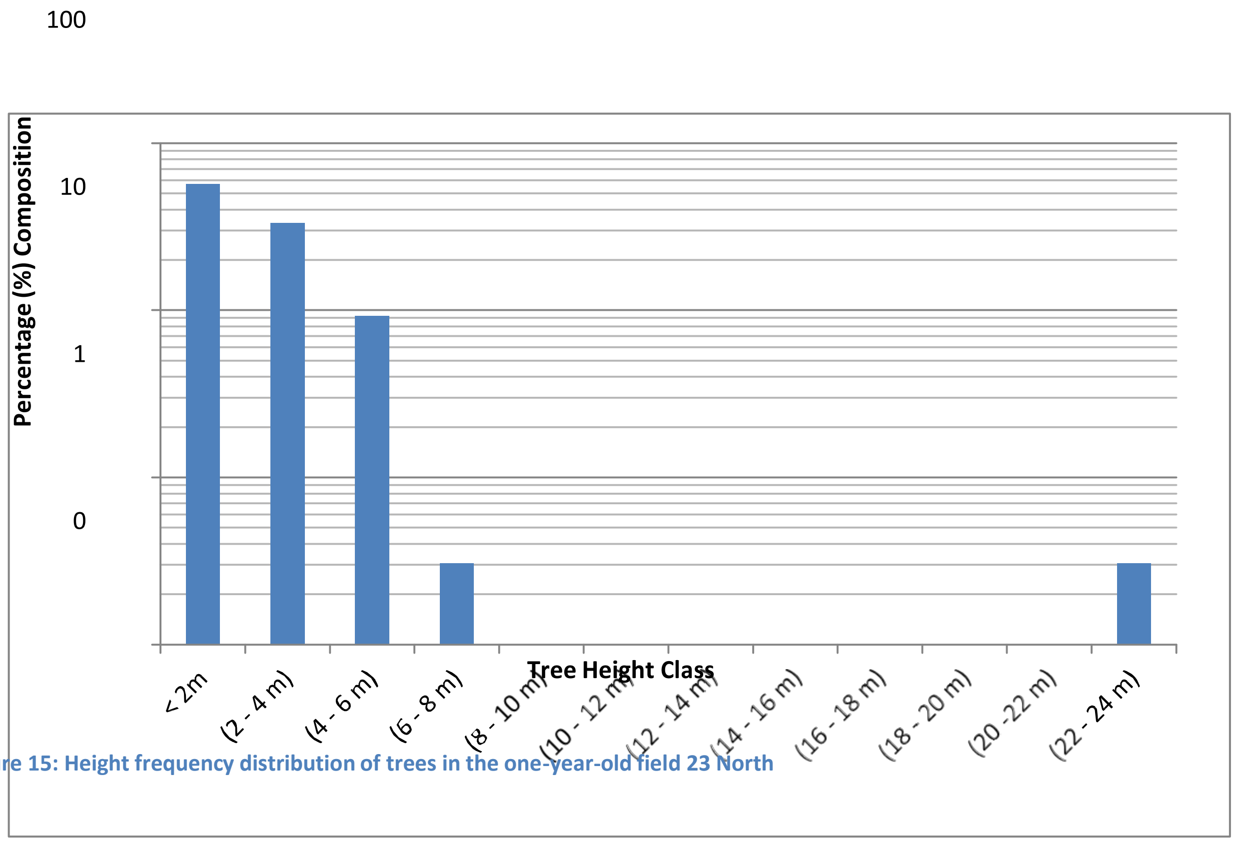

Figure 15: Height frequency distribution of trees in the one-year-old field 23 North

Three-year-old fields

The three-year-old fields 22 Central and 22 Central East are located adjacent to each other and can be accessed from East West Baseline Road approximately 200m west of the intersection with Murray Road. In terms of species diversity indices, numbers show an excellent range of different plants. Species richness was 34, which is excellent for a three-year-old field. A total of 563 individuals were found in the five transects across 22 Central and Central East, and given the high species richness, resulted in a good Shannon Diversity Index (H=2.87 out of H_{max}=3.53) and Shannon/Pielou value (81% - see Table 5). Simpon's D suggests the likelihood of two species being the same equals 10.8%, whilst evenness (E_d) was 0.30 indicating that a few species were more common and some more rare than others.

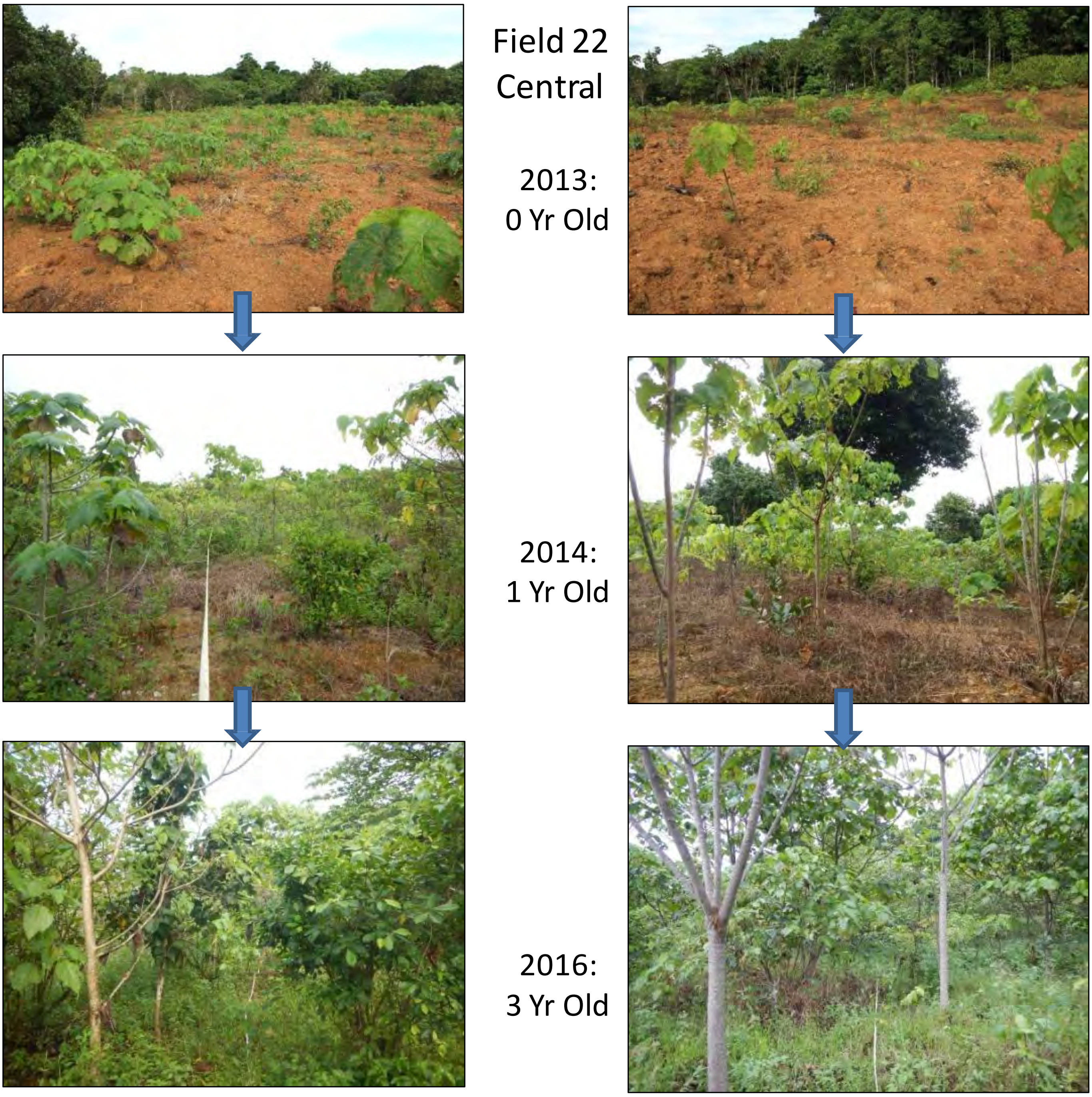

Figure 16: Photographs of monitoring transects at the three-year-old site 22C

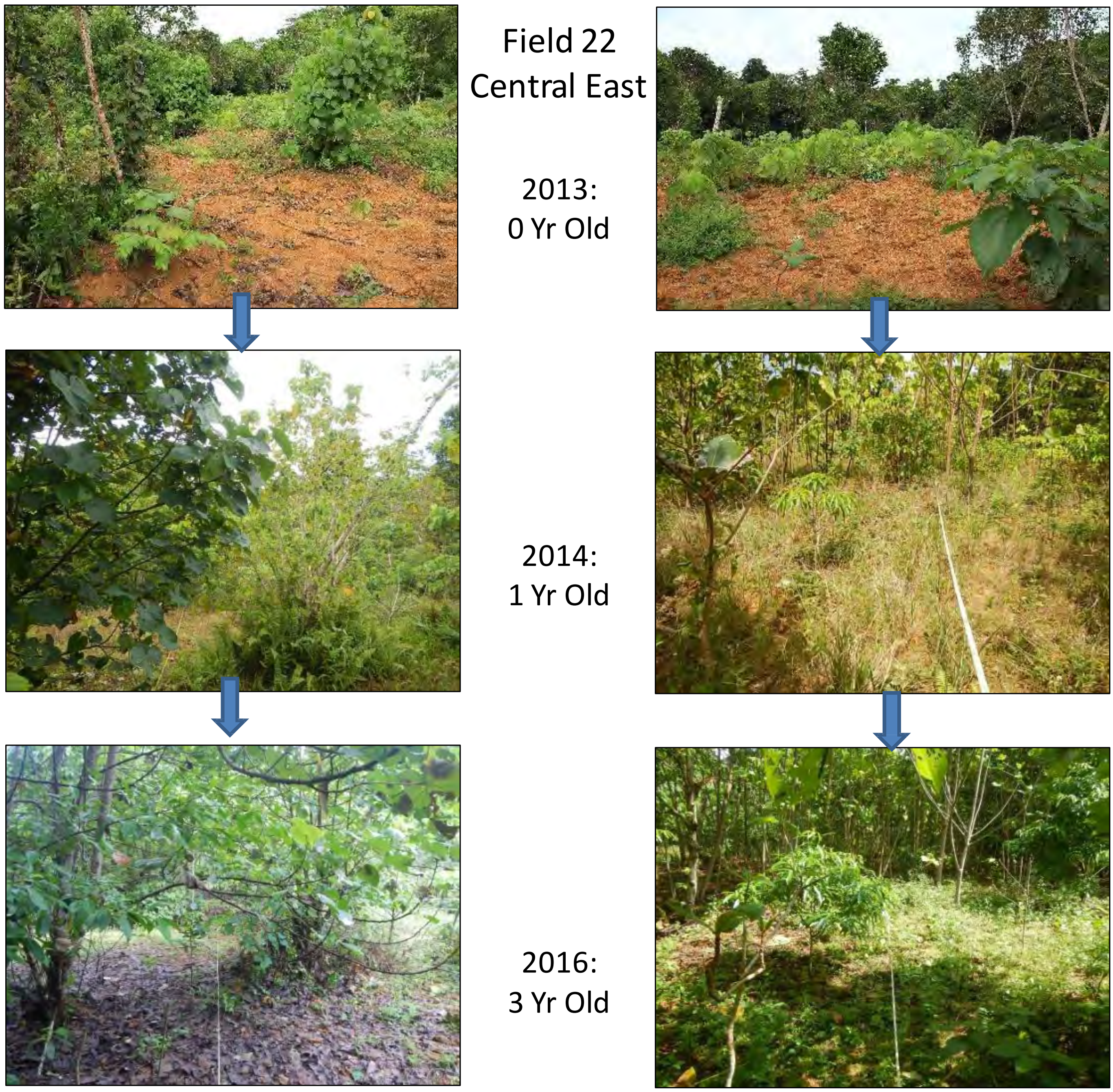

Figure 17: Photographs of monitoring transects at the three year old site 22CE

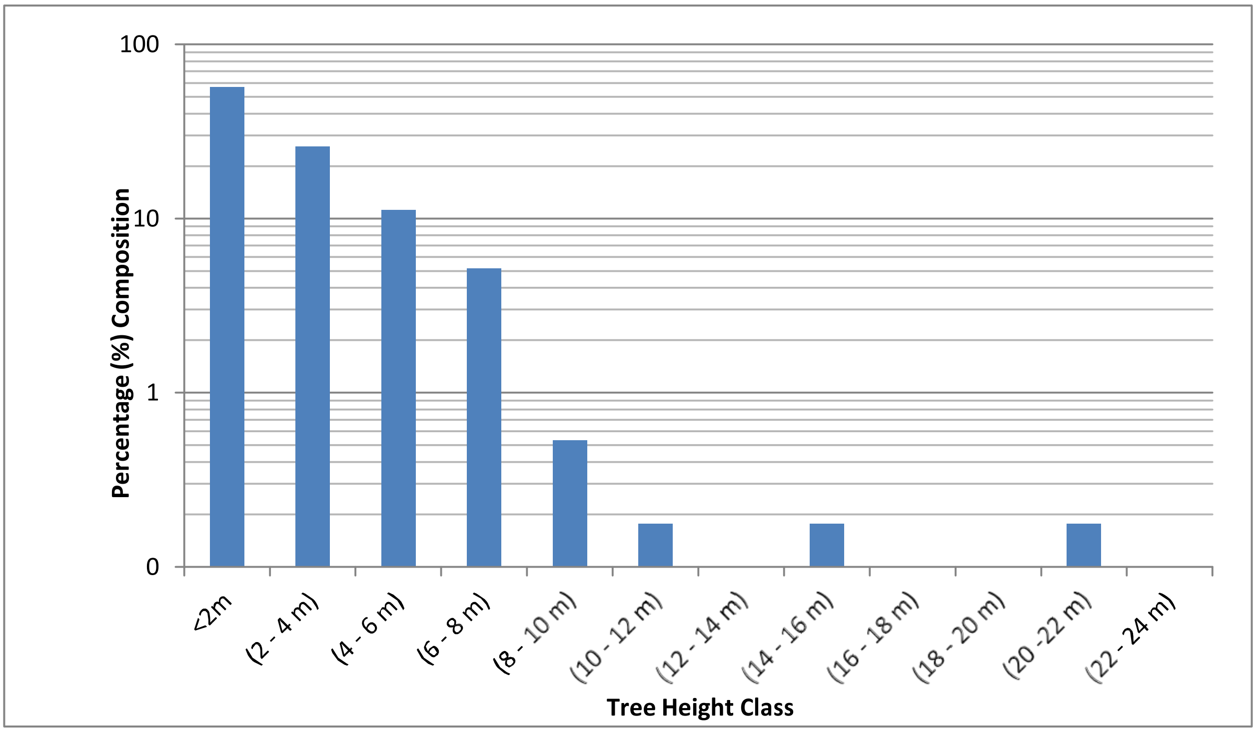

Figure 18: Height frequency distribution of trees in the three-year-old fields 22C and 22CE

Density of planted trees was around 2,800 per hectare, which is in line with expectation for fields of this age due to competition for space, light and allowable losses. The number of recruits was around 1,833 per hectare (Table 5)- a good number for a field of this age. In addition to the fact these fields have good connection to surrounding forest, the purposeful retention of some naturally-recruited Jamaican Cherry (*Muntingia calabura*) trees has also been responsible for bringing in dozens of extra recruits. Whilst not native, the cherry trees do attract flocks of local, endemic frugivorous birds such as the Christmas Island Imperial Pigeon (*Duclula whartoni*) who deposit the seed of native trees below. Species commonly found growing under the cherry trees include *Syzigium nervosum, Dysoxylum guadichaudianum, Ficus macrocarpa, Pittosporum ferrugineum, Pipturis argenteus, Claoxylum indicum, Arenga listeri* and *Tristiropsis actutangula*. Once the new recruits have sufficiently established, the cherry trees are easily thinned or killed (cutting down and stump treatment with herbicide). Natural recruits have a number of advantages over planted trees in that they are likely to have a broader genetic diversity (sourced from hundreds of trees rather than a few dozen) and they are likely to be more stable in the ground during the early stages.

Plants in these three-year old fields have an average height of 2.46 m (Figure 10). The height frequency distribution shows that 57% of plants were less than 2 m tall, 26% were 2-4 m tall, 11% were 4-6 m tall, 5% were 6-8 m tall and a small proportion (existing trees) over 8 m tall (Figure 18). Average stem cross-sectional area was 18 cm^2; again- a good value for fields of this age.

Canopy cover was very good at around 67% and leaf litter cover on the ground was reasonable at 30%, and fern cover was low at less than 13% (Table 5).

Five-year-old field

Field 21 West Roadside was the only five- year-old-field this reporting period consisting of one 50 m transect (Figure 19). Twenty- three species were found across this field. Consistent with other fields already discussed, biodiversity was high (H=2.37 out of H_{max}=3.14; and Shannon/Pielou value = 76% - see Table 5). Furthermore, Simpson's D indicates the likelihood of two plants (out of the 154 measured) being the same species equals 17.1%, whilst evenness was 0.25. As noted for similar figures previously, this indicates that some species where slightly more common than others, but there was no strong dominance of any particular one. This pattern is common in the natural forest ecosystem, so this is considered a good community composition.

Average density of planted trees was around 3,300 per hectare. In addition, around 4,400 recruits per hectare were emerging, of which about 18% were greater than 20 cm tall. Such high recruitment rates indicate there will be a great excess of trees to replace those which have been planted and that intense competition will develop over time.

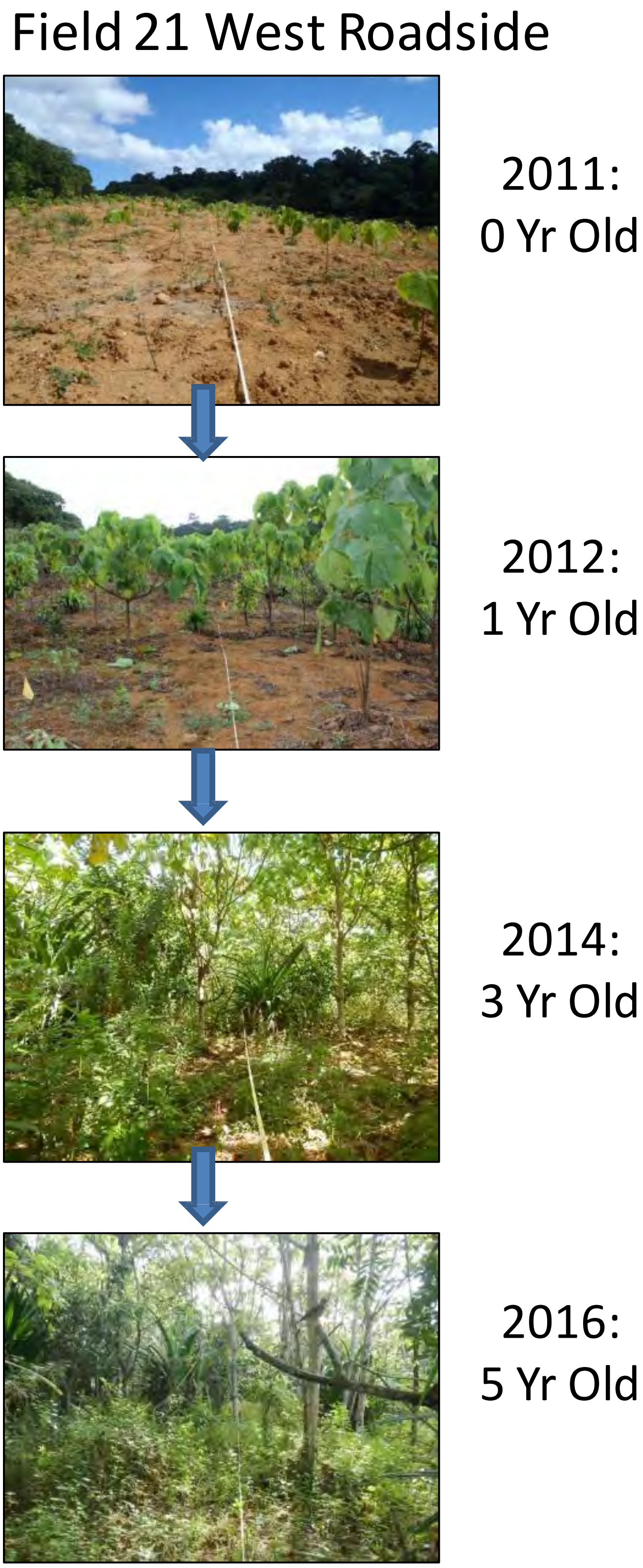

Figure 19: Photographs of monitoring transects at the five-year-old site 21 West Roadside

The height frequency distribution shows that 52% of plants were less than 2 m tall, 20% were 2-4 m tall, 16% were 4-6 m tall, 7% were 6-8 m tall and a 5% were over 8 m tall (Figure 20). Average height of planted trees was 4 m and the tallest trees were up to 10 m (Figure 10). Concomitantly, trunk cross-sectional area averages 57 cm^2, a large jump from the younger fields

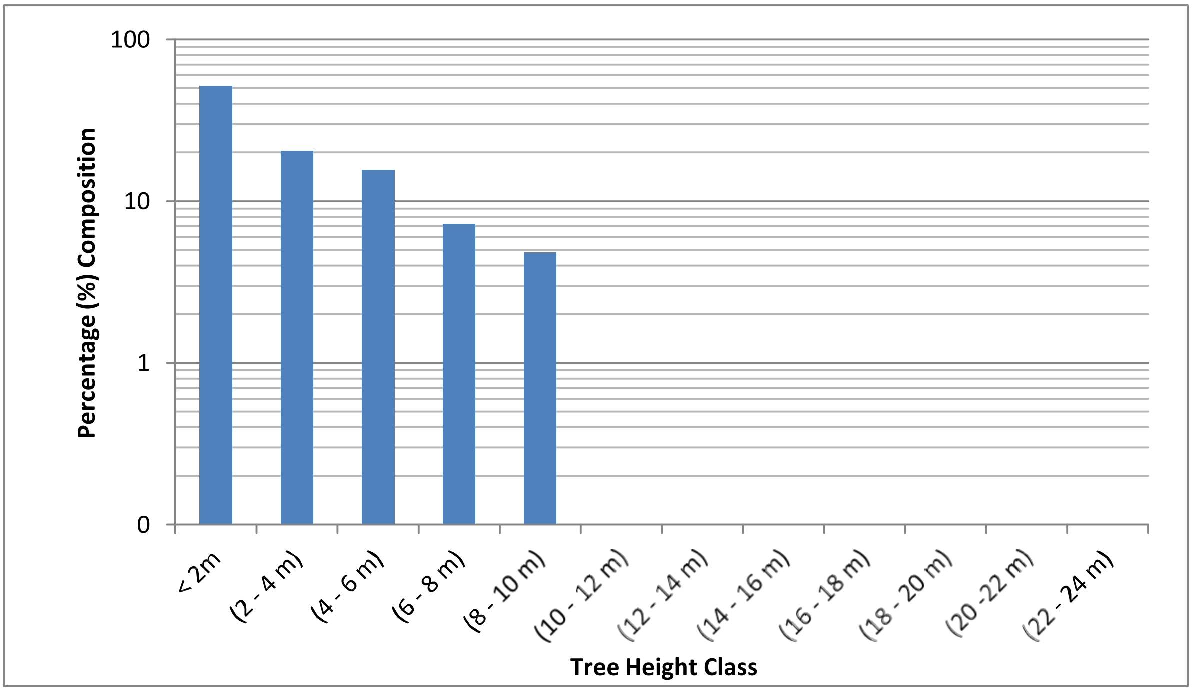

Figure 20: Height frequency distribution of trees in the five-year-old field 21 West Roadside

Canopy cover across these fields was, on average, very good at 86%. Again, this is a big increase from younger fields providing far more shade and leaf litter to the forest floor. Leaf litter projected cover was good at 68%, while no fern cover was detected within the transect.

Ten year-old fields

The ten-year-old fields include 24 East, 23 Upper (Figure 21), and 22 North, 22 North West, 23 Pit East (Figure 22). These fields are all in reasonable close proximity to one another with access off East West Baseline Road between 1.0 and 1.5 km west from Murray Road intersection.

As expected, growth parameters stand out showing large differences compared with younger fields. The tallest planted trees are now 22.3 m (Figure 23). Including the full spectrum of sizes, average height of planted trees was 8 m- the tallest of all fields measured. Average stem cross-sectional area was 222 cm^2 (Table 5). There is good representation across the range of height classes illustrating complexity in canopy structure, and strong recruitment in several cohorts.

Canopy cover was over 78% and approaching that of primary forest which averages around 90%. Given that trees in these fields are significantly larger than those in younger fields, less are needed to create the same level of canopy cover. Competition is also likely to have developed over this time and, as some trees have got larger, other trees have fallen away. Approximately 1,970 planted trees per hectare still persist with approximately 3,950 recruits per hectare, which represents very good recruitment within these fields.

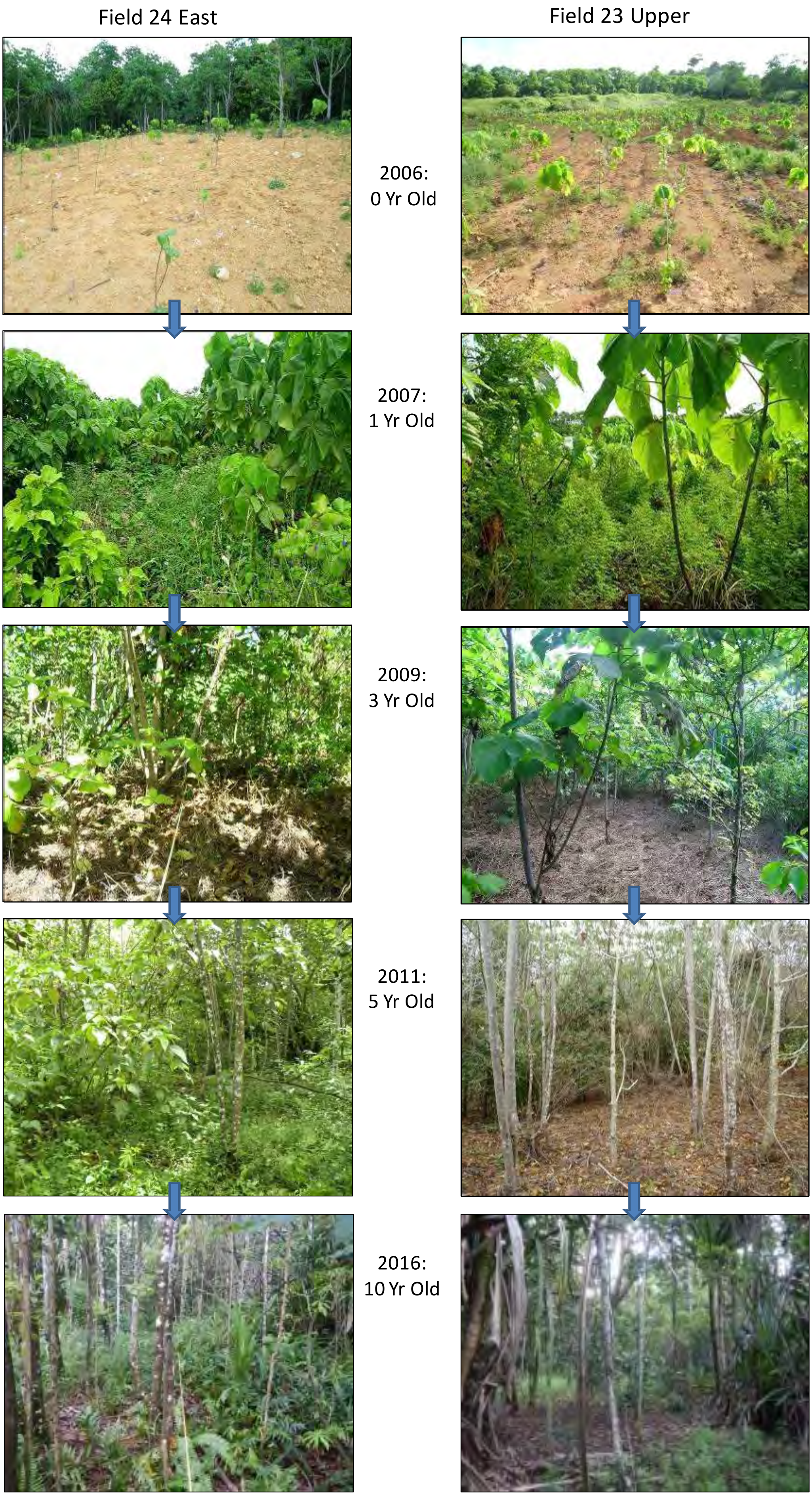

Figure 21: Photographs of monitoring transects at the ten-year-old sites 24E & 23 Upper

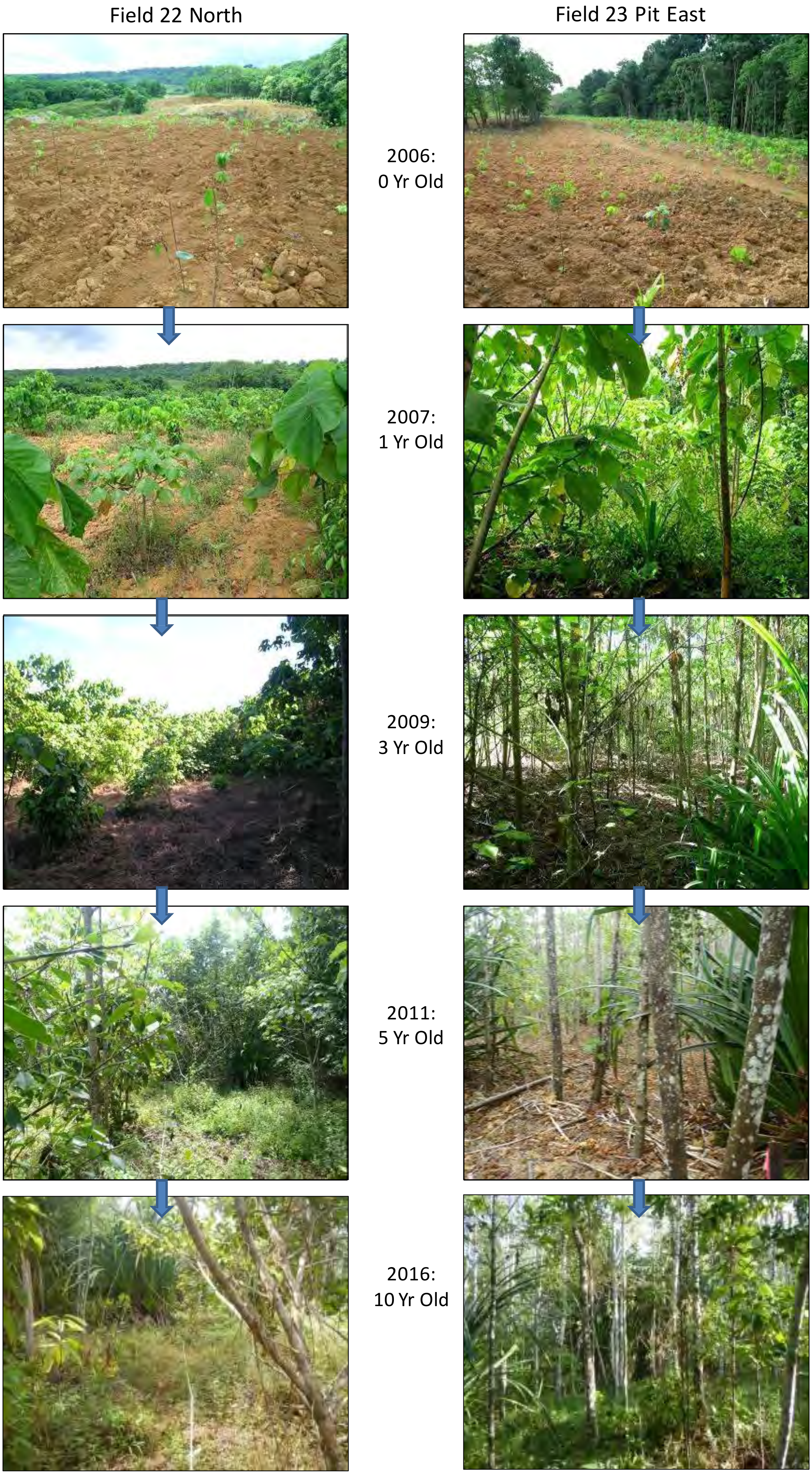

Figure 22: Photographs of monitoring transects in the ten-year-old sites 22 North and 23 Pit-East

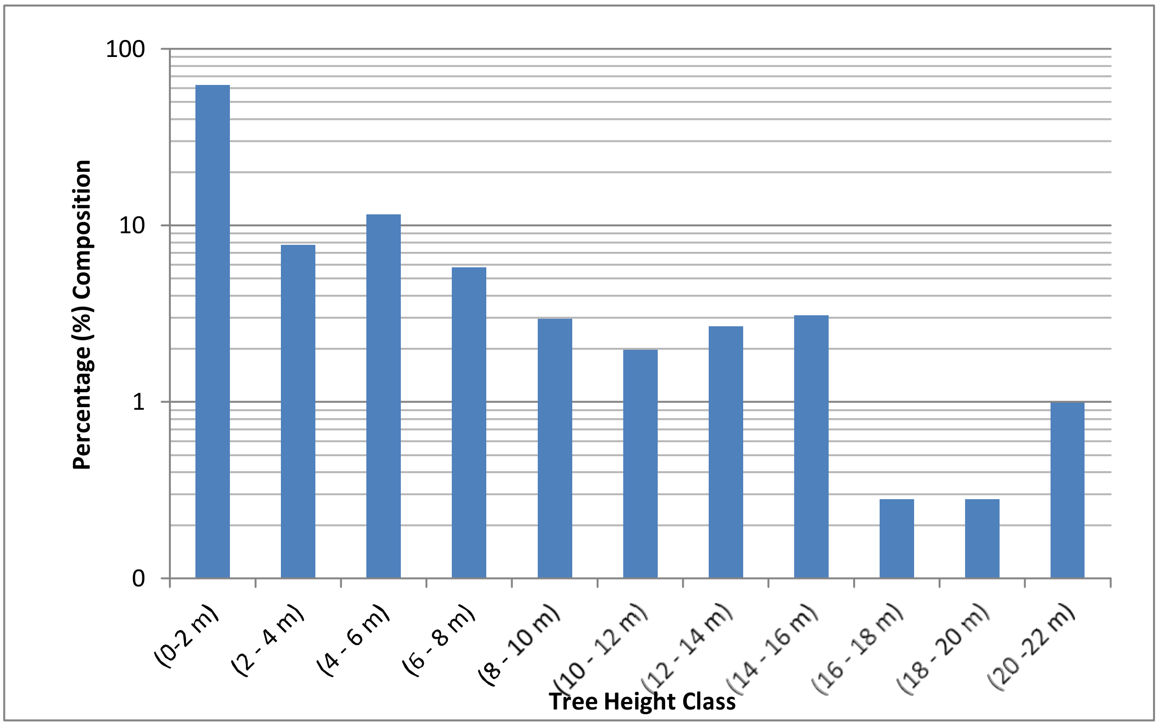

Figure 23: Height frequency distribution of trees in ten-year-old fields (22N, 22NW, 23 Upper, 23 Pit-E, 24E)

A total of 28 species were found, similar in number to the other fields sampled. There has been a large degree of consistency in plant species selection over the last ten years of the CIMFR program so this outcome is very much expected. Importantly, it affirms that the species mix being used is effective and suitable for the fields. In line with other fields, biodiversity indices were also very good. Shannon's *H* was 2.52 out of a possible 3.33 (H_{max}) so the Shannon/Pielou value *J*= 76%, which is very good (Table 5).

Simpson's *D* suggests there is a ~12% chance that any two species found will be the same, and evenness (E_d) was 0.31, meaning there is a good representation of each species with little dominance of any particular one (Table 5). Such diverse composition of the community offers a good degree of resilience to changing conditions- an important trait strongly reflected in primary forest.

Ground cover of leaf litter was around 72% and fern recruits 31% - both acceptable levels (Table 5).

All in all, vegetation assessments on the ten year old fields indicate they are doing well and soon ready for relinquishment of management activities (e.g. weeding, fertilising). Some areas have already been self-sustaining for two years, whilst others have recently had small scale weed control efforts. These fields are also becoming increasingly useful habitat for native flora and fauna, especially red crabs and native bird species.

Fauna Assessments

Invertebrates

Red crab burrows were found in the ten-year-old fields 22N, 23 Upper, 23 Pit East and 24 East, and are modest numbers in some parts of these fields (Figure 24). Taking into account the range in burrow counts across the transects, some areas were up to ~175 per hectare though the average is ~67 per hectare (see Figure 24 and Table 6). However, this is still low compared with primary rainforest on the plateau which displays an average of ~1700 red crab burrows per hectare in non-crazy ant-affected areas.

In the five-year-old field 21 West Roadside, Red crabs were seen foraging in the area after rains and are known to move through it during their annual migrations as there are under-road crab crossing nearby. However, the number of active red crab burrows was very low at ~25 per hectare. There was some evidence burrows may have been attempted, or old burrows abandoned. Other parameters for this field such as canopy cover, tree height, biodiversity and leaf litter cover are far better than satisfactory and would normally be conducive to the colonisation by red crabs. The lack of burrows may be due to factors other than environmental/ resource/microclimate/edaphic conditions of the site. Its location immediately adjacent to East West baseline with its heavy traffic at times (road trains carrying phosphate and vehicles heading out to North West Point) may be unfavourable. It is hoped that as resources at the site improve further, the site may become more attractive to habitation, not just foraging.

In the fields that were three-years old or younger, no burrows were found. However, both red crab and robber crabs were observed walking through these fields and occasionally foraging on leaf litter during overcast or rainy conditions.

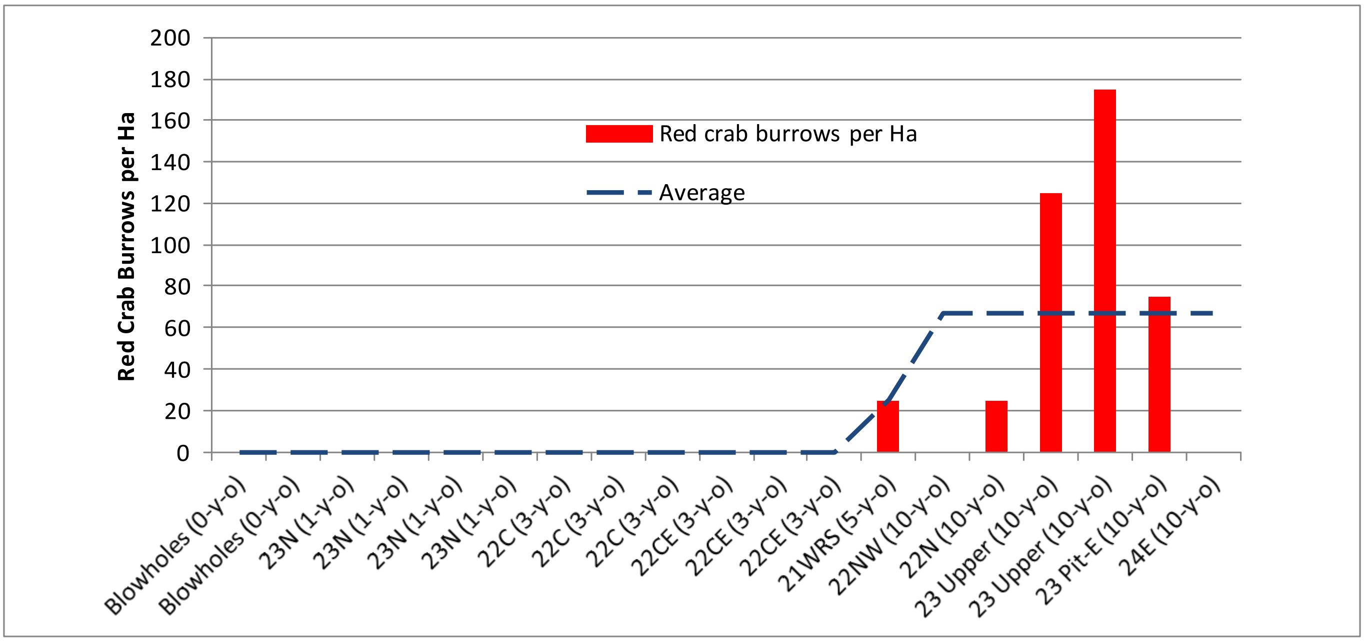

Figure 24: Red crab burrow counts per hectare in fields of different ages

Orb spiders, Millipedes and Giant African Land Snails were in low densities or not detected in fields of all ages. It appears that population numbers of these animals fluctuate from year-to-year and no obvious patterns in relation to field age have been detected so far.

Birds

There are seven native species of forest birds on Christmas Island, with six active during the day and the seventh (the CI Hawk owl) being active only at night.

The Christmas Island Imperial Pigeon (*Ducula whartoni*), and Christmas Island White Eyes (*Zosterops natalis*) displayed a similar usage pattern of rehabilitation fields of different ages (Table 7). Both were common or moderately common in most fields, with the exception of 21 West Roadside (five years-old), perhaps because of the traffic on the main road. The Imperial Pigeon has a largely frugivorous diet, and it feeds on both native species (such as *Pittosporum ferrugineum, Dysoxylum gaudichaudianum, Arenga listeri*, and others), as well as common non-native species (such as *Solanum americanum (glossy night-shade)*, *Muntingia calabura* (Jamaican Cherry) and *Psidium cattleianum* (guava). Coverage with 100% native species is the goal although low levels of non-native cherry trees are accepted in certain places for limited periods of time where natives struggle to grow in order to promote visitation by these birds. Once native recruits are brought in by the birds and the cherry trees are seen to have performed their function, they are removed. The Imperial Pigeon is an important seed dispersal vector across the island and a welcome visitor to rehabilitation fields. White eyes are small, omnivorous passerine birds that consume fruit, nectar and small insects or insect larvae. Herbivorous insects are often common in rehabilitation fields and seem to be an attractive food source. Visitation by both of these species appears to be influenced by proximity to healthy rainforest; the young fields (zero, one, three-years old) were all completely surrounded by intact rainforest, whereas the other fields, especially the 5-year-old field (21 West Roadside) had substantial edges to cleared, disturbed areas.

The Swiftlet, *Collocalia natalis*, was also observed in all fields, although it was more common in the younger fields (Table 7). The species was seen to be most active in the early mornings and late afternoons foraging for flying insects above the canopy. Because the canopy of the ten-year-old fields was quite dense (~78% cover on average), birds could only be spotted where there was a gap in the canopy hence some birds may have been missed in denser areas. Their presence and foraging behaviour indicates that there is a healthy abundance of insects and that rehabilitation fields do offer an ecosystem service to the species.

The Christmas Island Thrush (*Turdus poliosephalus erythropleurus*) was uncommon in the new, zero-year-old field, but moderately common in older fields (Table 7). They were usually seen seeking food items (e.g. insects or fruits).

The Emerald Dove (*Chalcophaps indica natalis*) was usually absent or rare in young fields (zero-, one-, three- and five-year-old fields), but moderately common in ten-year-old fields. It appears they are only interested in older fields once they have good leaf litter levels and more shade.

Goshawks, *Accipiter hiogaster natalis,* were uncommon and spotted only occasionally. It appears there may be an age demographic in usage of fields- adult birds tend to be seen in older fields (e.g. ten-year old fields), whilst juvenile birds were restricted to younger fields. Presumably, this separation is due to habitat quality, with older fields offering more complex habitat and food abundance than younger fields.

Hawk-owls (*Accipiter hiogaster natalis*) were not detected during the standard day-light surveys as they are nocturnal. They call and forage only between dusk and dawn, and are known to spend their days in hollows of large, old trees (*e.g. Syzigium nervosum*) or on branches densely covered with foliage where sunlight is all-but blocked out. Their diet apparently consists of insects (e.g. moths, crickets) and any vertebrate prey items (e.g. small rats, small birds) they are able to catch. Such resources are available in rehabilitation fields so it is likely that they utilise these areas. Additional research would however be needed to quantify the extent these areas are useful habitat.

In general, rehabilitation fields appear to provide a range of resources and habitat to most, if not all forest bird species, and there are mutual benefits to both the fields (e.g. recruitment and insect predation) and the birds as a result of their visitation.

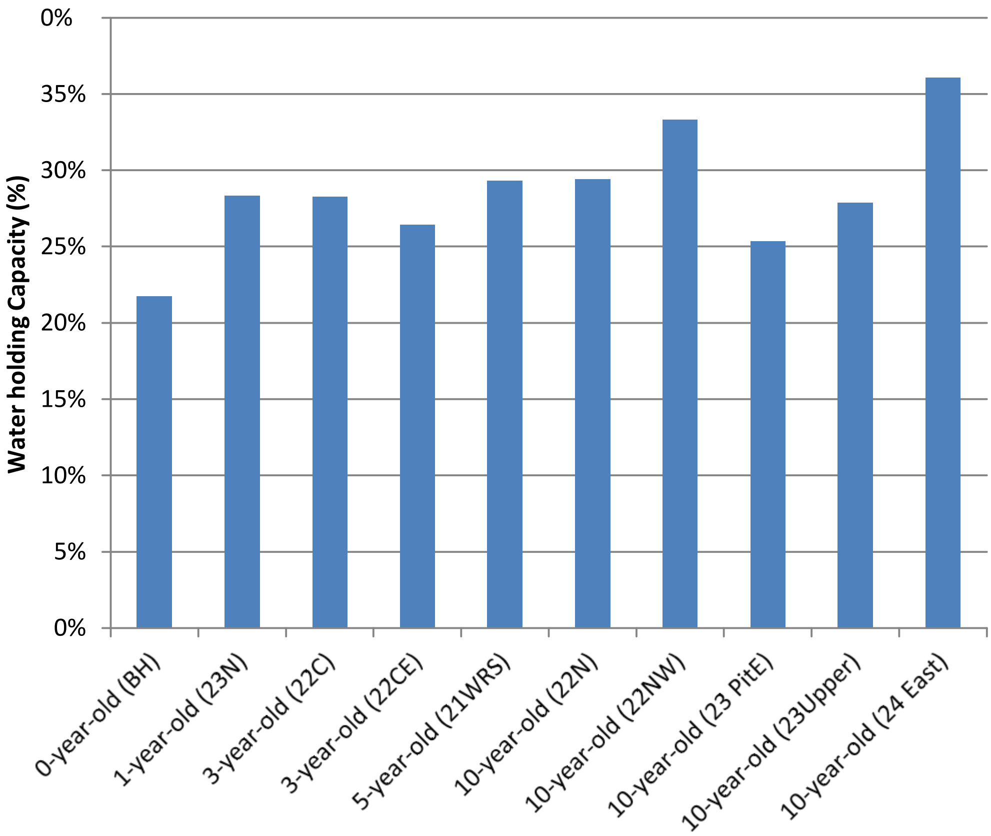

Figure 25: Soil water holding capacity for different fields

Soil Assessments

In general, each rehabilitation field will have had soil sourced from its closest stockpile, and depending on the stockpile size, will usually be fully allocated to one field alone. In some years, more than one field was rehabilitated, though these field areas vary greatly from <1 to >8 hectares, and budgets have fluctuated allowing more area to be rehabilitated in some years, and less in others. In years where more than one field received earthworks and these works were in different areas utilising different stockpiles, it is considered more relevant to examine the soils of these fields separately. As such, the figures below illustrate results from the different sites and will be discussed according to sites, not age. Therefore, the results of different age classes are presented in Table 6 only for general consideration.

Water-holding capacity (WHC) of soils ranged between 22% and 36% across the sites and, as expected, there was no reliable pattern associated with age (Figure 25). WHC for pure sands may be <10%, whilst heavy loams/silts/clays can be >50%. Soils of Christmas Island have a range of particle sizes including fractions of sand, silt, and clay. Dry bulk density of surface soils ranged between 0.81 and 1.34 and there was a descending trend in relation to soil water-holding capacity (Figure 26). This outcome is expected and explains that with increasing bulk density there are less pore spaces between soil particles, and thus less capacity to hold water. Given similar texture of these soils, the greater bulk density is indicative of greater compaction, although the range exhibited here is below the level expected to cause problems for plant root growth (possibly 1.4 g/cm3). Admittedly, the soils collected here were only from the top 50 mm and it is likely that where sub-soil compaction has occurred at deeper layers, bulk densities will be higher.

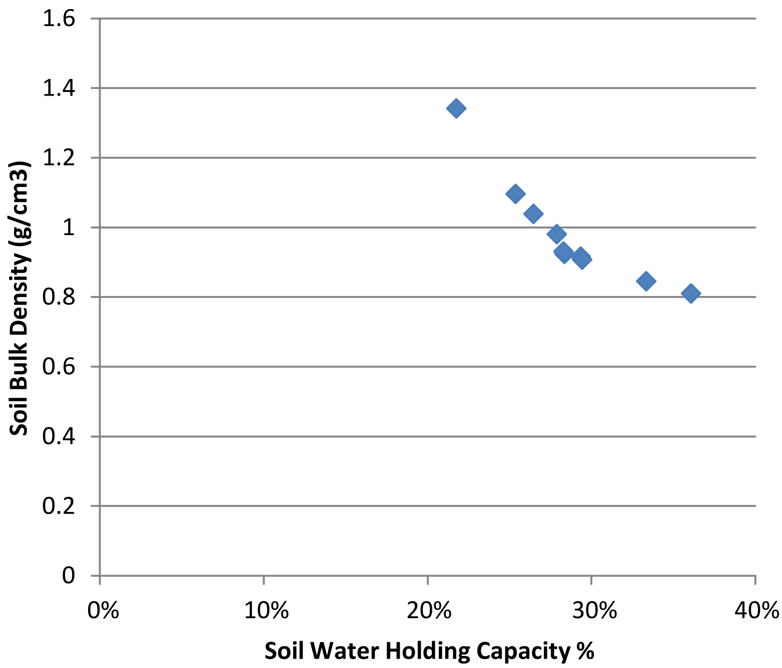

Figure 26: The relationship between soil bulk density and water holding capacity

In terms of soil chemical properties, pH and Electrical Conductivity (EC) were measured. Values for pH ranged between just below neutral 7 (6.37 at 24E) to just above 7.18 (at Blowholes) (Figure 27).

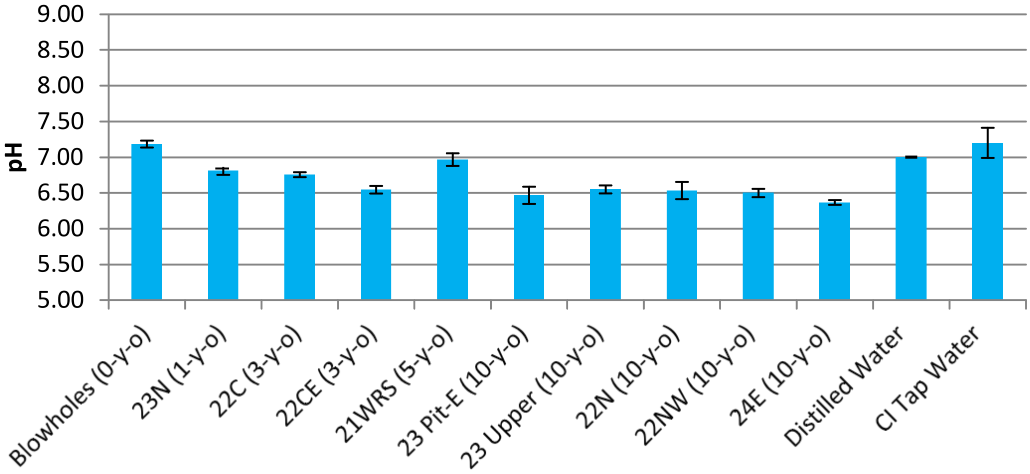

Figure 27: pH of surface soils from various fields

Electrical conductivity (EC) is an overarching measure of dissolved solutes (e.g. various inorganic compounds, salts and other soluble ions such as calcium, sodium, carbonates, chloride, nitrogen compounds etc) in a water sample. High rainfall tends to leach out many solutes from surface soils. All soils tested from rehabilitation fields demonstrated low EC, ranging from 196 (Blowholes) to 71 micro-Siemens per centimetre [µS/cm] (Field 23N) (Figure 28). It should be noted that if fertiliser has been added recently in the patch where soil was collected and if rain has not washed it in yet, the result may be elevated; caution should be exercised with interpretation of such data. Because the Blowholes 107 site was planted only ~4 months prior to soil sampling taking place, and fertilisers were added at the time of planting, the higher levels at this site are likely explained by remnant fertiliser. Interestingly, EC of Christmas Island tap water appears to be relatively high at around 500 µS/cm, yet this is still only moderate when compared with groundwater elsewhere. Many people can taste salt in water at ~1,500 µS/cm. Values around 2,000 µS/cm are considered high and not suitable for agricultural irrigation. Sea water is approximately 50,000 µS/cm, so about 100 times more salty than Christmas Island tap-water.

Soil organic carbon, as determined by furnace combustion, ranged from less than 1% up to 5% from the uppermost 50 mm of soil (Figure 29). These are low to modest levels and there was no pattern associated with field age. It should be noted that soil carbon levels can vary substantially across sites depending on proximity to leaf litter patches, invertebrate/crab activity and micro-topography (run on and run off zones). Another important factor is depth of sampling- these samples were taken from the top 50 mm, and this is the zone where most detritus-based organic carbon is likely to accumulate. Deeper layers typically to have far less organic matter.

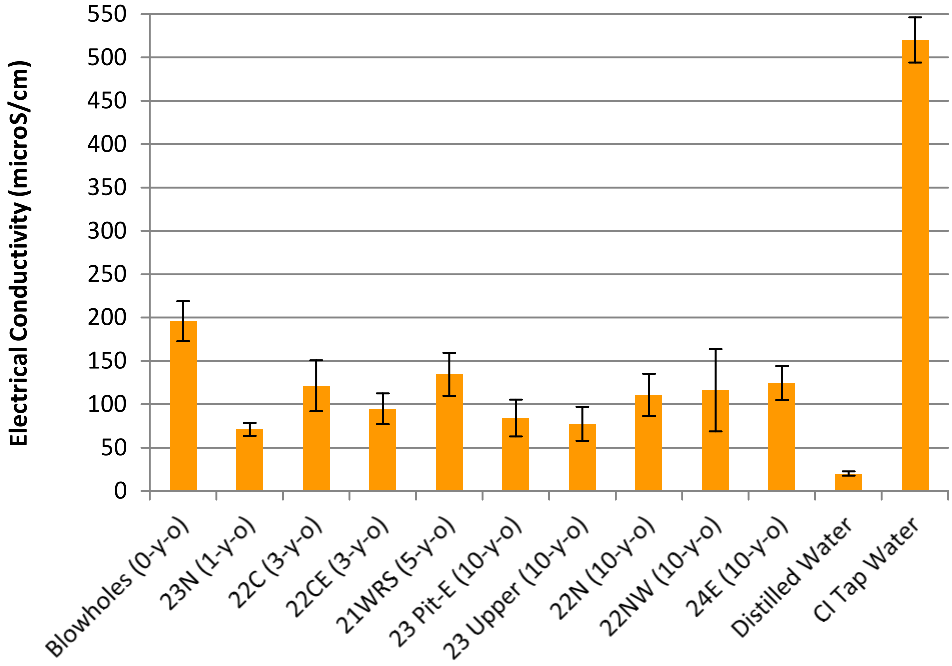

Figure 28: Electrical conductivity (micro-Siemens per cm) of soils from various field

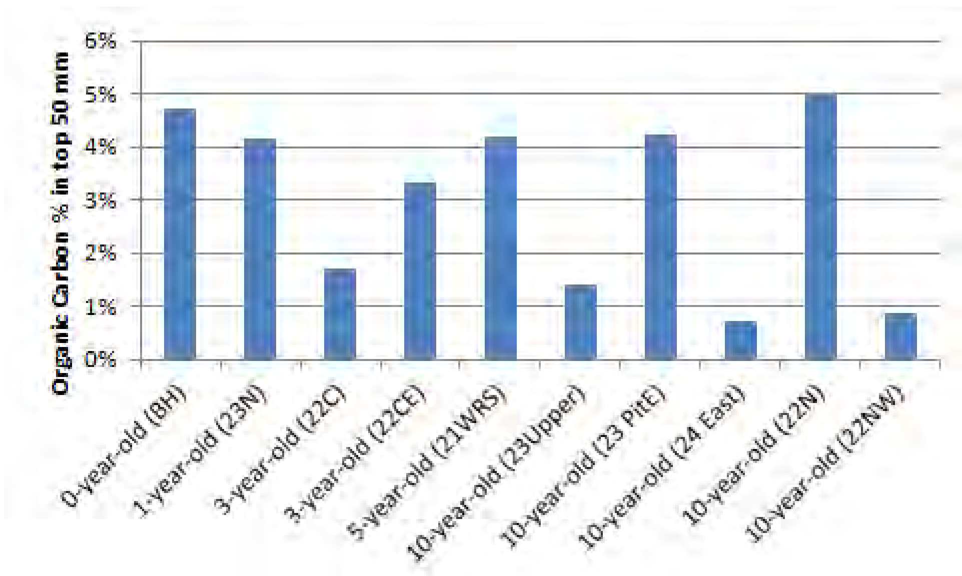

Figure 29: Organic carbon in the top 50 mm soils from various fields

Table 5: Vegetation assessment measures for fields of different ages

Type	Measurement	New / zero-year-old (Blowholes).	One-year-old (23N)	Three-year-old (22C + 22CE)	Five-year-old (21W-RS).	Ten-year-old (22NW, 22N, 23 Upper, 23 Pit-East, 24E)
Diversity measures	Number of individuals measured	164	316	563	154	710
Diversity measures	Count number of species	27	28	34	23	28
Diversity measures	Hmax	3.30	3.33	3.53	3.14	3.33
Diversity measures	Shannons Diversity Index H'	2.79	2.82	2.87	2.37	2.52
Diversity measures	Shannons/Pielou's Value J (H'/Hmax)	85%	85%	81%	76%	76%
Diversity measures	Simpson's Index D (Sum of Pi^2)	9.7%	10.5%	9.7%	17.1%	11.7%
Diversity measures	Simpson's Diversity 1-D	90.3%	89.5%	90.3%	82.9%	88.3%
Diversity measures	Simpsons Reciprocol Index (1/D)	10.36	9.57	10.30	5.84	8.56
Diversity measures	Simpson's Equitability (E d)	0.38	0.33	0.30	0.25	0.31
Trees per hectare	Planted trees per hectare	3,225	3,413	2,800	3,300	1,967
Trees per hectare	Large recruits (> 20 cm) per hectare	425	513	1,400	4,100	3,217
Trees per hectare	All recruits (large and small) per hectare	875	638	1,833	4,400	3,950
Trees per hectare	Existing trees per hectare	0	25	58	0	0
Trees per hectare	Total planted, existing and recruits per hectare	4,100	4,075	4,692	7,700	5,917
Heights	Average height of planted trees only	0.89	2.15	2.46	4.01	7.97
Heights	Max height of planted trees only	2.70	7.10	8.00	10.00	22.30
Heights	Max height of all trees present	2.70	23.00	21.00	10.00	22.30
Heights	Sum heights of planted trees only	115	585	818	0	0
Heights	Sum heights of all tree present	126	662	1,286	454	2,348
Stem area @ 10cm	Mean sum CS-area(cm2) per transect	221	1,133	1,124	3,765	8,691
Stem area @ 10cm	Max CS-area (cm2) for planted trees	36	134	209	256	2,483
Stem area @ 10cm	Average CS-area (cm2) for planted trees	3	14	18	57	222
Health	Tree Health- Good	100%	100%	99%	99%	96%
Health	Tree Health- Fair	0%	0%	0%	0%	1%
Health	Tree Health- Poor	0%	0%	0%	1%	4%
Canopy	Percentage Canopy Cover	17%	54%	67%	86%	78%
Ferns	Percentage Fern Cover	2%	0%	13%	0%	31%
Leaf Litter	Percentage Leaf Litter Cover	21%	30%	30%	68%	72%

Table 6: Measures for invertebrate fauna, soil properties, and ground-layer cover

Site:	New / zero-year-old (Blowholes)	One-year-old (23N)	Three-year-old (22C & 22CE)	Five-year-old (21W-RS)	Ten-year-old (22N, 22NW, 23 Upper, 23 Pit-E, 24E)
Invertebrate fauna measures					
Red crab activity	Field Edges Only	Transit Only	Transit Only	Foraging	Foraging and burrowing
Red crab burrow average density per hectare	0	0	0	~25	~67
Robber crab activity	Field Edges Only	Foraging	Foraging	Foraging	Foraging and burrowing
Orb spider density per hectare	0 (Not detected)	100 (Low)	67 (Low)	50 (Low)	8 (Very Low)
Millipede abundance per square meter	0 (Not detected)	2.1 (Low)	8.1 (Low)	0 (Not detected)	0 (Not detected)
Giant African Land Snail abundance per square m	0 (Not detected)	0 (Not detected)	0 (Not detected)	0.25 (Very Low)	0 (Not detected)
Soil measures:					
Dry Bulk Density (g/cm3)	1.42	1.19	1.20	1.09	1.17
Water holding % (water of oven dry soil)	9.0%	28.0%	27.0%	28.0%	30.0%
Soil pH	7.18	6.81	6.65	6.97	6.49
Soil EC (micro Siemens/cm)	195.67	70.83	107.94	134.33	98.28
Ground cover:					
Projected area cover of ferns	2%	0%	13%	0%	31%
Projected area cover leaf litter	21%	30%	30%	68%	72%

Table 7: Presence and activity of native forest bird species in fields of different ages

Bird	***Species***	**0-year-old**	**1-year-old**	**3-year-old**	**5-year-old**	**10-year-old**
CI White eye	*Zosterops natalis*	Common, foraging	Common, foraging	Common, foraging	Very uncommon	Common, foraging
CI Swiftlet	*Collocalia natalis*	Common, foraging	Common, foraging	Uncommon, transient	Uncommon, transient	Uncommon, transient
CI Thrush	*Turdus poliocephalus erythropleurus*	Uncommon, transient	Moderately common, foraging	Common, foraging	Moderately common, foraging	Moderately common, foraging
CI Imperial Pigeon	*Ducula whartoni*	Common, foraging	Common, foraging	Common, foraging	Very uncommon	Moderately common, foraging
CI Emerald Dove	*Chalcophaps indica natalis*	Uncommon, transient	Uncommon, transient	Uncommon, transient	Uncommon, transient	Moderately common, foraging
CI Goshawk	*Accipiter hiogaster natalis*	Very uncommon	Very uncommon	Uncommon, transient	Very uncommon	Uncommon, transient

4. Schedule of Works: 1 July 2015-30 June 2016

A Schedule of Works for the 2016-17 financial year was proposed to DIRD in May 2016, as required under the CIMFR MoU 2012-2020. The plan for new earthworks and tree planting is outlined below.

4.1 Tree propagation, planting and earthworks 2016-17

New earthworks and open-field plantings are proposed for approximately 2.6 hectares within ex-mining lease 116 South (Figure 1). Taking into account conservation values (fauna and flora), and feasibility parameters in line with the 2012-2020 CIMFR Plan and thesis by Walker (2012), cost-benefit analysis determined this site is a high priority for rehabilitation. The area is considered of high conservation value because the surrounding forest is prime territory for the Abbott's booby, with several nesting trees identified to the east, south and west. In addition, it is high quality habitat region for land crabs and forest birds. Utilising the GIS decision model created by Walker (2012) in her thesis "Prioritising mine sites for rehabilitation on Christmas Island: an index modelling approach", this site ranked as the most important and beneficial to rehabilitate. This site is located approximately 300 m south of East-West Baseline down a track, the entrance of which is 1.1 km west of the main intersection with Murray Road (Figure 30). It is ~240 m above sea level and surrounded by intact forest on three sides- current mining lease exists on the northern boundary.

Figure 30: General location of ex mining lease 116 South where approximately 2.6 hectares of earthworks and new plantings are proposed for the 2016-17 financial year

The ~2.6 hectares we intend to rehabilitate is part of a 7.98 hectare block relinquished by PRL in September 2014. Of the whole block, approximately 60% is limestone pinnacle and fern, with some areas deeply incised or with steep depressions greater than 5 m deep. Only a limited amount of the pinnacle area will be possible to rehabilitate as there is not enough soil in the vicinity to cover it, and earthmoving equipment will not be able to access deep pinnacles or depressions. A small, old stockpile (22D= ~5 kT) between 50 and 150 m east of the field – inside National Park - was assessed as a potential source of soil for use in rehabilitation. As per section 4.1.4 of the Christmas Island National Park Management Plan 2014-2024, the DNP may take actions to remove old stockpiles inside the park "for rehabilitation purposes". The Western edge of the stockpile adjacent to the mine field is considered of 'low' habitat quality as it is characterised by swordfern and numerous weeds (e.g. *Leucaena leucocephala*). This vegetation will be removed, some soil recovered, and then rehabilitated with native species. However, the majority of the stockpile, the centre top and eastern side, is characterised by excellent regrowth, a diversity of native trees exceeding 15 m tall and abundant crab burrows - likely due to the connection to primary forest on the southern boundary. The habitat quality of this part of the stockpile is considered 'high' so will be left intact. Our assessments are in line with principles used by the West Australian Department of Environment and Regulation (DER) who assess clearing permit applications on Vacant Crown Land. The CIMFR program removes soil from stockpiles only when necessary and there is a net benefit to the conservation values of the area.

With limited soil available in situ and from soil mounds, it is likely that average depth will be around 0.5-0.9 m across much of the site after distribution has occurred. This is considerably less than the 1.5 m normally required for establishment of tall plateau rainforest species, so a different set of native species that can handle the shallow, rocky conditions will be employed. Those that do well on the upper and lower terraces will be strongly represented; e.g. *Calophyllum inophyllum, Pandanus elatus, Hibiscus tiliaceus,* and *Cordia subcordata* to name a few. As a consequence of less soil depth, ultimate tree height will also be reduced. Canopy cover and species diversity should however be similar, thus offering ecosystem services such as foraging habitat for land crabs and forest birds.

The 7.98 hectare site is Vacant Crown Land, and therefore a clearing permit application was lodged with DER 2nd May 2016. A clearing permit was ultimately approved CPS7060/1 on the 23rd June 2016. Earthmoving machinery will be required to remove weeds, swordfern and degraded vegetation across the site, then distribute soil where possible. It has been estimated that earthworks will cost approximately $150,000 at this site, although it is difficult to provide a precise figure due to not knowing the exact volume of soil within the site, severity of gullies/pinnacles requiring fill and extent of rockbreaking required for pinnacles etc. To revegetate the area, approximately 9,800 primary 'pioneer' plants will need to be propagated and planted (at a planting spacing density of 1.5 m x 1.5 m). About 20 native tree species will be included in the pioneer mix; these are generally fast-growing, sun-loving, hardy species tolerant of the exposed conditions in new fields.

In addition, a further 6,000 trees are proposed for infill and secondary plantings. Secondary plantings will occur over approximately 15 hectares of already established fields (at least two-years old). These are generally slower growing, better suited to shaded conditions under the canopy in their juvenile state, but ultimately taller and longer lived species. Included in the secondary species are the three forest giants of Christmas Island: *Hernandia ovigera*, *Planchonella nitida* and *Syzigium nervosum*. These three species can grow close to, or even greater than 50 m tall and are the main nesting habitat trees for the Abbott's Booby. Key target areas are 22 Central, 22 Central East, and 22 West.

5. Financial Expenditure 2015-16 Financial Year

During the 2015-16 financial year the CIMFR program expended $1.3 million (Table 8). Employee expenses constituted $817 k and covered all wages, superannuation, allowances for all staff employed (between 10 and 11 FTE). Supplies and operating expenses (e.g. fertiliser, herbicide, water bills, power bills, PPE, consumables, equipment, vehicle running and maintenance etc.) cost $286 k. Depreciation for infrastructure and vehicles was $116,561. Earthworks cost ~$84 k at Blowholes site 107; considerably cheaper than anticipated because of the amount of *in situ* soil on the site. In the absence of an intensive drilling program, and the large degree of heterogeneity in residual soil depth at post-mining sites, it is difficult to determine the volume of soil needed from stockpiles and the cost of rehabilitation earthworks until pilot holes are dug by an excavator and mapped at the commencement of the earthworks season.

Significant savings also resulted from improved water-use-efficiency at the CIMFR Nursery where an improved watering regime and new reticulation system saved over $18,000 in its first twelve months.

The original budget request was $1.45 m, so the savings made possible this year can be retained in the "Christmas Island Phosphate Mining Rehabilitation Special Account"

Table 8: Financial expenditure 2015-16

Expenditure 2015-16	$ Amount
Employee expenses	816,903.73
Earthworks	84,029.00
Supplies and operating expenses	286,364.13
Depreciation	116,561.78
Total	1,303,858.64

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Appendix 1

Biophysical monitoring methods

Depending on the size of the field, usually between two and four transects of 50 m long were sampled at each site. These transects were established in the year each site was planted and have been used as ongoing monitoring plots. A brief description of each sampling method is as follows:

A.1.1 Diversity indices

A flora survey was conducted along the 50 m length of each transect. The abundance and species of trees encountered within 2 m either side of the measuring tape was recorded. Diversity indices were calculated including:

- Shannon's Diversity Index (*H*). This is a mathematical measure of species diversity in a community and accounts for both abundance and evenness, as per the formulae:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

where *H* is Shannon's Diversity Index, *S* is the total number of species found in the transect (species richness), p_i is the proportion of the '*i*'th species out of the total *S,* and *ln* is the natural logarithm.

- Shannon's equitability value (E_H) ranges between 0 and 1 and is calculated by dividing *H* by H_{max} where H_{max} is the natural logarithm of *S*, as per the formulae:

$$E_H = H / H_{max} = H / \ln S$$

- Simpson's Evenness index (E_D) describes the relative representation of species in a given sample. It requires calculation of Simpson's diversity index (*D*) as per the formulae:

$$D = \frac{1}{\sum_{i=1}^{S} p_i^2} \longrightarrow E_D = \frac{D}{D_{max}} = \frac{1}{\sum_{i=1}^{S} P_i^2} \times \frac{1}{S}$$

where parameters are the same as for Shannon's Diversity Index, and D_{max} equals *S*. Evenness ranges between 0 and 1, where 1 represents an equal representation of all species in a sample.

A.1.2 Vegetation measurements

Tree height was measured using a height staff or clinometer for all trees encountered within 2 m either side of the measuring tape (using a 2 m length of PVC 40 mm pipe) along the full length of the 50 m transect. This measure took into account all strata of the vegetation in the transect, including tall canopy, mid-layer and small trees. General canopy height represents the uppermost canopy layer surrounding the transect. Recruits were recorded along the way- those which were considered well established and greater than 20cm tall were included in the diversity indices, those less than 20 cm tall were not.

Canopy % cover was measured using digital image analysis of hemispherical photographs looking vertically up into the canopy from a camera mounted on a tripod 30 cm above ground level. Image analysis was done using the software package "Gap Light Analyzer" Version 2.0 (Simon Fraser University, British Columbia, Canada and

Institute of Ecosystem Studies, New York USA). See Figure A1.1 for examples of canopy threshold images. Photographs were taken early in the morning under uniform sky conditions and before the sun was high enough to interfere with images.

Table A1: Comparison of example species diversity measures

Diversity Indices	Column 1 Even Community	Column 2 Biased Community	Column 3 Example Plantation	Column 4 Monoculture
Individuals	100	100	100	100
Number of Species (k)	20	20	2	1
Distribution	20 species of 5 individuals each	19 species of 1 individual, then 1 species of 81 individuals	1 species of 99 individuals, and 1 species of 1 individual	1 species of 100 individuals
Maximum possible diversity (H_{max})	2.996	2.996	0.693	0.000
Shannon's Diversity Index (H^1)	2.996	1.046	0.056	0.000
Proportion Shannon of Maximum H^1/H_{max}	100%	35%	8%	0%
Simpson's Equitability Evenness	1	0.076	0.510	1

Stem diameters were taken 10 cm above the ground and 100 cm above ground (once trees were tall enough) using a standard diameter tape.

Projected cover of ferns was determined using a 2 m x 2 m quadrat ($4m^2$) in the first and last two metres of the transect (at 0 m and 48 m) on opposing sides of the measuring tape. Ferns typically found include native species such as *Nephrolepis biserrata, Davallia solida, Microlepia speluncae* and *Microsorum scolopendria*. Low (10%) to moderate levels (<30%) are considered healthy and acceptable, although high levels (>50%) can become problematic by hindering recruitment and require control.

A.1.3 Fauna species measures

Fauna species measures were recorded along the same 50 m transects as vegetation measures. Golden orb spider counts were done first as soon as the measuring tape was rolled out so as to not disturb webs upon traversing the transect. Assessments included the space and branches up to ~4 m above ground (limit of investigators reach with 2 m PVC pipe length).

Bird observations were done over a 20 minute period at each transect and included only land-based forest birds (not seabirds). Below the canopy, birds were counted only within a 20 m radius of the observer, above

Crab burrows were counted with 4m either side of the tape measure along the full 50m length of the transect. Each transect was considered one replicate within that field. Because of the variable number of transects per field, numbers were averaged across transects and extrapolated to determine density per hectare. Sightings of red crabs and robber crabs were also noted, though these were strongly influenced by the time of day and presence or absence of recent rain.

the canopy, birds (e.g. raptors) were counted to approximately 50 m out, or as far as canopy openings and visibility would permit.

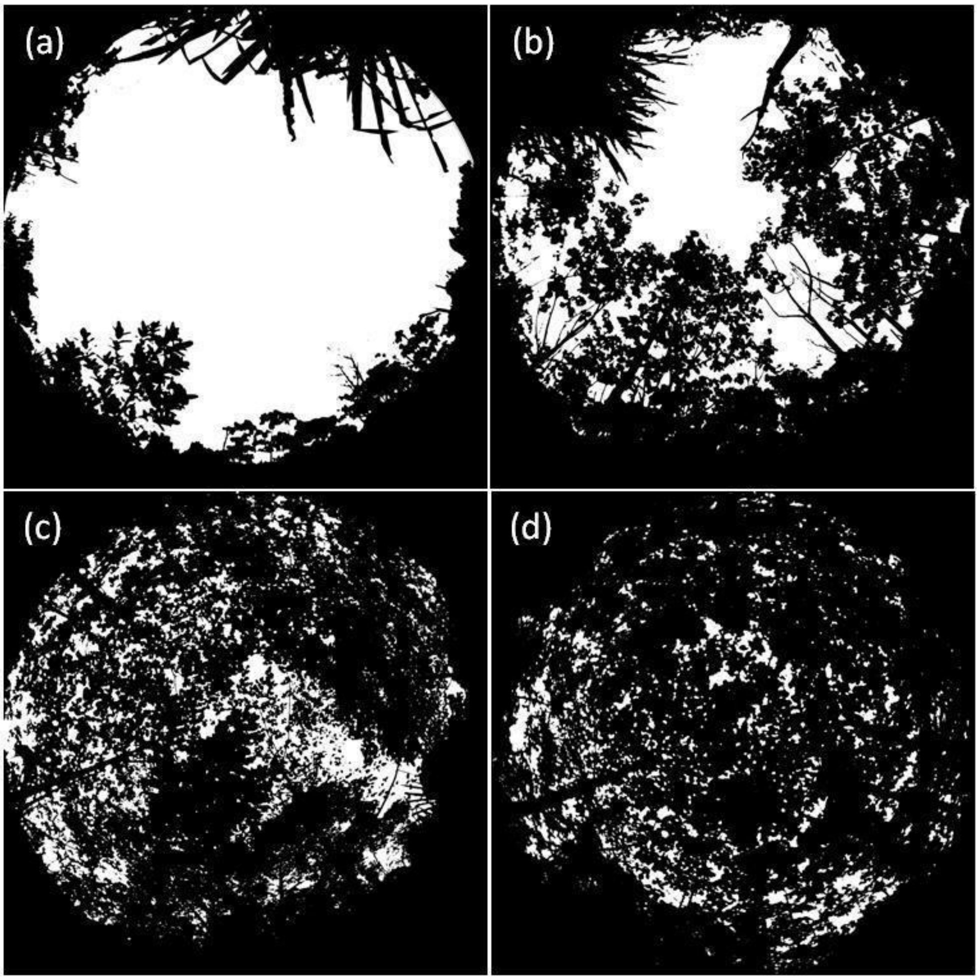

Figure A1.1: Examples of hemispherical canopy photographs following image analysis. Canopy cover for (a) is 22%, (b) is 60%, (c) is 81% and (d) is 88%.

Giant African land snails (including dead shells) were surveyed in the same 2 m x 2 m quadrat as Ferns at the start and end of the transect. Millipedes were assessed in 1 m and 1 m quadrats also at these points.

A.1.4 Soil parameters

Three soil samples of were taken at each transect. Samples (50 mm diameter x 50 mm deep) were collected at 10 m, 20 m, 30 m along the transect. Water Holding Capacity was done on core samples (as per methods described by Hunt and Gilkes 1992). Bulk soil was sieved to remove coarse particles/rocks for use in the measurement of pH, Electrical Conductivity (EC) and organic carbon content. Soil pH was measured on a 1:5 extract of soil and water following the method of (Rayment and Higginson 1992). The pH probe was regularly calibrated to pHs 4.0, 7.0 and 10.0. Electrical conductivity (EC) was measured on a 1:5 extract of soil and deionised water using a probe calibrated to a buffer of 14.13 µS cm^{-1} (Rayment and Higginson 1992).

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Annual Report for the Christmas Island Minesite to Forest Rehabilitation (CIMFR) Program

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July 2014 - June 2015

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1. Executive Summary

The Christmas Island Minesite to Forest Rehabilitation (CIMFR) program operates under a Memorandum of Understanding (MoU) between the Department of Infrastructure and Regional Development (DIRD) and the Director of National Parks (DNP/Parks Australia). The CIMFR programs purpose is to conduct ecological restoration on old, relinquished phosphate minefields adjacent to forest areas of high conservation value. The program is funded by a conservation levy paid by Christmas Island Phosphates (CIP) to the Australian Government as a condition of its mining lease. Under the 2012-2020 MoU, DIRD engages Parks Australia to conduct forest rehabilitation works. Works are carried out in accordance with the CIMFR Program 2012-2020 Plan; the Christmas Island National Park Management Plan 2014-2024; threatened species recovery plans (prepared in accordance with the *Environment Protection and Biodiversity Conservation Act 1999*); and other relevant guiding documents and research reports produced between 1981 and 2014.

During the period covered by this annual report (1 July 2014 to 30 June 2015) the CIMFR program carried out earthworks and new plantings over an area of 7 hectares. Infill and secondary plantings were also conducted across 8 hectares of already established fields. These follow up (infill and secondary) plantings are required for successional improvement and incorporation of a number of slower-growing, but longer-lived species which are better suited to partly shaded conditions when young. A total of 23,100 trees were planted, of which 20,800 were planted in the new bare field 23 North (previously known as ML 115). This field was entirely surrounded by high-quality forest on all sides in the middle of the plateau, so offered ideal conditions for establishment. As such, it provided an opportunity to use a wide selection of species (30 in total) including both primary 'pioneer' (81%) and secondary 'forest-mix' species (19%). The latter were largely used around edges with good contact to high-quality forest. A further 2,300 secondary 'forest mix' plants were planted in established fields including 21W, 21E and 22 Central.

Field maintenance, including physical and chemical control of weeds, fertiliser additions and track management were ongoing. Throughout 2014-15, field maintenance was conducted over 125 hectares, most of which has been planted under the CIMFR program since it began 2004. During this time, more than 275,000 native trees have been planted across Christmas Island, with 2015 being the tenth year of the CIMFR program. Biophysical monitoring of fields up to ten-years-old indicated that most fields were performing well.

In the 2014-15 financial year, the CIMFR program expended $1.72 million, which covered all costs associated with the program (e.g. up to 12 local staff, earthworks, nursery operation and production, infrastructure and vehicle depreciation and running costs, rates, and supplies such as herbicide and fertiliser). In accordance with the MoU, a schedule of works was submitted to DIRD in March 2015 outlining the plan and budget, with projected cost estimated at $1.45 million for next year (2015-16). Advanced notice of funds is essential to ensure there is enough lead time to grow the required number of plants to cover the area of new, open fields. It takes 12-24 months from the time seed is collected and germinated to the time when saplings have grown sufficiently to be planted. Early indication of funding for future years greatly improves planning effectiveness, efficiencies in costs and will maximise the conservation outcomes of the CIMFR program.

2. Introduction and background

Since the 1890s, phosphate mining has been a major part of Christmas Island's history. Approximately 3300 hectares of forest has been cleared on Christmas Island for phosphate mining and associated infrastructure. The majority of mine fields are located on the plateau >150m above sea level. Tall, evergreen rainforest is the vegetation community and ecosystem most severely impacted by this clearing. Due to a range of threats, particularly introduced species and habitat loss and decline, populations of several native species have decreased severely, some to the point of extinction (e.g. native mammals such as Maclear's rat and the bulldog rat). Under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) three flora species and fifteen fauna species are listed as threatened (critically endangered, endangered or vulnerable), with ten of these having existing national recovery plans. The EPBC Act obliges the Commonwealth to implement recovery plans to the extent to which they apply to Commonwealth areas. Protection of existing rainforest, as well as rehabilitation of areas with high conservation value potential, are actions stipulated in a number of threatened species recovery plans (e.g. those for Abbott's booby (*Papasula abbotti*), Christmas Island goshawk (*Accipiter hiogaster natalis*) and Christmas Island hawk-owl (*Ninox natalis*).

Approximately 336 hectares of relinquished mine lease have undergone rehabilitation work, achieving a range of vegetation types (e.g. evergreen plateau forest, semi-deciduous terrace forest, deciduous scrub forest) with varying stages of development. Parks Australia and its predecessors (e.g. the Australian National Parks and Wildlife Service - ANPWS) have been conducting rehabilitation works since 1989, with funding provided by the conservation levy paid by Christmas Island Phosphates (CIP). In 2004, the Christmas Island Minesite to Forest Rehabilitation (CIMFR) program began, and is distinguished from earlier programs by its foundation on research conducted by the Centre for Mined Land Rehabilitation at the University of Queensland (2000).

Based on evidence and comparisons of rehabilitation with varying degrees of success, the UQ research advised that the best outcomes are likely achieved when soil depth is at least 1.5 m, regular weed control is conducted and sufficient fertiliser is provided to the establishing plants. These conditions are the minimum requirements if the aim is to establish regrowth rainforest that may eventually attain levels of diversity, density and structure approaching that of the original rainforest community. Providing the right soil depth is fundamental to success, as it must hold enough moisture to support plant survival throughout years when rainfall is less than average, or dry spells that persist longer than normal. Deeper soils permit greater root development than shallow soils, and increase the potential for a broader range of plateau rainforest tree species to inhabit the area.

The aim of the CIMFR program is: *to revegetate abandoned minefields with rainforest tree species, and create biodiverse, resilient, self-sustaining ecosystems that provide or enhance habitat for native flora and fauna, especially land crabs, endemic forest birds and in the long term, the Abbott's Bobby*. Priority areas for rehabilitation are those that provide the greatest benefit to these species, especially sites adjacent to forest areas of high conservation value, as rehabilitation of these sites improves ecosystem connectivity. The CIMFR program is conducted by the Director of National Parks (DNP) in accordance with the CIMFR program (2012-2020) Plan. Funding is provided from a conservation levy paid by CIP to the Department of Infrastructure and Regional

Development (DIRD) and its predecessor departments and then provided to the DNP via a Memorandum of Understanding (MoU). The current MoU (2012-2020) was finalised and signed on 4 October 2012, supporting continuation of the program until 2020.

3. Year in review

3.1 Weather

The calendar year of 2014 received slightly below-average rainfall, 1922 mm compared with the long-term average of 2134 mm (Bureau of Meteorology 2015). The middle of the year was well below average so it was a very dry, dry season (Figure 1). There were average rains in November and December 2014, but the first half of January 2015 was very dry, so the start of the planting season was delayed until good rains arrived at the end of the month. March 2015 was very wet with 617 mm rainfall, more than double the average for that month (294 mm). The following months were significantly below average, and the dry season of 2015 has been very pronounced (Figure 1). The net effect for the first half on 2015 was close to normal rainfall for that period – 1462 mm out of 1514 (the long-term average total for 1 Jan – 30 June).

Daily average temperatures were usually between 22°C and 27 °C in the middle of the year (winter), and between 23 °C and 29 °C at the start of the year (summer). The coldest temperature recorded on Christmas Island during the 12 months covered by this annual report was 20.1 °C; the hottest was 30.6 °C (Bureau of Meteorology 2015).

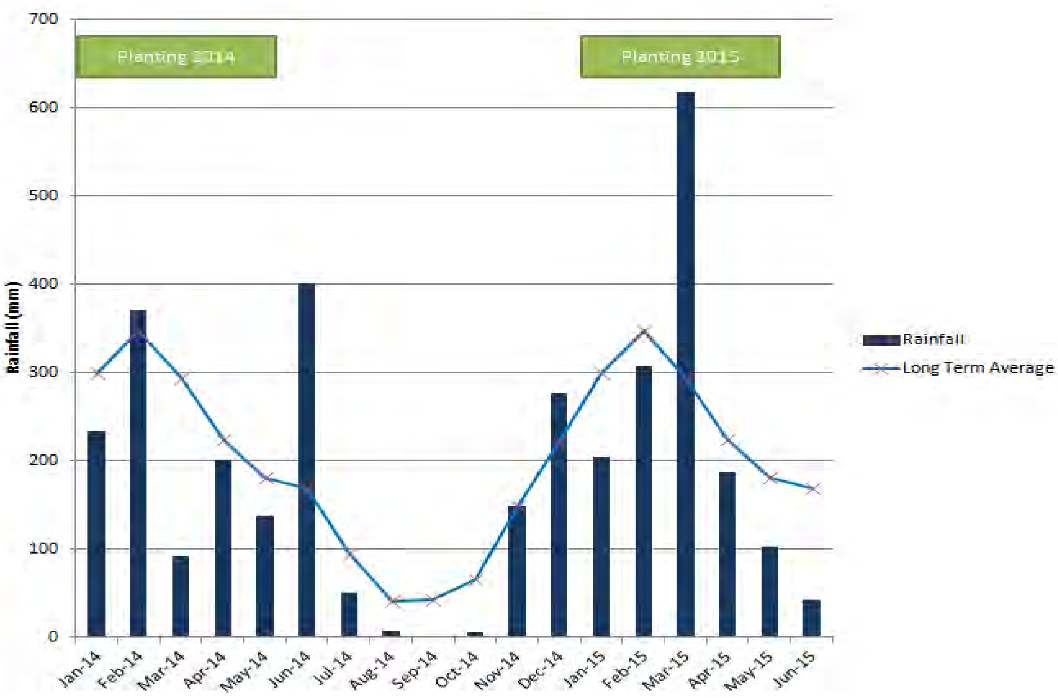


Figure 1: Monthly rainfall (bars) and long-term average rainfall (line) on Christmas Island from 1 January 2014 through to 30-June 2015. Data courtesy of the Bureau of Meteorology 2015.

3.2 Earthworks

Earthworks were conducted at site 23 North during the dry-season months from August to November 2014, in preparation for planting in early 2015. Previously, the field was known as Mine Lease (ML) 115. It is a 7 hectare area located in the middle of central plateau rainforest. The track accessing it turns-off from Murray Road 1.1 km south of Central Area Workshop, and the field entrance is 850 m down the track on the right-hand side (Figure 2). Because this site is Vacant/Unallocated Crown Land (VCL/UCL), a clearing permit was submitted to the Department of Environment and Regulation in 2014. This was necessary to gain approval to remove mixed woody weeds and some native trees (mainly *Macaranga*) predominantly on the stockpile in the southern section of the site. The permit was granted in July 2014 (permit number 6124/1). The majority of this site was 'fern-field', a weedy vegetation type that does not require a permit to clear, and the main focus for rehabilitation (Figure 3).

Figure 2: Location of earthworks and new plantings at Field 23 North

Whilst the majority of the site was fern-field, there was considerable variability in the soil depth beneath them. In many places there was less than 10 cm of soil overlying the limestone rock, however, in other places over 2 m of soil was present. Given that the intended depth for planting should average around 1.5, most areas required topping-up with more than 1 m of soil. Where *in-situ* soil was already 1.5m, no soil was added. In all cases, *in-situ* soil was ripped by a dozer to the full depth of the 1m ripping tine , or until rock was hit (see photo below), with rip lines spaced 1.5 m apart (Figure 4) .

Figure 3: Earthworks process at Field 23 North- before, during and after

Figure 4: Photograph showing rip lines and paddock-dumped soil mounds

3.3 Planting and Nursery

The planting season of 2015 started on 27th January shortly after rains began, and continued until 8th May. Field 23 North was planted first and completed in the middle of April. The last few weeks involved secondary plantings when rains permitted, though dry periods of several days at time offered limited windows of opportunity. A total of ~23,110 trees were planted, of which 20,800 were planted in the new, open field 23 North (Figure 5). This field was entirely surrounded by high-quality forest on all sides so created excellent conditions (e.g. micro-climate, bird and crab visitation, shade) for establishment. As such, it allowed planting of a wide selection of species (30 in total) including both primary 'pioneer' (85%) and secondary 'forest-mix' species (15%) (Table 1). The latter group, which included tall, long-lived species such as *Hernandia ovigera, Syzygium nervosum* and *Planchonella nitida,* were typically planted near edges with good contact to high-quality forest. Plant spacing was 1.5-2 m in rows to allow for efficient management and a suitable plant density (Figure 6). Survivorship after the first six months was very high, at >95%. A further 2,310 infill and secondary trees were planted in established fields including 21W, 21E and 22 Central. Infill primaries were planted where gaps had opened up and high light intensity, with secondary forest mix species planted under dappled shade conditions.

Figure 5: Tree planting process at the new field, 23 North

Table 1: Number of trees planting in the 2015 wet season (January to May)

Planting type	Area	Number
New field, primary 'pioneer' species	6 ha	17,740
New field, secondary 'forest mix' species		3,060
Established field, primary species for infill	8 ha	155
Established fields, secondary 'forest mix' species		2,155
Total		23,110

Figure 6: Aerial view of Field 23 North (Block 1) taken in the dry season of 2015 (October). Image courtesy of V-TOL Aerospace Pty Ltd.

3.4. Rehabilitation Field Maintenance

Weed control (using manual and chemical techniques) and fertiliser applications were conducted over ~130 hectares of established fields throughout 2014-15 (Figure 7). Most fields requiring weed control were planted since 2004 under the CIMFR program. As in previous years, the worst weeds requiring the most effort still include the vine species *Mikania micrantha* (mile-a-minute vine- Figure 8), *Macroptilium atropurpureum* (siratro), *Centrosema pubescens* (centro) and *Mucuna albertsii*, as well as the woody weeds *Cordia curassavica* and *Leucaena leucocephala.* Whilst these problem species do persist in some areas, ongoing management is successfully causing noticeable declines in many places. In general, with each round of weed removal, planted trees grow taller and increase canopy cover. These improvements gradually make it harder for weeds to compete for light and resources, leading to their decline. For instance, a field that may have taken 6 people, 8 days to weed when it was three- years-old, may take the same number of people only 5 days to weed when it is six-years-old.

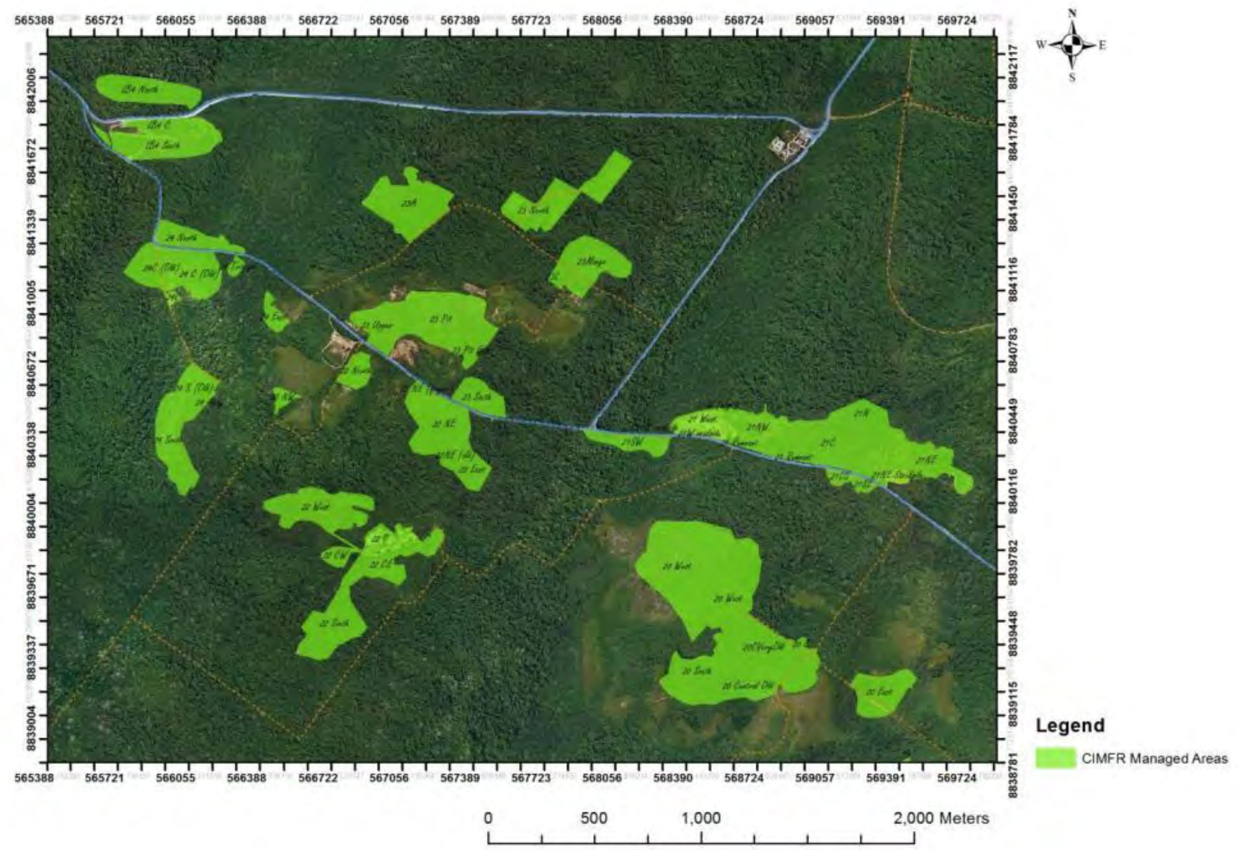


Figure 7: Rehabilitated areas under management for weed control, fertiliser additions and track maintenance in 2014-15

Fertiliser additions continued in all sites that were up to six years of age. This was done by hand to allow for targeted applications on native plants of both slow-release granular and tablet (40 g block) forms, which also reduces weed growth. Fields older than six years appear to be moving towards self sufficiency in nutrient cycling, so inputs are reduced compared with previous years.

Figure 8: Weed coverage of *Mikania micrantha* before and after spraying with glyphosate

3.5. Staffing

Staff numbers ranged from 8 to 12 (with an average full time equivalent (FTE) of 10 staff) throughout the 2014-15 financial year. In the lead-up to the planting season, three young local residents were hired on one-year contracts. The full complement of 12 staff was needed to successfully complete the planting of >23,000 trees in the wet season, and address heavy weed loads in fields in the early part of the dry. Of the current team, five people have worked with the CIMFR program at least four years, including two longer than 10 years. There is a good balance of well-trained young staff that bring fresh perspectives, as well as long term staff who provide valuable skills, experience and historical knowledge.

3.6. Knowledge Building and Collaborative Work

To further the skills and technical knowledge of local staff, the CIMFR program was fortunate to receive assistance and training from the Australian National Botanic Gardens (ANBG) Nursery Manager (Joe McAuliffe) from July to September 2014. This included numerous training sessions relating to nursery operation, horticultural techniques, propagation methods, plant hygiene practices, transplanting protocols, as well as teaching about plant nutrient requirements, identification of mineral deficiencies and pathogen/pest management. All staff benefited greatly from this experience and have put into practice the skills they learnt, resulting in a perceptible improvement in plant health and seedling survivorship since then.

To further invest in key local staff, a long-term field supervisor (Roslan Sani) was given the opportunity to work at the ANBG in Canberra for a two-week period in November 2014. Supervised by the Nursery Manager (Joe McAuliffe), Roslan gained first-hand experience in the operations of this high-profile botanical institution to further expand the knowledge of industry-best-practice techniques within the CIMFR program. Roslan is a permanent (on-going) employee and has been working with the rainforest rehabilitation program on Christmas Island for more than 15 years.

In terms of other training, three CIMFR staff members completed their Certificate III in Conservation and Land Management (Adijah Bingham, Jafni Jamil, and Shairazi Razak) in late 2014. Since then, three employees have undertaken their Certificate IV in Conservation and Land Management (Adijah Bingham, Roslan Sani, and Jason Turl). Christmas Island National Park is working alongside Indian Ocean Group Training Association (IOGTA) with the Great Southern Institute of Technology (GSIT) to provide local employees with the professional development opportunities they need to effectively carry out their duties and enhance their career aspirations. One staff member, who has performed particularly well, Adijah Bingham, also received funding from IOGTA to attend classes and workshops at the GSIT campus in Albany for a two-week period in May 2015.

3.7 Fertiliser trials

To further improve the cost effectiveness of fertiliser additions, identify which nutrients were most limiting and get the best growth possible, a new trial was started in March 2015 at the open field 23 North (Figure 9). Given that these new plants were receiving fertiliser anyway, it was an ideal opportunity to test nutritional requirements. The experimental design for this trial (a statistically valid, randomised block design) was developed in consultation with CSIRO. A total of eight fertiliser treatments were applied, including control plants which received no fertiliser, and seven different products (see those listed in Table 2). The products chosen were all identified as potentially offering benefits following consideration of soil nutrient data collected previously.

Table 2: Fertiliser treatments in experimental plots at Field 23 North

Treatment #	Treatment nutrient
1	No Fertiliser- control
2	Iron sulphate
3	Urea Nitrogen (Apex Polyon)
4	Trace Elements
5	General NPK+trace Tablets
6	Potassium Sulphate (Pot Ash)
7	Liquid fish emulsion+ fulvic acid
8	NPK granules

Six plant species were tested, each from a different plant family and with different ecological or functional traits (Table 3). For example, this included leguminous/nitrogen-fixing species (e.g. *Inocarpus fagifer*) and non-leguminous/non-nitrogen fixing species (e.g. *Calophyllum inophyllum* and others); fast-growing species (e.g. *Macaranga tanarius*) and relatively slow-growing (e.g. *Ochrosia ackeringae*) species, as well as others that are all important in the current species planting mix.

Replication was achieved by having seven separate plots throughout the 7 hectare field, and blocks were randomised within plots. Two plants of each species were used in each treatment block to provide some redundancy. As such, the total number of plants used may be calculated as follows:

Total number of plants = 8 (treatments) x 6 (species) x 7 (plots) x 2 (individuals) = 672

Table 3: List of species used in fertiliser trials at Field 23 North

Species #	Species	Family
1	*Barringtonia racemosa*	Lecythidaceae
2	*Calophyllum inophyllum*	Clusiaceae
3	*Gyrocarpus americanus*	Hernandiaceae
4	*Inocarpus fagifer*	Fabaceae
5	*Macaranga tanarius*	Euphorbiaceae
6	*Ochrosia ackeringae*	Apocynaceae

Figure 9: Fertiliser trial applications at Field 23 North

To quantify the effectiveness of each fertiliser treatment, the following parameters were measured on each of the 672 trees planted:

1. Tree height (cm) to the apical meristem
2. Stem diameter @ 10 cm above ground (important when they are less than 1.0 m)
3. Stem diameter @ 100 cm above ground (where applicable)
4. Leaf count
5. Leaf length. Using allometric relationship between length and leaf area, determine average leaf size. With leaf count, determine total leaf area of the plant
6. Leaf greenness (colourmetric determination of digital images)

7. Crown diameter on two axes
8. Pest infection type (e.g. scale, caterpillars, leaf minor, borers etc)
9. Pest infection severity (0=none, 1=insignificant effect on growth, 2=significantly effecting plant growth; 3=severely affecting plant growth)
10. Herbivory extent (percentage of leaves eaten/missing
11. Overall appearance of nutrition and health (5=excellent, 4=good, 3=fair, 2=poor, 1=very poor, 0=dead or apparently dead)

After planting in March, the first assessments were conducted shortly afterwards and before any fertiliser was applied, making this is the 'time zero' start point. In April 2015, fertilisers were applied. The next assessments will be in August 2015, December 2015 and April 2016. The response to fertiliser treatments should be evident by this time, after which, the first year of results will be analysed and written up. The experiment may be worth continuing beyond this time, depending on the strength of trends observed. Fertilisers will be re-applied as per label instructions.

3.8 Biophysical Monitoring 2015

In 2015, biophysical monitoring of planted fields was conducted in sites of varying ages from newly planted 'zero-year-old' (field 23 North); 'one-year-old' (field 22 West); 'three-years-old' (field 21 West); 'five-years-old' (fields LB4 South, 24 North, 21SC), and, for the first time, 'ten-years-old' (fields 20 East, 20 South and Central). The ten-year-old fields were planted in early 2005 and the first conducted under the CIMFR program which commenced in 2004.

This year, biophysical monitoring surveys were undertaken from May to July. Parameters measured were in three main categories:

1) *Vegetation assessments*: plant species abundance and diversity, tree heights and diameters, plant health, canopy cover, ground cover, recruitment of native species
2) *Fauna assessments*: presence of birds, crabs and other invertebrates
3) *Soil assessments*: soil bulk density, water-holding capacity, pH, electrical conductivity (EC)

Each of these categories is discussed below in context of field age (see Appendix 1 for methods).

In general, most fields are doing well and show progress in line with expectation for their age. The new field, 23 North, is doing exceptionally well in terms of plant survivorship, species diversity, cover and other parameters, largely because of being surrounded by high-quality primary forest on all sides. The one-year-old, five-year-old and ten-year-old fields are generally in excellent health and show high species diversity indices, good levels of canopy development and recruitment. The three-year-old fields are not doing very well in terms of canopy cover or tree health, likely due to the poor physical properties (e.g. compaction) of soil sourced from the only available stockpile in the area (in 2012). However, they are still showing reasonable plant survival and good levels of species diversity, so it is hoped that over time they will improve. Whilst little can be done to change soil physical properties post-planting, improved plant nutrition through appropriate fertilisers should help growth to some extent.

Vegetation Assessments

New/ zero-year-old fields

Planted in early 2015 (January to April), field 23 North was only 4 months old when monitoring was conducted (Figure 10). For the sake of consistency with older fields and keeping the naming pattern to annual increments, this field will be referred to as '0-years-old' in figures throughout the document. This field, previously known as ML 115, is located on the central plateau in forest bounded by Murray Road, East-West baseline and North-West Point Road on all three sides. It can be accessed from Murray Road. The turnoff is 1.1 km south of Central Area

Workshop, and the field is 850 m down the track on the right-hand-side (north). Four monitoring transects were established throughout 23 North.

Field 23 North

Figure 10: Photographs of monitoring transects at the newly planted zero-year-old site 23 North

A total of 28 native species were detected in these transects, which is very high for a field of this age. There are several contributing factors to this. Firstly, the field is entirely surrounded by tall, high-quality forest which offers ideal conditions for establishment such as favourable microclimate, shade around edges, minimal encroachment of weeds and maximum edge contact for seed dispersal from the surrounding forest. Such favourable conditions permitted the rare inclusion of secondary 'forest mix' species, alongside the primary 'pioneer' species in the original planting, especially towards the forest edge. A total of 30 species were produced in the nursery and planted this year, and virtually all were detected in the transects. New recruits from the surrounding forest were already appearing in the field, with over 1,000 recruits per hectare. Almost 900 of these were already over 20 cm tall. This is remarkably high for such a young field, but its close proximity to the forest on all sides provides such advantageous conditions. Plant density was very high- around 3,900 trees per hectare (Table 1).

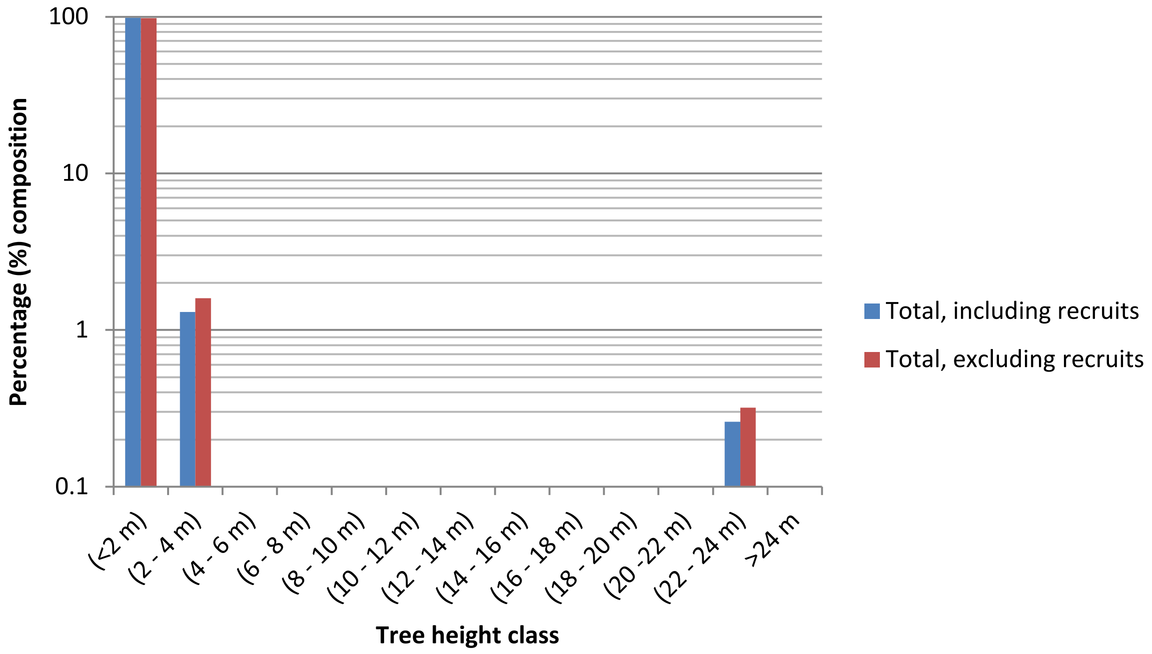


Figure 11: Height frequency distribution of trees in the new/zero-year-old field (23N)

Given this high species richness (i.e. total number of species), abundance and density, Shannon's Diversity Index (*H)* for this site was high (2.83 out of 3.33 (H_{max})) giving a Shannon/Pielou value of 85%. This diversity index '*H'* is a mathematical measure to quantify species diversity in a community. It takes into account the relative abundances of each species, the total number of individuals and number of species (for further information on how this is calculated, please refer to section A.1.1 of Appendix 1). Simpson's *D*, representing the statistical probability that any two species would be the same, equals 10.7%. Values close to zero approach infinite diversity and values approaching 100 means no diversity (i.e. a monoculture). Expressed as a 1-*D*, and therefore the statistical likelihood that any two plants will be *different* species, the value is thus 89.3% (where values approaching 100% indicate very high diversity). Such values are well above expectation and indicate that, in terms of biodiversity, the field is off to an excellent start.

Equitability (Simpson's E_d), which is also constrained between 0 and 1, was 0.33, which indicates stronger representation of some species than others. This is an expected outcome given that pioneer species like *Macaranga tanarius* were a significant part of the planting mix (~24%).

In terms of growth, not surprisingly, almost 99% of the trees encountered in these transects were less than 2 m tall, with only a few taller than this (Figure 11). Average height of these newly planted trees is 0.73 m and maximum height 2.4 m (excluding any existing trees) (see Table 4 and Figure 12).

As is standard practice and wherever possible, pre-existing native trees on the site were preserved throughout the earthworks process. In Transect 23N-4, a single ~23m tall *Macaranga* tree still exists, which accounts for the data point at the far right of Figure 11. Note that Figure 11 displays a logarithmic scale (base 10) on the vertical axis to represent the percentage composition. This gives more appropriate acknowledgement of tree size in the chart, as one large mature tree (e.g. with a height of say 23 m) will provide considerably more ecosystem value (e.g. roosting habitat for birds, leaf litter production) than one small recruit standing 0.3 m tall. Secondly, in terms of shade, one such large tree may well give more ground surface shade than 100 small saplings. This is an important consideration for the habitability of sites to red crabs. Remnant native trees are important as they provide patches of shade, seed, and leaf litter. Furthermore they provide bird-roosting habitat which also brings in seed of other species from adjacent forest, thus improving recruitment rates.

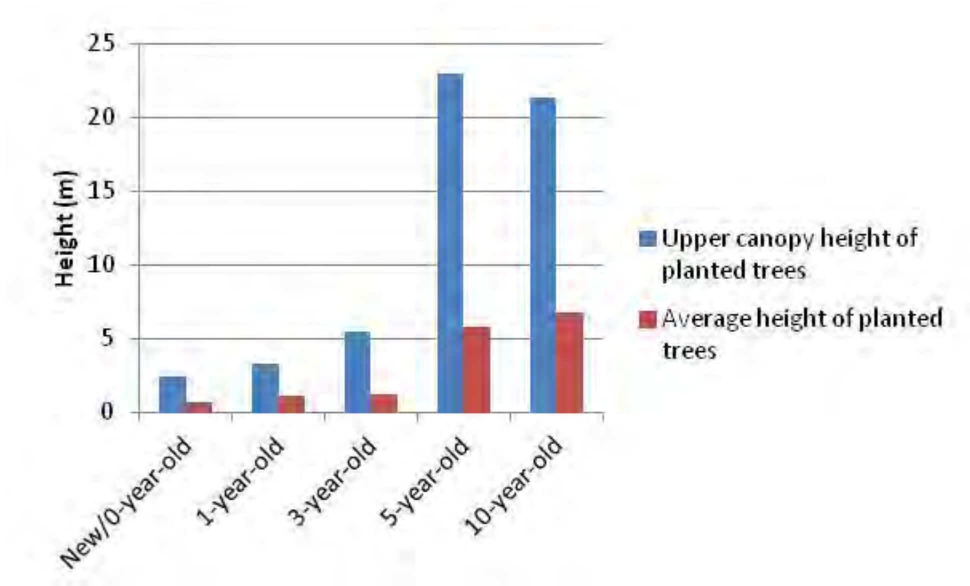


Figure 12: Average and upper canopy heights of planted trees in fields of various ages

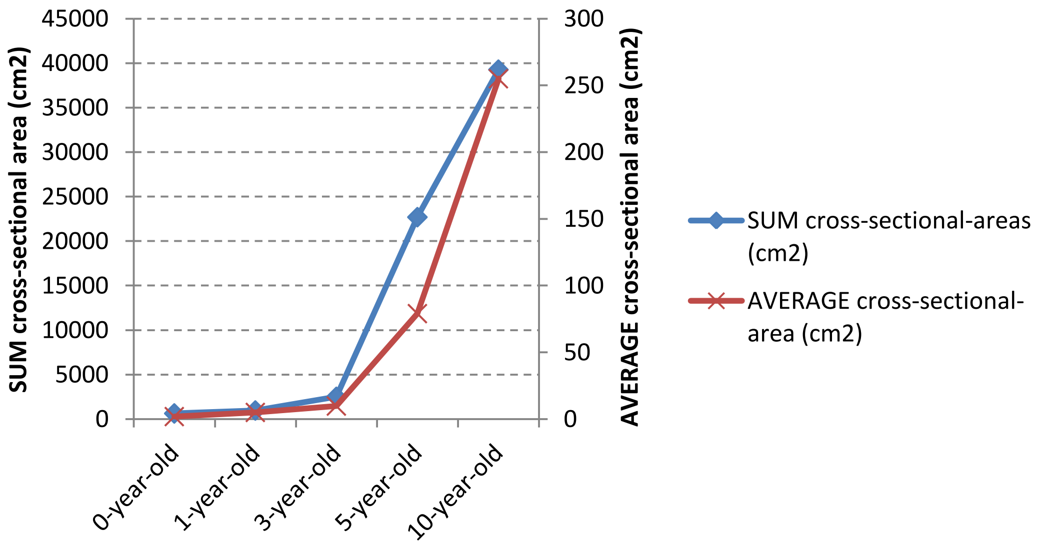


Figure 13: Sum and average cross-sectional area (cm2) of stems/trunks of planted trees measured at 10cm above ground level for fields of different ages. Note the strong correlation between these two parameters.

Another important measure of growth is trunk/stem diameter (at 10cm above ground level), or, the subsequent calculation of stem cross-sectional area. Of these 384 stems measured in the new field, average cross-sectional area 3 cm^2 (see Table 4 and Figure 13). This is seemingly small, but perfectly normal for trees with an average height on 73 cm tall.

Tree health was assessed to judge visually apparent plant nutrient status, leaf greenness, pathogen resistance and strength. In this new field, 92% were in 'excellent' health, 7% were 'satisfactory' and only 1% was 'poor' (Figure 14).

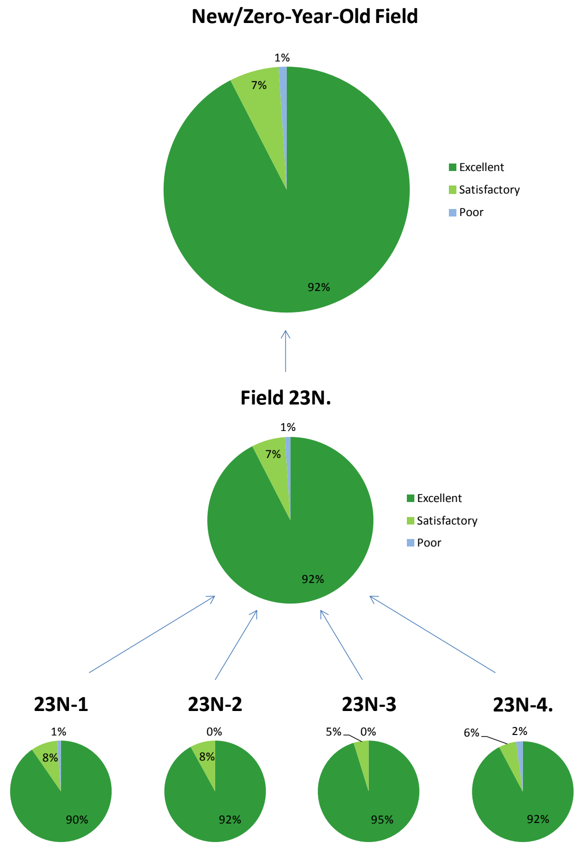


Figure 14: Pie charts of health ratings for trees in the new/zero-year-old field 23 North.

Canopy cover, as determined by hemispherical photography (with a fish-eye lens) and image analysis (Gap Light Analyser), was already 27%, which is very good for a field that is only 4 months old (see

Figure 15).

Leaf litter projected area on the ground was 9%, which is low but normal for such a young field. Ferns were largely absent from most areas with less than 5% of ground area covered by fronds. Low to moderate abundance of ferns (<30% projected cover) may be slightly beneficial for holding surface soils together and limiting weed growth, but high levels (>50%) can be problematic as they take over and inhibit the recruitment of native species (Table 4).

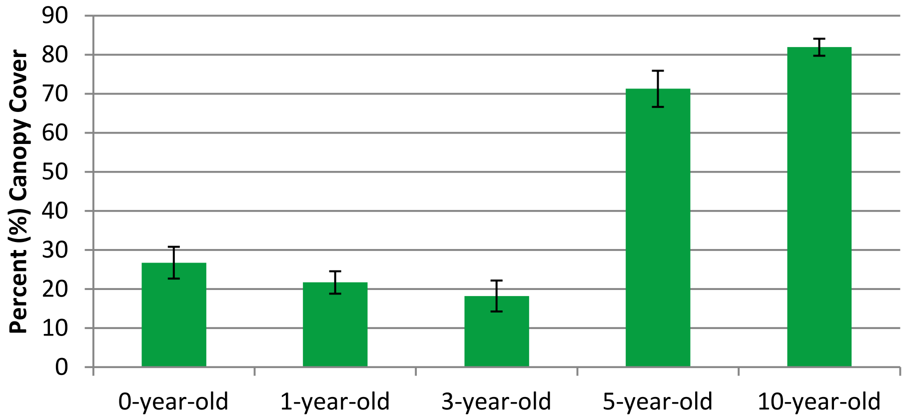


Figure 15: Percentage canopy cover for fields of different ages. Error bars are standard errors of the mean.

One-year-old fields

The one-year-old field was at site 22 West, a 6.4 hectare area on the plateau approximately 700 m south (as the crow flies) from East-West baseline, with its track entrance 500 m west of the junction with Murray Road. This field is 1.2 km down the 4WD track, past field 22 Central (see Figure 16).

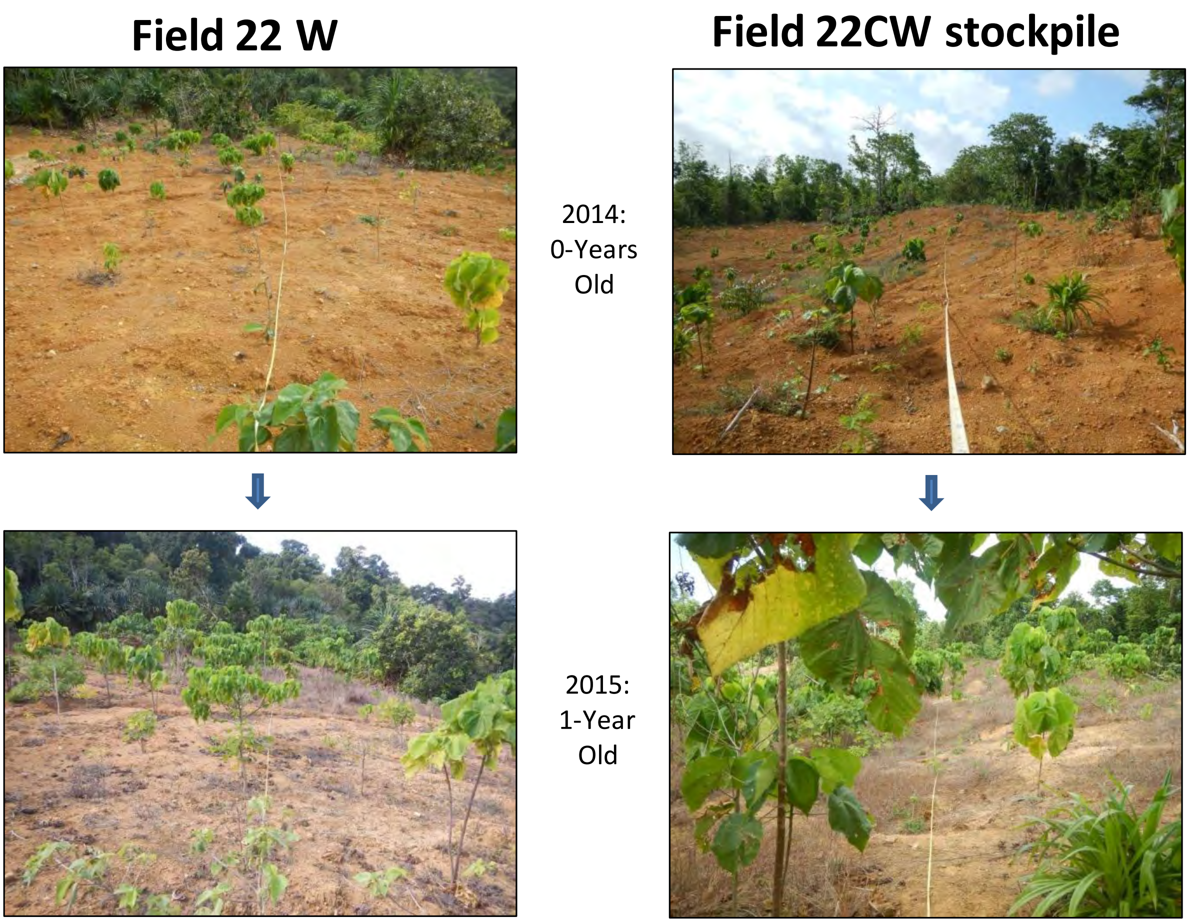


Figure 16: Photographs of monitoring transects at the one-year-old site 22 West

A total of 21 species were found in the three transects across this site, predominantly composed of primary pioneer species planted in 2014. Because of its young age, this field has not yet received secondary plantings of 'forest mix' species, except in a few favourable areas near the forest boundary. Vegetation diversity measures were encouraging, with Shannon's Diversity Index (H^1=2.62) representing 86% of maximum possible diversity for the given composition (H_{max}=3.04) (see Table 4). The statistical likelihood of two species in the population being the same (Simpson's Index *D*) was 10.5%. Evenness of the sample population was slightly more uniform than the new field- hence slightly less dominance of any particular species (Simpson's Equitability E_d=0.45).

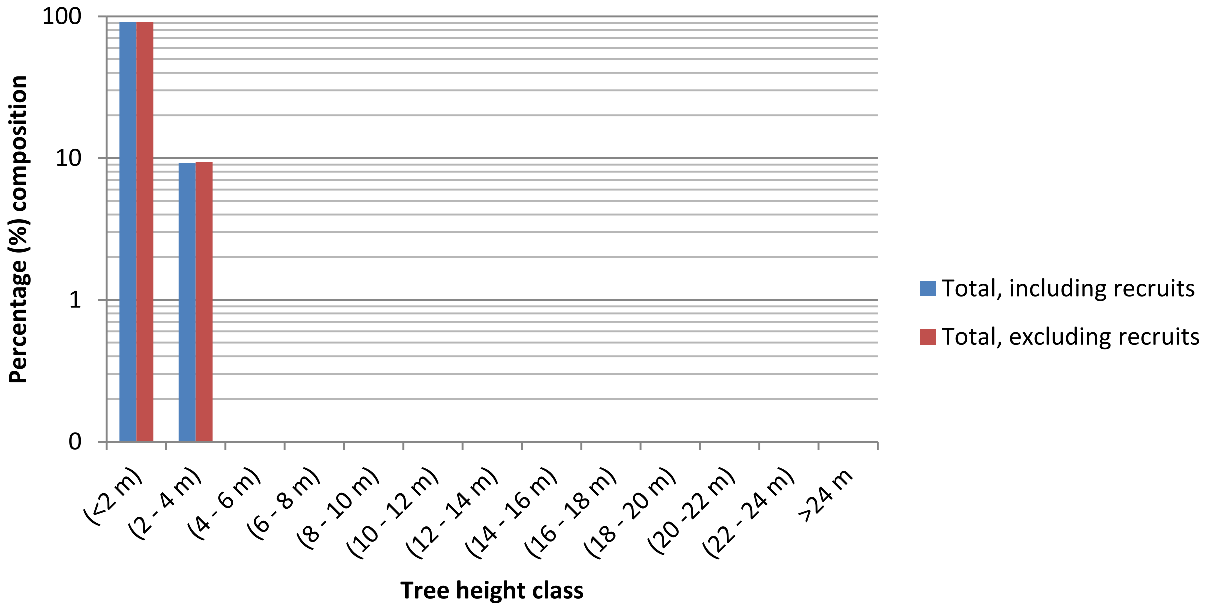


Figure 17: Height frequency distribution of trees in the one-year-old field 22 West

Density of plants was around 2440 per hectare, which is considered good. Recruitment was very low in these transects, with 38 individuals per hectare observed to date. Given that there were no remnant trees encountered within these transects, there is a reduced likelihood of seed dispersal hence this value is not unexpected. Fern cover was low at ~5% and leaf litter cover was 9% (Table 4), both being perfectly acceptable for a one-year-old field.

Average height of planted trees in field 23N was 1.1m and the upper canopy height was 3.3 m (Figure 12 and Table 4). Approximately 10% of planted trees were above 2 m in height (Figure 17). Average stem-cross-sectional area (measured at 10 cm above ground) was 5 cm^2. This growth is in line with expectation for a one-year-old field.

On the whole, tree health was very good, with 73% receiving a rating of 'excellent', 19% 'satisfactory' and only 8% as 'poor' (Figure 18). There was some variability across transects, with plants on the old stockpile (22CW-SP) performing less well than those in the open field. This is likely due to subsoil compaction. Compaction is a common problem on soil stockpiles and some fields as a result of heavy equipment traffic when they were originally formed. As is normally the case, this stockpile was ripped across the slope and the surface 1.0 m dug-up and turned over by the bucket of the excavator. This is the best method available, but goes only part way to solve compaction issues.

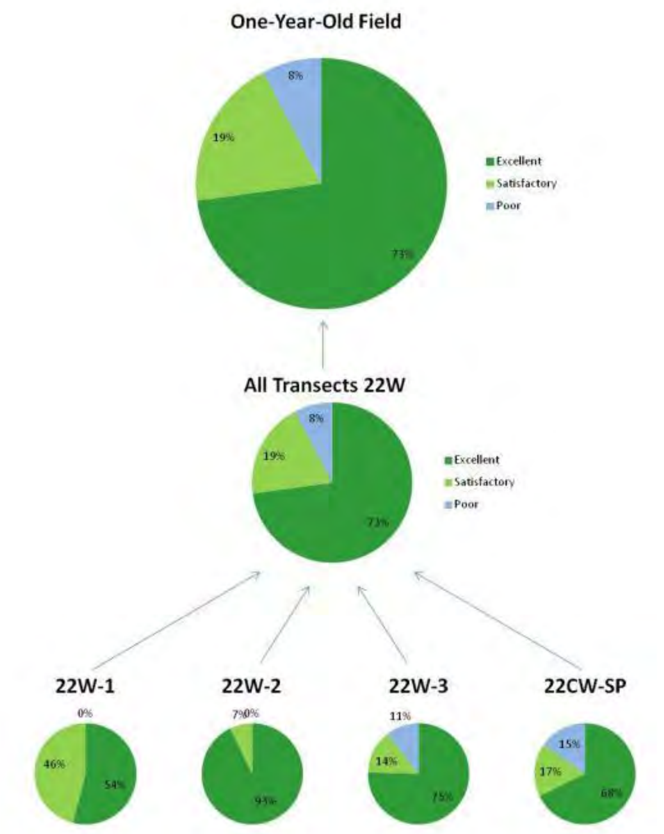


Figure 18: Pie charts of health ratings for trees in the one-year-old field 22 West.

Percentage canopy cover was 22% which is with the expected range for fields that are 1-year-old (Figure 15). Leaf litter cover on the ground was around 10% and fern cover around 5%, both of which are in line with expectation (Table 4).

Three-year-old fields

The three-year-old fields include 21 West and 21 East Stockpile; the latter of which was the source of soil for 21 W (Figure 19). In terms of species diversity indices, numbers show a good range of different plants. Species richness was 25, which is good for a three-year-old field. However, only a limited number of secondary 'forest mix' plants have been put in this field so far due to poor shade development in many areas. A total of 256 individuals were found in the five transects across 21W and 21E-SP, and given the high species richness, resulted in a good Shannon Diversity Index (H=2.65 out of H_{max}=3.22) and Shannon/Pielou value (82% - see Table 4). Simpon's D suggests the likelihood of two species being the same equals 10.8%, whilst evenness (E_d) was 0.37 indicating that a few species were more common and some more rare than others

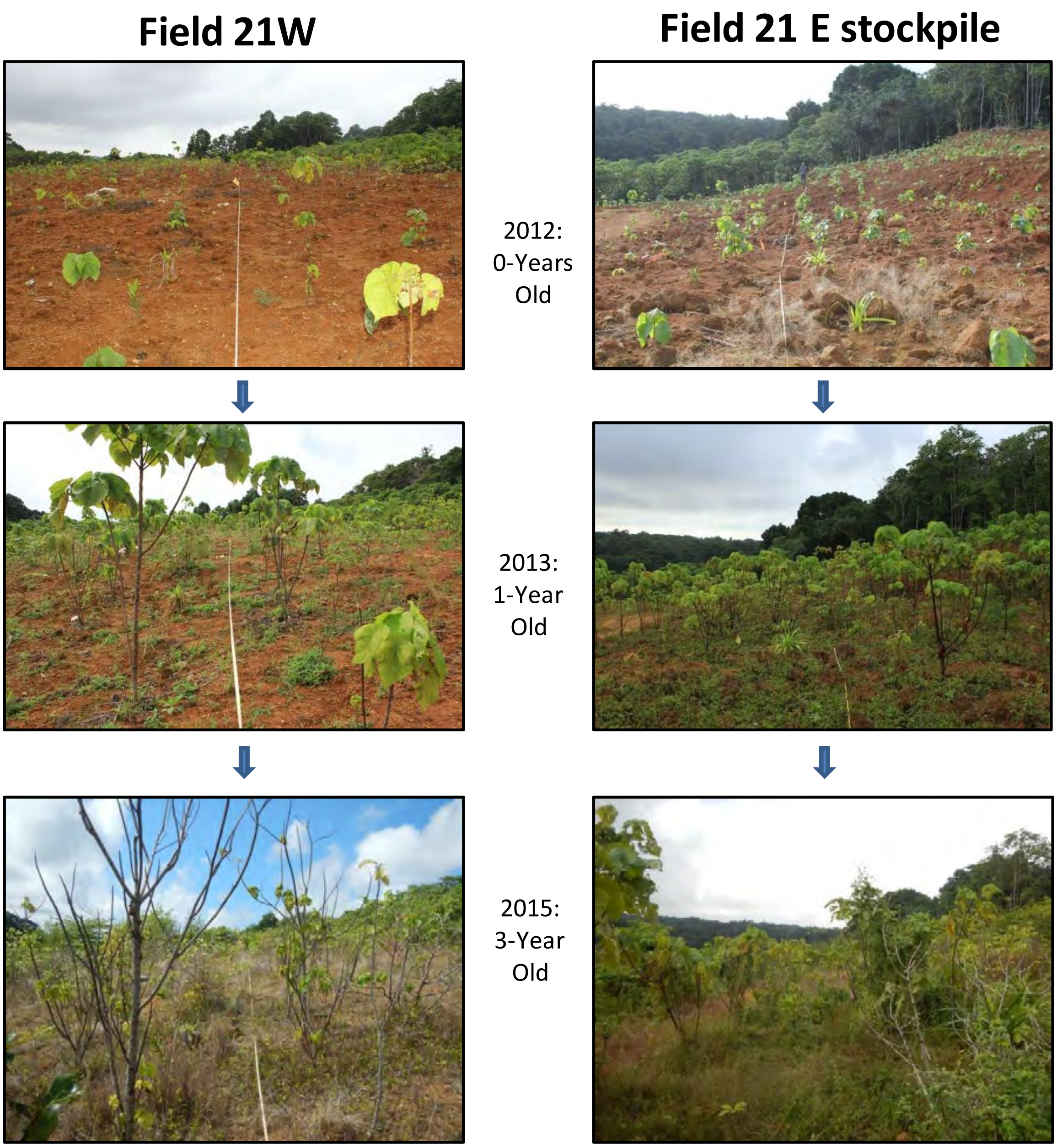


Figure 19: Photographs of monitoring transects at the three-year-old sites 21W and 21E-SP

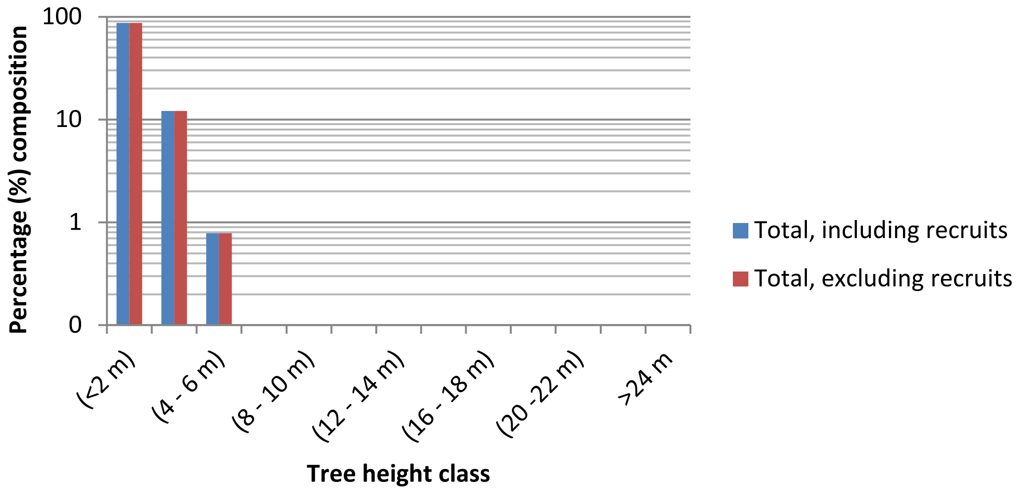


Figure 20: Height frequency distribution of trees in the three-year-old fields 21 W and 21E-SP

Density of planted trees was around 2550 per hectare, which is a good number. However, recruitment was very low being only around 20 per hectare (Table 4). Plants in this field were smaller and less foliated than expected, with average height being only 1.27 m (Figure 12). The height frequency distribution shows that 87% of plants were less than 2 m tall, 12% were 2-4 m tall and less than 1% were 4-6 m tall (Figure 20). Average stem cross-sectional area of 10cm^{2}cm, was quite low for a three year old field.

Canopy cover was also very low at around 18%. Where there is poor canopy establishment from pioneer species, it is not possible to incorporate secondary/forest mix species. Therefore, more infill and secondary planting will occur in this field during the wet season of 2016 (January to April).

Leaf litter cover on the ground was reasonable at 17%, and fern cover was very low at less than 5% (Table 4).

Plant health in these two fields was not as good as expected, with 37% in poor health, 35% satisfactory health and only 29% in excellent health (Figure 21). It is normally hoped that at least 80% would be satisfactory or better, so clearly there is an underlying problem.

The overall picture for these two related areas is currently quite poor. Given that the soil used in 21W all came from the stockpile at 21 E, it appears that the poor growth and performance in both these areas is due to adverse soil conditions, apparently unfavourable soil physical structure/compaction. During the 2011 earthworks for these areas, soil was paddock-dumped and spread by the excavator arm without trampling, but it seems that even this light handling was not enough to alleviate adverse physical properties and compaction caused by heavy machinery when the site was mined decades before. This 21E stockpile was ripped across the slope and the surface 1.0 m dug-up and turned over by the bucket of the excavator. Whilst this method does break up compacted layers to a reasonable extent and is the best method available (without specialised equipment), it still leaves blocks of soil that are difficult for plant roots to access. Nonetheless, over time, roots will work their way through, form bio-pores and allow greater utilisation, although this process may take several years.

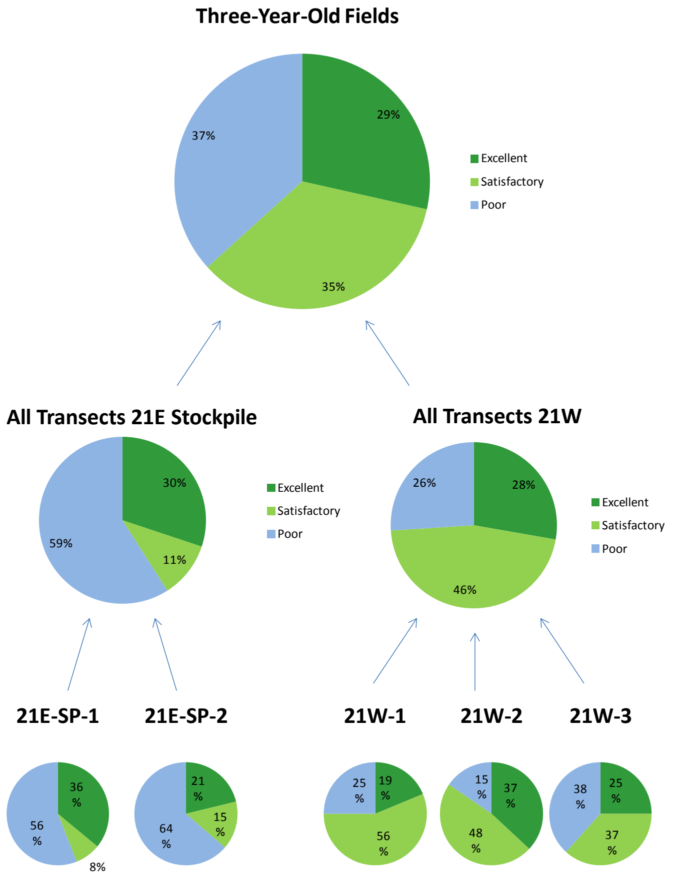


Figure 21: Pie charts of health ratings for trees in the three-year-old field 21 West and 21 E Stockpile

To assist this process, infill plantings in early 2016 will utilise a selection of tough, resilient and strong-rooted species such as *Pandanus elatus, Ochrosia ackeringae, Calophyllum inophyllum, Ficus microcarpa* and possibly a few *Muntingia calabura* (Japanese cherry) in these problem areas. Whilst this latter species is not native to the island, it is a pioneer species which breaks up hard ground, provides shade, attracts crabs, flying foxes, and birds, and as a result brings in native recruits. The ecological functions provided by this species have long been recognised and justified its use in the rehabilitation process. One other positive attribute for using this species is that it is easily killed, with just a few frill cuts in the stem and spray with Round-up (glyphosate). As such, its inclusion is only a temporary measure to achieve an overall net benefit.

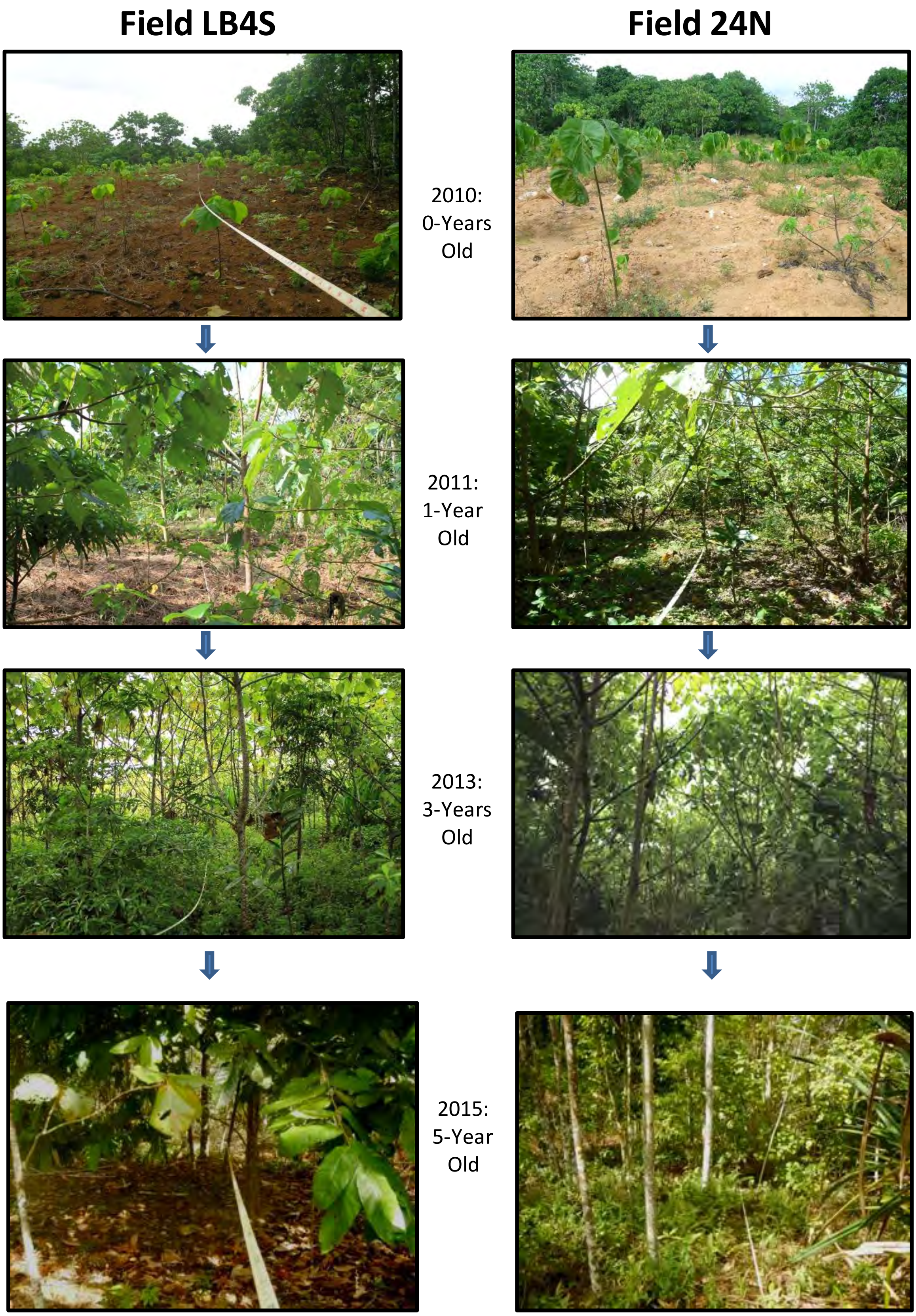


Figure 22: Photographs of monitoring transects at the five-year-old sites LB4S, 24N and 21SC

Five-year-old fields

The five-year-old-fields included LB4S, 24N and 21SC (Figure 22). Twenty-six species were found across these fields. Consistent with other fields already discussed, biodiversity was high (H=2.67 out of H_{max}=3.26; and Shannon/Pielou value = 82% - see Table 4). Furthermore, Simpson's D indicates the likelihood of two plants (out of the 529 measured) being the same species equals 9.2%, whilst evenness was 0.42. As noted for similar figures previously, this indicates that some species where slightly more common than others, but there was no strong dominance of any particular one. This pattern is common in the natural forest ecosystem, so this is considered a good community composition.

Average density of planted trees was around 2,100 per hectare. In addition, around 11,300 recruits per hectare were emerging, of which about 18% were greater than 20 cm tall. Such high recruitment rates indicate there will be a great excess of trees to replace those which have been planted and that intense competition will develop over time. If all recruits are included, individuals in the lowest height class (<2m) make up around 56% of the population, but without them, this height class represents only 22% of the population (Figure 23). Average height of planted trees was 5.8 m and the tallest trees were up to 23 m (Figure 12). Concomitantly, trunk cross-sectional area averages 79 cm^2, a large jump from the younger fields.

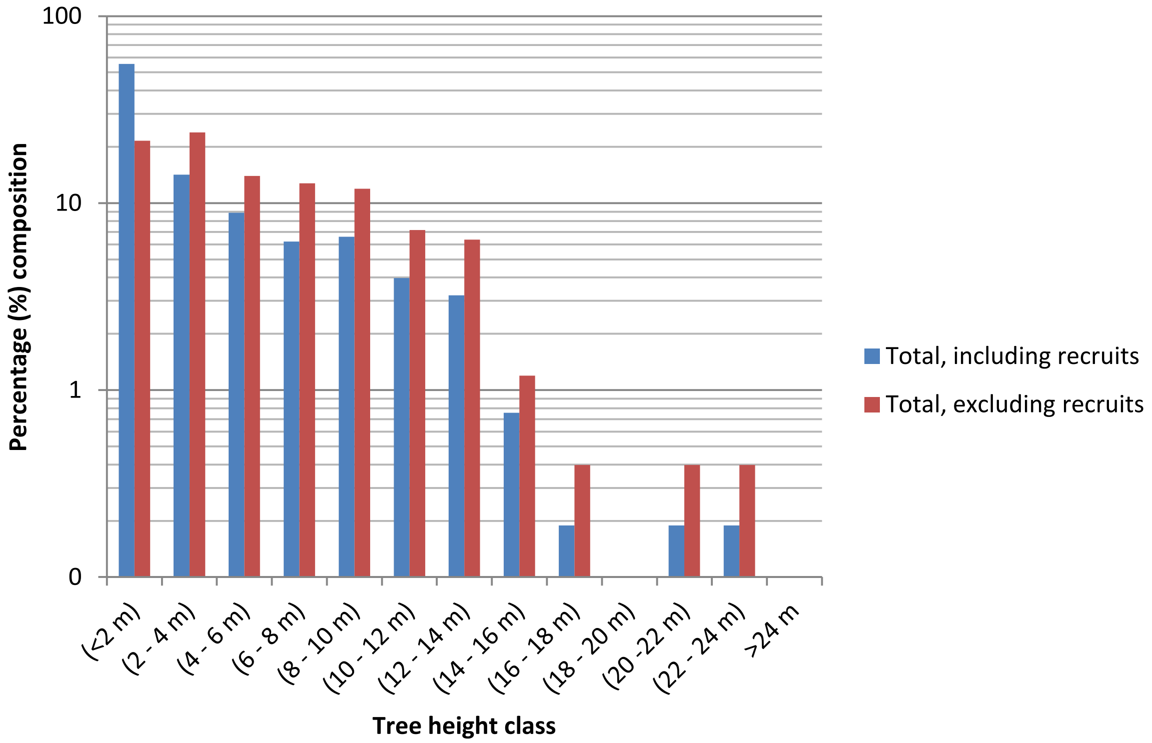


Figure 23: Height frequency distribution of trees in five-year-old fields (LB4S, 24N, 21SC)

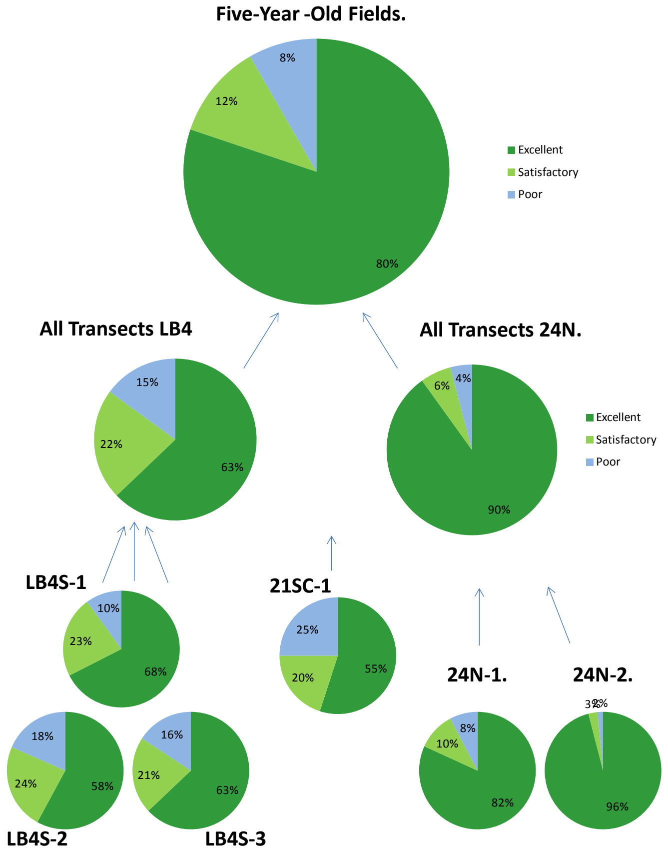


Figure 24: Pie charts of health ratings for trees in the five-year-old fields (LB4S, 24N, 21SC)

Health of trees in five-year-old fields was generally very good. Overall, 80% were excellent, 12% satisfactory and 8% were poor (Figure 24). There was however considerable variation between the different fields. Field 24N appears to be doing really well, with over 90% of plants rated in excellent health, whilst in 21SC (a small site by the main road) only 55% attained this rating. The three sites in LB4S were somewhere in between (Figure 24).

Canopy cover across these fields was, on average, very good at 71%. Again, this is a big increase from younger fields providing far more shade and leaf litter to the forest floor. Leaf litter projected cover was the highest out of all the fields at 42%. Such conditions provide amenable habitat for red crabs and will be discussed further in the section on fauna assessments. Fern cover was in the healthy range, being only around 10%.

Overall, it can be said that these five-year-old fields are doing very well.

Ten year-old fields

The ten-year-old fields include 20 East, South and Central, all in reasonably close proximity to one another. These sites were rehabilitated in early 2005, and as such, are the first to be assessed after ten years of management under the CIMFR program (Figure 25).

Growth parameters stand out as the main differences to younger fields. The tallest planted trees now exceed 21 m, though some pre-existing trees approach 30 m tall (Figure 26). Including the full spectrum of sizes, average height of planted trees was 6.8 m, the tallest of all fields measured (Figure 12). Average stem cross-sectional area was 255 cm^2, which is over 100 times larger than new-planted trees, and over 3 times larger than five-year-old trees. Excluding recruits, around a quarter of all trees present were greater than 10 m tall, and in the first four height classes (0-8 m tall) there was roughly even representation in the population (~10-12% each). This illustrates a high degree of complexity in the canopy structure and there are a possibly several cohorts of recruits that have established.

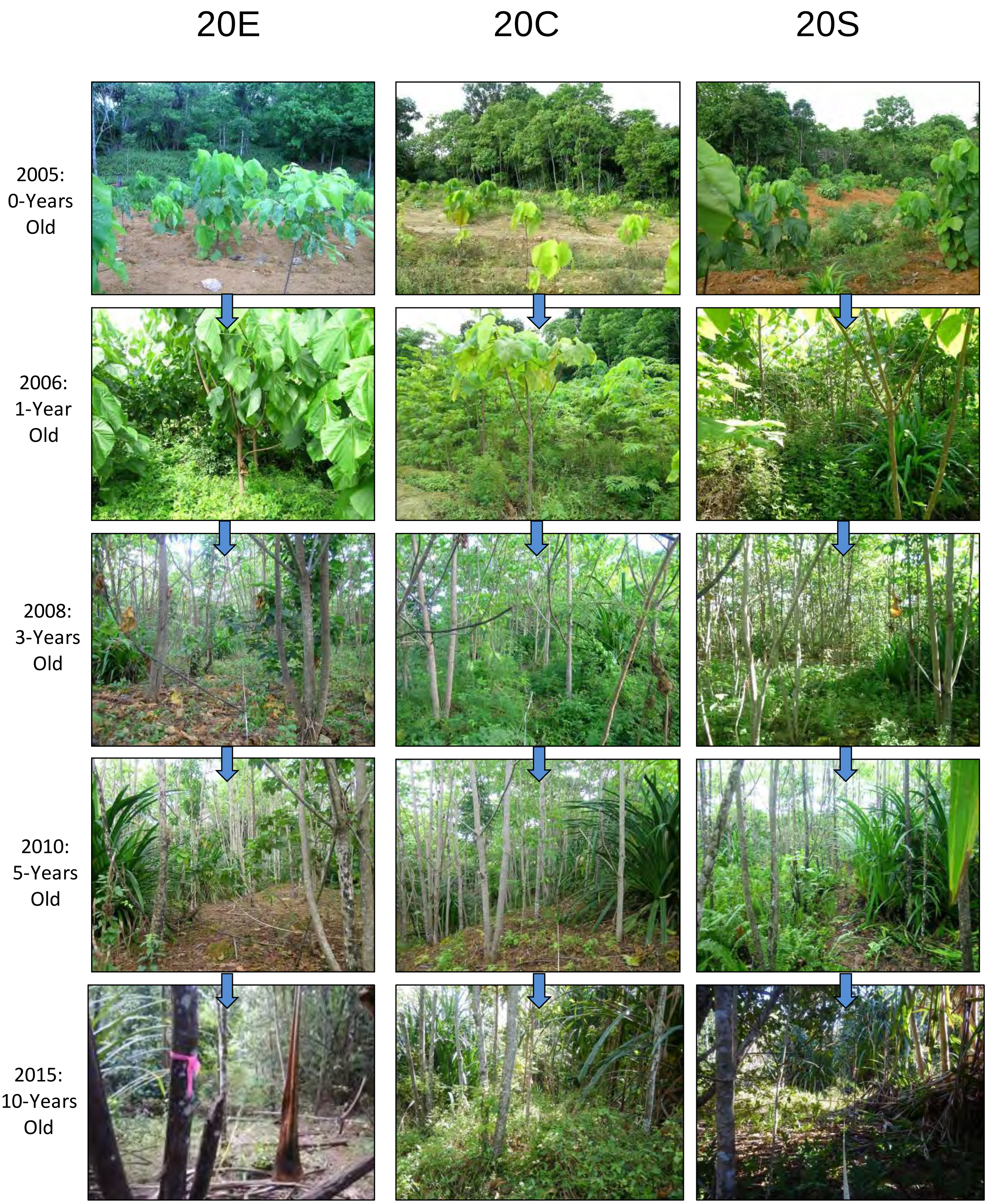


Figure 25: Photographs of monitoring transects at the ten-year-old sites 20E, 20C and 20S

Canopy cover was over 80% and approaching that of primary forest which averages around 87%. Given that trees in these fields are significantly larger than those in younger fields, less are needed to create the same level of canopy cover (or higher, as is the case here). Competition is also likely to have developed over this time and, as some trees have got larger, other trees have fallen away. Approximately 1025 planted trees per hectare still persist, and with approximately 50 existing trees per hectare, plant spacing equals one tree every 3.1 m on average. In amongst these are approximately 810 recruits per hectare. Whilst only a moderate number, many of these are likely to have been generated from within the rehabilitation field given there is quite a distance to primary forest. Field 20 E is about 100 m from primary forest, and 20 South over 250 m. These fields are part of the much larger 'Field 20' group which covers approximately 130 hectares. Local generation will be most applicable to short-distance, wind-dispersed species such as *Macaranga tanarius*. Bird-dispersed species such as *Dysoxylum gaudichaudianum*, and *Arenga listeri* could be sourced from both the rehabilitation field and primary forest.

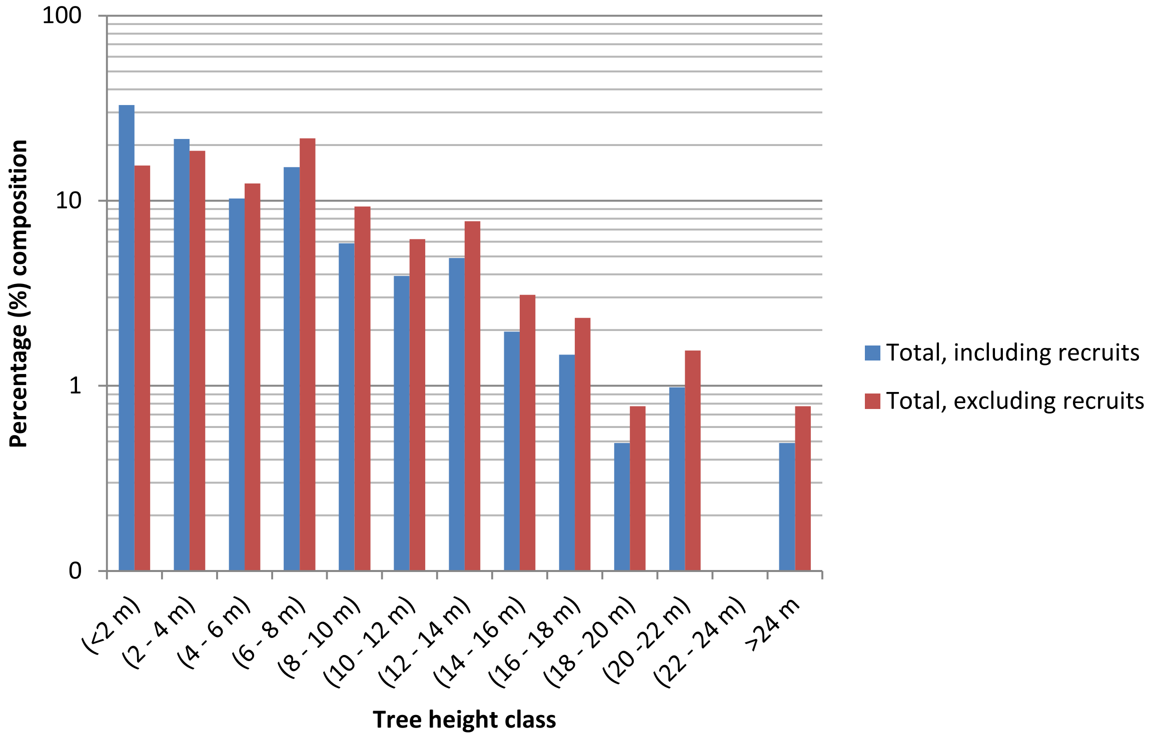


Figure 26: Height frequency distribution of trees in ten-year-old fields (20E, 20S+C)

A total of 24 species were found, similar in number to the other fields sampled. Given the consistency in plant species selection over the last ten years of the CIMFR program, this outcome is very much expected, and if anything, affirms that the species mix being used is effective and suitable for the fields. In line with other fields, biodiversity indices were also very good. Shannon's *H* was 2.81 out of a possible 3.17 (H_{max}) so the Shannon/Pielou value *J*= 89%, which is excellent (Table 4).

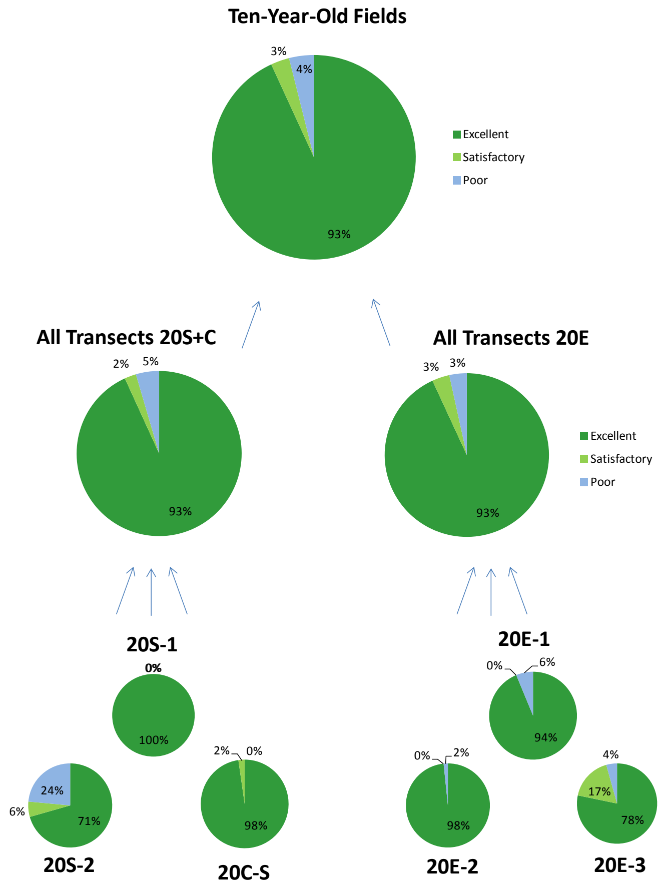


Figure 27: Pie charts of health ratings for trees in ten-year-old fields (20E, 20S+C)

Simpson's *D* suggests there is a ~8% chance that any two species found will be the same, and evenness (E_d) was 0.55, meaning there is a good representation of each species with little dominance of any particular one (Table 4). Such diverse composition of the community offers a high degree of resilience to changing conditions, traits strongly reflected by primary forest.

Ground cover of leaf litter was around 38% and fern recruits 23% - both acceptable levels (Table 4).

Encouragingly, plant health was good in general, with 93% of plants in excellent condition, 3% satisfactory, and only 4% poor (Figure 27). There was only a small amount of variation between the six transects, though one patch of 20S (where transect 2 is) was not doing so well. Such patchiness is not uncommon in rehabilitation fields given the heterogeneity in soil conditions and/or depths, especially on old stockpiles.

All in all, vegetation assessments on the ten year old fields indicate they are doing well and, for the most part, are ready for relinquishment of management activities (e.g. weeding, fertilising). Some areas have already been self-sustaining for two years, whilst others have recently had final weed control efforts. These fields are also becoming increasingly useful habitat for native flora and fauna, especially red crabs and native bird species.

Fauna Assessments

Invertebrates

Red crabs have started to colonise and burrow in the three-year-old field 21W, and are quite established in many parts of the five-year-old (24N, LB4S) and ten-year-old fields (20S, C, E) (Figure 28). Whilst the number of red crab burrows ranges from 0 to 1500 per hectare, the average for three-year-old fields is 60; five-year-old is 325; ten-year-old fields is 417 (see Table 5). According to the Christmas Island National Park Island-Wide Survey 2013 Report, primary rainforest on the plateau (>150 m ASL) displays an average of ~1700 red crab burrows per hectare, in non-crazy ant-affected areas. In one of the ten-year-old fields, 20S, a crazy colony appears to have kept out red crabs, so the average may well be higher and similar to numbers in 20E.

In terms of time frame for red crabs moving in to these areas, it is encouraging that burrows are already appearing in the three-year-old field 21W, as they are not usually expected until fields are five years old. In the younger fields planted this year and last year, no burrows were found (as expected). However, crabs were observed walking through these fields and occasionally foraging on leaf litter. Robber crabs were also seen encroaching into the fields and some burrows were found in the five- and ten-year old fields on stockpile banks.

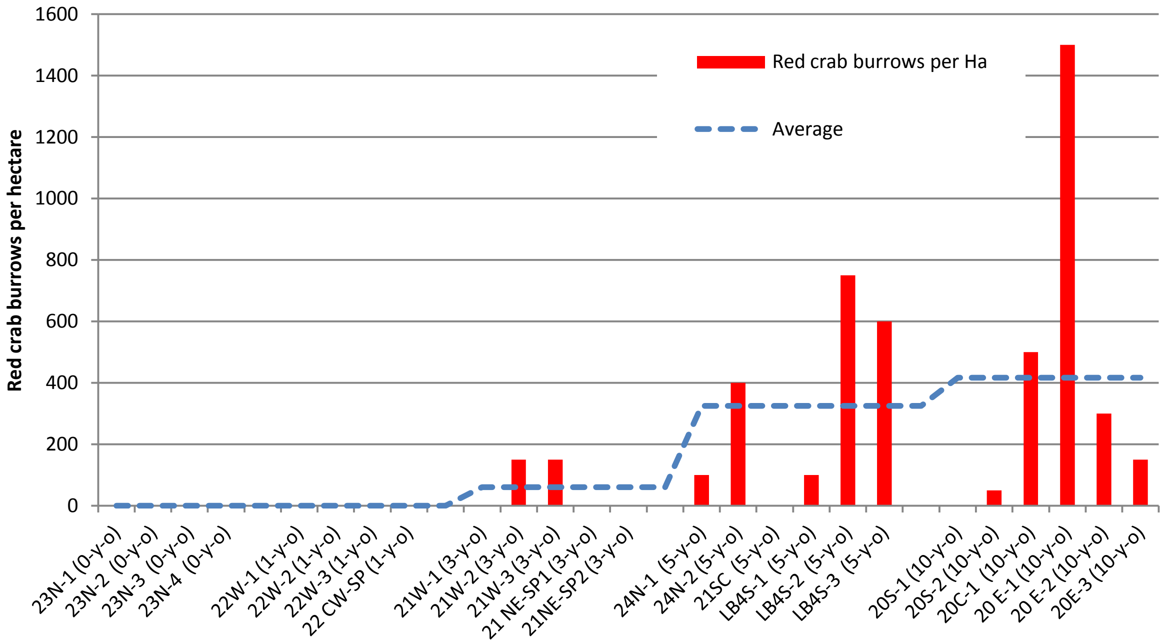


Figure 28: Red crab burrow counts per hectare in fields of different ages

Orb spiders, Millipedes and Giant African Land Snails were in low to very low densities across all fields of all ages. It appears that population numbers of these animals fluctuate from year-to-year and no obvious patterns in relation to field age have been detected so far.

Birds

There are seven native species of forest birds on Christmas Island, with six active during the day and the seventh (the CI Hawk owl) being only active at night.

The Christmas Island Imperial Pigeon, *Ducula whartoni*, was common in fields of all ages. Having a largely frugivorous diet, it feeds on a number of native species such as *Dysoxylum gaudichaudianum* and *Arenga listeri*, as well as widespread non-native species such as *Solanum americanum (glossy night-shade)*, *Muntingia calabura* (Jamaican Cherry) and *Psidium cattleianum* (guava). These non-native species are bird-dispersed, and if allowed to establish, seem to perpetuate a cycle of visitation and recruitment. In the new field 23N, a small patch of fruiting *Solanum* plants attracted significant numbers of Imperial Pigeons. Such visitation to feed on a non-native species has both a positives and negatives at the same time. The positive is that the birds bring with them and deposit seed of numerous native forest trees. The negative is that this comes with seed of non-native weed species. If left unaddressed, the non-native species often outcompete many of the indigenous ones. However, weed control efforts counteract this and preferentially allow native recruits to establish. The net effect of Imperial Pigeon visitation is thus rendered a positive one, hence it is considered a good thing that they were found to be common across the rehabilitation fields.

The Swiftlet, *Collocalia natalis*, was also observed and moderately common throughout all fields, regardless of age. The species was seen to be most active in the early mornings and late afternoons foraging for flying insects above the canopy. Their presence and foraging behaviour indicates that there is a healthy abundance of insects and that rehabilitation fields do offer an ecosystem service to the species.

Goshawks, *Accipiter hiogaster natalis,* were also moderately common in rehabilitation fields of all ages; however there appeared to be an age demographic difference. Only adult birds were found hunting in five- and ten-year old fields, whilst juvenile birds were restricted to younger fields. Presumably, this separation is due to habitat quality, with older fields offering more complex habitat and food abundance than younger fields.

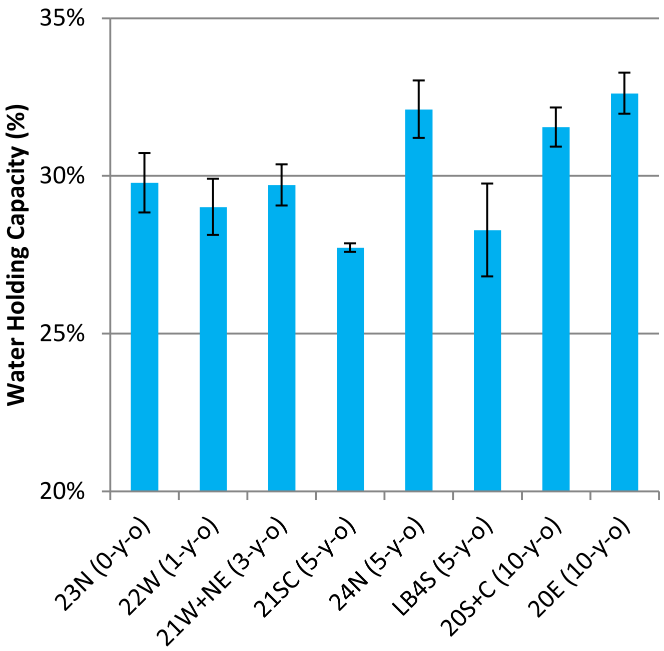
White Eyes (*Zosterops natalis*) and the Thrush (*Turdus poliosephalus erythropleurus*) were uncommon in young fields (zero, one and three years old), usually only transiting through them or occasionally seeking food items (e.g. insects or fruits). In five and ten year old fields however, these two bird species were common, actively foraging and nesting (Table 6). The Emerald Dove (*Chalcophaps indica natalis*) displayed a strong pattern associated with field age, usually being absent or rare in young fields (zero-, one-, and three-year-old fields) during the time of surveys. They were however moderately common in five-year-old fields, and common in ten-year-old fields. In these latter two categories they were seen foraging amongst the leaf litter and nesting.

Hawk-owls (*Accipiter hiogaster natalis*) were not seen during day-light hours, though their calls were noted in night-time surveys conducted by non-CIMFR program national park staff during the monitoring period (for the locations of monitoring sites see Appendix 2). Call detection appeared to be related to distance from intact forest rather than field age. For example, calls were typically heard at sites where forest was close by (e.g. the newly-planted field 23 North, and one-year-old field 22 West, the five year old field LB4), but not in the immediate vicinity of large fields where there was a long distance (>300m) to intact forest (e.g. the ten-year-old sites in the 20 Fields). Calls, however, may not necessarily reflect foraging behaviour, as birds may well be silent when actively hunting. Very little research has been published about the ecology of the Christmas Island Hawk-owl, although anecdotal evidence suggests that there a number of variables that affect call type, frequency and intensity including, but not limited to: 1) defence of the nest, 2) breeding season, 3) weather conditions or season, 4) territory demarcation, 5) response to incursions of home territory by other Hawk-owls, 6) moon phase or brightness, and possibly others. We do know that this species relies upon tree hollows for nesting, so we can be reasonably certain they will only achieve this in established forest and not yet in rehabilitation fields, unless pre-existing mature trees (>50 years old) were retained in the fields. Given the difficulty in seeing such birds at night, and their ability to perform noiseless flight (due to slow wing beats, relatively large wing surface area, low-friction texture and extremely fine fringing of flight feathers), Hawk-owls are difficult to detect when they are hunting. As such, it is hard to determine how much they are utilising rehabilitation fields. It is likely that their visitation is strongly couple with food availability (especially rodents, small birds and reptiles) parameters that will usually increase with field age. It appears, therefore, that their utilisation of rehabilitated areas is correlated to both distance from forest and field age. Dedicated research is needed if this question is to be answered more comprehensively, although this is not considered a priority research project for the CIMFR program.

In summary, it may be suggested that with increasing age, rehabilitated fields become more hospitable to the broader range of forest bird species, offering improved habitat and food resources.

Soil Assessments

In general, each rehabilitation field will have had soil sourced from its closest stockpile, and depending on the stockpiles size, will usually be fully allocated to one field alone. In some years, more than one field was rehabilitated, though these field areas vary greatly from <1 to >8 hectares, and budgets have fluctuated allowing more area to be rehabilitated in some years, and less in others. In years where more than one field received earthworks and these works were in different areas utilising different stockpiles, it is considered more relevant to examine the soils of these fields separately. As such, the figures below illustrate results from the different sites and will be discussed according to sites, not age. Therefore, the results of different age classes are presented in Table 5 only for general consideration. In this year's monitoring, the five and ten year old categories consisted of multiple fields; the five year old fields included 24N, LB4S and 21SC; the ten year old fields 20E and 20S+C. The rest were either in a single area, or sourced from the same stockpile (e.g. 21W and 21E Stockpile).



Water-holding capacity (WHC) of soils varied to a modest extent between sites (Figure 29). Interestingly, the greatest variation was found across five-year-old fields which ranged from 27.5% in 21SC to 32% in 24N. Ecologically, these figures are still relatively close and slightly above the mid-way point when taking into account the spectrum of soils elsewhere in the world. WHC for pure sands may be <10%, whilst heavy loams/silts/clays can be >50%. According to expert analysis in 2012, soils in planted fields have fractions of sand, loam and clay.

Figure 29: Water-holding capacity of surface soils from different fields

Dry bulk density of surface soils ranged between 1.01 and 1.20 and was there was a descending trend in relation to soil water-holding capacity (Figure 30). This outcome is expected and explains that, with increasing bulk density there are less pore spaces between soil particles, and thus less capacity to hold water. Given that these soils are of similar texture, the greater bulk density is indicative of greater compaction, although the range exhibited here is below the level expected to cause problems for plant root growth (possibly 1.4 g/cm3). Admittedly, the soils collected here were only from the top 10cm and it is likely that where sub-soil compaction has occurred at deeper layers, bulk densities will be higher.

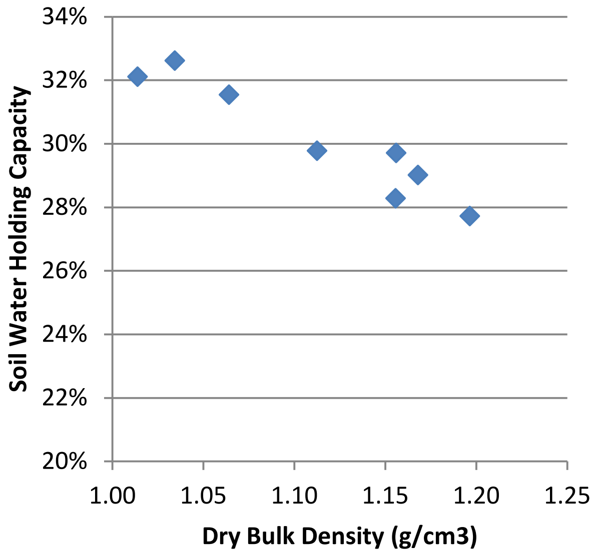


Figure 30: Relationship between soil water-holding capacity and dry bulk density

In terms of soil chemical properties, pH and Electrical Conductivity (EC) were measured. Values for pH ranged between just below neutral 7 (6.9 at 22W) to just above 7.5 (at 24N) (Figure 31). The slightly alkaline nature of most soils is likely due to the presence of calcium carbonates or 'chalk', which it is common across the island. In terms of nutrient availability, even slightly alkaline conditions can reduce nutrient availability. To correct for this, additions of sulphate forms of fertiliser – such as iron sulphate and potassium sulphate should be beneficial for growth.

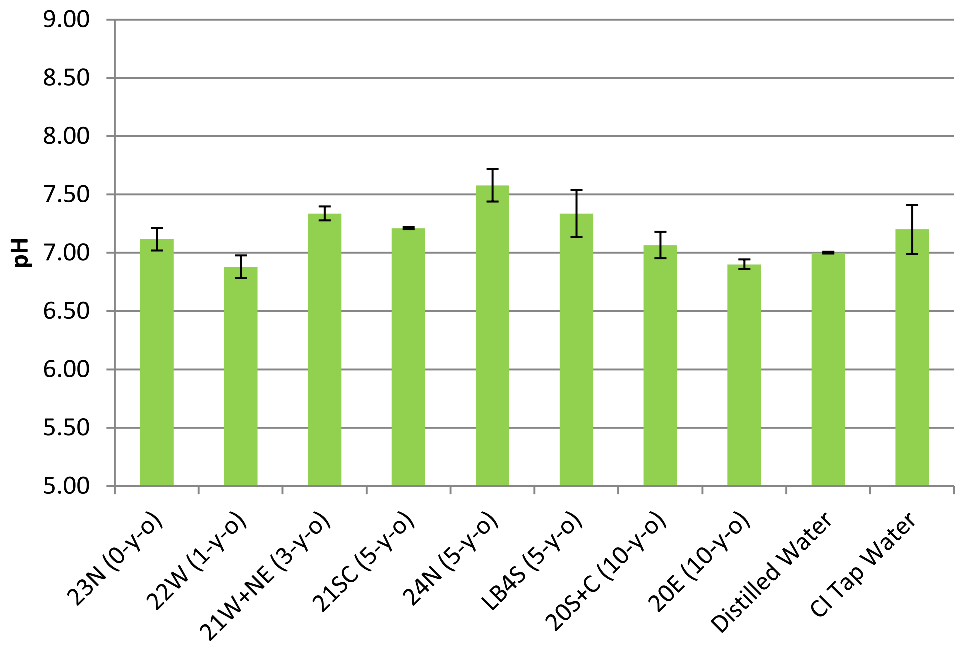


Figure 31: pH of surface soils from various fields

Electrical conductivity (EC) is an overarching measure of dissolved solutes (e.g. various inorganic compounds, salts and other ions such as calcium, sodium, bicarbonate, chloride, nitrogen, phosphorus, iron, sulphur etc) in a water sample. For all soils tested from rehabilitation fields, EC was very low, usually less than 50 micro-Siemens per centimetre [µS/cm] (Figure 32). There was little departure in EC readings from the distilled water (20 µS/cm) used to immerse the soil in the 1:5 soil-water extract. Interestingly, EC of Christmas Island tap water appears to be relatively high at around 500 µS/cm, yet this is still only moderate when compared with groundwater elsewhere. Many people can taste salt in water at ~1,500 µS/cm. Values around 2,000 µS/cm are considered high and not suitable for agricultural irrigation. Sea water is approximately 50,000 µS/cm, so about 100 times more salty than Christmas Island tap-water.

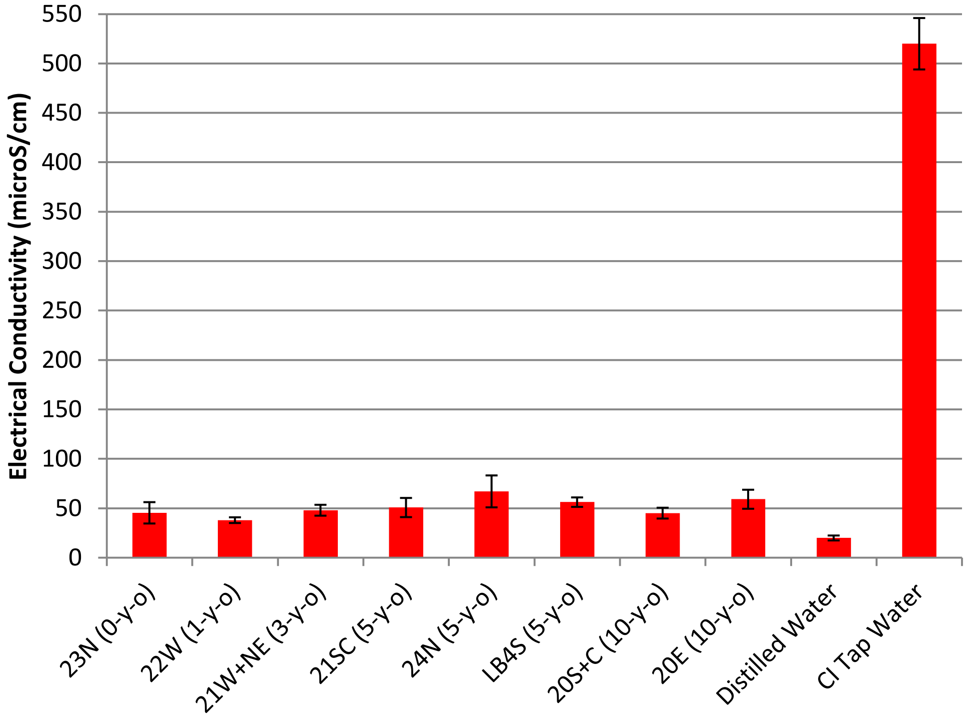


Figure 32: Electrical conductivity (micro-Siemens per cm) of soils from various fields

Table 4: Vegetation assessment measures for fields of different ages

Type	Measurement	New / zero-year-old (23N).	One-year-old (22W)	Three-year-old (21W + 21E SP)	Five-year-old (24N,LB4S,21SC).	Ten-year-old (20E,20S+C)
Diversity measures	Number of individuals measured	384	195	256	529	204
Diversity measures	Count number of species	28	21	25	26	24
Diversity measures	Hmax	3.33	3.04	3.22	3.26	3.18
Diversity measures	Shannons Diversity Index H'	2.83	2.62	2.65	2.67	2.82
Diversity measures	Shannons/Pielou's Value J (H'/Hmax)	85%	86%	82%	82%	89%
Diversity measures	Simpson's Index D (Sum of Pi^2)	10.7%	10.5%	10.8%	9.2%	7.6%
Diversity measures	Simpson's Diversity 1-D	89.3%	89.5%	89.2%	90.8%	92.4%
Diversity measures	Simpsons Reciprocol Index (1/D)	9.38	9.52	9.22	10.86	13.15
Diversity measures	Simpson's Equitability (E d)	0.33	0.45	0.37	0.42	0.55
Trees per hectare	Planted trees per hectare	3,900	2,400	2,550	2,092	1,025
Trees per hectare	Large recruits (> 20 cm) per hectare	888	38	10	2,317	625
Trees per hectare	All recruits (large and small) per hectare	1,088	38	20	11,290	810
Trees per hectare	Existing trees per hectare	13	0	0	0	50
Trees per hectare	Total planted, existing and recruits per hectare	5,001	2,438	2,570	13,382	1,885
Heights	Average height of planted trees only	0.73	1.11	1.27	5.76	6.80
Heights	Max height of planted trees only	2.40	3.30	5.50	23.00	21.40
Heights	Max height off all trees present	23	3.3	5.5	23	30
Heights	Sum heights of planted trees only	228	213	324	1,447	836
Heights	Sum heights of all tree present	272	214	324	1,742	1,055
Stem area @ 10cm	Sum CS-area (cm2) for planted trees	652	981	2,519	22,708	39,282
Stem area @ 10cm	Max CS-area (cm2) for planted trees	28	38	357	4,657	9,503
Stem area @ 10cm	Average CS-area (cm2) for planted trees	2	5	10	79	255
Health	Tree Health- Good	92%	73%	29%	80%	93%
Health	Tree Health- Fair	7%	19%	35%	12%	3%
Health	Tree Health- Poor	1%	8%	37%	8%	4%
Canopy	Percentage Canopy Cover	27%	22%	18%	71%	82%
Ferns	Percentage Fern Cover	5%	5%	4%	11%	23%
Leaf Litter	Percentage Leaf Litter Cover	10%	9%	17%	44%	38%

Table 5: Measures for invertebrate fauna, soil properties, and ground-layer cover

Site:	New / zero-year-old (23N)	One-year-old (22W+22CW)	Three-year-old (21W+21E SP)	Five-year-old (24N, LB4S, 21SC)	Ten-year-old (20E, 20S+C)
Invertebrate fauna measures					
Red crab activity	Transit Only	Foraging	Foraging and burrowing	Foraging and burrowing	Foraging and burrowing
Red crab burrow average density per hectare	0	0	60	325	420
Red crab burrow range in density per hectare	0	0	0 - 150	0 - 750	0 - 1,500
Robber crab activity	Transit Only	Foraging	Foraging	Foraging and burrowing	Foraging and burrowing
Orb spider density per hectare	0	50 (Low)	140 (Low)	70 (Low)	20 (Low)
Millipede abundance per square meter	0	0.25 (Very low)	1.2 (Low)	0.25 (Very Low)	2.6 (Low)
Giant African Land Snail abundance per square m	0	0	0	0.16 (Very Low)	0
Soil measures:					
Dry Bulk Density (g/cm3)	1.11	1.17	1.16	1.12	1.05
Water holding % (water of oven dry soil)	29.8%	29.0%	29.7%	29.5%	32.1%
Soil pH	7.12	6.88	7.34	7.40	6.98
Soil EC (micro Siemens/cm)	45.45	38.03	48.07	58.96	52.16
Ground cover:					
Projected area cover of ferns	5%	5%	4%	10%	23%
Projected area cover leaf litter	9%	10%	17%	42%	38%

Table 6: Presence and activity of native forest bird species in fields of different ages

Bird	***Species***	**0-year-old**	**1-year-old**	**3-year-old**	**5-year-old**	**10-year-old**
CI White eye	*Zosterops natalis*	Uncommon, transient	Uncommon, transient	Uncommon, transient	Common, foraging and nesting	Common, foraging and nesting
CI Swiftlet	*Collocalia natalis*	Moderately common, foraging	Moderately common, foraging	Moderately common, foraging	Moderately common, foraging	Moderately common, foraging
CI Thrush	*Turdus poliocephalus erythropleurus*	Uncommon, transient	Very uncommon	Uncommon, transient	Moderately common, some foraging and nesting	Common, foraging and nesting
CI Imperial Pigeon	*Ducula whartoni*	Very common, foraging	Common, foraging	Common, foraging	Common, foraging	Common, foraging
CI Emerald Dove	*Chalcophaps indica natalis*	Very uncommon	Very uncommon	Very uncommon	Moderately common, some foraging and nesting	Common, foraging and nesting
CI Goshawk	*Accipiter hiogaster natalis*	Moderately common, foraging	Moderately common, foraging	Moderately common, foraging	Moderately common, foraging	Moderately common, foraging
CI Hawk-owl	*Ninox natalis*	Daytime absent. Occasional calls at night in nearby forest.	Daytime absent. Frequent calls from nearby forest at night.	Daytime absent. Occasional calls from forest at night.	Daytime absent. Calls were common in vicinity of these fields at night time.	Daytime absent. Calls heard from good forest ~500 m to the south at night.

4. Schedule of Works: 1 July 2015-30 June 2016

The proposed Schedule of Works for 2015-16 below was provided to DIRD in March 2015 to provide a proposed plan of works and budget for 2015-16, as required under the MoU.

4.1 Tree propagation, planting and earthworks

New earthworks and open-field plantings are proposed for approximately 2.4 hectares in the vicinity of ex-mining lease 107 (Figure 33). Of this area, 1.96 hectares is Vacant Crown Land, and the remainder around the edge is National Park. This site is located 1.9 km south of East-West baseline on the Blowholes track. It is 170-180 m above sea level and a pocket of degraded land surrounded by intact forest on all sides. The area is considered of high conservation value because of its proximity to several Abbott's booby nesting trees, and it provides high quality habitat for land crabs and forest birds. This site was rated as the highest priority area for rehabilitation in the research thesis entitled "Prioritising mine sites for rehabilitation on Christmas Island: an index modelling approach" by Walker (2012).

A clearing permit application was submitted to the Department of Environment and Regulation (DER- WA) in May 2014, in order to obtain permission to remove mixed weeds and some degraded native vegetation from the Vacant Crown Land. The site was assessed by a DER Officer on 11 June 2014 and approval granted 18 July 2014. A small patch of good quality vegetation on a remnant mound of soil was excluded from the application as it will be retained. Initial surveys have found little soil in situ (10-20 cm on average) throughout the field; hence bulk soil will be needed from stockpiles on or nearby the site (SP 107A, 107B and 107C). The first stockpile to be utilised is SP107C (~15,000 tonnes) on the eastern side of the road. At the time of writing this report, earthmoving machinery had removed weeds and degraded vegetation, and replenished soil across the site.

To revegetate the area, approximately 9,000 primary 'pioneer' plants have been propagated for planting in early 2016. About 20 native tree species will be included in the pioneer mix; these are generally fast-growing, sun-loving, hardy species tolerant of the exposed conditions in new fields.

Figure 33: Location of ex mining lease 107 where approximately 2.4 hectares of earthworks and new plantings are proposed for the 2015-16 financial year

In addition, a further 6,000 trees have been propagated for infill and secondary plantings. Secondary tree species otherwise referred to as forest mix species, constitute an additional 10 species. These are generally slower growing, better suited to shaded conditions under the canopy in their juvenile state, but ultimately taller and longer lived species. Included in the secondary species are the three forest giants of Christmas Island: *Hernandia ovigera*, *Planchonella nitida* and *Syzygium nervosum*. These three species can grow close to, or even greater than 50 m tall and are the main nesting habitat trees for the Abbott's Booby. Secondary plantings will occur over approximately 14 hectares of already established fields. Key target areas are Field 21 West, 22 Central and 22 Central East, 21 Central and 21 East. It is also proposed that some enhancement plantings and maintenance work (i.e. weeding and fertilising) is conducted in Field 117 East- a newly relinquished site (October 2014) with an area of 2.1 hectares (Figure 2). This area was first subject to rehabilitation works in 1998 under a previous rehabilitation program (CIRRP) when the methods and plant species used were different to those that are used today.

The relinquishment of 89.8 hectares of mine lease in September 2014 has opened-up some additional options for rehabilitation works in 2016-17 and beyond Figure 35. Of the 14 individual parcels of land, some are in high-conservation value forest areas, while others are in low conservation value areas or are very degraded with insufficient soil on site or nearby to warrant replanting. Case-by-case assessments in April-May 2015 determined that approximately 12 hectares are suitable for rehabilitation. For a full explanation of assessments, please refer to Appendix 3. Site "122 East" – with an area of 2.68 hectares – was stated as primary rainforest in the CIP relinquishment letter, and according to the Vegetation and Clearing Map 2014 carried out by Geoscience Australia. This parcel was not included in the 12 hectare rehabilitation figure

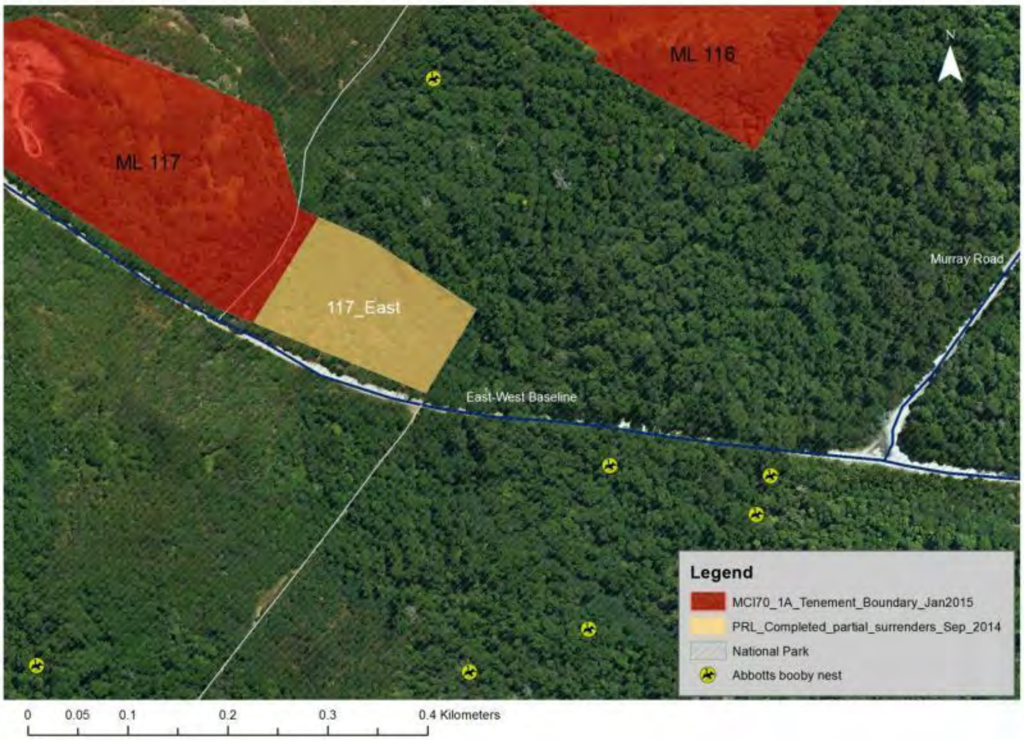


Figure 34: Location of Site 117 East (2.1 hectares) relinquished in September 2014.

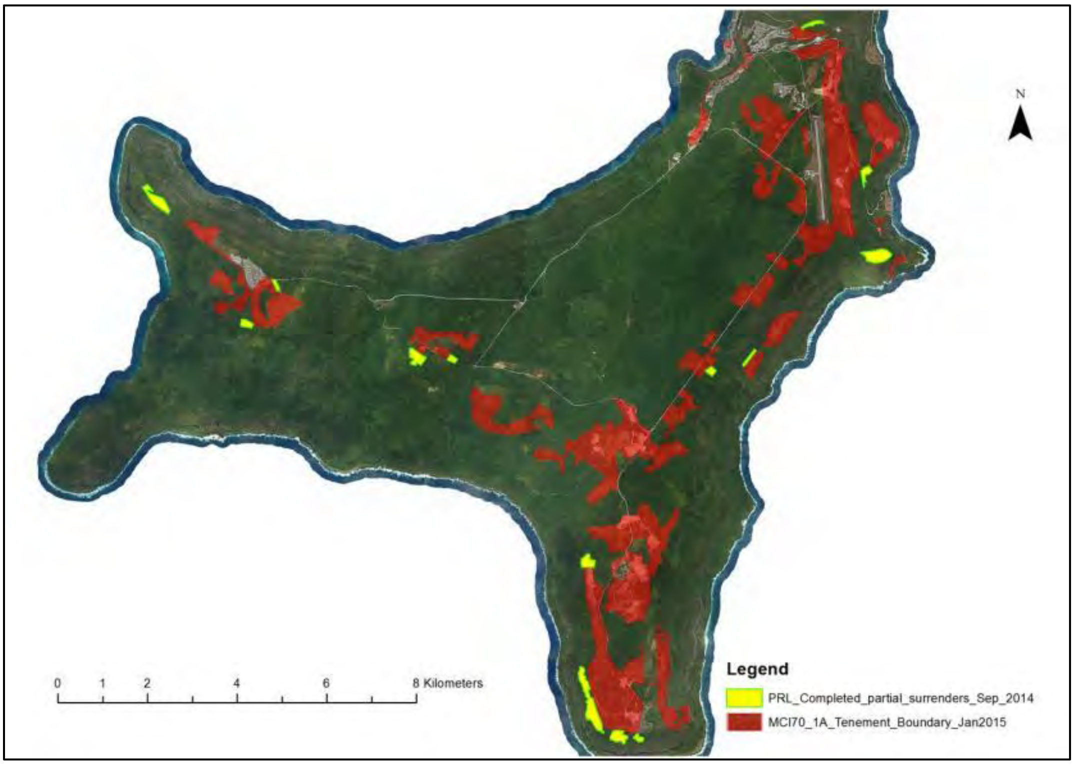


Figure 35: Location of areas relinquished by PRL to the Commonwealth in September 2014 (yellow parcels) and remaining mine lease (red areas).

5. Financial Expenditure 2014-15 Financial Year

During the 2014-15 financial year the CIMFR program expended $1.72 million (Table 7). Employee expenses constituted $898,445 and covered all wages, superannuation, allowances for all staff employed (between 10 and 12 FTE). Earthworks were $437,904, more expensive than originally anticipated. Supplies and operating expenses (e.g. fertiliser, herbicide, water bills, power bills, PPE, consumables, equipment, vehicle running and maintenance etc.) cost $265,930. Depreciation for infrastructure and vehicles was $116,982.

Table 7: Financial expenditure 2014-15

Expenditure 2014-15	Amount
Employee expenses	$898,445
Earthworks and transport	$437,904
Supplies and operating expenses	$265,930
Depreciation	$116,982
Total	**$1,719,261**

6. References

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Appendix 1

Biophysical monitoring methods

Depending on the size of the field, usually between two and four transects of 50 m long were sampled at each site. These transects were established in the year each site was planted and have been used as ongoing monitoring plots. A brief description of each sampling method is as follows:

A.1.1 Diversity indices

A flora survey was conducted along the 50 m length of each transect. The abundance and species of trees encountered within 2 m either side of the measuring tape was recorded. Diversity indices were calculated including:

- Shannon's Diversity Index (*H*). This is a mathematical measure of species diversity in a community and accounts for both abundance and evenness, as per the formulae:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

where *H* is Shannon's Diversity Index, *S* is the total number of species found in the transect (species richness), p_i is the proportion of the '*i*'th species out of the total *S,* and *ln* is the natural logarithm.

- Shannon's equitability value (E_H) ranges between 0 and 1 and is calculated by dividing *H* by H_{max} where H_{max} is the natural logarithm of *S*, as per the formulae:

$$E_H = H / H_{\max} = H / \ln S$$

- Simpson's Evenness index (E_D) describes the relative representation of species in a given sample. It requires calculation of Simpson's diversity index (*D*) as per the formulae:

$$D = \frac{1}{\sum_{i=1}^{S} p_i^2} \longrightarrow E_D = \frac{D}{D_{\max}} = \frac{1}{\sum_{i=1}^{S} p_i^2} \times \frac{1}{S}$$

  where parameters are the same as for Shannon's Diversity Index, and D_{max} equals *S*. Evenness ranges between 0 and 1, where 1 represents an equal representation of all species in a sample.

A.1.2 Vegetation measurements

Tree height was measured using a height staff or clinometer for all trees encountered within 2 m either side of the measuring tape (using a 2 m length of PVC 40 mm pipe) along the full length of the 50 m transect. This measure took into account all strata of the vegetation in the transect, including tall canopy, mid-layer and small trees. General canopy height represents the uppermost canopy layer surrounding the transect. Recruits were recorded along the way- those which were considered well established and greater than 20cm tall were included in the diversity indices, those less than 20 cm tall were not.

Canopy % cover was measured using digital image analysis of hemispherical photographs looking vertically up into the canopy from a camera mounted on a tripod 30 cm above ground level. Image analysis was done using the software package "Gap Light Analyzer" Version 2.0 (Simon Fraser University, British Columbia, Canada and Institute of Ecosystem Studies, New York USA). See Figure A1.1 for examples of canopy threshold images.

Photographs were taken early in the morning under uniform sky conditions and before the sun was high enough to interfere with images.

Table A1: Comparison of example species diversity measures

Diversity Indices	**Column 1 Even Community**	**Column 2 Biased Community**	**Column 3 Example Plantation**	**Column 4 Monoculture**
Individuals	100	100	100	100
Number of Species (k)	20	20	2	1
Distribution	20 species of 5 individuals each	19 species of 1 individual, then 1 species of 81 individuals	1 species of 99 individuals, and 1 species of 1 individual	1 species of 100 individuals
Maximum possible diversity (H_{max})	2.996	2.996	0.693	0.000
Shannon's Diversity Index (H^1)	2.996	1.046	0.056	0.000
Proportion Shannon of Maximum H^1/H_{max}	100%	35%	8%	0%
Simpson's Equitability Evenness	1	0.076	0.510	1

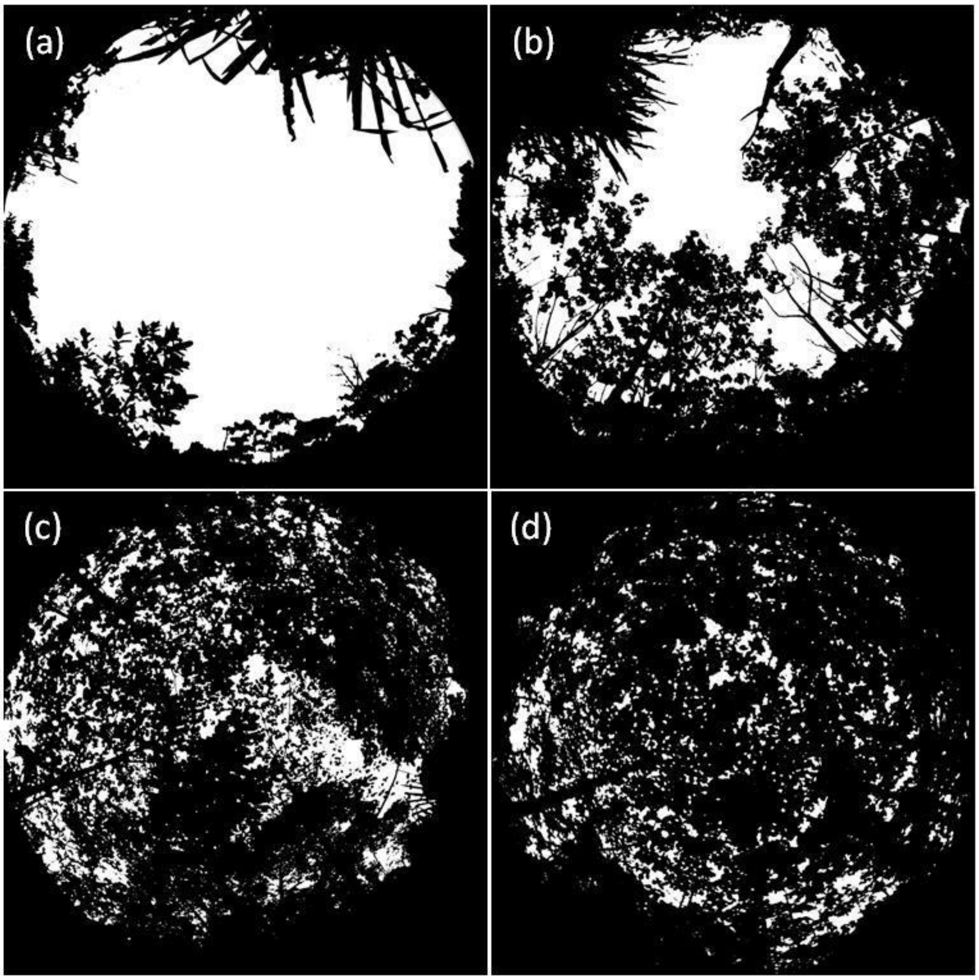


Figure A1.1: Examples of hemispherical canopy photographs following image analysis. Canopy cover for (a) is 22%, (b) is 60%, (c) is 81% and (d) is 88%.

Stem diameters were taken 10 cm above the ground and 100 cm above ground (once trees were tall enough) using a standard diameter tape.

Projected cover of ferns was determined using a 2 m x 2 m quadrat ($4m^2$) in the first and last two metres of the transect (at 0 m and 48 m) on opposing sides of the measuring tape. Ferns typically found include native species such as *Nephrolepis biserrata, Davallia solida, Microlepia speluncae* and *Microsorum scolopendria*. Low (10%) to moderate levels (<30%) are considered healthy and acceptable, although high levels (>50%) can become problematic by hindering recruitment and require control.

A.1.3 Fauna species measures

Fauna species measures were recorded along the same 50 m transects as vegetation measures. Golden orb spider counts were done first as soon as the measuring tape was rolled out so as to not disturb webs upon traversing the transect. Assessments included the space and branches up to ~4 m above ground (limit of investigators reach with 2 m PVC pipe length).

Bird observations were done over a 20 minute period at each transect and included only land-based forest birds (not seabirds). Below the canopy, birds were counted only within a 20 m radius of the observer, above the canopy, birds (e.g. raptors) were counted to approximately 100 m out, or as far as canopy openings and visibility would permit.

Crab burrows were counted with 2m either side of the tape measure along the full 50m length of the transect. Each transect was considered one replicate within that field. Because of the variable number of transects per field, numbers were averaged across transects and extrapolated to determine density per hectare. Sightings of red crabs and robber crabs were also noted, though these were strongly influenced by the time of day and presence or absence of recent rain.

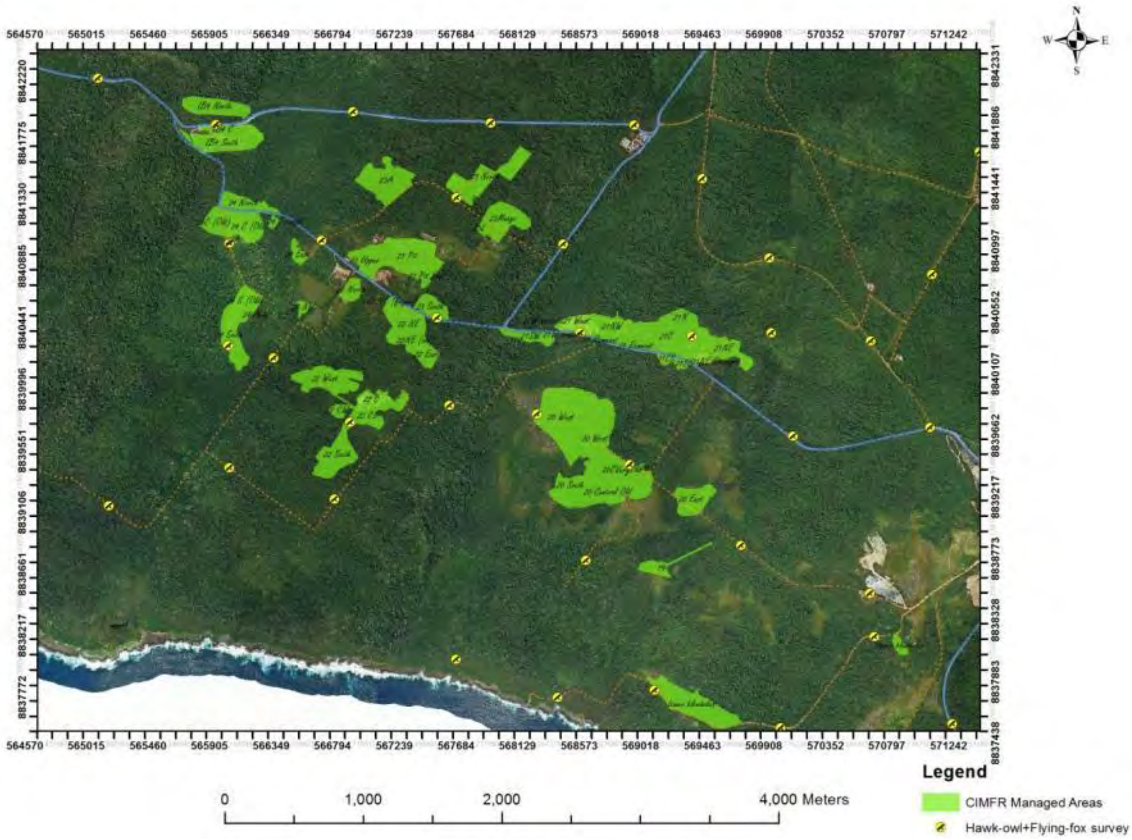
Giant African land snails (including dead shells) were surveyed in the same 2 m x 2 m quadrat as Ferns at the start and end of the transect. Millipedes were assessed in 1 m and 1 m quadrats also at these points.

A.1.4 Soil parameters

Three soil samples of were taken at each transect. Samples (50 mm diameter x 50 mm deep) were collected at 10 m, 20 m, 30 m along the transect. Water Holding Capacity was done on core samples (as per methods described by Hunt and Gilkes 1992). Bulk soil was sieved to remove coarse particles/rocks for use in the measurement of pH, Electrical Conductivity (EC) and organic carbon content. Soil pH was measured on a 1:5 extract of soil and water following the method of (Rayment and Higginson 1992). The pH probe was regularly calibrated to pHs 4.0, 7.0 and 10.0. Electrical conductivity (EC) was measured on a 1:5 extract of soil and deionised water using a probe calibrated to a buffer of 14.13 $\mu S\ cm^{-1}$ (Rayment and Higginson 1992).

Appendix 2

CIMFR managed areas and locations of night-time survey locations for Hawk-owl and Flying-fox conducted by the Christmas Island National Park Natural Resource Management (NRM) team



Appendix 3

Relinquished land assessments. The spreadsheet below (and continued over the following 3 pages) was prepared in 2014-15 by Parks Australia to describe the characteristics and conservation value of mining sites and their rehabilitation potential to help inform future planning for the selection of CIMFR sites (subject to relevant approvals)

Text in dark blue has been extracted from the GIS attribute table provided by CIP — Weighting >>>

Lease	Label	CIP Note "HECTARES"	CIP Note "Desc_"	CIP Note "Site_Remed"	CIP Note "Comment"	CIP Note "Stockpiles"	CIP Note "STP_tonnes"	FID	Proximity to primary forest
100	100(1)-SPW_North	6.26	CIP pinn field	needs bunding, flattening	easy to site remediate		0	4	Immediately surrounded by high quality primary forest on 3/4 of edge
100	100(2)-SP_South1	2.071	pinnacles from BPC/PMCI mining	no site remediation required	old pinn field, unlikely CIP to remine		0	6	Immediately surrounded by primary terrace forest on 3/4 of edge
100	100(3)-SP_South1	7.583	pinnacles from BPC/PMCI mining	no site remediation required	old pinn field, unlikely CIP to remine		0	11	Immediately surrounded by primary terrace forest on 3/4 of edge
100	100(4)-SP_West	22.401	pinnacles from BPC/PMCI mining	site remediation needed, bunding	old pinn field, unlikely CIP to remine		0	5	western boundary has primary terrace scrub forest, but eastern half is heavily disturbed and weed infested
116	116_South	7.983	shallow pinn from BPC/PMCI	abuts PAN rehab to west and east	central plateau PAN focus area		0	2	Over half the boundary of this field abuts onto primary forest, or good quality regrowth
117	117_East	2.108	PAN rehabbed area	Completed by PAN	site completed rehabbed by PAN		0	3	Primary rainforest is adjacent to approximately half the boundary
121	121_West	2.104	thin regrowth containing water source	no site remediation required	no approval due to water source in area		0	10	High quality regrowth adjacent to primary forest. Ross Hill Gardens and wet land areas close by.
122	122_East	2.684	primary rainforest/great regrowth	no site remediation required	primary forest, not able to mine under lease cond		0	9	This parcel is entirely made up of primary rainforest, and surrounded by primary forest of 3 out of 4 sides.
129	129	13.603	mined out by CIP	basic site remediation completed, more required	mined out, abuts NP to west, sea bird nesting area		0	7	Surrounded by undisturbed terrace forest. Sea bird nesting area.
131	131	4.312	remnant insitu and pinn from PMCI/BPC	no site remediation required	drilling proved no economic resource in area		0	13	Small sections of terrace forest on either side
136	136_North	2.731	pinnacles from BPC/PMCI/CIP	basic site remediation completed	PAN focus area, abut NP to N,S,E		0	8	Terrace forest along northern boundary. Heavily degarded to the south.
137	137	10.824	Pinnacle field, NWP Ravine access track	access track safety bund wall completed	good sea bird nesting site, veg regrowth already		0	0	Good terrace forest either side and sea bird nesting area.
138	138_East	1.687	pinnacles from BPC/PMCI mining	no site remediation required	shallow pinnacles, near dangerous intersection		0	1	Largely surrounded by disturbed land, with primary forest some 40 m from the small edge of the Northern border.
139	139-STP25E	3.487	stp from BPC/PMCI	no site remediation required	unlikely approval due to regrowth	25E	102,000	12	Primary forest to the west and good regrowth on all other boundaries. Abbott's Booby nests nearby.
	Total Area=	**89.838**							

Label	Natural values score of surrounding land/forest (0-5)	Natural values score of internal site (0-5)	Importance of local area for Red Crabs and migration	Importance of local area for Abbott's Booby (0-5)	Site Nature Value Score	Distance to National Park	Potential for rehabilitation
	35%	10%	30%	25%	100%		
100(1)-SPW_North	5	0	4	2	69%	Less than 100 m to the West	Potentially, but difficult due to lack of soil available. Moderate priority .
100(2)-SP_South1	4	1	1	0	36%	Approximately 500 m to the West	Little soil available. Not feasible using current approach. Only low scrub vegetation could be established if necessary.
100(3)-SP_South1	4	1	1	0	36%	Approximately 500 m to the West	Little soil available. Not feasible using current approach. Only low scrub vegetation could be established if necessary.
100(4)-SP_West	2	0	1	0	20%	Abuts NP on Western boundary	No reserves of soil available on site or close by. Will never be possible to rehabilitate back to forest.
116_South	3.5	0.5	4	5	75%	Abuts NP on about three quarters of the boundary	Excellent prospects for rehabilitation at some stage. Soil stockpiles in the area, high nature value score.
117_East	3.5	3	4	4.5	77%	Abuts NP on about three quarters of the boundary	Rehabilitation progressing well. Some weed control and small scale infill plantings would result in good conservation outcomes.
121_West	4.5	4	5	1	75%	800 m to the West	Regrowth progressing well. Some weed control and small scale infill plantings would result in good conservation outcomes.
122_East	5	5	5	2.5	88%	300 m to the West	Does not require rehabilitation as it is already primary rainforest
129	5	1	3	0	55%	Abuts National Park on Western boundary.	Little soil available. Rough ground. Not feasible using current approach. Only low scrub vegetation could be established if necessary.
131	3	2	3	0	43%	1.5 km from NP	Some stockpiles on minelease ~ 300 m away, but may be product for CIP and not acessible for rehab. Some soil on site. Could be feasible, but conservation value is quite low.
136_North	2.5	1	1	0	26%	Surrounded by NP on 90% of the boundary.	No soil or stockpile close by. Would be extremely difficult to rehabilitate. Cost benefit is not worth it.
137	5	2	2	0	51%	Fully surrounded by NP	Little soil available. Rough ground. Not feasible using current approach. Only low scrub vegetation could be established if necessary.
138_East	0.5	0	1	2	20%	NP on Northern and Eastern edges, about 40 m from boundary	Low. Soil may be available nearby, but likely to be utilised elsewhere more effectively.
139-STP25E	4	3	4	4	78%	Fully surrounded by NP	Highly desirable. Good soil availability on site.

Label	Priority score for CIMFR program (till 2020)	Wanted for CIMFR program between now and 2020?	Comment on zoning by Local Planning Strategy (LPS)
100(1)-SPW_North	3	Potentially at some stage in the future, but not in the next 5 years.	"Horticulture/aquaculture". Site is approx 16 km from town and terrain is rough - limestone chalk at surface. Likely to be high cost to set up. In addition to distance from town, may be cost prohibitive.
100(2)-SP_South1	0	No - not for establishment of forest. Not in the current scope of the CIMFR program.	"Horticulture/aquaculture" Site is approx 19 km from town, terrain is very rough. The work and expense required to prepare the site for this purpose would undoubtedly be cost prohibitive.
100(3)-SP_South1	0	No - not for establishment of forest. Not in the current scope of the CIMFR program.	"Horticulture/aquaculture" Site is approx 19 km from town, terrain is very rough. The work and expense required to prepare the site for this purpose would undoubtedly be cost prohibitive.
100(4)-SP_West	0	No	"Unassigned" is appropriate. The site is extremely rough and sloping. Would require major works if put to human use.
116_South	5	Yes, definitely.	The LPS was not referred to in the relinquishment document. If considered appropriate by all relevant stakeholders, and necessary approvals given, classification as National Park may be warranted in the future.
117_East	5	Yes, definitely.	"National Park" is proposed for this parcel of land according to the LPS. This is considered appropriate given the conservation values of the site and local area.
121_West	5	Yes, definitely.	"Unassigned". Given the conseration values and proximity to Hosnies Springs, Greta Beach and Dolly Beach, it may be worthy of consideration for National Park, if the larger area was to be reclassified in the future.
122_East	NA	Not necessary, as primary forest does not need rehabilitation	As defined in the CI Vegetation and Clearing map conducted by GeoScience Australia (2014), and stated by CIP in their relinquishment letter, this area is "entirely made up of primary rainforest". As such "Horticulture/Aquaculture" defined in the LPS is not appropriate. Should be considered for National Park in the future.
129	1	No - not for establishment of forest. Not in the current scope of the CIMFR program.	"Unassigned". No comment.
131	1	No - not for establishment of forest. Not in the current scope of the CIMFR program.	"Environmental Offset Area". This does not seem appropriate on face value, but further definition may be required.
136_North	1	No - not for establishment of forest. Not in the current scope of the CIMFR program.	"National Park" is proposed because this site is surrounded by it almost entriely. It is an odd shape, but for the sake of boundary of continuity, it may be incorporated into the Park if deemed appoporiate.
137	1	No - not for establishment of forest. Not in the current scope of the CIMFR program.	"National Park" is proposed because this site is entirely surrounded by it. Potentially could be incorprated into the NP for continuity.
138_East	1	Not in the foreseeable future.	"Community Infrastructure" could be appropriate as services are less than 100 m away and road access is very close.
139-STP25E	5	Yes, definitely	"Community Infrastructure" does not appear to appropriate for a remote site where services over 1.5 km away and there is poor road access. Site is covered with vegetation.

Label	Comment on zoning by Crown Management Plan (CMP)	Propose management by Parks Australia/CIMFR
100(1)-SPW_North	"Rural/Horticulture". Same comment for LPS. Surrounding forest may be appropriate for National Park if considered in the future.	No, not at this stage
100(2)-SP_South1	"Rural/Horticulture". Same comment for LPS. If the remainder of South Point was potentially considered for National Park, these blocks may be incorporated for continuity.	No, not at this stage
100(3)-SP_South1	"Rural/Horticulture". Same comment for LPS. If the remainder of South Point was potentially considered for National Park, these blocks may be incorporated for continuity.	No, not at this stage
100(4)-SP_West	"Rural/Horticulture". Site is approx 19 km from town, terrain is very rough and sloping. Inconceivable that it would be cost effective to use for this purpose.	No, not at this stage
116_South	The CMP was not referred to in the relinquishment document. Same comment for LPS.	Yes
117_East	"National Park" is proposed for this parcel of land according to the CMP. This is considered appropriate given the conservation values of the site and local area.	Yes
121_West	"Vacant Crown Land". Same comment for LPS.	Yes
122_East	As defined in the CI Vegetation and Clearing map conducted by GeoScience Australia (2014), and stated by CIP in their relinquishment letter, this area is "entirely made up of primary rainforest". As such "Rural/Horticulture" defined in the CMP is not appropriate. Should be considered for National Park in the future.	Yes
129	"Public Open Space"	No, not at this stage
131	"Public Open Space"	No, not at this stage
136_North	Same comment for LPS.	No, not at this stage
137	Same comment for LPS.	No, not at this stage
138_East	Heavily degraded pinnacle field. Low value for National Park in its current state.	No..
139-STP25E	Appropriate (National Park)	Yes

FOI 170312
Document 3

Application to release the microhymenopteran parasitoid *Tachardiaephagus somervillei* for the control of the invasive scale insect *Tachardina aurantiaca* on Christmas Island, Indian Ocean

Prepared by Peter T. Green, Dennis J. O'Dowd and Gabor Neumann (La Trobe University, Kingsbury Drive, Bundoora 3086) on behalf the Director of National Parks.

Submitted by The Director of National Parks, for assessment by the Australian Government Department of Agriculture

20 October 2014

Contents

Executive Summary

The invasive, non-native scale insect, the yellow lac scale *Tachardina aurantiaca* (Kerriidae) has been listed as a Target for biological control on Christmas Island (Indian Ocean), mainly because of the role it plays in the dynamics of supercolony formation of another invasive species, the yellow crazy ant *Anoplolepis gracilipes*. Invasion and supercolony formation by the yellow crazy ant is Listed as Threatening Process under the EPBC Act, because of the direct and indirect negative impacts it has native biota. The yellow lac scale occurs in extremely high densities in supercolonies, and supplies a large fraction of the honeydew required to maintain ecologically damaging, high densities of this ant.

This proposal is to introduce a microhymenopteran parasitoid to control the yellow lac scale on Christmas Island. In its native range in Southeast Asia, the yellow lac scale is very rare and patchily distributed, has a diverse assemblage of natural enemies, and is heavily parasitized. On Christmas Island, the species is abundant (especially so in association with yellow crazy ant supercolonies), and the females are not parasitized by any of the few natural enemies associated with the species on the Island.

Introduction of a host-specific parasitoid could bring the yellow lac scale under control and indirectly suppress supercolony formation by the yellow crazy ant, with immediate and long-lasting benefits to biodiversity on Christmas Island

The proposed agent is *Tachardiaephagus somervillei* (Mahdihassan 1923), an encyrtid endoparasitoid with a broad native geographic range (India, Thailand and Peninsular Malaysia, as well as Sarawak and Sabah in Borneo) and a broad climatic range (from consistently warm and wet in the aseasonal tropics of Southeast Asia to much drier and seasonally cool climates in India). Several lines of evidence indicate that *T. somervillei* has a very narrow host range restricted to species in the lac scale family Kerriidae, and that the probability of non-target impacts on other scale insects on Christmas Island is extremely low;

1. Historical data indicate this species is known from just five host species in a single family, the Kerriidae. This includes the target species *T. aurantiaca*, and four species in *Kerria*, the lac genus of commerce.
2. Database records further indicate that the genus *Tachardiaephagus* is narrowly specialized on lac scale insects; all seven species of *Tachardiaephagus* are known only from kerriid hosts (*Tachardina*, *Kerria*, and *Paratachardina*).
3. No-choice host-specificity tests conducted under field conditions within the native range of the agent confirm this degree of specificity. Of nine species tested, only the known host *T. aurantiaca* was parasitized, while four species of soft scales (Coccidae), one species of armoured scale (Diaspididae) and one species of mealybugs (Pseudococcidae) were not parasitized at all.
4. There are no native or endemic, non-target scale insect species on Christmas Island. More than 400 hours of structured field survey over two years has not detected any native or endemic species. *Paratachardina pseudolobata* (Kerriidae) occurs on Christmas Island and could possibly be parasitized by *T. somervillei*, but this species is not native to the Island.

There are seven endemic species or subspecies in the Order Hemiptera known on Christmas Island, but three lines of evidence indicate the risk posed by *T. somervillei* to these species is extremely low.

1. Parasitoids from the Encyrtidae, the family to which *T. somervillei* belongs, are very uncommon parasitoids of the families containing the endemics; four of the seven families to which the endemic hemipterans belong have no known encyrtid parasitoids, and the remaining three families are attacked by just 15 encyrtid parasitoid species, despite great diversity (3735 species) in that group.
2. Most encyrtid parasitoid species known to attack scale insects in the Kerridae, the family to which the yellow lac scale belongs, are restricted to hosts in that family. The host ranges of the remaining encyrtid species are restricted to the Superfamily Coccoidea. This suggests that any encyrtid parasitoid that attacks host taxa within the Kerriidae is highly unlikely to attack any hosts other than scale insects.
3. All of the endemic hemipteran species on Christmas Island occur in different suborders (either Suborder Auchenorrhyncha or Heteroptera) to the yellow lac scale (Suborder Sternorrhyncha). Thus, any potential for non-target impacts by *T. somervillei* on these endemic Hemiptera would require a host range that bridges this very substantial phylogenetic distance. No encyrtid parasitoid species that uses kerriid lac scales is known to bridge this substantial phylogenetic distance.

There are no morphological or genetic differences between populations of yellow lac scales in the native range in Malaysia and on Christmas Island. Further, there are no morphological or genetic differences between populations of the agent *T. somervillei* in the Southeast Asian part of its native range. This obviates the need to consider matching populations when selecting the source of the agent for introduction.

The founder population of *T. somervillei* will be sourced from Kuala Lumpur in Malaysia. This location is climatically well matched to Christmas Island, nearby an established rearing facility at the Forestry Research Institute of Malaysia, and close to an international airport. At the time of writing, it is likely the agent will be transported to Christmas Island from Kuala Lumpur via Perth, Western Australia.

A quarantine facility does not exist on Christmas Island, so the transport of *T. somervillei* to Christmas Island should conservatively be treated as the "release from containment" that would normally occur on the mainland. Therefore, sanitary procedures to ensure the agent is free of pathogens and hyperparasitoids will be conducted at the Forest Research Institute of Malaysia. Only the adults of *T. somervillei* will be introduced, minimizing the possibility of co-introducing any hyperparasitoid.

A dedicated screen house production facility is being built by Parks Australia on Christmas Island to mass-rear *T. somervillei* for field release. This involves the production of large populations of yellow lac scales on potted seedlings of suitable host species. A complementary program to rear and release parasitoids against honeydew-producing soft scales is also being developed, using parasitoids already present on Christmas Island.

A release and monitoring protocol has been designed to evaluate the program and can be used to adapt the program if needed. These protocols consider monitoring the incidence of parasitization before and after field releases, at release sites and other (control) sites remote from release sites. The activity of yellow crazy ants will be monitored at the same sites to determine if control of the yellow lac scale by *T. somervillei* indirectly leads to the suppression of yellow crazy ant abundance and supercolony formation.

Preamble

The detection of yellow crazy ant supercolonies, and their suppression using toxic bait, has been of central and ongoing management concern to Parks Australia on Christmas Island since supercolonies were first detected in the late 1990s. The concept of indirect biological control – that yellow crazy ant supercolonies could be suppressed through the use of parasitoids to control honeydew-producing scale insects – was first proposed in 2003. In 2009 a team from La Trobe University, funded by the (then) Department of Sustainability, Environment, Water, Populations and Communities through the Director of National Parks, commenced a four-year program of research and development to evaluate the concept and feasibility of indirect biocontrol. The program had three overarching questions:

1. Does the yellow crazy ant depend on honeydew-producing scale insects for supercolony formation?
2. Which species of honeydew-secreting scale insects occur on Christmas Island, and are appropriate natural enemies for scale insects available for introduction?
3. What regulatory frameworks govern the implementation of a biological control program on Christmas Island, an external territory of Australia?

Based on this research (2009-2013), Parks Australia is pursuing indirect biological control as a long-term, sustainable management solution to the yellow crazy ant invasion on Christmas Island. The biological control program will target the entire suite of honeydew-producing scale insects, and has two parts; 1) the introduction of a new parasitoid to target *Tachardina aurantiaca*, a scale insect strongly implicated as the key player in the dynamics of yellow crazy ant supercolonies (hence this Release Package), and 2) the use of parasitoids already present on Christmas Island to target soft scales.

Most of the primary research data supporting the concept of indirect biological control is contained in research reports produced for Parks Australia, and much of it is reproduced in this Release Package. However, for reasons of length, some data have not been reproduced here in its entirety, but should be available for evaluation as part of the approvals process. Below is a table listing key Supporting Documents submitted alongside this Release Package (in the order in which they appear in the text), and the sections within each document that are of direct relevance to the assessment of this Package.

Supporting Document	Relevant sections to this Release Package
1. Communications from Prof Penny Gullan (Australian National University) and Dr Lyn Cook (University of Queensland) outlining the results of morphological and genetic comparisons between populations of the target *Tachardina aurantiaca* in Southeast Asia and on Christmas Island	Whole Document
2. Green PT, O'Dowd DJ, Neumann G, Wittman S (2013) Research and development of biological control for scale insects: indirect control of the yellow crazy ant on Christmas Island, 2009-2013. Final Report to the Director of National Parks, 66 pp.	This report contains most of the research on which this Release Package is based. Important sections not reproduced in this Release Package are: • Research Projects 1a-d, pp 10-15, Figures and Tables as indicated: primary field and laboratory data demonstrating the key importance of carbohydrate resources to supercolony formation by yellow crazy ants. These data support the concept of indirect biological control for the yellow crazy ant on Christmas Island, through the use of parasitoids for scale insect control and honeydew suppression. • Research Project 2b, pp 21, Figures and Tables as indicated: details the considerable field research to document the scale insect fauna on Christmas Island, indicating the absence of native or endemic scale species.
3. Advice to the Director of National Parks, from the Chair of the Crazy Ant Scientific Advisory Panel	Whole Document
4. Peer-reviewed Host Specificity Testing Methodology	Whole Document
5. Summary of Expert Reviewer comments on the Host Specificity Testing Methodology	Whole Document
6. Environmental Referral 2013/6836	Whole Document
7. Environmental Assessment and Compliance Division – Decision and request for additional Information	Whole Document
8. Risk Assessment for Parks Australia	Whole Document

Acknowledgments

We wish to thank the following people and organizations for their assistance in the delivery of this Release Package:

Robert Pemberton (USDA Agricultural Research Service) for providing important advice and contacts throughout the project. He was the first to rear out parasitoids from Malaysian *Tachardina aurantiaca* and facilitated their identification as *T. somervillei*;

Sarah Wittman (La Trobe University) for her research on Christmas Island demonstrating the link between high densities of honeydew-producing scale insects and high densities of yellow crazy ants;

Ong Su Ping and Laurence Kirton (Forest Research Institute of Malaysia) for their assistance in establishing the research laboratory at FRIM. Ms Ong also assisted in collecting parasitoids and conducting the research on *Tachardina* in Malaysia;

Samantha Flakus, Dion Maple and Mike Misso (Christmas Island National Park) for providing important logistic support and advice throughout this project. Peter Cochrane (former Director of National Parks) and Judy West (Parks Australia) also provided long-term financial and logistic support for this project;

Penny Gullan (Australian National University) and Lyn Cook (University of Queensland) for their assistance with scale insect identification and population genetics;

Mohammad Hayat (Aligarh Muslim University, India) and Nick Murphy (La Trobe University) for their assistance with parasitoid identification and population genetics;

Gillian Watson (California Department of Food and Agriculture) and Paul Brown (British Natural History Museum) for providing additional records for the distribution of *Tachardina aurantiaca;*

Het Bin Kaliang (Sarawak Forestry) for his assistance with research and export permits in Sarawak, and access to laboratory facilities;

Bill Palmer (Biosecurity Queensland, Department of Primary Industry and Fisheries) for his advice on regulatory frameworks and preparation of the release package; and,

Tara Dempsey and Craig Hull (Department of Agriculture) for their advice on navigating governmental regulatory frameworks for this project.

Information on the target species, the yellow lac scale *Tachardina aurantiaca*

1.1. Taxonomy

SCIENTIFIC NAME
Tachardina aurantiaca Cockerell 1903

COMMON NAME
Yellow lac scale, Golden lac scale, Mooncake lac scale

RELATIONSHIPS
Tachardina aurantiaca is a honeydew-secreting scale insect:

Class:	Insecta
Order:	Hemiptera
Sub-order:	Sternorrhyncha
Superfamily:	Coccoidea
Family:	Kerriidae
Subfamily:	Tachardininae

1.2. Description

Female scales usually separate, sometimes coalescing, round when seen from above, 4 mm long, convex, but flattened dorsally, so that they are not half as high as broad; surface thrown more or less into concrete folds; colour bright yellow; median dorsal area ferruginous, with radiating ridges and the usual orifices, the minutely transversely ribbed larval exuviae in the middle. Young up to about 2 mm long, orange-ferruginous, with rather obscure radiating ridges. Resinous test of adult female (Fig. 1A, B) circular, somewhat flattened dorsally: the larval pellicle forming a crenulated ridge in the centre of the dorsal area: anal orifice circular or broadly oval, its posterior rim raised into a prominent tooth-like point: respiratory orifices small, very slightly prominent, situated one on each side of and close to the larval pellicle: sides more or less distinctly broadly radially fluted. Colour bright fulvous to castaneous, the larval pellicle reddish; semitranslucent (Ben-Dov 2012). The test (cover) of males is elongate and red or reddish brown with an operculum at the posterior end through which the winged, red males emerge (Fig. 1C). Males are short-lived and may not play an important role in reproduction. In the absence of natural enemies, females can be so common that they completely sheath twigs (Fig. 1D).

1.3. Distribution

Native Range: Southeast Asia (Sundaland) including Indonesia (Java); Malaysia (Peninsular Malaysia, Sarawak, Sabah); Singapore; Thailand (Ben-Dov 2012)(Fig. 2).

Introduced range ex-Australia: The species is also known from the Maldives and from Hong Kong (Fig. 2).

1.4. Australian Range

The yellow lac scale has not been recorded on the Australian mainland. Its range is confined to the Australian External Territory of Christmas Island in the eastern Indian Ocean (Campbell 1968, Ben-Dov 2012), with the earliest record of its presence on Christmas Island in 1964 (Campbell (1968). It occurs throughout rainforest on the island, and in the settled areas of the northeast.

Yellow lac scales collected from 5 different sites and host plant species across Christmas Island are morphologically and genetically identical, based on cuticular morphology and mitochondrial cytochrome c oxidase subunit 1 (COI) and 28S ribosomal RNA sequences (P. Gullan and L. Cook, unpublished data). Further, yellow lac scales collected from sites in Peninsular Malaysia and in Sarawak are morphologically and genetically identical to each other, and to yellow lac scales on Christmas Island (P. Gullan, personal communication, 2012). Thus, the available evidence indicates no measurable geographic variation in the species (see Supporting Document 1).

1.5. Ecology

The yellow lac scale has a broad host range, and has been recorded on at least 88 plant species in 33 families (Table 1). On Christmas Island, it has been recorded on 31 native rainforest plant species. However, its densities are highest on just a few hosts including *Inocarpus fagifer* (Fabaceae), *Milletia pinnata* (Fabaceae), *Ficus microcarpa* (Moraceae), *Terminalia catappa* (Combretaceae) and *Tristiopsis acutangula* (Sapindaceae). It has also been recorded on at least 15 horticultural species in the settled areas of the island, including three species of Citrus, Macadamia, Guava, Pomegranate, Chili, Eggplant, Star fruit, and Soursop (R.W. Pemberton and D.J. O'Dowd, unpublished results). On Christmas Island, ant associates (e.g. *Anoplolepis gracilipes*, *Camponotus melichorus* grp, *Solenopsis geminata*, *Paraparatrechina minutula*) tend yellow lac scales, collect honeydew and transport crawlers. In high-density supercolonies of the yellow crazy ant, densities of the yellow lac scale can be extraordinary on preferred host species such that individual females coalesce, forming sheaths around fine branches and stems (Fig. 1D). Densities of adult females can exceed 150 m^{-1} of stem, and reproduction as measured by crawler 'rain', can exceed 120 juveniles m^{-2} day^{-1} (Abbott and Green 2007).

The life cycle of the yellow lac scale is long relative to most scale insects, with one complete generation from F1 crawler settlement, through female maturation, to F2 crawler production and settlement completed between 88 - 100 days, depending on host plant species (Table 2). Males emerge about 6 weeks after crawler settlement, consistent across host plant species (Table 2). On Christmas Island, there are overlapping generations such that all stages including crawlers, female nymphs and mature females can all be found together on twigs and along the midribs of leaves. This suggests that suitable life stages of yellow lac scales susceptible to attack by the agent *T. somervillei* are available most of each year.

Female size and offspring production vary considerably and are significantly correlated at the time of crawler release both in field and laboratory populations ($R^2 = 0.295$, $p < 0.001$ in the laboratory and $R^2 = 0.207$, $p = 0.006$ in the field) (Fig. 4; Ong et al. 2014). Large females can produce over 600 crawlers, indicating that conditions that affect female growth before crawler production could have a very strong effect on population growth. Conditions affecting growth are not well understood but could relate to settlement density of crawlers, position of crawler settlement on the host, host plant identity, and time of year.

The role of males in reproduction is not clear, because it appears that some females are capable of producing offspring parthenogenetically (Ong Su Ping and Gabor Neumann, unpublished data). The approximately 6-week development time of males suggests that females are mature at that time. Females apparently continue to grow well beyond the completion of development and offspring production occurs long after the female becomes mature.

1.6. Impacts

Although the yellow lac scale can have severe negative impacts on its host trees (see below; O'Dowd et al. 2003), the basis of its successful Nomination as a Target Species for biological control is the key role it plays in the dynamics and impacts of another invasive species on Christmas Island, the yellow crazy ant, *Anoplolepis gracilipes*.

Yellow crazy ants form high-density 'supercolonies' on Christmas Island, in which the density of ants may reach several thousand m^{-2} (Abbott 2005). A systematic, island-wide survey in 2001 found multiple supercolonies ranging in area from tens to hundreds of hectares, totaling c. 2500 ha, and comprising 25% of all rainforest on the island (Green et al. 2004; Green and O'Dowd 2009). Supercolonies have continued to form or reform since the first islandwide control measures in 2001 (Green and O'Dowd 2009; Boland et al. 2011), and they have spread across over one-third of island forest in the past 14 years.

A key trait that has allowed the yellow crazy ant to form high-density supercolonies is its ability to form mutualistic associations with honeydew-producing hemipterans, principally scale insects (O'Dowd et al. 2003; Abbott and Green 2007). There are 24 species of scale insects on Christmas Island, all of which are non-native and 16 of which produce honeydew. Supercolony-level densities of yellow crazy ants and outbreak-densities of several species of scale insects invariably co-occur, and in supercolonies high densities of ants can typically be seen ascending the boles of most trees to visit scale insects in the canopy. The gasters of descending ants are swollen with carbohydrate-rich honeydew that they will take back to the nest to be shared with non-forager conspecifics. Site-scale, manipulative experiments on Christmas Island have demonstrated a bi-directional, causal link between co-occurring high densities and ants and scale insects – the exclusion of ants using toxic bait leads to a dramatic decline in scale abundance (Abbott and Green 2007), while the prevention of access by ants to scale insects using tree bands leads to a dramatic decline in ant density (see Supporting Document 2, Green et al. 2013).

This mutual dependence of one invasive partner on the other for population buildup – so called invasional meltdown (O'Dowd et al. 1999; O'Dowd et al. 2003), has had manifold negative impacts on species abundances, interactions among species, and forest structure. At the core of these impacts is the devastating effect of yellow crazy ants on land crabs, especially the omnivorous red land crab *Gecarcoidea natalis* (Fig. 4A). Yellow crazy ants spray formic acid as a weapon both to subdue prey and in self-defense, and although the amount sprayed by individual ants is tiny, at supercolony densities the overall effect is overwhelming. Supercolonies of yellow crazy ants reduce formerly high densities of red crabs (averaging c. 0.5 – 1.0 crabs m^{-2}) to nil, deregulating seedling recruitment and litter dynamics and resulting in a dense, diverse understory of seedlings and saplings with an almost permanent layer of leaf litter (O'Dowd et al. 2003)(Fig. 4C). In forest dominated by red crabs, the understorey is sparse and dominated by a few crab-resistant species, and the forest floor is almost devoid of litter for much of the year (Green et al. 1997, 2008). These impacts are widespread. Based on the spatial extent of supercolony formation over the last 12 years, it is likely that yellow crazy ants have extirpated at least 20 million red land crabs (estimated to be about 30% of the total population on the island) in areas where the ants have formed supercolonies.

Yellow crazy ants have also caused declines in the density of red land crabs at sites where high-density supercolonies have never formed. About half of the red crab population migrates to the coast each year to complete breeding activities, and many supercolonies have formed across the crabs' traditional migration routes. Thus, significant numbers of migrating red crabs have been killed *en route* to the coast over many years, never to return to their former home ranges. As a result, some areas of rainforest are practically devoid of red crabs even though supercolonies have never occurred there, and the same processes of understorey transformation are in train there too. It is hard to gauge the severity and extent of this "ghosting" effect because pre-invasion data on red crab densities are sparse, but is likely to be significant; Green et al. (2011) estimated that around 25% of rainforest may have been ghosted at some time in the 10 years from commencing in the late 1990s. The direct and indirect (ghosting) impacts of yellow crazy ant supercolony formation have been so widespread since the late 1990s that just 28% of rainforest could still be considered as "intact" (no supercolony formation, and unaffected by ghosting) by 2007 (Green et al. 2011).

In supercolonies, scale insects themselves can have large negative impacts on their host plants. Especially vulnerable is the Tahitian Chestnut *Inocarpus fagifer*, a widespread canopy tree that hosts very high densities of yellow lac scales on its outer twigs and leaves. Seedlings, saplings and small trees all suffer extremely high mortality, and the canopies of large trees are much reduced through the dieback of fine twigs and branches (Green et al. 2001, O'Dowd et al. 2003, P. Green and D. O'Dowd, unpublished results). There is also evidence that fruit production is reduced in supercolonies. Excess honeydew that yellow crazy ants do not harvest settles on leaves of all plant species and is colonized by sooty moulds, which probably interferes with photosynthesis and growth.

Yellow crazy ants may affect many of the island's bird species through direct interference and through altered resource availability and habitat structure (Davis et al*.* 2008, Davis et al*.* 2009). The Christmas Island Emerald Dove *Chalcophaps indica natalis* is 9-14 times less abundant in ant-invaded forest, and because it forages on the forest floor, is probably vulnerable to direct predation by the ants. The nesting success and density of juvenile Christmas Island Thrushes *Turdus poliocephalus erythropleurus* is lower in supercolonies, where they also show altered foraging and reproductive behaviours. Furthermore, these birds alter their choice of tree species in which to build nests, with lower frequency on tree species that typically experience high densities of scale insects and ants. The density of foraging Christmas Island white-eye *Zosterops natalis* is higher in supercolonies, perhaps because scale insects (as prey) are more common there. It is possible that impacts of yellow crazy ants on thrushes and white-eyes affect frugivory and seed dispersal on the island; assays with both real and model fruit showed handling rates to be more than two-fold lower in supercolonies, and manipulative experiments showed this to be a direct consequence of the presence of ants. There is no evidence that supercolony formation by yellow crazy ants significantly affects the density or nesting success of Abbott's Booby *Papasula abbotti* (P. Green, unpublished data), while the impact of these ants on other seabirds and on other land birds such as the goshawk and owl are unknown.

Several endemic vertebrate species, including the pipistrelle bat *Pipistrellus murrayi* and endemic reptiles have experienced precipitous declines over recent years, but the causes of the declines are opaque. In the case of the pipistrelle it is possible that supercolony formation by yellow crazy ants has contributed to the decline, either directly through predation of bats at roost sites or indirectly by eliminating red crabs and facilitating the expansion of predators such as giant centipedes *Scolopendra subspinipes*, wolf snakes *Lycodon aulicus*, cats and rats (Schulz and Lumsden 2004, Lumsden et al. 2007, Beeton et al. 2010). However, the decline of the pipistrelle was well in train before the rise of supercolonies in the late 1990s. The endemic reptiles were similarly in decline long before supercolonies became common, and the role of yellow crazy ants in their decline is also uncertain (Smith et al. 2012).

In addition to impacts on species of concern, supercolony formation by yellow crazy ants has also led to an altered web of species interactions that facilitates the entry and spread of other invasive species. The best example of this is the entry and spread of the giant African land snail *Achatina fulica* in rainforest on the island (Fig. 4D, E). This snail was introduced to the island in the 1940s, and despite being a notoriously invasive species (Lowe et al. 2000), its distribution was for many decades limited to settled areas, abandoned mining fields and roadsides. Experiments showed that predation by red crabs excluded this invader from establishing in rainforest (Lake and O'Dowd 1991), but the extirpation of red crabs in yellow crazy ant supercolonies, coupled with the ability of the snail to coexist alongside the ants at in supercolonies, has permitted the giant African land snail to establish high densities in rainforest at many locations across the island (Green et al. 2011). The facilitation of giant African land snails by yellow crazy ants could be due to the creation of enemy-free space, augmented understorey resources, or both.

The rise of yellow crazy ant supercolonies and the extirpation of red crabs have also affected the invasion dynamics of other non-native organisms. These effects encompass both inhibition and facilitation for a range of non-native ant and snail species (O'Dowd and Green 2010; P. Green and L. O'Loughlin, unpublished results), while invasion by several weeds including *Capsicum frutescens, Carica papaya, Cordia curassavica, and Muntingia calabura* appears to be facilitated in areas affected by supercolony formation (P. Green and D. O'Dowd, personal observations).

Management of yellow crazy ant supercolonies – toxic bait. Given all of the above, invasion by yellow crazy ants on Christmas Island has been Listed since 2005 as a Key Threatening Process under the EPBC Act (1999). Furthermore, the association between honeydew-secreting scale insects and invasive ants was recognized as a key threat to biodiversity on Christmas Island (Beeton et al. 2010). To date, the management of the yellow crazy ant invasion has depended on surveillance, monitoring, and control using toxic bait (Green and O'Dowd 2009, Boland et al. 2011). Nevertheless, new supercolonies continue to form, and there is concern for the sustainability of this program in terms of its expense ($1M allocated annually over four years from 2011-12 to 2014-15), non-target impacts, and the resources it diverts from other conservation programs (Beeton et al. 2010). Further, this program can only ever be reactive, and it has not been able to find an effective solution to the difficult issue of the management of incipient supercolonies. Here, the density of ants is not high enough for them to monopolize the toxic bait, making the risk of non-target impacts too high to justify the treatment of these areas.

An alternative approach – indirect biological control. Despite the diversity and significant ecological and economic impacts of invasive ants worldwide, they have proved to be an especially difficult target group for biological control. A program for the biocontrol of the Red Imported Fire Ant (*Solenopsis invicta*) using a parasitic fly and a protozoan disease as agents is currently under development in the southeastern United States, but no species of ants have yet been controlled in the field using biological control agents and principles. Instead, a novel solution for managing the yellow crazy ant invasion on Christmas Island has been proposed (O'Dowd and Green 2003); rather than targeting the ant itself, the yellow lac scale, a key mutualist species that plays a significant role in sustaining supercolonies at very high and ecologically damaging densities, would be targeted instead. Long-term, sustainable suppression of supercolonies could be achieved through the introduction of a host-specific biological control agent that would indirectly affect yellow crazy ants by reducing the carbohydrate supply provided by this species.

Supporting research for the concept of targeting the honeydew supply from scale insects for the indirect biological control of yellow crazy ant supercolonies on Christmas Island. Three lines of evidence suggest that reducing the honeydew supply from scale insects to yellow crazy ants could lead to supercolony suppression (Green et al. 2013, Supporting Document 2):

First, stable isotope analyses of yellow crazy ant workers, plants, herbivores and predators collected from four declining supercolonies in 2010-2011 indicated that at supercolony densities, a substantial fraction of the ants' dietary intake is plant-derived. This is consistent with the idea that supercolonies of yellow crazy ants depend heavily on honeydew derived from scale insects for a large fraction of colony food and energy requirements, and provides support for the idea that indirect control over supercolonies could be achieved by targeting honeydew-producing scale insects for biological control.

Second, the dynamics and behaviour of yellow crazy ants in laboratory colonies depended on carbohydrate supply**.** When sugar supply was elevated, reproductive output by queens increased, death rates of workers decreased, foraging tempo quickened, and interspecific aggression intensified. These results strongly suggest that sugar supply, through honeydew supplied from scale insects, plays an important role in the dynamics of yellow crazy ant supercolonies, foraging efficiency, and interspecific aggression.

Third, the exclusion of yellow crazy ants from access to scale insects at a large experimental field site caused their activity on the ground to decline 5-fold within 4 weeks, compared to pre-treatment levels. This large field experiment validates the key concept of indirect biological control for the yellow crazy ant on Christmas Island; exclusion of honeydew-producing scale insects from yellow crazy ants caused a significant and substantial reduction in ant abundance on the ground.

The yellow lac scale as the key mutualist of the yellow crazy ant. Although many species of honeydew-producing scale insects occur on Christmas Island, five are commonly encountered in high abundance in the supercolonies of yellow crazy ants; the yellow lac scale and the coccids *Coccus celatus, C. hesperidum*, *Saissetia oleae* and *S. coffeae*. Using data on tree abundance and size, and estimates of host-specific scale insect abundance, Green et al. (2013)(Supporting Document 2) calculated that yellow lac scales contribute a mean of 70% of the honeydew economy in supercolonies. This estimate assumes *per capita* parity in the quantity and quality of honeydew produced by the yellow lac scale and the coccoid soft scale species. However, adult female yellow lac scales are much larger than the adult females of the coccoid species, and it is reasonable to suppose that *per capita* honeydew production is much higher in the yellow lac scale. Assuming a three-fold higher rate of honeydew production, yellow lac scales may contribute a mean of 87% to the honeydew economy.

External review of the evidence supporting the premise for indirect biological control. In managing the crazy ant invasion on Christmas Island, Parks Australia considers advice provided by the Crazy Ant Scientific Advisory Panel (CASAP). CASAP is an independent group of scientists with expertise in ant ecology and the management of invasive ants, invasive species biology, the ecology of Christmas Island, and development of national policies for the conservation of Australia's biodiversity. CASAP advice was formally sought on the veracity of the research findings outlined above, and on the proposal to import, rear and release a biological control agent(s) as an option for controlling yellow crazy ant supercolony formation and spread. At a meeting in December 2012, CASAP assessed the scientific merit of the research conducted by La Trobe University as well as the feasibility and risks of introducing a biological agent to Christmas Island. CASAP members were convinced that high densities of honeydew-producing scale insects were required to sustain supercolony densities of yellow crazy ants, that the yellow lac scale was a key contributor to the honeydew economy of supercolonies, and that indirect biological control was a viable and feasible option for controlling yellow crazy ants. They were further convinced that the risks to the island's biodiversity were very low, and the risk of doing nothing outweighed the risk posed by the importation and release of a biological control agent. On that basis, CASAP advised the Director of National Parks to proceed with the implementation phase of the biological control research. This Release Package is the product of that advice (Supporting Document 3).

1.7. Information on all other relevant Commonwealth, State and Territory legislative controls of the target species

The yellow lac scale, *T. aurantiaca*, has not been declared in any State or Territory in Australia.

1.8. When the target was approved for biological control

T. aurantiaca was nominated as a target for biological control by Parks Australia, a section of the Department of Environment. The Plant Health Committee has responsibility for approving nominations of target species that are invertebrate pest species and approved the nomination of *T. aurantiaca* as a target species for a biological control agent on 9 April 2013.

1.9. History of biological control

There is no history of biological control for the yellow lac scale on mainland Australia, any external Territories, and any other location around the world.

Information on the potential agent *Tachardiaephagus somervillei*

2.1. Taxonomy

SCIENTIFIC NAME
Tachardiaephagus somervillei (Mahdihassan 1923)

COMMON NAME
None

RELATIONSHIPS
Tachardiaephagus somervillei is an encyrtid parasitoid:

Class:	Insecta
Order:	Hymenoptera
Sub-order:	Apocrita
Superfamily:	Chalcidoidea
Family:	Encyrtidae
Subfamily:	Encyrtinae

The Encyrtidae is one of the most important parasitic wasp (parasitoid) families for the biological control of harmful insects, including a variety of scale insects infesting woody plants (Noyes and Hayat 1994, Noyes 2012). The Encyrtidae currently comprises 460 genera and 3735 species in 2 subfamilies. The subfamily Encyrtinae includes 353 genera and 2920 species, while the Tetracneminae includes 107 genera and 815 species. Approximately half of all encyrtid species are associated with scale insects (Hemiptera: Coccoidea)(Noyes 2012). Encyrtids are generally endoparasitoids meaning that the parasitoid egg is laid directly inside the host's body where the hatching larva completes development feeding on the host's tissue, ultimately killing the host. Encyrtids mostly parasitize immature life stages (or, rarely, adults), but some species in one genus (*Microterys)* are egg predators (Noyes 2012).

2.2. Description

T. somervillei was first described by Mahdihassan in 1923 as *Lissencyrtus somervilli* but Ferrière (1928) transferred *L. somervilli* Mahdihassan to *Tachardiaephagus*. He later downgraded this taxon from specific to subspecific rank as *T. tachardiae somervilli* (Ferrière 1935), based on the presence of intermediate forms and the lack of defining characters. This subspecies was accepted by Mahdihassan (1957). Varshney (1976) emended spelling of the subspecific rank to *somervillei*. In a recent reconsideration of the taxon, Hayat et al. (2010) elevated *T. tachardiae* var. *somervillei* to *T. somervillei* as a valid species.

A detailed, formal taxonomic description of *T. somervillei* does not exist. Although the specific name was erected by Mahdihassan (1923) he provided no accompanying morphological description. In lieu of such a specific description, we first present a genus-level description based on the type species *T. tachardiae* (from Prinsloo 1977), and then note how *T. somervillei* differs from *T. tachardiae*.

Tachardiaephagus Ashmead

Tachardiaephagus Ashmead, 1904: 303; Ferriere, 1928: 171; 1935: 396. Type-species *Encyrtus tachardiae* Howard, 1896. *Lissencyrtus* Cameron, 1913: 99; Ferrière, 1928: 171. Type-species *Lissencyrtus troupi* Cameron, 1913.

The genus *Tachardiaephagus* was described from the type species, *T. tachardiae* (Howard) from South and Southeast Asia. For synonymy of the genus and species, descriptions and figures, consult Ferrière (1928, 1935), Prinsloo (1977), and Noyes (2012). The genus comprises seven species; four described from sub-Saharan Africa (*T. absonus*, *T. gracilus*, *T. similis*, and *T. communis* - Prinsloo 1977), and three from South and Southeast Asia (*T. tachardiae*, *T. somervillei*, and *T. sarawakensis* - Ferrière 1928, 1935, Hayat et al. 2010). All species are primary parasitoids known only from kerriid hosts (*Kerria* - the lac insect of commerce, *Paratachardina*, and *Tachardina* species) (Prinsloo 1983).

FEMALE. Primary parasitoids of Kerriidae. Medium-sized encyrtids, approximately 1.5-2.0 mm in length. Colour: head and body some shade of brown to black, the head and thoracic dorsum with or without faint to moderate metallic reflections; forewing hyaline or at most very faintly infuscated partly; hind wing hyaline.

Head, in dorsal view (occiput perpendicular) with posterior margin moderately concave, the anterior margin convex, deeply notched by upper scrobal confluence (except in *T. absonus*); frontovertex united acutely or abruptly with occiput; frontovertex moderately broad, more or less than one-third head width at median ocellus; ocelli in an acute to obtuse-angled triangle; head, in frontal view, with toruli placed well above mouth margin, their upper limits approximately level with lower eye margins; scrobes strongly sulcate (except in *T. absonus*), long, their lateral margins sharply angled, confluent dorsally, impressed on face as an inverted 'V'. Antenna eleven-segmented; scape subcylindrical or at most moderately expanded ventrally, not less than three times as long as its greatest width; pedicel longer than basal funicle segment; funicle six-segmented, with all segments longer than wide or at most with distal one or two segments wider than long; club three-segmented, as long as or longer than the distal three funicle segments together, rounded apically, at most a little wider than funicle segment VI; maxillary palpi each with four segments, the labial with three; mandibles tridentate (sub-Saharan species) or with two teeth and a truncation (in *T. tachardiae* from South and Southeast Asia). Sculpture of head cellulate-reticulate, the cells relatively small, not raised, the frontovertex with fine setigerous punctations.

Thorax moderately convex from side to side and anteroposteriorly, the mesoscutum plainly wider than long, the scutellum approximately as wide as long; mesoscutum without parapsidal sulci; mesoscutum with posterior margin overlapping mesal union of axillae partly or entirely, the latter not raised, separated medially by a narrow sulcus; sculpture of mesonotum cellulate-reticulate, the cells with very fine aciculations in some species; mesonotum moderately densely setose, the scutellum with one pair of suberect setae near apex. Legs not especially modified. Forewing moderately broad, approximately 2.5 times as long as broad; venation well developed: submarginal vein slender; postmarginal vein usually longer than marginal, the former reaching to a level near apex of stigmal; wing disc evenly and rather densely setose from speculum to apex, the basal triangle never devoid of setae.

Abdomen as long as or longer than thorax, the gaster usually heart-shaped, pointed or truncate at apex; cercal plates not strongly advanced towards base of gaster; gaster without paratergites; ovipositor varying in length, less than one-half to as long as gaster, as seen through the derm in cleared slide-mounted specimens; ovipositor protruding at most slightly caudally.

MALE. Differing mainly from the female as follows: head and body generally black, with stronger metallic reflections (yellow variant in Oriental *tachardiae*). Head with frontovertex broader, approximately one-half head width at median ocellus; toruli placed higher on face, their lower margins about level with lower eye margins; ocelli in an obtuse-angled triangle. Antenna nine-segmented, the club not segmented, approximately as long as the distal two funicle segments together; flagellum with moderate to rather long, curved setae.

Tachardiaephagus somervillei (Mahdihassan 1923)(Fig. 5)

Lissencyrtus somervilli Mahdihassan, 1923: 71. Female. India, Karnataka.
Tachardiaephagus somervilli (Mahdihassan): Ferrière, 1928: 71, taxonomy; Namkum (India) record.
Tachardiaephagus tachardiae var. *somervilli* (Mahdihassan): Ferrière, 1935: 396, taxonomy; Malaysia record. Mahdihassan, 1957: 73-74.
Tachardiaephagus tachardiae somervillei (Mahdihassan): Varshney, 1976: 61-62, emendation of specific name as it was based upon the name of Prof. Somerville.

No detailed species description is available for *T. somervillei*. However, Hayat et al. (2010) treat *T. somervillei* as a valid species as it differs from *T. tachardiae* not only in the yellow to orange-yellow colour of the head, but also in having F6 or F5 and F6 quadrate to slightly broader than long; and in having third valvula 0.73x mid-tibial spur. (In *T. tachardiae*: F5 and F6 longer than broad; and third valvula subequal in length to mid-tibial spur). Ferrière (1935) indicated that he found intermediate forms in two females from West Malaysia] (Rawang and Kuala Selangor Road) in which "the head has the vertex, the temples and cheeks dark green like *T. tachardiae*, and the face and inner margin of eyes reddish, as in somervilli". He therefore downgraded the species *somervillei* to a variety of *tachardiae*. However, Hayat et al. (2010) reinstated the species-level status for *T. somervillei* after examining specimens from Thailand and Malaysia and failing to find any specimens intermediate in head colour to *T. somervillei* and *T. tachardiae*.

2.3. Distribution, biology, behavior and life cycle of the agent

T. somervillei is a primary parasitoid of kerriid lac scale species. It is an endoparasitic species, meaning that it uses an ovipositor to insert eggs within the test of its female lac hosts. These eggs hatch and the larvae slowly consume the lac insect as it develops, finally pupating and emerging as winged adults, which results in the death of the host lac insect. Unlike the vast majority of encyrtids, *T. somervillei* attacks the mature stages of its hosts.

The genus *Tachardiaephagus* has been known for almost a century due to the pest status of *T. tachardiae* in lac scale cultures in India and parts of Southeast Asia. Lac is produced from the lac scale, *Kerria lacca*, and *T. tachardiae* and *T. somervillei* parasitize *K. lacca*, often causing economic injury (Narayanan 1962, Sharma 2006). Surprisingly, while the taxonomy of lac parasitoids as well as their control in lac production systems have been researched in India, detailed information about the life history and biology of *T. tachardiae* and *T. somervillei* is missing from the published literature. Some basic information on the life history of *T. tachardiae* is available, mostly from workers from the first half of the 20th century, but recent observations on *T. somervillei* extend and clarify this earlier research.

Our observations in Peninsular Malaysia and Sarawak provide basic information on the distribution, biology, behavior and life cycle of *T. somervillei* in relation to its host the yellow lac scale.

Distribution. *T. somervillei* has a broad geographic range and has been recorded from India, Thailand, Peninsular Malaysia as well as Sarawak and Sabah in Borneo (Fig. 6). However, it has a highly restricted host range across this distribution, with all records from either the yellow lac scale (southern Thailand, Peninsular Malaysia, Sarawak, and Sabah) or *Kerria* (Bangkok, Thailand; India)(see Section 2.5 on host specificity testing for further details on host range).

Biology, behavior and life cycle. *T. somervillei* (Fig. 7A) attacks mature females of the yellow lac scale. Emerging females cut circular holes with smooth edges through the test, and oviposit soon afterwards. The importance of mating prior to oviposition is unknown. Search and oviposition behaviors in the presence of aggregations of yellow lac scales were observed for 28 female parasitoids under laboratory conditions. The female parasitoid walked relatively rapidly in the host aggregate, moving repeatedly over and between individual hosts rather than walking around them, even if there was a shorter path between them. Active walking in the aggregate may stop at any time; in the observation arenas the duration of activity was between approximately 1-8 minutes. Walking speed remained constant except either when the parasitoid was interested in honeydew or when host acceptance and oviposition occurred. Host acceptance was surprisingly quick with very little inspection by the parasitoid. It is possible that females inspected potential host individuals during prior short visits. When a host individual was accepted, the female assumed a typical oviposition posture with the head and thorax elevated and the abdomen pressed down (Fig. 7B). Narayanan (1962) claims that parasitoids of *K. lacca*, including *Tachardiaephagus* spp. oviposit through the anal pore of the host. This was not observed in oviposition on yellow lac scales. Instead, *T. somervillei* oviposited in the upper part of the side of the host's test. This may be an adaptive behavior: honeydew is excreted through the anal pore and could interfere with oviposition. Furthermore, ants tending yellow lac scales collect honeydew and oviposition away from the anal pore may decrease the encounter rate between ants and *T. somervillei*. Oviposition itself was also relatively rapid, between 10-15 seconds. Once oviposition was completed, the parasitoid left the host immediately and if self-grooming took place, it was usually done outside of the host aggregate. Without exception, inactivity was observed only after the parasitoid was outside of the host aggregate. The female may or may not groom after leaving the aggregate and enters an inactive state where it remains stationary. Inactivity ranged from just a few minutes to at least 30 minutes.

T. somervillei has multiple generations per year. Development time, from oviposition to adult emergence, was 23-26 days at 23-32 ^{o}C. Although longevity under field conditions is not known, laboratory experiments indicate that water and nutrition are important; females (n = 14) provided with both water and 50% honey solution survived at least 33 days, but those denied access to both water and honey solution (n = 14) survived only 1-3 days. *T. somervillei* was observed utilizing honeydew from yellow lac scales under field conditions, and it is probably an important food source that sustains adult parasitoids. Some parasitoids feed directly on their host by stabbing it with their ovipositor and feeding on the leaking hemolymph, but this has not been observed in *T. somervillei*.

T. somervillei exhibits superparasitism, in which more than one offspring may emerge from a single female of *T. aurantiaca* (Fig. 7C). However, it is unknown whether this results from polyembryony (multiple embryos developing from a single egg), multiple eggs laid by the same female, or different females ovipositing multiple eggs. The number of successfully emerging progeny of *T. somervillei* is positively correlated with size of yellow lac scales females ($R^2 = 0.47$, $n = 50$, $p < 0.001$) (Fig. 8). Larger hosts are likely to provide more food resources, allowing more parasitoid larvae to complete development. This positive relationship between host size and production of *T. somervillei* progeny will be important in captive rearing, release site selection, and ensuring establishment during inoculative releases on Christmas Island.

2.4. Host range of the agent and related species – a database analysis of host specificity and potential for non-target impacts

The genus *Tachardiaephagus* comprises seven described species distributed in Southeast and South Asia (*T. tachardiae*, *T. somervillei*, and *T. sarawakensis* - Ferrière 1928, 1935, Hayat et al. 2010) and sub-Saharan Africa (*T. absonus*, *T. gracilus*, *T. similis*, and *T. communis* - Prinsloo 1977). Known host species records for all species were evaluated using the Universal Chalcidoidea Database (UCD; Noyes 2012) so that host range could be estimated and risk of release of *T. somervillei* assessed for listed species and communities, flora and fauna species, listed migratory species, populations and communities etc on Christmas Island (see Sands and Van Driesche 2004). The UCD is the most comprehensive database for chalcidoid parasitoids, with over 120,000 host/associate records (including associations with food plants of the hosts) and >140,000 distribution records of the parasitoids in the superfamily Chalcidoidea. It is very well developed, regularly updated and extremely well referenced. Nevertheless, large databases can contain errors affecting reliability, such as erroneous published host records and outdated parasitoid taxonomy (Kuhlmann et al. 2006). The most important source of error in this database is actual published erroneous records. Since all records are referenced, any doubtful records can be investigated and if deemed appropriate, filtered out.

The most obvious non-target group on Christmas Island are other scale insects (Superfamily Coccoidea: Sternorryhncha). We used the UCD to assess the likely host breadth of *T. somervillei*, and its congeners and confamilials to evaluate non-target risks to other scale insect species on the Island. Further, we used the database to evaluate the number and host breadth of all encyrtid species known to attack Kerriidae. Much less likely is that the introduction of *T. somervillei* could pose a risk to much more phylogenetically distant, endemic (non-scale insect) hemipterans (e.g. Suborders Auchenorryhnca and Heteroptera). We used the UCD to consider the host breadth of encyrtid parasitoids known to attack species in hemipteran families with known endemics on Christmas Island, as a way of inferring whether the host range of any known encyrtid parasitoid encompasses both scale insects and the families to which the endemic hemipterans belong.

Host breath of *T. somervillei*, its congeners, and confamilials. Host records show that *T. somervillei* is associated with only two host genera (*Kerria* and *Tachardina*) in the Kerriidae (Table 3) while host records for the remaining six species in the genus add only one more host genus *Paratachardina lobata (= P. silvestri)*, also in the Kerriidae (Table 3). There is a single record of the African *T. similis* from the coccid scale insect *Ceroplastes eucleae*, but this has been discounted as erroneous by Prinsloo (1977). These records suggest that even at the generic level, *Tachardiaephagus* is a narrow host specialist on scale insects in the family Kerriidae.

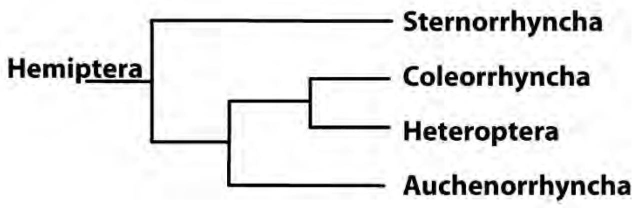
A broader analysis of host records for 40 encyrtid species in 16 genera known to attack Kerriidae indicate that 80% (32/40) are restricted to hosts within the Kerriidae, and that the host range of the remaining 8 species is restricted to the Superfamily Coccoidea (Table 4). This strongly suggests that any encyrtid parasitoid that attacks host taxa within the Kerriidae is unlikely to attack any hosts other than scale insects.

Records for occurrence of scale insect species (Superfamily Coccoidea, the same superfamily to which *T. aurantiaca* belongs) on the island were compiled from the literature and then supplemented by conducting >400 hours of structured search over two years for endemic scale insects (Green et al. 2013, Supporting Document 2). A total of 25 species of scale insects in six families, incorporating both 'neococcid' and 'archeococcid' taxa (sensu Gullan and Cook 2007) have been recorded from Christmas Island (Table 5). Although *Tachardiaephagus* species appear to be kerriid specialists, a few encyrtid species in other genera have host ranges that encompass other scale insects (see above). Although unlikely, the introduction of *T. somervillei* could pose a risk to other scale insect taxa (e.g. Coccidae). However, none of the scale insect species on Christmas Island are native or endemic. Furthermore, none of these introduced scale insects species is known to be beneficial.

Endemic hemipterans on Christmas Island and host breadth of encyrtid parasitoids. Host breadth records of *T. somervillei* suggest that it will not attack endemic hemipterans on Christmas Island. We used the database to infer risk in a different way by considering whether any encyrtid parasitoid species have host ranges that include both scale insects and the families to which the endemic hemipterans belong.

We obtained a list of known endemic insect species on Christmas Island (James and Milly 2006) and narrowed consideration of taxa on this list to the closest endemic relatives of lac scales on Christmas Island in the Order Hemiptera, the same order to which the yellow lac scale belongs. These species comprise one true bug, a cicada, a leafhopper, a spittlebug, and three planthoppers (Table 6). Two lines of evidence suggest the risk posed by *T. somervillei* to these species is extremely low.

First, encyrtids are not common parasitoids of the families containing the endemics. Indeed, 4 of the 7 families to which the endemic hemipterans belong have no known encyrtid parasitoids, and the remaining three are attacked by just 15 encyrtid parasitoid species, despite great diversity (3735 species) in that group. Based on these data alone the probability of an encyrtid parasitoid attacking an endemic hemipteran on Christmas Island is extremely low.



Second, all of the endemic species occur in different suborders (either suborder Auchenorrhyncha or Heteroptera) to the yellow lac scale (suborder Sternorrhyncha)(see above, Fig. 2 in Cryan and Urban 2012). Thus, any potential for non-target impacts by *T. somervillei* on these endemic Hemiptera would require a host range that bridges this very substantial phylogenetic as well as distinctive morphologies, life-histories and ecological attributes to its known host taxa in the Kerriidae. Not one of the 3735 known species of encyrtid parasitoid species is known to bridge this substantial phylogenetic distance.

2.5. Report on host specificity testing

A host-specificity testing protocol was developed (Supporting Document 4) and then expert reviews were requested from five internationally known biological control practitioners. The main issues on which we sought their opinions were the selection of test species, the use of no-choice tests over either choice or sequential no-choice tests, and the location and conditions under which the testing should be conducted. Four of the five reviewers agreed with the protocol in terms of conducting the testing under field conditions in the area of origin, and all agreed with the use of no-choice tests with suitable controls and use of test species both closely related and more distantly related to the target *T. aurantiaca* (Supporting Document 5). Despite the logistical challenges of conducting this kind of research in a foreign country, the host specificity testing was completed more-or-less according to plan (Table 7). Testing proceeded with a combination of no-choice tests in the field paired with both negative and positive controls (see below).

Study site. Host specificity studies were conducted in Kuching, (Sarawak, Malaysia) at a *c*. 24 ha site on the north side of the Sarawak River in the Kampung Boyan area ($1^{o} 33' 42'' N$, $110^{o} 21' 03' E$). This area was chosen for several reasons: 1) the target species *T. aurantiaca* was found there at two different locations approx. 700 m apart in May 2012 on *Acacia mangium* and *A*. *auriculiformis*, as well as their hybrids, 2) *T. somervillei*, the natural enemy of choice as a biological control agent, was found parasitizing the target at both of these locations but no other primary parasitoid was detected, 3) suitable host plants were found throughout the area along with a variety of other plant species, and 4) the area was not protected and, therefore, research permits were less complicated to acquire. The study site included several different types of environments: a settled area with gardens and backyards, managed parkland with higher diversity of plant species, and moderately disturbed but unmanaged bush land with young trees and secondary growth with older trees reaching 30 metres or more in height (Fig. 9A-D). Insecticide use was observed in 2012 but was limited to the settled area and targeted mosquitoes by fumigation in mosquito habitats. No pesticide use was observed during host specificity studies from August 2013 to March 2014.

The yellow lac scale and *T. somervillei* at Kampung Boyan. Commencing June 2012, crawlers of the yellow lac scale were continuously moved within the study site from the two original locations to other host plants. Once adults had established, crawlers from these new locations were spread further through the study area until populations were established at 47 different locations, each with several lac insect aggregates. A "location" was defined as either a single host plant or group of host plants with overlapping canopies and the minimum distance between locations was 30 m. After 14 months (August 2013), no live yellow lac scales remained in any aggregate at 31 of the locations. Although it was impossible to verify the source of mortality at these locations, parasitism by microhymenoptera was suspected since emergence holes were obvious in the dead scales. A subsequent collection of 30 mature female yellow lac scales at each of the remaining 16 locations with live scales showed evidence of parasitism by *T. somervillei*. No primary parasitoids other than *T. somervillei* were detected, suggesting that it alone was responsible for the elimination of yellow lac scale in all of the extinguished aggregates. *Promuscidea unfasciativentris*, a hyperparasitoid that attacks *T. somervillei*, was also present at the remaining aggregates with live yellow lac scale.

Parasitoids dispersed naturally in the study area and were only moved among locations during the conduct of host specificity tests. These parasitoids were always contained in cages and never reintroduced into the wild population. Similarly, offspring that emerged during tests were never returned to the natural population. This avoided any artificial selection that might have lowered fitness of *T. somervillei* in the tests.

The 16 locations with live yellow lac scale locations served as the source of parasitoids used in the tests. Yellow lac scale was propagated at these locations throughout the testing period to provide hosts for the parasitoid. When collecting parasitoids for testing, female yellow lac scales were examined at all sites and females suspected to be parasitized and nearing parasitoid emergence were collected from as many sites as possible. Some parasitized females were always left intact to ensure the continuity of the local parasitoid population. Identifying parasitized females was relatively straightforward using just a 20X hand lens. Healthy female yellow lac scales, or females that are parasitized with young larvae, are yellow on the sides and deep red or mostly red-brown on the top. In mature females nearing crawler release, the bright red crawlers can sometimes be seen through the translucent test. In contrast, parasitized females with parasitoid pupae often show black areas under the test (Fig. 7D).

Yellow lac scale females suspected of being parasitized were gently detached from their host plant and placed in a round plastic jar with a diameter and height of approximately 10 cm (Fig. 9E). A hole was drilled in the lid of the container just big enough to fit the opening of a 5-ml glass vial. The container was covered with black tape all around. Parasitoids emerging from the lac scales tended to move from the darker container towards the light vial, and were then collected from the vial. The sex of the parasitoids was determined by examination of the antennae: females have club-like antennae shorter than the males' antennae and males have longer antennae with whorls of setae (see Fig. 5, male). For each round of testing, parasitoids were randomly selected from a pool of individuals that emerged from lac scales collected at 3-5 locations within the study area. Only recently emerged parasitoids (<24 h) were used. Parasitoids not used in testing were destroyed. This ensured that parasitoids used in the tests were the progeny of field-adapted individuals – they had located their hosts without experimenter assistance, were exposed to intraspecific competition in the process of locating their hosts, and were sourced from several locations.

Test species. Selection of scale insect families for testing was based on phylogenetic distances inferred from genetic sequencing of nuclear 18S rRNA for 72 species in the Coccoidea (Fig. 10). Eight species were used in host specificity tests. In descending order of relatedness to the yellow lac scale, these included four soft scales (Coccidae), one diaspidid (Diaspididae) and three mealybug species (Pseudococcidae)(Table 8 and Fig. 11). Three of the four species of Coccidae also occur on Christmas Island (Table 8).

Some test species were sufficiently abundant at Kampung Boyan that enough naturally occurring aggregates could be located (*Coccus hesperidum*, *C. longulus*, *Paraputo* near *P. corbetti*, and *Chionaspis* near *C. broughae*) for all tests. Other test species were less common (*Milviscultulus mangiferae*, *Pseudococcus jackbeardsleyi*, *Pulvinaria urbicola* and *Rastrococcus iceryoides*) so additional aggregates were established by transferring crawlers to additional locations, but always to the same host plant species. All aggregates were inspected for natural parasitism prior to testing and when necessary, manipulated to ensure that only healthy, unparasitized females were enclosed in mesh bags. Parasitism in soft scales can usually be detected by visual inspection – compared to unparasitized females, parasitized females are noticeably darkened. As a further check, 30 individuals from three random aggregates for each species were collected and placed in glass vials for parasitoid emergence, if any, at the beginning of propagation (or before testing where propagation was not necessary). Initially, two test species (*M. mangiferae* and *P. urbicola*) were heavily parasitized and aggregates had to be culled and then newly established aggregates protected using mesh bags. Parasitism levels of *Coccus hesperidum* were initially low and easily eliminated. Natural parasitism in the other test species did not occur over the study period.

No-choice tests. The unit of replication in the no-choice tests was an aggregate of 25 mature female scale insects on a leafy branch, enclosed inside a fine mesh bag under field conditions (Fig. 9F). Five female and 5 male *T. somervillei* were liberated inside each bag (Day 0). The parasitoids were removed at Day 5 but the bag was left in place until Day 20, at which time the aggregate was cut from the plant and stored in plastic boxes until Day 35. Any emerging *T. somervillei* were counted. The aggregates were destroyed after Day 35 unless crawler emergence was detected; in that case the twig was returned to the host plant and fixed on it with a rubber band to allow crawler settlement and propagation of the yellow lac scale. The mesh bags excluded tending ants from test species during the period of exposure to the parasitoid. Ten replicates per species were used for each of the four coccid and three pseudococcid species, and five replicates for the diaspidid species. Replicates of test species were always located on the same species of host tree, and usually spread across 2-7 trees. Replicates were established on different branches when more than one was used per tree. Each replicate involved a different batch of parasitoids, a different day of experimental set up and a different group of test species individuals in a mesh bag, i.e. test species individuals were never reused even in the case of long-lived species. If mortality was detected in a test group that was unlikely to be caused by the parasitoid (e.g. fungal disease), the replicate was discarded and replaced.

Although conducted in the field, these no-choice tests were not completely open field tests. The tests were conducted within mesh bags, the parasitoids were confined, and interspecific competition was excluded. The pros and cons of this approach over testing under laboratory conditions in containment have been discussed elsewhere (see Discussion, below), but four of the five *ad hoc* expert reviewers consulted before the testing was conducted were either happy with this approach, or preferred it over testing under laboratory conditions (see Supporting Document 5).

Negative Controls. Negative controls, i.e. where test scale insect species are enclosed in mesh bags but without the parasitoid, were used to detect background mortality of scale insects in the absence of the parasitoid. As in no-choice tests, aggregates of 25 individuals were enclosed in mesh bags, but without parasitoids. For all test species, the same number of negative control replicates was used as in the test replicates. Negative controls were staggered in time to match each of the test replicates. Mortality in each negative control was evaluated seven days after the end of exposure to parasitoids in the corresponding no-choice tests.

Positive Controls. Positive controls were used to determine the quality of the parasitoids being used against the test species. If *T. somervillei* failed to parasitize a test species, it could have been because the individuals used in the tests were somehow of inferior quality to "wild type", rather than the test species being an unsuitable host *per se*. The validation of parasitoid quality is critical when parasitoids are reared in the laboratory because they may undergo laboratory selection, resulting in lower fitness. Laboratory conditions usually allow individuals of average or less than average fitness to reproduce (van Lenteren 2003). In our case, all parasitoids were collected from different locations in the wild, arguably obviating the need for these trials. However, to follow best practice, positive controls were used by retaining some of the reared *T. somervillei* individuals for testing against yellow lac scales. Successful parasitization of these scales would demonstrate high parasitoid quality, and lessen the probability of false negatives in the test species.

As in the no-choice tests, a positive control consisted of 25 unparasitized adult yellow lac scales, enclosed in a mesh bag to which 5 female and 5 males of *T. somervillei* were added. The yellow lac scales were exposed to parasitoids for 5 days, after which the parasitoids were removed from the bag. Yellow lac scales were left in the bags for a further 15 days, and then the branch was excised and placed in a plastic container to monitor parasitoid emergence over the next 10 days. As *T. somervillei* often superparasitizes its host (more than one progeny can emerge from a single host), the measure of parasitism used in the positive controls was the total number of emerging parasitoids rather than the percentage of parasitized hosts.

Ideally, each no-choice and negative control replicate would have been accompanied by a positive control. Given the limited availability of aggregates of a given test species, variation in the availability of emerging parasitoids, and the occasional loss of test replicates due to fungal disease, it was not possible to complete host specificity testing for a scale insect species at one time. Therefore, the eventual total number of replicates for each test species was accumulated over several months. Parasitoids were produced in batches over this period that were then subdivided into lots of 10 individuals for use against test species replicates (Table 9). Thus, it was appropriate to test the quality of parasitoids at the batch level, rather than attempt to match every no-choice and negative control replicate with their own positive control. A randomly-selected subsample of each batch of parasitoids was reserved for testing against yellow lac scales, so that parasitoid quality was assessed regularly during the testing period. In all, 20 batches of parasitoids were produced over several months, but because of the vagaries of both parasitoid and yellow lac scale availability, 13 positive controls were conducted (Tables 9 and 10).

Results of host specificity testing. In the no-choice tests, none of the eight test species were parasitized by *T. somervillei*. Not a single individual of *T. somervillei* emerged from any replicate aggregate in any species over several months of trials (Table 8). The absence of mortality in corresponding negative controls for each scale test species indicated that the mortality observed in the no-choice test replicates was attributable to parasitism by *T. somervillei*.

Positive controls showed that all batches of *T. somervillei* used throughout the tests parasitized the yellow lac scale and were near equivalent in terms of reproductive performance (Table 10). Emergence of adult parasitoids per replicate (18.7 ± 1.1 [SE], n = 13 and the *per capita* fecundity of female parasitoids (3.74 ± 0.22 progeny, n = 13) were similar in all 13 batches of *T. somervillei* released against aggregates of the natural (target) host the yellow lac scale and used against the test species yielded parasitoids (Table 10).

Discussion. These field-based experiments and observations suggest that *T. somervillei* has an extremely narrow host range. First, during preliminary surveys at the field site it never successfully attacked any of the other scale insects used in this study. Second, the parasitoid did not successfully parasitize any of the tested species during no-choice tests, despite being put under pressure to do so by the lack of a suitable alternative host (i.e. the yellow lac scale). Further, the tested scale insect species occur in the native range of the parasitoid and often shared habitat with the yellow lac scale. *Coccus longulus*, for example, occurred on the same host plant (*Acacia mangium* x *A. auriculiformis*) as the yellow lac scale, and often in mixed aggregates. Yet, *C. longulus* was never parasitized by *T. somervillei* under natural conditions.

We used outdoor mesh bags to carry out the tests on host plants on which the test species were originally found. Sands and Van Driesche (2003) emphasize that such test conditions have some advantages over laboratory tests because the full range of the parasitoid's behaviors that lead to host acceptance, feeding, and oviposition can occur in the natural environment of the parasitoid's habitat. The use of wild-collected parasitoids in the tests also eliminated the chance of reduced parasitoid fitness, which might otherwise have been the case with laboratory-reared parasitoids. The possible negative 'arena effects' that could influence parasitoid behavior and subsequently parasitism (Sands and Van Driesche 2003) were ruled out by the positive controls, because the target hosts were exposed to the parasitoid in the enclosures as were the non-target test species. Without exception, the positive controls yielded parasitoid emergence suggesting that it was capable of high levels of parasitism in the mesh bags, and the parasitoid batches collected from the wild were of consistently high quality. A reasonable inference then is that the parasitoids from the untested batches (Table 10) were of equal quality and that the replicates of test species using these batches are still valid.

Soft scale insects (Coccidae), the family most closely related to lac scales (Kerriidae), were most represented in the test species list. The database analysis of host records showed that most encyrtid primary parasitoid species (32/40 species, 80%) were restricted to host species in the Kerriidae. Of the few remaining parasitoid species, their most probable alternative hosts were soft scales and no reliable host records were found outside of the Coccoidea. Mealybugs (Pseudococcidae) represent a farther phylogenetic distance than soft scales and the lack of parasitism in the mealybug test species in field tests was expected, given the failure of *T. somervillei* to parasitize the more closely related coccid and diaspidid species.

The results of the field study strongly suggest that the host range of *T. somervillei* is limited to species in the family Kerriidae (lac scales), consistent with inferences from the taxonomic literature and historical records (see Section 2.4). These data suggest further that no other other scale insect species on Christmas Island is at risk from the introduction of *T. somervillei*, with the possible exception of the lobate lac scale, *Paratachardina pseudolobata* (Kerriidae). However, this species, like all other scale insects (Superfamily Coccoidea) on Christmas Island, are not native. The endemic hemipteran taxa on Christmas Island fall far outside the narrow host range of *T. somervillei*, all occurring in two suborders (Auchenorrhyncha or Heteroptera) that are quite phylogentically distant from the Sternorrhyncha, the suborder to which the target species belongs (see section 2.4, above). All available evidence suggests that the host range of *T. somervillei* is substantially too narrow to bridge such phylogenetic distance, and that the risk posed to these species by the introduction of *T. somervillei* to Christmas Island is extremely low.

2.6. The agent's potential for establishment on Christmas Island

For a parasitoid, at least two factors affect probability of establishment; the 'match' between the host species in its native and introduced ranges, and the local climate.

Match between hosts. All of the genetic, morphological and life-history data we have accumulated on the yellow lac scale (Section 1.4) indicate no geographic variation in the host species. Therefore, based on host similarity, *T. somervillei* should be equally likely to parasitize yellow lac scales in its introduced range on Christmas Island as it is in Southeast Asia.

Match between climates. *T. somervillei* has been recorded from sites with a diverse range of climates, from consistently warm and wet in the aseasonal tropics of Southeast Asia (e.g. Kuching and Singapore) to much drier and seasonally cool climates in India and Taiwan (Table 12). This suggests that as a species the agent can persist in a broad range of climates, but there may be geographic differentiation in the ecophysiological tolerances of populations, in which case the match between the climates of the source location and Christmas Island should be considered. The climate on the Island is moderately wet and seasonal (mean annual rainfall=2110 mm, $CV_{monthy\ rainfall}$ = 59.2%) and consistently warm (mean annual temperature = 25^{O}C, $CV_{monthly\ temp}$ = 2.4%). Using the data for rainfall, maximum and minimum temperatures outlined in Table 12 and algorithms outlined in the CLIMEX software (Sutherst et al. 2007), we compared the climate on Christmas Island to all other sites where *T. somervillei* has been recorded. CLIMEX uses the absolute values of the difference between weekly site averages to compare the climate between the source and target sites, and a full CLIMEX comparison can include parameters based on temperature, rainfall, humidity and soil moisture. However, some of these parameters can be omitted, and useful climate comparisons can still be made using just the standard four variables of minimum and maximum temperature, annual rainfall total and rainfall pattern (e.g. Kriticos 2012). We used the equations and parameter values outlined in the CLIMEX User Guide (Sutherst et al. 2007) and in Kriticos (2012) to generate values for the combined Temperature Index (TI), the combined Moisture Index (MI), and the Rainfall Pattern Index (RPI). CLIMEX uses weekly data, but we only had access to monthly data from http://www.bom.gov.au/climate/averages/tables/cw_200790.shtml for Christmas Island (38-year record) and http://www.climate-charts.com for the Malaysian and Thai (30-year records) and Indian sites (17-year records). Christmas Island lies in the southern hemisphere but all potential source sites lie in the northern hemisphere, so the Christmas Island data was offset by six months to align the seasons for comparison. Average temperature was calculated as the mean of the maximum and minimum temperatures. The humidity parameter in the combined Moisture index was set to zero, effectively making the Moisture index a total rainfall index. All indices were weighted equally to calculate the Composite Match Index (CMI) as the cube root of the product of TI x MI x RPI, times 100 (Kriticos 2012).

Based on these comparisons, the site with the most similar climate to Christmas Island is Chumphon in Thailand (10^{o}29'N) with a match of 79.8% (Table 11). Kuala Lumpur, the intended source site of the founding population is also well matched with 71.2%. According to the CLIMEX parameters, the climates are best matched for the Temperature and Moisture Indices, but less so for the Rainfall Pattern Index; Kuala Lumpur has a less severe dry season that does Christmas Island. The impact of a drier dry season on the likelihood of establishment by *T. somervillei* on Christmas Island is not known.

2.7. The agent's potential for control of the target

The agent's potential for the control of the target can be considered at two levels: the success of programs using parasitoids against scale insects generally, and the specific case of the yellow lac scale on Christmas Island.

Scale insects as targets of biological control. Scale insects (Hemiptera: Coccoidea) have been the target of many, perhaps the majority, of biological control projects targeting insect pests (DeBach et al. 1971, Greathead 1989), including some of the most spectacular successes in the annals of biological control (e.g. control of cottony cushion scale *Icerya purchasi* - Caltagirone and Doutt 1989). One of the clearest patterns in the historical record of biological control is that the greatest rates of success have been achieved against the Coccoidea and related sternorrhynchous Hemiptera (Mills 2006). Historically, the Coccoidea have dominated the scene as targets for biological control, accounting for nearly half of all projects in which some degree of success has been obtained (67% of all complete successes, 31% of all substantial successes, and 43% of all partial successes). Together with related the sternorrhynchous Hemiptera (e.g., aphids, whiteflies) they account for about 2/3 of all successes in biological control of insects and for more than 4/5 of all projects in which complete success has been achieved (Clausen 1978).

The reasons why scale insects have been so frequently targeted in biological control programs are numerous. First, they comprise a disproportionately large proportion of introduced major pests (Greathead 1989). Small, sedentary and cryptic, they have been readily co-introduced into new areas with their many host plant species in the absence of effective quarantine measures. Many are parthenogenetic so populations can be established from very few individuals. In the absence of many or most of their natural enemies in their native region, population densities in introduced areas can build up to threaten economically important crops or species of special conservation value. As such, there has been both an economic and conservation imperative to focus biological control efforts on the Coccoidea.

Life-history and ecological attributes of scale insects may be conducive to their successful biological control (Mills 2006). They are typically colonial, aggregative, and sedentary, with many generations per year on perennial, woody plant hosts, such that all life stages can be simultaneously present. Small size means that population densities per plant can be high. These attributes facilitate population stability, giving parasitoids with many generations per year, like the encyrtid *T. somervillei*, a broad window of host attack.

Biological control of scale insects on islands and in natural areas. Many programs for the biological control of scale insects have been conducted on islands, mostly in an agricultural context. Over half of all biological control attempts in the BIOCAT database (Greathead 1989) have been on islands (1285/2484 records) and many of these have been defined as successful (DeBach 1962, Greathead 1989).

Increasingly, insect pests in natural areas, including national parks, have become targets of biological control (van Driesche et al. 2010, Van Driesche 2012). Most simply this is because few other control methods are applicable to broadscale control of insect pests that threaten the conservation value of natural areas, especially in remote locations like oceanic islands. When successful, biological control in natural areas, relative to other methods of control, is lower in cost, self-sustaining, and self-dispersing. An exemplar of successful biological control of a scale insect to prevent the extinction of a rare endemic plant in natural areas on a remote oceanic island is Fowler (2004).

Biological control of other Kerriidae. Other than the research described here, only one other attempt has been made to develop biological control for any other lac scale insect (Kerriidae). Research and development for the biological control of the lobate lac scale *Paratachardina pseudolobata*, native to Peninsular Malaysia and invasive on Christmas Island, in southern Florida, the Bahamas, Cuba, Puerto Rico, and recently Hawaii, commenced in 2003 but funding by the State of Florida USA was discontinued in 2008 before a suitable candidate for biological control was located and no releases have yet been made (Pemberton 2003, R.W. Pemberton, pers. comm. 2013). The lac insect of commerce *Kerria lacca* was deliberately introduced to Taiwan from Thailand in 1940 where it became a pest of arboriculture. Natural enemy exploration was conducted in Taiwan, but no further research was carried out (Chiu et al. 1985).

Vulnerability of the target *T. aurantiaca* to control by natural enemies. Field research on Christmas Island and foreign exploration in Southeast Asia indicate that the yellow lac scale is extremely vulnerable to control by it natural enemies. In its native range, the yellow lac scale is very rare, has a diverse assemblage of natural enemies, and shows widespread evidence of parasitism. On the other hand, this species is abundant in its introduced range on Christmas Island (especially so in association with yellow crazy ant supercolonies), and the females are not parasitized by any of the few natural enemies associated with it on the Island.

Diversity of natural enemies: The assemblage of natural enemies of the yellow lac scale is much more diverse in the area of origin that in its introduced range on Christmas Island (Table 12 and Fig. 12). Using a combination of historical records (Noyes 2012) and direct field surveys, there are six primary parasitoids that use yellow lac scales as a host in Malaysia, but only one (*Marietta leopardina*) on Christmas Island. In addition to this parasitoid, two lepidopteran predators of female yellow lac scales have also been found in both the native and introduced ranges, but on Christmas Island these are extremely rare. Two hyperparasitoids, *Promuscidea unfasciativentris* and *Aprostocetus purpureus*, were isolated from yellow lac scales in Malaysia, but not on Christmas Island (Table 12).

Incidence of parasitism: the yellow lac scale is rare and there is frequent evidence of female parasitization in its native range in Southeast Asia (Fig. 1), varying from a mean of 29% to 81% at different sites (Table 13). These rates are based on the incidence of emergence holes, and almost certainly underestimate actual parasitization rates because at the time of counting there would have been additional parasitized females from which parasitoids had not yet emerged. In contrast to the widespread parasitism of yellow lac scales in Southeast Asia, parasitism of females has never been observed on Christmas Island despite considerable search effort (Table 13; > 11,000 females from multiple sites collected and inspected under magnification over two years). Clearly, the one parasitoid on Christmas Island, *M. leopardina*, is not capable of parasitizing female yellow lac scales. Observations in the laboratory indicate female *M. leopardina* attempt to lay eggs inside females, but the test is seemingly too tough for the ovipositor to penetrate. *M. leopardina* can however parasitize male yellow lac scales, with single exit holes being observed in some males at a few sites on the Island. However, parasitization rates were low, ranging from 0 - 57% (N= 558, 751, and 696 males examined on three trees at Hugh's Dale, Anderson's Dale, and Sydney's Dale). Clearly, parasitization of males by *M. leopardina* is not sufficient to control this scale insect on Christmas Island, either because the incidence of male parasitization is not high enough to have an impact on the fertilization of female scales, or possibly, *T. aurantiaca* could be parthenogenetic and males are unimportant to reproduction (G. Neumann, unpublished results).

Vulnerability of the target *T. aurantiaca* to the agent *T. somervillei*. The stark contrast between the incidence and diversity of parasitoids between the home and introduced ranges suggests that on Christmas Island, the yellow lac scale has escaped its key natural enemies and will be vulnerable to the introduction a suitable biological control agent. The clearest indication we have that *T. somervillei* can control the yellow lac scale comes from the difficulty with which experimental aggregates of the latter could be established for host specificity testing in the presence of the former; *T. somervillei* dispersed of its own accord to all 47 experimental aggregates of yellow lac scales established at the field site in Kuching, and parasitized 100% of females at 31 of the aggregates.

More generally, the pest status of *T. somervillei* and its sister species *T. tachardiae* in lac production systems also emphasize their ability to control lac scales. These parasitoids attack *Kerria lacca*, the lac-producing scale insect. As early as 1930, Glover recognized the economic importance of parasitoids of *K. lacca* as a group of enemies capable of causing a "great deal of damage" in lac production. Glover (1930) mentioned *T. tachardiae* as a very abundant parasitoid, and Narayan (1962) mentioned *T. somervillei* and *T. tachardiae* among six others that are associated with *K. lacca* as pests. Although Narayan (1962) did not attempt evaluate the effect of individual parasitoid species, he emphasized that parasitism rates can be very high. Chattopadhyay (2011) mentions *T. tachardiae* as the most abundant lac-associated parasitoid. The cultural (preventative) and mechanical methods of control against parasitoids mentioned by Glover (1930) and Narayan (1962) are still recommended and used today (Chattopadhyay 2011).

Parasitism in the presence of tending ants. A variety of ant species, including the yellow crazy ant *A. gracilipes* tend yellow lac scales in Peninsular Malaysia, Sarawak, and Sabah and collect honeydew (Figs. 1B, 7D, 10H; Table 14). Nevertheless, the incidence of parasitism by *T. somervillei* is high. This runs counter to widespread reports of ants protecting honeydew-secreting insects from their natural enemies (e.g. Way 1963, Addicott 1979, Buckley and Gullan 1991, Itioka and

Inouye 1996), and to a recent report of a myrmecine ant protecting the lac scale *Kerria yunnanensis* from *T. tachardiae*, the sister species to *T. somervillei* (Chen et al. 2014). However, the ant *Crematogaster macaoensis* protected the lac scales from *T. tachardiae* by building carton structures (a physical barrier to access by flying parasitoids) over the scale insects, a behaviour not exhibited on Christmas Island by yellow crazy ants when tending lac scales. In any case, many parasitoids have sophisticated behavioural, chemical, and morphological adaptations that avoid tending ants so that they can still effectively parasitize their host scale insects (e.g. Bartlett 1961, Völkl 1994, 2001; Barzmann and Daane 2001, Kaneko 2007). Some parasitoids have higher rates of parasitism in the presence of ants than in their absence (Völkl and Novak 1997, Tegelaar et al. 2011) and tending ants can even provide "ant-adapted" parasitoids with protection from their natural enemies, including hyperparasitoids (Völkl 1992). Our data indicate that *T. somervillei* is able to successfully parasitize yellow lac scales across a variety of host plant species in the presence of a variety of tending ants, including yellow crazy ants. These observations alleviate concerns that high densities of tending yellow crazy ants on Christmas Island necessarily protect yellow lac scales from *T. somervillei*.

2.8. Information and results of any other assessments of the agent

To our knowledge, *T. somervillei* has never been assessed as a biological control agent before.

2.9. Possible interactions with existing biological control programs (of same or related targets and other targets)

The yellow lac scale is one of five non-native, honeydew-producing scale insect species that are common in yellow crazy ant supercolonies on Christmas Island (Section 2.4, above and Table 5). Although the yellow lac scale is strongly implicated as the main contributor to the honeydew economy of yellow crazy ant supercolonies, there is considerable site-to-site variation in its likely contribution, from 46-86 % (Green et al. 2013, Supporting Document 2). While we think *T. somervillei* will provide a high level of biological control over populations of yellow lac scales, it is not certain that targeting this species alone would provide consistent indirect control for the yellow crazy ant in all supercolonies, especially where its contribution is lowest. Based on information presented in Green et al. (2013), CASAP advised Parks Australia that the program on Christmas Island be expanded to include agents for the control of these coccoid soft scales (see Supporting Document 3). The rationale was that the complementary use of agents against both the yellow lac scale and the soft scales would provide a high and consistent level control the entire assemblage of honeydew-producing scale insects, and thus increase the likelihood of successful indirect biological control for supercolonies of the yellow crazy ant.

The parasitoids *Coccophagus ceroplastae, C. longifasciatus* (both Hymenoptera: Aphelinidae) and *Encyrtus infelix* (Hymenoptera: Encyrtidae) were discovered on Christmas Island as part of the supporting research leading up to this Release Package (Green et al. 2013). All three species were recovered from *Coccus* sp., and are known to attack a variety of scale insect species on Christmas Island, including the *Coccus* and *Saisettia* species common in supercolonies (Table 15). The parasitoids were almost certainly introduced inadvertently to the island with importation of plant material with host scale insects. Indeed, Christmas Island has a rich parasitoid fauna, probably of mixed origin; at least 206 parasitoid species in 19 families have been recorded on the island (CSIRO 1990, CESAR Consultants 2013). The difficult issues of foreign exploration, host-specificity testing and navigating regulatory frameworks have been obviated by the presence of these parasitoids on the Island. Experience with the efficacy of these agents in dealing with the outbreak of *Pulvinaria urbicola* on Christmas Island (Neumann et al., unpublished data, and see Neumann et al. 2014) suggests that the current lack of control of soft scales in supercolonies is a result of dispersal limitation of their parasitoids. Dispersal limitation will be overcome by releasing these parasitoids at multiple sites and at multiple times across the island.

Records in the UCD (Noyes 2012) indicate that the host ranges of *C. ceroplastae, C. longifasciatus,* and *E. infelix* are relatively well-known (57, 10, and 14 scale insect species, respectively), and that none have been recorded from kerriid scale hosts. Further, none have ever been recorded to parasitize yellow lac scales on Christmas Island, despite their co-occurrence in some areas. These observations indicate that none of these agents use the yellow lac scale as a host, and that once distributed in the forest, they would be highly unlikely to affect the establishment and efficacy of *T. somervillei* against yellow lac scales through competition for the same host.

Although this Release Package focuses on *T. somervillei*, preparations are also being made for the mass rearing of *C. ceroplastae* and *E. infelix* on Christmas Island. The two programs are thoroughly integrated at all levels; the same scientific staff oversee both programs, the same natural resource agency staff are propagating plants and will assist in rearing hosts and parasitoids, and both programs are funded as a single entity by the Department of Environment.

2.10. Possible indirect effects of the agent

In essence, the main purpose of this biological control project is to achieve a conservation outcome via an indirect effect. We are proposing to import a parasitoid that will control an ecologically damaging, honeydew-producing scale insect, which is strongly implicated as a main player in the dynamics of an invasive ant. It is intended that the suppression of the scale will lead to suppression of the ant. Thus, we intend indirect suppression of the ant by a parasitoid. Achieving indirect control of the invasive yellow crazy ant should eventually lead to the widespread recovery of species that are currently under severe pressure from yellow crazy ant supercolonies, especially the land crabs *Gecarcoidea natalis* and *Birgus latro*, and the canopy tree *Inocarpus fagifer*. Further, recovery and recolonisation by red land crabs should return key ecosystem processes, such seed dispersal, as seedling recruitment and litter dynamics to their pre-invasion states, and should also remove invasive giant African landsnails from the rainforest. In other words, this program is aiming to achieve a range of indirect effects that are regarded as positive for ecosystem recovery and biodiversity values on Christmas Island.

Some concern has been expressed that if the yellow lac scale is suppressed by an agent, this could provide opportunities for other species of honeydew-secreting scales insects (principally the soft scales) to expand their feeding niches in yellow crazy ant supercolonies by utilizing host species formerly monopolized by lac scales. Presumably, this could lead to further population build-up of these other scales in supercolonies and the possible compensation of the yellow lac scale's missing contribution to the honeydew economy. This of course would be inimical to the overall aim of the program. Soft scales have been recorded on all of the main lac scale host plants in yellow crazy ant supercolonies (*Inocarpus fagifer*, *Terminalia catappa*, *Tristiropsis acutangula*, *Ficus microcarpa* and *Milletia pinnata*) but in much lower densities than on other species such as *Planchonella nitida*, *Syzygium nervosum*, *Dysoxylum gaudichaudianum*, and *Clayoxylon indicum* (O'Dowd et al. 2003, Abbott 2004). The basis of this niche differentiation between the yellow lac scale and soft scales has not been investigated, but is more likely based on the match between sucking mouthparts and plant anatomy rather than contemporary competition for hosts. If so, then suppression of yellow lac scales by the agent *T. somervillei* should not lead to population outbreaks of soft scales and the maintenance of supercolonies. In any case, the planned release of *C. ceroplastae* and *E. infelix* against the soft scales should obviate this scenario.

Scale insects and the honeydew they produce are food resources for other consumers, and conceivably, the widespread suppression of invasive yellow lac scales by the agent *T. somervillei* may deny some native species an important resource. No listed threatened or migratory species on Christmas Island appears dependent on lac scales. The Sunda pygmy woodpecker (*Dendrocopos moluccensis*) has been observed pecking at this species in Labuan, Sabah, Malaysia (C.L. Chin, personal communication 2013), and on Christmas Island, the endemic CI White-eye *Zosterops natalis*, an insectivore/frugivore, has also been observed pecking adult females (Davis et al. 2008). However these few observations and the rarity of observations of damaged tests of yellow lac scales suggest that it is not an important food source. The CI White-eye could conceivably collect honeydew produced by yellow lac scales, but this was not observed during a five-month study of *Z. natalis* and other endemic bird species in yellow crazy ant supercolonies (N. Davis, pers. comm. 2011).

2.11. Environmental risk assessments undertaken on the species both in Australia and overseas

The EPBC Act (1999) requires that any action likely to have a significant impact on any matters of environmental significance must be referred to the Minister for the Environment. Accordingly, the proposal to release *T. somervillei* as a biological control agent of the yellow lac scale on Christmas Island was referred to the Environment Assessment and Compliance Division (EACD) on behalf of the Minister for the (then) Department of Sustainability, Environment, Water, Population and Communities in April 2013 (EPBC 2013/6836, Supporting Document 6). The Decision was that the proposal be classed as a Controlled Action, meaning that it required further assessment. Under the EPBC Act, the extent of further assessment can range from that undertaken solely on the information provided in the original referral, to information in the referral plus any other relevant information identified by the Minister as being necessary to adequately assess a proposed action (called Preliminary Documentation), to assessment by Environmental Impact Statement of Public Environment Report, to assessment by public enquiry.

The EACD determined that further assessment was required only as Preliminary Documentation, and requested additional information about the biology of the agent, potential non-target impacts, host specificity of the agent, the role of CASAP in the decision making process for this program, and details about release sites and post-release monitoring (Supporting Document 7). This information is being provided to the EACD in a separate document, all of which also appears in this Release Package.

In addition, a Risk Assessment was prepared for Parks Australia. Besides assessing the risk and consequences of non-target impacts, this assessment also considered the consequences of not proceeding with the biological control program on Christmas Island (Supporting Document 8).

Both of these assessments focus on the potential risk to non-target organisms on Christmas Island, but a more complete assessment of risk should include the Australian mainland. Recent surveys of pest organisms on Christmas Island (Bellis et al. 2000, 2004; Woods and Steiner 2012) have been conducted in part because of the perceived quarantine risk that Christmas Island poses to mainland Australia. For a long time the entry of goods from Southeast Asia to Christmas Island was poorly regulated through quarantine legislation, and the Island was regarded as a 'dirty port' that could be a conduit via which pest species could reach the mainland. Although the importation of non-native species to Christmas Island is now much more tightly regulated by the Quarantine Act 1908 and subordinate legislation in the Quarantine (Christmas Island) Proclamation 2004, pest species already present on the Island could still pose a threat to mainland biota.

Once introduced to Christmas Island, the risk of *T. somervillei* inadvertently reaching Australia (via air to Perth, or via sea to Fremantle) is extremely low. The only way this could happen is if live plant material (whole plants or cuttings), carrying parasitized scale insect hosts, was to be carried from Christmas Island to the mainland. There is currently no trade in live plant material to the mainland, and in any case, such movement requires a permit from Biosecurity Australia and the plant material would be subject to inspection upon arrival at the mainland.

Even if *T. somervillei* did reach the mainland in this manner, the risk of it establishing there is also extremely low because of its limited host range. As described above, all the available evidence indicates the host range is restricted to scale insects in the family Kerriidae, and Scalenet (Ben Dov 2012) lists seven species in this family on the mainland; *Austrotachardina acaciae*, *A. angulata*, *A. australis*, *A. convexa*, *A. melaleucae*, *Kerria meridionalis* and *Paratachardina decorella*. Only two of these have been listed as occurring in Western Australia; *A. convexa* on the host *Hypocalymma* sp. (Myrtaceae) at "Swan River", and *A. melaleucae* on *Kunzia* sp or *Melaleuca* sp. (both Myrtaceae) in "Perth" (Fuller 1899). Further, the Mediterranean climate of Perth is unlikely to be conducive to establishment.

2.12. The proposed source of the agent, sanitary procedures and arrangements for its release on Christmas Island

Proposed source of the agent. The proposed source of *T. somervillei* is west Malaysia, from around Kuala Lumpur and the port city of Klang. This is not the population that was used for the host specificity testing (Kuching, Sarawak in east Malaysia), but there is no evidence for population-level variation that might otherwise allow for the possibility local adaptation and that west Malaysian populations will be any less effective than the ones used for testing. Specimens from east and west Malaysia are morphologically indistinguishable (M. Hayat pers. comm. to G. Neumann 2014), and genetic barcoding of the mitochondrial cytochrome-c oxidase subunit 1 (COI) gene of individuals from both locations indicates they are same species with no geographic variation (Table 16). Although conducting the host specificity testing in Kuching was logistically feasible, the Malaysian permitting system treats east and west Malaysia as separate entities, and it will be much less difficult to export a founder population from Kuala Lumpur than first attempting to move live insects from Kuching to Kuala Lumpur. At the time of writing there are no direct flights between Kuala Lumpur and Christmas Island, and so it is likely that the parasitoids will be flown from Kuala Lumpur to Perth, held overnight in quarantine, and then flown on to Christmas Island the next day. Preliminary discussions have been held with Biosecurity Australia.

An experienced biocontrol professional, Dr. Gabor Neumann (La Trobe University, g.neumann@latrobe.edu.au) will supervise the production of the founder parasitoid population in Malaysia, ensure that the insects are free of pathogens and hyperparasitoids, hand carry the founder population to Christmas Island, and supervise rearing in the rearing facility on Christmas Island. Dr Neumann has conducted the exploration for natural enemies, determination of biology and life cycle of the potential biological control agent, and host specificity testing of the potential biological control agent.

Elsewhere (Supporting Document 4) we have argued that testing in containment on Christmas Island is problematic because a suitable quarantine facility does not exist, and building one is impracticable. We have further argued that testing in a containment facility on the mainland poses a different set of logistical challenges, and there is also risk associated with the co-importation of the yellow lac scale that would be necessary to maintain laboratory populations of agent *T. somervillei*. Instead, the host specificity testing was conducted in the native geographic range of the biological control agent, without the need for containment. So, unlike most other Australian programs for biological control (Palmer et al. 2010), *T. somervillei* has not been brought into a secure quarantine facility in Australia (mainland or Christmas Island) for host specificity testing and sanitary controls prior to its release. Therefore, two aspects of the 'release' of *T. somervillei* on Christmas Island will differ from the typical sequence for mainland programs. First, sanitary procedures to ensure the agent is free of pathogens and hyperparasitoids will be conducted in Malaysia, not in quarantine in Australia. Second, because a secure quarantine facility does not exist, the transport of *T. somervillei* to Christmas Island should conservatively be treated as the "release from containment" that would normally occur on the mainland.

Protocol for ensuring that hyperparasitoids associated with *T. somervillei* are not imported to Christmas Island. The inadvertent importation of a hyperparasite of *T. somervillei* is inimical to the successful suppression yellow crazy ant supercolonies, because it could compromise the capacity of the agent to build up population densities sufficient to control the target. For this reason, great care will be taken to implement standard agent rearing and sanitary techniques to ensure that the founding population of *T. somervillei* from Malaysia is free of hyperparasitoids and pathogens. Free-living adults are the safest to import because this would ensure that hyperparasitoids would not be co-introduced.

T. somervillei is frequently attacked by *Promuscidea unfasciativentris* (Aphelinidae)(see Table 12). This hyperparasitoid was abundant near Kuching, Sarawak and present in Selangor, West Malaysia, although rare there. Although the impact of hyperparasitism on populations of *T. somervillei* in its native distribution is not known (the incidence of parasitism in field populations of the yellow lac scale by *T. somervillei* can still be very high in the presence of hyperparasitoids – Table 13), the exclusion of any hyperparasitoids from captive colonies in Malaysia is critical before adult *T. somervillei* are imported to Christmas Island as the founding population.

The exclusion of hyperparasitoids from captive populations at locations where the hyperparasitoids are native can be difficult unless care is taken. Basic containment is usually sufficient but standard practices to keep hyperparasitoids out of captive populations will be followed. These steps include:

1. Field-collected, parasitized yellow lac scales will never come into contact with laboratory populations used for rearing *T. somervillei*. Field-collected stems with parasitized scale insects will be placed into emergence cages in a separate facility from the rearing facility.
2. Emerging parasitoids will be examined individually before being removed from emergence cages. The range of parasitoids and hyperparasitoids is known (Fig. 12) and all are identifiably distinct from *T. somervillei*. If hyperparasitoids (or any organism other than *T. somervillei*) are found in the emergence cages, they and the cage will be destroyed.
3. Emergence cages will be kept in a dedicated room (the emergence room, see below) in a separate building from that where the dedicated room with captive scale/parasitoid populations (the rearing facility) is located.
4. *T. somervillei* will be moved to the rearing facility and placed on host plants with suitable scale insect hosts in a fine mesh bag; the mesh bag ensures that parasitoids remain on the plant and the scale insects are protected.
5. Mesh bags will not be removed (only shortly for monitoring purposes) from the plants until parasitoid emergence.
6. When parasitoid emergence is expected, host plants with parasitized scales in their mesh bags will be moved to the emergence room.
7. Personnel conducting field collections or any other field activity will not be allowed in the rearing facility on the same day, and will be required to change their field clothes if entering the facility the next day.

It is critical that the captive population is monitored continuously for the presence of hyperparasitoids even if best practices are followed closely. In addition to individual examinations of parasitoids, yellow sticky cards will be placed in both the emergence room and the rearing facility to monitor (and also trap) any hyperparasitoids or other insects. Controlled exposures inside mesh bags will protect *T. somervillei*.

The elimination of hyperparasitoids before importation of adult *T. somervillei* to Christmas Island will involve the following steps.

1. The sanitary practices followed during emergence and rearing (see above) will ensure a "clean" captive population.
2. Emerged, adults of *T. somervillei* will be placed in airtight, glass vials. All individual parasitoids will be inspected under magnification prior to packing. No yellow lac scale hosts will leave the rearing facility.
3. Glass vials with parasitoids will be packed in plastic containers and then placed inside a rigid, lockable aluminium carrying case. This case will be insulated to buffer the insects against extremes of temperature in transit. The case will be hand-carried from the rearing facility at the Forestry Research Institute of Malaysia in Kuala Lumpur to Christmas Island Airport. The parasitoids will be provided with honey solution during transit (see Section 2.3) to keep mortality to a minimum.

4. All individuals will be examined again under magnification at the point of entry on Christmas Island while still in the glass vials. Training will be provided in advance for quarantine personnel on Christmas Island to identify *T. somervillei* and differentiate it from any other parasitoid(s) or other organism(s). If in any doubt, the vial containing the questionable organism(s) will be destroyed.
5. All individuals will be inspected again in the rearing facility on Christmas Island before the parasitoids are removed from the glass vials.

Our observations of *T. somervillei* in natural and laboratory populations in Kuching (Sarawak) and Kuala Lumpur suggest that pathogens do not play a significant role in *T. somervillei* populations. Based on external inspection and dissections, not a single *T. somervillei*, either field collected or lab reared in Malaysia, showed any signs of infection by entomopathogenic fungi or nematodes.

2.13. Where, when and how the initial release from the rearing facility will be made

A dedicated screen house production facility is being built by Parks Australia on Christmas Island to mass-rear *T. somervillei* for field release. As in Malaysia, the maintenance of captive parasitoid populations depends on the production and maintenance of optimal host life stages of yellow lac scales on suitable host plants. The best local host plant species are *Inocarpus fagifer* and *Milletia pinnata*, but *Tristiropisis actutangula*, *Ficus microcarpa* and *Terminalia catappa* are also being produced. The rearing of the parasitoid will occur in two stages. First, potted host plants will be transferred into one half of the screen house where they will be inoculated with yellow lac scales. Once populations have built up, plants will be relocated into the other half of the screen house where they will be exposed to *T. somervillei.* Careful consideration has been given to the design of the screen house to enable the internal transfer of plants between the two sides of the facility, while containing the parasitoid to the second half.

Yellow lac scales and *T. somervillei* may be difficult to mass-rear due to the relatively long life cycle of the former (Table 2 - from crawler stage to reproductive female is 80-100 days, but generations overlap) and the need for fresh host plants (that may or may not be reused) on a regular basis. Depending on the difficulty of rearing *T. somervillei*, their availability for releases maybe limited at any given time. As mass-rearing methods improve and production increases on Christmas Island, the goal will be to provide the biological control agent for releases in all areas as needed.

The population of *T. somervillei* will require careful monitoring and maintenance to minimize any selection of shadehouse-adapted insects that perform poorly under field conditions. It may be necessary to replenish the genetic diversity of the captive population through the subsequent introduction of more insects from the founder population in Malaysia, or, more likely, from the field on Christmas Island once the initial releases have been conducted. Population renewal will also counter the inherent susceptibility of microhymenoptera to the loss of population heterozygosity. Sex determination in microhymenoptera is usually haplodiploid – males are haploid, females diploid, and heterozygosity at a multi-allelic sex-determining locus is required for femaleness. Inbreeding can lead to a preponderance of homozygous diploids that will either be sterile males, or experience a very high rate of mortality.

Field release of *T. somervillei*. The goal in releasing biological control agents is to generate sufficient 'propagule pressure' (e.g., the size of each release, the frequency of releases, and the number and spatial arrangement of release sites) to enable their successful establishment. Increasing propagule pressure can enhance the likelihood of establishment by diminishing the role of chance (i.e., both demographic and environmental stochasticity), and potentially increase the rate of spread from release sites (Simberloff 2009). Initial timing, number of individuals released, and the frequency of releases of both agents will depend on (a) the capacity and sustainability of mass rearing, (b) knowledge of the biology of *T. somervillei*, especially in relation to its host the yellow lac scale; and, (c) the attributes of release sites.

Criteria for choosing suitable primary release sites will include: (a) positive evidence of host scale infestation; (b) relatively high percentage of host plants the yellow lac scale or soft scales in the overstory and understory; (c) occurrence of a high-density yellow crazy ant supercolony or at least the presence of these ants; and, (d) site not subjected to current pesticide exposure (contact or systemic) or residues that could compromise establishment of the agents. Some criteria (e.g., c and d) can be gleaned from the biennial Islandwide Survey (Green and O'Dowd 2009) and followed up by more detailed site assessments to determine (a) and (b). A specified number of adult insects will be released at each selected site.

Fipronil, the intoxicant in Antoff®, the bait currently used to control supercolonies on Christmas Island, is known to affect the longevity, fecundity, and behaviour of some parasitoids. For example, fipronil used in vineyards to control ants can have acute toxic effects on *Anagyrus* sp. nr *pseudococci* and *Coccidoxenoides perminutus*, two microhymenopteran parasitoids of mealybugs (Mgocheki and Addison 2009). Thus, exposure of the biological control agents at release sites to baiting (especially aerial baiting where a fine dust is produced and a fraction of the bait is retained in the canopy) will be avoided. Coordination between field release and monitoring of biological control agents with National Parks staff involved in chemical control of yellow crazy ant supercolonies will be critical during this phase of this project.

Training on release methodology and criteria will be provided to National Park personnel. Some additions to the Islandwide Survey (e.g., determination of host tree species composition, inspection of understory for yellow lac scales and soft scale insects) could facilitate selection of release sites. Interrogation of the survey database to identify the baiting history at waypoints will be an essential precursor to release of the biological control agents. The National Parks field crew will receive training in identifying and collecting scale insects and parasitoids.

2.14. Establishment and evaluation

The absence of effective, quantitative monitoring for the establishment, spread and impact of most introduced biological control agents has been the Achilles' heel of many biological control programs (McEvoy 1996). Estimation of the success or failure of many past biological control programs has relied on subjective measures, often *post hoc* expert opinion alone (e.g., DeBach et al. 1971, Greathead 1989, Griffiths and Julien 1998). For biological control on Christmas Island, protocols to quantify the establishment, population status, spread, and impact of biological control agents are essential.

Two approaches will be used. First, a field experiment will be conducted using a Before-After-Control-Impact design to determine the establishment and population dynamics of the agents, and the effect of their release on host scale densities (counts per length of stem or per leaf) and parasitization rates, both in the canopy (random sampling of host plant material collected using a shotgun) and in the understory (from saplings of known host trees), and abundance of yellow crazy ants (using counts on tree trunks and on the forest floor) at release and control sites before and after release of biological control agents. Sites (each 2-4 hectares) would be sampled 4 times before release of the agents and 4 times afterwards at two monthly intervals. Results will be analyzed as a one-way repeated measures ANOVA, using release of the biological control agents as the main factor, and comparing response variables before and after release. In this design, the time x treatment interaction is the key term, with a significant difference in response variables after, but not before release. Thus, this experiment at the forest plot scale would establish both the outcome of the release and the mechanism(s) driving any change in the abundance of yellow crazy ants.

Second, at the much broader, island-wide scale the outcome of agents releases on yellow crazy ant supercolonies will be determined by comparing changes in ant trunk traffic and ground activity (using card counts) at four-month intervals at replicated release and control sites across the island. The number of control sites will be determined based on the release sites and area availability. Ideally, control sites should be distant enough from release sites so that the chances for biological control agent dispersal are low for a reasonable period of time. It will be necessary to determine how many of the selected release sites will be actually available for releases and the available areas for control sites where no other management practices (i.e., application of toxic ant baits) for yellow crazy ants will be applied.

Spread of the biological control agents beyond release sites will be determined by placing potted 'sentinel' host plants, infested with yellow lac scales or coccoid scales, at set distances (probably at a logarithmic scale) from replicated release points, followed by their later collection to determine parasitization rates with distance from each release point. It may also be feasible to use the biennial Islandwide Survey to document spread of the biological control agent, at least onto understory seedlings and saplings, at waypoints surrounding release sites.

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Table 1. Host plant species of *Tachardina aurantiaca* (Hemiptera: Kerriidae) arranged alphabetically by family. Nomenclature follows that used in The Plant List (http://www.theplantlist.org/). For host location, putative native distribution is in green, introduced distribution is in red; BRUN = Brunei, CI = Christmas Island; EM = East Malaysia; HK = Hong Kong; INDO = Indonesia; MAL = Maldive Islands; SIN = Singapore;

Family	Species	Host location	Specific locality	Growth form	Source
Acanthaceae	*Avicennia marina* (Forssk.) Vierh.	SIN	Singapore	tree	Murphy 1990
Annonaceae	*Annona glabra* L.	MAL, EM	Tenom, Sabah	tree	Watson et al. 1995; R. Pemberton, pers. obs. 2007
	Annona squamosa L.	MAL, WM, EM, THAI	Addu Atoll, Meedhoo, Maldives; Bandar Utama, Petaling Jaya, Selangor, Malaysia; Kuching, Sarawak; Chonburi, Thailand	tree	Watson et al. 1995; Pemberton & O'Dowd, pers. obs. 2007; G. Neumann, pers. obs. 2013; BMNH record
	Annona sp.	WM	Banda Hilirs, Melaka, Malaysia	tree	TARI record
Asparagaceae	*Cordyline* sp.	MAL	Malé, Maldives	shrubby 'herb'	BMNH record
Boraginaceae	*Ehretia microphylla* Lam.	CI	CINP	shrub	Abbott 2004
Cannabaceae	*Celtis timorensis* Span.	CI	CINP	tree	Abbott 2004
Combretaceae	*Bucida molineti* (M.Gómez) Alwan & Stace	WM	Penang Council Nursery, Penang, Georgetown	tree	Pemberton & O'Dowd, pers. obs. 2007
	Terminalia catappa L.	CI, MAL, WM	CINP; Male, Maldives; Penang, WM	tree	Abbott 2004; Watson et al. 1995; BMNH record
Euphorbiaceae	*Acalypha indica* L.	CI	Settlement CI	shrub	Pemberton & O'Dowd, pers. obs.2007
	Claoxylon indicum (Reinw. ex Blume) Hassk.	CI	CINP	tree	Abbott 2004
	Croton caudatus Geisler	CI	CINP	vine	Abbott 2004
	Macaranga tanarius (L.) Müll.Arg.	CI	CINP	tree	Abbott 2004
	Unidentified	INDO	Bogor, West Java		G. Watson, per obs. 1997
Hernandiaceae	*Hernandia ovigera* Lam.	CI	CINP	tree	Abbott 2004
Lamiaceae	*Callicarpa longifolia* Lam.	CI	CINP	shrub	Abbott 2004
	Leucas decemdentata (Willd.) Sm.	CI	CINP	herb	Abbott 2004
	Premna lucidula Miq.	CI	CINP	tree	Green & O'Dowd, pers. obs.
	Premna obtusifolia R. Br.	MAL		tree	Watson et al. 1995
Lauraceae	*Cryptocarya nitens* Koord. & Valeton	CI	CINP	tree	Abbott 2004
Lecythidaceae	*Barringtonia racemosa* (L.) Spreng.	CI	CINP	tree	Abbott 2004
Leguminosae	*Acacia auriculiformis* x *mangium*	EM, WM	Klang, Selangor, WM; Sarawak Cultural Centre, Kuching, Sarawak	tree	Lim 2007; R. Pemberton & D. O'Dowd, pers. obs. 2007; G. Neumann, pers. obs.
	Acacia farnesiana L. (Willd.)	WM	Malaya (no further specifics)	tree	BMNH record
	Acacia jamesiana Maslin	SIN	Singapore	tree	BMNH record
	Acacia leucophloea (Roxb.) Willd.	INDO	Java - collected by E. Jacobson so must be Semarang, Java record	tree	BMNH record

	Acacia sp.	EM, SIN	Sandakhan, Sabah; Singapore	tree	G. Neumann, pers. obs. 2013; BMNH record
	Acacia sphaerocephala Schltdl. & Cham.	SIN	Singapore	tree	Morris 1921, Chamberlin 1923
	Albizzia chinensis (Osbeck) Merr.	INDO	Java (no specifics beyond)	tree	Green 1913, BMNH record
	Amherstia nobilis Wall.	WM	Malaya (no further specifics)	tree	BMNH record
	Cajanus cajan (L.) Millsp.	SIN, WM	Singapore; Kuala Lumpur	shrub	Morris 1921, Chamberlin 1923; BMNH record
	Calliandra haematocephala Hassk.	EM, SIN	Sepilok, Sabah	tree	G. Neumann, pers. obs. 2013
	Cassia fistula L.	WM	Selangor, West Malaysia	tree	BMNH record
	Cynometra ramiflora L.	CI	CINP	tree	Abbott 2004
	Dendrolobium triangulare (Retz.) Schindl.	SIN	Palau Sinang, Singapore	shrub/tree	BMNH record
	Dendrolobium umbellatum (L.) Benth.	INDO	Rakata (Krakatoa), Indonesia	shrub/tree	Williams and Miller 2010 (BMNH record, 1984)
	Erythrina variegata L.	CI	CINP	tree	Abbott 2004
	Inocarpus fagifer (Parkinson) Fosberg	CI	CINP	tree	Abbott 2004
	Milletia pinnata (L.) Panigrahi	CI, WM, EM	CINP; Taman Ehsan, Selangor, Kuala Lumpur; Bako National Park, Sandakan - Sabah	tree	Abbott 2004; G. Neumann, pers. obs. 2013; BMNH record
	Mucuna bennettii F. Muell.	WM	Malaya (no further specifics)	vine	BMNH record
	Pithecolobium sp.	SIN		tree	Takahashi 1941, Kapur 1958
	Strongylodon sp.	BRUN	Bandar Seri Begawin, Brunei	vine	BMNH record
Lythraceae	*Punica granatum* L.	CI	Settlement CI	tree	Pemberton & O'Dowd, pers. obs. 2007
Malvaceae	*Berrya cordifolia* (Willd.) Burret	CI	CINP	tree	Green & O'Dowd, pers. obs.
	Hibiscus tiliaceus L.	MAL	--	tree	Watson et al. 1995
	Kleinhovia hospita L.	CI	CINP	tree	Abbott 2004
	Theobroma cacao L.	EM	Kota Kinabalu, Sabah	tree	BMNH record
Meliaceae	*Dysoxylum gaudichaudianum* (A. Juss.) Miq.	CI	CINP	tree	Abbott 2004
Moraceae	*Ficus benjamina* L.	WM	Penang Botanic Garden, Penang; Pantai Ache, Penang	shrub	BMNH record
	Ficus microcarpa L.f.	CI	CINP	tree	Abbott 2004
	Ficus saxophila Blume	CI	CINP	tree	Abbott 2004
	Ficus sp.	EM, SIN	--	tree	Takahashi 1941; G. Neumann, pers. obs. 2013
	Ficus tinctoria subsp. *gibbosa* (Blume) Corner	SIN	Singapore	tree	BMNH record
	Maclura cochinchinensis (Lour.) Corner	CI	CINP	vine	Abbott 2004
	Morus nigra L.	MAL		tree	Watson et al. 1995
Myrtaceae	*Psidium guajava* L.	CI	Settlement CI	tree	Pemberton & O'Dowd, pers. obs. 2007
	Syzygium nervosum A.Cunn ex DC.	CI	CINP	tree	Abbott 2004

	Syzygium samarangense (Blume) Merr. & L.M.Perry	CI	Settlement CI	tree	Pemberton & O'Dowd, pers. obs. 2007
Ochnaceae	*Ochna serrulata* Walp.	EM	Tenom, Sabah	shrub	Pemberton, pers. obs
Orchidaceae	*Corymborkis veratrifolia* (Reinw.) Blume	CI	CINP	herb	O'Dowd, pers. obs.
Oxalidaceae	*Averrhoa bilimbi* L.	CI	Settlement CI	tree	Pemberton & O'Dowd, pers. obs. 2007
	Averrhoa carambola L.	HK, CI	Fanling, New Territories, Hong Kong; Settlement CI	tree	Martin & Lau 2011, Pemberton & O'Dowd, pers. obs. 2007
Phyllanthaceae	*Bridelia tomentosa* Blume	WM	Forestry Research Institute Malaysia, Selangor, WM	tree	G. Neumann, pers. obs. 2013
	Cleistanthus monoicus (Lour.) Müll. Arg.	INDO	Bogor, Java	tree	BMNH redord
Primulaceae	*Ardisia colorata* Link	CI	CINP	tree	Abbott 2004
Proteaceae	*Macadamia integrifolia* Maiden & Betche	CI	Settlement CI	tree	Pemberton & O'Dowd, pers. obs. 2007
Rhamnanceae	*Ziziphus jujuba* Mill.	THAI, MAL	Bangkok Noi, Thailand; Addu Atoll, Meedhoo, Maldives	tree	Takahashi 1941, Watson et al. 1995
	Ziziphus mauritiana Lam.	?		tree	Kapur 1958
	Ziziphus sp.	EM	Rambangi Station, Kuching, Sarawak	tree	Pemberton, pers. obs. 2007
Rosaceae	*Rosa* sp.	EM	Across river, Kuching, Sarawak	shrub	Pemberton, pers. obs. 2007
Rubiaceae	*Ixora macrothyrsa* (Teijsm. & Binn.) T. Moore	SIN	Singapore	shrub-tree	Morrison 1921, Chamberlin 1923
	Aidia racemosa (Cav.) Tirveng.	CI	CINP	shrub	Abbott 2004
Rutaceae	*Acronychia trifoliata* var. *trifoliata* Zoll. & Moritzi	CI	CINP	tree	Abbott 2004
	Aegle marmelos (L.) Correa	MAL		tree	Watson et al. 1995
	Citrus aurantifolia (Christm.) Swingle	CI	Settlement CI	shrub	Pemberton & O'Dowd, pers. obs. 2007
	Citrus hystrix DC.	CI, WM	Settlement CI, Penang WM	shrub	Pemberton & O'Dowd, pers. obs. 2007; BMNH record
	Citrus japonica Thunb.	WM		shrub	G. Neumann, pers. obs. 2013
	Citrus sp.	EM, WM	Tuaran, Sabah; Sarawak	shrub	BMNH records; TARI record
	Citrus x *paradisi*	INDO	Garoet, West Java	shrub	Cockerell 1903
Salicaceae	*Flacourtia inermis* Roxb.	WM	Kelah Sanctuary, Putrajaya, Kuala Lumpur, Malaysia	tree	Ong Su Ping and G. Neumann, pers. obs. 2013
	Flacourtia sp.	INDO	Semarang, Central Java	tree	Green 1913
Sapindaceae	*Allophylus cobbe* (L.) Raeusch.	CI	CINP	tree	Abbott 2004
	Arfeuillea arborescens Pierre ex Radlk.	SIN, WM	Penang Botanic Garden, Penang, WM; Civil Aviation Authority Nursery, Changi, Singapore	tree	BMNH record; G. Watson, per obs. 2001; G. Neumann, pers. obs. 2013
	Dimocarpus longan Lour.	CI	Settlement CI	tree	Pemberton & O'Dowd, pers. obs. 2007

	Dimocarpus longan var. malesianus Leenh.	CI	Settlement CI	tree	Pemberton & O'Dowd, pers. obs. 2007
	Nephelium maingayi Hiern.	WM	Taman Ehsan, Kuala Lumpur, Malaysia	tree	Ong Su Ping and G. Neumann, pers. obs. 2013
	Tristiropsis acutangula Radlk.	CI	CINP	tree	Abbott 2004
Sapotaceae	*Manilkara sapota* van Royen	MAL	North Malé Atoll	tree	Watson et al. 1995
	Planchonella duclitan (Blanco) Bakh.f.	CI	CINP	tree	Abbott 2004
Solanaceae	*Cestrum nocturnum* L.	WM	"Malaya"	vine	BMNH record
	Capsicum annuum L.	CI, MAL	Settlement CI; Addu Atoll, Hithadhoo, Maldives	herb	Pemberton & O'Dowd, pers. obs. 2007; Watson et al. 1995
	Solanum melongena L.	CI	Settlement CI	herb	Pemberton & O'Dowd, pers. obs. 2007
Thymeleaceae	*Phaleria* sp.	INDO	Java	tree	BMNH record
Urticaceae	*Dendrocnide peltata* (Blume) Miq.	CI	CINP	tree	Abbott 2004
Vitaceae	*Leea angulata* Korth. Ex Miq.	CI	CINP	tree	Abbott 2004
Unidentified	Unidentified		Java	--	BMNH record
	Unidentified	EM	Palau Labuan, Sabah	tree	C.L Chin, pers. comm. 2013
	Unidentified	EM	Batu Lintang, Kuching, Sarawak	--	BMNH record
	Unidentified	WM	Selangor, Serdang UPA Uni Campus	--	BMNH record
	Unidentified	THAI	Chumphon, Thailand	--	Hayat et al. 2010

THAI = Thailand; WM = West Malaysia. CINP = Christmas Island National Park. BMNH = record from the British Museum of Natural History, TARI = record from the Taiwan Agricultural Research Institute.

Table 2. Time (days ± SE) from crawler stage to emergence of either (a) adult males or (b) the production of the next generation of crawlers from adult females in *Tachardina aurantiaca* on seedlings of *Acacia mangium* x *A. auriculiformis* (n = 6), *Milletia* sp. (n = 7) and *Inocarpus fagifer* (n = 6) under laboratory conditions. All host plants were potted plants less than 1 m tall. Observations on hosts *A. mangium x A. auriculiformis* and *Milletia* sp. were conducted in at the Forest Research Institute in Selangor, Malaysia (Ong et al. 2014). Observations on *I. fagifer* were conducted on Christmas Island.

	Acacia mangium* x *A. auriculiformis	***Milletia* sp.**	***Inocarpus fagifer***
Days to male emergence	40.1 ± 0.2	41.7 ± 0.1	42.5 ± 1.3
Days to female crawler production	87.6 ± 0.2	98.3 ± 0.5	99.7 ± 1.2

Table 3. Records of known host families and genera[1] for the primary parasitoid *Tachardiaephagus* (Encyrtidae). The proposed biological control agent, *Tachardiaephagus somervillei*, is in bold. As a genus, *Tachardiaephagus* has an extremely broad geographic range. With the exception of one host record in Africa reported as erroneous by Prinsloo (1977), all *Tachardiaephagus* species appear to be family specialists and restricted to the Kerriidae. For host genera, number of species recorded as hosts is in parentheses. Based on Noyes (2012, Universal Chalcidoidea Database, http://www.nhm.ac.uk/research-curation/research/projects/chalcidoids/ database/), except for additional records for *T. somervillei* and *T. sarawakensis* (Hayat et al. 2010; Green et al. 2013; R.W. Pemberton, pers. comm.).

Parasitoid species	Distribution	Recorded hosts (all Kerriidae)
Tachardiaephagus somervillei	India, Malaysia, Thailand	*Kerria* spp. (4)[1] *Tachardina aurantiaca* *Tachardina* sp.[2]
T. sarawakensis	Sarawak (East Malaysia)	*Tachardina aurantiaca*
T. tachardiae	Brunei, China, India, Indonesia, Malaysia, Sri Lanka, Taiwan, Vietnam, Azerbaijan	*Kerria* spp. (8) *Paratachardina lobata*[3] (= *P. silvestri*)
T. similis	Afrotropical, South Africa	*Tachardina* sp. (1)
T. absonus	Afrotropical, South Africa	*Tachardina* spp. (2)
T. communis	Afrotropical, South Africa	*Tachardina* spp. (5)
T. gracilis	Afrotropical, South Africa	*Tachardina* sp. (1)

[1] Ben-Dov et al. (2012) indicate that the kerriid genus *Laccifer* is a synonym for the genus *Kerria*. Therefore, we have combined records for *Laccifer* spp. in Noyes (2012) with records for *Kerria*.

[2] Probably *T. aurantiaca*, since it is the only *Tachardina* species known in Asia.

[3] Noyes (2012) lists *P. lobata* as a host for *T. somervillei*. However, this is based on an incorrect reading of Pemberton 2003; the author of that paper states that while *T. somervillei* has not been recorded from *P. lobata*, it was worth testing *T. somervillei* against *P. lobata* because the congeric species *T. tachardiae* had been recorded to parasitize it.

Table 4. Known host range of primary parasitioid species in the 16 genera of encyrtids (Chalcoididea: Encyrtidae) known to attack members of the scale insect family Kerriidae (lac scales, the family of the target insect *Tachardina aurantiaca*)(Data from the Universal Chalcidoidea Database - Noyes 2012). Phylogenetic distance from the Kerriidae increase from left to right (see Gullan and Cook 2007).

	Known host range				
Encyrtid genus	No. species	Kerriidae only	Kerriidae + Coccidae only	Kerriidae + 'neococcids'	Kerriidae + Coccidae +'archeococcids'
Adencyrtus	3	2/3	1/1	-	-
Ageniaspis	1	1/1	-	-	-
Ammonoencyrtus	1	-	1/1	-	-
Clausenia	1	1/1	-	-	-
Coccidaphycus	1	-	-	-	1/1
Coccopilatus	1	1/1	-	-	-
Erencyrtus	6	6/6	-	-	-
Laccacida	1	1/1	-	-	-
Lakshaphagus	1	1/1	-	-	-
Metaphycus	7	3/7	2/7	2/7	-
Microterys	2	1/2	1/2	-	-
Ooencyrtus	3	3/3	-	-	-
Ruandella	1	1/1	-	-	-
Tachardiaephagus	7	7/7	-	-	-
Tachardiobius	3	3/3	-	-	-
Tyndarichus	1	1/1	-	-	-

Table 5. Scale insects of Christmas Island. It is highly probable that all of these species, with broad host plant ranges and geographic distributions, are exotic to Christmas Island and introduced following human settlement. The target species for biological control, *Tachardina aurantiaca*, is in bold. Honeydew-producing scale insects in bold occur commonly tended by the yellow crazy ant in supercolonies. Families are arranged in increasing phylogenetic distance from the Kerriidae based on Gullan and Cook (2007) and Ross et al. (2012). All scale insect taxa are 'neococcids' except for *Icerya purchasi* ('archeococcid'). Taxonomy and distributions from Ben-Dov et al. (2012), http://www.sel.barc.usda.gov/scalenet/scalenet.htm).

Family and Species[1]	Common Name	Distribution	Honeydew Producer
Kerriidae (lac scales)			
Paratachardina pseudolobata (Kondo & Gullan)	False lobate lac scale	Oriental, Nearctic, Neotropical	yes[2]
***Tachardina aurantiaca* (Cockerell)**	**Yellow lac scale**	**Oriental**	**yes**
Coccidae (soft scales)			
Ceroplastes ceriferus (Fabricius)	Indian wax scale	Cosmopolitan	yes
C. destructor Newstead	White wax scale	Afrotropical, Australasia, Oriental	yes
***Coccus celatus* De Lotto**	**Green coffee scale**	**Afrotropical, Australasia, Oriental**	**yes**
***C. hesperidum* Linnaeus**	**Brown soft scale**	**Cosmopolitan**	**yes**
Milviscutulus mangiferae (Green)	Mango shield scale	Cosmopolitan	yes
Parasaissetia nigra (Nietner)	Nigra scale	Cosmopolitan	yes
Pulvinaria urbicola Cockerell	Urbicola soft scale	Pantropical	yes
P. psidii Maskell[3]	Green shield scale	Cosmopolitan	yes
***Saissetia coffeae* (Walker)**	**Black olive scale**	**Pantropical**	**yes**
***S. oleae* (Olivier)**	**Hemispherical scale**	**Cosmopolitan**	**yes**
Diaspididae (armoured scales)			
Aspidiotus destructor (Signoret)	Coconut scale	Cosmopolitan	no
Hemiberlesia palmae (Cockerell)	Tropical palm scale	Cosmopolitan	no
Ischnaspis longirostris (Signoret)	Black thread scale	Cosmopolitan	no
Lepidosaphes beckii (Newman)	Citrus mussel scale	Cosmopolitan	no
Lindingaspis tingi McKenzie	--	Oriental	no
Pseudaulacaspis pentagona (Targioni Tozzetti)	White peach scale	Cosmopolitan	no
Unaspis citri (Comstock)	White louse scale	Cosmopolitan	no
Cerococcidae (ornate pit scales)			
Cerococcus indicus (Maskell)	Spiny brown coccid	Cosmopolitan	yes?
Pseudococcidae (mealybugs)	Asian coconut mealybug		
Dysmicoccus finitimus Williams		Australasia, Oriental	yes
Ferrisia virgata (Cockerell)	Striped mealybug	Cosmopolitan	yes
Nipaecoccus viridis (Newstead)	Spherical mealy bug	Cosmopolitan	yes
Pseudococcus longispinus (Targioni Tozzetti)	Long-tailed mealy bug	Cosmopolitan	yes
Monophlebidae (giant scales)			
Icerya purchasi (Maskell)	Cottony cushion scale	Cosmopolitan	yes

[1]Records from Campbell (1968), CSIRO (1999), O'Dowd et al. (2003), Bellis et al. (2004), Abbott (2004), Woods and Steiner (2012) and Neumann et al. (unpubl. results);
[2]*Paratachardina pseudolobata* produces honeydew but ejects it instead of producing droplets that can be collected by ants (Howard et al. 2010)

Table 6. Endemic hemipteran species known from Christmas Island and primary parasitoids (superfamily Chalcidoidea: family Encyrtidae) associated with the families represented by the endemic species. The data were extracted from the Universal Chalcidoidea Database (Noyes 2012). The families Nogodonidae and Rhopalidae have no associated chalcidoid primary parasitoids and therefore endemic species in these families on Christmas Island can most likely be excluded from all further consideration. Cicadellidae and Delphacidae have the highest diversity of chalcidoid primary parasitoids but have magnitudes lower diversity of encyrtid primary parasitoids. These data suggest that the encyrtid primary parasitoids of families with endemic species on Christmas Island appear to not have host range overlap with taxa where the target lac scale is included and the host range separation is at the suborder level suggesting very distant phylogenetic separation. During the database analysis, only records with species-level chalcidoid identification were used. N/A indicates not applicable.

Endemic species	Family	No. chalcidoid associates of family	No. encyrtid 1° parasitoid species of family	Suborder/Family host range of encyrtids parasitizing family
Xestocephalus izzardi[1]	Cicadellidae	627	6	Auchenorrhyncha (Cicadellidae)
Oxypleura calypso	Cicadidae	35	0	N/A
Clovia eximia	Cercopidae	71	4	Auchenorrhyncha (Cercopidae-Aphrophoridae)
Ugyops aristella	Delphacidae	248	5	Auchenorrhyncha (Delphacidae-Cicadellidae)
Varcia flavicostalis	Nogodinidae	0	N/A	N/A
Salona oceanica				
Leptocoris subrufescens[2]	Rhopalidae	0	N/A	N/A

[1] *Xestocephalus izzardi* is also reported from Palau in the western Pacific Ocean (Linnavuori 1975). Its status as an endemic on Christmas Island is questionable.
[2] *Leptocoris subrufescens* on Christmas Island has been classified to subspecies status (*L. subrufescens subrufescens*). Another subspecies (*L. s. flava*) is described from Yap, western Pacific Ocean (Göllner-Scheiding 1980). More research is needed to resolve the taxonomic status of these two subspecies of *L. subrufescens*.

Table 7. Comparison of key features of the Host Testing Protocol that was peer-reviewed by expert biological control practitioners, and the actual methods used for the Testing.

Key Feature of Externally Reviewed Protocol	Original Parameters	Eventual Outcome
Number of test species	10 to 15, but fewer if high specificity is found initially	8 species tested
Relatedness of test species to the target species, *Tachardina aurantiaca*	Focus on neococcid taxa including the Kerriidae, the family to which the target host belongs (see Gullan and Cook 2007). Considering the phylogenetic relationships of scale insect families, aim to test more than one species from the family Coccidae.	4 Coccidae species tested No Kerridae other than *Tachardina* tested
Inclusion of phylogenetic 'outgroups'	Species in the family Diaspididae will also be considered as a less closely related group of scale insects. Early in the host testing process, an 'out-group' (test species phylogenetically more distant) will also be used, most likely selected from the family Pseudococcidae	1 Diaspididae tested 3 Pseudococcidae tested
Approach to testing	No-choice tests preferred over choice tests or sequential no-choice tests. Tests accompanied by both positive controls (test parasitoid against known host to confirm their quality) and negative controls (test species enclosed without parasitoids to determine background mortality)	No-choice tests used, each replicate paired with a negative control. Positive controls conducted on 'batches' of parasitoids produced for tests, rather than paired with test and negative control replicates
Location of testing	Field trials in area of origin preferred over testing in containment at the release location (Christmas Island), or testing in containment on mainland Australia.	All field trials were conducted within the area of origin at a site in Kuching (Sarawak).
Replication	In no-choice tests, 10 trials per test species, with 50 individuals of the test species exposed to 10 female and 10 male parasitoids. Hosts and parasitoids enclosed on branches by mesh bags	There were 10 replicates for 7 test species, and 5 replicates for the other test species. There were 25 individuals of the test species per trial, exposed to 5 female and 5 male parasitoids.

Table 8. Test species, their host plants, replication and experimental outcomes for the host specificity testing conducted at Kampung Boyan near Kuching (Sarawak, Malaysia) in 2013-2014. N_{reps} is the number of independent replicates undertaken for each test species (see Table 9). $N_{insects/rep}$ is the number of individuals of a given test species used in each replicate.

Test Species (Family)	Host Plant Species (Family)	N_{reps}	$N_{insects/rep}$	No. emerging parasitoids/rep	Progeny per female parasitoid
Coccus hesperidum **(Coccidae)***	*Ficus* sp. (Moraceae)	10	25	0 ± 0	0 ± 0
Coccus longulus **(Coccidae)**	*Acacia* sp. (Mimosaceae)	10	25	0 ± 0	0 ± 0
Milviscutulus mangiferae **(Coccidae)***	*Morinda citrifolia* (Rubiaceae)	10	25	0 ± 0	0 ± 0
Pulvinaria urbicola **(Coccidae)***	*Pisonia grandis* (Nyctaginaceae)	10	25	0 ± 0	0 ± 0
Chionaspis **near** ***C. broughae*** **(Diaspididae)**	*Mangifera* sp. (Anacardiaceae)	5	25	0 ± 0	0 ± 0
Paraputo **near** ***P. corbetti*** **(Pseudococcidae)**	*Mangifera* sp. (Anacardiaceae)	10	25	0 ± 0	0 ± 0
Pseudococcus jackbeardsleyi **(Pseudococcidae)**	?*Aglaonema* sp. (Araceae)	10	25	0 ± 0	0 ± 0
Rastrococcus iceryoides **(Pseudococcidae)**	*Croton* sp. (Euphorbiaceae)	10	25	0 ± 0	0 ± 0

*species that also occur on Christmas Island.

Table 9. The number replicates (solid circles in each column) for each test species, the batch of *T. somervillei* used for each test replicate, and which of those batches were quality-tested in Positive Control trials (see Table 10). For test species, *Ch* = *Coccus hesperidum*, *Cl* = *Coccus longulus*, *Mm* = *Milviscutulus mangiferae*, *Pu* = *Pulvinaria urbicola*, *Ch* = *Chionaspis* near *C. broughae*, *Pc* = *Paraputo* near *P. corbetti*, *Pj* = *Pseudococcus jackbeardsleyi*, *Ri* = *Rastrococcus iceryoides*.

	Test Species								
Parasitoid batch	***Ch***	***Cl***	***Mm***	***Pu***	***Cb***	***Pc***	***Pj***	***Ri***	**Positive control**
1	•	•	•	•					Yes
2	•	•	•						No
3	•	•	•				•		Yes
4	•	•	•			•	•		Yes
5	•	•	•	•	•	•	•		Yes
6	•	•	•	•	•	•	•		Yes
7	•	•	•	•	•	•	•		No
8	•	•	•	•	•	•	•		Yes
9	•	•	•	•	•	•	•		Yes
10	•	•	•	•	•	•	•		No
11					•	•	•		Yes
12				•	•	•	•		Yes
13					•	•			Yes
14				•	•				No
15				•					No
16								•	Yes
17								•	No
18								•	Yes
19								•	No
20								•	Yes
Total Test Replicates	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**5**	

Table 10. Performance of batches of *T. somervillei* used as the positive controls in host specificity testing. A total of 20 batches of parasitoids were produced for use in the host specificity testing. *T. somervillei* from 13 batches were tested against the natural (target) host, *Tachardina aurantiaca* under field conditions over several months of trials at Kampung Boyan near Kuching (Sarawak, Malaysia) in 2013-2014.

Batch	No. ♀ *T. aurantiaca* (host)	No. ♀ *T. somervillei* (agent)	No. emerging parasitoids	Parasitoids per scale	Progeny per ♀ parasitoid
1	25	5	17	0.68	3.4
3	25	5	12	0.48	2.4
4	25	5	14	0.56	2.8
5	25	5	21	0.84	4.2
6	25	5	18	0.72	3.6
8	25	5	16	0.64	3.2
9	25	5	19	0.76	3.8
11	25	5	22	0.88	4.4
12	25	5	20	0.80	4.0
13	25	5	26	1.04	5.2
16	25	5	24	0.96	4.8
18	25	5	15	0.60	3.0
20	25	5	19	0.76	3.8

Table 11. Climate matching between weather stations closest to the collection sites of *Tachardiaephagus somervillei* in South and Southeast Asia and the proposed area of introduction, Christmas Island (Indian Ocean). Climate Parameters are given for temperature and rainfall, and seasonality indices are coefficients of variation based on monthly averages. For Matching Parameters (TI = temperature index, MI = moisture index, RPI = rainfall pattern index, CMI = composite match index), sites with higher values are more similar to Christmas Island; after Christmas Island, sites are arranged in descending order of CMI. Christmas Island and Kuala Lumpur (the proposed source site for introduction of *T. somervillei*) and are in bold. Distribution of sites is shown in Fig. 6. See text for methods.

	Climate parameters						**Matching Parameters**			
Site	Max Temp (^{O}C)	Min Temp (^{O}C)	Avg Temp (^{O}C)	Temp Seasonality (%)	Annual Rainfall (mm)	Rainfall Seasonality (%)	TI	MI	RPI	CMI
Christmas Island 10°30'S 105°40'E	**27.3**	**22.8**	**25.0**	**2.4**	**2110**	**59.2**	**-**	**-**	**-**	-
Chumphon, Thailand 10°29'N 99°11'E	31.4	22.8	27.1	4.2	1956	57.4	0.79	0.89	0.72	79.8
Singapore 01°22'N 103°59'E	30.9	23.9	27.4	1.9	2150	28.2	0.84	0.97	0.59	77.9
Kaohsiung, Taiwan 22°37'N 120°18'E	28.5	23.7	26.1	12.2	1885	106.8	0.82	0.84	0.64	76.4
Kuala Lumpur, Malaysia 03°07'N 101°33'E	**32.3**	**22.8**	**27.5**	**1.4**	**2366**	**29.6**	**0.78**	**0.83**	**0.55**	**71.2**
Taoyuan, Taiwan 25° 03'N 121° 13'E	25.0	19.2	22.1	23.3	1714	34.4	0.73	0.72	0.63	69.6
Bangkok, Thailand 13°45'N 100°30'E	32.4	23.7	28.1	4.7	1467	83.4	0.74	0.57	0.77	69.1
Sandakan, Malaysia 05°54'N 118°04'E	31.1	23.2	27.2	2.1	3010	44.6	0.82	0.55	0.45	59.3
Jamshedpur, India 22°48'N 86°11'E	32.8	21.6	26.4	20.9	691	118.9	0.64	0.23	0.84	49.7
Jabalpur, India 23.17°N 79.93°E	31.9	20.0	25.9	19.8	670	139.8	0.63	0.22	0.82	48.6
Kuching, Malaysia 01°33'N 110°20'E	31.7	23.1	27.4	2.1	4117	42.4	0.80	0.33	0.28	42.5
Patna, India 25°36'N 85°07'E	31.2	21.6	26.4	20.9	238	119.5	0.64	0.11	0.94	40.6

Table 12. Natural enemy assemblages of the yellow lac scale *Tachardina aurantiaca* on Christmas Island and in Malaysia. + = present, -- = absent. For associates of *T. aurantiaca*, primary parasitoids oviposit on or in a host and develop within, ultimately killing the host. Hyperparasitoids seek out hosts with primary parasites, oviposit, and develop within the primary parasitoid. Predators feed externally and consume multiple scales. See also Fig. 12.

Species (Family)	**Association with *T. aurantiaca***	**Christmas Island**	**Malaysia**
Tachardiaephagus somervillei Mahdihassan (Encyrtidae)	primary parasitoid	--	+
T. sarawakensis Hayat et al. (Encyrtidae)	primary parasitoid	--	+
Coccophagus euxanthodes Hayat et al. (Aphelinidae)	primary parasitoid	--	+
C. tschirchii Mahdihassan (Aphelinidae)	primary parasitoid	--	+
Coccophagus sp. (Aphelinidae)[1]	primary parasitoid[2]	--	+
Promuscidea unfasciativentris Girault (Aphelinidae)	hyperparasitoid	--	+
Aprostocetus (syn. *Tetrastichus) purpureus* Cameron (Eulophidae)[1]	hyperparasitoid[3]	--	+
Marietta leopardina Motschulsky (Aphelinidae)	primary parasitoid[4]	+	+
Eublemma sp. (Noctuidae)	predator	+	+
?*Holcocera* sp. (Blastobasidae)	predator	+	+

[1]Tentative identification

[2]Attack male *T. aurantiaca* only

[3]primary parasitoid of many Coccidae, Diaspididae, Kerriidae, Margarodidae, and Pseudococcidae but known as a hyperparasitoid of *C. tschirchii* and *Tachardiaephagus* sp.

[4]On Christmas Island and in Malaysia, *Marietta leopardina* is known only to attack male *T. aurantiaca*. It has never been observed emerging from female *T. aurantiaca*. In Southeast Asia, it is also a hyperparasitoid of primary parasitoids of a variety of scale insects.

Table 13. Parasitization rates on mature females of *Tachardina aurantiaca* in the native range (Southeast Asia) and in the introduced range (Christmas Island). Parasitization rates were calculated as the proportion of mature female scale insects with one or more visible parasitoid emergence hole, either in isolated aggregates (N = 5) at sites in Southeast Asia or pooled within sites on Christmas Island (N is in brackets). This gives rates of parasitization at each site, but not the identity of the parasitoids. However, only *T. somervillei* was collected at sites in Kuching and Singapore. All other locations in Southeast Asia had a parasitoid assemblage of more than one species. For Christmas Island, number in parentheses after site name indicates the total number of mature females examined.

Location	**Incidence of Parasitization (%, mean ± SE)**
Native range (Southeast Asia)	
Klang (Selangor, West Malaysia)	38 ± 17
Taman Ehsan (Selangor, West Malaysia)	46 ± 21
Singapore (National University Singapore campus)	73 ± 12
Kampung Istana, Kuching (Sarawak)	42 ± 23
Kampung Boyan, Kuching (Sarawak)	81 ± 6
Sandakan (Sabah)	76 ± 8
Sepilok (Sabah)	29 ± 13
Introduced Range (Christmas Island)	
The Dales (Hugh's – Sydney's) (4000)	0 ± 0
Martin Point to CINP Boundary (1500)	0 ± 0
Dolly Beach Track (1000)	0 ± 0
North West Point Track (1500)	0 ± 0
Circuit Road (2000)	0 ± 0

Table 14. Ant attendance of adult females of *Tachardina aurantiaca* and incidence of parasitism by *Tachardiaephagus somervillei* (±SE, N = 5 aggregates of *T. aurantiaca* at each site) in Peninsular Malaysia, Sarawak and Sabah. Parasitism rates of T*. aurantiaca* are high in the presence of tending ants, including *Anoplolepis gracilipes*, on a variety of host plants across the region.

Location	**Site**	**Host plant**	**Tending ants**	**Female parasitism (%)**
Singapore	National University Singapore	*Acacia* sp.	*Dolichoderu*s sp.	73 ± 12
Peninsular Malaysia	Klang (Selangor)	*Acacia mangium* x *A. auriculiformis*	*Oecophylla smaragdina*	38 ± 17
	Tahman Ehsan (Selangor)	*Milletia pinnata*	*Dolichoderus* sp.	46 ± 21
Sarawak	Kampung Istana, Kuching	*Acacia mangium* x *A. auriculiformis*	*Anoplolepis gracilipes*	42 ± 23
	Kampung Boyan, Kuching	*Acacia mangium* x *A. auriculiformis*	*Oecophylla smaragdina*	81 ± 6
Sabah	Sandakan	*Milletia pinnata*	*Anoplolepis gracilipes*	76 ± 8
	Sepilok	*Calliandra haematocephala*	*Anoplolepis gracilipes*	29 ± 13

Table 15. Scale insects species on Christmas Island that are known hosts of three chalcidoid parasitoids introduced to the island since human settlement (Noyes 2014). All scale insect species listed, except the diaspidid *Aspidiotus destructor*, are honeydew producers. Scale insect species in bold are those that are commonly tended by yellow crazy ants in supercolonies (see Table 10).

Coccophagus ceroplastae **(Aphelinidae)**	***Coccophagus longifasciatus*** **(Aphelinidae)**	***Encyrtus infelix*** **(Encyrtidae)**
Coccidae	**Coccidae**	**Coccidae**
Coccus hesperidum	*Ceroplastes spp.*	*Ceroplastes destructor*
Parasaissetia nigra	***Coccus hesperidum***	***Coccus hesperidum***
Pulvinaria psidii	*Parasaissetia nigra*	*Parasaissetia nigra*
Pulvinaria urbicola	*Pulvinaria psidii*	*Pulvinaria urbicola*
Saissetia coffeae	***Saissetia oleae***	***Saissetia coffeae***
Saissetia oleae		***Saissetia oleae***
Diaspididae		
Aspidiotus destructor		
Pseudococcidae		
Nipaecoccus viridis		

Table 16. Mitochondrial COI base pair sequences of *Tachardiaephagus somervillei* individuals from the site in east Malaysia where the host specificity testing was conducted (KUCHING, n = 3) and sites in west Malaysia from which the founder population will be collected (FRIM, n = 5 and KLANG, n = 2). A 600 base-pair sequence is shown for each individual. The sequences are identical for this gene fragment across all individuals with no evidence of population-level differentiation. This strongly suggests that *T. somervillei* across this geographic range is a single species. Unpublished data courtesy of Dr Nick Murphy, La Trobe University.

Site	**Base Pair Sequence**
KUCHING_1	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
KUCHING_4	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
KUCHING_9	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
FRIM_16	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
FRIM_19	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
FRIM_20	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
FRIM_21	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
FRIM_3	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
KLANG_2	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
KLANG_5	GATGTATTTATATTACGATCAAATAAAAGTATTGTAATAGCTCCTGCTAATACAGGTAAA
KUCHING_1	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
KUCHING_4	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
KUCHING_9	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
FRIM_16	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
FRIM_19	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
FRIM_20	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
FRIM_21	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
FRIM_3	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
KLANG_2	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
KLANG_5	GATAATAATAATAAAATAGCTGTTAATAATATTGCCCAAGAAAATAAAGGTAAAATCTCT
KUCHING_1	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
KUCHING_4	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
KUCHING_9	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
FRIM_16	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
FRIM_19	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
FRIM_20	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
FRIM_21	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
FRIM_3	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
KLANG_2	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
KLANG_5	ATTTTATATAATTTTATATTAATAATAGTAGTAATAAAATTAATTGAACCTATAATTGAA
KUCHING_1	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
KUCHING_4	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
KUCHING_9	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
FRIM_16	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
FRIM_19	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
FRIM_20	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
FRIM_21	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
FRIM_3	GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT

KLANG_2 GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT
KLANG_5 GATAGTCCAGCAATATGAAGAGAAAAAATAGATAAATCTACTGAAGGCCCTATATGAGAT

KUCHING_1 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
KUCHING_4 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
KUCHING_9 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
FRIM_16 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
FRIM_19 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
FRIM_20 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
FRIM_21 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
FRIM_3 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
KLANG_2 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT
KLANG_5 AAATTTGAAGATAAAGGAGGGTAGACAGTTCACCCGGTTCCGGTACCTCTACCTACAAAT

KUCHING_1 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
KUCHING_4 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
KUCHING_9 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
FRIM_16 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
FRIM_19 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
FRIM_20 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
FRIM_21 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
FRIM_3 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
KLANG_2 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC
KLANG_5 ATCCTAGAAATTAACAAAATAATTCTAGGAGGTAATAATCAAAAACTTATATTATTTATC

KUCHING_1 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
KUCHING_4 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
KUCHING_9 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
FRIM_16 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
FRIM_19 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
FRIM_20 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
FRIM_21 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
FRIM_3 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
KLANG_2 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC
KLANG_5 CGAGGAAATACTATATCAGGAGCCCCTATAATTAAAGGAATTAAAAAATTACCAAAACCC

KUCHING_1 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
KUCHING_4 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
KUCHING_9 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
FRIM_16 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
FRIM_19 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
FRIM_20 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
FRIM_21 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
FRIM_3 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
KLANG_2 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA
KLANG_5 CCCATCATTACTGGTATTACAAAAAAAAAAATCATTACAAAAGCATGAGCTGTAACAATA

KUCHING_1 GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
KUCHING_4 GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
KUCHING_9 GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
FRIM_16 GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
FRIM_19 GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
FRIM_20 GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA

FRIM_21	GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
FRIM_3	GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
KLANG_2	GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA
KLANG_5	GAATTATAAATCTGATCATTCCCAATAAAGGAACCAGGAGTCCCTAATTCTAAACGAATA

KUCHING_1	ATTATT
KUCHING_4	ATTATT
KUCHING_9	ATTATT
FRIM_16	ATTATT
FRIM_19	ATTATT
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KLANG_2	ATTATT
KLANG_5	ATTATT

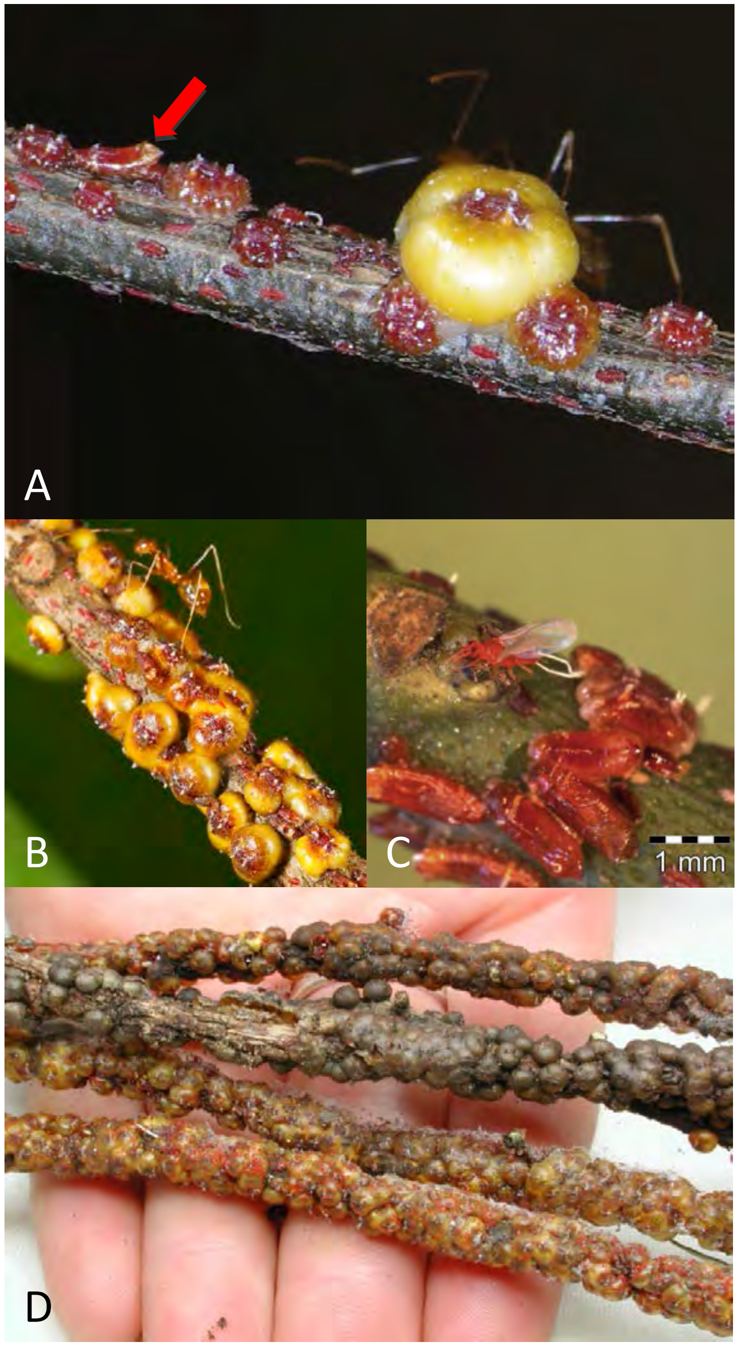

Figure 1. A. Mature yellow female of *Tachardina aurantiaca*, with several female nymphs and recently settled crawlers nearby (Photo: P. Green). The three white threads on top of the female are waxy filaments that surround the anal pore. Red arrow points to a male of *T. aurantiaca*. **B.** Female *T. aurantiaca* produce honeydew that is attractive to a variety of ants, including the yellow crazy ant *Anoplolepis gracilipes* (Photo: S. Belcher). **C.** A male of *T. aurantiaca* (upper middle) and male tests (Photo: Ong Su Ping). **D.** In high-density supercolonies of the invasive ant *A. gracilipes* on Christmas Island, adult females of *T. aurantiaca* can sheath the fine branches and stems of its preferred host tree *Inocarpus fagifer*. The stems in the foreground shows coalesced live females with recently emerged crawlers; stems in the background are sheathed in mostly dead females (Photo: P. Green).

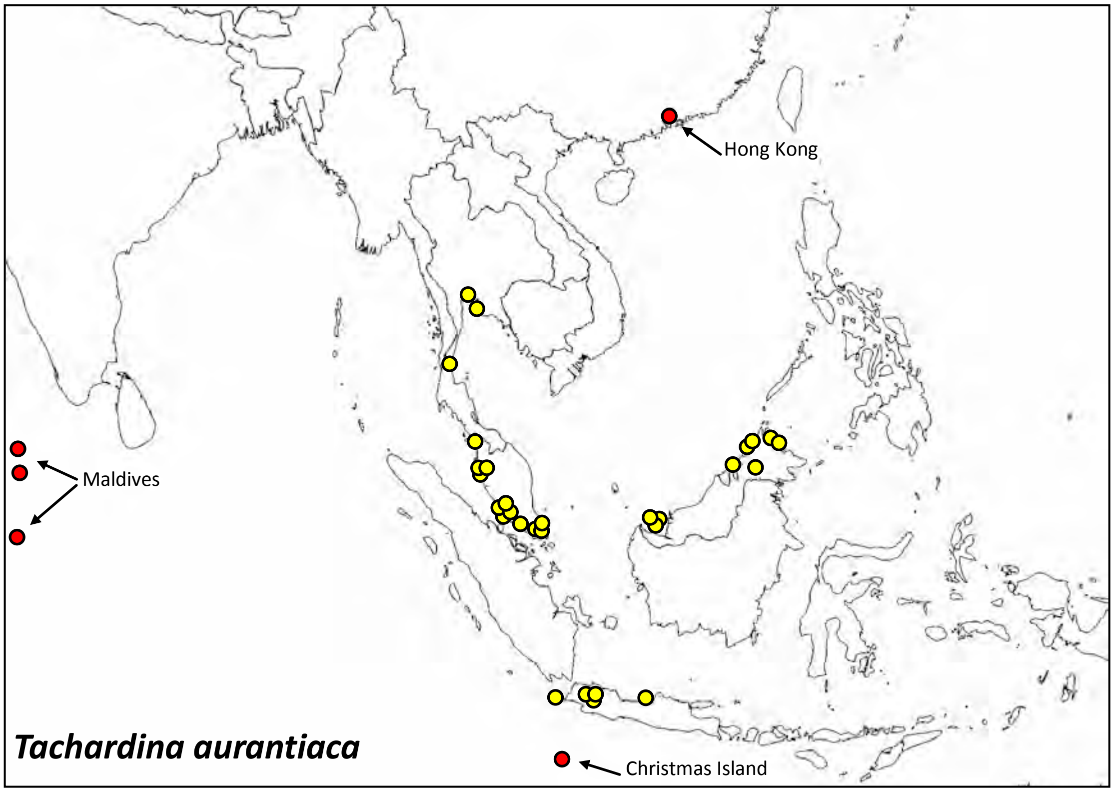

Figure 2. Distribution of the yellow lac scale *Tachardina aurantiaca*. The putative native distribution is indicated by yellow circles and the likely introduced distribution by red circles. The native distribution includes sites in Peninsular Malaysia (e.g. Penang Island, Klang, Selangor, Singapore) and Malaysian Borneo (e.g. Sarawak - Kuching; Sabah - Sandakan, Sepilok) where live aggregates of *T. aurantica* were found as part of the foreign exploration leading up to this Release Package (R. Pemberton and D. O'Dowd, unpublished results; G. Neumann, unpublished results), and sites in Malaysia (Sabah, Tenom), Thailand (Bangkok, Chumphong), Java (Garoet) and the Sunda Straits (Rakata Krakatau) where the species has also been recorded by other workers (Green 1913; Morrison 1921; Takahashi 1941, Campbell 1964; Watson et al. 1995; Hayat et al. 2010; Williams and Miller 2010, Martin and Lau 2011, G.W. Watson, pers. comm. 2014, P. Brown, pers. comm. 2014).

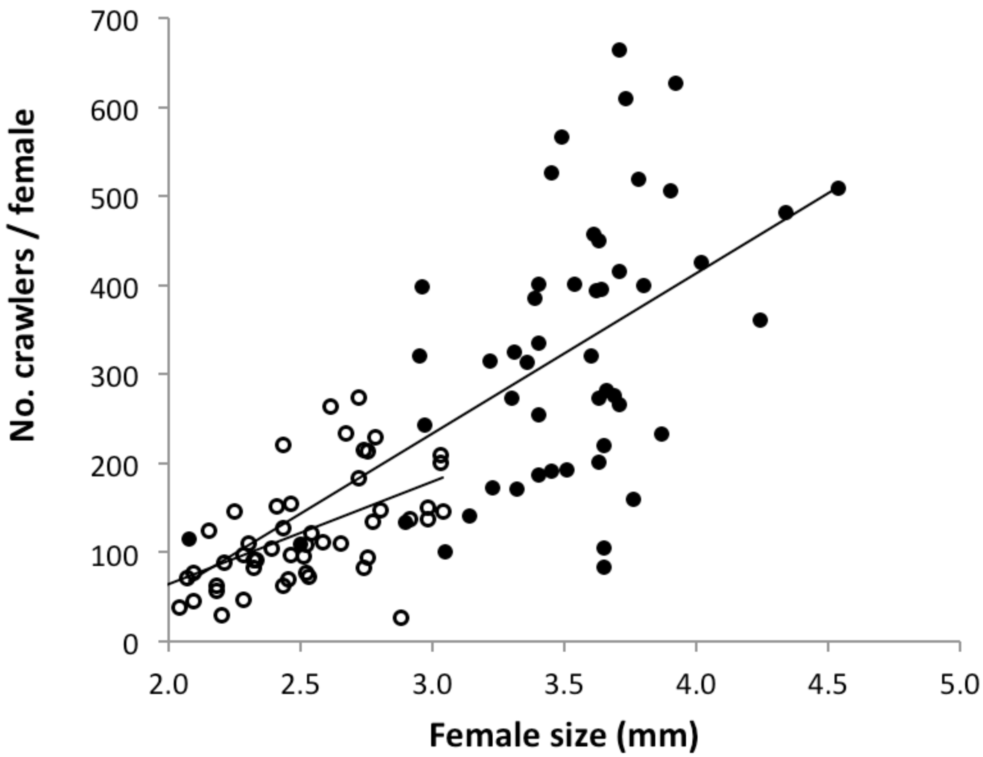

Figure 3. Size-dependent fecundity of female *Tachardina aurantiaca* under laboratory and field conditions, across a range of plant hosts. Female size was determined by measuring the test at the greatest horizontal diameter with callipers. The number of crawlers was determined by dissecting the females shortly before crawler release. There is a significant correlation between female size and number offspring produced (open circles indicate laboratory populations, $R^2 = 0.295$, $p < 0.001$, $n = 50$; solid circles indicate field $R^2 = 0.207$, $p = 0.006$, $n = 50$)(Ong et al. 2014).

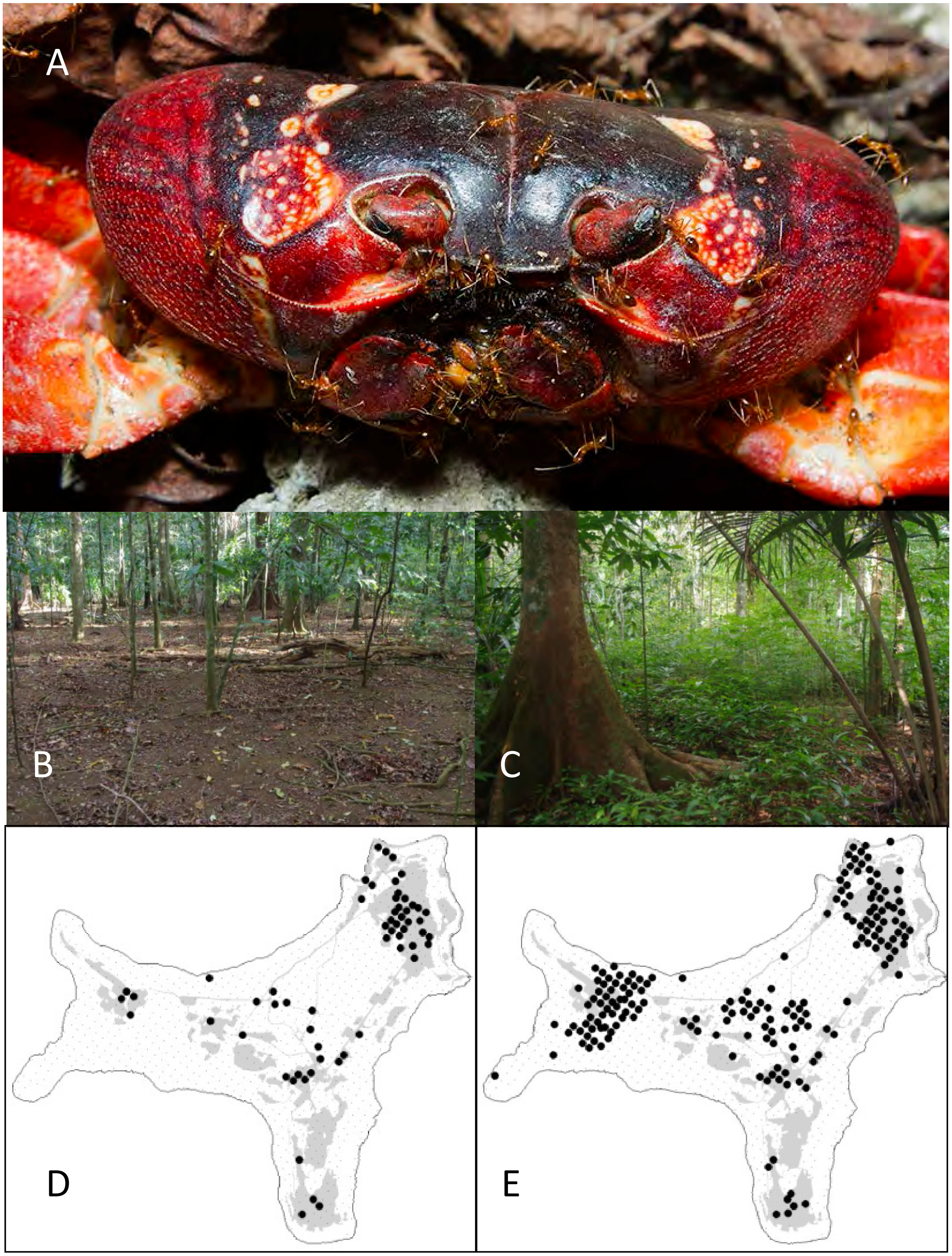
A
B
C
D
E

Figure 4. Impacts of the mutualism between non-native honeydew-secreting scale insects and the invasive ant *Anoplolepis gracilipes* on Christmas Island. **A.** In yellow crazy ant supercolonies, ants attack and kill the endemic red land crab *Gecarcoidea natalis* (Photo: S. Belcher). **B.** Red land crabs normally occur at high densities throughout rainforest across the island, and they regulate seedling recruitment and litter decomposition. As a result, the understorey is typically very open (Photo: P. Green). **C.** High densities of yellow crazy ants in supercolonies extirpate local populations of red land crabs, deregulating seedling recruitment and litter decomposition resulting in understory transformation. In some places plants that recruited in supercolonies during the early days of the invasion are now > 10 cm diameter at breast height and c. 15 m tall (Photo: P. Green). Mutualism between non-native honeydew-secreting scale insects and invasive yellow crazy ants promotes invasion by other non-native species - the absence of red land crabs has allowed the giant African landsnail *Achatina fulica* to colonize rainforest. **D.** Distribution of *A. fulica* in 2001. Bold black dots indicate survey points where this species was detected in a systematic, islandwide survey in 2001. Pale dots indicate absences, grey areas indicate roads and clearings. In 2001, *A. fulica* was almost never found in rainforest. **E.** Distribution of *A. fulica* in 2007. In the intervening six years, GALS had moved from disturbed vegetation along roadsides and the edges of abandoned phosphate mining areas into the forest, especially in the western and central areas of the island. Adjacent waypoints are 370 m apart, indicating penetration of more than 1 km into rainforest in some cases (see Green et al. 2011).

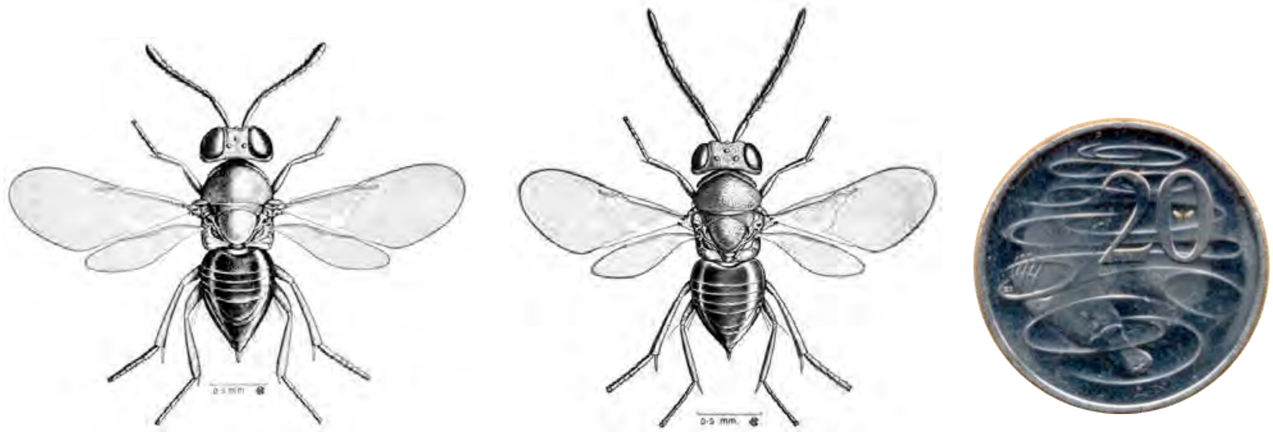

Figure 5. *Tachardiaephagus somervillei*, a primary parasite of the yellow lac scale *Tachardina aurantiaca* in Malaysia and Singapore (female, left; male, right). Males have longer antennae, with whorls of setae. These parasitoids are minute, with a body length of ~2.0 mm and a wingspan of around 3.5 mm (scale bars are 0.5 mm). For scale, one individual fits inside the 0 of the '20' on an Australian 20^{c} piece. Line drawings reproduced from Madhihassan 1957.

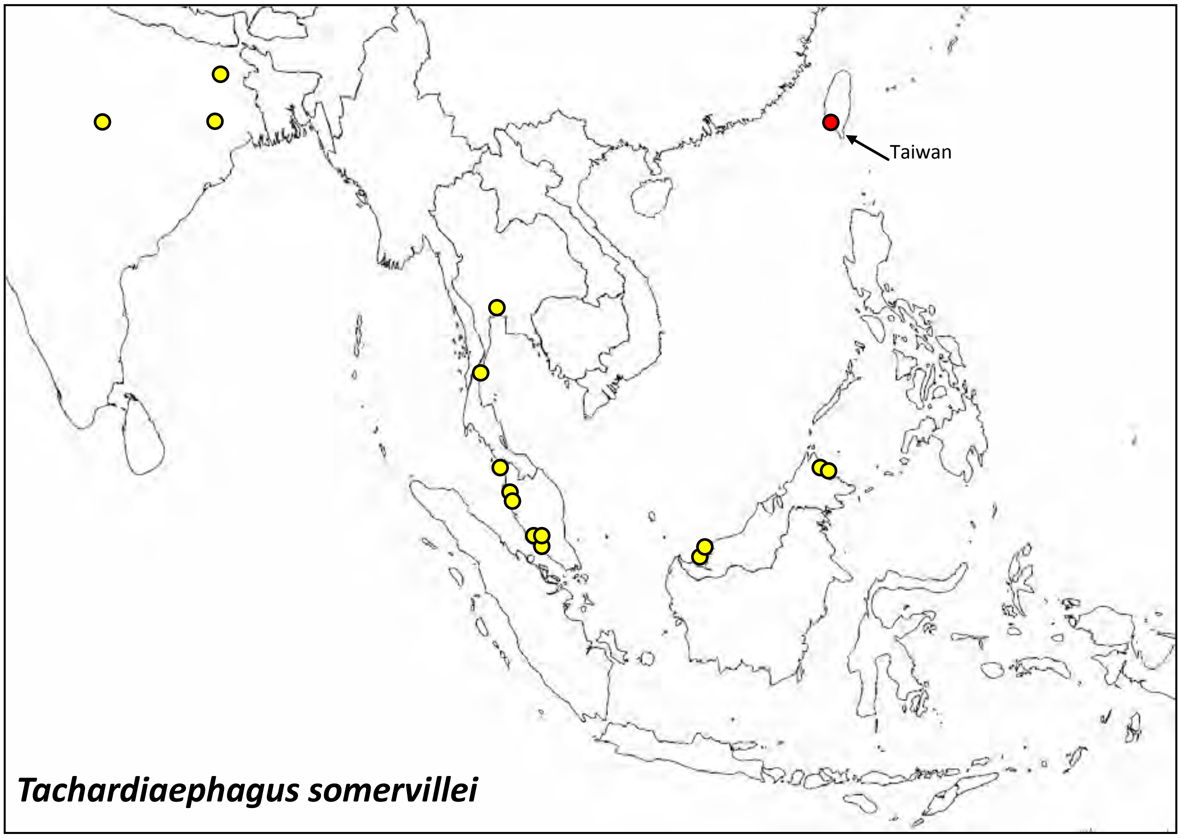

Figure 6. Distribution of *Tachardiaephagus somervillei* (yellow circles) based on records from Mahdihassan (1923), Ferrière (1935), Hayat et al. (2010), and G. Neumann, unpublished results. The putative native distribution is indicated by yellow circles and the only likely introduced record by a red circle. A *Tachardiaephagus* sp., likely to be *T. somervillei*, established in Taiwan after it was introduced accidentally with lac brood (*Kerria lacca*) from Thailand in 1940 (Chiu et al. 1985).

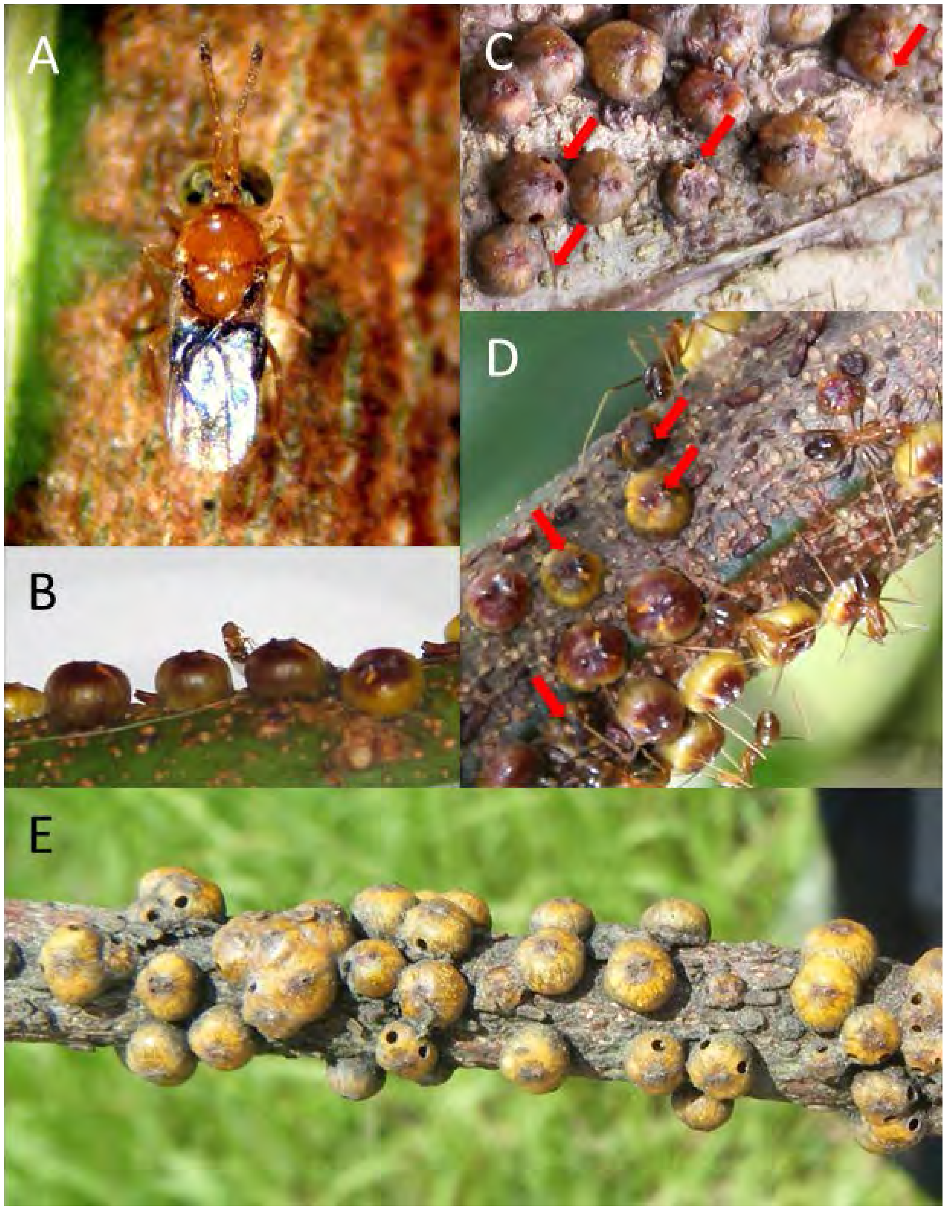

Figure 7. **A.** Adult female of *Tachardiaephagus somervillei* on *Acacia mangium* x *A. auriculiformis* in Kuching, Sarawak. **B.** Adult female *T. somervillei* in typical position for oviposition (head and thorax elevated) on the "sidewall" of an adult female of *Tachardina aurantiaca.* **C.** Multiple exit holes in individual *T. aurantiaca* (red arrows), indicating superparasitism by *T. somervillei*. **D.** Parasitism of adult females of *T. aurantica* by *T. somervillei* in the presence of the yellow crazy ant *Anoplolepis gracilipes.* Arrows indicate discoloured *T. aurantiaca,* characteristic of parasitized individuals. **E.** Parasitoid emergence holes in tests of an aggregate of old adult females of *T. aurantiaca* on *Milletia pinnata* near Sandakhan, Sabah. Yellow crazy ants tended *T. aurantiac*a at this site. Photos: G. Neumann.

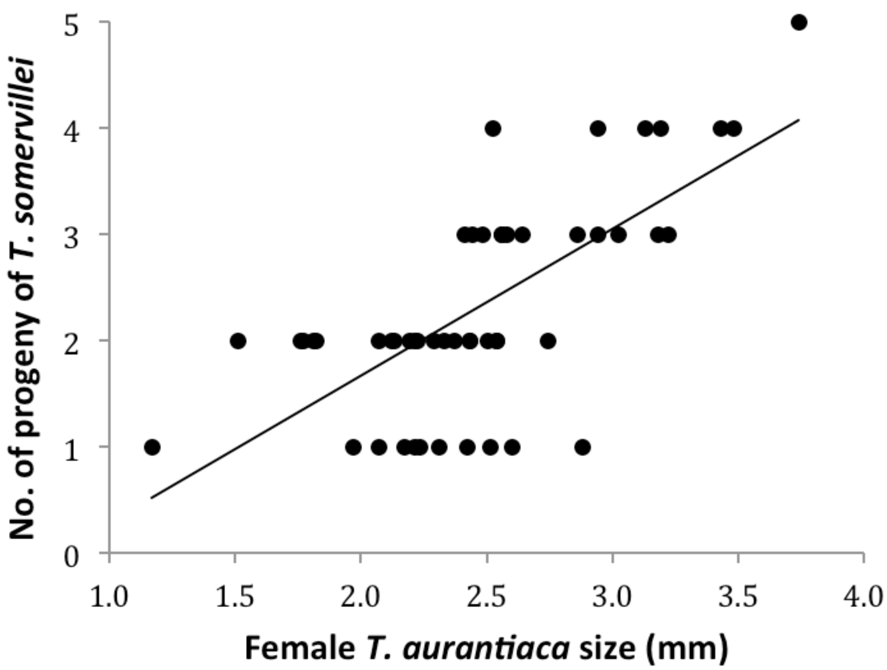

Figure 8. The positive and significant relationship between female size of the yellow lac scale *Tachardina aurantiaca* and the number of progeny of the parasitoid *Tachardiaephagus somervillei* emerging from each host scale under field conditions in Kuching, Sarawak, Malaysia. A random sample of 50 parasitized female *T. aurantiaca* was measured (greatest horizontal diameter of test) and emerging adult parasitoids counted from each host (R^2 = 0.471, N = 50 females, $p < 0.01$).

Figure 9. A – D. The variety of vegetation types in which the host specificity tests were conducted at Kampung Boyan near Kuching (Sarawak, Malaysia). The vegetation varied from managed parkland to secondary rainforest. **E.** The device used to capture individuals of the agent *Tachardiaephagus somervillei* as they emerged from detached individuals of the host *Tachardina aurantiaca*. The large plastic container was covered in black tape, and the parasitoids tended to fly up into the small glass vial fitted to the larger plastic lid, where they could be easily collected. **F.** A replicate used for host specificity testing. The mesh bag enclosed 25 unparasitized individuals of the test species, together with 5 female and 5 male *T. somervillei*. The same mesh bags were used for negative controls (test species without exposure to parasitoids) and for positive controls (*T. aurantiaca* enclosed with *T. somervillei*). Photos: G. Neumann.

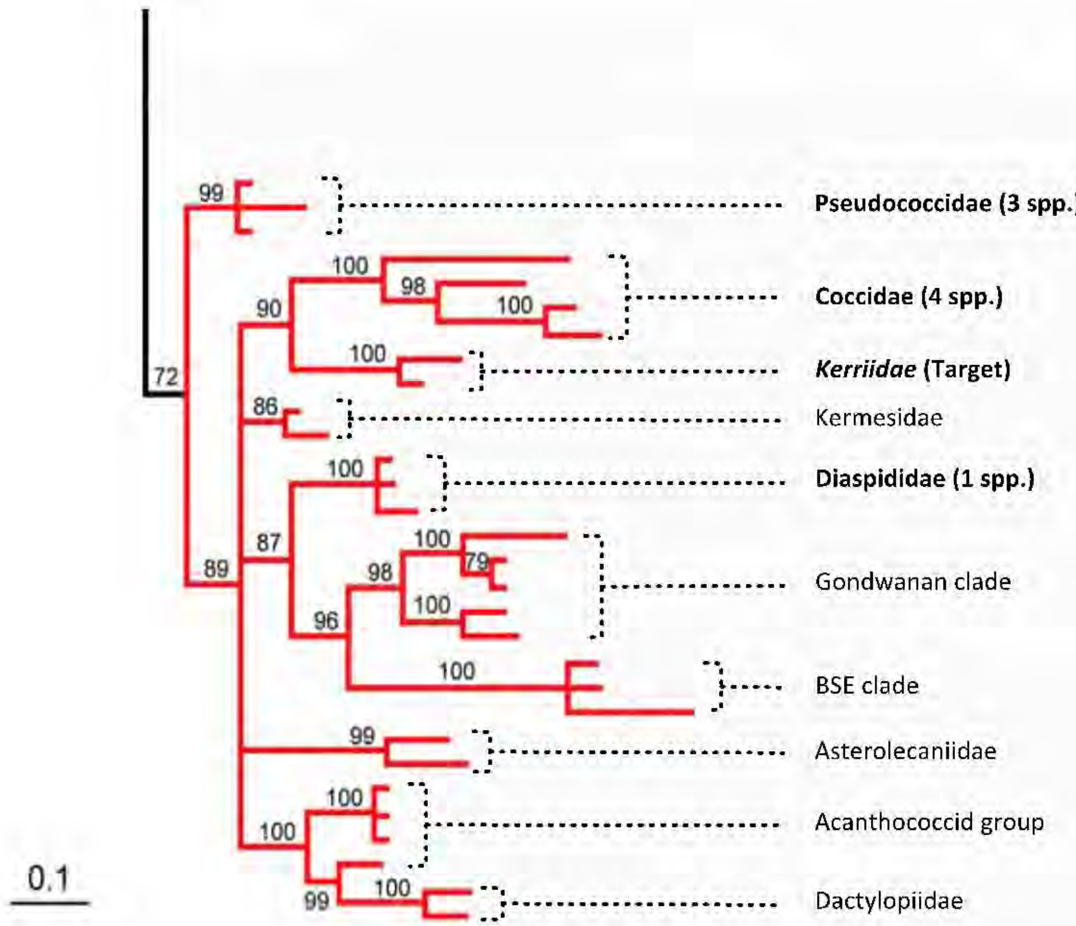

Figure 10. Portion of a phylogram of the scale insects based on nucleotide sequencing of nuclear 18S rRNA for 72 species of scale insects and 10 outgroup taxa (see Gullan and Cook [2007] for details). Only the 'neococcoid' taxa (red) are shown here. For all families given here (except the Kermesidae), Bayesian posterior probabilities (numerical values above branches) are >90%. For a host test list, we selected species (number of species tested is in brackets) from those families given in bold. The Kerriidae (bold and italics) is a sister family of the Coccidae, more distant to the Diaspididae, and even further removed from the Pseudococcidae.

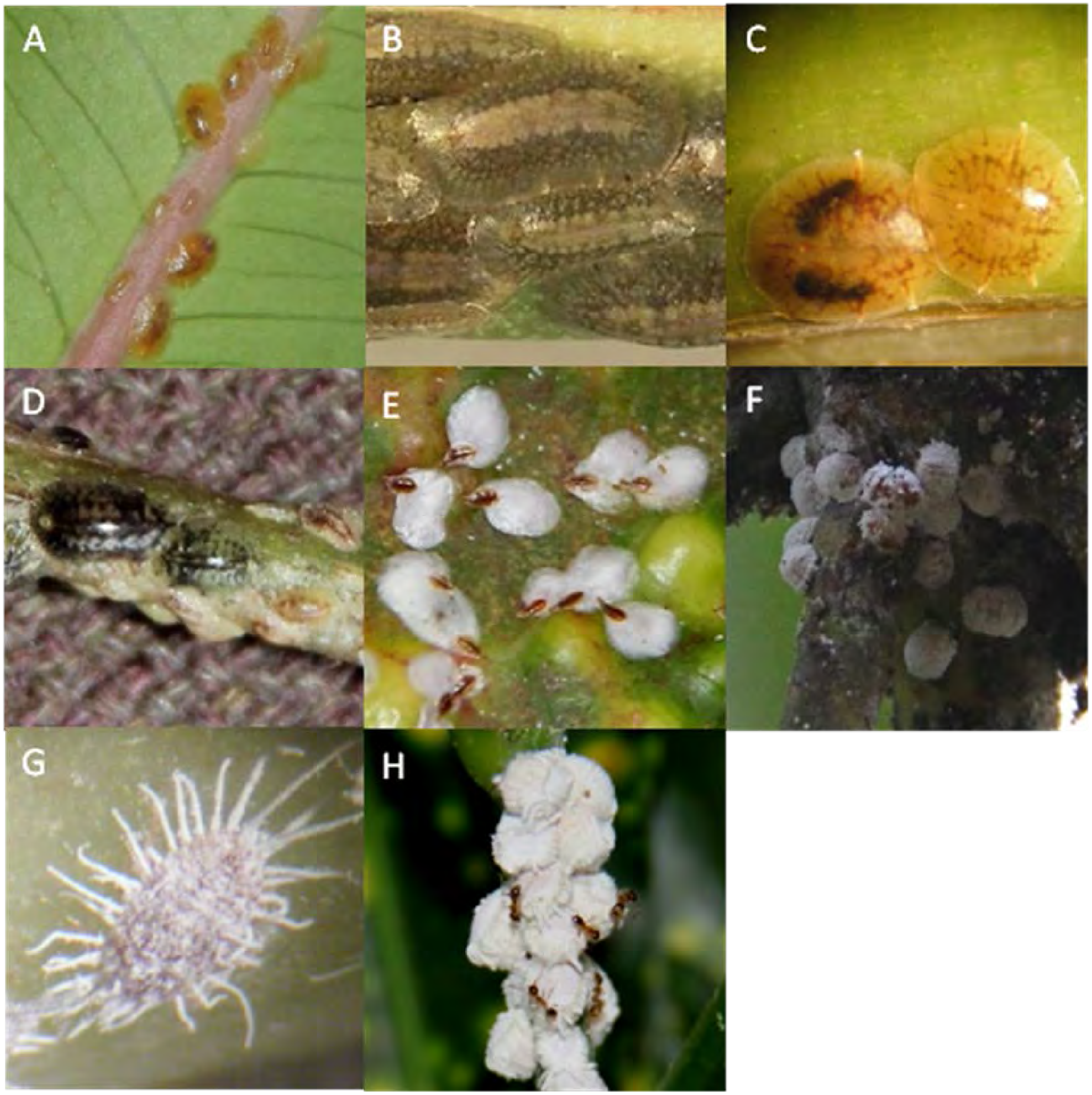

Figure 11. The eight species used in the host specify testing, arranged in descending order of relatedness to the target species *Tachardina aurantiaca* (Kerriidae); Coccidae – **A.** *Coccus hesperidum* Linnaeus, **B.** *Coccus longulus* (Douglas), **C.** *Milviscutulus mangiferae* (Green), **D.** *Pulvinaria urbicola* Cockerell. Diaspididae – **E.** *Chionaspis* near *C. broughae* Williams & Watson. Pseudoccidae – **F.** *Paraputo* near *P. corbetti* (Takahashi), **G.** *Pseudococcus jackbeardsleyi* Gimpel and Miller, **H.** *Rastrococcus iceryoides* (Green). Photos: G. Neumann except **B**, *Coccus longulus* by Ian Stocks, bugguide.net.

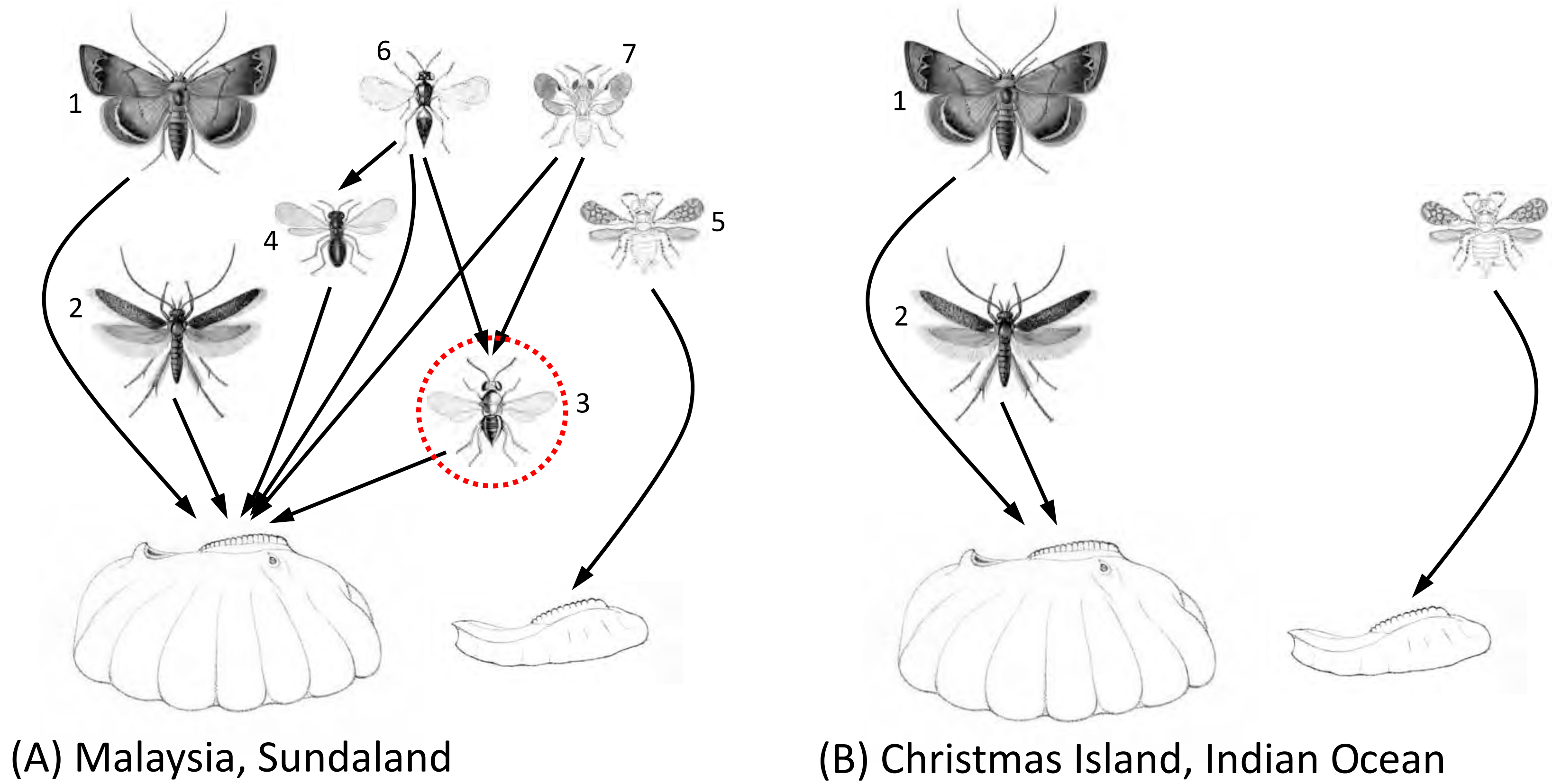

Figure 12. Food web interactions centred on *Tachardina aurantiaca* (♀, left; ♂right) in (A) its area of origin (Malaysia, Sundaland) and (B) in its area of introduction on Christmas Island, Indian Ocean (see also Fig. 2). In Malaysia, food web interactions are complex involving two predaceous noctuid moths, *Eublemma* sp. (1) and *Holcocera* sp. (2), three primary parasitoids, including the potential biological control agent, *Tachardiaephagus somervillei* (3, stippled circle), *Coccophagus tschirchii* (4), *Marietta leopardina* (5), which attacks only males of *T. aurantiaca*, and two facultative hyperparasitoids, *Aprostocetus purpureus* (6) and *Promuscidea unifasciativentris* (7) that attack either *T. somervillei* and *C. tschirchii* as well as *T. aurantiaca*. In contrast, on Christmas Island, only three natural enemies of *T. aurantiaca* are known (1, 2, and 5), and all at low densities that do not affect population densities of *T. aurantiaca*.

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Document 4

AN ISLAND-WIDE SURVEY OF ABBOTT'S BOOBY *PAPASULA ABBOTTI* OCCUPANCY ON CHRISTMAS ISLAND, INDIAN OCEAN

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SUMMARY

BOLAND, C.R.J., SMITH, M.J., MAPLE, D., TIERNAN, B., & NAPIER, F. 2012. An island-wide survey of Abbott's Booby *Papasula abbotti* occupancy on Christmas Island, Indian Ocean. *Marine Ornithology* 40: 99–103.

Decades of phosphate mining on Christmas Island in Abbott's Booby *Papasula abbotti* nesting habitat has created a conservation threat to this rare endemic seabird. The status of Abbott's Boobies could be further jeopardised by other processes, such as the impact of Yellow Crazy Ants *Anoplolepis gracilipes* and other invasive species. Here we report on the current distribution of Abbott's Booby on Christmas Island based upon occupancy data collected during an island-wide survey in 2009. We used a combination of sightings and the characteristic vocalisations of the species to establish presence/absence within the area of each survey point. A subset of the survey points was repeat-surveyed, allowing us to estimate detection probabilities. Average detectability using our approach was 0.65 (SE 0.04). We related occupancy by Abbott's Booby to several environmental covariates using site-occupancy species distribution modelling techniques. We did not find any evidence of a significant relationship between occupancy by Abbott's Booby and distance to the nearest road or to high-density Yellow Crazy Ant colonies. However, we did find that occupancy by Abbott's Booby was significantly and positively related to both elevation and distance to the nearest disturbed area. Abbott's Booby nesting habitat is restricted to the central plateau on Christmas Island and has diminished because of major disturbances. There is evidence that the species now inhabits previously unoccupied areas but still does not re-occupy habitat that immediately surrounds areas cleared for phosphate mining several decades ago.

Key words: Abbott's Booby, phosphate mining, Yellow Crazy Ant, Christmas Island, occupancy modelling

INTRODUCTION

Abbott's Booby *Papasula abbotti* is the rarest and largest of the sulids. The species formerly nested on islands in the central and western Indian Ocean, but was lost from these localities because of habitat degradation (Nelson and Powell 1986). Now the only breeding colony is on Christmas Island, an Australian external territory in the eastern Indian Ocean where the most recent Abbott's Booby population estimate was 2 500 pairs in 1991 (Yorkston & Green 1996). Accordingly, the species is listed as endangered under the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999*. The low rate of recruitment of this large, long-lived seabird inhibits its capacity to recover quickly from a population decline. Breeding is biennial, parents raise a single young, and juveniles suffer high mortality. As a result, pairs successfully replace themselves only once every 24 years on average (Nelson & Powell 1986, Reville *et al*. 1990).

On Christmas Island, the population has been threatened by habitat loss due to phosphate mining (Reville *et al*. 1990). From 1968 until 1987, when clearing primary forest for phosphate mining ceased, one-third of the species' remaining nesting habitat was cleared, and the breeding population experienced a concomitant decline (Nelson 1971, Nelson & Powell 1986, Reville *et al*. 1990, Yorkston & Green 1996). Furthermore, Abbott's Boobies build nests on thin lateral branches high in the canopy of rainforest trees. Wind tunnel experiments demonstrated that clearing forest increases turbulence in the canopy (Brett 1989), lowering breeding success and site fidelity, and increasing adult mortality of Abbott's Booby nesting in surrounding areas (Reville *et al*. 1990). Although forest clearing for phosphate mining stopped in 1987, the resulting clearings remained, probably constraining the rate of recovery of the Abbott's Booby population (Yorkston & Green 1996). This may explain why the population was still found to be in decline in 1989 (Reville *et al*. 1990). In 1996, Yorkston and Green reported that the population on Christmas Island was stable, but still expressed concern for the species should significant habitat disturbance continue.

Unfortunately, significant habitat disturbance has continued in the form of a biological invasion by Yellow Crazy Ants *Anoplolepis gracilipes*. In the late 1990s, vast, high-density Crazy Ant colonies began to be recorded (O'Dowd *et al*. 2003). By 2002, more than 2 500 ha (or about 25% of the island's forest) were invaded by high-density Crazy Ant colonies, now considered to be one of the major environmental threats to Christmas Island (O'Dowd *et al*. 2003). The ants potentially further degrade Abbott's Booby habitat (Department of Environment and Heritage 2004) by extirpating the terrestrial Christmas Island Red Crabs *Gecarcoidea natalis* from the area. Because the Red Crabs are a dominant primary forest floor consumer of leaf, shoot, and seed material, their removal from an area typically results in a denser, more diverse and different forest understorey (O'Dowd *et al*. 2003), which may ultimately degrade Abbott's Booby nesting habitat. Also, they forage for honeydew secreted by introduced scale insects high up in the canopy, swarming over nesting birds, which can cause the birds to abandon their nesting attempt (Davis *et al*. 2008, 2010). However, there are few data on the threat that Yellow Crazy Ants (or their control) might pose to Abbott's Booby, so claims of an impact relating to Crazy Ants are largely speculative. As the major environmental management authority on the island, Christmas Island National Park attempted to control the spread of high-density colonies by baiting with Presto (active ingredient: fipronil) in 2002 and 2009 (Boland *et al*. 2011).

Since 2001, Christmas Island National Park has been conducting a biennial, island-wide survey for Yellow Crazy Ants and Christmas Island Red Crabs. In 2009, this survey was extended to include an estimate of presence/absence of Abbott's Booby, which allowed the bird's current distribution to be mapped and the relationship between occupancy and several environmental variables to be assessed. As a baseline dataset, this information will allow future monitoring of changes in distribution.

METHODS

Study area

Christmas Island (10°25'S, 105°40'E) is a 135 km^2 limestone and basalt oceanic island located 360 km south of Java, Indonesia. The island has a central plateau that rises steeply to 361 m above sea level and is fringed by a coastal terrace. The climate is monsoonal with the wet season generally between November and May. Mean annual rainfall is 2 068 mm, mean maximum temperature is 27.3 °C and mean minimum temperature is 22.8 °C (Australian Bureau of Meteorology). About 74% of the island is covered with natural vegetation, mostly structurally simple, broad-leaved rainforest (Claussen 2005). Christmas Island National Park covers 63% of the island (Christmas Island National Park 2002).

Field surveys

Since 2001, Christmas Island National Park has carried out annual ant-baiting programs and biennial island-wide surveys (see Boland *et al*. 2011 for more detail). In 2009, the 889 near evenly spaced survey points (≈ 366 m apart) were sampled once, and a subset of randomly chosen blocks of sites were surveyed on two (n = 223) or three (n = 14) occasions (Fig. 1). Sites for repeat surveying were grouped in randomly chosen blocks that encompassed an area around 2.25 km^2. This approach was required because of the logistical difficulties associated with traversing the island. Once the effort was made to travel to a particular area, it was important to repeat-survey as many sites in that area as possible. The number of sites repeat surveyed in a block on any occasion varied depending on the difficulties associated with moving between sites in a given area, the weather, and the number of surveyors available on a particular day. Each site was surveyed by two or three individuals from a team of 14. At any time, each team always included one of the five most experienced surveyors and all individuals were trained in the survey protocol before commencement of the program.

At each survey point, we counted Abbott's Booby by watching and listening for birds for a minimum of 10 minutes. The species is very vocal and aural assessment of their occupancy was particularly important. High-density Yellow Crazy Ant colonies were identified and mapped after each island-wide survey following the procedures outlined in Boland *et al*. (2011). Surveys were conducted between May and August 2009.

Breeding biology

Abbott's Boobies build their nests near the top of rainforest trees (about 10–40 m above the ground). The breeding cycles last 15–18 months. Successful pairs can nest once every 2 years, but often take rest years between attempts to raise a chick. Most pairs breed only once every 3 years. Mating usually takes place in April. Each pair lays a single egg between April and July, which is incubated for about 56 days. Chicks hatch from June to November; they fledge about 170 days later and become independent after an additional 200 days (Marchant & Higgins 1990).

Statistical approach

We classified survey sites by their linear distance in kilometres to the nearest high-density Yellow Crazy Ant colony, as mapped in

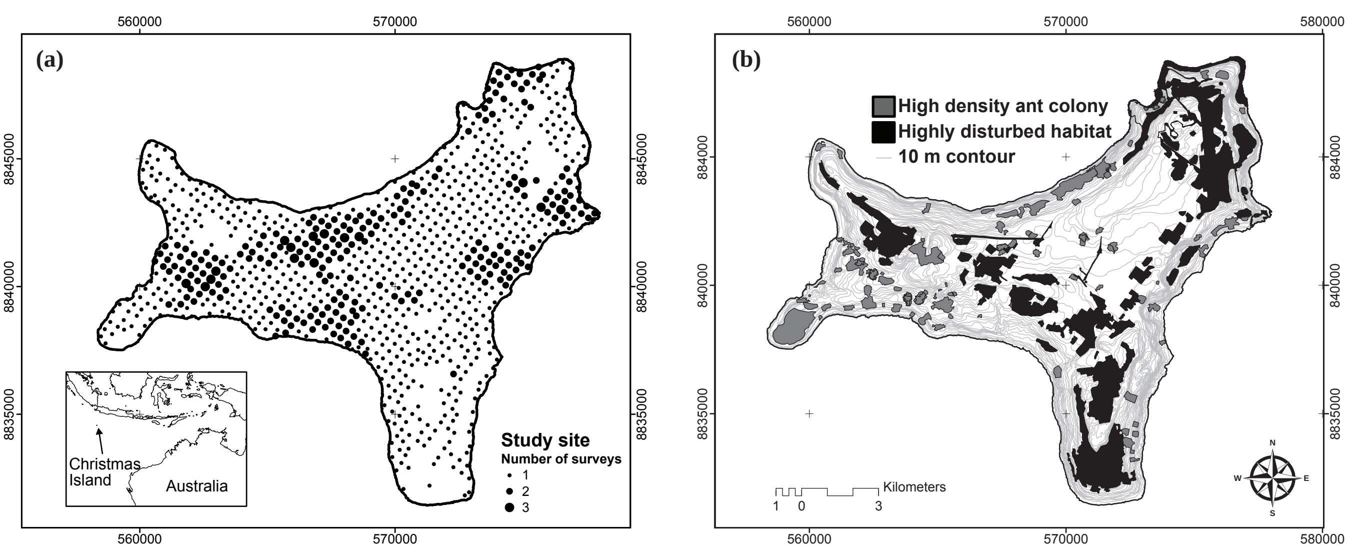

Fig. 1. Christmas Island and the island-wide survey points (a). The size of the point symbol depicts the number of times we surveyed the site. Highly disturbed areas, roads, contours, and high-density Yellow Crazy Ant colonies as of 2009 (b). Projection is in UTM (WGS84, Zone 48 S).

2009 (Fig. 1), and used this value as a covariate in the model. Sites were also classified by their elevation and distance to the nearest road. A habitat disturbance map from the Christmas Island GIS (Commonwealth of Australia 1987–2011) was used to classify sites by their distance in kilometres to the nearest significantly disturbed area. Because most of the disturbed habitat on Christmas Island is in the central part of the island (Fig. 1) and Abbott's Booby does not breed in low elevation coastal habitats, we suspected *a priori* that a quadratic term may better represent occupancy by Abbott's Booby, as occupancy would be more likely with increasing distance from a disturbed area, but less likely with proximity to the coast. If so, we would expect a positive relationship between occupancy and distance from disturbance and a negative quadratic term.

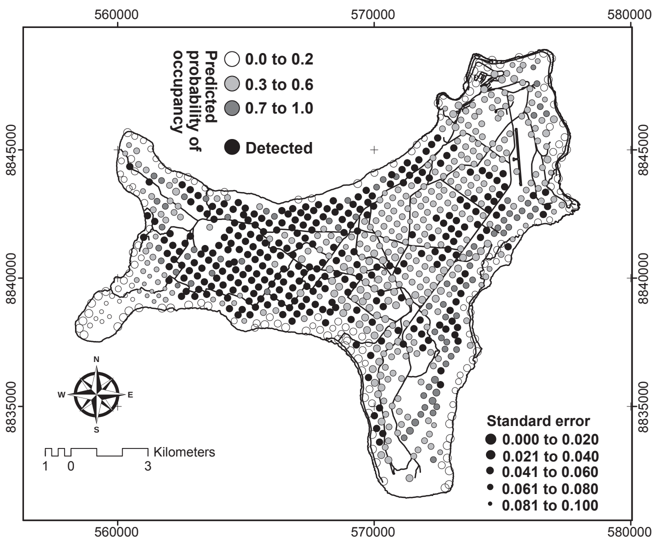

Fig. 2. Sites at which Abbott's Booby was detected (solid black circle), model averaged probability of occupancy (shading of circles) and associated standard error (size of circles) at non-detection sites. Projection is in UTM (WGS84, Zone 48 S).

Because detection of a particular species occupying a site is not guaranteed during a brief visual and aural survey, we used site-occupancy species distribution modelling that explicitly accounted for imperfect detection as part of model-fitting (Royle & Dorazio 2008, Kéry 2010). Each site was categorized as occupied (where on each visit the species can be detected with an unknown probability) or unoccupied (where the probability of detection is zero; Royle & Dorazio 2008, Kéry 2010). Because data were collected from a subset of sites that were repeat surveyed, we could infer the probabilities of detection of Abbott's Booby (cf. Royle & Dorazio 2008, Kéry 2010). By using this approach, we could reduce bias in our inferences about occupancy and better examine relationships between the probability of occupancy by Abbott's Booby and potential indicators of the impacts associated with high-density Yellow Crazy Ant colonies and habitat disturbance.

Accordingly, the probability of occurrence (Ψ_i) of the Abbott's Booby at the *ith* site was modelled as a logistic function of distance to nearest high-density Yellow Crazy Ant colony (YCA_C_i), highly disturbed area (D_i) and road (Rd_i), in addition to site elevation (Ele_i) and a quadratic distance to disturbed area term ($D2_i$), using the logistic regression equation:

$$\log\left(\frac{\Psi_i}{1 - \Psi_i}\right) = \beta + \beta.YCA\_C_i + \beta.D_i + \beta.Rd_i + \beta.Ele_i + \beta.D2_i$$

The β parameters represent the intercept and slopes of the relationships between the log-odds of occupancy by Abbott's Booby and the various predictor variables.

The probability of detection was modelled as constant because the detection of Abbott's Booby at each site was predominantly associated with their aural signals and was unlikely to be affected by any of the covariates we could use. Models were run in the "unmarked" package (version 0.8-7) in R software (R Development Core Team 2007). In particular, we used the "occu" function

TABLE 1
Parameter estimates from the models that accounted for 95% of the accumulative AIC weights

Model	AIC	ΔAIC	AIC weight	Detection	Occupancy					
				Intercept	Intercept	Elevation	Distance to nearest road	Distance to nearest disturbed area	Quadratic term (distance to nearest disturbed area)	Distance to nearest high-density Crazy Ant colony
1	1213.05	0.00	0.58	0.61	0.40	1.27		1.17	-0.70	
2	1214.93	1.88	0.23	0.61	0.40	1.27	0.04	1.15	-0.70	
3	1215.30	2.25	0.19	0.63	0.38	1.25	0.04	1.06	-0.69	-0.15
Model-averaged estimate				0.61	0.40	1.27	0.04	1.14	-0.70	-0.15
2.5 CI[a]				0.29	-0.04	0.93	-0.19	0.78	-0.99	-0.39
97.5 CI				0.93	0.83	1.61	0.27	1.51	-0.41	0.09

[a]CI = confidence interval

(e.g. model_1<-occu(~1~Rd, Data)). All possible covariate combinations were compared with AIC (Burnham and Anderson 2002). Models that accounted for 95% of the cumulative AIC weights were considered to be equally well supported. Model-averaged estimates of the most supported models were calculated within the AICcmodavg R package (e.g. modavg(cand.set = cand. models, modnames = modnames, parm = "Elevation", parm.type = "psi") Mazerolle 2012). All covariates were log-transformed and standardised. We checked model fit by examining simulated datasets from each fitted model using the parametric bootstrapping technique of Fiske and Chandler (2010). Specifically, we used a chi-square statistic to compare observed and expected values generated from simulated datasets.

RESULTS

Abbott's Booby was detected at 287 survey sites across the island (32% of sites), mostly on the island's central plateau (Fig. 2). The model-averaged probability of detection for Abbott's Booby using our survey protocol was 0.61 (95% CI 0.29 to 0.93). Three models accounted for over 95% of the AIC accumulative weight and, collectively, these models included all covariates (Table 1). Examination of the goodness-of-fit for the three models indicated adequate model fit.

Despite their inclusion in some of the supported models, the model-averaged 95% confidence intervals for relationship of occupancy to the distance to nearest high-density Yellow Crazy Ant colony and to the distance to nearest road included zero, and consequently, were judged not to be important (Table 1). We did find significant evidence for positive relationships between occupancy and both distance to nearest disturbance and elevation (95% CI did not include zero; Table 1). Additionally, a negative quadratic term was also important (95% CI did not include zero). Collectively, these relationships indicate that Abbott's Booby was more likely to occupy higher elevation sites with increasing distance from disturbance (Fig. 2 and Fig. 3).

DISCUSSION

Before human settlement, Christmas Island had thick vegetation, with an unbroken forest canopy reaching heights of 30–45 m. Abbott's Booby nested principally in the centre and west of the island (Gibson-Hill 1947, Nelson 1971) in the tops of certain species of emergent trees on the central plateau (Nelson and Powell 1986). Our data demonstrate that this preference of Abbott's Booby for nesting on the central plateau has remained. The birds continue to avoid the more exposed fringing coastal terrace and the eastern edge of the island, which is subject to prevailing southeast wind.

Between 1968 and 1987, approximately one-third of the rainforest nesting habitat of the Abbott's booby was felled for phosphate mining (Yorkston & Green 1996). Much of the bird's preferred habitat in the western and central portions of the plateau was cleared (Fig. 1). This land clearing induced a significant edge effect: birds nesting within 300 m of the mined area suffered lower breeding success and increased mortality because of greater wind turbulence (Brett 1989, Reville *et al*. 1990). By comparing rates of recruitment and mortality, Reville *et al*. (1990) concluded that the population was still in decline in 1989, two years after forest clearing had ceased. Our data indicate that this land clearing is still affecting the Abbott's Booby – more than 20 years after clearing ceased – as these birds are less likely to occupy habitat within or near a disturbed area, because such sites lack emergent, high-canopy trees suitable for nesting.

One impact of edge-induced canopy turbulence is that adult Abbott's Booby abandon traditional nest sites and seek new ones (Brett 1989, Reville *et al*. 1990). Our island-wide survey data indicate that Abbott's Booby have begun occupying areas that traditionally have been avoided, such as the eastern third of the island and the western edge of South Point (compare Fig. 2 with Nelson 1971, Nelson & Powell 1986, Yorkston & Green 1996). Whether these habitats have improved or the birds are now using suboptimal habitat remains unknown but should be the focus of future research. In addition, our results showing increasing likelihood of occupancy with increasing distance from disturbance

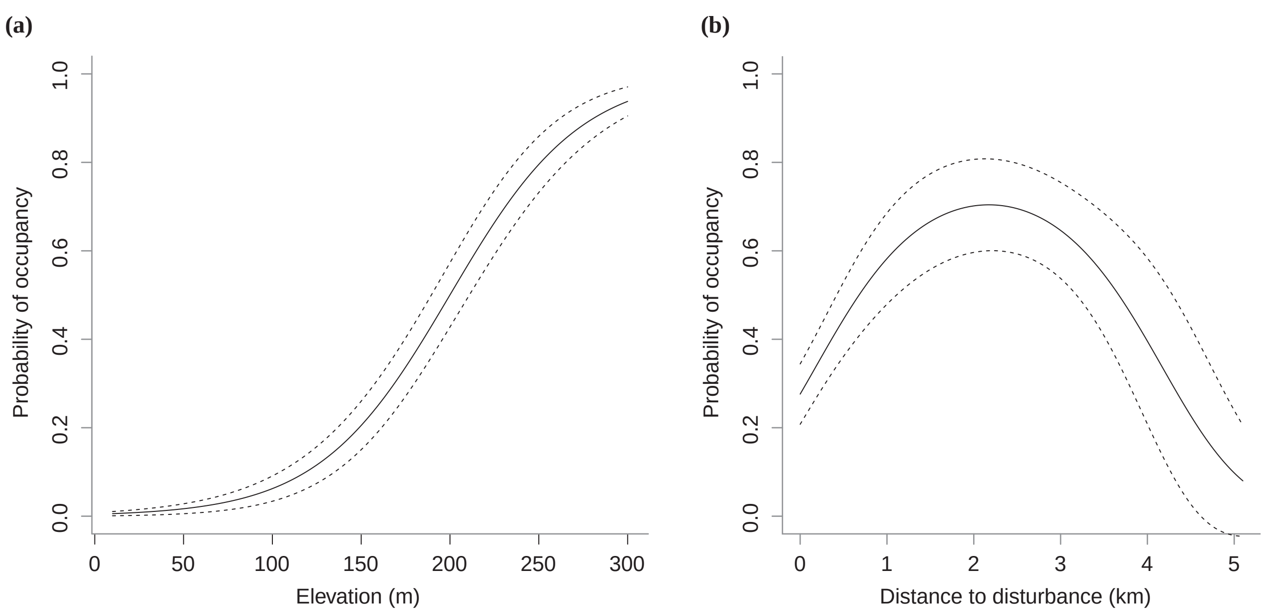

Fig. 3. Predicted relationship between occupancy by Abbott's Booby and elevation (a) and distance to the nearest disturbed area (b), mean model-averaged estimate and 95% CI (dashed lines).

suggest that areas surrounding disturbed habitats continue to represent suboptimal habitat for Abbott's Booby.

In 2000, Christmas Island National Park embarked on a program to control the spread of high-density Yellow Crazy Ant colonies by baiting with Presto (active ingredient: fipronil). Nonetheless, by 2002, more than 2 500 ha (or about 25%) of the island's forest was invaded by high-density Crazy Ant colonies, which were treated by a large-scale heli-baiting campaign in September 2002. Over the ensuing seven years, Crazy Ant infestations began to gradually reappear, requiring a second heli-baiting campaign across 784 ha in September 2009 (Boland *et al*. 2011). Our data do not support the idea that the presence of these high-density Crazy Ant infestations has negatively affected the distribution of Abbott's Booby on Christmas Island. Indeed, if anything, Abbott's Booby was more likely to occupy sites near Crazy Ant infestations (negative but non-significant relationship between occupancy and distance to nearest high-density Crazy Ant colony). However, our results are based upon presence/absence data, and detailed population studies may identify a negative impact yet to be detected by our survey protocol. Lag effects associated with high-density Crazy Ant infestation and control (i.e. changes in vegetation communities) may be detected in future surveys.

Our results suggest that the approach taken here provides reliable mapping of Abbott's Booby nesting habitat on Christmas Island. If data are collected regularly (e.g. during the biennial island-wide survey), they should provide natural resource organisations on the island with timely indications of significant change. However, this survey approach is not a substitute for detailed study of the species' demography and breeding behaviour; rather, in combination with other information, the survey approach will allow managers to detect and better understand broad changes in distribution over time. The attraction of this approach is that it provides sound census information at a low cost, adding value to an existing program.

However, our approach has limitations. Abbott's Booby forage at sea and, accordingly, may be detected simply moving through an area and, conversely, may be missed when individuals are away from their nests. Both of these factors would reduce detection probabilities (our estimate was 0.65) and could lead to some degree of overestimation of occupancy. With continued surveying, our understanding of the species' distribution and its variability should improve. Such surveys will help to determine the need for management action in the future.

Should major changes in the distribution of Abbott's Booby be detected, management actions would be justified. What degree of decline should trigger a management response, and what that management response should be, are yet to be determined by the appropriate natural resource management agencies. However, it is clear from this and previous work that any new disturbance will further restrict a limited and reduced habitat resource upon which the species depends.

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Document 5

Australian Government
Director of National Parks

The presence/absence and distribution of native and introduced flora and fauna of Christmas Island: a collection of biennial island-wide survey results from 2001 to 2013 and other sources.

Internal Report
Christmas Island National Park
2014

DOCUMENT INFORMATION

This report was prepared by the Christmas Island National Park, Natural Resource Management team.

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Survey development and preparation: CINP NRM team

GIS preparation: Dion Maple, Caitlyn Pink, Tanya Detto and Nina Trikojus

Data management: Dion Maple, Tanya Detto and Caitlyn Pink

Data analysis: Dion Maple, Caitlyn Pink, Tanya Detto and Nina Trikojus

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COVER IMAGE

A field officer *in situ* during the 2011 island-wide survey.

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BACKGROUND

The Yellow Crazy Ant, *Anoplolepis gracilipes* (hereafter YCA) was accidentally introduced to Christmas Island sometime between 1915 and 1934 (Donisthorpe 1935). The abundance of this species remained low and it had little impact on the island's biota until 1989 when the first high density 'supercolony' was discovered in the northeast of the island.

Supercolonies are areas of extremely high ant abundance that kill or drive out native wildlife, in particular the islands keystone (and iconic) species, the Christmas Island Red Crab, *Gecarcoidea natalis* (hereafter Red Crab). Additionally, vertebrates, other land crabs and invertebrates may be killed and/or displaced from areas resulting in dramatic changes to the structure of the forest (O'Dowd, Green & Lake 2003). Yellow Crazy Ants also allow the persistence of secondary invasive species such as the Giant African Land Snail (O'Dowd & Green 2008).

YCA are listed as one of the world's 100 worst invasive species of natural ecosystems recognised by the IUCN and the Global Invasive Species Database as one of the world's 100 worst invasive species (Lowe et al. 2000) and are described as the most significant threat to Christmas Island's biodiversity in the Draft Christmas Island National Park Management Plan (2012) and by the Expert Working Group (Beeton et al 2010) and are listed as a 'key threatening process' for Christmas Island under the EPBC Act 1999.

A control program, based on detection and chemical treatment of super colonies, was initiated in 2000 after YCA invaded 2,500 hectares of the islands rainforest. The control program, that continues to this day, relies on gathering detailed information on the distribution and abundance of YCA and conversely, Red Crabs, across the 135km^2 land mass. In 2000, members of the Crazy Ant Steering Committee designed an island-wide survey to gather this critical data (O'Dowd & Green 2001). This survey, undertaken biannually, measures the abundance of YCA and Red Crabs at approximately 1000 sites spread in a grid equidistantly across the island.

The survey is based on a transect methodology where YCA activity is measured every 5 meters along a 50 metre transect and Red Crab burrows are counted and measured 1 metre each side of the same transect tape (100m2). If the sum of ant count is greater than 37 the site is considered a super colony (subject to later verification). Data on the presence/absence and distribution of YCA collected during the island-wide survey are used to guide control and management programs of this invasive species.

Since its inception, the island-wide survey has evolved into a multi species presence/absence and distribution survey. A group of over 40 species now have their distributions measured with minimal additional effort. Surveyors are trained to detect the presence of many flora and fauna species, both at survey sites and while in transit.

Island-wide surveys were completed in 2001, 2003, 2005, 2007, 2009, 2011 and 2013. Each survey has been undertaken in slightly different ways and has developed in line with advances in technology, especially for navigation. Where data is available, this report compares species distribution results of all seven surveys and incorporates data from additional sources where applicable, such as weed treatment records or the individual detection of a rare and cryptic species.

In this report, for each species a map/s appropriate to the category of data collected on the species is illustrated and conclusions are drawn from this data regarding the species presence/absence , distribution and (where possible) any changes or trends in its apparent status on Christmas Island.

The examination of island-wide survey data within this report is undertaken in a fundamental manner and it is hoped that in the future more detailed and powerful statistical analysis of the data sets be undertaken.

SURVEY DESIGN

The island-wide survey was designed around a Christmas Island Geographical Information System (CIGIS) database produced by the Australian Geological Survey Organisation. This database, which is now updated annually by Geoscience Australia, contains a variety of spatial information (e.g. topography, digital elevation models, vegetation and soil types, roads), much of which adds to the function of the island-wide survey methodology both on the ground and during analysis.

For the initial survey in 2001, a grid of approximately 1000 points was superimposed across the island with intervals of around 365m between sampling sites (i.e. grid intersections). To maximise access to the sites, the grid was rotated to superimpose it on a network of drill lines and then offset by 25m. Drill lines are exploratory clearing tracks used for phosphate mining. Sites in inaccessible areas, such as mine lease areas were removed.

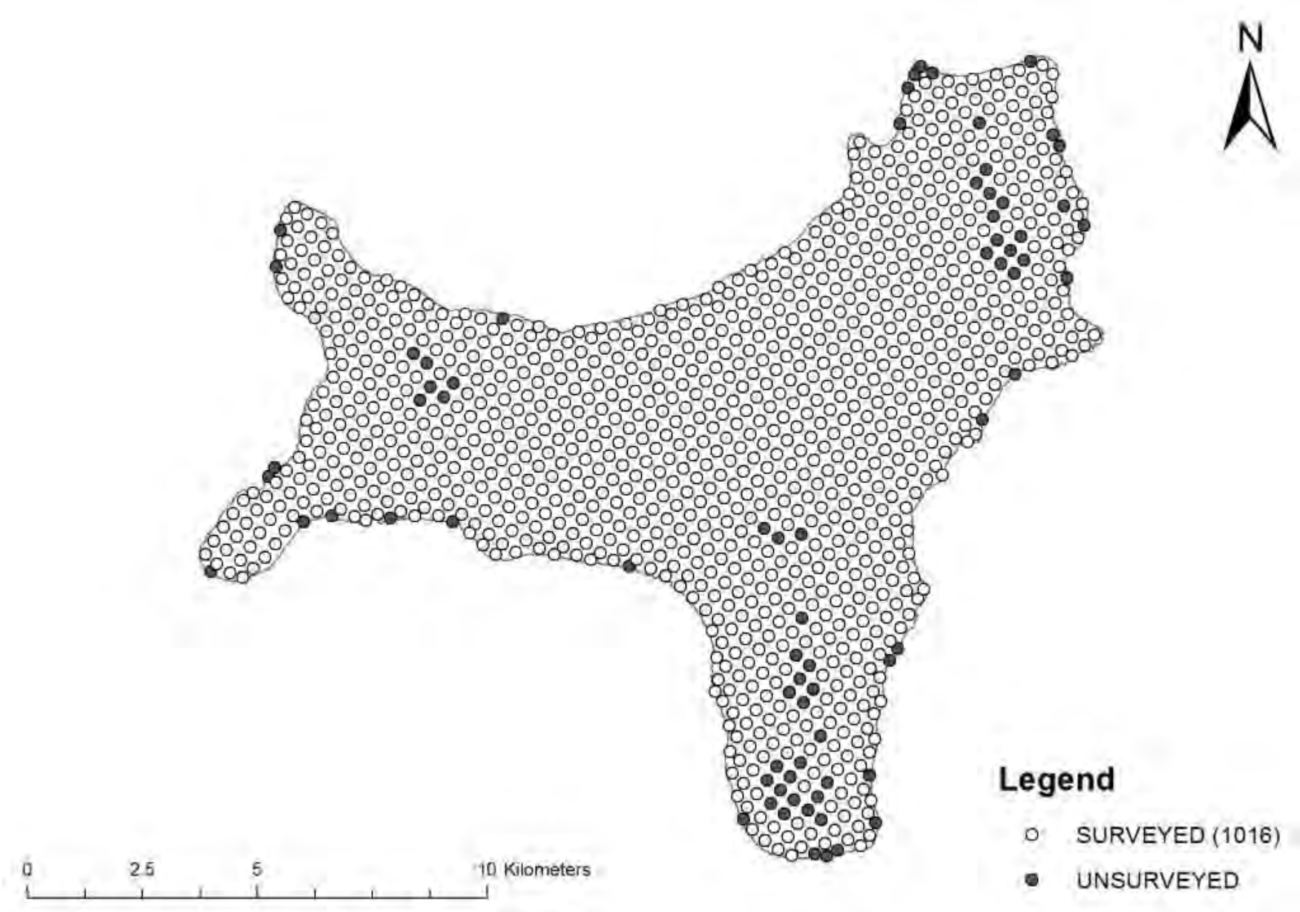

Figure 1: Distribution of the 1016 sites surveyed in 2013.

In 2013, there were 1016 individual sites surveyed (Figure 1). Advances in GIS technology, in particular a detailed terrain raster image of high resolution, enabled staff to reincorporate or create new survey sites that had been excluded as the raster image facilitated the accurate mapping of access routes prior to the commencement of field activities.

For reasons such as this the number of survey sites has differed in each island-wide survey. In 2001 there were (972); 2003 (988); 2005 (980); 2007 (877); 2009 (893); 2011 (933) and 2013 (1016) survey sites. In addition, the transect bearing at a proportion of survey sites differs each survey due to tree falls, land clearing or other such influences. It is doubtful that these changes impact greatly on the comparative power of a particular site between years as a basic premise of the survey is that the transect data represents the entire grid section.

The island-wide survey is also undertaken in the dry season between May and September. At this time YCA is are active and most parts of the island are accessible.

The number of species recorded at each site and during transit from site to site is also an evolving component to the survey. From the beginning YCA and Red Crabs have been at the core of the survey but species like *Achatina fulica* (hereafter GALS) and *Turdus poliocephalus erythropleurus* the island Thrush have also been recorded diligently at each of the seven surveys. Through time, more species have been added to the survey data sheet in a presence/absence record form. This includes both flora and fauna species of native and introduced status. Also, during particular surveys certain additional data collection activities have been incorporated such as the collection of ants in 2005 and 2011, and the recording of tree species in 2013.

Because of the added complexity in the survey and the need to accurately identify a large and varied list of flora and fauna, a comprehensive training regime is also implemented prior to the island-wide survey. This training of staff also incorporates activities designed to reduce the inherent variance in techniques employed by each individual so that data are truly comparable both across sites and survey years.

GRID SURVEY METHOD

Site

The methods for the 2013 survey generally followed those of past surveys. All data collected at a survey site are recorded on a standardised data sheet. An example of a site data sheet can be found in Appendix 1. At each survey site, a 50m x 2m transect tape is deployed in a predefined random bearing direction. Along each transect, one surveyor counts the number of YCA to cross a 10cm × 10cm card on the ground for 30 seconds at eleven 5m intervals, the other counts all Red Crab burrows within the 100m^2 transect and measures the internal width of the first 12 burrows from the far end.

In addition to the ant and crab data collection both surveyors also spend five minutes listening and looking for various native and invasive flora and fauna species and collecting specimens of interest.
Ants were sampled during the island-wide survey of 2005 to determine species composition and distribution across the island (Framenau and Thomas 2006). In 2011, this feature of the survey was reincorporated using a similar methodology to Framenau and Thomas (2006) so as to assess changes in species presence/absence and distribution.

In 2013 a vegetation survey of twelve key tree species that play a role in YCA-Scale mutualism was undertaken along site transects. These tree species are an effective proxy for the scale species present in an area. Often scale is high in the canopy and cannot be observed directly however where scale is detected a record was also marked on the survey data sheet. The data collected will be used to select sites for the release of lac scale and soft scale biological control agents.

In previous surveys, field teams classified the vegetation at a waypoint into one of several broad categories but this was very subjective and team members often disagreed. As a more objective assessment of vegetation, during the 2011 survey a photograph was taken of every site from the waypoint tree, looking down the transect, for subsequent analysis of vegetation type and cover.

A more detailed, step by step description of the survey methods used for staff training purposes is produced biannually (CINP 2013).

Repeat survey

Repetition was incorporated into the survey in 2009. In order to determine detection probabilities and occupancy of different species, a randomly selected number of sites are surveyed a second and third time. Repetition also allows the use of ink cards as an additional survey technique as these detection devices must be collected after a set duration, usually a week.

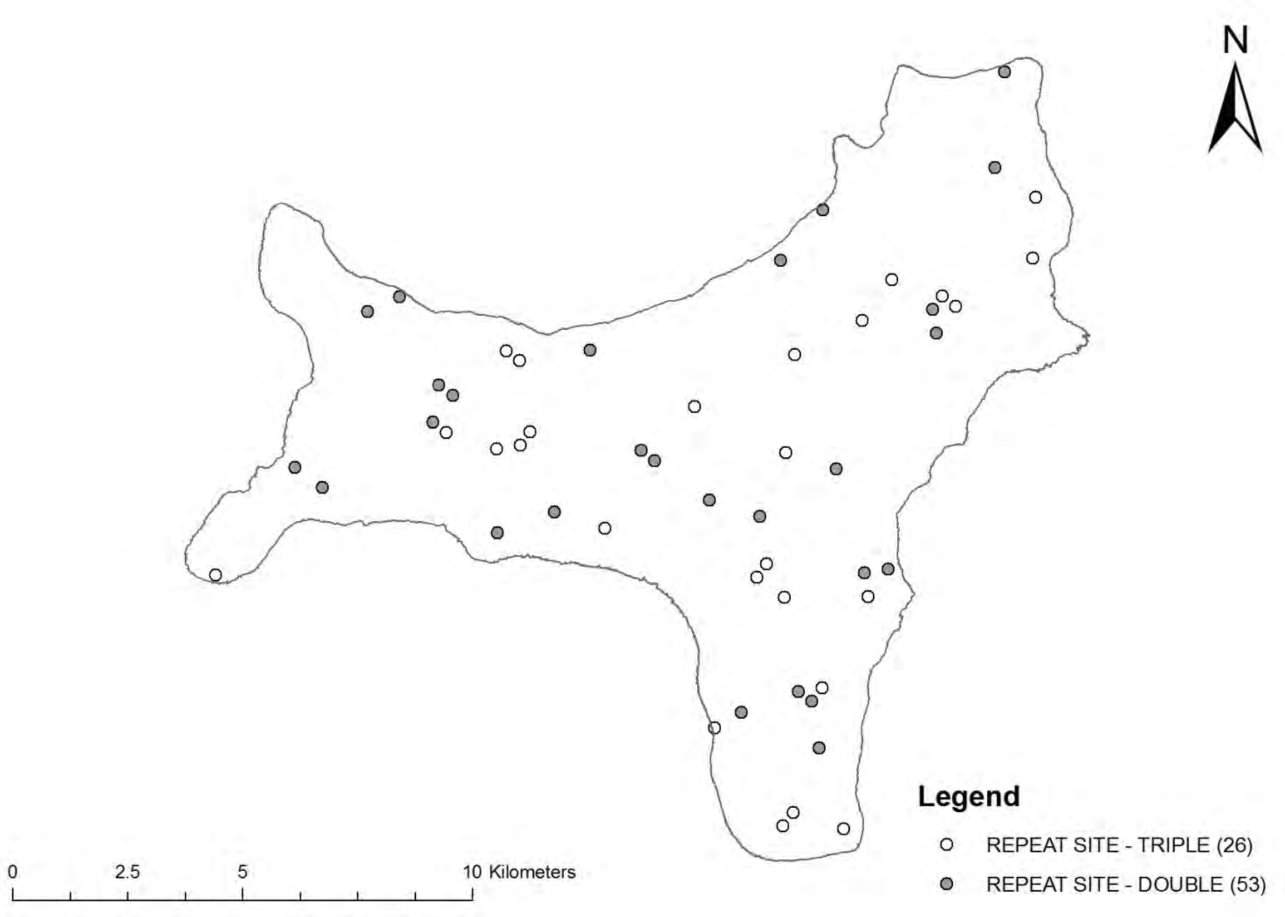

Figure 2: Distribution of the 53 double and 26 triple repeat sites surveyed in 2013.

In 2013, there were 53 sites surveyed twice and 26 sites surveyed three times (Figure 2). These were not the same sites repeat surveyed in 2009 and 2011 as it was considered that the use of ink cards in a variety of locations is preferable for the detection of rare species, such as native reptiles, than for the statistical gains made through biennial visits to the same repeat locations.

Repeat surveys are conducted in exactly the same way as the initial surveys. During the initial survey, transects are marked using flagging tape every five metres so as to ensure burrow counts incorporated the exact same $100m^2$. The only difference is the deployment and collection of ink cards for which there is a separate data sheet.

Ink cards

Black Trakka® ink cards (Gotcha Traps Ltd) are designed to record the foot prints of passing animals across their surface using sticky weatherproof ink and have become an important ecological survey tool for Christmas Island National Park over the last four years. Their passive data recording capabilities are an effective methodology for the detection of cryptic diurnal and nocturnal species.

At each repeat survey site, ten ink cards are stapled to live and dead trees, or secured onto pinnacles at varying heights. They are collected after a week or more but can last much longer during the dry season. Reptile poo, mixed with water and sprinkled onto the cards when deployed, acts as a lure, both to attract reptiles and their predators. The ink cards effectively record insects, mammals, birds and reptiles. Where possible, ink card data from multiple island-wide surveys will be incorporated into the following results section. Appendix 2 shows an example of a filled out ink card datasheet, showing the information collected.

Transit Survey

Any detection of flora and fauna species of interest, or historical sites and landmarks of interest are actively recorded while teams hike between survey sites. These data include point information (e.g., an individual reptile sighting) and polyline information (e.g., the width of a weed patch). Large amounts of accurate; mostly error free and replicable data are collected during survey operations. Figure 3 illustrates the numerousness of transit data collected with over 600 individual points taken and over 70 kilometres of polyline data recorded.

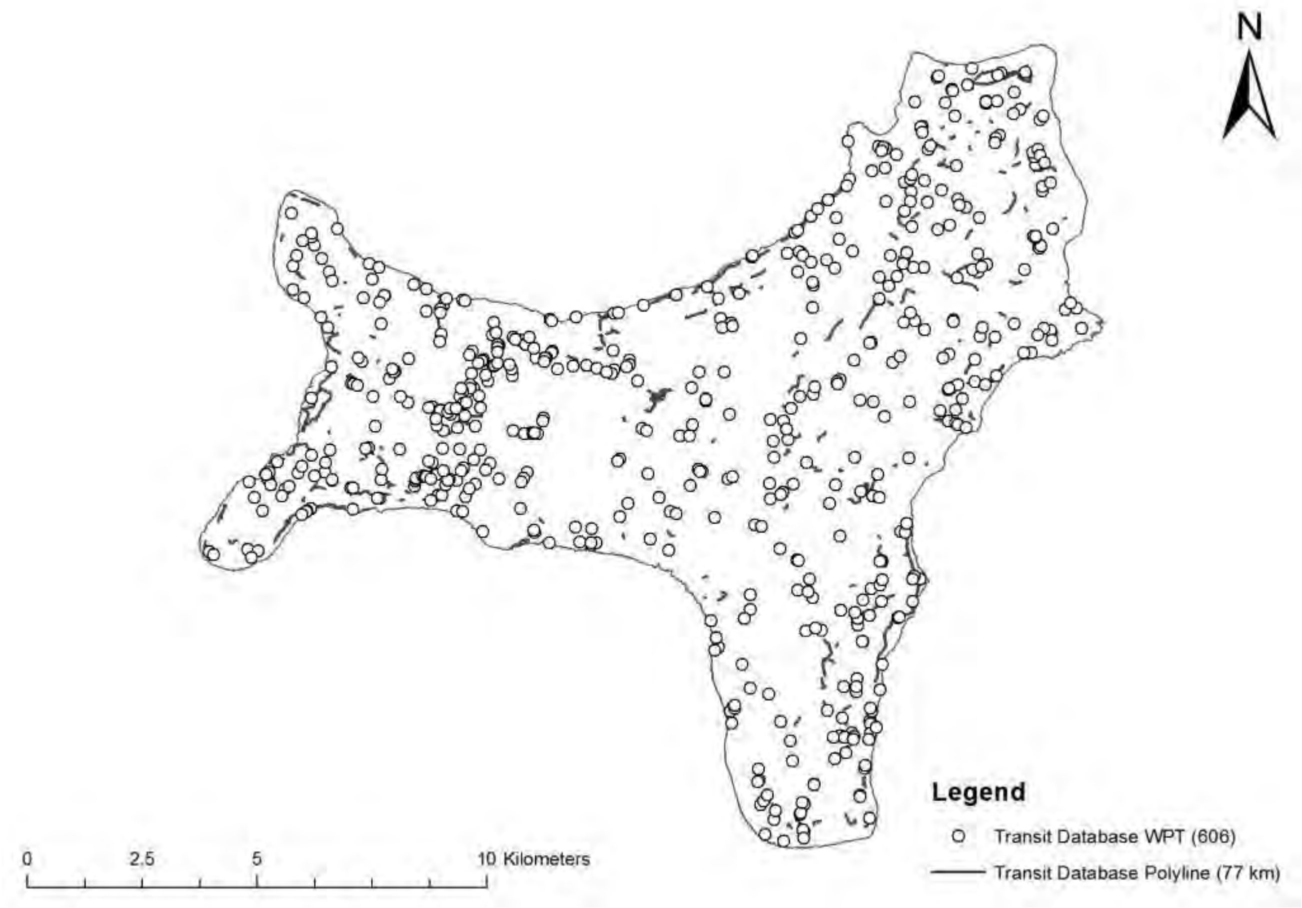

Figure 3: Point and polyline transit data collection locations in 2013.

In the 2013 survey, staff logged spatial data, using *Garmin GPSmap 62s* units. For simplicity, the transit data sheet contained only those species most likely detected during transit, though surveys are free to record any data they see as valuable (e.g., an unknown plant species). Appendix 3 shows an example of a filled out transit data sheet.

A critical part of this process is to have the GPS units recording tracks whenever field teams are walking in the field. When a species of interest is detected a waypoint mark is taken and the default label is then recorded on the datasheet. If recording a polyline (for example a YCA supercolony), teams take a mark at the start and end of the supercolony, these two marks are joined on the datasheet to denote a polyline and the tracks bounded by these marks can subsequently be used as a more accurate estimate of distribution.

Some forest birds, such as the Christmas Island Imperial Pigeon; *Ducula whartoni*, Emerald Dove; *Chalcophaps indica natalis*; Thrush, *Turdus poliocephalus erythropleurus* and White-eye, *Zosterops natalis* are excluded from transit data collection because of their widespread abundance. Other species of bird are only recorded if they are nesting, such as Brown Booby, *Sula leucogaster plotus* and Abbott's Booby, *Papasula abbotti*. Appendix 4 shows the list of possible transit species.

RESULTS

Species presence/absence and distribution data from site surveys are illustrated in the individual species sections below. Species presence data from replicated waypoints (visual, aural, or ink card) and transit data collections are also incorporated here as grid detections i.e. any detection of a species be it at the site or during transit will result in a positive grid detection.

Where applicable, data from other sources are incorporated to better illustrate species distributions across Christmas Island. Not all species or data types collected during surveys will be analysed here though the majority of all species ever recorded during island-wide surveys are present.

In 2011 and 2013 a number of additional survey sites were incorporated or reinstated to fill knowledge gaps in sections of the island. For simplicity, the following illustrations will default to the grid survey as undertaken in 2013 (as it has the greatest coverage) and display surveyed or not surveyed grids accordingly for other years if the species data is sufficient to be illustrated in multiple year maps.

To analyse the presence/absence trends of species that have been recorded over multiple surveys, each species (not including red crabs and yellow crazy ants) will be allocated a detection range based on the number of grid detections recorded for each survey year (Table 1). Differences in the percentage of grid detection will be used to determine if a species is increasing in distribution or is in decline or stable based on survey data. A swing of greater than 10% between surveys is used as evidence of these changes in the population of the species.

The distribution of a species will be analysed based on the location of grid detections across the island.

For a species with a consistently low detection rate and limited distribution illustrations will be a compilation of multiple years of survey data that better demonstrate the total distribution of the species where individual survey maps would not.

The YCA and Red Crab results differ somewhat from the standard approach defined above in that these two species have density data as well as presence/absence and distribution.

Table 1: Species commonality based on the percentage of all grid detections.

Commonality of Species			
0-25%	26-50%	51-75%	76-100%
Low detection	Moderate detection	Common detection	Very detectable

Note: data collected in the field are error checked multiple times when added to databases however this does not preclude an incorrect species identification in-situ, and as such, records of species presence should be verified prior to inclusion in further analysis beyond the scope of this report.

Papasula abbotti – Abbott's Bobby

Status: Native and endemic species.

Survey History: Included in the island wide survey from 2009 to 2013.

Presence/absence : Abbott's Booby has a moderate detection rate with between 31.10% (2013) and 34.83% (2011) coverage recorded across three survey years (Figure 41). This species is easily identified visually and aurally at survey sites and during transit.

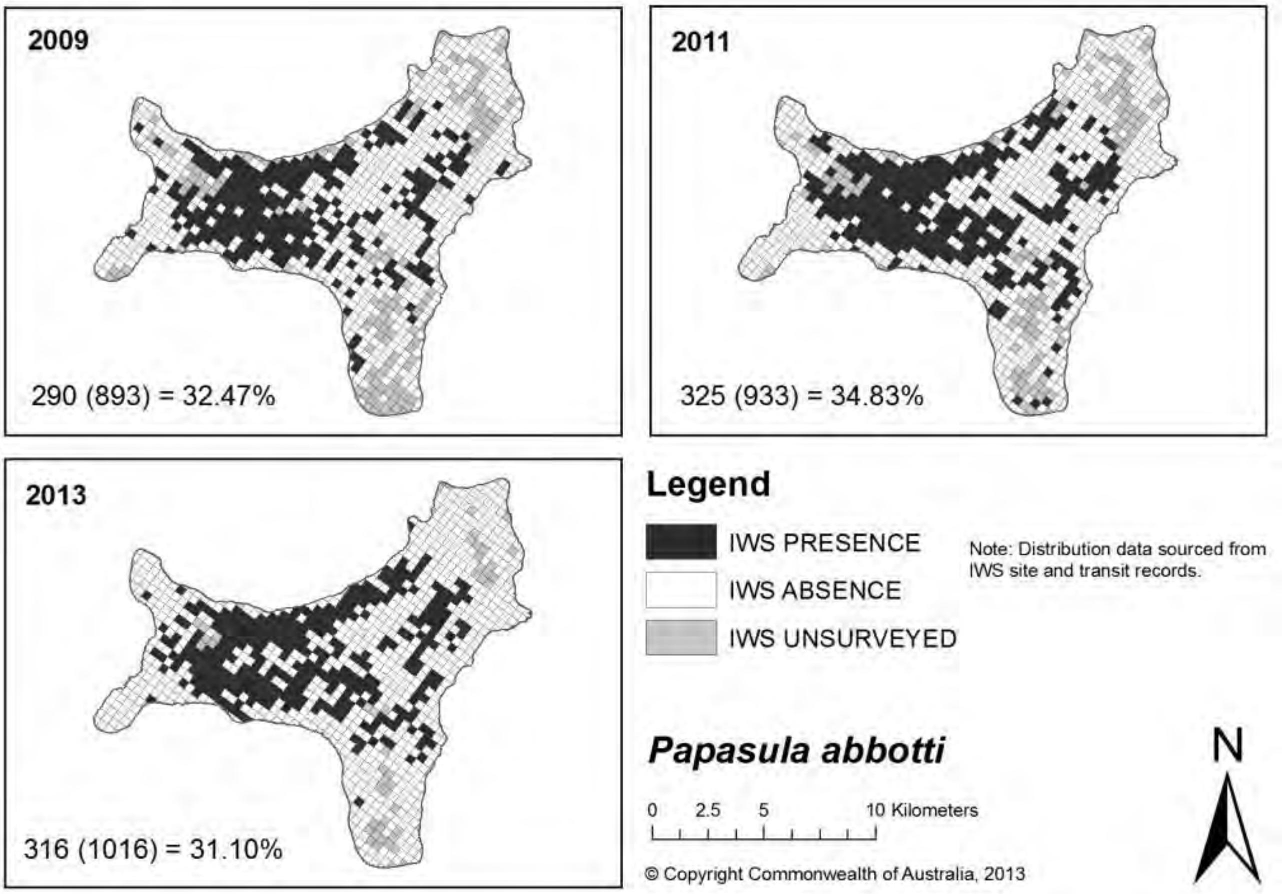

Figure 4: *Papasula abbotti* (Abbott's Booby) presence/absence and distribution on Christmas Island from island-wide surveys between 2009 and 2013.

Distribution: This species is distributed in the islands central plateau with conspicuous sub-populations located between the North Coast and South Coast, to the West of Gannet Hill and in Hidden Valley. They are rarely detected on the first terrace or on North West Point, Egeria Point, South Point or North East Point.

Habitat: This species roosts and nests in the tall closed forest located in the central plateau.

Trending: Data in Figure 41 suggest that the distribution of Abbott's Booby is stable with a difference in island coverage of only 3.73% between three survey years.

Conclusion: The island-wide survey site and transit methods effectively detect this species. Abbott's Bobby should remain in the island-wide survey species list so as to monitor its distribution.

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Coping with variable and oligotrophic tropical waters: foraging behaviour and flexibility of the Abbott's booby *Papasula abbotti*

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ABSTRACT: Seabirds of tropical oceanic waters have to cope with an extremely oligotrophic habitat, but little is known about their foraging behaviour and flexibility which enables them to catch sufficient prey for themselves and their chicks. In a 7 yr study encompassing contrasting oceanographic conditions, the foraging behaviour of chick-rearing Abbott's boobies *Papasula abbotti*, seabirds endemic to Christmas Island, Indian Ocean, was investigated using GPS- and dive-loggers to examine (1) if the species exhibits foraging strategies that indicate specific adaptations to unproductive tropical oceanic waters, and (2) if (or how) the birds adjust their foraging behaviour to inter-annually varying marine conditions. Abbott's boobies displayed a number of distinct characteristics in their foraging behaviour: flight velocities were slower and diving activity lower than in other booby species. Foraging efficiency was enhanced by distinct temporal tuning of diving activity and trip timing, peaking in the morning and again in the afternoon. The birds exhibited some flexibility in foraging behaviour: when conditions deteriorated (i.e. when waters became warmer and less productive), their diet composition changed, they increased their trip durations, trip range and maximum dive depth, although other parameters such as diving activity and sinuosity did not change. Remarkably, the time spent on the water increased simultaneously with trip length. By those adaptations, Abbott's boobies were able to keep their body condition (as well as that of their chicks) stable even under poor marine conditions.

KEY WORDS: Abbott's booby · *Papasula abbotti* · Tropical Indian Ocean · Marine variability · Foraging behaviour · Foraging flexibility · Prey availability · Christmas Island

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INTRODUCTION

Seabirds forage in a heterogeneous and variable environment in which prey abundance is patchy and ephemeral and varies considerably on a temporal and spatial scale (Ashmole 1971, Shealer 2002). This environmental variability and unpredictability has led to the evolution of foraging strategies and behavioural plasticity that enable seabirds to find enough food to sustain themselves and to reproduce successfully under challenging conditions (e.g. Furness & Monaghan 1987, Shealer 2002).

Tropical waters, as defined by Ashmole (1971) as having sea surface temperatures ≥23°C, are characterised by generally lower productivity than 'non-tropical' marine areas (i.e. waters of high latitudes or up-welling systems; Longhurst & Pauly 1987). As a result, tropical waters generally have a relatively low abundance and patchy distribution of seabird prey (Ainley & Boekelheide 1983, Ballance & Pitman 1999). Consequently, seabirds inhabiting those waters (i.e. tropical seabirds following the definition of Ashmole 1971 and Ballance & Pitman 1999), have evolved specific foraging behaviours in order to cope

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with these extreme conditions. For example, most species have a unique wing morphology for a highly proficient flight which enables them to search large marine areas for food while reducing energy expenditure (Flint & Nagy 1984, Ballance 1995, Spear & Ainley 1998, Ballance & Pitman 1999, Hertel & Ballance 1999). As a trade-off, those seabirds are generally poor divers (del Hoyo et al. 1992, Ballance & Pitman 1999), but they have compensated for this by feeding in aggregation with large sub-surface predators such as tuna that drive prey up to the surface and make it accessible (e.g. Au & Pitman 1986, Ballance & Pitman 1999). However, even though research efforts have increased over the last few decades, knowledge of the foraging behaviour of tropical seabirds is still relatively limited compared to that of non-tropical seabirds. For example, information about how they cope with the variability in their marine habitats is scarce, as the majority of studies that have examined the flexibility in foraging behaviour have been conducted on non-tropcial seabirds. Those studies showed that non-tropical seabirds exhibit a high degree of phenotypic plasticity in order to adjust their foraging behaviour to varying oceanographic conditions and buffer the resulting variability in prey availability (e.g. Zador & Piatt 1999, Abraham & Sydeman 2006, Harding et al. 2007). Moreover, comprehensive studies that have investigated temporal as well as spatial (horizontal = displacement, vertical = diving) aspects of foraging behaviour and its flexibility are rare overall, but again particularly rare for tropical seabirds.

Boobies are medium-sized, pantropical seabirds belonging to the Family Sulidae, which also includes the gannets inhabiting higher latitudes (Nelson 1978, Carboneras 1992). Boobies occur in a wide variety of tropical and sub-tropical marine environments — from oceanic, oligotrophic waters to highly productive upwelling areas — and hence have evolved adaptations to cope with different oceanographic habitats (Nelson 1978, Carboneras 1992). The Abbott's booby *Papasula abbotti* differs from all other sulids as it has existed as a separate species for about 22 million years, before all other extant sulid species (Olson & Warheit 1988, Carboneras 1992, Patterson et al. 2011), and as it is thought to have predominantly inhabited islands in tropical oceanic waters (Bourne 1976, Nelson 1978). Therefore, Abbott's boobies might exhibit distinct foraging behaviours to cope with the especially oligotrophic characteristics of these habitats, although information on these potential behaviours is scarce.

This paper presents the first study on the foraging behaviour of Abbott's boobies, focusing on habitat utilization, activity patterns, diving behaviour and diet. In addition, the study covers a 7 yr period and is therefore the first to investigate in detail the foraging flexibility of a pelagic tropical seabird under varying oceanographic conditions. The aims of the study were (1) to investigate if Abbott's boobies show foraging behaviours that indicate specific adaptations to the relatively unproductive tropical oceanic waters, and (2) to examine if and how Abbott's boobies adjust their foraging behaviour to inter-annual variability in their marine habitat.

MATERIALS AND METHODS

Study animals, data loggers and sampling procedures

This study was carried out on Christmas Island (CI), in the Indian Ocean (10° 25′ S, 105° 40′ E), the only location in the world where Abbott's boobies are known to breed. CI is the emergent tip of a submarine mountain rising steeply from the surrounding 2000 m deep ocean floor (Gray 1995). Abbott's boobies nest in the canopy of the tropical rainforest that covers the island (Nelson 1978). Fieldwork was conducted on CI from late August until early October (when Abbott's boobies have small chicks) each year from 2004 to 2010. Nests were located in the primary rainforest by systematic ground searches in 2 areas of CI about 5 km apart where nest densities were known to be the highest: in the northwest (North-West-Point, NWP; 2004 to 2010) and in the southwest of the island (Eastern Circuit Track, ECT; 2005 to 2010). Nests were at heights of 12 to 40 m in the canopy, and were accessed by tree climbing. In 2004, nests alongside roads were also accessed using a 45 m mobile crane. Because of the difficulty involved in finding and accessing nests (nest search to logger retrieval took on average about 10 d per deployment), only a relatively small number of loggers were deployed each breeding season.

Birds were caught on their nest by hand or by using a ca. 1 m noose pole. Upon capture, birds were lowered to the ground in a bag for measurements and logger attachment/retrieval, and marked with colour paint on the lower abdomen for easier identification from the ground. At logger deployment and retrieval, birds were weighed to the nearest 10 g using a spring balance (Super Samson, Salter), and culmen length

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was measured to the nearest 0.05 mm using calipers (except in 2004). Those 2 measurements were used to calculate body condition at deployment as scaled mass index (SMI) following Peig & Green (2009, 2010).

After handling, birds were taken back up into the tree in the bag and released on their nests, where they immediately resumed breeding duties. Logger attachment/removal took approximately 10 to 15 min; total time from catch to release was about 30 min. Attachment and retrieval times occurred randomly throughout the day.

All study birds had chicks, which were guarded by 1 adult at all times. If reachable by hand, chicks were measured (mass, culmen length) at logger deployment and/or retrieval and were aged by mass and culmen length following Nelson (1978). All chicks were between 1 and 8 wk of age. As with adults, body condition of chicks was calculated as SMI using mass and culmen length following Peig & Green (2009, 2010).

In all years, adults were equipped with GPS loggers, temperature-depth-recorders (TDR) or both, to record foraging movements and diving behaviour. Logger models, attachment methods and sampling intervals varied between years (Table 1). The mass of loggers was always <5% of adult body mass (females: 1687 ± 98.7 g, n = 26; males: 1456 ± 96.3 g, n = 27), the weight limit for which loggers could potentially have adverse effects on bird behaviour (Phillips et al. 2003). Loggers were deployed for relatively short periods (1 to 10 d); the heaviest loggers used in the early years of the study (Table 1) were on the birds for a maximum of only 2 or 3 d.

GPS loggers were protected from water by an epoxy housing or by sealing them into a condom and a plastic bag. GPSs were attached to tail or back feathers, and TDRs to a plastic leg ring using Tesa Tape (Beiersdorf) (Table 1). In total, 54 birds (49 different individuals as some birds were equipped in several years) were equipped with GPS loggers from 2004 to 2010, and data on 134 foraging trips were recorded (Table 2). This yielded 1313.4 h of data on foraging movements with 128 619 location fixes. Data on diving behaviour were recorded for 49 birds (44 different individuals) during 95 foraging trips, yielding a total of 1077 dives (Table 2).

The GPS loggers recorded the birds' positions with a precision of ±10 m (according to manufacturers). The sampling interval was 10 s or 3 min for all but 3 individuals in 2004 and 3 in 2010, for which the sampling interval was 15 min (Table 1). The resolutions

Table 1. *Papasula abbotti*. Details of loggers used on chick-rearing Abbott's boobies from 2004 to 2010

Year	GPS					TDR					Total logger weight as max. % of bird weight
	Logger type	Weight incl. housing (g)	Sampling interval (s)	Attachment (with Tesa Tape)	No. of birds	Logger type	Weight (g)	Sampling interval (s)	Attachment (with Tesa Tape)	No. of birds	
2004	GPS-log (Earth & Ocean Technologies)	65	900	On back, between wings	1	n/a	n/a	n/a	n/a	n/a	4.5
2007	GPS-log (Earth & Ocean Technologies)	45	180	Under tail	1	LAT 1110 (Lotek)	5	2	Leg ring	1	3.4
2004–2006	GPS-TDlog (Earth & Ocean Technologies)	70	180 (2 × 900)	On back, between wings	2004: 6 2005: 8 2006: 4	GPS-TDlog (Earth & Ocean Technologies)	see GPS	1	On back, between wings	2004: 6 2005: 7 2006: 4	4.8
2006–2008	GiPSy (Techno Smart)	42	10	Under tail	2006: 8 2007: 6 2008: 6	LAT 1110 (Lotek)	5	2	Leg ring	2006: 6 2007: 8 2008: 7	3.2
2009–2010	iGotU GT-120 (Mobile Action)	17	180 (3 × 900)	Under tail	2009: 6 2010: 8	LAT 1110 (Lotek)	5	2	Leg ring	2009: 5 2010: 5	1.5

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Table 2. *Papasula abbotti*. Number of Abbott's boobies equipped with GPS and/or TDR loggers, and number of foraging trips recorded during the study years 2004 to 2010. GPS-TDR-combination: either 1 device, or 2 separate devices on the same bird (see Table 1)

Year	GPS & TDR combined	Foraging trips recorded with GPS	GPS trips also covered with TDR	Only GPS	Foraging trips recorded	Only TDR	Foraging trips recorded
2004	6	12	12	1	1	–	–
2005	7	20	20	1	2	–	–
2006	10	27	26	2	3	(2)[a]	2
2007	7	11	9	–	–	2	2
2008	5	9	7	1	1	2	3
2009	5	20	8	1	4	–	–
2010	5	12	6	3	12	–	–
Total	**45**	**111**	**88**	**9**	**23**	**4**	**7**

[a]Actually a GPS-TDR-combination, but GPS loggers failed after first trip in both animals while TDR loggers recorded another trip; individuals are taken into account in 'GPS & TDR combined'

of the pressure sensors of the GPS-TDlog and LTD 1110 (see Table 1) were 6 cm and 10 cm respectively, with a measurement accuracy of 20 cm and 12.5 cm (according to manufacturers).

When handled, adults occasionally (chicks rarely) spontaneously regurgitated their prey. From 2004 to 2008, regurgitates were collected in a sealable plastic bag and taken to the laboratory for analysis.

No negative effects of the investigations could be detected. Abbott's boobies are very calm birds compared to other Sulid species; they stayed on their nests as we approached (whether by tree climbing or by crane), remained calm during handling, and could easily be recaptured for logger retrieval. After release, all animals resumed their breeding duties. Treated nests were monitored until the end of the field season, and in all nests breeding was continued successfully. Birds exhibited no weight loss from logger deployment to retrieval (paired *t*-test, t_{53} = –0.262, p = 0.794, n = 54). Although the weights of GPS-log and GPS-TDlog loggers (used in 2004 to 2006, Table 1) were higher than that of the other logger types, foraging trip durations were not influenced by logger type (linear mixed model, LMM: $F_{3,58.4}$ = 0.715, p = 0.547, n = 134), and the birds with the heavier loggers did not significantly lose weight during their trips (paired *t*-test, t_{18} = –1.374, p = 0.186, n = 19).

Foraging parameters

The start and end of foraging trips were determined using locational data of the GPS loggers (bird on nest vs. off nest), averaging the time of the last fix on the nest and the first fix at sea, and vice versa. In 7 cases, GPS loggers failed or were lost, and therefore trip start and end times were determined by TDR temperature profiles — which showed clear temperature shifts when birds started from or arrived at the nest (as temperatures at the nests were higher and more variable than temperatures at sea). The validity of this approach was controlled by using trips with both GPS and TDR data. Some trips were not completely covered by GPS recording due to battery exhaustion. Data on those trips were only used in analyses when appropriate (e.g. time of trip start). Distances of birds from CI were calculated by using spherical trigonometry (arc distance formula; Robinson et al. 1978).

To distinguish between flying and floating/drifting/swimming on water, the frequency distribution of instantaneous displacement velocities (recorded by the GPS logger by Doppler shift at each location fix) was plotted. A local minimum at 7.0 km h^{-1} was found for both day and night. This velocity was considered to be the threshold between the bird being on the water surface and being in the air. All instantaneous displacement velocities >7 km h^{-1} were considered flight velocities, and were used to calculate the parameters of the birds' foraging trips.

To calculate time spent on the water, average displacement velocities were calculated for each sampling interval (i.e. the time between 2 location fixes), by dividing the distance between fixes by the time passed between fixes. If the velocity for a sampling interval was <7.0 km h^{-1}, the interval was counted as time spent on water. For this calculation, only trips with complete GPS coverage were taken into account, and only data of loggers with 10 s and 3 min

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sampling intervals were used to keep precision high. For the calculation of this parameter for 'day', overnight trips as well as their 'day parts' were excluded. 'Day' (i.e. hours of daylight), was defined as the time between the earliest departure of a bird from the nest (05:09 h) and the latest arrival time of a bird at the nest (18:16 h) during the study years; thus, day length was 13.1 h. For overnight trips, the night period (10.9 h) was subtracted from total trip duration to calculate diving activity (dives h^{-1}), since birds did not dive at night.

Dive data were analysed with MultiTrace-Dive 4.0 (Jensen Software Systems). The minimum diving threshold was 30 cm, accounting for the resolution and measurement uncertainty of the pressure sensors (see logger specifications in the previous section). Locations of diving events were determined by interpolation between the GPS fixes preceding and following the dive event, assuming a constant flight velocity and a direct flight path between the fixes.

To determine the distribution of diving activity over the course of the day, numbers of dives per 30 min time slot were corrected for the number of birds at sea equipped with a TDR during any specific time slot. A bird was included for a given time slot if it spent at least 15 min at sea during that 30 min time slot. Only foraging trips that were completely covered by TDR recordings were included in analyses of diving activity (dives h^{-1}, timing of diving activity).

The distribution of dives over the course of the foraging trip was calculated as the ratio of the time of the dive since the start of the trip to the duration of the trip (i.e. a value of 0.5 indicates that the dive was conducted at the midpoint of the trip). Trips that were not completely covered by TDR recording were not included in this analysis. Only day trips were analysed, as overnight trips are likely to require different diving strategies than day trips and, in addition, dive data on overnight trips were only available for females.

To calculate sinuosity, positional data of 3 min sampling intervals were used as well as the positional data of 10 s intervals which were re-sampled at 3 min intervals. Sinuosity was calculated for each location fix as the ratio of the cumulative distance covered between 5 positions before and after the fix to the straight-line distance between the first and the last position within this 30 min sliding window. A value of 1 indicates a straight flight path.

For the calculation of foraging area sizes as well as for extraction of oceanographic parameters of the marine areas used by the birds, kernel density estimations were conducted with the R package 'adehabitatHR' using positional lat/long data transformed in UTM (Zone 48) and ad hoc h-values for kernel smoothing (Seaman & Powell 1996, Wood et al. 2000). Trajectories of the 15 min sampling intervals were interpolated to locations every 3 min, assuming a constant flight speed and direct flight path between fixes, and were then combined with the positional data used for sinuosity and travelling speed; i.e. all trips (sampling intervals of 10 s, 3 min and 15 min) were divided into 3 min intervals to make them comparable. A 95% fixed kernel density estimation was used to determine total foraging areas, while 50% kernel estimations were considered core areas. The core areas of each foraging trip were subsequently used to extract the oceanographic parameters of the marine habitat used by the birds. To obtain meaningful results, positional fixes were taken into account for the analyses instead of only dive locations (i.e. actual hunting events) as dive frequencies were low (see Results) and oceanographic data coarse (see below). Core areas were used instead of all fixes or total foraging areas to exclude marine areas that were only used for commuting.

Diet

A total of 37 regurgitates containing 131 prey items of 26 different chick-rearing Abbott's boobies were collected from 2004 to 2008. Complete spines, spine fragments, and vertebrae were cleansed of remaining flesh using Bio-tex® (Blumøller) following Watt et al. (1997). Digested chyme was dispersed in water in a Petri dish and searched for diagnostic prey remains such as otoliths and vertebrae of fish, and/or squid beaks.

For intact fish, identification keys of the Food and Agriculture Organization (FAO identification sheets; www.fao.org), open source data of Fishbase (Froese & Pauly 2013), and literature sources (Harrison et al. 1983, Smale et al. 1995, Rivaton & Bourret 1999) were used. A reference collection was compiled for otoliths and vertebrae to identify incomplete prey items. Squid species were identified using the identification key of Clarke (1986) and Lu & Ickeringill (1999) as well as the reference collection of Dr. U. Piatkowski, Institute for Marine Sciences, Kiel, Germany.

The length of intact fish was determined to the nearest mm as total length (TL) following Froese & Pauly (2013) using a ruler, and mass was determined to the nearest g using a digital balance. Otolith size was measured to a precision of 0.1 mm and size of vertebrae to a precision of 0.05 mm using calipers or a binocular dissecting microscope with scaled ocular

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(Wild M 7 S, Heerbrugg). To determine the length and mass of incomplete prey items, various regression equations between otolith and vertebra size with fish length and mass were used, which were derived from intact fish collected in this study or taken from the literature following Härkönen (1986) and Watt et al. (1997).

The dorsal mantle length (ML) of intact squid was determined to the nearest mm using a ruler, and mass was determined to the nearest g using a digital balance. Rostral lengths of upper and lower beak were measured to a precision of 0.05 mm using calipers or a binocular dissecting microscope. If the upper and lower beak of the same individual were present, measurements were derived from the lower beak. As for fish, length and mass of incomplete squid were calculated using regression equations derived from intact squid collected in the study, following Clarke (1986) and Croxall & Prince (1996).

Loose otoliths, vertebra and squid beaks were grouped according to species/family and size to determine the actual number of prey items for the analyses. For length and mass determination, the same methods were used as for intact prey items.

All prey items were identified to species or family level, and were subsequently pooled into different groups of prey (i.e. flying fish, non-flying fish or squid), to allow more meaningful and sound statistical analyses. Frequency of occurrence was calculated on the basis of individual birds (not on the number of regurgitates), as several birds regurgitated at both logger deployment and retrieval.

Oceanographic parameters

Sea surface temperature (SST) and chlorophyll *a* (chl *a*) concentration were chosen as parameters to characterise the oceanographic conditions around CI, as it has been shown in various seabird studies that they are suitable proxies for prey availability, and consequently have the potential to influence various parameters of seabird foraging behaviour (e.g. Peck et al. 2004, Weimerskirch et al. 2005a, Erwin & Congdon 2007). Other parameters, such as bathymetry, sea level height or gradients of any of the oceanographic parameters — which have also been shown to potentially affect seabird foraging behaviour — were not included in the analyses due to the small foraging range of the boobies (see Results) combined with the low temporal resolution of the oceanographic data (see below). SST and chl *a* data were compiled from NASA, through its GIOVANNI data gateway (http://disc.sci.gsfc.nasa.gov/giovanni/overview/index.html). MODIS Aqua data were used for both parameters with a spatial resolution of 9 km. For SST, daytime 11 micron data were used. As daily and weekly data coverage within the study area was poor due to substantial cloud coverage, available data were averaged over the month of September for each year according to the yearly study period. For the general description of the marine habitat around CI, an area of 4 × 4° with CI in the middle was chosen, as that size corresponds approximately to the boobies' maximum foraging range (248.3 km; excluding the outlier of over 550 km in 2005). In addition, SST and chl *a* values of this 4° × 4° area were linked to the birds' body condition at de-

Table 3. *Papasula abbotti*. Correlations of adult and chick body condition with SST and chl *a* in the 4 × 4° area around Christmas Island, and of foraging parameters with SST and chl *a* of each respective foraging trip (**bold**: significant)

Parameter	n	SST		chl *a*	
		Kendall's τ-b	p	Kendall's τ-b	p
Adult body condition (SMI)	48	−0.060	0.574	0.126	0.239
Chick body condition (SMI)	44	−0.061	0.584	0.061	0.584
Trip duration (h)	114	0.194	**0.003**	−0.170	**0.008**
Max. foraging range (km)	115	0.198	**0.003**	−0.185	**0.003**
Total distance travelled (km)	114	0.168	**0.011**	−0.173	**0.006**
Avg. flight speed day (km h^{-1})	118	−0.003	0.957	−0.065	0.295
Avg. flight speed night (km h^{-1})	17	−0.150	0.407	0.185	0.303
Time spent on water, day (% of trip)	106	0.162	**0.019**	−0.133	0.087
Total foraging area (km^2)	118	0.170	**0.009**	−0.154	**0.014**
Sinuosity	118	−0.039	0.533	0.067	0.290
Dives h^{-1}	69	−0.047	0.595	0.087	0.302
Avg. dive depth (m)	78	−0.030	0.711	0.020	0.799
Max. dive depth (m)	78	0.175	**0.030**	−0.132	0.089
Dive pause (s)	78	−0.078	0.331	0.017	0.829
Closest dive to island (km)	78	0.167	**0.038**	−0.137	0.076

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ployment (see Table 3), as it also integrates the marine conditions before the study (i.e. the conditions that determined the body condition of the birds at deployment). To determine the oceanographic conditions of the marine areas chosen by the birds, average SST and chl *a* values for each foraging trip were calculated by overlaying the oceanographic data with the core areas of the trips.

SST anomalies in the 4 × 4° area around CI during September were compiled for the study years, with the lowest and highest SSTs from the NASA POET data gateway (http://thredds.jpl.nasa.gov/las/getUI.do [original link was http://poet.jpl.nasa.gov, now retired]) using the Reynolds Optimally Interpolated SST dataset, to obtain a relative measure of 'how low/high' the SST was.

Statistical analyses

Statistical analyses were performed with SPSS 11.5 (SPSS), and R Studio (Version 0.94.92) using R version 2.13.0 (R Development Core Team 2010) and the R packages 'nlme' and 'circular'.

Normality of response variables were checked by Q-Q-plots or, in case of small sample sizes, with application of the Shapiro-Wilks test. If necessary, appropriate transformations were performed to gain normality, e.g. ln-transformations of trip duration, dives h^{-1}, and dive duration. Sinuosity values were transformed using the logit (ln) of the inversed sinuosity. Heteroscedasticity was checked using plots of residuals over fitted values or, in case of small sample sizes, with Levene's test for heteroscedasticity. If necessary, test statistics and degrees of freedom were adjusted appropriately.

To determine the influence of bird sex and study year and their interaction on foraging parameters, LMMs were fitted with sex and year as fixed factors. Bird identity was included as a random factor to avoid pseudo-replication, since, for most individuals, data on several foraging trips were recorded. Significance of models was determined by *F*-statistics using a backward stepwise testing procedure based on Akaike's information criterion values. As there were no significant effects of sex or the interaction of sex and year on any foraging parameter, data from both sexes were pooled for all further analyses.

Depending on sample size, either Kendall's τ-b or Spearman's rank correlations were used to examine correlations between foraging parameters (e.g. trip duration vs. trip range), and to investigate the effect of year on foraging behaviour (i.e. if and how the oceanographic variability between years influenced foraging parameters).

For all tests, the threshold for significance was $p < 0.05$, and all tests were 2-tailed. Means are given ±SD, and medians with minimum and maximum values.

RESULTS

Foraging movements and activity patterns

Abbott's boobies foraged over deep oceanic waters around Christmas Island, covering a total area of 108 503 km^2 (90% kernel of all location fixes) with a core area of 12 186 km^2 (50% kernel; Fig. 1)

The median duration of foraging trips was 6.2 h (n = 133), with the shortest trip being 0.4 h and the longest, 152.8 h. The frequency distribution of trip durations showed 3 peaks: short single-day trips, intermediate trips including 1 night at sea, and long trips including 2 (n = 2), 3 (n = 1) and 6 (n = 1) nights at sea (Fig. 2). Most trips (88.0%) were single-day trips (<12.2 h), while the remaining were overnight trips.

On their foraging trips, birds travelled a median distance of 154.3 km, with the shortest trip covering 12.4 km and the longest, 2218.3 km (n = 126 trips). The median foraging range (= max. distance from nest) was 56.8 km, ranging from 3.6 to 556.7 km (n = 127 trips). Foraging trip duration was significantly

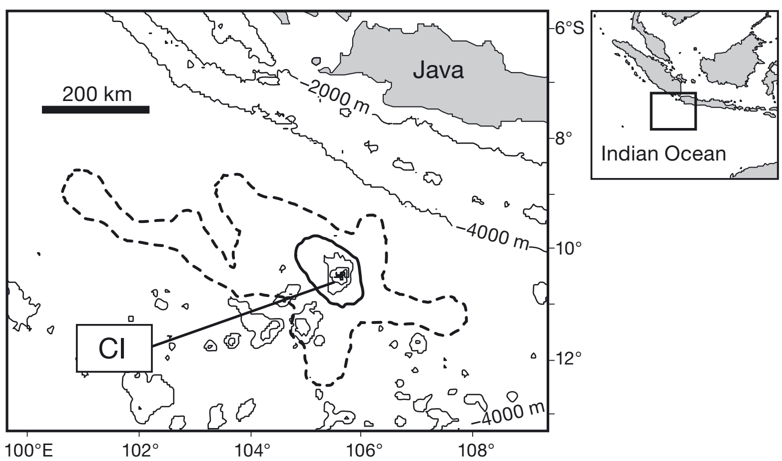

Fig. 1. *Papasula abbotti*. Eastern Indian Ocean (including isobaths), showing the location of Christmas Island (CI) and foraging areas of Abbott's boobies around the island from 2004 to 2010 — dotted line = 95% kernel, solid line = 50% kernel

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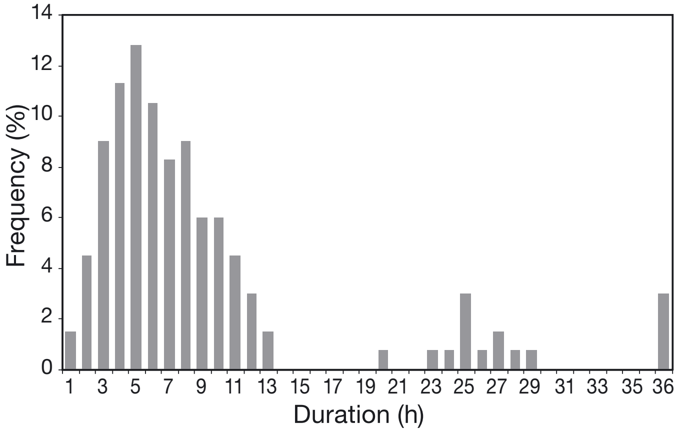

Fig. 2. *Papasula abbotti*. Frequency distribution of foraging trip durations of Abbott's boobies from 2004 to 2010 (n = 133)

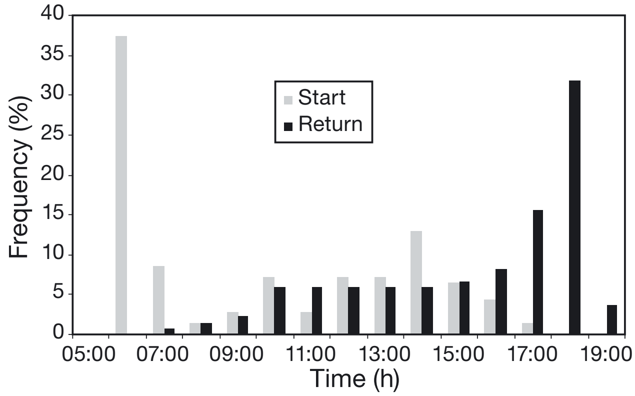

Fig. 3. *Papasula abbotti*. Departure (n = 139) and return times (n = 135) of Abbott's boobies from 2004 to 2010

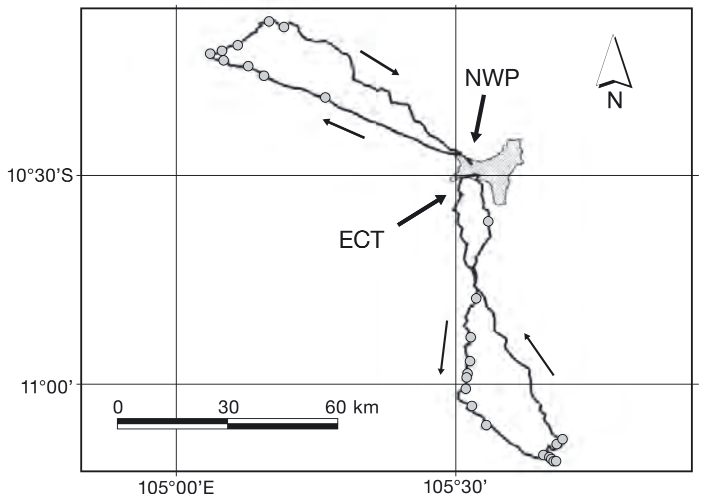

Fig. 4. *Papasula abbotti*. Typical tracks of foraging trips of Abbott's boobies of the North West Point (NWP) and Eastern Circuit Track (ECT) colonies on Christmas Island. Circles represent dives and thin arrows show flight directions (examples from 2005)

correlated with maximum foraging range, total trip distance, and total foraging area (τ = 0.749, 0.826, 0.726, respectively; for all parameters: $p < 0.001$, n = 126).

Departure times showed a bimodal distribution (Fig. 3). The majority of trips (46.0%) started between 05:00 h and 07:00 h. The start of the remaining the trips varied over the day, with a second peak around 14:00 h. The latest departure was at 16:36 h. Birds returned to the island from 06:53 h onwards. Return times varied over the entire day, although returns were most common in the late afternoon, with 59.3% occurring after 16:00 h.

Median flight velocities during the day were 30.0 km h^{-1} (n = 79 690 velocity recordings). At night, velocities were lower, with a median of 20.0 km h^{-1} (n = 19 523 velocity recordings). During the day, birds spent only a small proportion of the foraging trip on the water surface (median = 5.9%, range = 0.0 to 31.9%, n = 102 trips), while at night a mean of 49.1% (±27.71, n = 15) was spent on the sea surface. The paths of foraging trips were typically linear to curvilinear, and for the most part lacked major directional changes, showing a relatively low sinuosity with a median of 1.19 (range = 1 to 191.5, n = 22 345; Fig. 4).

Diving behaviour

Dives were shallow and short, with a mean dive depth of 2.21 ± 1.04 m (n = 1077, max. = 9.51 m; Fig. 5a) and a median duration of 5 s (range = 2 to 23 s, n = 1077). Dive depth was significantly correlated with dive duration (τ = 0.334, $p < 0.01$, n = 1077). Birds dove infrequently, with a median of 1.7 dives h^{-1} at sea (range = 0.0 to 5.0, n = 84) and a median duration between dives of 10.4 min (range = 0 to 370 min, n = 978). The first dives during a foraging trip were 4.6 to 93.2 km away from CI (median = 22.6 km, n = 85).

Diving occurred throughout the foraging trip (including the outbound leg), but during the last 20% (inbound leg) only few dives were performed (Figs. 4 & 5b). The distribution of dives over the course of the day was bimodal, with peaks occurring in the morning (06:30 to 07:00 h) and in the afternoon (14:00 to 15:00 h; Fig. 5c). No dives were performed at night.

Diet

The diet of chick-rearing Abbott's boobies consisted mainly of flying fish, with non-flying fish species and squid as secondary prey. The tropical two-

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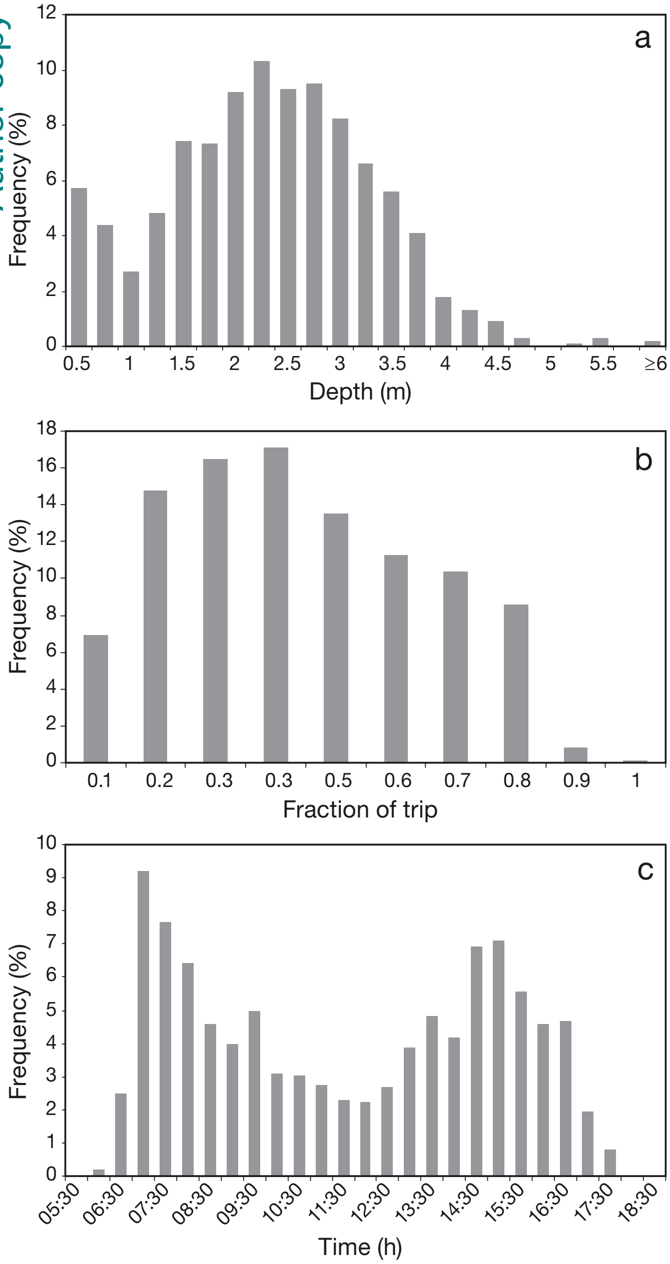

Fig. 5. *Papasula abbotti*. Characteristics of the diving behaviour of Abbott's boobies from 2004 to 2010: (a) frequency distribution of dive depths, (b) distribution of dives over the course of the foraging trip (fraction of 0.5 = midpoint of trip, 1 = end of trip), (c) frequency distribution of diving activity over the course of the day; (n = 1077 for all graphs)

wing flyingfish *Exocoetus volitans* was the most numerous prey item overall, although within the flying fishes (family Exocoetidae) other species were also found, such as margined flyingfish *Cheilopogon cyanopterus* and manyspotted flyingfish *C. spilopterus*. Non-flying fish belonged to the families Coryphaenidae (dolphin fishes), Hemiramphidae (halfbills), Scombridae (mackerels, tunas, bonitos), and Carangidae (jacks and pompanos), such as the mackerel scad *Decapterus macarellus*. The squids found in regurgitates were all purple-back (flying) squid *Sthenoteuthis oualaniensis* of the family Ommastrephidae (flying squids).

Over the 5 study years, flying fish contributed the most to the total prey biomass (81.5 ± 12.7%), followed by non-flying fish (15.5 ± 11.8%) and squid (2.9 ± 2.7%). Within the group of flying fish, *Exocoetus volitans* made up on average 37.5% (± 12.2).

Inter-annual differences in oceanographic conditions, foraging behaviour, diet and body condition

Oceanographic conditions in the foraging zone of Abbott's boobies around CI (i.e. the 4 × 4° area) varied among years (Fig. 6). In 2006, SST was the lowest, at 25.3°C (± 0.25; − 0.77°C SST anomaly) and chl *a* concentration was the highest at 0.433 ± 0.358 mg m^{-3}, almost twice as high than the average of the 7 yr study period (0.235 ± 0.104 mg m^{-3}). The warmest year was 2010, with a mean SST of 27.9°C (± 0.48; +1.44°C SST anomaly), 1.7°C higher than the mean temperature of the study period (26.2 ± 0.83°C). During this year, chl *a* concentration was the lowest at 0.092 ± 0.018 mg m^{-3}, about 2.5 times lower than the average concentration during the study period.

The foraging behaviour of Abbott's boobies was influenced by the varying oceanographic conditions. When waters were warmer and less productive, birds went on longer foraging trips, had larger ranges and covered longer distances and areas (foraging trip duration, foraging range, total distance travelled and

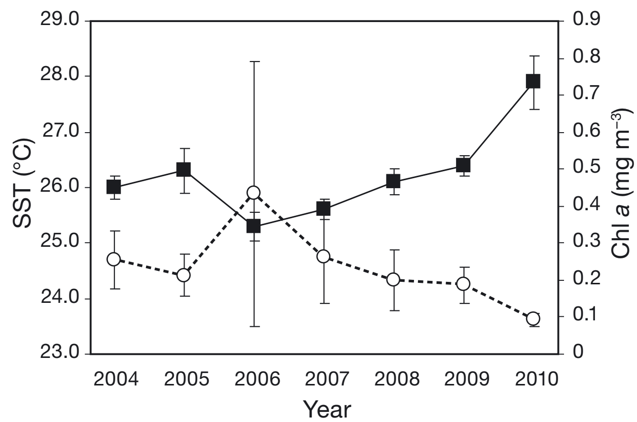

Fig. 6. Sea surface temperature (SST, solid line) and chlorophyll *a* concentrations (chl *a*, dashed line) in a 4 × 4° area around Christmas Island. Error bars show ±SD

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total foraging area all correlated positively with average SST in the core foraging area and negatively with chl *a*; Table 3). Relative time spent on water, maximum dive depth, and closest dive to CI did not correlate with chl *a*, but were positively correlated with SST (Table 3). Other parameters such as body condition, diving activity, sinuosity, and flight speeds were not influenced by SST or chl *a* (Table 3).

Prey composition (i.e. relative numbers, number of occurrence and relative biomass of flying fish, non-flying fish and squid) varied among years, but no coherent relationships of those parameters with SST or chl *a* were found, apart from in the frequency of occurrence of non-flying fish. This parameter increased with increasing SST ($r_S = 0.9$, $p = 0.037$, $n = 5$) and decreasing chl *a* ($r_S = 1.0$, $p < 0.001$, $n = 5$). Prey lengths within the different prey groups were affected by the marine conditions: the lengths of flying fish correlated negatively with SST ($\tau = -0.295$, $p < 0.001$, $n = 95$) and positively with chl *a* ($\tau = 0.174$, $p = 0.023$, $n = 95$). In contrast, squid length correlated positively with SST ($r_S = 0.594$, $p = 0.019$, $n = 15$) but not with chl *a* ($r_S = -0.465$, $p = 0.081$, $n = 15$). The length of non-flying fish did not correlate with either SST ($r_S = -0.084$, $p = 0.807$, $n = 11$) or chl *a* ($r_S = 0.502$, $p = 0.115$, $n = 11$).

Body condition of adults and chicks did not differ among years (ANOVA, $F_{5,47} = 0.907$, $p = 0.486$, $n = 48$, and $F_{5,43} = 1.007$, $p = 0.427$, $n = 44$) and did not correlate with either SST or chl *a* (Table 3).

DISCUSSION

The present study is the first to gather detailed data on the foraging ecology of Abbott's boobies as well as, to our knowledge, the first that investigates the foraging behaviour and flexibility of a pelagic tropical seabird using data loggers over several subsequent breeding seasons.

Foraging behaviour of Abbott's boobies

Abbott's boobies exhibited several foraging behaviours that reflect adaptations to their oligotrophic marine habitat, some of which differed from findings in other booby species. The average flight speed of 30.0 km h^{-1} during daytime foraging was considerably lower than that of other booby species, for which average speeds of about 38 km h^{-1} have been recorded (38.3 km h^{-1} in masked/Nazca booby *Sula dactylatra* and 39.1 km h^{-1} in blue-footed booby *S. nebouxii*, Anderson & Ricklefs 1987; and 38 km h^{-1} in red-footed booby *S. sula*, Weimerskirch et al. 2005b). Those species have broader wings and flap often when flying (Nelson 1978, Weimerskirch et al. 2005b), whereas Abbott's boobies have long and narrow wings that are generally assumed to have evolved for a gliding and hence generally slower flight — which can substantially reduce the energetic costs of foraging. Thus, the slow flight speeds might be related to this morphological difference, but differences in prevailing wind speeds between the respective foraging habitats might also contribute. Comparative investigation between the other CI booby species (brown and red-footed booby) would help to clarify this point.

Abbott's boobies were hitherto thought to be one of the most pelagic booby species, foraging at long distances from CI (Becking 1976, Hirons et al. 1976, Nelson 1978, Reville et al. 1990, van Balen 1996). Unexpectedly, although the furthest foraging location was over 550 km away from CI, Abbott's boobies foraged relatively close to the island, with an average foraging range of <60 km. In comparison to other booby species, this is an intermediate foraging range. Chick-rearing Peruvian boobies *Sula variegata* and blue-footed boobies *S. nebouxii* were found to have average foraging ranges of 25 km (Zavalaga et al. 2010) and 39 km (Zavalaga et al. 2008), respectively; brown boobies *S. leucogaster* between 17 and 39 km (Weimerskirch et al. 2009b), and red-footed boobies *S. sula* of 39 km (Weimerskirch et al. 2005a), while Nasca boobies *S. granti* and masked boobies *S. dactylatra* had larger foraging ranges than Abbott's boobies, with average ranges of 98 km (Zavalaga et al. 2012) and 103 km (Weimerskirch et al. 2008), respectively. The relatively small foraging range of Abbott's boobies that was recorded in this study, in contrast to previously published information, might be because the data for this study was collected during the early chick-rearing period. At this breeding stage, seabirds have relatively limited foraging ranges in order to provision their chicks frequently and relieve their partners regularly from brooding the young on the nest. During incubation, Abbott's boobies forage much further away from CI with a median range of 169.6 km (n = 8, J. C. Hennicke unpubl. data). Thus, Abbott's boobies might show foraging ranges that match those previously assumed during other breeding stages (such as late chick-rearing or post-fledging care) when chicks can be left alone on the nest.

Like all other boobies, Abbotts boobies are diurnal foragers, typically leaving the nest in the morning

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and returning before nightfall. A second peak of trip departures, however, occurred around the middle of the day. As only 1 partner is at the nest during the day guarding the chick, the other partner appears to do a change-over around midday, rather than switching over the course of the entire day as it is has been found in other booby species (e.g. Zavalaga et al. 2007, 2010, Weimerskirch 2009a). This distinct behaviour is highly adaptive as it allows both partners not only to forage on the same day, and consequently to reduce the duration of fasting stints for the adult on the nest, but also gives both partners the opportunity to increase foraging efficiency — as both can take advantage of one of the 2 peaks of high prey availability generated by sub-surface predators early in the morning and late in the afternoon (see below).

Although spending the night at sea is generally a rare behaviour in boobies (Nelson 1978, Carboneras 1992), it was not rare in Abbott's boobies — with 12% of all trips being overnight trips. Masked boobies have been found to make parts of their return flights back to the colony at night (Weimerskirch et al. 2009a), red-footed boobies have been recorded to make overnight trips in the Galapagos (Nelson 1978, H. Weimerskirch unpubl. data), but only recently have frequent overnight trips been observed in Nazca boobies (Zavalaga et al. 2012). Sulids are visual hunters, and hence depend on light to capture prey (Nelson 1978). During their overnight trips, Abbott's boobies did not dive, and therefore most likely no feeding took place — probably because darkness prevented prey capture. In addition to the decreased energy intake, foraging at night increases the risk of attack by predatory fish such as sharks, which are common in tropical waters and often hunt from dusk to dawn (cf. Nelson 1978, Weimerskirch et al. 2005b, Zavalaga et al. 2012). Indeed, Abbott's boobies spent only about 50% of their time on the water surface, flying at low velocities for the rest of the night, in contrast to the behaviour of Nazca boobies that rest on the water most of the night (Zavalaga et al. 2012). However, despite the decreased energy intake and reduction in chick provisioning frequency, it was found, unexpectantly, that Abbott's boobies made many overnight trips. Most likely, these trips allowed the birds to increase their foraging range and hence search larger marine areas for food.

The present study shows that Abbott's boobies are shallow divers, with an average dive depth of only 2.2 m. This depth corresponds well to findings in other booby species that feed on similar prey (i.e. flying fish) and depend strongly on sub-surface predators driving prey species to the water surface. Red-footed boobies dove on average only 0.9 m (Weimerskirch at al. 2005b), Nazca boobies had a mean dive depth of 1.1 m (Zavalaga et al. 2012), and brown boobies of 1.1 to 1.3 m (Weimerskirch et al. 2009b), while masked boobies and Peruvian boobies had similar average dive depths to Abbott's boobies at 2.2 m (Weimerskirch et al. 2008) and 2.5 m (Zavalaga et al. 2010), respectively. In plunge-diving boobies, dive depth is strongly linked to body mass — which determines the bird's momentum when plunging (cf. Ropert-Coudert et al. 2004). This is well reflected in Abbott's boobies, which dive deeper than smaller species and reach comparable depths as species of similar weight.

Diving took place during the entire foraging trip, including the outbound leg. This spatial distribution of dives matches the assumed homogeneous distribution of prey patches in tropical oceanic waters, and reflects the highly opportunistic foraging behaviour of Abbott's boobies. However, this behaviour contrasts with that of other boobies that forage mainly at the maximum range of their trips using extensive area-restricted search (e.g. brown and blue-footed booby, Weimerskirch et al. 2009b; Peruvian booby, Weimerskirch et al. 2012). In general, the sinuosity in the foraging paths of Abbott's boobies was relatively low, suggesting the potential use of a different search strategy — but only comparative investigations of several booby species within the same marine habitat could elucidated this question further.

Abbott's boobies exhibited a relatively low diving frequency of 1.7 dives h^{-1}. In other booby species feeding on similar prey, higher dive rates have been recorded. Lewis et al. (2004) reported 3.8 dives h^{-1} and 2.4 dives h^{-1} for brown and red-footed boobies, respectively, and Weimerskirch et al. (2005b) recorded 4.5 dives h^{-1} for red-footed boobies, while masked boobies made 3.7 to 8.2 dives h^{-1} (Weimerskirch et al. 2009a). Only Nazca boobies in the Galapagos had similarly low diving rates (Zavalaga et al. 2012). It is possible that Abbott's boobies are using foraging techniques other than diving which were not detectable with the methodologies used in this study; either taking prey in flight (like red-footed boobies; Weimerskirch et al. 2005b) or catching prey from the water surface. The main prey of Abbott's boobies are flying fish, which are fast moving, agile prey that are unlikely to be caught often by a booby sitting on the water, whereas prey capture in flight would certainly be possible. Also, Abbott's boobies may have generally higher prey capture rates than other boobies, reducing their requirement for more frequent diving. On the other hand, the low diving

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activity might simply reflect low prey availability in their foraging habitat. Thus, further studies using additional techniques such as accelerometers would be necessary to clarify this point.

Diving activity changed substantially over the course of the day. The majority of dives were performed in the morning and afternoon, a behaviour which has also been found in other boobies (e.g. Weimerskirch et al. 2005b). These peaks of diving activity can be associated with the feeding activity of large predatory fish, such tuna or billfish. These predators mainly feed during the morning and afternoon, and hunt flying fish and squid—which are also prey for Abbott's boobies (Weimerskirch et al. 2005b, Froese & Pauly 2013). Due to their limited diving capabilities, Abbott's boobies can only catch prey that is found close to the surface. However, the prey species of Abbott's boobies frequently occur at deep depth (Froese & Pauly 2013). As such, Abbott's boobies, like many other tropical seabirds, seem to depend strongly on sub-surface predators to drive prey up to the surface and make it accessible to the birds (Au & Pitman 1986, Anderson and Ricklefs 1987, Ballance & Pitman 1999). By foraging during periods when sub-surface predators are most likely to provide enhanced access to prey, Abbott's boobies can increase their foraging efficiency.

Until now, knowledge of the diet of Abbott's boobies has been limited to flying fish and cephalopods (Nelson 1978); prey upon which the majority of all tropical seabirds feed (Nelson 1978, Schreiber et al. 1996, Schreiber & Norton 2002). In the present study the main prey of Abbott's boobies was indeed flying fish. This prey group, comprised mainly of *Exocoetus volitans*, was dominant in the prey spectrum with respect to numbers, biomass and frequency of occurrence. Non-flying fish and flying squid played only a minor role in those 3 parameters. This prey composition matches the prey spectrum of other boobies foraging in tropical pelagic marine environments (Nelson 1978, Schreiber et al. 1996, Schreiber & Norton 2002, Weimerskirch et al. 2009a).

Variation in oceanographic conditions and flexibility in foraging behaviour

CI has neither a shelf nor a considerable sublittoral zone, but the seafloor drops off to about 2000 m close to the shore and is not exposed to pronounced upwellings, currents, or water influx of rivers or surface water (Gray 1995). Thus, the foraging habitat of chick-rearing Abbott's boobies represents a tropical oceanic marine environment of deep waters. This type of marine environment is generally low in productivity (Longhurst & Pauly 1987). Consistently, the oceanographic conditions around CI during the study years were characterised by generally high SST and low concentrations of chl *a*. However, there was variability in those parameters among years, with 2006 being the coldest and most productive year, while in 2010 SST was highest and chl *a* lowest during the 7 yr study period; this variability significantly affected the foraging behaviour of Abbott's boobies.

In studies on seabirds of higher latitudes, birds were found to buffer food shortages caused by unfavourable oceanographic conditions by adjusting parameters such as time spent at the colony (e.g. Harding et al. 2007), trip duration (e.g. Welcker et al. 2009), diving activity (e.g. Ronconi & Burger 2008), prey selection (e.g. Abraham & Sydeman 2006, Erwin & Congdon 2007), meal size and feeding rates (e.g. Peck et al. 2004). Abbott's boobies used some of those behavioural adjustments, and managed to keep their body condition, as well as that of their chicks, stable despite varying marine conditions. Foraging trips became longer in duration and further from the nest, and covered more distance and larger areas when SST increased and chl *a* decreased. In addition, when SST increased, birds spent more time on the water's surface, and maximum dive depths were deeper than under colder conditions. On the other hand, diving activity, sinuosity, flight speeds, and pauses between dives were not affected by either SST or chl *a*.

To counterbalance decreased prey availability, birds must intensify foraging effort. As such, increasing trip duration (and thus foraging time) is an often observed behaviour in seabirds in order to adjust to lower prey densities (e.g. Peck et al. 2004, Hamer et al. 2007, Welcker et al. 2009). Accordingly, trip duration of Abbott's boobies correlated positively with SST and negatively with chl *a*. However, the longer trip durations not only resulted in more time at sea, but also led to an increase in foraging range. Faced with the widely distributed and rare prey patches (as indicated by the low diving activity and long pauses between dives), Abbott's boobies increased their foraging range to cover a larger marine area in search of prey. Obviously, staying longer in the same impoverished marine area would not have resulted in increased prey capture.

Another often observed adjustment by seabirds in areas of poor prey densities is a change in time allocation. To compensate for lower prey availability, seabirds reduce their time spent at the nest and/or

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increase their time at sea, both of which results in more foraging time (e.g. Harding et al. 2007, Piatt et al. 2007, Ronconi & Burger 2008). During early chick-rearing, Abbott's booby partners do not spend extended periods together at the nest during the day (Nelson 1978, J. C. Hennicke unpubl. data), and no time is spent elsewhere on the island (this study). This suggests that there is not a lot of 'loafing' time that the birds could reduce in order to increase foraging time. Accordingly, Abbott's boobies increased their time at sea, but surprisingly, the time spent on the water's surface relative to foraging trip duration also increased. If anything, the reverse would have been expected intuitively. At the moment, we cannot offer a conclusive explanation for this finding. Birds may also simply spend less time searching if feeding opportunities (such as the presence of sub-surface predators) are rarer, which should have resulted in longer pauses between dives. Potentially, this unusual behaviour is a unique constraint in the foraging plasticity of Abbott's boobies, although further investigations on other pelagic tropical seabirds are needed to explain the finding.

While several foraging parameters were affected by the varying marine conditions, trip sinuosity, flight speeds, pauses between dives and diving activity did not change with SST and chl *a*. This suggests that birds had similar search strategies during the different oceanographic conditions and, in addition, that the spatial dispersion and temporal occurrence of the ephemeral prey patches remained similar. Under varying oceanographic conditions, the prey spectrum was similar whereas prey lengths changed. Notably, the average length of the main prey, flying fish, decreased by 12.6% (2.9 cm) with rising SST and decreasing chl *a*. Consequently, the energy gain per flying fish may have decreased under unfavourable conditions. To compensate for this potential reduction in energy gain per prey item, the boobies shifted to non-flying fish, which showed no changes in body size between varying marine conditions. Shifts in diet composition have often been observed in seabirds as a means to successfully buffer unfavourable oceanographic conditions (e.g. Erwin & Congdon 2007). However, it seems that Abbott's boobies were not able to fully buffer a reduced energetic value of smaller flying fish by consuming more non-flying fish, as the contribution to total biomass of both prey groups did not change according to marine conditions. In addition to the prey size, diving depth was affected by marine conditions. When SST increased, maximum dive depth also increased—and in 2010 (the year with the highest SST), the deepest dives were recorded. The deeper dive depths might have reduced the success rate of prey capture per dive, but certainly have increased energy expenditure per dive — both of which will have decreased the birds' diving efficiency. Thus, changes in both prey energy content and diving efficiency are likely to have affected the foraging success of Abbott's boobies under poor conditions, resulting in the observed longer and more distant foraging trips.

Conclusions

Abbott's boobies have adapted to the oligotrophic conditions of their marine environment by a suite of foraging behaviours that reduce foraging costs and enhance foraging success. However, the species exhibits only a few foraging behaviours that differ from other tropical booby species, despite their presumably more intensive exposure to tropical oceanic waters. Most remarkable are their low flight speeds, change-over patterns and frequent overnight trips — all of which seem to enhance the Abbott's boobies' gross foraging efficiency. With regard to the variability in their marine habitat, those behaviours will also contribute to the birds' remarkable ability to keep their body condition, and that of their chicks, stable even under unfavourable oceanographic conditions, at least during the early chick-rearing period. However, Abbott's boobies have one of the longest chick-rearing periods of all seabirds: up to 14 months (Nelson 1978), thus the birds may not be able to buffer low prey availability over this extended period, despite the manifold adaptations to their challenging marine habitat.

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Foraging movements of Abbott's Boobies during early chick-rearing and implications for a marine Important Bird Area in Christmas Island waters

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Abstract. Abbott's Booby *Papasula abbotti* is a relictual species now endemic to Christmas Island, Indian Ocean, and one of the world's most threatened seabird species. While actual and potential threats to the species on Christmas Island are being managed, no conservation measures concerning the marine habitat of the birds, such as the delineation of marine Important Bird Areas (IBA), are currently being implemented as knowledge on the foraging areas of Abbott's Booby has been scarce. Using GPS-loggers to track Abbott's Boobies during their foraging trips, the present study provides detailed information about the foraging movements of the species during early chick-rearing. The birds foraged relatively close to the island with a median range of 56.8 km (range = 3.6–56.7 km). They chose trip directions according to their nesting sites in the north and south of the island and foraged preferably in north-westerly and south-easterly directions of Christmas Island, respectively. Applying the protocol of BirdLife International, the tracking data were used to identify a potential IBA for Abbott's Booby during early chick-rearing. According to the small foraging distances and the limited range of trip bearings, the delimited IBA was relatively small, encompassing only a narrow corridor of about 4,500 km^2 to the north-west and south-east of Christmas Island. Given the small size and low economic relevance of this area, the delineation of this IBA appears feasible and would be an important first step to protect Abbott's Boobies at sea as well as the species' foraging habitat.

Key words. Abbott's Booby, *Papasula abbotti*, foraging movements, Important Bird Area, conservation, Christmas Island

INTRODUCTION

Abbott's Booby *Papasula abbotti* is one of the most threatened seabirds in the world. It is a relictual species now endemic to Christmas Island (hereafter CI), a small oceanic island in the tropical eastern Indian Ocean. The species once was abundant in the western Indian Ocean where it was extirpated due to harvest and habitat destruction around the 1920s (Bourne, 1976; Nelson, 1978; potentially a subspecies existed in the western Pacific, Steadman et al., 1988). Its remaining population on CI is small, about 5000–8000 individuals, and assumed to be declining but information on population trend as well as reasons for the potential decline are scarce (Garnett et al., 2011). At present, Abbott's Booby is listed as Endangered by IUCN criteria (IUCN, 2013) and under the *Environment Protection and Biodiversity Conservation (EPBC) Act* 1999.

In the past, a major impact on Abbott's Booby on CI has been the destruction of its breeding habitat by mining. The birds nest in the canopy of primary rainforest, which up until 1985 was being progressively cleared for phosphate mining (Nelson, 1978; Reville et al., 1990). In the 1980s, Christmas Island National Park was created to protect the species by prohibiting further mining within the park's boundaries. Today, the park encompasses most breeding areas, and a rainforest rehabilitation programme was initiated to reduce wind turbulence caused by previous forest clearing potentially affecting breeding birds negatively (Director of National Parks, 2002). In addition, a programme to control the Yellow Crazy Ant (*Anoplolepis gracilipes*), an invasive species thought to affect the reproductive success of Abbott's Booby (Garnett & Crowley, 2000), was commenced in 2000 (Director of National Parks, 2002).

While those conservation measures target threats on CI, no protection measurements are currently implemented or developed concerning the marine habitat of the species. However, the booby is thought to be potentially threatened in its marine habitat by disruption of its feeding ecology caused by heavy tuna fishing in the Indian Ocean over the last 50 years and by entanglement in fishing gear (Garnett et al., 2011). In addition, it has been found that Abbott's Boobies may be exposed to off island harvest (Hennicke, 2012).

Marine Important Bird Areas (hereafter IBA) have been shown successfully to be management tools that can

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contribute positively to the protection of threatened seabirds (e.g., Fishpool & Evans, 2001; BirdLife International, 2010). As such, they might also be useful conservation measures for Abbott's Booby and its foraging habitat. However, knowledge on the habitat utilisation of Abbott's Booby has been scarce and insufficient for identifying marine areas relevant to the species (DEH, 2004; Garnett et al., 2011). The only recorded foraging area of Abbott's Booby is off the southern coast of Java (Becking, 1976), but it is assumed that the birds use a much larger marine foraging area (e.g., Hirons et al., 1976; Nelson, 1978; van Balen, 1996; DEH, 2004). Thus, improved knowledge on where the birds forage is crucial to protect Abbott's Boobies at sea as well as their foraging habitat.

This study aimed to collect detailed data on foraging movements of Abbott's Boobies during early chick-rearing, a breeding stage generally considered to being crucial to the reproductive success of seabirds (Schreiber & Burger, 2002), and to use this information to identify marine areas which are important to the species during this stage and might therefore qualify as IBA.

MATERIAL AND METHODS

Study animals and field sites. The study was carried out on Christmas Island, Indian Ocean (10°25'S, 105°40'E) from 2004–2010. Every year, fieldwork took place from late August till early October, when Abbott's Boobies rear young chicks. Study nests of Abbott's Boobies were located in the canopy of the primary rainforest by systematic ground searches in two areas of CI about 5 km apart where nest densities were high: in the north-west of the island (North-West-Point, NWP; 2004–2010) and in the south-west (Eastern Circuit Track, ECT; 2005–2010). Study nests were at heights of 12–40 m and were accessed by tree-climbing: A thin line was shot into the top of the nest tree with a catapult and used to pull up a 10.5 mm static climbing rope. This rope was then used to climb the tree with jumars. From searching a nest to retrieving a logger took on average about 10 days per deployment, thus allowing only relatively small numbers of deployments during each breeding season. In addition to tree climbing, in 2004 nests alongside roads were accessed using a 45 m mobile crane fitted with a two-person cage that was carefully directed by a crane rigger towards nests.

Birds were caught on their nest by hand or using a ca. 1 m noose pole. Upon capture, birds were brought down to the ground in a bag for logger attachment/retrieval. Birds were marked with colour paint on the lower abdomen for identification from the ground.

After handling, birds were taken back up into the tree in a bag and released on their nest where they immediately resumed breeding duties. Logger attachment/removal took approx. 10–15 min; total time from catch to release was about 30 min.

All study birds had chicks between 1–8 weeks of age which were guarded by one adult at all times.

Foraging movements. In all years, birds were equipped with different types of GPS loggers to record foraging movements. Between years, logger models varied slightly. The logger mass was never higher than 5% of the adult mass, the limit for which loggers may have adverse effects on bird behaviour (Phillips et al., 2003).

GPS loggers were protected from water by an epoxy housing or by sealing them into a condom and a plastic bag. Devices were attached to tail or back feathers using Tesa Tape (Beiersdorf, Germany). In total, 54 birds (49 different individuals as some birds were equipped in several years) were equipped with GPS loggers from 2004–2010 and data on 141 foraging trips were recorded. This yielded 1313.4 h of data on foraging movements with 128,619 location fixes.

The GPS loggers recorded the positions of birds with a precision of ±5 m. The sampling interval was 10 s or 3 min for all but three individuals in 2004 and three in 2010 for which the sampling interval was 15 min.

Before, during and after logger deployment, nests were monitored regularly from the ground to check for absence and presence of study birds and their partners on the nests.

Foraging range was defined as the maximum distance of a bird from Christmas Island during a foraging trip and was calculated using spherical trigonometry (arc distance formula, Robinson et al., 1978).

The bearing of a trip was defined as the direction (angle) from the nest to the furthest location from nest. For easier visualisation, angles were categorised in groups of 45° (N, NE, E, SE, etc., see Fig. 2), while analyses were performed with actual values (angular degrees/radians).

Wind direction. Data on wind direction was obtained from the Australian Bureau of Meteorology collected at the weather station at the CI airport at 0900 hours every day. Median values for September were calculated for every study year.

Statistical analyses. Statistical analyses were performed with SPSS 11.5 (SPSS Inc., Chicago, USA), and R Studio (Version 0.94.92, RStudio, Inc) using the R version 2.13.0 (The R Foundation, R Development Core Team, 2010).

For the analysis of angular data circular statistics (R package "circular") were used (Batschelet, 1981; Zar, 2010). Bearings of foraging trips were examined on the trip level as average bearings for birds do not necessarily reflect the actual orientation of the animals' trips (cf. Zar, 2010 and Zavalaga et al., 2008).

A 95% fixed Kernel Density Estimation was used to determine the total foraging area. Kernel Density Estimations were conducted with the R package "adehabitatHR" using positional long/lat data transformed in UTM (Zone 48) and *ad hoc* h-values for kernel smoothing (Seaman & Powell, 1996; Wood et al., 2000). Trajectories of the 15 min sampling intervals were interpolated to locations every 3 min assuming

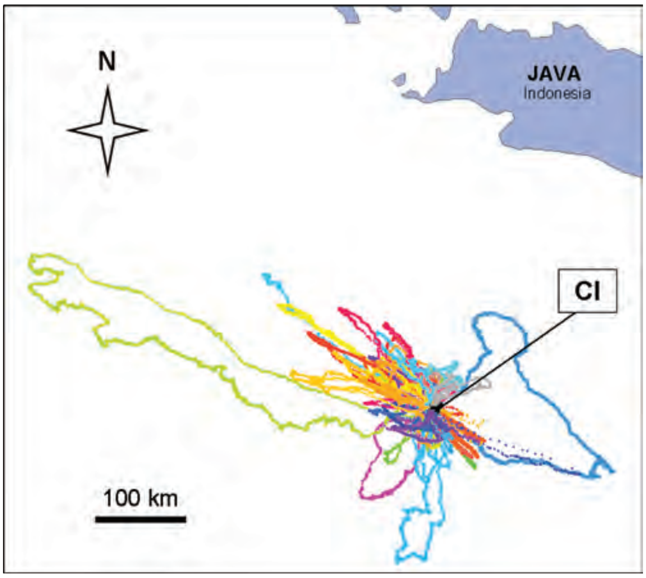

Fig. 1. Foraging movements of Abbott's Boobies during early chick-rearing recorded with GPS-loggers from 2004–2010. Each colour represents a different individual.

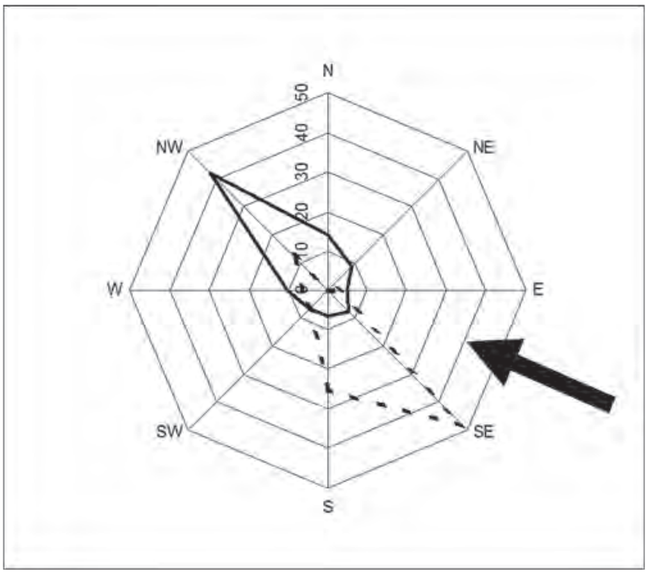

Fig. 2. Directions of foraging trips of Abbott's Boobies from the two sub-colonies (ECT = dotted line; NWP = solid line) during early chick-rearing from 2004–2010. The arrow indicates the main wind direction during the study period, numbers show relative frequencies (%).

a constant flight speed and direct flight path between fixes while every 18th location fix was taken into account from loggers with 10 s sampling intervals, i.e., all trips were divided into 3 min intervals to make them comparable.

For all statistical tests, the threshold for significance was $p < 0.05$ and all tests were 2-tailed.

Marine Important Bird Area. To identify important marine areas within the foraging habitat of Abbott's Boobies, the protocol of the marine IBA toolkit from BirdLife International was used (BirdLife International, 2010, http://www.BirdLife.org/datazone/info/marmethods). This method was specifically developed as a standardised, scientifically sound and widely applicable protocol to delimit marine IBA for seabirds.

The protocol uses First-Passage-Time analysis (Pinaud & Weimerskirch, 2005) to determine the scale at which each tracked individual is interacting with the environment (i.e., foraging, travelling). Kernel Density Estimation (see above) is then applied to each trip to determine 'core use areas' using the scale determined by First-Passage-Time analysis. Final IBA boundaries are determined by merging all overlapping 'core use areas' so that the resultant area is the largest site necessary to adequately cover the foraging movements of the individual birds triggering the area. As some individuals contributed several trips to the database, variance tests comparing the site fidelity to specific marine areas within and between individuals were used to avoid pseudo-replication, and bootstrapping was used to assure representativeness of the available data on individual birds for the population.

RESULTS

Abbott's Boobies used a large area around CI as foraging habitat (Fig. 1), covering in total 108,503 km^2 (95% Kernel Estimation of all location fixes).

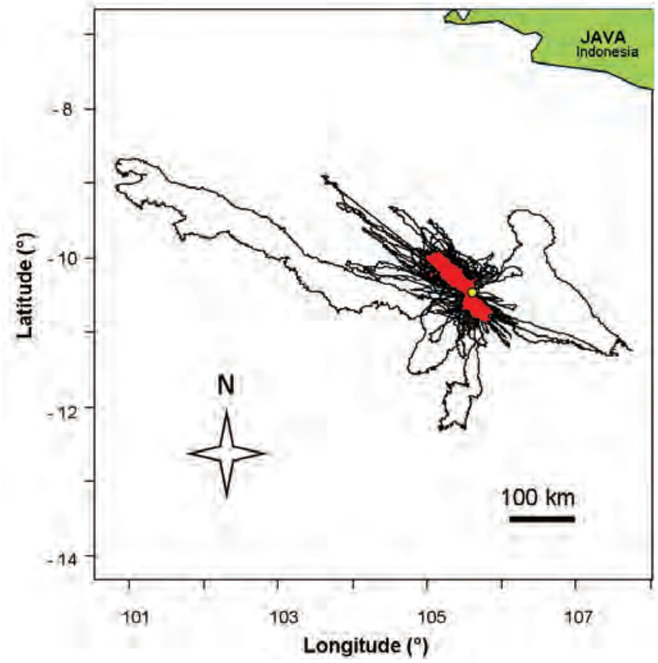

Fig. 3. Marine Important Bird Area (red) for Abbott's Boobies during early chick-rearing according to the methodology of BirdLife International. Paths of foraging trips are shown as black lines (see also Fig. 1), CI is depicted as yellow dot.

The median foraging range (= max. distances from nest) was 56.8 km, ranging from 3.6–556.7 km (n = 127).

The bearings of the foraging trips were not distributed uniformly but trips were mainly directed towards north-westerly and south-easterly directions. There were significant differences in trip bearings between NWP and ECT colonies (Watson's U^2 test, $U^2 = 1.049$, $p < 0.001$). Birds breeding in the north-west of the island (NWP) headed mainly for north-westerly directions (41.8% of trips; median bearing of all trips= 315.7°), whereas birds breeding on the south-west of the island (ECT) preferred south-easterly directions (47.9% of trips; median bearing of all trips = 158.4°) (Watson's one-sample U^2 tests against Uniform distribution, $U^2 = 1.078$, $n = 79$ and $U^2 = 1.084$, $n = 48$ respectively, $p < 0.01$ for both colonies; Fig. 2).

Over the study years, wind direction was relatively constant with a mean of 112.5° (±13.0) (Fig. 2).

The area that was identified as marine Important Bird Area was a corridor of about 30 km width and 160 km length, encompassing about 4,500 km² and being orientated in a south-east–north-west axis with CI in its middle (Fig. 3).

DISCUSSION

The present study provides detailed information about the foraging movements of the Endangered Abbott's Boobies during early chick-rearing.

Although the total foraging area of Abbott's Booby was large, covering over 100,000 km², and the furthest foraging location was over 550 km away from the island, the birds foraged on average relatively close to CI, with an average foraging range of less than 60 km. In addition, the birds did not fly to the Java Trench up-welling area or the Banda Sea where they have been observed before (Becking, 1976; Hirons et al., 1976; Nelson, 1978; van Balen, 1996). Thus, as Christmas Island has neither a shelf nor a considerable sublittoral zone but the seafloor drops off to about 2000 m close to the coastline (Gray, 1995), the Abbott's Boobies' foraging habitat during early chick-rearing represents a truly oceanic tropical environment. Those waters are generally considered to have a relatively low, unpredictable abundance but, at the same time, homogenous distribution of prey (Longhurst & Pauly, 1987). Apparently, prey availability close to CI was sufficient to find enough food to allow the adults sustaining themselves as well as their chicks and it was not necessary for them to forage in highly productive areas such as the Java Trench up-welling.

Abbott's Boobies headed out to marine areas in all directions off Christmas Island but the majority of trips was made to north-westerly and south-easterly directions. Those two directional preferences arose from birds of the two colonies heading out to different directions and having a narrow range of trip directions. Although study colonies were only about 5 km apart, animals nesting in the north foraged mainly in north-westerly directions whereas birds nesting in the south preferred to head out towards south-easterly directions. Consequently, the birds utilised different foraging areas. This spatial segregation between the colonies might reduce intra-specific competition and should therefore enhance foraging success under the oligotroph marine conditions of their marine habitat.

Potentially, the relatively narrow range of trip bearings of both colonies and their foraging zones lying in opposite directions of CI can be linked to wind. Seabirds often use wind to reduce energy expenditure during flight (Furness & Bryant, 1996; Spear & Ainley, 1997; Weimerskirch et al., 2000) and Abbott's Boobies having evolved a wing morphology for a dynamic soaring/gliding flight suggests a strong interconnection of their foraging behaviour with wind (Nelson, 1978). During the study years, winds blew constantly from south-southeast resulting from CI being usually under the influence of south-east trade winds during the study periods (Gray, 1995). As such, wind direction was relatively predictable and could have been taken into account by the boobies for foraging decisions. Being exposed to a marine environment with relatively homogenous prey distribution, foraging on the opposite side of CI would not necessarily have increased the prey availability for birds of either colony. Therefore, the choice of the trip bearing could reflect a behavioural adaptation of Abbott's Booby to reduce energy expenditure, i.e., flying to the other side of CI, under the prevailing conditions of predictable winds and unpredictable but relatively homogenous prey distribution.

According to the narrow range of trip bearings of both colonies and their opposite trip directions, the important foraging areas of Abbott's Boobies encompassed only a narrow, south-east–north-west oriented corridor of about 160 km length with CI in its middle. Given its relatively small size of only about 4,500 km²and its directional orientation, this IBA lies completely within the Exclusive Economic Zone of Australia around CI. Moreover, the marine areas around CI are not used intensively for industrial fisheries, like tuna fisheries (IOTC, 2006), and hence their economic importance is rather small. As the present study was limited to the period of early chick-rearing, further investigations are necessary to include foraging movements and habitat utilisation also during other stages of the Abbott's Booby's reproductive cycle into the considerations of delimiting IBAs, like incubation, post-fledging care and post-breeding. In addition, other seabirds breeding on CI should also be taken into account, particularly the Critically Endangered CI Frigatebird *Fregata andrewsi*. However, using the identified IBA as a spatial nucleus for the creation of a marine protected area for chick-rearing Abbott's Boobies would be a significant first step to expand the protection of this endangered species to its marine habitat.

ACKNOWLEDGEMENTS

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Document 08

Australian Government

Department of the Environment

Christmas Island Biodiversity Conservation Plan

DRAFT

March 2014

Prepared by: Director of National Parks

Made under the *Environment Protection and Biodiversity Conservation Act 1999*

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Note: This recovery plan sets out the actions necessary to stop the decline of, and support the recovery of, listed threatened species. The Australian Government is committed to acting in accordance with the plan and to implementing the plan as it applies to Commonwealth areas. The plan has been developed with the involvement and cooperation of a broad range of stakeholders, but individual stakeholders have not necessarily committed to undertaking specific actions. The attainment of objectives and the provision of funds are subject to budgetary and other constraints affecting the parties involved. Proposed actions may be subject to modification over the life of the plan due to changes in knowledge.

While reasonable efforts have been made to ensure that the contents of this publication are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

This plan should be cited as:

Director of National Parks (2014) *Christmas Island Biodiversity Conservation Plan.*
Department of the Environment, Canberra.

CHRISTMAS ISLAND BIODIVERSITY CONSERVATION PLAN

DRAFT

Invitation to comment

Before 'making' a recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the Minister must consider all comments made. Under s.275 of the EPBC Act, comments are invited on the draft Christmas Island Biodiversity Conservation Plan.

All comments submitted by the due date (below) will be carefully considered and this draft plan will be revised accordingly.

To ensure your comments are clear and concise please:

- list your points in order, numbered according to the relevant parts and page numbers of the draft plan
- state whether you agree or disagree with statements and give your reasons
- if you disagree, suggest alternatives
- include any matters you may wish to raise that are relevant to the plan but not covered by the draft plan.

Comments on the draft plan must be submitted by 9 July 2014 and may be emailed to recoveryplans@environment.gov.au or posted to:

The Director
Terrestrial Species Conservation Section
Wildlife, Heritage and Marine Division
Department of the Environment
GPO Box 787
CANBERRA ACT 2601

Acknowledgements

The Director of National Parks is grateful to the many organisations and individuals who contributed to or provided information for the preparation of this recovery plan and have been or are still involved in implementing conservation and threatened species recovery efforts on Christmas Island.

In particular the Director acknowledges authors of previous recovery plans, researchers and conservation experts, including university, Commonwealth and Western Australian Government staff, Christmas Island National Park staff, the Crazy Ant Scientific Advisory Panel as well as the contribution of its individual members, the Christmas Island community and island based individuals and organisations, and the Christmas Island Expert Working Group.

Finally, the Director acknowledges the Christmas Island based Working Group, established to contribute to and provide advice for the plan's preparation. The Working Group comprised representatives of the Shire of Christmas Island; Australian Government departments and agencies with biodiversity conservation and/or land management responsibilities on Christmas Island; Christmas Island Phosphates; and the then Administrator of the Indian Ocean Territories, who was the Chair of the Working Group.

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Executive summary

Both residents and visitors recognise Christmas Island as a very important and unique part of Australia's and the world's natural heritage.

Christmas Island is of international conservation significance and value for many reasons which include: the presence of several internationally threatened species and many endemic species (species found nowhere else in the world), including internationally significant seabird breeding areas; the presence of over 20 land crab species, most notably tens of millions of red crabs; subterranean ecosystems that contain endemic species; two wetlands of international importance, The Dales and Hosnies Spring; and the largely pristine coral reef marine ecosystems, which include internationally threatened and/or significant fauna.

Christmas Island's native species and their habitats have been subject to a range of threatening processes since settlement. These include invasive species, such as crazy ants, cats, rats and weeds; as well as direct human impacts, such as vehicle impacts on red and robber crabs and vegetation fragmentation from clearing of native vegetation, resulting in the loss habitat for many threatened species.

This biodiversity conservation plan meets the requirements of a recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* and has been developed to provide the management and research actions necessary to stop the decline of, and support the recovery of, terrestrial threatened species listed under the Act. It includes actions needed to protect their habitats, including the recovery of red crabs, which are responsible for maintaining the health of Christmas Island's forests. The recovery of Christmas Island's native species and their habitats will rely on the use of the latest information from research and scientific studies, as well as a coordinated approach and cooperation between stakeholders, both on and off-the island.

This plan has been prepared based on the latest available information from research, scientific and natural heritage studies, and under the advice of a Working Group comprising:

- Shire of Christmas Island
- Department of Regional Australia, Local Government, Arts and Sport (now the Department of Infrastructure and Regional Development)
- Department of Immigration and Citizenship (now the Department of Immigration and Border Protection)
- Christmas Island Phosphates
- DAFF Biosecurity (now the Department of Agriculture)
- The Director of National Parks
- The Administrator of the Indian Ocean Territories, who was the Chair of the Working Group.

The long-term vision for the natural environment of Christmas Island is*: Resilient ecosystems with self-sustaining populations of native species*. Achieving this vision will conserve Christmas Island's native species and their habitats and may also provide socio-economic benefits for the Christmas Island community by maintaining populations of iconic species, such as red crabs and seabirds like the Abbott's booby, which are major attractions for nature-based tourism, as well as helping to support environmental educational and research activities.

The plan's objectives, which will help achieve the long-term vision, are to:

1. Maintain the ecological integrity of forest ecosystems.
2. Maintain or increase populations of significant species.
3. Maintain the ecological character of Ramsar wetlands.
4. Contribute to maintaining groundwater ecosystems.
5. Increase community and stakeholder understanding of, and engagement in, the recovery of ecosystems and native species.
6. Effectively coordinate and implement actions to address threatening processes and recover ecosystems and native species.

The actions in this plan have been designed to protect and ensure as far as possible the recovery and continued survival of Christmas Island's threatened and iconic species and their habitats, avoiding the species declines of the past. The plan will be implemented in an adaptive manner to ensure that actions for recovering and reversing the decline of the island's native species and their habitats are based on the most up-to-date information, from management, monitoring and research programs.

Executive summary in Bahasa Malay

Ringkasan eksekutif

Pulau Krismas diakui oleh penduduk mahupun pelawat sebagai warisan semula jadi yang sangat penting dan unik bagi Australia dan dunia.

Pulau Krismas memiliki nilai pemuliharaan yang tinggi di mata antarabangsa, antara lain kerana: wujudnya sebilangan spesies yang terancam di peringkat antarabangsa dan banyak spesies yang endemik (tidak ditemui di mana-mana tempat lain di dunia), termasuk kawasan pembiakan burung-burung laut yang besar; wujudnya lebih 20 spesies kertah (ketam darat), terutama ketam merah yang berpuluh juta bilangannya; ekosistem bawah tanah yang mengandungi pelbagai spesies endemik; dua taman tanah lembap yang penting di mata antarabangsa, iaitu The Dales dan Hosnies Spring; serta ekosistem terumbu karang laut yang sebahagian besarnya masih belum diceroboh, merangkumi spesies fauna terancam dan/atau penting di mata antarabangsa.

Spesies asli Pulau Krismas dan habitatnya telah diancam oleh berbagai-bagai proses sejak pulau ini didiami manusia. Ancaman ini termasuk pelbagai spesies penceroboh, seperti semut kuning, kucing, tikus dan rumpai; juga kesan langsung kegiatan manusia, seperti kesan kenderaan pada ketam merah dan ketam kelapa, serta fragmentasi tumbuh-tumbuhan akibat penebangan tumbuh-tumbuhan asli, menyebabkan hilangnya habitat untuk banyak spesies terancam.

Rancangan pemuliharaan kepelbagaian hayat ini memenuhi syarat-syarat rancangan pemulihan di bawah *Akta Perlindungan Alam Sekitar dan Pemuliharaan Kepelbagaian Hayat 1999*. Rancangan ini dibangunkan bagi mewujudkan tindakan pengurusan dan penyelidikan yang perlu demi menghalang kemerosotan pelbagai spesies darat terancam yang disenaraikan dalam Akta, serta menyokong pemulihannya. Rancangan ini merangkumi tindakan yang perlu bagi melindungi habitat spesies tersebut, termasuk pemulihan ketam merah yang berperanan menjaga kesihatan hutan Pulau Krismas. Pemulihan pelbagai spesies asli Pulau Krismas dan habitatnya akan menggunakan maklumat terkini daripada kajian penyelidikan dan sains, serta pendekatan dan kerjasama terselaras antara pelbagai pihak berkepentingan, baik di pulau ini mahu pun bukan.

Rancangan ini disiapkan berdasarkan maklumat terbaru daripada kajian penyelidikan, sains dan warisan alami, serta dengan nasihat sebuah Kumpulan Kerja yang terdiri daripada:

- Daerah Pulau Krismas (Shire of Christmas Island)
- Jabatan Australia Rantauan, Kerajaan Tempatan, Seni dan Sukan (kini Jabatan Infrastruktur dan Pembangunan Serantau)
- Jabatan Imigresen dan Kewarganegaraan (kini Jabatan Imigresen dan Perlindungan Sempadan)
- Christmas Island Phosphates
- DAFF Biosecurity (kini Jabatan Pertanian)
- Pengarah Taman Negara
- Pentadbir Wilayah Lautan Hindi, yang pernah menjadi Pengerusi Kumpulan Kerja.

Visi jangka panjang bagi persekitaran semula jadi Pulau Krismas adalah: *Ekosistem yang berdaya tahan, mengandungi pelbagai spesies asli yang lestari populasinya*. Pencapaian visi ini akan memulihara pelbagai spesies asli Pulau Krismas dan habitatnya, dan mungkin juga membawa manfaat sosioekonomi untuk masyarakat Pulau Krismas, dengan memelihara populasi spesies ikonik seperti ketam merah dan burung-burung laut seperti burung booby Abbott, yang merupakan daya tarikan utama pelancongan alam semula jadi, selain menyokong aktiviti pendidikan alam sekitar dan penyelidikan.

Objektif rancangan ini, yang akan membantu mencapai visi jangka panjang tersebut, adalah:

1. Memelihara keutuhan ekologi ekosistem hutan.
2. Memelihara atau meningkatkan populasi pelbagai spesies utama.
3. Memelihara sifat ekologi taman tanah lembap Ramsar.
4. Membantu memelihara ekosistem air tanah.
5. Meningkatkan kefahaman masyarakat dan pihak berkepentingan, serta penglibatan mereka, dalam pemulihan ekosistem dan spesies asli.
6. Menyelaraskan dan melaksanakan tindakan secara berkesan bagi mengendalikan ancaman proses serta memulihkan ekosistem dan spesies asli.

Tindakan-tindakan dalam rancangan ini direka untuk seberapa dapat melindungi dan memastikan pemulihan dan kelangsungan hidup pelbagai spesies terancam dan ikonik Pulau Krismas serta habitatnya, demi mengelakkan kemerosotan spesies yang pernah terjadi. Rancangan ini akan disesuaikan pelaksanaannya, agar tindakan bagi memulihkan dan membetulkan kemerosotan spesies asli pulau ini dan habitatnya dilakukan mengikut maklumat paling terkini, daripada pelbagai program pengurusan, pemantauan dan penyelidikan.

Executive summary in Mandarin

执行摘要

居民和访客都认为圣诞岛是澳大利亚以及世界自然遗产中非常重要和独一无二的一部分。

圣诞岛具有国际保护意义和价值的原因很多，包括：一些国际濒危物种的存在以及许多地方性物种（在世界其他地方找不到的物种），包括国际重大

海鸟繁殖区域， 超过20个存在的陆地蟹种类， 尤其重要的是数以千万计的红蟹； 包含有地方物种的地下生态系统；具有国际重要性的两个湿地，The Dales 和 Hosnies Spring；以及大量的原始珊瑚礁海洋生态系统，包括国际濒危以及/或者重要动物群。

圣诞岛的本土物种以及他们的栖息地自移居开始就已经遭受一系列的濒危过程。 这些包括入侵物种，像疯狂的蚂蚁，猫， 老鼠， 以及杂草，还有直接的人类影响， 例如机动车对红蟹和椰子蟹的影响，以及清除本地植被产生的植被破坏，导致

很多濒危物种失去栖息地。

根据环境保护和生物多样性保护法案1999, 这个生物多样性保护计划符合恢复计划的要求，而且进一步发展，从而

提供管理和研究措施, 使列在法案内的濒危物种不再减少并支持恢复这些物种。这包括必要的行动来保护他们的家园，包括恢复红蟹数量，使圣诞岛的森林健康状态得到保持。本土物种以及他们的栖息地的恢复将会依赖于来自调查和科学研究的最新信息的使用，以及岛内外的协调措施和利益相关者间的合作。

这一计划的制备源自调查，以及科学和自然遗产研究得出的最新信息

同时还接受了以下成员组成的合作团队的指导：

- 圣诞岛行政区
- 澳大利亚区域署， 本地政府， 艺术和体育（现为基础设施和区域发展部）
- 移民及公民事务部（现为移民及边境保护部）
- 圣诞岛磷酸盐
- DAFF 检疫安全 （现为农业部）
- 国家公园主管
- 印度洋地区行政管理员，也是合作团队主席 。

圣诞岛自然环境的远期目标为：具备一个可自身维持本地物种数量的高适应性生态系统。达到这一目标需要保护圣诞岛本地物种及其栖息地，同时通过维持标志性

物种的数量，例如红蟹和Abbott’s booby海鸟这些主要自然旅游景观，来给圣诞岛带来社会经济收益；同时也帮助扶持环境教育和研究活动。

为了有助于实现远期目标，这个计划的宗旨为：

1. 保持森林生态系统的生态完整性。

2. 维持或者增加重要物种的数量。

3. 维持Ramsar湿地的生态特征。

4. 致力于保持地下水的生态系统。

5. 增加社区及利益相关者对生态系统及本地物种恢复的理解和参与。

6. 有效协调及采取措施来解决濒危进程及恢复生态系统和本地物种。

这一计划的实行是为了尽可能保护并确保圣诞岛濒危和标志性物种及其栖息地的恢复和生存的持续，避免过去物种的恶化。这一计划的实行采用合适的手法。通过管理、监控和研究项目来确保以最新信息为依据采取行动，从而恢复和逆转岛上本地生物数量及其栖息地的削减。

Part 1—Introduction

1.1 Vision

The long-term vision for the natural environment of Christmas Island is:
Resilient ecosystems with self-sustaining populations of native species

This biodiversity conservation plan, which is a recovery plan for the purposes of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), sets out a range of objectives and actions which will contribute to the achievement of this long-term vision for 17 threatened taxa listed under the Act in a more holistic manner.

1.2 Why conserve Christmas Island native species and their habitats

As identified in the Christmas Island 2018 Plan *"The natural environment of Christmas Island is one of our greatest assets. We recognise its uniqueness in a global arena and the need to protect its biodiversity"* (Change Sustainable Solutions 2011), Christmas Island's native species and their habitats are of international conservation significance and value for many reasons. Christmas Island:

- supports 17 taxa which are listed as threatened under the EPBC Act
- is an internationally significant seabird island, providing habitat for thousands of seabirds including the endemic and threatened Abbott's booby (*Papasula abbotti*) and Christmas Island frigatebird (*Fregata andrewsi*)
- supports over 20 land crab species, including tens of millions of red crabs (*Gecarcoidea natalis*), which shape and maintain the health of the island's unique rainforests and are internationally renowned for their annual breeding migration
- provides habitat for a range of endemic species including the Christmas Island goshawk (*Accipiter hiogaster natalis*), Christmas Island hawk-owl (*Ninox natalis*), Lister's gecko (*Lepidodactylus listeri*), at least 18 plant taxa and many subterranean/cave dwelling invertebrates
- has two wetlands, The Dales and Hosnies Spring, which are Wetlands of International Importance under the Ramsar Convention
- has largely pristine marine environments which support coral reefs and threatened whale sharks (*Rhincodon typus*) and green turtles (*Chelonia mydas*).

Despite the island's conservation values, there have been declines or extinctions of some of Christmas Island's endemic and other significant native species. This plan recognises the need to conserve and/or recover threatened, endemic and other significant species and their habitats in a more holistic way.

Part 3 of this plan describes Christmas Island's natural features and values in more detail.

Christmas Island's native species and their habitats are not only significant from a conservation perspective, but can also provide social and economic benefits for the Christmas Island and other Australian communities, and help define the island's unique character. Christmas Island's native species and their habitats provide:

- natural attractions, such as seabirds, land crabs and marine life, for bird watchers, scuba divers and other nature-focused tourists, which can help support Christmas Island's tourism enterprises, especially if/as tourism expands in future years

- important ecosystem services and products that are used by and benefit the Christmas Island community and visitors, such as water filtration and the protection of fish habitat
- opportunities for unique research and educational activities, particularly the study of oceanic island ecology and biogeography, threatened and endemic species, invasive species dynamics and red crab ecology. For example, in recent years there have been several international school visits focused on the study of the island's ecology and native species. These activities are not only valuable in their own right for their educational value but can also help support the island's economy
- nature-based recreational opportunities for Christmas Island's community, such as rainforest walks and observing wildlife which contribute to the health and well-being of the community.

1.3 Purpose and scope of the plan

The primary purpose of the Christmas Island Biodiversity Conservation Plan is to provide the research and management actions necessary to stop the decline of, and support the recovery of, threatened species on Christmas Island so that the chances of their long-term survival in nature are maximised. A major focus of this plan is to address threatening processes, particularly invasive species, affecting threatened species listed under the EPBC Act as well as other species, notably red crabs, which are pivotal to the ecological integrity of the island's ecosystems. Actions in this plan are also intended to benefit the broader Christmas Island ecosystem.

This plan is a formal national recovery plan for all species on Christmas Island which are nationally listed as critically endangered, endangered or vulnerable under the EPBC Act (Table 1) and inhabit the island's terrestrial environments. Some of these species, such as seabirds and land crabs, also utilise marine or wetland habitats. This plan replaces a number of formerly adopted recovery plans for individual species endemic to Christmas Island (Appendix J) but does not replace existing threat abatement plans.

Due to the relatively high proportion of endemic and/or threatened species, as well as the intrinsic vulnerability of oceanic island species and their habitats (particularly to invasive species), the scope of this plan covers:

- native terrestrial species listed as threatened under the EPBC Act (Table 1)
- species which have an important role in the ecological integrity of the island's ecosystem
- species of conservation concern (those which have a substantial decline on Christmas Island)
- all endemic vertebrate species
- species which have a high level of international and community conservation interest
- ecosystems and habitats critical for the survival of significant species (see Part 3.2 of this plan) including maintenance of critical ecological processes.

The scope recognises the need to recover populations of existing threatened species as well as reduce the likelihood of native species that are currently not threatened becoming so in the future. Consequently, the plan provides an integrated and holistic approach to the conservation and recovery of the island's threatened native species, which is reflected in the plan's objectives and management and research actions (Part 6 of this plan).

The scope is mandated to focus on listed threatened species only but as a regional biodiversity conservation plan it aims at more broad-ranging conservation, including other matters of National Environmental Significance and biodiversity conservation in general.

Table 1: Terrestrial plants and animals of Christmas Island listed as threatened

Species Name	Common Name	EPBC Act Status[1, 2]
VASCULAR PLANTS		
Asplenium listeri	Christmas Island spleenwort[3]	CE
Pneumatopteris truncata	a fern	CE
Tectaria devexa var. *minor*[4]	a fern[3]	EN
MAMMALS		
Crocidura trichura	Christmas Island shrew[3]	EN
Pipistrellus murrayi	Christmas Island pipistrelle[3]	CE
Pteropus melanotus natalis	Christmas Island flying-fox	CE
Rattus macleari[5]	Maclear's rat	EX
Rattus nativitatis[5]	bulldog rat	EX
FOREST BIRDS		
Accipiter hiogaster natalis[6]	Christmas Island goshawk[3]	EN
Chalcophaps indica natalis	emerald dove (Christmas Island)	EN
Ninox natalis	Christmas Island hawk-owl[3]	VU
Turdus poliocephalus erythropleurus	Christmas Island thrush	EN
SEABIRDS		
Fregata andrewsi	Christmas Island frigatebird[3]	VU
Papasula abbotti	Abbott's booby[3]	EN
REPTILES		
Cryptoblepharus egeriae	blue-tailed skink	CE
Cyrtodactylus sadleiri	giant gecko	EN
Emoia nativitatis	forest skink	CE
Lepidodactylus listeri	Lister's gecko[3]	CE
Ramphotyphlops exocoeti[7]	Christmas Island blind snake[3]	VU

(1) EX—Extinct; CE—Critically Endangered; EN—Endangered; VU—Vulnerable
(2) EPBC Act status of species at the time of preparing the plan
(3) Recovery plan covering this species has previously been adopted (nine plans for 10 species)
(4) Species is listed, but only *Tectaria devexa* var. *minor* occurs on Christmas Island
(5) Not covered by this plan due to EPBC Act status as extinct
(6) At the time of listing this subspecies was known as *Accipiter fasciatus natalis*
(7) At the time of listing this species was known as *Typhlops exocoeti*

The EPBC Act provisions relating to the referral, assessment and approval of actions are not affected by this plan. Similarly, the EPBC Act exemptions are not affected by this plan. This plan does not (see Part 1.5 of this plan for details):

- affect the operation of activities undertaken consistent with an approval under the EPBC Act
- affect the operation of exemptions under the EPBC Act, including activities undertaken consistent with a 'prior authorisation' or that constitute a 'continuing use' or
- change the environmental referral and assessment requirements of the EPBC Act in relation to development proposals.

This plan is not a recovery plan for Christmas Island's territorial marine ecosystems and species, but it recognises their conservation significance, particularly in relation to interactions between terrestrial and marine ecosystems and species. Consequently, the focus of the marine component of this plan is on actions for species that rely on both terrestrial and marine ecosystems for their survival (e.g. red crabs and other land crabs, seabirds and anchialine systems).

1.4 Interaction with other documents and other management programs

Existing terrestrial recovery plans

This plan will replace eight of the existing recovery plans[1] for 10 terrestrial species on Christmas Island which have been previously adopted under the EPBC Act (see Table 1). However, these plans may continue to be used as reference documents to inform the implementation of this plan.

A number of key threatening processes listed under the EPBC Act occur on Christmas Island, some of which are covered by threat abatement plans made under the Act (Table 2—see Part 4.1 of this plan for further details of threats). This plan does not replace the relevant threat abatement plans but, where appropriate, includes relevant actions from and complements these plans.

Table 2: Relevant national threat abatement plans

Threat abatement plan to reduce the impacts of tramp ants on biodiversity in Australia and its territories (DEH 2006)
Threat abatement plan for predation by feral cats (DEWHA 2008)
Threat abatement plan to reduce the impacts of exotic rodents on biodiversity on Australian offshore islands of less than 100 000 hectares (DEWHA 2009)

Christmas Island National Park Management Plan and related environmental plans and reports

This plan is consistent with and will support implementation of the *Christmas Island National Park Management Plan* (DNP 2014). Similarly, the management plan will support the implementation of this plan in relation to actions that apply to the Christmas Island National Park. This plan may also inform the preparation and implementation of other land and marine management plans on Christmas Island.

In 2009 the then Australian Government Minister for the Environment formed a scientific Expert Working Group (EWG), primarily in response to the decline of the Christmas Island pipistrelle, to provide the Minister with advice about biodiversity decline on Christmas Island. In its final report in 2010, the EWG found that the extremely high biodiversity values of Christmas Island are in a parlous state and made 32 broad-ranging recommendations aimed at reversing the decline of the island's biodiversity. The majority of those recommendations were accepted by the Australian Government in its 2011 response to the report, either without qualification or in principle subject to the availability of additional resources.

1 The exception is the existing *Tectaria devexa* recovery plan, which includes actions for the Queensland distribution of *Tectaria devexa* var. *devexa*.

This plan is a mechanism to give effect to relevant recommendations made by the EWG, recognising that some of those recommendations are outside its scope. Appendix A sets out the EWG's recommendations and the Australian Government's response to each, together with an indication as to how those recommendations are reflected in the recovery actions in this plan.

In 2010 Ecological Character Descriptions (ECDs) were prepared for The Dales (Butcher & Hale 2010) and Hosnies Spring (Hale & Butcher 2010) Ramsar sites. The ECDs describe, and aim to assist with monitoring and maintaining, the ecological character of The Dales and Hosnies Spring; this biodiversity conservation plan includes actions to support these aims.

Marine recovery and threat abatement plans

As noted in Part 1.3, marine ecosystems and species priorities and actions are not specifically addressed by this plan except for terrestrial species that rely on both terrestrial and marine ecosystems for their survival. Table 3 lists the recovery plans and threat abatement plans which may be specifically relevant to marine areas of Christmas Island. While these plans have not been incorporated into this plan, relevant actions have been considered.

Table 3: National recovery plans and threat abatement plans relevant to marine areas

Recovery plan for marine turtles in Australia (EA 2003)
*Whale shark (*Rhincodon typus*) recovery plan 2005–2010* (DEH 2005)
Threat abatement plan 2006 for the incidental catch (or bycatch) of seabirds during oceanic longline fishing operations (DEWR 2006)
Threat abatement plan for the impacts of marine debris on vertebrate marine life (DEWHA 2009a)

Through the process of preparing this plan several marine conservation priorities were identified, which may help inform the management of the island's marine areas, particularly the coral reef ecosystems that fringe the island. However, these priorities should not be seen as a definitive list of marine conservation priorities for Christmas Island.

(a) researching and monitoring marine ecosystem and species diversity and richness

- collecting further/baseline data on coral reef species diversity and richness, including species of conservation significance, like hybrid fauna and ecological indicator species
- identifying and mapping marine ecosystems and habitats
- monitoring coral reef condition and changes, including reef structure; species diversity and richness; ecological indicator species and species under threat/at risk of local extinction and whale sharks migratory patterns
- genetic studies of fish, particularly deep and mid water fish, to help determine migration movements

(b) identifying and monitoring threats to and impacts on marine ecosystems and species

- assessing threats to marine environments and species
- monitoring threats to and impacts on marine environments including coral disease, coral bleaching, climate change, marine pests and threats of terrestrial origin, such as pollution including effluent, chemicals, fuels/oils and phosphate runoff

(c) minimising threats to and impacts on marine environments, marine species and the marine habitat of species that rely on marine ecosystems such as seabirds and land crabs

- introduction and adoption of sustainable fish bag/take limits
- establishment of oil spill response capability
- minimising the likelihood of introducing marine pests including through the rapid disposal of asylum seeker boats and effective management of ship ballast water
- minimising pollution of marine environments from boats/ships and terrestrial sources such as effluent outflow and oil/fuel spillages
- minimising impacts of marine debris on marine species such as nesting sea turtles
- control of loss of plastic from land to the marine environment to protect sea life

(d) education and awareness raising activities

- conducting educational and awareness raising activities that help promote the island's marine conservation values and ways of minimising impacts on marine environments and species (e.g. sustainable fish bag/take limits and minimal impact visitor use guidelines).

Crown land management plan

Territories Administration is responsible for the administration of Crown Land on Christmas Island. In 2009 Territories Administration commissioned the preparation of a *Report for Crown Land Management Plan for the Indian Ocean Territories—Christmas Island* (CLMP). Its purpose was to assess Crown Land to enable informed decisions to be made on its most suitable future uses. Crown Land comprises Uncommitted Crown land; leased Crown land, including mining and commercial land; vested land; reserved land; and Crown land under management orders. The assessment included identifying the conservation, economic, cultural and social values of Crown Land, as well as appropriate potential future land uses, development priorities and management options.

The CLMP recognised the importance of the island's environmental assets, including the threatened Abbott's booby and Ramsar listed wetlands (The Dales and Hosnies Spring). As this biodiversity conservation plan describes these and other conservation assets (particularly threatened species, their habitats and major threats affecting them), it may help proponents and decision-makers in the planning and assessment of developments and approvals, including those that may trigger the environmental assessment provisions of the EPBC Act (see Part 1.5 of this plan) or other relevant applied Western Australian legislation. This biodiversity conservation plan may also support or complement some of the priorities and opportunities outlined in the CLMP, such as evaluating the island's groundwater resources and expanding the island's research and educational facilities and opportunities.

Local planning and community directions

The Christmas Island Local Planning Strategy (LPS) is prepared by the Shire of Christmas Island. The LPS sets out the long-term planning directions for the local government, applies State and regional planning policies and provides the rationale for the zones and other provisions of the Town Planning Scheme (TPS). The Shire administers the TPS which is the statutory mechanism under Western Australian planning legislation for managing shire-related land uses on the Island. The TPS governs the way land may be used and developed through land use zoning and defines what developments are acceptable (from a town planning perspective) within these designated zones. It is not within the scope or the purpose of this biodiversity conservation plan to prescribe or define the types of actions and land uses that may or may not be considered, assessed or approved under the TPS and LPS or other plans, such as the CLMP and economic development plans. However, assessments of specific development proposals submitted to the Shire for consideration under the TPS and LPS may also need to be assessed under the environmental assessment requirements of the EPBC Act, as well as any applicable applied Western Australian legislation.

In 2011 the Shire of Christmas Island prepared the *Our Future: Christmas Island 2018 Plan* (Change Sustainable Solutions 2011). The 2018 Plan articulates shared community directions and priorities for the future of Christmas Island across a broad range of themes: land use planning; infrastructure planning; economic diversification; community capacity and well-being; governance and institutional capacity; and protecting the natural environment. This biodiversity conservation plan will help support community directions and priorities identified in the 2018 Plan, particularly in relation to protecting the natural environment. For instance the 2018 Plan states that '*it is our duty as a concerned community to ensure that these beautiful attributes of Christmas Island remain intact or are indeed improved, now and into the future*' (Change Sustainable Solutions 2011). The 2018 Plan includes reference to this biodiversity conservation plan, the need for collaborative cat and rat management, and the development of sustainable nature-based tourism, which will rely on healthy populations of native species for activities such as birdwatching and observing the red crab migration.

Other island stakeholders have environmental management plans in place to address particular issues, such as that of Christmas Island Phosphates to reduce impacts on red crabs from mining operations (also see Part 5.1 of this plan).

1.5 Legislative context

Legislation relevant to this biodiversity conservation plan includes the following:

Environment Protection and Biodiversity Conservation Act 1999 and Environment Protection and Biodiversity Conservation Regulations

The Commonwealth EPBC Act is the primary environmental legislation that applies to Christmas Island. The relevant matters regulated by the EPBC Act and EPBC Regulations include:

- listing of nationally threatened species and ecological communities, migratory species, and marine species
- preparation of conservation advice and/or recovery plans for threatened species and communities, and additional protection for listed species in Commonwealth areas
- compliance with recovery plans by Commonwealth agencies
- implementation of recovery plans within Commonwealth areas
- listing of key threatening processes and preparation of threat abatement plans
- protection and management of Commonwealth reserves, declared Ramsar wetlands, and National and Commonwealth Heritage places
- assessment and approval of actions likely to have a significant impact on matters of national environmental significance. For Christmas Island these are:
  - listed threatened species (see Table 1)
  - migratory species protected under international agreements (see Appendix B)
  - Ramsar wetlands of international importance (Hosnies Spring and The Dales)
  - Commonwealth marine areas
- assessment and approval of actions that are likely to have a significant impact on the environment, on Commonwealth land (all of Christmas Island) or by Commonwealth agencies
- international movement of wildlife and wildlife products
- conservation of biodiversity in Commonwealth areas, including regulation of actions affecting members of native species on crown land.

Christmas Island National Park is a Commonwealth reserve established under the EPBC Act and covers approximately 63 per cent of Christmas Island's land area. The park includes a marine area (extending 50 metres seaward of the low water mark of the park's terrestrial areas) and both the island's declared Ramsar wetlands.

Part 9 of the EPBC Regulations provides for the protection and conservation of biodiversity in Commonwealth areas outside the park (i.e. all land outside the park) and prohibits and/or regulates actions affecting members of the species identified in Schedule 12 to the Regulations, and their habitat.

This biodiversity conservation plan does not change the environmental referral and assessment provisions of the EPBC Act—these provisions apply regardless of this plan—and the biodiversity conservation plan does not affect the operation of activities undertaken consistent with existing approvals under the EPBC Act. Under the EPBC Act any person proposing to undertake an action which is likely have a significant impact on a matter of national environmental significance (listed above) or which is likely to have a significant impact on the environment on Commonwealth land (Christmas Island), should refer the action to the Minister for the Environment. The Minister will determine whether a referred action requires assessment and approval under the EPBC Act. Further guidance in deciding whether to submit a referral (for a decision on whether assessment and approval is required) is available in *Significant Impact Guidelines—Matters of National Environmental Significance* (DEWHA 2009b) and *Significant Impact Guidelines—Actions on, or impacting upon, Commonwealth land, and actions by Commonwealth agencies* (DEWHA 2010).

This biodiversity conservation plan does not affect the operation of exemptions under the EPBC Act. Sections 43A and 43B of the EPBC Act exempt certain actions from the assessment and approval provisions of the EPBC Act. They apply to lawful continuations of land use that started before 16 July 2000 or actions that were legally authorised before 16 July 2000, the date of commencement of the EPBC Act. These exemptions allow for the continuation of activities that were fully approved by state and local governments before the EPBC Act came into force ('prior authorisation'), or otherwise lawful activities which commenced before the EPBC Act came into force, and which have continued without substantial interruption ('continuing uses'). Further details on these provisions can be found in the Practice Guide titled *Prior authorisation and continuing use exemptions—Sections 43A and 43B* (DEWHA 2009c).

WA environment protection legislation

In addition to any relevant EPBC Act and EPBC Regulation requirements, vegetation clearance on Christmas Island is also regulated by the Western Australia (WA) *Environmental Protection Act 1986.* The clearing provisions of this Act are described in the *Environmental Protection Amendment Act 2003* and the *Environmental Protection (Clearing of Native Vegetation) Regulations 2004.*

Other relevant WA legislation and Christmas Island subordinate legislation

At the commencement of this plan a range of other WA laws are applied to Christmas Island under the *Christmas Island Act 1958* as laws of the Territory, and administered by the WA government under arrangements with Territories Administration. The applied laws relevant to this plan include:

- *Agriculture and Related Resources Protection Act 1976*
- *Animal Welfare Act 2002*
- *Approvals and Related Reforms (No.4) (Planning) Act 2009*
- *Cat Act (Christmas Island) 2011*
- *Dog Act 1976*
- *Fish Resources Management Act 1995*

- *Mining Act 1978*
- *Plan Diseases Act 1914*
- *Road Traffic Act 1974*
- *Soil and Land Conservation Act 1945.*

In addition to legislation referred to elsewhere in this plan other Commonwealth Acts, and Territories Ordinances made under the Christmas Island Act are relevant either directly or indirectly to this plan, including:

- *Administrative Ordinance 1968*
- *Cats Local Law 2010*
- *Fisheries Management Act 1991*
- *Importation of Dogs and Cats Ordinance 1973*
- *Lands Ordinance 1987.*

Quarantine legislation

The Department of Agriculture administers a range of legislation in order to protect Australia's animal, plant and human health status and to maintain market access for Australian food and other agricultural exports. In 2004 quarantine legislation—the *Quarantine (Christmas Island) Proclamation 2004*—was introduced for Christmas Island under the *Quarantine Act 1908.*

1.6 Planning approach

The approach of using a regional recovery plan or multi-species plan, rather than maintaining single species recovery plans, is consistent with that adopted for other regions including Norfolk Island and Lord Howe Island. During the planning process a number of key elements were identified as essential for the preparation and implementation of this plan.

Coordinated ecosystem and holistic approaches

Addressing many threats, particularly invasive species, that impact on individual and multiple native species may require some actions, particularly the control of invasive species like cats, crazy ants and weeds, to occur in a coordinated manner over different land tenures in order to achieve intended recovery outcomes. This allows more efficient use of conservation resources, and complementary and consistent approaches between responsible parties.

Use the best available evidence and adaptive management approaches

This plan has been prepared using the best available information and advice from local knowledge; research and monitoring studies/papers/reports; relevant plans; and recommendations from a range of researchers and other natural resource management experts. Much of this information was collated in a *Regional Recovery Plan Issues Paper—Conservation status and threats to the flora and fauna of the Christmas Island Region* (DNP 2008c) which was prepared to assist with the preparation of this plan.

Other expert opinion and scientific information used includes the final report of the Expert Working Group (2010); advice from the Crazy Ant Scientific Advisory Panel and other scientific experts; existing recovery plans and information from conservation focused research, studies; and monitoring programs carried out by the DNP, such as the Island Wide Survey and Biodiversity Monitoring Program (DNP 2008b).

Despite the considerable scientific information regarding the island's natural heritage and native (and invasive) species, there are many recovery knowledge gaps such as the key threats leading to the decline of some species. The plan acknowledges this by including research and ongoing monitoring actions so that management responses can be adapted as new information and evidence arises, ensuring the capacity to adapt and respond to uncertainty and change.

Engagement of land managers/holders and other relevant stakeholders

The approach used in developing this plan recognised the need to engage major island-based stakeholders and land holders/managers before and during the preparation of this plan, and accordingly, a Christmas Island Recovery Plan Working Group (the working group) was formed. The working group comprised island-based representatives of the then Department of Regional Australia, Local Government, Arts and Sport (now the Department of Infrastructure and Regional Development and referred to in this plan as Territories Administration); the Shire of Christmas Island (SOCI); the then Department of Immigration and Citizenship (now the Department of Immigration and Border Protection—DIBP)); Christmas Island Phosphates (CIP); DAFF Biosecurity (now the Department of Agriculture); the Director of National Parks (DNP); and the Administrator of the Indian Ocean Territories, who chaired the Working Group.

The Working Group's terms of reference were to:

- advise on the recovery planning process, particularly communication and engagement strategies for the Christmas Island community and stakeholders
- provide advice and input into the content of the recovery plan, including what priorities should be addressed in the plan and providing comments on drafts
- where possible, work together to integrate and coordinate land management planning processes on Christmas Island, including conducting community and stakeholder consultation
- promote information sharing between the working group and Christmas Island community/stakeholders including working group members' own organisations
- make recommendations for the implementation of the recovery plan, such as future stakeholder engagement and identifying funding and partnership opportunities.

It is acknowledged that a diverse group of participants in such a team will not always share a common view on all matters. However, the Working Group provided a forum for members to raise issues on a range of matters associated with the preparation of this plan.

Other activities were also conducted to engage on and off-island stakeholders. These included community and stakeholder meetings and presentations that included CIP; Territories Administration; the Department of Agriculture; Customs; SOCI; the Christmas Island Economic Development Consultative Group (EDCG); Christmas Island Tourism Association (CITA); and community meetings. In addition, flyers and other information about the recovery plan were prepared and distributed in the local paper (*The Islander*) and by email. Letters, advising of the intent to prepare and opportunity to provide input into the recovery plan, were also sent to several off-island conservation groups and management agencies.

Part 2—Description of Christmas Island

2.1 Socio-economic aspects of Christmas Island

Christmas Island is located in the Indian Ocean, approximately 2800 kilometres west of Darwin, 2600 kilometres north-west of Perth and 500 kilometres south of the Indonesian capital Jakarta. It covers an area of 135 square kilometres, with 73 kilometres of coastline (Figure 1).

The people of Christmas Island

Prior to its settlement in 1888 there were no permanent inhabitants of Christmas Island and there are no peoples considered indigenous to the island. Most Christmas Island residents were born in mainland Australia or Malaysia and are of Chinese, Australian/European and Malaysian origin. English is widely spoken but many residents are bi- or multi-lingual, speaking Malay, Mandarin, Cantonese or other languages. Religious diversity is evident through Chinese temples (Buddhist, Taoist, Confucian), a Christian church, a Muslim Mosque and a Baha'i Centre; many religious and cultural festivals are observed during the year.

In 2011 the resident population of Christmas Island was recorded as 2072 people. The population may have exceeded 4000 people at various times over the past few years due to fluctuating numbers of asylum seekers in detention and staff employed in detention management activities.

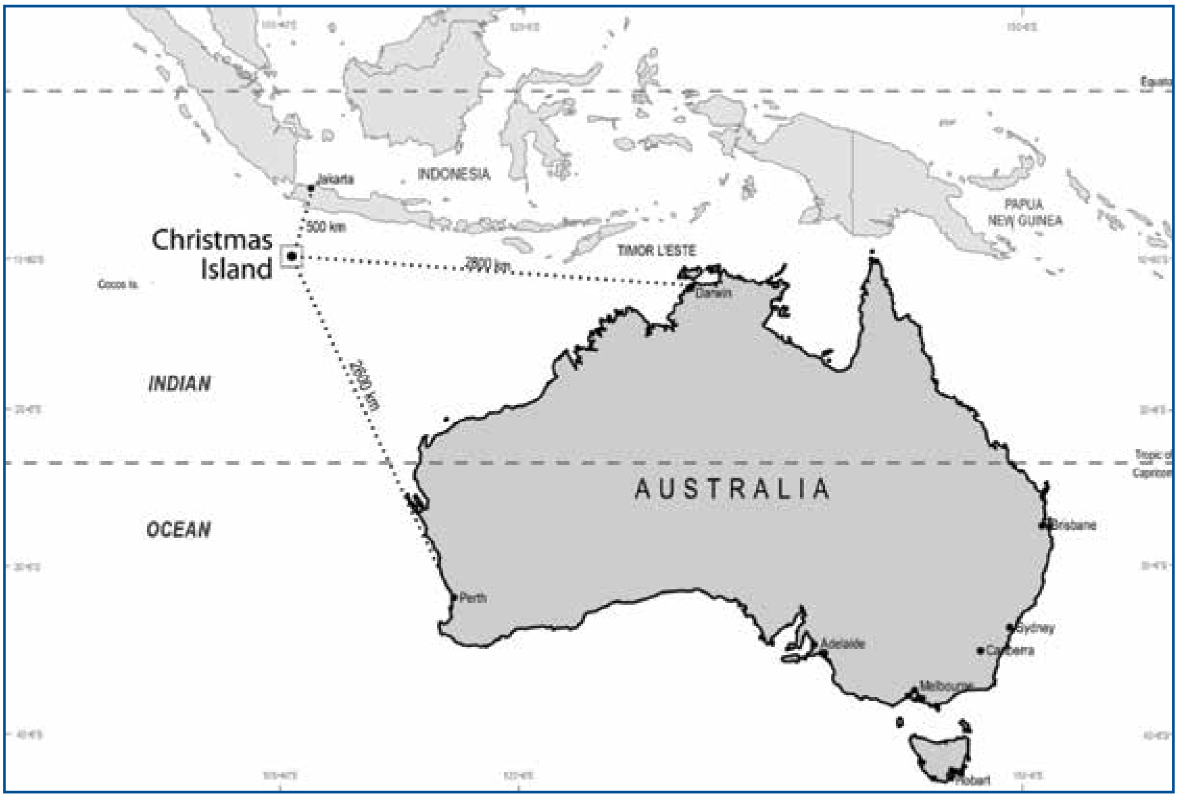

Figure 1: Location of Christmas Island

History and governance

Settlement of Christmas Island commenced when the island was annexed by the British Crown in 1888 and George Clunies-Ross from Cocos (Keeling) Islands established a settlement at Flying Fish Cove in November 1888. In 1891 Clunies-Ross and John Murray (a Scottish scientist) negotiated a joint lease to export timber, phosphate and other minerals and in 1897 formed the Christmas Island Phosphate Company. Soon after C.W. Andrews of the British Museum was commissioned by Murray to undertake a ten-month study of the island's natural history. Such a study, conducted prior to the commencement of phosphate mining, provided a rare opportunity to assess the flora, fauna and geology of the island and establish a scientific baseline. Andrews did a comprehensive study when he returned in 1908, providing the opportunity to assess the impact of ten years of settlement; his monograph remains the classic scientific reference on the island's natural history.

Phosphate mining commenced in 1898 and in 1900 the first phosphate shipments were made. Mining continued up until World War II, ceased during the war and resumed in 1946; it has continued since except for 1988 to 1989. After the war, the lease and assets of the Christmas Island Phosphate Company were sold to the Australian and New Zealand governments. In 1949 the Christmas Island Phosphate Commission was formed by the governments. More mine workers were employed from Malaysia, Singapore and the Cocos (Keeling) Islands, and established strong religious and cultural practices that continue today. Mining was increasingly mechanised, but working conditions remained poor. This led to the formation in 1975 of the Union of Christmas Island Workers, which successfully campaigned for improved working conditions.

On 1 January 1958, Christmas Island, which had until then been administered as part of the Colony of Singapore, became a separate colony of Great Britain. On 1 October 1958, sovereignty was transferred to Australia and has since remained an external territory of Australia.

In 1967 the British Phosphate Commission sponsored Dr J.B. Nelson, an ornithologist, to study the status of Abbott's booby. The report he produced triggered world-wide interest in the conservation of the species (Gray 1995).

In 1980 Mr W.W. Sweetland was commissioned to investigate the future of phosphate mining. From 1981 to 1987 mining was conducted by the government owned Phosphate Mining Company of Christmas Island and Phosphate Mining Corporation of Christmas Island. In 1987 the Australian government ceased mining and began winding up the corporation. Mining resumed in 1990 when a mining lease was issued to a private company, Phosphate Resources Limited, trading as Christmas Island Phosphates (CIP). In 1997 Phosphate Resources Limited was granted a 21-year lease which restricts mining to previously mined areas. In June 2013 Phosphate Resources Limited was granted a renewed mine lease which expires in 2034.

Administration

Christmas Island is administered as an external territory of the Commonwealth of Australia. The location of major land tenures and uses are shown in Figure 2. The *Christmas Island Act 1958* provides the basis for the Territory's administrative and legislative systems including, from 1992, the application of a range of laws of Western Australia.

The Territories Administration administers Christmas Island, including the provision of state government-type services and manages associated infrastructure including essential services like power and water supply infrastructure and facilities, as well as Uncommitted Crown Land. Some areas of Uncommitted Crown Land, such as previously uncleared evergreen tall rainforest, provide habitat for threatened species like the Abbott's booby. In recent years there have been upgrades/expansions of some essential services including sewage, power and water infrastructure. Future infrastructure developments are also planned, including new housing developments. The Territories Administration provides some services through service delivery arrangements with WA government departments. For instance, the management of water supply is the responsibility of the WA Water Corporation, under an arrangement with Territories Administration.

SOCI has a central role in implementing and administering the Town Planning Scheme (TPS) and managing public roadsides and recreational areas. SOCI is also responsible for a range of social and municipal services, including waste collection and domestic animal control such as administration of local (pet) cat by-laws. Lands managed by SOCI are used for a range of purposes including residential, light industrial, commercial and recreational purposes. SOCI has proposed, through the TPS, the expansion, upgrade or development of these areas. The TPS identifies areas of land considered suitable (from a town planning perspective) for residential, commercial and light industrial uses and developments, including tourism developments.

Land tenure

Current land tenures and their areas and major uses are outlined in Table 4. Major land managers, owners and/or lease holders are the Director of National Parks; Territories Administration; the Shire of Christmas Island; Christmas Island Phosphates and the Department of Immigration and Citizenship. There are also small private (e.g. commercial and residential) land holdings.

Table 4: Land tenure and uses on Christmas Island

Land tenure and uses	Percent of island
National park	63%
Mine lease	13.7%
Uncommitted Crown Land	19.2%
Other committed land	4.1%

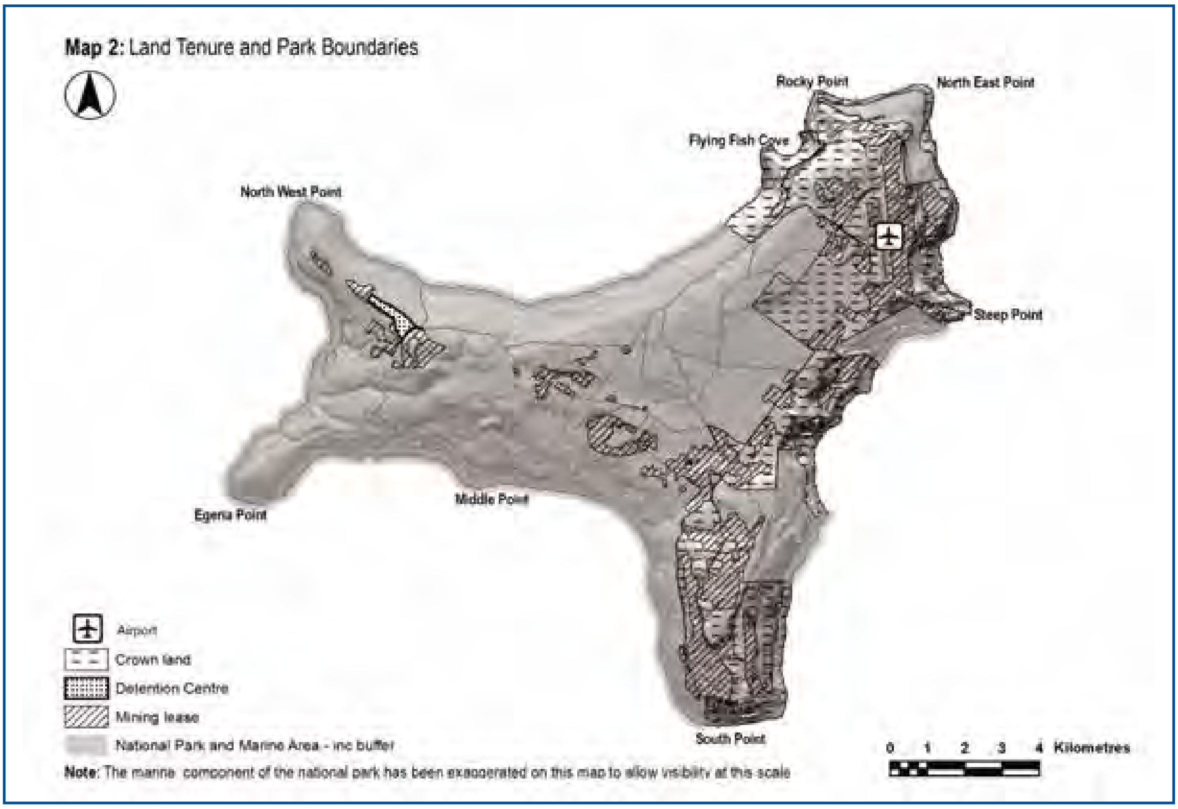

Figure 2: Land tenure and park boundaries

Land use and management

Christmas Island National Park (CINP or the park) is a Commonwealth reserve managed by the Director of National Parks (DNP) in accordance with the EPBC Act and the park's management plan. The park covers approximately 63 per cent of the island's land area and includes a small but ecologically significant marine area. The park is managed primarily for: the preservation of the area in its natural condition and the encouragement and regulation of the appropriate use, appreciation and enjoyment of the area by the public. Visitor facilities in the park include board walks and walking trails that lead to natural features and attractions such as The Dales Ramsar wetland site. There is also a small research facility (the Pink House) located in the centre of the island and a headquarters and nursery facility located on Crown Land in the north-east (residential/settled) part of the island.

DIBP manages several facilities on Christmas Island. The major DIBP facility is the Immigration Detention Centre (IDC) at the north-western end of the island. This was built in 2007, with expansion and upgrading to include supporting infrastructure such as staff accommodation since 2007. At the time of preparing this plan, other DIBP facilities included the Phosphate Hill Detention Centre and staff accommodation at Poon Saan.

Christmas Island Phosphates (CIP) has phosphate mining leases covering approximately 1982 hectares (14 per cent) of Christmas Island, as well as associated infrastructure, including phosphate drying and port loading facilities located at the north-east of the island. CIP's mining leases were assessed and approved under the *Environment Protection (Impact of Proposals) Act 1974* (EPIP Act) and are valid to 2019. The EPIP Act approval only enables mining to occur on specific areas of land (mostly in the eastern part of the island) where the original native vegetation has been previously cleared. Under the previous and renewed mine lease with the Territories Administration, CIP pays a conservation levy (per tonne of phosphate shipped) to the Commonwealth. This levy funds the Christmas Island Minesite to Forest Rehabilitation (CIMFR) Program, conducted by the DNP on behalf of the Commonwealth through a Memorandum of Understanding between the DNP and Territories Administration. A new MoU was negotiated and a long term rehabilitation plan was prepared by the DNP in 2012, covering the period 2012 to 2020.

There is also number of other existing developments including a resort and a number of other visitor accommodation facilities, as well as new development proposals. A small market garden grows produce for local consumption and in 2010 a study was prepared for CIP to assess the feasibility of establishing a sustainable horticultural industry in the Indian Ocean Territories. There are also small areas of private land for residential and commercial purposes and a public golf course. The island has an international airport as well as significant seaport facilities and an extension to the existing wharf facilities at Flying Fish Cove was proposed at the time of preparing this plan.

Uncommitted Crown Land covers approximately 19 per cent of Christmas Island and may be considered suitable for a number of future land uses including recreation, conservation and new developments/commercial activities.

Economy and industry

Phosphate mining is the major industry on the island. Phosphate Resources Limited—trading as Christmas Island Phosphates (CIP)—reported a 2012–13 after tax profit of $20.9 million for mine operations (PRL 2013) and in 2011 employed over 100 Christmas Island residents. At the time of preparing this plan the industry is a major source of employment and is one of the critical foundations for the island economy.

Many island residents are employed directly or indirectly to deliver government services which include the administration of the Territory (e.g. providing services like police, power, water, health, schools and local government services) as well as national park management and asylum seeker processing and care activities.

The island's natural attractions help support a small number of on- and off-island tourism businesses including diving/boating, land-based tours and wildlife/bird watching tours. There are a few nature-focused tour operators who are based on or visit Christmas Island (e.g. dive and land based tour operators) and the current contribution of tourism to the island's economy and employment is relatively modest. However, the *Inquiry into the changing economic environment of the Indian Ocean Territories* (Parliament of the Commonwealth of Australia 2010) identified tourism as a viable growth industry that has the potential to be further developed and spur the growth of complementary industries to assist in diversifying the economy (also see Part 7.5 of this plan).

2.2 Climate and geography of Christmas Island

Climate

Christmas Island lies at the southern edge of the equatorial low pressure belt that moves north and south of the equator during the year, resulting in a tropical, equatorial, oceanic climate with distinct wet and dry seasons. The wet season is generally from November to April when the north-west monsoon blows. Passing cyclones and high ocean swells arising from low pressures systems from the north sometimes affect the island during the wet season. For the rest of the year south-east trade winds bring slightly lower temperatures and humidity and less rain.

Mean annual rainfall is approximately 2000 millimetres with little temperature variation during the year (daytime mean temperature of 27–29°C and overnight mean temperature of 24°C). Relative humidity is generally constant at 80–90 per cent.

Landscape, geology and soils

Christmas Island is formed on the peak of a basaltic volcanic seamount which rises steeply for about 5000 metres from the ocean floor. The highest point on the island, Murray Hill, is 361 metres above sea level. The island has undergone a series of geological uplifts and successive layering of coral reefs over the basaltic volcanic core at each stage of uplifting, leading to the development of a near-continuous limestone cap. Successive uplifting events led to the excavation of new cliffs by the ocean, forming stepped terraces and inland cliffs. The lowest, most recent terrace was probably formed about 120 000 years ago. The island is surrounded by a narrow fringing coral reef shelf.

Most of the coastline consists of sheer rocky and often undercut cliffs 10 to 20 metres high, interspersed with a few sand and coral rubble beaches. Behind the coastal cliffs is the shore terrace which varies between about 50 and 200 metres wide, while inland cliffs and terraces are found between the shore terrace and the central plateau. The central plateau has an elevation mostly between 180 and 240 metres.

There is little to no runoff across the island as most rainfall infiltrates into the limestone and soil substrate and recharges groundwater drainage systems and/or flows to the ocean. There are only a few surface drainage systems, most notably The Dales and Hosnies Spring, where groundwater accumulates at the base of the interface between the limestone cap and volcanic basaltic core of the island.

A major geological feature of Christmas Island is its limestone karst landforms and subterranean cave ecosystems. For example, there are at least 95 known karst features including approximately 30 caves (Spate & Webb 1998). The island's carbonate karst setting has important implications for many aspects of management of the island's natural resources including ecology, hydrology, waste management and water resources. Karst management has been well-studied internationally (e.g. Gillieson 1996; Ford & Williams 2007) which can inform appropriate management regimes for the island.

The majority of Christmas Island's soils are classified as phosphatic. These were most likely derived from marine sediments (both organic and inorganic) before the island rose above the sea surface, and from seabird guano reacting with limestone (Trueman 1965, Gray 1995). These soils are deepest on the central plateau, becoming progressively thinner towards the lower terraces. Remaining substrates are mostly derived from weathered parent materials including limestone (terra rossa soils) or volcanic basalt (krasnozem soils). Soils derived from basaltic extrusive rocks occur in fault zones or areas of past volcanic activity. The soils are usually neutral to slightly alkaline (pH 7.0–8.0).

Part 3—Ecology and biodiversity of Christmas Island

Christmas Island is known as an oceanic island because it has always been isolated from and never connected to other land masses. This gives it some ecological characteristics that are similar to other oceanic islands, as well as several distinct and unique ecological characteristics including:

- its importance as a seabird rookery of international importance and endemic bird area of international significance
- the dominance of land crabs, particularly red crabs, which significantly influence the ecology of the island's forests.

Ecological characteristics of Christmas Island that are similar to many other oceanic islands include:

- a relatively high proportion of endemic terrestrial species
- evolutionary isolation for thousands or millions of years
- native species that have evolved with few competitors
- many species with small population sizes.

Like other oceanic islands, these characteristics make Christmas Island particularly vulnerable to threats such as those posed by introduced invasive species.

3.1 Ecosystems and ecological processes

For the purposes of this plan the major ecosystems/habitats identified and described are forest ecosystems, wetland ecosystems, subterranean and groundwater ecosystems, and marine and coastal ecosystems.

3.1.1 Forest ecosystems

Christmas Island's forest ecosystems have developed their present structure and composition largely due to the influences of warm temperatures, rainfall levels and patterns, geological history, geographic isolation and fauna interactions, particularly those of the red crab. These influences have created unique forest ecosystems that provide essential habitat for many of the island's flora and fauna species.

Christmas Island's vegetation has been described in *Flora of Australia* Vol 50 (Commonwealth of Australia 1993) and by several subsequent authors (most recently Claussen in 2005) all identifying four primary vegetation types (see Table 5 and Figure 3):

- evergreen tall closed forest ('primary rainforest') which occurs in areas with deep soils on the plateau but is also found on deep soil terraces
- semi-deciduous closed forest ('marginal rainforest') which is found on shallower soils and is common on terraces and slopes leading from the plateau to the coast and on shallow soil plateau areas
- deciduous scrub which is restricted to areas with very little soil on terraces, steep slopes and inland cliffs
- coastal fringe shrubland and herbland which is the least common vegetation type and occurs between the scrub and the coastal cliffs in more exposed areas.

Beyond this broad classification there is limited knowledge of the types of vegetation and location across the island.

The rainforests of Christmas Island are biogeographically significant; species have evolved from being either shoreline forest or early rainforest succession species to those that fill a tall climax rainforest role. The presence of seventeen endemic plant species in the climax rainforest community contributes to the place's significance for understanding evolutionary relationships. Notable examples include a rare fern *Asplenium listeri*, a tall tree-like pandanus *Pandanus elatus* and a palm *Arenga listeri*.

The ecological integrity of forest ecosystems is vital to their value for threatened species. Ecological integrity is *"the ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region. An ecological system has integrity, or a species population is viable, when its dominant ecological characteristics (e.g. elements of composition, structure, function, and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions"* (Parrish et al. 2003).

The ecological integrity of the island's forests is dependent on the red crab, the most numerous and widespread crab on Christmas Island. Red crabs are omnivorous and opportunistic, feeding on green and dead leaves, fruits, seeds, seedlings, carrion and some animals. Through the differential predation of fruit, seeds and seedlings they influence the species composition of plants in Christmas Island forest and may provide biotic resistance to invasive weeds. The crabs have a significant role recycling nutrients by burying and consuming leaf litter on the forest floor. This influences growth rates of plants and the composition of invertebrate assemblages. The crabs also prey on and control the invasive giant African land snail (*Achatina fulica*). It is likely that their burrowing influences rainwater permeation and dehydration of forest soils, although this has not been studied. The habitat and survival of a range of other species, many endemic, are, or are likely to be, linked to the ecology of the red crab. The removal or decline of red crabs has a dramatic effect on the forest ecology of Christmas Island (Green et al. 1998) and results in many adverse and cascading ecological effects.

Also considered a key component of the island's rainforest ecosystem is the Christmas Island flying-fox (*Pteropus melanotus natalis*) which is a primary seed disperser and pollinator for a variety of rain-forest trees and other plants (Tidemann 1985). The floral characteristics of some forest trees indicate that they are principally pollinated by this species (DNP 2008b). Christmas Island white-eyes (*Zosterops natalis*) are abundant and have brush-tipped tongues, which are important for plant pollination of diurnal flowers. White-eyes also disperse the seeds of very small-fruited plants and could have a large influence on the population levels of some insects. Christmas Island imperial pigeons (*Ducula whartoni*) are abundant and swallow fruits whole, so will also disperse many seeds. Changes in the abundance and behaviours of the white-eye and imperial pigeon may also disrupt key ecosystem processes such as seed dispersal (Davis et al. 2009). Other animals, including insects and forest birds such as the Christmas Island thrush (*Turdus poliocephalus erythropleurus*) and emerald dove (*Chalcophaps indica natalis*), may also pollinate and disperse some plant species.

Other species may also have forest pollination, seed dispersal, nutrient cycling or other important ecosystem functions. Examples include seabirds cycling nutrients from their droppings, invertebrates which may be the prey of some species or have other important ecosystem functions. Such interactions are poorly or not understood for Christmas Island.

Since settlement of Christmas Island, approximately 25 per cent of the island's original landscape and vegetation has been cleared for mining and settlement, resulting in fragmentation of the island's native forest ecosystems. Some previously cleared or disturbed areas can support low second-growth forest of native colonising trees such as *Macaranga tanarius*, *Claoxylon indicum* and introduced exotic plants such as *Leucaena leucocephala*. Nonetheless mined sites tend to have little soil remaining and are generally comprised of dense fern (*Nephrolepis multiflora*) herblands, as well as introduced scramblers and occasional low trees. Some previously mined sites have been rehabilitated with native and non-native flora species.

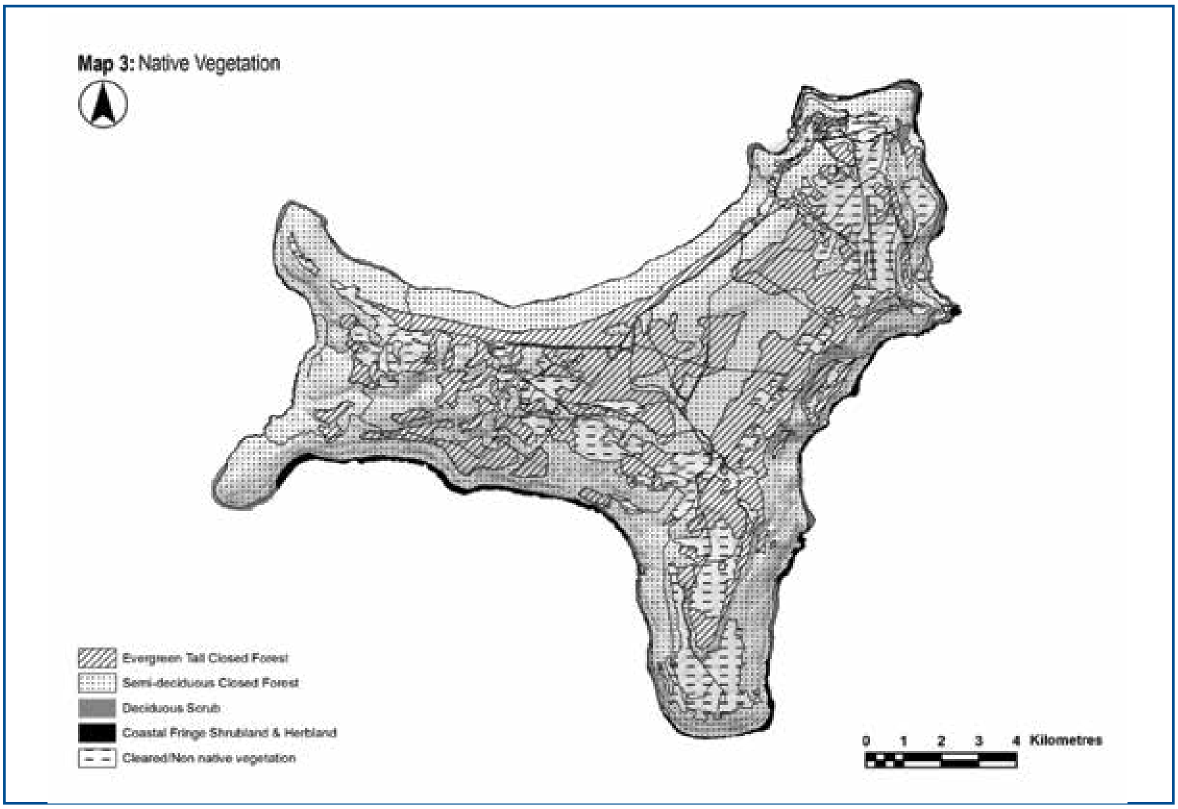

Figure 3: Native vegetation

Table 5: Description and distribution of rainforest vegetation

Vegetation Type	Vegetation Structure	Description and Key Species	Distribution
Evergreen tall closed forest ('primary rainforest')	Complex mesophyll vine forest with tall emergents	Dense to open, 25–35 metres in height with scattered emergents (principally *Hernandia ovigera, Planchonella nitida, Syzygium nervosum*) to 50 metres. Many layers comprising specialist sub-canopy and mid-stratum species (e.g. *Barringtonia racemosa, Cryptocarya nitens, Pisonia umbellifera*) mixed with medium-sized individuals of canopy species. Stem diameters irregular and range up to 130cm dbh. Host tree crowns do not extend more than one-third down the stem. Plank buttressing well developed; epiphytic ferns, orchids and climbers prominent.	Best developed in sheltered valleys and drainage depressions on the plateau; a lower stature form is present on steeper slopes sheltered from the prevailing south-easterly trade winds.
	Complex mesophyll vine forest	Similar to above but with emergent layer not as prominent (less than 8 metres between maximum height of canopy and maximum height of emergent trees).	Widespread on gentle slopes and plains of the plateau, often interspersed with mesophyll vine forest where outcropping limestone or limestone ridges are present.
	Mesophyll vine forest	Canopy height varies between 20 and 30 metres and uneven but emergents rarely present. Compared to complex mesophyll vine forest, plank buttressing and epiphytes less common and stem diameters of canopy trees more regular; *Hernandia ovigera* not present. A specialised class of this structural type occurs as low-diversity forests associated with freshwater seepages.	Occurs on thinner soils and more exposed areas on the plateau and in more sheltered areas on terraces. *Inocarpus* forest at The Dales and mangrove forest at Hosnies Spring are sites for the freshwater seepage class.
	Mesophyll vine forest with *Ficus*	Canopy of lower stature (18–24 metres) than mesophyll vine forest, with *Ficus microcarpa* often dominant.	Generally occurs on undifferentiated limestone outcrops surrounded by complex mesophyll vine forest on the plateau. Also present on limestone scree and rubble slopes in sheltered situations.
Semi-deciduous closed forest ('marginal rainforest)'	Semi-deciduous mesophyll vine forest	Canopy even but varying in height from 14 to 25 metres depending on site conditions. Emergent trees to 32 metres common, often widely spaced but sometimes clumped; principally deciduous species (e.g. *Terminalia catappa, Celtis timorensis, Gyrocarpus americanus*). Both deciduous and evergreen species in the canopy and mid-stratum layers but increasing dominance of deciduous species on thinning soils and more exposed sites.	Common on terraces. A variant with *Ficus macrocarpa* intergrades with mesophyll vine forest with on more exposed scree slopes.
Deciduous scrub	Deciduous vine thicket	Uneven canopy, 6–8 metres in height, varying from dense to open. Occasional emergents to 10 metres. Most emergents and canopy species deciduous and branch from base or mid-stem height. Annual or perennial herbs common in ground layers. Dense pandanus thickets also present in some areas.	Common on inland cliffs and exposed karst areas and on exposed terrace areas on skeletal soils.
Herbland	Sclerophyllous shrublands and heathlands	Low stature sclerophyllous vegetation often interspersed with pandanus thickets.	Confined to shoreline and coastal cliffs where wind and exposure to salt spray affect vegetation stature.

Source: Adapted from Reddell & Zimmermann (2003) and Claussen (2005)

3.1.2 Wetland ecosystems

Christmas Island's landscape has a lack of surface runoff, but there are perennial streams at Dolly Beach, the Ravine, Ross Hill Gardens, Jones Spring, Waterfall, Freshwater Spring, The Dales and Hosnies Spring. The Dales and Hosnies Spring (Figure 4) are listed under the Ramsar Convention as Wetlands of International Importance and are declared Ramsar wetlands under the EPBC Act. The conservation values of other streams and springs are not well described but they support species such as red, blue (*Discoplax celeste*) and robber crabs (*Birgus latro*).

Consistent with the requirements under the Ramsar Convention (Appendix B), Ecological Character Descriptions are available for The Dales (Butcher & Hale 2010) and Hosnies Spring (Hale & Butcher 2010). These describe each wetland, its critical components and ecosystem services, threats to the ecological character of the wetland and limits of acceptable change.

Hosnies Spring is an area of permanent shallow freshwater wetland fed by a natural spring system located approximately 30 metres above sea level and 120 metres inland from the seaward cliff. The wetland is covered by a stand of mangroves including *Bruguiera gymnorhiza* and *B. sexangula* estimated to be 120 000 years old. The margins of the wetland are well defined by limestone cliffs to the north and west and a sharp transition to a hibiscus and pandanus community to the south. The area that surrounds the wetland site is predominantly rainforest characterised by 20 to 30 metre canopy of evergreen and deciduous trees such as *Pisonia grandis* and *Barringtonia racemosa* with a conspicuous lack of herb and shrub layers. There is a narrow band of coastal scrub of hardy species such as *Scaevola taccada* at the seaward margin of the shore terrace with an unvegetated area of limestone pinnacles on top of the sea cliffs. The cliff descends some 17 metres almost vertically to the rocky marine shore below. The site extends 50 metres seaward of the low water mark and includes areas of shallow, coral reef.

Hosnies Spring is remarkable for a number of reasons:

- it is one of the few permanent freshwater areas on Christmas Island
- the mangroves occur at an elevation not recorded elsewhere in the world
- the age of the mangrove stand is extraordinary
- the size of the individual trees is very large.

The site also supports a large numbers of crabs, in particular red, robber and blue crabs. Of note is the presence of endemic bird species including the Christmas Island imperial pigeon, emerald dove, goshawk, hawk-owl, thrush and white-eye. In addition, the Christmas Island flying-fox is found at this site.

The Dales Ramsar site is a series of seven dales (or valleys), three of which support permanent springs and four with intermittent streams. The Dales are surrounded predominantly by semi-deciduous forest. On the seaward side at the edge of the shore terrace is a line of coastal shrubland which merges with sea cliffs and rocky marine shores. The site extends seaward 50 metres and includes part of a narrow shallow and sloping reef. Mixed amongst the terrestrial and marine environments are a range of karst features, highly representative of the Christmas Island environment. The combination of this variety of habitats and the presence of permanent surface water provides the physical habitat to support several endemic, threatened and wetland dependent species.

The Dales site plays host to the annual red crab migration and provides critical habitat for blue crabs as well other land crabs. A diverse community of tree species and epiphytes also occurs here. At Hugh's Dale, and in parts of Anderson Dale and Sydney's Dale, there are mono-specific stands of Tahitian chestnut (*Inocarpus fagifer*) and the rare epiphytic ribbon fern (*Ophioglossum pendulum*). The endemic arenga palm (*Arenga listeri*) and endemic Ridley's orchid (*Brachypeza archytas*)—not to be confused with *Zeuxine exilis*, the rare Ridley's ground orchid—are common in The Dales. *Terminalia catappa* grows to an unusual size on Christmas Island and several large specimens occur in The Dales. A number of endemic fauna species occur within The Dales including Abbott's booby and Christmas Island hawk-owl, thrush and goshawk. The native fish, the brown gudgeon (*Eleotris fusca*), has also been sighted within The Dales.

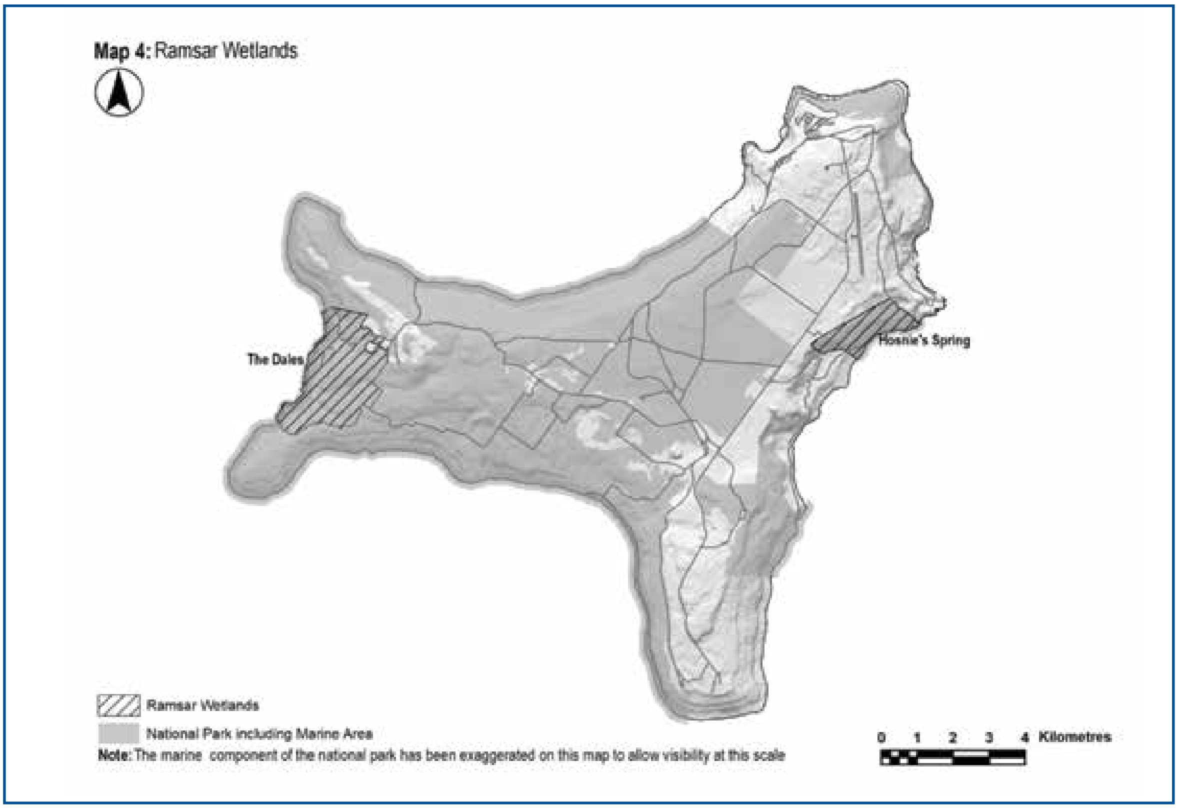

Figure 4: Ramsar wetlands

3.1.3 Subterranean and groundwater ecosystems

The limited availability of permanent, above-ground freshwater sources restricts the abundance and type of freshwater aquatic vertebrates on Christmas Island. On the other hand, Christmas Island's subterranean ecosystems are diverse and include terrestrial, aquatic/freshwater, marine and anchialine habitats (Humphreys & Eberhard 1998).

The subterranean fauna of Christmas Island consists of a range of cave-dwelling species, including one of only two known blind scorpions in Australia (EWG 2010), stygofauna and anchialine fauna. Some aquatic taxa are endemic while others, such as the shrimp *Macrobrachium lar*, are closely related to populations in the Pacific. Christmas Island has one of only two anchialine systems known in the southern hemisphere (Humphreys & Eberhard 2001). Christmas Island is also the only known global location where representatives from both types of anchialine fauna communities, the procaridid type—which is restricted to isolated seamounts—and the remiped type, co-occur (EWG 2010). The island's numerous caves also provide habitat for the Christmas Island swiftlet (*Collocalia linchi natalis*).

Christmas Island's subterranean fauna remains relatively poorly known and surveyed and little is known or understood about ground water flow rates or quality and the flow requirements of native species. Undoubtedly, many additional taxa remain undiscovered (Humphreys & Eberhard 2001). The high degree of endemism and the ancient lineages of several species highlight the global conservation significance of Christmas Island's subterranean fauna (EWG 2010). No formal conservation status or listing has been assigned to any cave species of Christmas Island. However, Schedule 12 of the EPBC Regulations protects obligate cave-dwelling species.

Most of the water that enters Christmas Island's aquifers reaches the sea as submarine groundwater, while some of it discharges to the sea as surface water flow. Many ecosystems and species on Christmas Island, including its

Ramsar wetlands and cave/subterranean ecosystems, depend on continued submarine or surface groundwater flows. For example, the island's stygofauna is dependent on groundwater, while the anchialine systems depend on the balance between freshwater outflow and marine inflow (EWG 2010). As well as maintaining anchialine systems, freshwater discharge is likely to locally influence the marine biota on the periphery of the anchialine system through salinity and nutrient effects, and may thus support novel biota (EWG 2010).

3.1.4 Marine and coastal ecosystems

Christmas Island's territorial waters extend 12 nautical miles from the island's shoreline but the description below largely focuses on the coastal waters and fringing reef systems immediately surrounding Christmas Island. Brewer et al. (2009) provides a detailed description of the deep oceanic waters of the Christmas Island–Central Ridge subregion that surrounds Christmas Island. This plan only covers marine areas to the extent of the interaction between marine and terrestrial habitats for some species.

Christmas Island's largely intact fringing reefs and adjacent deep waters support a number of marine and coastal ecosystems and species typical of the Indian Ocean region. Although species diversity is lower than in some other places in the Indian Ocean region, there are fewer threats and pressures (e.g. pollution, fishing pressures and habitat degradation/loss) than for many other coral reef systems in the region.

Christmas Island's marine and coastal ecosystems include:

- shore rock platforms—occurring at many locations around the island but more extensively on the western coastline between North West Point and Egeria Point. There are also tidal rock pools which are maintained by wave splash and tidal surge
- beaches—formed of sand and coral and shell rubble, often with limestone outcrops. Dolly Beach and West White Beach are two of the largest beaches on the island, while Dolly Beach and Greta Beach hold sufficient sand to provide habitat for hermit (*Coenobita* spp.) and ghost crabs (*Ocypode* spp.) and enable green turtles to dig nests
- shallow fringing coral reef shelves—the subsurface marine habitat immediately surrounding the island consists of a relatively narrow and shallow fringing coral reef shelf about 20 to 100 metres wide in approximately 6 to 20 metres of water depth. Caves are also located in some of the island's rocky sea cliffs that adjoin the coral reef shelves. Coral reef shelves also contain areas of sand and rubble
- mid and deep marine waters—the shallow coral reef shelves drop off steeply to the island's mid and deep marine water habitats which include outer reef seaward slopes, vertical walls that lead to deeper oceanic waters.

The shallow fringing coral reef shelf surrounding Christmas Island is extremely limited in area and this, combined with the island's geographic isolation, limits the diversity of shallow marine species. However, over 600 marine fish species have been recorded, including endemic and hybrid reef fish (Allen et al. 2007, Hobbs et al. 2008), making the island an internationally significant marine hybrid hotspot (Hobbs et al. 2008).

Whale sharks are the world's largest fish, one of only three filter-feeding sharks (DEH 2005) and are listed as vulnerable under the EPBC Act. The whale shark recovery plan (DEH 2005) identifies the waters of Christmas Island as being part of Australia's critical habitat for this species' survival and protection. Whale sharks aggregate seasonally around Christmas Island, usually between November and April, feeding on red crab and other planktonic larvae (Hobbs et al. 2009).

Small numbers of green turtles, and more rarely hawksbill turtles (*Eretmochelys imbricata*), nest on Christmas Island while endangered loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) turtles are also thought to forage in its marine habitats (Brewer et al. 2009). Short-beaked common dolphins (*Delphinus delphis*) and long-snouted spinner dolphins (*Stenella longirostris*) have been recorded feeding and possibly breeding around Christmas Island, while three (possibly four) species of whale have been infrequently sighted near the island (Brewer et al. 2009).

The marine invertebrate fauna recorded around Christmas Island includes at least 89 reef-building scleractinian coral species (Done & Marsh 2004), more than 200 species of decapod crustaceans, and about 490 mollusc and 90 echinoderm species including some endemic species (Brewer et al. 2009). Future surveys are likely to increase the number of coral reef species recorded around Christmas Island.

The oceanic surface waters of the Central Ridge subregion that surrounds Christmas Island are influenced by a range of ecological processes. The region is influenced by the Indonesian Throughflow—south-easterly and north-westerly monsoon winds which impact on currents and upwelling from Java's coastal waters. These factors, as well as local processes interacting with the Christmas Island seamount, influence marine productivity and nutrients (Brewer et al. 2009). In addition, a drop in water temperatures associated with current up-welling supports seasonal influxes of larger pelagic fish species (Brewer et al. 2009).

There are important ecological interactions between Christmas Island's terrestrial and marine ecosystems and the species these support. The surrounding ocean exerts a strong influence on the climate and therefore the structure and function of the island's terrestrial ecosystems, which in turn provide critical resources for many of the island's terrestrial species. For example, all of the island's seabirds are dependent on the ocean for their dietary needs but require terrestrial habitats for roosting and breeding. Land crabs depend on marine ecosystems for their survival as they migrate to the ocean for spawning and recruitment, while migrating whale sharks feed on red crab larvae (Hobbs et al. 2009). Marine turtles that nest on a few of the island's beaches spend the rest of their life cycle in the ocean. While some of the interactions are relatively well understood, there are still gaps in knowledge in relation to some interactions, particularly the marine and juvenile lifecycles of red and other land crabs.

3.2 Species

This section provides broad overview of the flora and fauna of Christmas Island.

3.2.1 Significant species

A key consideration in development of this plan is recognition that protection and recovery of significant species relies on the conservation and recovery of the assemblage of species that make up the ecosystems and habitats on which those species rely, especially the plants that make-up the island's rainforest ecosystems.

For the purposes of this plan, a significant species is a native terrestrial species which meets one or more of the following criteria:

1 A species listed (or under consideration for listing) as threatened under the EPBC Act.
2. A species with an important or 'keystone' role in maintaining the island's ecology or which characterises a significant ecosystem.
3. Species which are of conservation concern (those which have a substantial decline on Christmas Island) but not listed as threatened.
4. An endemic vertebrate.
5. A species of international conservation significance with strong community support for its conservation.

Table 6 identifies those species considered significant species at the time of this plan's preparation, based on the above criteria. Additional species may be identified as significant during the life of this plan, in particular under criterion 3, such as through monitoring, survey or research actions. The individual species profiles (Appendix K) provide more detailed descriptions and management information for significant species.

3.2.2 Overview of flora species

Terrestrial vegetation communities of Christmas Island comprise several types of rainforest, dominated by plants that are pan-tropical tramp species, most probably of South Asian origin.

Christmas Island has over 240 native flora species, with at least 18 known to be worldwide endemics (Appendix C) including a tall tree-like pandanus, *Pandanus elatus* and a palm *Arenga listeri*, as well as the critically endangered fern *Asplenium listeri*. About half of the non-endemic native species are not known to occur anywhere else in Australia or its Territories. The native flora has strong taxonomic affinities with those of the Indonesian and Malaysian regions (Reddell & Zimmermann 2003) and many species have distributions extending from south-east Asia to Australia (north-east Queensland), New Guinea and the Pacific Islands (Du Puy 1988). Three species are listed as threatened under the EPBC Act (Table 1, Appendix B). Appendix E provides a summary of the non-endemic vascular plants of possible conservation concern and their abundance and distribution. Appendix K includes detailed profiles for significant flora species on Christmas Island.

Exotic species now comprise a major component of the island's flora. At least 390 exotic species are known (Swarbrick 1997) with 221 of these identified as posing a current or potential weed threat (DNP 2009a). Details on the impacts of exotic plant species on significant native species is provided in Part 4 of this plan.

Some important features of Christmas Island's flora are:

- many species occurring in different habitats compared to their distribution in Indonesia and Malaysia and often occur in larger forms
- fewer flora species compared with continental forest ecosystems, largely reflecting the island's remoteness and limited availability of freshwater sources
- low structural diversity due to the ecological role of land crabs, particularly red crabs
- the presence of at least 18 endemic species and three ferns listed as threatened under the EPBC Act
- relict populations of species that have been isolated since the island's tectonic uplift, including coastal mangroves at Hosnies Spring and the cycad, *Cycas rumphii*.

The conservation status of much of Christmas Island's flora is unclear. Other than one extensive flora survey (Holmes & Holmes 2002) which identified 53 species of possible conservation concern, there has been little recent survey effort. Information about distribution, abundance, population trends and threats is poorly understood for most species. Some endemic species appear to have restricted distributions and small population sizes, and could qualify for listing as threatened under the EPBC Act.

Along the shore terrace, especially the northern coastline, tall forests and salt tolerant species such as *Pandanus* spp., *Pemphis acidula* and *Scaevola taccada* grow on the cliff tops. A number of deciduous species are common to this area such as *Gyrocarpus americanus*, *Terminalia catappa* and *Erythrina variegata*. This area includes some of the most diverse forest on the island with about 25 canopy species (Gray 1995).

The rainforest canopy of the central plateau contains about 12 dominant species, some of which are deciduous during the dry season (such as *Terminalia catappa*). A number of emergent tree species (*Hernandia ovigera*, *Planchonella nitida* and *Syzygium nervosum*) play an important role in the island's ecosystem through providing nesting sites for Abbott's booby. A number of other species found in this forest are unusual for occurring as large forest trees; in other locations in the tropics they normally occur as small to medium trees growing close to the shore. This vegetation community also includes a number of seashore plants found some distance from the ocean (Gray 1995).

Table 6: Species of Christmas Island identified as significant

Species		Significance criteria
Vascular plants		
Asplenium listeri	Christmas Island spleenwort	1
Bruguiera gymnorhiza, B. sexangula	mangroves	2
Pneumatopteris truncata	a fern	1
Tectaria devexa var. *minor*	a fern	1
Seabirds		
Fregata andrewsi	Christmas Island frigatebird	1,4
Papasula abbotti	Abbott's booby	1,4
Phaethon lepturus fulvus	golden bosun, white-tailed tropicbird	4
Forest birds		
Accipiter hiogaster natalis	Christmas Island goshawk	1,4
Chalcophaps indica natalis	Christmas Island emerald dove	1,4
Collocalia linchi natalis	Christmas Island swiftlet	4
Ducula whartoni	Christmas Island imperial pigeon	2,4
Ninox natalis	Christmas Island hawk-owl	1,4
Turdus poliocephalus erythropleurus	Christmas Island thrush	1,4
Zosterops natalis	Christmas Island white-eye	2,4
Mammals		
Crocidura trichura	Christmas Island shrew	1,4
Pipistrellus murrayi	Christmas Island pipistrelle	1,4
Pteropus melanotus natalis	Christmas Island flying-fox	1,2,4
Reptiles		
Cryptoblepharus egeriae	blue-tailed skink	1,4
Cyrtodactylus sadleiri	giant gecko	1,4
Emoia atrocostata	coastal skink	3
Emoia nativitatis	forest skink	1,4
Lepidodactylus listeri	Lister's gecko	1,4
Ramphotyphlops exocoeti	Christmas Island blind snake	1,4
Land crabs		
Birgus latro	robber crab	5
Discoplax celeste	blue crab	2
Gecarcoidea natalis	red crab	2,3,5

A number of plant species are known only from one or a few sites with a small number of individuals and are potentially of conservation concern. Some of these species are pioneer, edge or disturbance specialists that may have always had a precarious foothold in the ecology of the island but are now likely to be out-competed by the many more vigorous exotic plants (EWG 2010). Other species provide an important food source e.g. the palm *Arenga listeri* which is important in the diet of robber crabs.

The plateau forest's understorey consists of a small number of species, predominantly *Pandanus elatus*, while ferns are a feature of some areas. The threatened Christmas Island spleenwort *Asplenium listeri* is endemic to Christmas Island and was originally known from a single location. Although additional locations are now known there is thought to be less than 300 individuals (Holmes & Holmes 2002). The species appears to favour limestone rock crevices at the highest parts of inland cliff terraces and often occurs below strangler fig (*Ficus microcarpa*) (Butz 2004b). *Tectaria devexa* is a threatened terrestrial fern which occurs as two known varieties. The var. *minor* occurs in Sri Lanka and Christmas Island, while the var. *devexa* occurs in Queensland. On Christmas Island *T. devexa* var. *minor* grows in shaded positions in the evergreen tall closed forest on the plateau where it may be the only forest floor species. It does not appear to be very widespread and is not abundant in any of its known occurrences (Butz 2004a). The only Australian occurrence of the threatened fern *Pneumatopteris truncata* is located on Christmas Island.

Due to higher moisture retention and fertility, vegetation on the higher terraces is more diverse than that of the plateau. It includes strangler fig, the stinging tree (*Dendrocnide peltata*) and the succulent shrub *Procris pedunculata*. A feature of the wet season is the appearance of a number of flowers in the rainforest, including orchids (such as *Thrixspermum carinatifolium*) and hoya (*Hoya aldrichii*) (Gray 1995). Ridley's orchid (*Brachypeza archytas*) and Ridley's ground orchid (*Zeuxine exilis*) are endemic to Christmas Island. Eleven orchids occur on Christmas Island, eight of which are epiphytes.

During the wet season algae, ferns, mosses, fungi and lichens come to life in the rainforest, including the stinkhorn fungus (*Dictyophora* spp.) (Gray 1995).

The stands of *Bruguiera gymnorhiza* and *B. sexangula* mangroves at Hosnies Spring are some of the largest specimens of these species in the world. While mangroves normally occur in saltwater environments, the Christmas Island populations have adapted to grow in freshwater over 30 metres above sea level, making them especially significant. The mangroves play an important role in defining the ecological character of Hosnies Spring and as such have an important role in the ecosystem of the wetlands.

3.2.3 Overview of fauna species

Christmas Island's native fauna is notable for the high proportion of species and subspecies which are either endemic (only occur on Christmas Island) or have their only Australian occurrence on the island. The island's proximity to the Indonesian Archipelago explains why the fauna has Indonesian–Malay rather than Australian affinity. As an oceanic island isolated from other land-masses, the native fauna species assemblage is characterised by species able to utilise wind, ocean currents or flight to colonise this remote site. Christmas Island's fauna is dominated by large numbers of resident seabirds and a diverse range of land crabs, most notably red crabs. Appendix B lists fauna species for Christmas Island that are listed under the EPBC Act and appendices F to H provide information on the island's fauna species. Appendix K includes detailed profiles for significant fauna species on Christmas Island.

Birds

Christmas Island has 14 species of resident native birds, two of which are self-introduced, and nine regular breeding seabirds. The remaining birds are non-breeding migrants or occasional visitors. Appendix F provides a summary of the birds of Christmas Island and their status and abundance. Christmas Island is of international conservation significance as a seabird breeding area and because many of its bird species are endemic; there are three endemic seabird taxa and seven endemic land bird taxa. In recognition of the island's international conservation significance for birds, it has been declared an Endemic Bird Area by Birdlife International. In addition to birds playing a significant role in the environment, the Christmas Island community has a strong connection to several species, particularly the golden bosun (*Phaethon lepturus fulvus*) an endemic subspecies of the white-tailed tropicbird and the wildlife symbol of Christmas Island, which appears on the island's flag.

The endangered and endemic Abbott's booby now occurs only on Christmas Island, having formerly bred on other Indian Ocean islands (DEH 2004). It nests in tall trees of the western and southern plateau rainforest. The other two endemic seabirds are the endangered Christmas Island frigatebird (*Fregata andrewsi*) and the golden bosun; the three endemic seabirds are also listed as migratory species under the EPBC Act. The most numerous of the island's seabirds is the pan-tropical red-footed booby (*Sula sula*) which nests colonially in trees on many parts of the shore and inland terraces. The widespread brown booby (*Sula leucogaster*) nests on the ground at the edge of the seacliff and inland cliffs. Other seabirds breeding on Christmas Island include the silver bosun or red-tailed tropicbird (*Phaethon rubricauda*), great frigatebird (*Fregata minor*), lesser frigatebird (*Fregata ariel*) and common noddy (*Anous stolidus*). The island supports more than one per cent of the world's populations of silver bosun, great frigatebirds, red-footed boobies and brown boobies.

Prior to settlement only eight land and freshwater birds were resident on the island, seven of which are endemic species or subspecies. The Christmas Island swiftlet (*Collocalia linchi natalis*) feeds on flying insects and nests in caves or overhangs. The Christmas Island imperial pigeon feeds mainly on fruits from the rainforest and settled areas, while the emerald dove feeds on fruits, seeds and insects from the forest floor. The Christmas Island hawk-owl and goshawk feed on small mammals, birds, reptiles and invertebrates. The Christmas Island white-eye and thrush feed on fruit, nectar and insects.

The original resident bird fauna remains intact but has been joined by a range of self-introduced and introduced species (Johnstone & Darnell 2004). The Nankeen kestrel (*Falco cenchroides*) and the white-faced heron (*Egretta novaehollandiae*) self-established from Australia since settlement and utilise open habitats created by vegetation clearing.

In addition to resident land and seabirds, at least 104 vagrant or migrant bird species—largely of south-east Asian origin—have been recorded on the island from time to time (Johnstone & Darnell 2004). Nineteen species are regularly recorded as non-breeding migrants or occasional visitors, including migratory shorebirds.

While several bird species have been studied on Christmas Island, there is little robust information available on population sizes or long-term trends for most species. Six of the island's endemic birds are listed as threatened under the EPBC Act (Table 1, Appendix B) while the conservation status of the golden bosun is unknown. The silver bosun is not listed as threatened under the EPBC Act, but at times chick recruitment has significantly declined at the Settlement nesting colony due to cat (*Felis catus*) predation and other factors that may be related to food availability. Although listed as threatened, the Christmas Island thrush and emerald dove appear to be numerous and stable.

Mammals

Five endemic native mammals have been recorded on Christmas Island with only one, the Christmas Island flying-fox, now known to remain. Two endemic rats became extinct soon after settlement. The Christmas Island pipistrelle (*Pipistrellus murrayi*) and the Christmas Island shrew (*Crocidura trichura*) are thought to be extinct but, given their last recordings occurred relatively recently, they are not officially confirmed as such in legislation and opportunistic monitoring is undertaken. Appendix G provides a summary of the mammals of Christmas Island and their status and abundance.

Maclear's rat *(Rattus macleari)* and the Christmas Island rat or bulldog rat *(Rattus nativitatis*) were two large, nocturnal, endemic rats that became extinct shortly after introduction of the black rat (*Rattus rattus*) in the early 1900s. The extinction of both endemic rats was likely due to a pathogenic trypanosome carried by fleas that were hosted by black rats (Wyatt et al. 2008).

The endemic Christmas Island shrew is the only known occurrence of the shrew family on Australian territory. This species was once extremely common across the island and had a distinctive shrill squeak but declined rapidly following settlement, possibly because of the introduction of a disease (Schulz 2004). It was thought to be extinct before two specimens were found in 1985 but it has not been sighted since. The shrew is listed as endangered under the EPBC Act but is now likely to be extinct. Formerly considered a subspecies of a more widely distributed species, molecular studies have confirmed it as a separate species endemic to Christmas Island (Eldridge et al. 2009).

The Christmas Island pipistrelle was previously common and widespread on Christmas Island. However, since the 1990s this small insectivorous bat declined markedly in distribution and abundance, the cause of which is not fully understood (Lumsden et al. 2007). Fixed detector stations have failed to record this species since mid-2009 and, while it is listed as critically endangered under the EPBC Act, it is now presumed extinct.

The Christmas Island flying-fox is found across the island and is largely diurnal. The flying-fox has been recorded feeding on fruits, flowers and seeds and is likely to play an important role in seed dispersal and pollination. Several studies and reports indicate that flying-fox numbers have declined significantly over recent years and because of this decline it was listed under the EPBC Act as critically endangered in 2014.

Reptiles

Christmas Island has six species of native terrestrial reptiles, five of them endemic. In addition two marine turtles are recorded as nesting on the island. Appendix G provides a summary of the reptiles of Christmas Island and their status and abundance.

Endemic species are the blue-tailed skink, forest skink (*Emoia nativitatis*), giant gecko (*Cyrtodactylus sadleiri*), Lister's gecko (*Lepidodactylus listeri*) and the burrowing Christmas Island blind snake (*Ramphotyphlops exocoeti*). The coastal skink (*Emoia atrocostata*) is a wide-ranging skink found on many other islands through the Pacific and Indian Oceans. On Christmas Island it occupies (or occupied) the rocky coastal intertidal zone and adjacent fringing limestone rock outcrops.

All of Christmas Island's native terrestrial reptiles have undergone rapid population declines and are highly threatened (Schulz & Barker 2008). The blue-tailed skink, forest skink and coastal skink have undergone dramatic range contractions since the late 1990s and may now be extinct in the wild. Lister's gecko had not been recorded for more than 20 years until a small population was found in 2009 (Smith et al. 2012). CINP staff also confirmed a sighting of the Christmas Island blind snake in 2009, the first time it had been recorded since 1986 (Smith et al. 2012). The species was apparently more abundant prior to recent decades, being described as 'fairly common' between 1938 and 1940 (Gibson-Hill 1947) although it may have been confused with the introduced flowerpot snake (*Ramphotyphlops braminus*). Due to its cryptic habits, the Christmas Island blind snake is difficult to locate through surveys, but the extremely low number of confirmed records suggests that this species is probably in very low numbers.

The giant gecko is now the only regularly encountered native reptile species, particularly in the evergreen tall closed forest of the central plateau, but it too is uncommon and declining in abundance and distribution (Schulz & Barker 2008). Its decline has been most marked since the late 1990s, when it was considered to be abundant and widespread (Cogger & Sadlier 2000).

All of the five endemic reptiles are listed as threatened under the EPBC Act. The reason for declines of native terrestrial reptiles is poorly understood and it is not possible to attribute the declines to specific threatening processes (see Part 4 of this plan).

Two marine turtles, the green turtle and hawksbill turtle, are found in Christmas Island's marine waters and occasionally nest on some of the island's beaches (Dolly and Greta beaches) in small numbers. Both are listed as vulnerable under the EPBC Act and a recovery plan (Environment Australia 2003) provides a national framework for their conservation management. This plan does not identify Christmas Island as habitat critical for their survival.

Fish

The limited availability of permanent, above-ground freshwater sources restricts the abundance and type of freshwater aquatic vertebrates on Christmas Island. At least seven freshwater fish species have been recorded from pools and streams however these are largely introduced. A single freshwater eel (*Anguilla bicolor*) was captured in 1983 and there have been more recent sightings at Hugh's Dale. The only other native freshwater species is the brown gudgeon. Both species have marine life-stages, accounting for their presence on Christmas Island, and are widely distributed in the Indonesian–Malaysian Archipelago and beyond (Allen et al. 2007).

Invertebrates

A large number of endemic species from a range of invertebrate groups are known to occur. While none of Christmas Island's invertebrate fauna is currently listed as threatened under the EPBC Act, populations of several species (notably red crabs) have declined over recent decades and there is a possibility that some invertebrate species have become extinct.

Crustaceans, particularly in the form of land crabs, are the most conspicuous invertebrate fauna of Christmas Island. They are remarkable for their diversity and abundance, and for the role they play in the island's rainforest ecology. Christmas Island supports over 20 terrestrial and intertidal crab species of which 14 are regarded as true land crabs, depending on the ocean only for their larval development. This diversity and abundance of land crabs is not matched on any other island. Appendix H provides a list of land and shoreline crabs of Christmas Island and their status, abundance and distribution.

The red crab occurs only on Christmas Island (and sporadically on North Keeling Island) and is the most conspicuous and abundant land crab. At the beginning of the wet season (usually October/November), most adult red crabs suddenly begin a spectacular migration from the forest to the coast to breed. The red crab annual breeding migration is recognised as one of the world's spectacular wildlife events with tens of millions of adult red crabs migrating to the coast where they mate in burrows close to the ocean. Females then deposit fertile eggs in the ocean, and return to the forest. After about a month in the ocean—growing through several stages—the larvae gather in pools close to the shore for one to two days before growing into young crabs that leave the water to begin their inland migration. In most years very few or no baby crabs emerge from the sea, but the occasional very successful breeding year results in a large return of young red crabs. The ecological role that red crabs have on the unique structure, characteristics and plant composition of Christmas Island's forests is profound (Lake & O'Dowd 1991). While there has been a substantial amount of research into red crab biology and ecology there are still a number of unknown or poorly known aspects, particularly their juvenile lifecycles and aspects of their migration, including the factors influencing the size and patterns of their migration.

There are also a number of other important land crab species. Blue crabs have a restricted distribution on Christmas Island in wetland areas, which includes The Dales area of CINP where it is locally common; formally considered a form of a widely distributed species, it now constitutes an endemic species (Ng & Davie 2012). Christmas Island also supports the world's largest population of the world's largest terrestrial invertebrate, the robber crab, which may attain a mass of over 2.5 kg. Robber crabs have a wide distribution across many Indian and Pacific oceanic islands but in most of their range they are now scarce, heavily hunted and in serious decline. Although abundant on Christmas Island their exact conservation status is unknown. There are a number of other endemic crabs on Christmas Island which are not listed, and whose population is uncertain. These include Jackson's crab (*Karstama jacksoni*) and the recently described Christmas Island yellow-eyed crab (*Chiromantes garfunkel*).

Christmas Island's ant fauna is mostly composed of species that are regarded as worldwide tramps or are widespread in the Indonesian–Australian region and none are considered endemic. Fifty-two species have been recorded, most of which are likely to have been accidentally introduced through human habitation, of which crazy ants are the most prominent and most destructive (see Part 4.1 of this plan). Ant species likely to be native to the island include *Camponotus melichloros, Leptogenys harmsi*, *Pachycondyla christmasi, Odontomachus simillimus*, and possibly *Hypoponera confinis* (Framenau & Thomas 2008).

Most of the 28 butterfly species recorded on Christmas Island are likely to be introduced, as they feed only on introduced plants. The number of butterfly species native to the island is difficult to determine, but by 1900 naturalists had found nine species, including one endemic species, the Christmas Emperor (*Charaxes andrewsi*) (DNP 2011a).

Thirty-eight snail species have been recorded from Christmas Island, including 22 introduced species and nine endemic species (Kessner 2006). However, the ecological role of native land snails is poorly known.

There is a suite of subterranean invertebrates, including one of only two known blind scorpions in Australia (EWG 2010), stygofauna and anchialine fauna. Some aquatic taxa are endemic while others, are closely related to populations in the Pacific. The island's subterranean fauna remains relatively poorly known and surveyed. Undoubtedly, many additional taxa remain undiscovered (Humphreys & Eberhard 2001). The high degree of endemism and the ancient lineages of several species highlight the global conservation significance of Christmas Island's subterranean fauna (EWG 2010). No formal conservation status or listing has been assigned to any cave species of Christmas Island. However, Schedule 12 of the EPBC Regulations protects obligate cave-dwelling species.

Part 4—Threats

Since the settlement of Christmas Island, the natural environment has been modified by threatening processes associated with introduced invasive species, and human activities or a combination of both. Some threatening processes interact, or may interact, leading to compounding ecological impacts. Although some existing and potential threats are clearly identified, threatening processes responsible for the decline of some species are poorly understood or not known and this lack of information is a barrier to addressing such declines.

In general, oceanic island species and ecological communities are far more vulnerable to decline and extinction than mainland populations. The factors responsible for this include small population sizes, small geographic ranges, limited genetic diversity due to small numbers of founding individuals, limited dispersal opportunities or refuges, evolution under limited exposure to predators, pathogens, disease and competitors, and the limited ecological resistance of simplistic island ecosystems to disturbance (e.g. exotic species invasions). As an oceanic island, these factors all apply to Christmas Island.

The threats described below have been assessed for their risk to the significant species of Christmas Island without any recovery action, based on the pervasiveness of the threat and the impacts to species essential to the ecosystem (see Appendix I for details). Potential threats outside Christmas Island (described below) such as possible hunting of frigatebirds and Abbott's booby, habitat clearing on other (non-Australian) islands, and marine threats which may affect terrestrial species, are not included in the risk assessment. These threats are beyond the scope of this plan.

Invasive species pose the greatest known threats to Christmas Island's ecology and biodiversity, and their impacts may be exacerbated by other threatening processes, such as climate change. Invasive species are exotic introduced species which adversely affect native species or their habitat and may result in negative environmental and/or economic impacts. As identified in the EWG report (2010), "elements of Christmas Island's biodiversity have declined and are currently in severe decline because of introduced species and diseases. The addition of more invasive species to the already high load can only make matters worse". The species profiles (Appendix K) provide more details of the specific threats known or thought to be operating on significant Christmas Island species.

4.1 Known threatening processes

Four 'key threatening processes' listed under the EPBC Act are considered to apply to Christmas Island (Table 7). These threats are discussed in further detail below.

Table 7: Key threatening processes relevant to Christmas Island

Key Threatening Process	Threat Abatement Plan
Loss of biodiversity and ecosystem integrity following invasion by the Yellow Crazy Ant (*Anoplolepis gracilipes*) on Christmas Island, Indian Ocean	Yes
Loss of terrestrial climatic habitat caused by anthropogenic emissions of greenhouse gases	No
Predation by exotic rats on Australian offshore islands of less than 1000 km^2 (100 000 ha)	Yes
Predation by feral cats	Yes

In addition to these listed key threatening processes, a number of other threatening processes are known to be affecting the ecology and biodiversity of Christmas Island.

4.1.1 Introduced species

Yellow crazy ants and scale insects

Major threat risk

The yellow crazy ant (*Anoplolepis gracilipes*) is a 'tramp ant' species accidentally introduced to Christmas Island between 1915 and 1934 (O'Dowd et al. 1999). Yellow crazy ants ('crazy ants') are recognised by the IUCN and the Global Invasive Species Program as one of the world's 100 worst invasive species (Lowe et al. 2000). On Christmas Island crazy ants are recognised as the most significant and pervasive threatening process affecting biodiversity, as reflected by their listing as a key threatening process and as identified in a threat abatement plan to reduce the impacts of tramp ants on biodiversity in Australia and its territories (DEH 2006).

Crazy ants establish nests in a variety of locations, including holes in the ground (e.g. crab burrows), tree bases and hollows, logs, and under rocks (O'Dowd et al. 1999, O'Dowd et al. 2003, Abbott 2005). Highest densities are at ground level, but they are also active high into the forest canopy (O'Dowd et al. 2003, Abbott 2005).

Crazy ants apparently occurred in low numbers with no obvious impact on the island's biodiversity until the late 1980s, when the first multi-queen high density colonies, referred to as 'supercolonies', were recorded (Framenau & Thomas 2008). A supercolony is determined based on the density of ants that results in red crab mortality and is counted using a standardised monitoring method. By 2001 it was estimated that supercolonies covered 25 per cent of the island's rainforest areas (O'Dowd et al. 2003) before an aerial baiting program was implemented in 2002. By 2009 supercolonies had again increased and were estimated, through the Island Wide Survey, as covering an area of just under 800 hectares, before further aerial baiting programs were undertaken in 2009 and 2012. Baiting programs only target mapped supercolonies, which are lethal to red crabs. Crazy ants at sub-supercolony densities are widely distributed across the island (Abbott 2005), with many high density colonies present (Figure 5).

Crazy ants form mutualistic associations with scale insects which suck sap from trees and secrete carbohydrate-rich honeydew on which the ants feed. The ants protect the scale insects from parasitoids, parasites and predators. The formation of crazy ant supercolonies has been particularly associated with high densities of the cryptogenic lac scale *Tachardina aurantiaca* and the introduced scale *Coccus celatus* (O'Dowd et al. 2003).

Crazy ants and scale insects have a variety of known and potential direct, indirect and interacting impacts on Christmas Island's species and their habitats. Their most significant impact is on the mortality of land crabs, which in turn can cause significant changes to forest habitats. Ants spray formic acid and crabs are either killed directly in ant-invaded forest, or during the annual migration when large numbers of craps intercept supercolonies. Other crabs such as blue crabs and robber crabs are also affected.

Forests from which red crabs have been removed have been called 'ghost forests'. There are two types of ghost forest—those from which crazy ant supercolonies have been eliminated but in which red crab recovery has been limited and those in which red crabs have disappeared due to their death during migration through distant supercolony areas. By 2003, it was estimated that 10–15 million red crabs had been killed, removing or severely depleting local populations over an area of 25 square kilometres (O'Dowd et al. 2003).

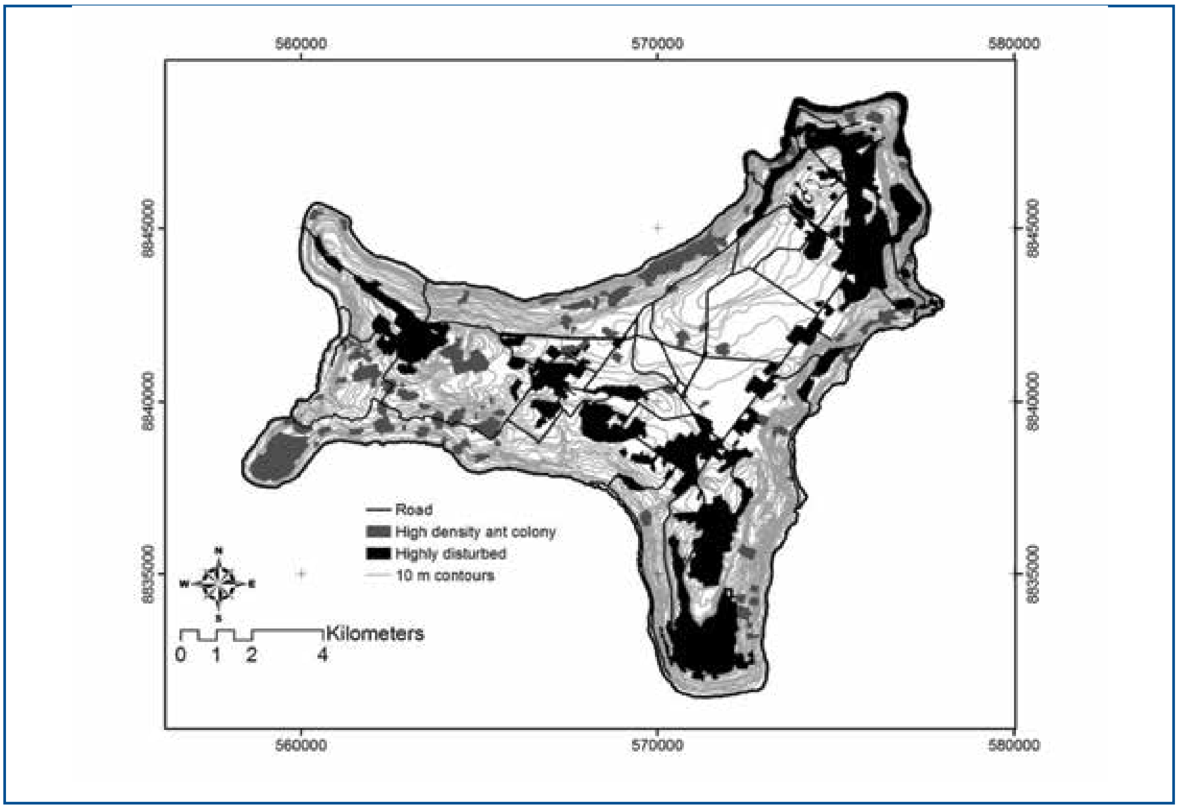

Figure 5: High density crazy ant colonies

Source: Boland et al. 2011

The removal or reduction of red crabs is likely to result in long-term changes to the forest structure, species composition and habitat quality, through the disruption of ecological processes such as nutrient cycling and seed recruitment and dispersal. Removal of red crabs can also result in the increased abundance and distribution of other invasive fauna. For example, red crabs prey on introduced giant African land snails and restrict their invasion of rainforest (Lake & O'Dowd 1991) and reductions in the number of red crabs, due to crazy ants, may result in an increase in giant African land snails. Other invasive fauna species may also be advantaged by removal of red crabs.

High densities of scale insects in association with crazy ant supercolonies have resulted in canopy dieback and tree death due to the removal of large quantities of sap and the accumulation of excess honeydew on the leaves promoting the growth of photosynthesis-reducing sooty moulds (O'Dowd et al. 2003). Seed production and the growth rates of adult and juvenile trees can also be affected (O'Dowd et al. 2003, Abbott & Green 2007). Lac scale insects can reduce growth rates of adult and juvenile trees and lower seed production in Tahitian chestnuts (Abbott & Green 2007) as well as leading to high mortality of chestnuts through canopy dieback.

Red crabs can help suppress the growth of some weed species though the consumption of seedlings (Green et al. 2004). Removal of red crabs from forests by crazy ants and increased light levels from canopy dieback has facilitated the invasion of several shade-intolerant weed species including *Capsicum frutescens, Carica papaya, Cordia curassavica* and *Muntingia calabura* (Green et al. 2004).

Crazy ants affect some of the island's bird species through direct interference and through altered resource availability and habitat structure (Davis et al. 2008, Davis et al. 2009). Altered foraging behaviour, fewer reproductive behaviours, and altered nest sites location by Christmas Island thrushes have been observed in ant-invaded forest and higher nest failures and fewer juvenile thrushes have also been recorded (Davis et al. 2008). However, these birds are common so the cumulative effect of crazy ants is hard to quantify. Crazy ant supercolonies have been found to reduce frugivory by the Christmas Island thrush and white-eye through direct interference as well as the likely indirect impacts on resource availability and habitat structure (Davis et al. 2009). Despite that reduction, the white-eye has been found to be more abundant and have greater foraging success in ant-invaded forest, probably due to the increased abundance of scale-insect prey (Davis et al. 2008). The evidence suggests little ecologically significant impact, if any, on thrushes or white-eyes. Studies showed that the Christmas Island emerald dove was 9–14 times less abundant in ant-invaded forest. As emerald doves forage on the forest floor and often nest low in the vegetation (where crazy ant densities are high), crazy ants may harass nesting adults and/or predate on nestlings and juveniles.

Crazy ant impacts on other tree-nesting or seabird species are not known. It is possible that crazy ants may directly or indirectly impact Christmas Island swiftlet, imperial pigeons, red-footed booby, Christmas Island frigatebird, Abbott's booby, golden bosun, silver bosun, goshawk and hawk-owl.

While the exact causes for the rapid decline and likely extinction of the pipistrelle are unclear, it is possible that crazy ants contributed through a range of mechanisms e.g. directly interfering with bats or young at roosts, excluding bats from their preferred roost sites, facilitating increases in potential predators such as giant centipedes (*Scolopendra subspinipes*), wolf snakes (*Lycodon aulicus*), cats and rats and reductions in invertebrate prey numbers (Schulz & Lumsden 2004; Lumsden et al. 2007; EWG 2010). There is no direct evidence that crazy ants significantly affect the Christmas Island flying-fox but they are considered a potential threat, with potential impacts being disturbance to roosting and foraging patterns including reduced fruit handling, tree death or reduced fruit and pollen production as a result of scale and sooty mould.

The impacts of crazy ants on native reptiles are unclear. There is observational evidence of lizards being killed by crazy ants; however, the persistence of some endemic lizards has previously been recorded in crazy ant supercolonies, suggesting that crazy ants are unlikely to be solely responsible for reptile decline across the island. Potential impacts may include direct predation and habitat alteration, and crazy ants facilitating increases in other potential reptile predators and/or competitors (Schulz & Barker 2008). While there are many direct impacts which are apparent in the short term, there is likely to also be a number of indirect impacts, such as changes in plant species composition due to differential mortality caused by scale host specificity, which may take many decades to manifest.

Crazy ants are likely to prey on a range of litter and canopy invertebrates but the impact of crazy ants and other exotic ants on native invertebrate fauna are not well understood. There is the possibility that some management activities undertaken to control crazy ants, such as the use of chemical baits, may also provide some risks to native species, if the risks are not managed effectively.

Given how widespread crazy ants are on the island, they represent a major threat and their effective management is essential to the recovery of many species on Christmas Island.

Cats

Major threat risk

Cats are considered a key threatening process affecting biodiversity on Christmas Island, as reflected by the relevant national threat abatement plan (DEWHA 2008). Cats became established on Christmas Island about 1904 and are now widespread and abundant (Algar & Johnston 2010). Surveys in 2008 suggested an index abundance of 1.34 cats per km along the vehicle survey route (Algar & Johnston 2010) but abundance across the island is unlikely to be uniform, with generally more cats (feral, stray and domestic) in settled areas such as around the island's tip site. While pet cats pose some threat to wildlife, feral and stray animals are of greater concern due to their higher numbers and capacity to reproduce (Shire by-laws introduced in 2010 require all pet cats to be de-sexed and registered).

Eight threatened species are identified as being at risk in part from impact by cats including the emerald dove, hawk-owl, thrush, Lister's gecko, blue-tailed skink, forest skink, Christmas Island blind snake and the flying-fox. Ground-nesting seabirds are also at risk; predation by cats, and also rats, at the silver bosun nesting colony at the Settlement area in 2005 and 2006 resulted in a nil survival rate of chicks in that colony (Algar & Johnston 2010). As part of a collaborative cat management program, approximately 450 feral cats were removed from settled areas of the island and surrounding forest areas, with survival of chicks at the Settlement nesting colony increasing to 66 per cent in response.

However, as studies into cat abundance have only recently occurred, it is difficult to determine at this stage the extent to which changes in the cat population affect mortality rates of native species, compared with other factors.

Rodents

Major threat risk

Two introduced rodent species occur on Christmas Island, the black rat (*Rattus rattus*) and the house mouse (*Mus musculus*). On other oceanic islands, introduced rodents have had serious impacts on species including bats, seabirds, forest birds, native plants, reptiles and insects. Black rats were responsible for the extinction of native rats on Christmas Island through disease (Wyatt et al. 2008).

Along with cats, black rats are potentially implicated in the decline of species such as emerald dove, thrush, white-eye, silver bosun (through predation of eggs) and native reptiles. Rats may have also contributed to the decline of the pipistrelle.

Black rats are widespread across the island (but are more common in settled areas) and can be considered to be a potential threat across the entire island. Rat management at critical sites is likely to be important for the recovery of several species such as ground-nesting seabirds. However, further studies are required to assess the types and levels of impacts on native species before major control programs across the island are considered. This is because, unlike many other oceanic islands, the native fauna of Christmas Island included two endemic rodents with which other native species co-evolved. In addition, the ecological dominance of land crabs (especially red crabs) may play some role in limiting black rat numbers. House mice are found on the island but their distribution, numbers and impacts are not known.

Giant centipedes

Giant centipedes were introduced to the island around settlement. They became abundant by 1907 (Andrews 1909) and may have undergone further increases in the last 10 to 20 years. They are now found in all habitats across the island. Giant centipedes may predate on a range of native species, particularly native reptiles (Schulz & Barker 2008) such as the blue-tailed skink, Christmas Island blind snake and Lister's gecko. DNA studies in 2011 confirmed that centipedes feed on reptiles on Christmas Island but were inconclusive as to whether native or introduced species were consumed (Donnellan et al. 2011).

Giant centipedes have been observed climbing roost trees of the Christmas Island pipistrelle and similar centipedes in South America are known to catch small insectivorous bats (Lumsden et al. 2007). Giant centipedes are widespread and can be considered a threat across the entire island, especially given the evidence that they predate on reptiles.

Giant African land snails

The giant African land snail is listed in the top 100 of the world's worst invasive alien species (Lowe et al. 2000). They were probably introduced to Christmas Island as a food source during World War II (Sproul 1983). A reduction of the red crab population by crazy ants has increased the potential for snails to expand their range. The impacts of giant African land snails are not well understood but snails have been observed feeding on a wide variety of plants, and could potentially have impacts on listed threatened ferns and other plant species. Giant African land snails are widespread and can be considered to be a threat across the entire island.

Wolf snakes and other exotic reptiles

Five exotic reptile species have been accidentally introduced to Christmas Island since settlement—the Asian (or barking) house gecko (*Hemidactylus frenatus*), Pacific gecko (*Gehyra mutilata*), grass skink (*Lygosoma bowringii*), flowerpot snake and wolf snake. The wolf snake may have been introduced to Christmas Island from the north in the 1980s (Schulz & Barker 2008) and it was estimated to be in the many thousands by the early 1990s.

These exotic reptiles potentially threaten native reptiles. Wolf snakes are now found across the entire island including in evergreen tall closed forests. In other parts of its natural range it is often closely associated with human dwellings and gardens, feeding predominantly on geckos. On Christmas Island the wolf snake is known to threaten native reptiles via predation and may also be implicated in the decline of the pipistrelle. Analysis of wolf snake stomach contents in 2010 by DNP staff found blue-tailed skink remains and Lister's gecko was last seen in large numbers prior to the snake's introduction (Cogger 2005). The two introduced geckos and grass skink may have contributed to the decline of native reptiles through competition, while the flowerpot snake may compete with the endemic Christmas Island blind snake (Cogger 2006). There is also potential for introduced reptiles to spread disease amongst native reptiles.

Weeds

A survey of the exotic flora of Christmas Island in 1996 identified approximately 390 exotic species some of which are naturalised while others are under cultivation or in gardens as ornamentals (Swarbrick 1997). Of these species, 221 have been identified as posing a current or potential weed threat (DNP 2009a). Minesite rehabilitation in the 1970s and 1980s often included a wide range of exotic species but this practice has since been discontinued.

Weeds threaten the survival and distribution of native plants through competition for habitat space and resources which turn diminishes biodiversity and the integrity of ecosystems and reduces habitat for native fauna. High risk weeds on Christmas Island are those considered to pose the greatest threat or potential threat to endemic and native species. The weeds considered to be of highest management priority for control are Siam weed (*Chromolaena odorata*) and species that have or may be likely to invade shaded/intact rainforest (e.g. *Clausena excavata*). Siam weed was first detected in 2010 in a single site on the north south baseline on the north-east of the island; it is now thought to have been eradicated, subject to the results of further monitoring. Parthenium weed (*Parthenium hysterophorus*) occurs on the island and, while its distribution keeps changing, it may have some impact on rehabilitated sites.

Weeds are now particularly prevalent in highly disturbed areas including mine fields, roads and tracks and rainforest margins. Some weed species may also invade evergreen tall closed forests, semi-deciduous and deciduous thickets and there is recent evidence that some shade-tolerant sleeper weeds are now spreading into areas where they were previously not detected, making them a high risk to rainforests. One species of particular concern is *Clausena excavata,* which as well as being shade-tolerant is resistant to crab herbivory (Green et al. 2004).

Undisturbed evergreen tall closed forest is relatively resistant to weeds that require full or part sun, but the expansion of shade tolerant weeds into evergreen tall closed forest poses a serious threat. Undisturbed semi-deciduous closed forest is less resistant to weed invasion, as it provides niches and light for weeds to establish and spread. Weeds may appear below the frequent canopy gaps provided by tree falls. Disturbed rainforest, rainforest margins, roadsides and rehabilitated minesites are extremely susceptible to weed invasion (DNP 2009a).

The replacement and exclusion of various native understorey and canopy species by weed competition, shading or chemical suppression (allelopathy) can occur, especially when monocultures of species such as *Clausena excavata*, *Leucaena leucocephala*, *Delonix regia* and *Cordia curassavica* are allowed to dominate. Invasive weeds have the potential to affect the distribution of endemic and threatened flora species as well as other rare and threatened indigenous plants by direct competition for habitat space and resources (Holmes & Holmes 2002). Competition from invasive weeds may affect the three listed threatened ferns (*Tectaria devexa* var. *minor*, *Pneumatopteris truncata* and spleenwort). Weeds can threaten the integrity of ecosystems, especially if combined with other threatening processes such as habitat clearing and crazy ants (DNP 2009a).

Three invasive weed species may threaten the endemic Christmas Island frigatebird. The disturbed fringes of the Cemetery breeding colony may be at risk of being invaded by the coastal vine *Antigonon leptopus*, which can smother nest trees and restrict access by frigatebirds. *Leucaena leucocephala* has formed monocultural stands around the edges of some frigatebird nesting habitat, reducing recruitment of preferred native nest tree species (e.g. *Terminalia catappa*, *Celtis timorensis*). The spread of *Clausena excavata* throughout the Cemetery breeding colony has the potential to form monocultures, out-competing preferred nest tree species and thus reduce recruitment of nest trees (DNP 2009a).

Three invasive weed species may represent a threat to the endangered endemic Abbott's booby. The invasive vine *Mucuna albertisii* can form enormous vine towers in canopy gaps and forest edges; it occurs directly adjacent to existing nest sites and would exclude birds from trees that it smothers. The woody weeds *Clausena excavata* and *Aleurites moluccanus* have the ability to germinate in full shade under intact rainforest and are a potential threat to the survival of the bird's preferred nest tree species (e.g. *Planchonella nitida, Syzygium nervosum, Celtis timorensis*) (DNP 2009a). Invasive weeds also threaten the success of forest rehabilitation efforts, which is largely focused on rehabilitating Abbott's booby habitat.

The cliff-nesting habitat of silver bosun and brown boobies is threatened by the spread of *Antigonon leptopus*, particularly in settled areas. Weeds, especially newly introduced species, are a potential threat to the goshawk and hawk-owl as these could form vine towers over nesting trees (Hill 2004a, 2004b).

Invasive weeds may also cause localized impacts on other fauna species, including invertebrates, by changing vegetation structure and habitat values.

Introduction of new invasive terrestrial species

Major threat risk

As identified in the final report of the Expert Working Group (2010), many of the current biodiversity conservation problems on Christmas Island are due to introduced species, and the introduction of new invasive species could have catastrophic effects on the island's biodiversity. The past introductions of many exotic species that now threaten native species, are the result of previously inadequate biosecurity/quarantine measures or from deliberate introduction for human use. If additional invasive species are introduced and become established through inadequate biosecurity and/or eradication/response measures, then further declines of native species are anticipated.

4.1.2 Traffic-induced mortality and disturbance

Major threat risk

Red and robber crabs are frequently killed on the island's roads and, while measures are taken to reduce impacts on crabs, substantial mortality still occurs. The construction and operation of the IDC has greatly increased vehicle traffic on the island, leading to large increases in red and robber crab mortality. This is particularly an issue on Murray Road because of the high numbers of crabs and high traffic volumes.

Based on surveys, 425,000 red crabs were estimated to have been killed by vehicles during the IDC's construction phase in 2005–06 and losses following commencement of the IDC's operation continued to be significant. Although no formal surveys have been conducted since 2005–06, it was estimated that vehicles killed at least 400,000 red crabs in 2010 however more effective road management activities (including closures) undertaken since then have led to reductions. A study of robber crab mortality recorded 854 deaths from vehicles in 2010, 667 deaths in 2011 and 677 deaths in 2012 (DNP unpub. data).

There have been previous reports of road mortalities of other species, including the hawk-owl, pipistrelle, emerald dove and swiftlet. Increased traffic has also led to a reduction of use of nests by the goshawk in habitat near roads. The level of mortality or disturbance on these and other species is unknown but it is not considered to be a major threat.

4.1.3 Habitat disturbance and loss

Major threat risk

Christmas Island has a long history of vegetation and habitat disturbance, most notably as a result of phosphate mining and settlement. Mining commenced in 1898 and vegetation clearing reached a peak with a 1969 grid line survey in which vegetation was cleared across the island in a grid of lines up to nine metres wide and 20 to 30 metres apart (Corbett et al. 2003). Additionally, during the 1970s, all existing mining leases were completely cleared by the British Phosphate Commission.

Approximately 25 per cent of the island's original rainforest has been cleared. Further removal of previously uncleared primary rainforest could be a major threat to several significant species. Clearing for mining up to 1987 resulted in the removal of approximately one-third of the primary rainforest nesting habitat of Abbott's booby (Reville et al. 1987) as well as critical habitat for other species. In addition, the resulting mosaic of cleared and forested areas allowed wind to enter the canopy causing increased turbulence particularly in areas downwind of clearings, resulting in higher adult mortality and lower breeding success of Abbott's booby (Reville et al. 1987, 1990). Clearing not only results in habitat loss but can also increase the spread of introduced species, such as weeds. Habitat removal arising from past clearing (whether through mining, road construction or other activity) may have also impacted on the spleenwort, *Tectaria devexa* var. *minor*, *Pneumatopteris truncata*, goshawk, hawk-owl, shrew and flying-fox. Further removal of previously uncleared rainforest would potentially threaten these and other species, in particular Abbott's booby and the Christmas Island frigatebird, through direct impacts and/or by reducing the area of their critical habitat.

Mining conducted by CIP under the previous and renewed mine lease only occurs on areas that have previously been cleared of their original native vegetation and that now contain a mix of secondary regrowth native vegetation and weeds. As primary/tall evergreen rainforest is not now cleared for mining, mining on existing leases is not generally considered to be a major threat when compared to the removal of previously uncleared primary rainforest or other threats, particularly existing and new invasive species. While mining (or other forms of land clearing) on secondary regrowth areas may have local impacts, these impacts may be mitigated to some degree by, for example, timing works on specific sites to avoid the red crab migration or seabird nesting times.

Figure 2 illustrates the land tenure on the island and the areas of mining lease illustrate the locations where clearing for mining has occurred. Similarly other developments, such as new buildings, that involve clearing of secondary regrowth areas (i.e. that have previously been cleared) may not pose a major threat to threatened species if any negative impacts can be mitigated or reduced. However, such proposals may need to be assessed under the environmental referral and assessment provisions of the EPBC Act and these provisions apply regardless of this plan (see Part 1.5 of this plan for details).

4.1.4 Pathogens, disease and parasites

The extent by which introduced pathogens, disease and parasites currently impact on native species is poorly understood, although there is some evidence of their impact and/or presence, including their role in past extinctions.

The disease-causing parasite *Trypanosoma lewisi* carried by black rats and transmitted by fleas has been demonstrated as the cause of extinction of Christmas Island's endemic Maclear's rat in the early 1900s (Wyatt et al. 2008) and possibly also the endemic bulldog rat. A study by Adams et al. (2008) showed that Christmas Island's cats contained a number of parasites, most commonly *Toxoplasma gondii*, but their impacts on native species on Christmas Island are not known.

In 2011 the DNP contracted Taronga Zoo to undertake an assessment of disease prevalence in native and invasive species (Hall et al. 2011). While this assessment did not identify any major known disease threats, it is still possible that disease may have an impact on blue-tailed skink, giant gecko, coastal skink, forest skink, Lister's gecko, Christmas Island blind snake and the flying-fox. There is a potential that disease also contributed to the decline of the shrew.

While not currently a major issue, the introduction of any avian diseases has the potential to impact all the land birds of Christmas Island. Disease may also impact on plant health but there is little information in relation to the impact of potential diseases on Christmas Island's flora.

4.1.5 Climatic impacts

Cyclones and storm events

Christmas Island currently does not experience frequent cyclones though occasional severe tropical storms or cyclones do occur. These events can impact on forest ecosystems through the creation of light gaps that may be invaded by weeds, and damage to coral reef systems. A 1988 cyclone blew Abbott's booby chicks from their nests resulting in their death (Reville et al. 1990). The same cyclone may have had a serious impact on the flying-fox and frigatebird populations (Corbett et al. 2003). Cyclones and storm events are naturally occurring events and disturbance may provide some ecosystem benefits e.g. through new native plant regeneration in forest canopy gaps. However, climate change may affect the frequency and/or intensity of cyclones and storm events and increase the scale or frequency of forest disturbance, thereby increasing the vulnerability of vegetation patches to other threats, particularly weed invasions.

Climate change

Changing climatic conditions may include less predictable onset of the monsoon season, more prolonged dry spells and increased intensity of storms (Hyder Consulting 2008).

Species and communities most at risk from the impacts of climate change include:

- fern species, including listed threatened species, that might be susceptible to changes in rainfall
- semi-deciduous forest on shallow soil that may be put under water stress through prolonged dry spells
- seabirds, which might be sensitive to changing oceanic conditions and coral reef systems
- red, blue and robber crabs, as well as other land crabs.

Some of the effects of climate change could include exacerbation of other threats:

- changes to vegetation resulting from drier conditions might result in conditions more susceptible to wildfire, particularly on the coastal terraces and in areas of semi-deciduous forest
- increased cyclone frequency or intensity may result in forest canopy tree losses and increased opportunities for weed invasion of forest canopy gaps.

4.1.6 Chemical use

A range of fuels, oils and chemicals, including chemicals used for controlling invasive species like crazy ants, weeds and rodents, could potentially have impacts on native species and their habitat.

Fipronil bait is currently the only known effective broadscale means of controlling crazy ants on Christmas Island (EWG 2010) and is only used to bait crazy ant supercolonies. Fipronil may exist in a number of metabolite forms of significant toxicity and are a potential threat to native species. However, studies of Fipronil use on Christmas Island have not detected any significant off-target impacts or accumulation of Fipronil in the environment (CESAR Consultants 2011, 2013) and delivery methods are routinely employed which minimise its known or potential impacts (Boland et al. 2011). For example, baiting is done in the dry season when crab activity and rainfall is low; robber crabs are physically removed or food lures are used to attract them away from areas that are to be baited; and baiting does not occur near the ocean or wetlands.

The indiscriminate use of second-generation rodent poisons as part of rodent control activities is a potential threat to predatory species through secondary poisoning; species particularly at risk include the goshawk, the hawk-owl and the robber crab. Heavy metal poisoning (including from drinking at contaminated sites) is an unknown but potential threat to a number of species including the Christmas Island frigatebird and the flying-fox.

4.1.7 Small population size

Current small population size is a potential risk to the long-term survival of a number of declining species due to, for example, inbreeding or vulnerability to threatening processes. The fern *Tectaria devexa* var. *minor*, hawk-owl and native reptiles are prime examples.

4.2 Likely or potential threatening processes

4.2.1 Introduced species

Other introduced invertebrates

In addition to crazy ants, Christmas Island has been invaded by many other tramp ant species (Framenau & Thomas 2008), some of which may be potential sleeper species. These sleeper species may, under appropriate conditions, become as threatening as other invasive species on the island. A species of high concern is the big-headed ant *(Pheidole megacephala)*.

There are numerous species of other exotic invertebrates on Christmas Island which could pose significant threats to native species. For example, a high number of introduced land snails (Kessner 2006) have been recorded and feral honeybees (*Apis mellifera*) were identified as a potential threat to the pipistrelle (Lumsden et al. 2007). Bees may also threaten nesting seabirds and land birds. However, in general the potential impacts of exotic invertebrates (other than those already identified as threats) are poorly understood.

Introduced and self-introduced birds

Feral fowl (*Gallus gallus*) are common in settled areas and occur in and around the fringes of rainforests. Their impacts are unknown, but they may have direct impacts through predation on some native invertebrate species such as land snails and may provide a vector for diseases that pose risks to native birds. Java sparrows (*Lonchura oryzivora*) were introduced between 1908 and 1923 and tree sparrows (*Passer montanus*) were a ship-assisted introduction in the 1980s (Johnstone & Darnell 2004). Both species are established around the settled areas. Their impacts are not known, but they may compete with white-eyes particularly in settled areas.

The Nankeen kestrel self-colonised between 1940 and 1950 and is now common in settled and cleared areas. There is no evidence that it is having an impact on threatened species, but large insects and lizards, including the forest skink, form part of its prey elsewhere in its range and it is known to prey on the Christmas Island swiftlet (Lumsden et al. 2007).

Introduced fish

Several introduced freshwater fish are found on Christmas Island including the Asian bony tongue (*Scleropages formosus*), tilapia (*Oreochromis* spp.), guppy (*Poecilia reticulata*), mosquito fish (*Gambusia affinis*), and swordtail (*Xiphophorus maculatus*) (Humphreys & Eberhard 2001). Some of these species are potential threats to native fauna, including fauna in anchialine systems.

4.2.2 Water use and condition

Christmas Island's wetland ecosystems and stygofauna depend on groundwater flows while anchialine ecosystems and their fauna depend on the balance between fresh groundwater flow and the underlying intrusion of marine water. Almost all water used for human purposes on Christmas Island is groundwater. Over recent years there has been an increasing pressure on water resources due to an expanding population. If climate change does result in reduced rainfall, reductions in available water that recharges groundwater systems may occur. Although some monitoring bores are established, there is no detailed groundwater model or adequate monitoring program for the extraction of groundwater (EWG 2010). Therefore, the level of usefulness of present groundwater use monitoring in determining human impacts on the environment is unknown (EWG 2010). This is a major knowledge gap, as groundwater extraction resulting in a decrease in flow and loss of permanent surface water has been described as a threat to both The Dales and Hosnies Spring (Hale & Butcher 2010, Butcher & Hale 2010). Assessed as having a medium likelihood of occurring, the result could be a change in the wetland type, and a loss of mangroves and blue crabs.

4.2.3 Impact of recreational activities

Christmas Island's unique natural heritage provides tourists, visitors and residents with opportunities to participate in a range of recreational activities, which can also help promote appreciation and understanding of the island's natural conservation values. However, if recreational activities and/or visitor sites are poorly or inappropriately managed, these activities could pose a threat to native species and their habitat e.g. visitors impacting on plant regeneration in sensitive sites such as wetlands.

4.2.4 Fire

Forest fires are not currently regarded as a major threat on Christmas Island. However, if dry seasons become more severe or more frequent as the climate changes, or forest vulnerability increases because of increased forest complexity and fuel loads through red crab removal, then impact from fires may become an issue for many species that are not adapted to fire (EWG 2010). Fire is a potential threat to the Christmas Island spleenwort, *Tectaria devexa* var. *minor* and *Pneumatopteris truncata* and could also be a potential threat to other species in the future.

4.2.5 Threats or changes to marine habitat

Disturbance to, and/or changes in the condition of, the marine environment beyond the territorial waters of Christmas Island may affect significant terrestrial species.

Over-fishing, direct interaction with long-line fishers or interaction with lost fishing gear are potential threats to seabirds. Research (Hennicke 2007) suggests the foraging success of Abbott's booby is dependent on subsurface predators such as yellowfin tuna (*Thunnus albacares*) and billfish forcing potential prey fish close to the water surface. Over-fishing of predators may pose a risk to the Abbott's booby, Christmas Island frigatebird and other seabirds through reduced access to prey species.

Other potential marine threats which may affect significant terrestrial species include:

- changes in marine conditions, for example sea temperature and currents may lead to sustained increases in mortality of immature stages of land crabs
- marine pollution which is a global threat to seabirds and therefore a potential threat to Abbott's booby, Christmas Island frigatebird, golden bosun and other seabirds
- changes in sea surface temperature could affect the Christmas Island frigatebird, Abbott's booby and golden bosun.

Marine changes and threats are beyond the scope of this plan.

4.2.6 Extralimital hunting of seabirds

As migratory species, hunting in areas outside Christmas Island such as Indonesia is a potential threat to Abbott's booby and Christmas Island frigatebird. As the terrestrial range within Australia for each species is currently restricted to Christmas Island and this threat does not occur on Christmas Island, actions to abate this potential threat are not included.

4.3 Processes considered and determined not to currently be a threat

4.3.1 Predation or disturbance by dogs

A small number of pet and feral dogs (*Canis familiaris*) are present on Christmas Island. Their impact on the island's native fauna has not been measured but their direct impacts are not thought to currently be significant.

4.3.2 Overfishing and hunting within the Territory of Christmas Island

Recreational fishing, including charter fishing, is a popular activity on Christmas Island. Generally, deepwater marine species rather than reef species are targeted (Brewer et al. 2009). Currently fishing does not appear to be impacting on fish stocks or coral reef health, but changes in fishing intensity could reduce stock sizes of some species due to small population size, the small amount of coral reef habitat and the island's isolation (Gilligan et al. 2008). Over-fishing of reef species could result in the local decline of some species, particularly as re-colonisation from other seeding reef sites may be difficult (Gilligan et al. 2008). Overfishing may have a subsequent impact on seabirds such as Abbott's, brown and red-footed booby. However, while fishing can impact on seabirds, impacts are more likely to be associated with increases in commercial fishing outside of territorial waters rather than recreational fishing for local consumption.

Imperial pigeons, flying-foxes, robber crabs, blue crabs and turtle eggs were commonly taken for food in the past but hunting is now considered rare or not to occur and therefore is not considered a threat. However, small takes of robber crabs are still thought to occur.

4.3.3 Illegal collecting

In some areas of Australia illegal collection of ferns and/or orchids is considered a threat or potential threat to these taxa, particularly when a species is desirable to collectors and the plant population small and restricted. Illegal collecting was regarded as a potential threat to the Christmas Island spleenwort and the fern *Tectaria devexa* var. *minor* at the time their respective recovery plans were drafted (Butz 2004a; 2004b). On Christmas Island illegal collection of plants is considered rare or not to occur.

Part 5—Overview of previous and existing biodiversity management

Although Christmas Island has faced substantial conservation challenges and biodiversity decline over recent decades, there have also been some significant achievements and programs for the conservation, recovery, restoration and monitoring of Christmas Island's native species and ecosystems. The major recovery programs that had recently been or were being implemented at the time of preparing this plan are described below. Appendix J summarises and reviews the existing recovery plans and provides the status of recovery actions to which these programs have contributed.

As identified by the Expert Working Group report, the lessons from the pipistrelle must be applied to other species. The early recognition of the rapid change in the island's ecological function in the mid-1990s should "have initiated an urgent and comprehensive review followed by management actions" (EWG 2010). As described in Appendix J, a number of the single species recovery plan monitoring actions have not been undertaken, or the monitoring which has been undertaken was not able to provide appropriate information on species' population trends, distributions and sizes. It will be important to continue and build on the regular Island Wide Survey (IWS) and the integrated species surveys to ensure that regular monitoring is conducted to collect the appropriate information, and that the outcomes of this are used to adapt management practices.

The Expert Working Group emphasised the need for adaptive management to be a stronger focus of recovery plans. Robust monitoring processes and timely analysis are required to ensure the results of monitoring are effective in shaping decisive management actions. While this plan will be reviewed within five years, the results of the IWS and other monitoring programs must be used to routinely consider appropriateness of actions and to alter management and control actions.

5.1 Management of threats

5.1.1 Introduced species

Crazy ant control

To provide scientific advice for the management of the crazy ant control program, the Crazy Ant Scientific Advisory Panel was formed by the DNP and relevant researchers. Crazy ant baiting using Fipronil, including aerial baiting in 2002, 2009 and 2012, has been conducted by the DNP and since 2001 a biennial IWS has been used to monitor red crab distribution and abundance; map the distribution of crazy ant supercolonies and to help plan and assess the success of baiting programs. Post-bait monitoring shows that crazy ant numbers in supercolonies are reduced by at least 99 per cent immediately after baiting. However, over time supercolonies can form again. As part of the 2009 and 2012 baiting programs, studies were conducted to assess the off-target impacts of baiting with Fipronil bait (CESAR Consultants 2011, 2013). These studies showed that Fipronil bait did not accumulate in the environment and no off-target impacts were detected. Although the impact on robber crabs was not specifically tested, a baiting strategy uses food lures to attract robber crabs away from areas to be baited. In 2009 the DNP contracted La Trobe University to undertake a three-year research project for the feasibility of indirect biological control of crazy ants. In 2011 the DNP expanded crazy ant control measures, including further biological control research and investigation of alternative control methods, as part of a suite of integrated control options. Eradication of crazy ants from Christmas Island is not considered possible, so sustained control or suppression of supercolonies is essential.

In 2009 CIP commenced boric acid bait station trials for crazy ant control and published the results of these studies in 2012 (Stewart et al. 2012). These trials involved the use of a fluid form of boric acid (borax) contained within a bait dispenser, covered with a wire mesh to minimise the likelihood of crabs taking borax bait as well as damaging the bait dispenser. While this method may not be suitable for the landscape scale control of crazy ants, it is potentially suitable for targeted control of crazy ants in sensitive areas like wetlands.

Cat and rat management

The Shire of Christmas Island has a range of requirements for owners of domestic cats to ensure the threat posed by cats is appropriately managed (SOCI 2007). These include:

- owners must apply for a permit to keep a cat
- cats must be sterilised
- cats must be able to be identified
- cats can be impounded if found by the Shire Ranger
- cats are not to be abandoned.

Under the current service delivery agreement between the Commonwealth and the WA government, the provisions of the WA *Cat Act 2011* apply.

As part of a collaborative national project, in 2008 and 2009 trials were conducted on Christmas Island to assess the efficacy of the Curiosity© feral cat bait. Trials showed that the bait and baiting strategy was effective at controlling feral cats with an 87 per cent decline of cats in areas trialled (Johnston et al. 2010). Following these trials feral cat management efforts on Christmas Island increased.

In 2010 SOCI and DNP coordinated the preparation a cat and black rat management plan (Algar & Johnston 2010), which was supported by CIP and prepared for SOCI by consultants funded by Territories Administration. Initial implementation of the plan comprised the introduction of new Shire by-laws for pet cat ownership in 2010 which include the prohibition of imports of new cats onto the island and compulsory de-sexing (jointly funded by SOCI, Territories Administration, CIP and DNP). A total of 152 pet cats were registered and de-sexed and there has been positive community support for the program. Under stage 2 of the plan, approximately 500 feral cats were removed from settled areas via a collaborative control program from 2010 to 2013. Rat control has also been conducted in selected seabird nesting sites around the Settlement area.

Weed management

A weed management plan for 2005 to 2010 was prepared for the island, and updated to cover 2010 to 2015 (DNP 2009a). This plan outlines the strategy for weed management on the island. Significant weed management efforts are associated with the CIMFR program to control weeds affecting the regeneration of native plants. In addition to weed control undertaken as part of the CIMFR program, weed control work over an area of 250 hectares was conducted from 2006 to 2009 via funding from the Natural Heritage Trust, primarily on the plateau areas. Other weed management programs include a control program for parthenium weed conducted by the WA Department of Agriculture and Food (DAFWA) under a service delivery arrangement with Territories Administration.

In 2010 Siam weed was first detected on Christmas Island. If established it could severely affect the island's forests, especially rehabilitated forests. Efforts by the DNP, in combination with DAFWA, have resulted in the eradication of the single known infestation but regular surveys are needed with possible follow-up control.

Other island stakeholders, such as the Shire, also conduct weed management activities, although these are largely for amenity rather than conservation focused outcomes and CIP is also expected to conduct some weed control on its mine leases.

Quarantine/Biosecurity

There has been an Australian government quarantine presence on the island since 1994 and in 2004 quarantine legislation—*Quarantine (Christmas Island) Proclamation 2004*—came into force under the *Quarantine Act 1908*. This legislation allows the import of some species by permit.

The Australian Government Department of Agriculture carries out quarantine and biosecurity services under a service delivery arrangement with Territories Administration. Services conducted under this arrangement include screening of airport passengers and freight, inspections of ships and ship cargo and regulating plant and animal imports.

In 2000, a survey of the island found a number of target or highly invasive plants that are a threat to the Australian mainland. This is a result of the island's close proximity to South-East Asia and the lack of robust quarantine presence on the island.

In 2010, the final report of the Expert Working Group identified biosecurity hazards as a major threat to the island's native species and their habitats. In addition to the maintenance and review of quarantine, the Expert Working Group recommended that quarantine management be upgraded to a standard consistent with the island's biodiversity values (EWG 2010). In response to the recommendations in the EWG report, Parks Australia and the Department of Agriculture have commenced an examination of biosecurity procedures and requirements (refer to Action 2 in Section 6.3 of this plan).

5.1.2 Mitigating vehicle impacts on red and robber crabs

The DNP and relevant stakeholders, including SOCI, implement strategies to reduce the numbers of red crabs killed by vehicles during their early wet season breeding migration. Specially designed crab underpasses and fences have been constructed on some roads along main crab migration routes to channel crabs safely under the road. Some roads within and outside of the national park are also closed during the migration. Education and awareness-raising activities are also conducted. Regular migration updates are provided to the community by Parks Australia and a local conservation group 'Island Care' has prepared red crab protection road signs. Christmas Island District High School and a visiting school have prepared signage to promote the conservation of red and robber crabs. In recent years the Christmas Island community has played a significant role in the protection of crabs during the red crab migration. This includes some community members actively removing crabs from roads during times of high red crab movements and supporting other red crab protection activities, such as road management activities.

Other organisations, such as DIBP, also promote awareness of issues associated with crab deaths from vehicles amongst their staff, and CIP also has a red crab management plan to reduce the impacts of their operations on migrating red crabs.

In 2010 the DNP developed a program to monitor and raise awareness of robber crab mortality from traffic. Although this program has helped to reduce crab deaths, mortality continues to occur and it is essential to maintain education activities, as well as other impact reduction measures, including setting and enforcing of appropriate vehicle speed limits. The Australian Federal Police (AFP) has supported the DNP to reduce red and robber crab deaths, for instance, by promoting driving techniques that help maximise driver safety and minimise crab deaths and enforcing speed limits.

5.1.3 Minimising the impacts of human activities

Under the EPBC Act there are processes for assessing the impacts of proposed actions that may have an impact on matters of national environmental significance. In addition WA vegetation clearance legislation applies to Christmas Island. Refer to Part 1.5 of this plan for details.

CIP operates under a mining lease granted by the Commonwealth in 1997 which was approved under the *Environmental Protection (Impact of Proposals) Act 1974*. A renewed lease was granted in 2013. The previous and renewed mine lease includes conditions to:

- not clear, degrade or damage any primary rainforest on Christmas Island
- comply with all requirements of an Environmental Management Plan
- pay a conservation levy to the Commonwealth for the rehabilitation of mining leases on Christmas Island
- implement a dust suppression program.

5.1.4 Climate change

Both the Territories Administration and Parks Australia have prepared a number of strategic documents on the impact of climate change on Christmas Island. The Indian Ocean Territory Climate Change Risk Assessment (AECOM 2010) assesses the risk associated with the future impacts of climate change on Christmas Island. It includes an assessment of the impacts on the economy, tourism, infrastructure, as well as ecosystems and biodiversity. The report can be used as a guide to future decision-making.

Parks Australia has established five objectives which focus the work of each park in regards to climate change (DNP 2009b):

- To understand the implications of climate change.
- To implement adaptation measures to maximise the resilience of the reserves.
- To reduce the carbon foot print of the reserves.
- To work with communities, industries and stakeholders to mitigate and adapt to climate change.
- To communicate the implications of, and the management response to, climate change.

The Christmas Island National Park Climate Change Strategy 2011–2016 (DNP 2011b) outlines the likely impacts of climate change on the national park and includes a series of actions built around the above objectives.

5.2 Species and ecosystem recovery and management

5.2.1 Minesite to forest rehabilitation

The Christmas Island Minesite to Forest Rehabilitation (CIMFR) program is conducted by the DNP through an agreement with Territories Administration, and is funded by a conservation levy paid by CIP to Territories Administration. In 2012 a long-term CIMFR program plan was prepared which outlines the priorities and approaches for the program from 2012 to 2020 (DNP 2012g).

Rehabilitation work undertaken by the program aims to "establish a tall, dense native forest tree canopy with a similar species composition and structure to that of the surrounding forest, to help mitigate wind turbulence impacting Abbott's booby nesting sites" (DNP 2012g). Priority areas selected for rehabilitation are based on three main criteria (DNP 2012g):

- the fauna conservation priorities and potential for the recovery of their habitat
- the conservation value for vegetation and landscape priorities
- the economic and logistical feasibility of rehabilitating sites.

In addition to Abbott's booby, other native species which also benefit from the forest rehabilitation works are land crabs, particularly red crabs; forest birds, including the Christmas Island hawk-owl, goshawk, white-eye, emerald dove, imperial pigeon and thrush; and a number of tall evergreen forest flora species.

Many former minesites have been colonised by weeds which have the potential to invade adjacent forest. The CIMFR program contributes to a functioning forest ecosystem by providing adequate soil depth and sufficient plant biomass to allow the recolonisation of red crabs and restoring forest areas which in the long-term will provide emergent trees suitable for Abbott's booby roosting and recolonisation. Experience to date indicates that the rehabilitated sites become self-sustaining after seven to ten years.

In the context of the CIMFR Program, rehabilitation refers to the establishment of ecological attributes and function approaching native forest within the first decade. Key parameters include (DNP 2012g):

- development of forest vegetation structure (a canopy height of greater than eight metres and a canopy cover of greater than 80 per cent)
- high plant species richness (greater than 30 species on site)
- recruitment of local flora species (greater than 5000 individuals per hectare)
- nutrient cycling (leaf litter breakdown and organic matter build-up in soil)
- food web productivity and return of native fauna (e.g. land crabs, forest birds and Abbott's booby).

Rehabilitation work on Christmas Island has involved numerous aspects including seed collection, nursery operation, earthworks, soil replacement, tree planting, fertilising, track maintenance and particularly weed management. Between 1998 and 2012, 200 hectares have been rehabilitated through the program, and approximately a further 450 hectares of high conservation area may have rehabilitation value and feasibility/potential. Details of monitoring proposed for this program are outlined in the rehabilitation program plan (DNP 2012g).

Standard minesite rehabilitation practice now includes:

- rebuilding the landscape, replacing soil and planting a range of native plant species
- controlling weeds in rehabilitated sites until native plants dominate and are self-sustaining
- maintaining and developing good nutrition balances and cycles within rehabilitated sites until native plants become self-sustaining
- conducting biophysical monitoring to assess the effectiveness of rehabilitation efforts
- prioritising the selection of sites to those with the greatest conservation benefit potential and that are cost effective to rehabilitate
- preparing and adaptively implementing a long term rehabilitation plan and securing associated funding.

5.2.2 Wetlands

In 2010 Ecological Character Descriptions (ECDs) were prepared for Christmas Island's two declared Ramsar wetlands, The Dales (Butcher & Hale 2010) and Hosnies Spring (Hale & Butcher 2010). The ECDs describe the wetlands' ecological character and threats likely to impact on their ecological character, as well as the monitoring required to enable changes to their ecological character to be detected. While no specific on-ground actions have occurred in relation to wetlands, conservation activities in or adjacent to wetland areas will help maintain native flora and fauna of wetland areas. For example crazy ant control will help maintain red crabs across the whole island, and Siam weed control will reduce the risk of spread into wetlands.

5.2.3 Native reptile recovery

In 2008 the DNP funded a terrestrial reptile survey of Christmas Island (Schulz & Barker 2008). The results of this survey led to increased recovery efforts for a number of reptile species from 2009. These have involved developing and implementing a captive breeding program for several species; increasing public awareness; increased and more robust monitoring; and investigation of threatening processes, particularly invasive fauna species and disease. A reptile advisory panel established in 2011 provides advice to DNP on activities for the recovery of Christmas Island terrestrial reptiles.

The reptile recovery program has included the establishment of a successful island-based captive breeding program for two native species (blue-tailed skink and Lister's gecko). In 2011 the captive breeding program was extended off-island in partnership with Taronga Zoo.

In 2010 Taronga Zoo was contracted by DNP to provide services for assessing disease threats to native reptiles. Results of this work did not indicate that disease was a threat; however, ongoing monitoring of disease threats for native reptiles and other species is likely to be needed (Hall et al. 2011).

5.3 Research and monitoring

5.3.1 Research

Christmas Island National Park is or has been involved in several research collaborations which have contributed to increasing understanding and supporting the management of native (and invasive) species and their habitats (Table 8). Major research projects undertaken since 2007 include the impact of crazy ants; the foraging ecology of the Abbott's booby; the efficacy of the Curiosity© feral cat bait; taxonomic study of the Christmas Island shrew; and crazy ant biological control.

Despite research, there are still gaps in knowledge in areas such as the impacts and control of crazy ants, the population trends and ecology of significant species, threats to declining species, groundwater resources, the ecology of crabs, vegetation classifications, cave fauna and invertebrates.

Table 8: Some research studies conducted on Christmas Island since 2002

2002	Survey of plants of conservation concern (Holmes and Holmes)
2003	Island wide survey (IWS) PhD on crazy ants (Abbott's booby)
2005	Island wide survey (IWS)
2006–07	Goshawk monitoring (Holdsworth) Pipistrelle survey (Lumsden et al.) Investigation of the foraging ecology of Abbott's booby (conducted in conjunction with Hamburg University) Island wide survey (IWS)
2008	survey of native reptiles (Barker and Schulz) Marine resources study (Gilligan et al.) Biodiversity monitoring program Efficacy trial of the Curiosity© feral cat bait as part of a national trial program
2009	Monitoring for the Christmas Island pipistrelle Taxonomic study of the Christmas Island shrew Surveys for the pipistrelle (Australasian Bat Society) Island wide survey (IWS) Borax bait station trials for crazy ant control commence (CIP)
2010	Development of Ecological Character Descriptions (ECDs) for The Dales and Hosnies Spring Ramsar sites Expert Working Group final report Crazy ant biological control research commences (La Trobe University) Robber crab vehicle impact study commences (DNP) Studies to inform cat and rat management (WA Department of Environment and Conservation in partnership with the DNP and SOCI)
2011	Disease investigation by Taronga Zoo Fipronil impact assessment (CESAR Consultants) Island wide survey (IWS) Studies to inform cat and rat management continued (WA Department of Environment and Conservation in partnership with the DNP and SOCI) Research papers on red crab, Abbott's booby, crazy ant management published
2012	Targeted survey for flying-fox (DNP/consultant) Targeted survey for hawk-owl (DNP/consultant) Targeted survey for native reptiles (DNP) Expert-based conservation workshop for flying-fox Research papers on reptiles published
2013	Completion of crazy ant biological control research Island wide survey (IWS) Targeted survey for flying-fox (DNP) Targeted survey for hawk-owl (DNP) Fipronil impact assessment (CESAR Consultants)

5.3.2 Monitoring

A range of biodiversity and threatened species monitoring programs are conducted by independent researchers, universities, the DNP and other government and non-government researchers. These programs include sea and land bird population studies; land crab population studies; studies of invasive species distribution and abundance; and biodiversity monitoring including through the Island Wide Survey (Table 8).

Biophysical monitoring under the CIMFR program commenced in 2005 and collects data on tree diversity and growth as well as soil properties. The results of this monitoring program will be analysed over the next few years. The IWS has been conducted every two years since 2001 and includes data collection at approximately 900 waypoints. Data collected include red crab burrow distribution and abundance and distribution of crazy ant supercolonies. Data are also collected on the occupancy (distribution and presence) of other native and invasive species. The Biodiversity Monitoring Program (DNP 2008b) collected baseline data prior to the construction of the IDC, including Abbott's booby nesting sites adjacent to the centre. Surveys have also been conducted of disturbed sites to identify areas of weeds requiring treatment.

5.4 Communication

To assist in residents and visitors appreciating the values of and impact of threats to the Island's biodiversity, a number of community and visitor education programs are conducted:

- activities for the annual Bird Week which are coordinated by the Christmas Island Tourism Association
- presentations on national park conservation programs for residents and visiting cruise ships
- production of information such as brochures and maps that record the number of robber crabs killed by vehicles
- education activities at the school for example by CINP staff and WA Fisheries
- education activities provided by visiting researchers and scientists
- commercial tour activities conducted by individual tour operators.

5.5 Marine conservation

The Territories Administration has service delivery arrangements with the WA Department of Fisheries that include marine pest monitoring and management of fishing, including educational and awareness-raising activities. Research and monitoring of coral reef condition, threats (e.g. disease and bleaching) and diversity, including studies of hybrid fauna, has been conducted by independent researchers. In 2009 a study to assess the conservation values of Commonwealth waters of Christmas and Cocos (Keeling) Island territories was completed (Brewer et al. 2009). This study may be used to help with potential marine protection planning in the future.

Volunteers, including 'Island Care', occasionally conduct beach clean ups of Greta Beach in order to protect green turtle nesting habitat. Another outcome of this program is increased awareness in the community regarding the impacts of marine debris on wildlife.

The various marine conservation actions described are not directly focused on the recovery of species identified under this plan, as they are aimed at the conservation and management of marine biodiversity and resources. However, marine conservation actions may contribute to conserving species covered by this plan, such as seabirds, that rely on both terrestrial and marine environments.

Part 6—Objectives and actions

6.1 Objectives

The long-term vision for the natural environment of Christmas Island is:
Resilient ecosystems with self-sustaining populations of native species

The vision is only achievable through ensuring no further species decline to the point where they become threatened and eligible for listing as threatened species under the EPBC Act.

This plan has been designed to cover a 10–year timeframe and the plan's objectives have been developed to progress towards the long-term vision.

The biological objectives within the timeframe of this plan are to:

1. Maintain the ecological integrity of forest ecosystems.
2. Maintain or increase populations of significant species.
3. Maintain the ecological character of Ramsar wetlands.
4. Contribute to maintaining groundwater ecosystems.

The following underpinning objectives are essential in order to achieve the biological objectives. These are to:

5. Increase community and stakeholder understanding of, and engagement in, the recovery of ecosystems and native species.
6. Effectively coordinate and implement actions to address threatening processes and recover ecosystems and native species.

As recovery actions are implemented, progress in meeting the biological objectives will be assessed using performance criteria. The performance criteria and their relevance to each objective are described below.

Objective 1: Maintain the ecological integrity of forest ecosystems

This objective is focused on forest ecosystems that support significant species. In order to function as habitat these systems need to contain an appropriate assemblage of species and suitable structural elements and have low levels of threat (such as from invasive weeds and animals). The highest priority areas—most important for significant species—are previously uncleared/intact native vegetation and other habitats identified as being critical to the survival of significant species, and areas identified as a high priority for rehabilitation. Maintaining a large red crab population across the island is vital to shaping and maintaining the island's forests, and influences the survival of a range of native species.

Expected outcomes for this objective and measures to determine outcome achievement are:

Expected outcomes	Performance criteria	
1. Invasive animals and weeds do not threaten forest ecosystems	**1**	Crazy ant supercolonies cease to form
	2	Threat risk* of invasive weed species in previously uncleared/ intact native forests/vegetation decreases
	3	No new high risk invasive animal or weed species (as identified in actions 2.3) become established
2. The structure and species composition of forest ecosystems is maintained	**4**	Red crab population numbers are maintained or increase when compared to the population number from the 2011 Island Wide Survey
	5	The number of Island Wide Survey sites at which red crabs are recorded is maintained compared to 2011 levels
3. Rehabilitated areas provide habitat for significant native species	**6**	High priority areas are rehabilitated with native flora that is self-sustaining 7–10 years after planting
	7	Red crab burrows are recorded in rehabilitated forest sites after five years and the number of burrows increases after 10 years

The main actions contributing towards achieving these outcomes are threat abatement (Actions 1, 2, 3).

Objective 2: Maintain or increase populations of significant native species

This objective addresses all significant species (as defined in Part 3.2 of this plan).

Maintaining the size of populations is relevant to many of the significant species and involves reducing declines, while *increasing* the size of populations is possible for only a small number of significant species in the wild and for captive populations.

For significant species that are rarely detected it is intended to capture as much information as possible and initiate necessary management. For significant species not known to be declining, it is intended to ensure that sufficient survey and monitoring is undertaken to detect any decline whilst there is time to initiate conservation measures.

Expected outcomes for this objective and measures to determine outcome achievement are:

Expected outcomes		Performance criteria
1. Populations of significant species are maintained, or declines slow and populations begin to recover	**4**	Red crab population numbers are maintained or increase when compared to the population number from the 2011 Island Wide Survey
	5	The number of Island Wide Survey sites at which red crabs are recorded is maintained compared to 2011 levels
	8	Occupancy levels of Abbott's booby at nesting sites is maintained or increases
	9	The population of the flying-fox is maintained
	10	The populations of each forest bird (emerald dove, white-eye, thrush and imperial pigeon) are maintained
	11	The population of the goshawk is maintained or increases
	12	The population of the hawk-owl is maintained
	13	The population of the Christmas Island frigatebird is maintained or increases
	14	The population of the golden bosun is maintained
	15	The population of the giant gecko is maintained
	16	For each threatened fern (*Asplenium listeri*, *Tectaria devexa* var. *minor* and *Pneumatopteris truncata*) the number of known populations is increased within five years and recovery actions initiated for all new populations
	17	The population of robber crabs is maintained
2. Captive populations contribute to the conservation of significant species	**18**	Captive populations of reptile species are increased to a size that ensures maintenance of genetic diversity and to the extent they can be re-introduced into the wild in the future
	19	Threatened native reptile species are recorded in the wild and/or trial releases of species bred in captivity occurs in 10 years
3. Management is initiated where necessary, where rarely recorded species are detected	**20**	If the shrew, pipistrelle, Christmas Island blind snake, forest skink or coastal skink are detected, conservation measures are implemented
4. Declines in native species are detected early enough to implement conservation measures	**21**	Any declines** in native species are detected and conservation measures initiated

The main actions contributing towards achieving these outcomes are threat abatement (Actions 1, 2, 3), captive breeding (Action 4) and monitoring and survey (Action 5).

Objective 3: Maintain the ecological character of Ramsar wetlands

A separate objective for Ramsar wetlands emphasizes their importance to the environmental values of Christmas Island and as habitat for significant species. The ecological character of each Ramsar wetland is the combination of the ecosystem components, processes and benefits/services that characterise the wetland, as defined under the EPBC Act and Ramsar Convention (see Part 3 of this plan).

Expected outcomes for this objective and measures to determine outcome achievement are:

Expected outcomes		Performance criteria
1. The Dales and Hosnies Spring continue to support ecologically characteristic native fauna and flora species	**22**	Mangroves at Hosnies Spring are retained at a density of at least 10 trees per 100 square metres (trees greater than 2.5 cm diameter at breast height) and seedlings and saplings are present
	23	Extent of Tahitian chestnuts at The Dales does not decline
	24	Blue, robber and red crabs remain present throughout the year and utilise the site for breeding migration and/or spawning
2. The Dales and Hosnies Spring maintain their hydrological characteristics	**25**	The First, Hugh's and Anderson Dale retain surface water connection to the sea
	26	Hosnies Spring has no loss of permanent water and retains a surface water area of greater than 0.3 hectares

The main actions contributing towards achieving these outcomes are threat abatement (Actions 1, 2, 3).

Objective 4: Contribute to maintaining groundwater ecosystems

As there is currently limited knowledge of groundwater ecosystems this objective is based on the possible contribution the actions can make within 10 years.

Expected outcome for this objective and measures to determine outcome achievement are:

Expected outcome		Performance criteria
1. Understanding of ground water ecosystems is increased and human impacts are minimised	**27**	Groundwater flow rate and water quality baselines are established
	28	Understanding of groundwater systems is increased and management initiated

The main actions contributing towards achieving this outcome are threat abatement (Action 3) and monitoring and survey (Action 5).

NOTES ON PERFORMANCE CRITERIA:

- Any measures of change must be statistically significant and will take into account seasonal and other natural fluctuations.
- Given the limited quantitative data on population sizes and decline rates for most species, the expected outcomes for each species (slow decline of, maintain, or increase total population) have been selected based on expert knowledge of the species (including estimated current declines, extent to which threats can be abated, and potential rates of increase if all recovery actions are implemented and successful).

- Targets for proportional changes in populations have not been set. In many cases, ecologically acceptable population indicators, baselines and percentage targets will need to be determined by those with appropriate scientific expertise, as part of the recovery program. Population trend data (e.g. based on occupancy measures) will be used for most species as actual population numbers are difficult to measure.
- Threat risk of invasive weeds (*) to be measured by appropriate risk assessment that can take into account the distribution and abundance of a range of weed species.
- Potential future declines (**) cannot be estimated and the significance of any particular declines detected will need to be assessed by those with appropriate scientific expertise, as part of the recovery program.

6.2 Recommended actions

This section provides the overarching recovery actions required to achieve the plan's objectives. All actions that are currently considered essential to meet these objectives and assess progress towards the objectives have been included within the plan. However, relative priorities for implementation have been assigned (see Part 7 of this plan for details).

The strategy used to develop the plan's actions includes:

- assessing the conservation status and trend for major biodiversity attributes (i.e. significant taxa and ecologically significant ecosystems—forests, wetlands, groundwater and subterranean systems)
- identifying and assessing the primary risks to and threats affecting these attributes
- controlling these threats to a sufficient extent to allow for recovery of, or prevent the decline of, these attributes
- monitoring trends for all these attributes in a manner sufficient to evaluate the effectiveness of management interventions
- if threats leading to threatened species declines:
- are not known—the likelihood of determining and mitigating threats
- are not likely to be mitigated for some time—the feasibility and effectiveness of implementing interventionist programs, such as captive breeding, that have the long-term aim of conserving species in the wild.

Where information was available these steps have been followed, with the relevant information used to determine recovery actions (e.g. action to control crazy ants). Where information was not available, actions have been included to follow these steps and determine future actions.

Many actions identify broad activities but not the specific methods to be applied. This enables actions to be adaptive in character to ensure capacity to respond to uncertainty and change over the 10–year life of the plan.

The conduct and timing of many of the actions will be based on the availability of resources which will be allocated according to implementation priorities (see Part 7 of this plan). These priorities will be regularly reviewed and reported on by the recovery team (Action 9.4).

The individual species profiles in Appendix K provide specific management actions for the 26 Christmas Island species identified by this plan as significant; these management actions combine to form the basis of the broader integrated island-wide recovery requirements listed below. Action 7 (*Manage and analyse data*) Action 8 (*Communicate with and engage the community and other stakeholders*) and Action 9 (*Coordinate biodiversity conservation plan implementation*) are underpinning actions which are essential in order to achieve both the underpinning and the biological objectives of this plan.

Action 1	Continue threat abatement actions to address major threats
Action 1.1	***Control and reduce the impacts of crazy ants*** **Priority 1 Action:** based on the impacts of crazy ants on Christmas Island's red crabs and forest ecosystems and a number of significant species across the island. This is reflected in the listing of *Loss of biodiversity and ecosystem integrity following invasion by the Yellow Crazy Ant (*Anoplolepis gracilipes*) on Christmas Island, Indian Ocean* as a key threatening process under the EPBC Act and as identified by the Expert Working Group (2010).
	1.1.1 Ground or aerially bait crazy ant supercolonies with Fipronil bait until other effective alternative control methods are developed. 1.1.2 Continue to research and monitor the impacts of crazy ants on the island's biodiversity. This will include the Island Wide Survey (Action 5.1) and other studies to, particularly, gain a better understanding of poorly understood impacts, such as the density of crazy ants that prevents effective red crab recruitment. 1.1.3 Research and trial alternative low off-target impact methods for controlling and reducing the impacts of crazy ants: • give priority to the biological control of scale insects, as a means of indirectly controlling crazy ants • investigate additional control methods/baits, delivery systems and strategies, such as integrated methods using attractants like pheromones with other control methods/delivery systems, such as bait stations • investigate other measures to reduce supercolony formation and the control of crazy ants at sub supercolony densities 1.1.4 Assess the environmental risks of implementing any new/alternative crazy ant control methods that may be considered. 1.1.5 Subject to the results of the research, trials and risk assessments conducted in tasks 1.1.3 and 1.1.4, implement and monitor the effectiveness of new/alternative crazy ant control methods. 1.1.6 Assess and monitor the off target/environmental impacts of crazy ant control, including the use of Fipronil bait and any new/alternative control methods. Use this information to adaptively assess any environmental risks and to inform crazy ant control methods. 1.1.7 Continue to seek and utilise scientific advice to inform crazy ant control. 1.1.8 Compile research, monitoring and other relevant information on the biology, ecology, impacts and management of crazy ants. Use this information to review and, if needed, adapt control actions.
Action 1.2	***Control and reduce the impacts of cats and rats*** **Priority 1 Action:** based on the impact or potential impact of cats and rats on a number of significant species across the island. This is reflected by the national *Threat abatement plan for predation by feral cats* (DEWHA 2008) and the report of the Expert Working Group (2010) which identifies several of Christmas Island's native species as being vulnerable to feral cat and rat predation.
	1.2.1 Continue to monitor compliance with local cat ownership by-laws. 1.2.2 Eradicate feral and stray cats across the island. The program will begin in light industrial, tip and settled areas, including the Immigration Detention Centre and settled areas including the nesting colony of the silver bosun and habitats for significant species. This will include adopting strategies to minimise any off-target impacts including from toxin use and changes to prey abundance. 1.2.3 Conduct targeted rat control in priority locations, especially ground-nesting seabird colonies.

	1.2.4 Determine the ecological effects of and need for eradicating rats across the island. Major considerations will include determining: • the types and extent of impacts rats have on significant species • the affects that feral and stray cat eradication may have on the rat population and how any increases in rats may affect significant species • the role played by land crabs in limiting the rat population. 1.2.5 If rat control across the island is determined necessary, assess the feasibility of and determine methods for controlling or eradicating rats across the island and implement programs if feasible. This will include assessing and adopting strategies to minimise any off-target impacts from control methods (including from chemical baits) as well as assessing the likelihood of maintaining the island rat-free if eradication were to be achieved. 1.2.6 Adaptively trial cat and rat control methods. 1.2.7 Use the monitoring data from Action 5 to evaluate the effectiveness of control programs and adapt them as necessary. Effectiveness measures include low off-target impacts; cat and rat population levels; and post-control recovery of significant species.
Action 1.3	***Reduce vehicle impacts on significant species, particularly red crabs during their annual breeding migration*** **Priority 1 Action:** due to the keystone species role that red crabs have in the island's forest ecosystems and the level of community support and expectation for the protection of land crabs.
	1.3.1 Temporarily close or manage roads in and outside the national park that contain high densities of migrating red crabs. This will include but may not be limited to The Dales, Blowholes, Greta Beach, Gaze, Murray and Lily Beach roads and the Cove. 1.3.2 Maintain existing and, if needed, install additional red crab crossings on roads that are not closed during the migration and that intersect major migration routes. 1.3.3 Implement other road management measures to reduce robber and red crab mortality and potential bird mortality and disturbance, including driver education, setting and enforcing appropriate speed limits and through more effective road design, if and when roads are developed and/or upgraded.
	1.3.4 Support community efforts to mitigate the impacts of vehicles on land crabs, such as increased awareness through signs. 1.3.5 Monitor crab deaths as a result of vehicles. 1.3.6 Monitor deaths of forest birds particularly the goshawk and emerald dove and implement mitigation measures if vehicle deaths are identified as a threat (see 1.3.3). Other communication and awareness-raising activities will occur as part of Action 8.
Action 1.4	***Continue to assess the environmental impacts of proposals in accordance with relevant legislation*** **Priority 1 Action:** as further loss of or disturbance to habitat, particularly previously uncleared primary rainforest, has the potential to further impact on critical habitat for threatened species.
	1.4.1 Assess the environmental impacts of proposed actions on significant species and their habitats in accordance with the referral and assessment processes under the EPBC Act, as well as other relevant legislation, including any applied Western Australian legislation. 1.4.2 Avoid or minimise removal of previously uncleared and protected vegetation (as described under Schedule 12 of the EPBC Regulations) through, for example, strategic placement of infrastructure on cleared sites or sites with secondary vegetation regrowth.

Action 2	Reduce the likelihood of new invasive species threats
Action 2.1	***Reduce the likelihood of new invasive species entering Christmas Island*** **Priority 1 Action:** new invasive species could have catastrophic effects on the island's biodiversity, as outlined by the Expert Working Group (2010).
	2.1.1 Implement actions to reduce the possibility of entry of high risk invasive species, including extending existing biosecurity measures to address high risk pathways and species. 2.1.2 Prepare a biosecurity risk assessment for Christmas Island which examines the adequacy of existing procedures and requirements to minimise the risk of further introductions of invasive species, including species that may be a threat to human health. 2.1.3 Monitor likely invasive species entry pathways (including the airport, cargo unloading areas and seaport/marine areas and surrounding areas) to detect any new high risk invasive species (plant, animal, disease, pathogen or parasite). 2.1.4 Assess (using monitoring data from Task 2.1.3 and Action 5) the effectiveness of biosecurity strategies and adapt strategies as required.
Action 2.2	***Rapidly eradicate new invasive species that enter Christmas Island*** **Priority 1 Action:** new invasive species could have catastrophic effects on the island's biodiversity, as outlined by the Expert Working Group (2010).
	2.2.1 Develop strategies to rapidly eradicate/respond to new invasive species that may be detected. This will include strategies for high risk invasive species with a high likelihood of entry, as well as strategies to reduce threats from high risk entry vectors. 2.2.2 If new invasive species are detected, implement strategies to rapidly eradicate them before they can establish. This will include but not be limited to species not assessed and approved for import, racing/homing pigeons and Weeds of National Significance. 2.2.3 Assess (using monitoring data from Action 5) the effectiveness of eradication strategies and adapt strategies as required.
Action 2.3	***Assess risk of threat from invasive animals, diseases and pathogens*** **Priority 2 Action:** increased impacts from invasive species could have catastrophic effects on the island's biodiversity, as outlined by the Expert Working Group (2010).
	2.3.1 Conduct risk assessments on invasive animals, diseases and pathogens. 2.3.2 Conduct weed risk assessments. Assessments will consider known highly invasive species and sleeper species present on the island, and their potential impacts on conservation assets (particularly significant species and their habitats). Assessments under tasks 2.3.1 and 2.3.2 will consider known highly invasive species not currently present on island that may have the potential to enter and sleeper species present on the island, and their potential impacts on conservation assets (including significant species). The risk assessment will include distribution and abundance.
Action 3	**Implement secondary threat abatement actions**
Action 3.1	***Manage weeds***
	3.1.1 Control high risk weeds (identified in Action 2.3) that can be feasibly controlled. Currently identified high risk weeds are Siam weed and weed species that have or may be likely to invade shaded/intact rainforests, such as *Clausena excavata*. This will include adopting strategies to minimise any off-target impacts. 3.1.2 Based on weed risk assessments and other relevant information, review and as needed update the Weed Management Plan 2010–2015.

Action 3.2	***Assess and manage the impacts of recreational activities***
	3.2.1 Assess the impacts (using monitoring data from Action 5) of visitors and recreational activities on significant species and their habitat. 3.2.2 If required, implement strategies to minimise visitor and recreational impacts on natural environments. This may include installation of facilities and infrastructure, management of visitor access at sensitive sites or preparation of educational guidelines as part of communication activities (Action 8).
Action 3.3	***Rehabilitate previously mined areas of high conservation potential***
	3.3.1 Continue to implement the Christmas Island Minesite to Forest Rehabilitation program as agreed between DNP and Territories Administration and in accordance with and subject to the mine lease conditions. The program will focus on high priority areas that can be cost effectively rehabilitated, especially rehabilitation of areas of the central plateau located adjacent to Abbott's booby habitat (and including red crab and forest bird habitat) and is based on the methods detailed in Part 5 of this plan and in the long-term rehabilitation plan.
Action 3.4	***Assess and manage the impacts of newly identified threatening processes***
	3.4.1 Assess the level of risk (based on monitoring and survey Action 5 and research Action 6) of newly identified threatening processes. Priority threatening processes/invasive species related to this action include wolf snake, giant centipede and giant African land snail. 3.4.2 If the risks/impacts (actual or potential) of a threatening process are considered unacceptable, investigate and adaptively research and trial management programs to address threatening processes.
Acton 3.5	***Monitor and manage use of subterranean groundwater***
	3.5.1 Map or otherwise quantify the island's baseline groundwater resources, capacity and flow. 3.5.2 Develop a sustainable groundwater use plan for the island that includes assessing and monitoring groundwater habitat values and threats. 3.5.3 Minimise the risks of polluting groundwater resources, including by effectively managing toxic materials/wastes that could leach into and contaminate groundwater. 3.5.4 Prepare agreements between Territories Administration, DNP and WA Department of Water to help monitor, regulate and sustainably manage groundwater use.
Action 4	**Develop and implement targeted recovery programs for declining significant species**
Action 4.1	***Maintain and adaptively develop conservation programs, including captive breeding program, for terrestrial reptiles under threat of extinction in the wild*** **Priority 1 Action:** as there is an imminent risk of extinction in the wild.
	4.1.1 Continue to develop and implement the captive breeding program for native reptiles. The program will aim to provide insurance populations to avoid their extinction in the wild and to breed enough genetically diverse individuals to enable the adaptive re-establishment of wild populations. It will include significant species that can be feasibly caught and bred in captivity, particularly the blue-tailed skink and Lister's gecko and, if needed, the giant gecko. 4.1.2 Develop and implement adaptive programs to trial the reintroduction of captive-bred reptiles into the wild and to monitor their status, if and when threats (particularly those covered by Actions 1.1, 1.2 and 3.4) are sufficiently mitigated.

Action 4.2	**_Establish ex situ cultivation for significant flora species where needed and feasible_**
	4.2.1 Prepare decision support systems to determine if and when to establish *ex-situ* cultivation for: • Christmas Island spleenwort—include reintroduction to areas including, but not restricted to, the east coast terrace cliff tops • the fern *Pneumatopteris truncata* • the fern *Tectaria devexa* var. *minor* • mangrove species at Hosnies Spring. This will include the targets and thresholds determined under Action 9.2 and seeking advice regarding the feasibility of *ex situ* cultivation for the fern *Pneumatopteris truncata,* mangrove species at Hosnies Spring and any other native flora species detected as being in decline. 4.2.2 If a decision is made to cultivate a species, conduct cultivation trials; manage *ex situ* population/s; propagate and translocate plants; and monitor and manage planted population/s in their natural habitat.
Action 4.3	**_Assess the need for and feasibility of captive breeding for other species and implement programs where feasible_**
	4.3.1 Seek advice regarding the need for and feasibility and requirements of a captive management program for the flying-fox. If a decision is made under Action 9.2 that management intervention is required, implement a captive management program in tandem with threat research and threat abatement actions covered elsewhere in the plan. 4.3.2 If the Christmas Island shrew is found: • implement Action 5.2 (conduct survey to locate population) • seek immediate scientific advice on the feasibility of a captive breeding/management program and implement if feasible. 4.3.3 If the Christmas Island pipistrelle is found: • implement Action 5.2 (conduct survey to locate population) • seek immediate scientific advice on the feasibility of a captive breeding/management program and implement if feasible. 4.3.4 If a decline in other native species is detected and a decision is made under Action 9.2 that management intervention is required: • immediately seek scientific advice on the feasibility of a captive breeding program, in tandem with modifying threat research and threat abatement actions covered elsewhere in the plan • if feasible implement a captive breeding program, with the ultimate aim of re-introducing the species to the wild.
Action 4.4	**_Re-establish red crabs in forests_**
	4.4.1 Re-establish red crabs in forests from which they have been eliminated by crazy ants, as a means of helping to assist in the recovery of forest ecosystems. 4.4.2 Monitor the results of red crab re-establishment.
Action 4.5	**_Develop and implement additional programs to recover declining significant species_**
	4.5.1 Implement appropriate threat management or other programs where a significant species has declined to a threshold determined under Action 9.2 and a decision has been made to intervene, including where a species is rediscovered. Appropriate management could include captive breeding or management or other *ex situ* conservation programs, in addition to developing or modifying threat research and threat abatement actions covered elsewhere in the plan.

Action 5	Monitor and survey species and their habitats
Action 5.1	***Implement island-wide ecosystem monitoring*** **Priority 1 Action:** as this is a key activity to detect changes in populations of select significant species.
	5.1.1 Adaptively develop and periodically undertake the Island Wide Survey (IWS). This program is primarily aimed at mapping and monitoring crazy ant supercolonies, including to assess the success of crazy ant control programs, as well as mapping and monitoring red crab burrow abundance and distribution trends. The IWS will also: • continue to monitor Abbott's booby nesting occupancy, flying-fox, forest birds (white-eye, imperial pigeon, emerald dove, thrush and goshawk presence and distribution) • monitor invasive plant and animal species, including cats, rats, Siam weed and *Clausena excavata* (monitoring of Siam weed will include confirmation of whether control programs have been successful) • collect data on opportunistic sightings of significant species, including native reptiles, Christmas Island pipistrelle and shrew.
Action 5.2	***Monitor and survey other significant species*** **Priority 1 Action:** as this is a key activity to detect changes in populations of other significant species.
	5.2.1 Develop and implement monitoring programs for significant fauna species not effectively monitored by the IWS. This will include determining and monitoring threats (e.g. invasive species) impacting or likely to impact on the ecological integrity of ecosystems. Monitoring which will be incorporated in these programs includes but need not be limited to: • flying-fox populations including trends, camps and demographics • Christmas Island hawk-owl distribution and population trends • Christmas Island goshawk population trends and recruitment • Abbott's booby breeding success, population demographics and population trends • Christmas Island frigatebird site occupation and population trends • golden bosun population trends • population trends for forest bird species • targeted surveys to test for the presence and/or persistence of native wild or (where applicable) reintroduced terrestrial reptiles • if the Christmas Island pipistrelle or shrew is located, conducted targeted surveys to determine population extent and habitat • population trends for all other significant species. 5.2.2 If there are indications (e.g. through opportunistic records during other monitoring) that native species previously thought to be stable are in decline, develop and implement a targeted monitoring program for those species.

Action 5.3	***Monitor the annual red crab migration*** **Priority 1 Action:** as this is a key activity to detect how well the red crab population is recovering following crazy ant control.
	5.3.1 Develop a program to monitor the annual red crab migration. 5.3.2 Monitor the patterns, distribution and size of the red crab migration. Methods will include monitoring of the return of red crabs from the sea as well as the spatial pattern and intensity of the migration.
Action 5.4	***Monitor and survey forest and wetland habitats*** **Priority 1 Action:** as this is a key activity to detect changes in forest and wetland ecosystems.
	5.4.1 Survey and map the vegetation of Christmas Island (using where applicable remote sensing techniques and if needed ground-truthing). This will include accurately mapping: • total vegetation cover and detailed vegetation types • habitat critical to survival of significant species as determined under Action 7.1. 5.4.2 Monitor vegetation changes over time using mapping data and via surveys. 5.4.3 Monitor the ecological character of Ramsar wetlands at least every five years. This will include monitoring: • extent of Tahitian chestnut at The Dales • monitor density of mangrove trees and presence of seedlings and saplings at Hosnies Spring • water connection to sea at First, Hugh's and Anderson Dales • surface water area and seasonal duration at Hosnies Spring • blue, red and robber crab presence and migration and/or spawning activity at The Dales and Hosnies Spring.
Action 5.5	***Conduct targeted surveys of significant plant species***
	5.5.1 In order to determine environmental factors affecting distribution, and if needed to determine population size, conduct targeted surveys of known occurrences of: • Christmas Island spleenwort • the fern *Pneumatopteris truncata* • the fern *Tectaria devexa* var. *minor* • mangroves at Hosnies Spring. 5.5.2 Conduct targeted surveys for additional populations of other significant plant species, with those listed as threatened as highest priority, in sites identified through Action 7.1.

Action 6	Conduct research to inform management of significant species and habitat
Action 6.1	***Research threatening processes likely to be impacting significant species*** **Priority 1 Action:** invasive species are the major threat to the island's biodiversity, yet reasons for the decline of some species are not known (as outlined by the Expert Working Group 2010).
	6.1.1 Conduct research on the impacts of threats which may be or are affecting significant species. If impacts are identified, research threat mitigation methods (as required) for significant species (see also Action 3.4). High priority invasive species for which research which has been identified include: • rats • cats • giant centipedes • wolf snakes • flowerpot snakes • introduced ants (see Action 1.1 for crazy ants) • giant African land snails and other exotic land snails
	• introduced bees • pathogens, diseases and parasites • chemical use. 6.1.2 For significant species that are or may be under threat of decline and where threatening processes are not well understood, research potentially threatening processes.
Action 6.2	***Research the biology and ecology of significant species***
	6.2.1 Where necessary for the conservation of species in decline (as based on population monitoring) conduct research on the biology (including, if/as needed, behavioural and taxonomic studies) and ecology of significant species. Current priority research which has been identified includes: • native terrestrial reptiles, including the giant gecko, Christmas Island blind snake and Lister's gecko • Christmas Island frigatebird at-sea feeding ecology • Christmas Island goshawk foraging, nesting and breeding behaviour and habitat preferences as well as taxonomic distinctiveness • Christmas Island hawk-owl foraging, nesting and breeding behaviour and habitat preferences • Christmas Island spleenwort • the fern *Pneumatopteris truncata* ecology and habitat requirements • the fern *Tectaria devexa* var. *minor* • Christmas Island flying-fox ecological and biological studies to inform recovery actions • golden bosun particularly critical nesting habitat • robber crabs • at-sea distribution of Abbott's booby • at-sea lifecycle of red crabs and how this influences the return of red crabs migrating back to land • blue crab reproduction and juvenile dispersal.

Action 6.3	***Research poorly known species***
	6.3.1 In order to determine future conservation requirements, conduct research on species diversity and ecology of: • poorly studied endemic plant species, especially those with small populations (see Appendix C) • non-endemic plant species of possible conservation concern (see Appendix E) • cave dwelling including groundwater fauna • selected priority poorly studied land crab species, especially endemic species with small populations (see Appendix H) • other endemic invertebrates.
Action 7	**Manage and analyse data**
Action 7.1	***Analyse monitoring, survey and research data in order to determine future conservation requirements*** **Priority 1 Action:** as future conservation efforts will not be as effective without assessment of collated data.
	7.1.1 Analyse data collected from Actions 1 to 6 and existing information in a timely manner. This will include: • analysing IWS data • assessing and using monitoring results to help inform management actions, such as managing crazy ants and traffic impacts (Action 1) • identifying sites for targeted surveys (Action 5) • identifying and describing areas of high conservation value. This will include sites with populations of endemic plant species, major red crab migration routes and habitats critical for the survival of threatened and other significant species. These analyses will contribute to Action 9.4.
Action 7.2	***Effectively manage data*** **Priority 1 Action:** as knowledge to inform conservation management is the key to effectively protecting significant species and the island's ecosystems.
	7.2.1 Document knowledge of long-term island residents in relation to significant ecosystem and species changes observed over time, including the red crab migration; and changes in the distribution and abundance of significant and other species, including invasive species. 7.2.2 Develop, maintain and, as needed, update systems to record, store and analyse data, including GIS. Data derived from Actions 3, 5 and 6 will contribute to this task. 7.2.3 Store and enable easy access to research papers and other relevant natural resource management documents and reports.
Action 8	**Communicate with and engage the community and other relevant stakeholders**
Action 8.1	***Develop and implement communication and awareness raising programs*** **Priority 1 Action:** as the success of this plan is largely dependent on informed and supportive stakeholders and an engaged public.
	8.1.1 Develop educational and awareness raising programs which include information about significant species' status, values, and threats, as well as recovery activities and outcomes. This will include but not be limited to: • information about cat and rat control (Action 1), crazy ant control (Action 1) and weed control programs (Action 3)

	• information about existing legislation such as cat by-laws, clearing regulations, protection of native species and requirements for approvals of actions under the EPBC Act and Regulations • information on vehicle impacts on red and robber crabs, road closures and promotion of impact reduction measures (e.g. car pooling and re-timing of works/events and travel) • ways to become involved in recovery activities • threatened species, including updates on progress of their recovery • information on minimising visitor and recreational impacts on significant species, if required (Acton 3.2) • the value of wetlands, including the Ramsar Convention Program of Communication, Education, Participation and Awareness tools. A range of communication methods will be used, such as identification guides, *The Islander* and school-based activities and will take account of the cultural backgrounds of residents. 8.1.2 Publish a booklet on recovery of the island's species based on the biodiversity conservation plan.
Action 8.2	***Promote research partnerships***
	8.2.1 Provide logistical and/or in-kind support for relevant research studies. 8.2.2 Promote research findings and opportunities widely. 8.2.3 Build on existing research partnerships (Part 5 of this plan) and develop new research partnerships.
Action 9	**Coordinate biodiversity conservation plan implementation**
Action 9.1	***Establish and maintain a recovery team*** **Priority 1 Action:** as implementation requires a whole of island approach a team representing island wide responsibilities and relevant scientific expertise is essential.
	9.1.1 Establish a recovery team with appropriate community, scientific and stakeholder representation within the first year of this plan coming into force. The team will be required to undertake the following tasks: • integrate and guide the implementation and monitoring of this plan, particularly for island-wide projects • pursue collaborative funding opportunities, particularly for island-wide projects • facilitate effective off and on island information-sharing and communication • review, consider and advise on management priorities and scheduling • provide regular updates to stakeholders, including the community, on progress in implementing the plan • guide the review of the biodiversity conservation plan in its fifth year of operation.

Action 9.2	***Determine target and threshold criteria for management intervention*** **Priority 1 Action:** as this is critical to our understanding of when to undertake particular actions to prevent species extinctions.
	9.2.1 Use risk management frameworks to assess threats to significant species as an ongoing means of adjusting recovery priorities. 9.2.2 Determine appropriate population measures, baselines and targets/criteria for significant species where required. 9.2.3 Investigate population viability for significant species and determine thresholds for potential intervention. 9.2.4 Establish a framework to guide implementation of relevant actions from this plan and, in particular, to determine when and how to respond if a species declines to its threshold for potential intervention. These tasks will involve experts with relevant expertise on each species and priorities for implementation to be determined under Action 9.1. Species more likely to require intervention (e.g. the flying-fox) are the highest priority.
Action 9.3	***Prepare a business case for funding the implementation of this plan*** **Priority 1 Action:** as additional targeted resources are critical to further halt the decline, and begin the recovery, of significant species.
	9.3.1 Prepare a whole-of-government business case(s) outlining funds required for implementing this plan beyond existing resources (see Part 7 of this plan). This should also include investigation of private sector and non-government organisation resourcing and funding.
Action 9.4	***Monitor and review the implementation of this plan*** **Priority 1 Action:** so management efforts and resources continue to be targeted in the most effective ways to meet the plan's objectives.
	9.4.1 Monitor, report on and evaluate the status of the implementation of this plan annually, including a review of future priorities. 9.4.2 Where needed, seek independent scientific and other specialist advice for adaptively developing and implementing this plan. This may include adjusting existing actions or new actions where monitoring has detected significant declines in native species. 9.4.3 Undertake an independent review of this plan after four years. The review should consider if the plan has been implemented effectively and efficiently; outcomes achieved from the implementation of the actions; whether the objectives have been met; and if plan priorities and actions are still appropriate or need to be revised. 9.4.4 Ensure the actions from this plan and any subsequent reviews are incorporated in future park management plans or other on-island environmental management plans as appropriate.

6.3 Management practices

Management practices and measures to address potential threats other than those contained in the plan have been developed and are being implemented through the CINP management plan; weed and predator management strategies; forest rehabilitation strategies; and quarantine operation procedures.

When using chemicals (e.g. for weed control) Material Safety Data Sheets must be followed to avoid spray drift and other off-target impacts and to ensure chemicals are used in a safe and appropriate manner.

Management practices associated with activities such as the development and maintenance of infrastructure (e.g. roads, new commercial buildings and visitor facilities) should be conducted in ways to avoid significant impacts on native species. Box 1 provides guidance for considering and minimising the impacts of proposed activities and actions but does not replace assessments processes under the EPBC Act (or any other assessments required under any relevant applied WA legislation) as these processes apply regardless of this plan (see Part 1.5 of this plan for details).

Box 1: Guideline for considering and minimising the impacts of proposed activities and actions

These guidelines and practices should be considered to help minimise the potential impacts of actions on Christmas Island's native species and their habitat.

Factors to consider when assessing and/or undertaking a proposed action or activity include but are not limited to:

- biosecurity and quarantine threats
- threats to terrestrial/forest, coastal/marine, wetland and groundwater/subterranean ecosystems, including impacts on the extent and quality of previously uncleared rainforest vegetation
- threats to significant species or their habitats
- threats to protected species listed under Schedule 12 of the EPBC Regulations 2000, including red and robber crabs
- incremental and compounding impacts that may not be immediate
- the capacity of ecosystems to sustain natural processes
- the capacity of the natural environment to meet the needs and aspirations of future generations, for example in relation to water use and fishing activities.

Subject to the assessment and approval processes under the EPBC Act and the nature and scope of a proposed action or activity, management practices or measures should be adopted to avoid, minimise or mitigate impacts of the action or activity on native species and their habitats. These practices and measures should consider at least one of the following:

- alternative low impact proposals or actions such as the use of previously disturbed sites
- avoiding disturbance of sensitive areas such as seabird nesting habitats, previously uncleared rainforest and high density red crab habitat and migration routes
- design measures such as red crab road underpasses, water efficiency designs, minimising impacts of linear infrastructure and effective waste management
- timing of works and activities, for example to avoid impacts on red crabs by not conducting major works or major events during their annual migration and/or at times of the day when red crab activity is at its highest
- work practice or activity impact mitigation, such as the retention of native vegetation on building sites or temporary road closures during the annual red crab migration.

Part 7—Implementation

7.1 Priorities

Determining priorities includes determining priority areas for action to take place; and determining priorities for implementation of recovery actions.

Priority areas

All of Christmas Island's natural areas are of high conservation value. Nonetheless, some areas or ecosystems are considered, through formal protection under the EPBC Act or EPBC Regulations and/or from scientific research and other studies, to be particularly significant. At this point in time the highest priority areas are considered to be:

Relatively intact and previously uncleared forest ecosystems and habitats

While all previously uncleared areas of native vegetation are considered to be of significance, evergreen tall closed forest (as described in Table 5), particularly on the central plateau, is of particular importance as it provides habitat for several endemic and threatened species, including habitat critical for the Abbott's booby. Uncleared rainforest vegetation also provides habitat for the endangered Christmas Island frigatebird and Christmas Island flying fox, as well as important habitat for red crabs. Areas of high red crab densities may change over time due to several factors, including recovery from, or as a result of, crazy ant impacts, and are generally located in areas of uncleared rainforest vegetation. While migration routes may be broadly defined, the intensity and patterns of the red crab migration around the island may vary each year. Consequently, important actions of this plan are to continue to map areas of high crab densities, through the Island Wide Survey, and further research the red crab migration routes.

The Dales and Hosnies Spring declared Ramsar wetlands

While there are other wetlands on the island, The Dales and Hosnies Spring are considered the most significant. This is because they are listed as wetlands of international importance under the Ramsar Convention on wetlands due to their unique ecological characteristics (see Part 3.1.2 of this plan). These wetlands also play a broader role in the ecology of the island, for example as critical and drought/refuge habitat for species such as forest birds, blue crabs and mangrove species (at Hosnies Spring).

Subterranean, cave and groundwater ecosystems

The island's subterranean systems provide habitat for several endemic invertebrate species and contain one of only two anchialine habitats known in the southern hemisphere. While many cave sites are known, subterranean and groundwater ecosystems and species remain poorly defined and surveyed. As the island's groundwater systems provide water for human uses, their sustainable management is important for both conservation and human use purposes.

Christmas Island National Park

The spatial definition of the park may be arbitrary in ecological terms, however, Christmas Island National Park's status as a Commonwealth reserve under the EPBC Act, which protects representative examples of the island's rainforest ecosystems (as well as the island's two Ramsar wetlands) and habitat for significant species, makes the park a priority area.

Prioritisation of recovery actions

Prioritising recovery actions for implementation was based on the following principles:

1. The use of evidence from scientifically sound research and monitoring programs and advice should guide the adaptive implementation and monitoring of management actions/responses. This includes incorporation of relevant priorities identified by the Expert Working Group (2010).
2. Ongoing assessments and prioritisation of threats to native species should use a risk management framework and recognise the feasibility of addressing threats.
3. The impacts and risks of not implementing particular recovery actions (based on the above point) should be identified.
4. The likelihood of actions addressing ecosystem or multiple species threats and objectives should be assessed.
5. The costs, benefits and effectiveness of implementing proposed recovery actions should be identified.
6. The level of or ability to gain stakeholder, community and organisational support, including technical and financial support, as well as community expectations that action should be taken (e.g. in relation to protection of red and robber crabs from traffic impacts), particularly for actions requiring long-term island-wide responses should be taken into account.

The results of the threat risk assessment, including explanatory notes, are shown in Appendix I. This assessment has resulted in prioritisation of the actions, as shown in Table 9, to abate the 'major risk threats' being given the highest priority rating. As all recovery actions are considered essential to meeting the objectives of this plan, the priorities are relative to other recovery actions only. In future these priorities may change depending on the results of recovery actions, changes to circumstances, and changes in knowledge, including through ongoing threat assessments.

7.2 Implementation stakeholders

The DNP assisted by Parks Australia (a division of the Department of the Environment) is the major agency with responsibilities for biodiversity conservation on Christmas Island. Christmas Island National Park is managed by the DNP and covers approximately 63 per cent of Christmas Island; as such the DNP (with, where applicable, relevant Commonwealth agencies) will have a major role in the implementation of this plan's actions. However, implementation of several of the actions, for instance, invasive species control, protection of land crabs from traffic impacts and the sustainable use and management of groundwater, may require responses over different land tenures and the collaboration and/or cooperation of a number of relevant organisations and agencies. These organisations and agencies may include, but are not be limited to, the Territories Administration; SOCI; DIBP; CIP; the Department of Agriculture; and off-island organisations such as research organisations.

Previous relationships and collaboration will be continued under this plan. While one of the roles of the recovery team is to determine implementation of priorities and to work with the delivery partners to establish responsibilities for implementing certain actions, a number of agencies have already identified they will have a role in specific actions.

DIBP has identified a role in:

- contributing communication and engagement planning skills to the recovery team
- continuing to support the feral cat management program through providing in-kind support
- contributing resources and staff time to education programs for residents and visitors.

Territories Administration has identified a role in:

- any changes to speed limits required to protect crabs during migration
- potential for a partnership to map and understand the groundwater system.

The Commonwealth, under s269 of the EPBC Act, must implement a recovery plan to the extent to which it applies to Commonwealth areas. This plan does not bind and there is no obligation on individuals, businesses or other organisations, including SOCI, to contribute resources or funds to implement this plan. However, it is hoped that this plan will help maintain or enhance opportunities for collaboration in regard to supporting the implementation of priority recovery actions, particularly those needing island-wide responses.

The recovery team will have a role in guiding the plan's collaborative implementation (as described under Action 9.1). The recovery team will have appropriate community, scientific and stakeholder representation. Membership may change over the life of the plan, and specific expertise may be called on to provide advice on specific issues.

7.3 Timing and costs

The estimated total cost of the biodiversity conservation plan is $58.865m over 10 years. Table 9 provides a breakdown of the estimated costs, including which actions are currently funded, including through the annual budget of the DNP for management of Christmas Island National Park.

The costs are based on a mix of estimates including the cost of conducting similar actions over the last few years; projections based on the historical cost of conducting the same on-going operations; and more detailed costings of particular actions. The more detailed cost estimates include:

- cat and rat control costs which are broadly based on the *Proposed management plan for cats and rats on Christmas Island* (Algar & Johnston 2010)
- crazy ant control costs which are based on a proportion of funding allocated to crazy ant control over the period 2011–12 to 2015–16 (noting that this funding also supports monitoring of crazy ant impacts and other invasive species control work)
- mining site rehabilitation costs which are based on the per hectare funding modelling from the *Christmas Island Minesite to Forest Rehabilitation Plan 2012–2020* (DNP 2012g).

Implementing the actions identified in the plan is subject to budgetary and other constraints affecting the key stakeholders, particularly the Commonwealth. Given the length of the biodiversity conservation plan and external factors impacting funding it is not practicable to provide a year-by-year budget.

Recovery Action 9.3 includes developing a business case which will detail funding required for implementation of this plan.

7.4 Plan review

The plan will be implemented over a ten year period and a review to determine whether variation is required will be conducted in the fifth year (Action 9.4). The review should be guided by the Christmas Island recovery team. This review is not intended to replace the ongoing need for adaptive management approaches, for instance when new information arises from research studies that will inform management decisions, priorities and actions. The recovery team will guide annual assessments of the status and success of the implementation of this plan.

Table 9: Estimated cost and current priority of recovery actions

	ACTIONS[a]	Total cost ($) over 10 years EXISTING FUNDING	Total cost ($) over 10 years ADDITIONAL FUNDING	Total cost ($) over 10 years TOTAL FUNDING	Action Priority[b]
Action 1 Continue threat abatement actions to address major threats					
1.1	*Control and reduce the impacts of crazy ants*	4,000,000	3,500,000	7,500,000	1
1.2	*Control and reduce the impacts of cats and rats*	500,000	4,500,000	5,000,000	1
1.3	*Reduce vehicle impacts on significant species, particularly red crabs during their annual migration*	1,500,000	1,000,000	2,500,000	1
1.4	*Continue to assess the environmental impacts of proposals in accordance with relevant legislation*	n/a[c]	n/a[c]	n/a[c]	1
Action 2 Reduce the likelihood of new invasive species threats					
2.1	*Reduce the likelihood of new invasive species entering Christmas Island*	3,500,000	3,500,000	7,000,000	1
2.2	*Rapidly eradicate new invasive species that enter Christmas Island*	200,000	800,000	1,000,000	1
2.3	*Assess risk of threat from invasive animals, diseases and pathogens*	100,000	500,000	600,000	1
Action 3 Implement secondary threat abatement actions					
3.1	*Manage weeds*	750,000	1,500,000	2,250,000	2
3.2	*Assess and manage the impacts of recreational activities*	500,000	500,000	1,000,000	2
3.3	*Rehabilitate previously mined areas of high conservation potential*	13,600,000[d]	0	13,600,000[d]	2
3.4	*Assess and manage the impacts of newly identified threatening processes*	500,000	1,500,000	2,000,000	2
3.5	*Monitor and manage use of subterranean groundwater*	0	350,000	350,000	3
Action 4 Develop and implement targeted recovery programs for declining significant species					
4.1	*Maintain and adaptively develop conservation programs, including captive breeding, for terrestrial reptiles under threat of extinction in the wild*	600,000	1,400,000	2,000,000	1
4.2	*Establish* ex situ *cultivation for significant flora species where needed and feasible*	20,000	200,000	220,000	3
4.3	*Assess the need for and feasibility of captive breeding for other species and implement programs where feasible*	0	2,000,000	2,000,000	2
4.4	*Re-establish red crabs in forests*	0	200,000	200,000	3
4.5	*Develop and implement additional programs to recover declining significant species*	500,000	1,000,000	1,500,000	2

ACTIONS[a]		Total cost ($) over 10 years EXISTING FUNDING	Total cost ($) over 10 years ADDITIONAL FUNDING	Total cost ($) over 10 years TOTAL FUNDING	Action Priority[b]
Action 5 Monitor and survey species and their habitats					
5.1	*Implement island-wide ecosystem monitoring*	1,000,000	1,000,000	2,000,000	1
5.2	*Monitor and survey other significant species*	800,000	1,200,000	2,000,000	1
5.3	*Monitor the annual red crab migration*	200,000	300,000	500,000	1
5.4	*Monitor and survey forest and wetland habitats*	200,000	800,000	1,000,000	1
5.5	*Conduct targeted surveys of significant plant species*	100,000	200,000	300,000	2
Action 6 Conduct research to inform management of significant species and habitat					
6.1	*Research threatening processes likely to be impacting significant species*	250,000	750,000	1,000,000	1
6.2	*Research the biology and ecology of significant species*	400,000	700,000	1,100,000	2
6.3	*Research poorly known species*	100,000	400,000	500,000	3
Action 7 Manage and analyse data					
7.1	*Analyse monitoring, survey and research data in order to determine future conservation requirements*	200,000	200,000	400,000	1
7.2	*Effectively manage data*	100,000	100,000	200,000	1
Action 8 Communicate with and engage the community and other relevant stakeholders					
8.1	*Develop and implement communication and awareness raising programs*	100,000	150,000	250,000	1
8.2	*Promote research partnerships*	50,000	50,000	100,000	2
Action 9 Coordinate biodiversity conservation plan implementation					
9.1	*Establish and maintain a recovery team*	0	500,000	500,000	1
9.2	*Determine target and threshold criteria for management intervention*	0	200,000	200,000	1
9.3	*Prepare a business case for funding the implementation of this plan*	0	20,000	20,000	1
9.4	*Monitor and review the implementation of this plan*	0	75,000	75,000	1
TOTAL COST OF PLAN OVER 10 YEARS:		**29,770,000**	**29,095,000**	**58,865,000**	

(a) All actions are considered essential to achieve the objectives. Estimated costs of actions are based on a mix of estimates including the cost of conducting similar actions over the last few years; projections based on the historical cost of conducting the same on-going operations; and more detailed costings of particular actions. The costs of actions have been estimated individually and the total amount does not reflect efficiency savings that would result from integrated management approaches such as for invasive species management.

(b) Priority levels are relative only to other actions within the plan and reallocation of funds will be subject to priorities, as described in Part 7.1 of this plan.

(c) Not applicable as environmental assessment processes under the EPBC Act (or other relevant legislation) apply regardless of this biodiversity conservation plan so are not considered an additional cost associated with the plan.

(d) Amount subject to amount of conservation levy payable under the mine lease.

7.5 Social and economic benefits and impacts

Implementing this biodiversity conservation plan is expected to have positive social and economic consequences for the Christmas Island, Australian and international communities, through the recovery of threatened species and avoiding further loss of native species.

Significant adverse social or economic impacts are not expected as a result of implementation, but during preparation of the plan some stakeholders raised concerns that the implementation of the plan may impact on existing and future development activities on the island. However, on further consultation these stakeholders did not identify any specific actions in the plan that were of concern and that could result in such an outcome.

Although the information in this biodiversity conservation plan may be used to help assess the impacts of proposals that may trigger the assessment and approval provisions under the EPBC Act, proponents (organisations and individuals) are required to comply with the provisions of the EPBC Act regardless of whether a recovery plan is in place or not. In addition, the biodiversity conservation plan does not affect the operation of activities that are undertaken consistent with an existing approval under the EPBC Act or are subject to exemptions under the EPBC Act, including activities undertaken consistent with a 'prior authorisation' or that constitute a 'continuing use' (see Part 1.5 of this plan for more detail). The information collated in this plan was sourced from existing documents and reports, including the nine existing recovery plans for Christmas Island's species and the Expert Working Group report, and the collation of this information may help make environmental assessment and approval considerations more transparent for the Christmas Island community and the broader public.

Anticipated social and economic impacts from the implementation of this plan's actions are considered minimal. Further changes to use of the road network to enhance protection of native species, particularly red crabs during their migration, may lead to slightly increased travel times for residents and visitors. This already occurs during red crab migration and generally has wide community and organisational support. If increased quarantine and bio-security efforts are applied, there may be inconvenience and delays to residents and visitors, especially with regard to shipping of goods. However, there would also be potential benefits. For instance, the likelihood of the entry of species that may impact on human health, such as mosquitoes carrying dengue fever and malaria, could be reduced.

Anticipated social and economic benefits are detailed below, and include:

- more efficient and effective coordination of recovery efforts
- nature-based tourism and recreational benefits
- environmental management and research
- ecosystem services and products.

7.5.1 More efficient and effective coordination of recovery efforts

This plan addresses threats to significant species of Christmas Island including red crabs. Incorporating single species and ecosystem-wide recovery actions into one plan will assist with the effective coordination of recovery actions, such as invasive species control, and the efficient and effective use of available resources and funding.

Monitoring the plan's implementation, and the ongoing review of priorities, will enable the recovery team and delivery partners to ensure available resources are used to gain the most conservation benefit. Through identifying a number of priority actions to manage the principal threats to a number of significant species and their habitats, this plan enables the most efficient and effective use of available resources. This is one of the key benefits of having a single island wide biodiversity conservation plan rather than up to 17 separate plans for the listed taxa.

As noted under Part 7.2, several collaborative and cross-tenure recovery programs were operating during the preparation of this plan. This demonstrates the benefits of agencies and stakeholders working in a collaborative fashion to achieve recovery outcomes. The continuation of this approach may have broader positive benefits and contribute to maintaining a collaborative approach between agencies in other areas of their work on Christmas Island. As outlined in Part 5.1 of this plan, the cat and rat management program is one example of where this is successfully working. Such partnerships will be important for securing funding in the future.

7.5.2 Sustainable tourism and recreational benefits

Nature-based tourism refers to tourism opportunities and experiences which are based on ecologically sustainable visitation (Tourism WA 2006) to natural areas and which foster environmental and cultural understanding, appreciation and conservation (Ecotourism Australia 2012). The term nature-based tourism is often interchanged with ecotourism. Sustainable tourism is another term often used and it refers to the maintaining a balance between tourism and conservation. In 2009, 64 per cent of international visitors to Australia participated in nature-based tourism, with significantly longer lengths of stay per trip compared to visitors who did not participate in nature activities (Tourism Australia 2009).

The uniqueness of Christmas Island's natural heritage and its current and future potential to support nature-based tourism and development is widely recognised. For example, the Christmas Island Tourism Association (CITA) states 'Christmas Island is one of nature's most impressive feats, an island full of natural wonders: from the unique annual red crab migration to rare and unusual birds'. Similarly, 'with a proper plan, tourism and other natural industries that rely on natural attractions of the island that may be established' (Zekulich 2008). Furthermore, the Commonwealth Parliament's *Inquiry into the changing economic environment in the Indian Ocean Territories* in 2010 recommended that Christmas Island stakeholders 'examine ways to diversify the local economy with a focus on developing tourism'. Likewise, the 2018 Plan considered the further development of tourism, with an emphasis on low-impact, high-yield tourism, to be one of several vital aspects for the island's social and economic sustainability.

Christmas Island currently attracts a relatively small number of nature-based tourists but because of the island's natural and cultural attractions, there is potential for numbers to increase. In recent years there have been a number of significant nature-based tourism and conservation-focused events on Christmas Island. These include the annual Bird Week and the Underwater Festival, organised by CITA; the Indian Ocean Seabird Conference in 2008; and educational activities, such as annual visits by international schools, hosted by the Christmas Island District High School. It is estimated that in 2002 tourism contributed $3–5 million to the Christmas Island economy (Planning for People 2008).

The 2010 inquiry into the changing economic environment (Joint Standing Committee on the National Capital and External Territories 2010) acknowledged a number of challenges but found that tourism could provide a new economic driver on Christmas Island, 'spurring complementary industries and moving the economy towards greater sustainability'.

Tourism Australia defines a number of markets for international visitors to Australia, and Christmas Island's unique species and their habitats are ideally placed to target the experience seeker market (Planning for People 2008). Experience seekers:

- are highly interested in travel for travel's sake—it is a big part of their life
- look for inspiration; research extensively; take all their needs and wants into consideration; and often know where they are going next—there are so many destinations geared for them
- are intrigued by stories of exotic places, people, lifestyle, histories and environment
- yearn for ways to involve themselves in experiences with exotic places and people's lifestyles and histories
- recognise the role of communications and mass media but tune into personally relevant information.

The key, however, to having a nature-based tourism product is having an environment that is sufficiently preserved and unique (CIP 2010). Consequently, achieving the vision of this plan by preserving and recovering the island's unique native species will be fundamental to maintaining the island's natural visitor attractions. This will in turn play a part in supporting nature-based sustainable tourism on Christmas Island.

7.5.3 Environmental management, research and education

The 2018 Plan considered economic diversification as being vital the sustainability of the Christmas Island, and that there was a need to investigate the establishment of centre/s for international education and scientific research, as these were some of several industries that the community would embrace.

At the time of preparing this plan the Christmas Island District High School and a local tour company, had facilitated several international school visits over a number of years. These visits had a large environmental educational focus centred on the island's natural features and native species, including red crabs. In addition, each year several researchers visit Christmas Island to conduct environmental research, such as on species that are unique (endemic) to Christmas Island. These activities have the potential to expand and promote the island's natural values, whilst helping support the island's economy. As with nature-based tourism, environmental research and educational activities rely on preservation of the island's natural environment.

Furthermore, the information gained through environmental management and research activities associated with this plan may contribute information that may be valuable for other conservation managers, both in Australia and internationally.

7.5.4 Ecosystem services and products

Christmas Island's ecosystems provide a number of services and products that are used by and benefit the Christmas Island community and visitors. These include storage and filtration of the island's water supply; regulation of the local climate; nature-based recreational activities; and provision of fish habitat, enabling fish to be caught for human consumption. If the island's ecosystems become degraded, these products and services may no longer be available or may be of diminished quantity or quality. Implementing some recovery actions, for example the sustainable management of groundwater and the control of crazy ants, will help ensure that some ecosystem products and services can continue to be sustainably provided in the future.

7.6 Affected interests

The interests listed below may be affected by the plan's implementation as they own or manage relatively large areas of land (or may otherwise influence the way land is managed). Consequently, these parties may be affected by and/ or have a role in the implementation of recovery actions, for instance, invasive species control and environmental monitoring, which may need to occur across different land tenures. The major affected interests are:

- Administrator of Indian Ocean Territories
- Director of National Parks, Department of the Environment
- Territories Administration
- Department of Immigration and Border Protection
- Shire of Christmas Island
- Department of Agriculture
- Christmas Island Phosphates.

As Commonwealth agencies, the Australian Federal Police (AFP), Australian Customs and Border Protection Service (ACBPS) and Royal Australian Navy (RAN) may be affected by this plan. However, because they do not directly own and/or manage land areas, their role in relation to implementing or being affected by this plan is likely to be minimal. Their roles may include the AFP enforcing vehicle speed limits as part of their ongoing duties (which may help reduce crab deaths) and the RAN and ACBPS promptly disposing of suspected illegal entry vessels (SIEVs) that carry asylum seekers to Christmas Island's waters (in order to minimise the risks of biosecurity threats).

There are a number of relevant WA government agencies, such as, but not limited to, the Department of Parks and Wildlife and Department of Fisheries, that provide services under service delivery agreements with Territories Administration. WA agencies are unlikely to be directly affected by this plan but the plan may be used to help guide the types of environmental services that are conducted under relevant service delivery agreements, for example in relation to invasive species control.

There are also a number of non-government organisations, businesses and individual land/house owners on Christmas Island. Non-Commonwealth government organisations and individuals are not bound by or obliged to implement this plan, but may choose to support the implementation of recovery actions. Consequentially, it is not anticipated that they will be negatively affected by this plan. Social and economic effects are considered to be minimal and are described in Part 7.5 of this plan.

7.7 International agreements

Australia is a signatory to a number of international agreements relevant to this biodiversity conservation plan. This plan is consistent with Australia's international responsibilities under these agreements, and implementation of the plan will help meet these obligations. Appendix B describes the international agreements which relate to species on Christmas Island.

Glossary and acronyms

In this plan:

Administrator means the Commonwealth Administrator of the Indian Ocean Territories

AFMA means the Australian Fisheries Management Authority

Anchialine means a subterranean water body with connections to the ocean

BMP or **Biodiversity Monitoring Program** means the 2003–2007 biodiversity monitoring programme funded by the Department of Finance and Deregulation and carried out by the Director of National Parks

Bonn means the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)

CAMBA means the Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment

CIMFR or **rainforest rehabilitation program** means the Christmas Island Minesite to Forest Rehabilitation Program

CINP or **Christmas Island National Park** means the area declared as a national park by that name under the *National Parks and Wildlife Conservation Act 1975* and continued under the EPBC Act by the *Environmental Reform (Consequential Provisions) Act 1999*

CIP means Christmas Island Phosphates, also known as Phosphate Resources Limited (PRL)

CITA means the Christmas Island Tourism Association

CITES means the Convention on International Trade in Endangered Species of Wild Fauna and Flora

Crazy ant/s means the yellow crazy ant (*Anoplolepis gracilipes*)

CSIRO means the Commonwealth Scientific and Industrial Research Organisation

DAFWA means the Western Australian Department of Agriculture and Food

DIBP means the Australian Government Department of Immigration and Border Protection

DNP or **Director** means the Director of National Parks under s.514A of the EPBC Act, and includes Parks Australia and any person to whom the Director has delegated powers and functions under the EPBC Act in relation to Christmas Island National Park

Department means the Australian Government Department of the Environment or such other department or agency that succeeds the functions of the Department

ECD or Ecological Character Description means descriptions of Ramsar wetlands

Ecological community means an assemblage of interdependent plant and animal species interacting with one another in a particular area

Ecological integrity is "the ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region. An ecological system has integrity, or a species population is viable, when its dominant ecological characteristics (e.g. elements of composition, structure, function, and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions." (Parrish et al. 2003)

Ecosystem means an ecological community together with the physical non-living environment interacting as a functional unit

EDCG means Economic Development Consultative Group

Endemic means native plant and animal species that have a restricted geographical distribution and, for the purposes of this plan, species that are only found on Christmas Island and nowhere else in the world

EPBC Act means the *Environment Protection and Biodiversity Conservation Act 1999*, including Regulations under the Act, and includes reference to any Act amending, repealing or replacing the EPBC Act

EPBC Regulations means the Environment Protection and Biodiversity Conservation Regulations 2000 and includes reference to any Regulations amending, repealing or replacing the EPBC Regulations

EWG means the Christmas Island Expert Working Group established to advise the Minister on conservation of biodiversity on Christmas Island

Exotic species means species not native to Christmas Island

Ghost forests are forest from which the resident Red Crabs have been eliminated by the direct impact of yellow crazy ants

High risk invasive species means invasive species that has been identified through a risk assessment process as having an impact on a significant species

IDC means the Immigration Detention Centre at North West Point on Christmas Island

Introduced species means species (plant, animal, disease, pathogen or parasite) not native to Christmas Island

Invasive species means exotic introduced species (plant, animal, disease, pathogen or parasite) that threatens native flora and fauna

Island or **the island** means the Territory of Christmas Island located in the Indian Ocean unless otherwise stated

IUCN means the International Union for Conservation of Nature

IWS means the 'Island Wide Survey' monitoring program, as described in Part 5.9

JAMBA means the Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds and Birds in Danger of Extinction and their Environment

Keystone species means those native species whose removal or substantial decline would result in major changes to ecosystem structure and function

Landscape means an area of land composed of interacting ecosystems that are repeated in a similar form throughout an area and include living and non-living natural aspects as well as human influenced or made aspects

Minister means the Minister administering the EPBC Act

MOU means Memorandum of Understanding

Native species means species which occur on Christmas Island but may also naturally occur at other locations

Nature-based tourism means tourism opportunities and experiences which are based on ecologically sustainable visitation to natural areas and which foster environmental and cultural understanding, appreciation and conservation

Park or **the national park** means Christmas Island National Park

Parks Australia means that part of the Department that assists the Director of National Parks in performing the Director's functions under the EPBC Act

PRL means Phosphate Resources Limited, also known as Christmas Island Phosphates (CIP)

Ramsar means the Convention on Wetlands of International Importance (Ramsar Convention)

Recovery plan, the plan or **this plan** means the Christmas Island Biodiversity Conservation Plan unless otherwise stated

ROKAMBA means the Agreement between the Government of Australia and the Government of the Republic of Korea for the Protection of Migratory Birds and their Environment

SOCI means the Shire of Christmas Island

Stygofauna means subterranean fauna living in freshwater-filled voids

Supercolony means an area of high density crazy ants comprised of multi queen colonies that is determined based on density of crazy ants that result in red crab mortality. A supercolony is determined using a standardised density monitoring method

Territories Administration means the Australian Government department with responsibility for administering the Christmas Island Act. At the time of preparing this plan that agency is the Department of Infrastructure and Regional Development

WA means Western Australia

Working Group means the Christmas Island Recovery Plan Working Group

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Appendix A—How the recovery plan addresses the Government response to the recommendations of the Expert Working Group

Recommendations to protect the integrity of Christmas Island ecosystems from further unwanted introductions, prevent additional detrimental changes to the landscape and establish better environmental governance and management frameworks for the island

Expert Working Group Recommendation	Australian Government Response	How Addressed in Recovery Plan
Recommendation 1: (High priority) Biosecurity management on Christmas Island be upgraded urgently to a standard commensurate with the Island biodiversity values using Chevron Australia's Barrow Island Quarantine Management System as a model (see sections 3.3.4, 4.2, 4.5.4 and 4.6).	Enhancement of biosecurity management supported in principle, subject to availability of additional resources	Addressed by actions 2.1 and 2.2
Recommendation 2: (High priority) The governance of Christmas Island be modified so that environmental governance, including matters of biological protection, conservation management and quarantine, is brought under a single authority with both the power and the resources to be effective (see sections 4.2, 4.3.1 and 4.6).	Not supported	Not addressed (not appropriate)
Recommendation 3: (High priority) The pressures on the environment posed by the increasing use of the Island as an Immigration Detention Centre and the continuation of mining be recognised and minimised or adequately managed through new governance arrangements, with biodiversity conservation being the highest priority. This must include much better management of the roads between the Settlement and the IDC to greatly reduce the high level crab deaths due to vehicles (sections 3.2, 3.3.4, 4.5.7 and 4.11).	Supported in part Better management of roads between the Immigration Detention Centre and settlement is supported however major changes to governance arrangements not required and not supported	Addressed in part by action 1.3

Expert Working Group Recommendation	Australian Government Response	How Addressed in Recovery Plan
Recommendation 4: (High priority) The utilisation and management of surface and subterranean water and coastal marine waters be addressed as part of improved island governance (section 4.5.7). In practice this recommendation should include the following: 1. Urgent completion of a Service Delivery Agreement between the Attorney General's Department and the Western Australian Department of Water so that the water supply on Christmas Island can be properly regulated. 2. Proclamation of Christmas Island as a water reserve under relevant WA legislation and development of a Water Resource Management Plan ensuring that water allocation is dependent on a licence with suitable conditions issued by the Department of Water in consultation with the authority proposed in Recommendation 2. Water supply to be permitted only where it is sustainable for both human use and environmental needs. 3. Development of a groundwater model for Christmas Island and installation of new monitoring bores as required to ensure model calibration and the sustainability of water use. 4. Sharing of costs associated with implementation of the above recommendations between the Commonwealth government and the WA Water Corporation.	Supported in principle, subject to availability of additional resources and further detailed consideration of appropriateness of proposed actions	Addressed by action 3.5
Recommendation 5: Priority (High priority) Environmental management of the island, including quarantine, research, restoration, environmental approvals and associated compliance, be improved through a single line budget, an appropriate level of funding and management accountability supported by a scientific advisory system and an appropriate research facility (section 4.3.1, 4.5.3 and section 6).	Not supported	Not addressed (not appropriate)
Recommendation 6: Priority (High priority) Where commercial leases or other commercial regulatory instruments exist or are proposed, their negotiation should include additional resources to research and manage areas or matters of high conservation importance (sections 4.5.6 and section 6 lesson 5).	Supported	Not addressed (out of scope)
Recommendation 7: (High priority) A science management strategy be developed for Christmas Island as a whole and the management lessons identified elsewhere in this report become part of this process and a Christmas Island Conservation Research Centre be established (sections 4.3.1, 4.5.3 and 4.13).	Supported in principle, subject to availability of additional resources	Not specifically addressed (out of scope) but addressed generally by actions 7.1. and 7.2; and key research and monitoring priorities being identified

Expert Working Group recommendations for management of the island's ecological processes so as to prevent further loss of biodiversity

Expert Working Group Recommendation	Australian Government Response	How Addressed in Recovery Plan
Recommendation 8: (High priority) In the absence of any alternative, baiting Yellow Crazy Ant supercolonies with Fipronil continues as a short-term control measure, but with greatly enhanced monitoring of its non-target effects (sections 4.4 and 4.5.3).	Supported	Addressed by actions 1.1 and 5.1
Recommendation 9: (High priority) The initial steps taken already to explore biological control of the introduced scale insects be accelerated and biological control trials be started as soon as possible (sections 4.4, 4.5.3, 4.11.1). In addition helicopter bait delivery trials be conducted over larger areas of the island with the aim of preventing rapid re-establishment of Yellow Crazy Ant supercolonies. These and other initiatives should be implemented within an adaptive management and integrated pest control framework (sections 4.4 and 4.11.1).	Supported, subject to the development of new baits	Addressed by action 1.1
Recommendation 10: (High priority) Monitoring of biodiversity condition and trends be continued but with a high priority for continuous improvement and adaptive management that is informed by the independent scientific advisory system of Recommendations 5 and 7 (sections 4.3.2, 4.13).	Supported subject to availability of additional resources	Addressed by actions 5.1 to 5.5
Recommendation 11: (Medium to High priority) Threats to the island's subterranean fauna and marine ecosystems be assessed and appropriate processes developed to address them (section 4.14).	Supported in principle, subject to availability of additional resources	Addressed in part by actions 3.5 and 6.3 (marine element out of scope)
Recommendation 12: (High priority) A comprehensive review that builds on this report be commissioned to determine gaps that must be filled in our understanding of the biology and population ecology of Red Crabs. Subsequently commissioned research needs to focus on informing adaptive management that concentrates on crab population enhancement and reestablishment in areas from which they have been eliminated (sections 4.4, 4.9.2 and 4.11.1).	Supported in principle, subject to availability of additional resources	Addressed in general terms by action 6.2
Recommendation 13: (Medium priority) Red Crabs be re-introduced experimentally to ghost forests (section 4.4).	Supported in principle, subject to availability of additional resources	Addressed by action 4.4
Recommendation 14: (High priority) Robber Crabs be given a high conservation priority and a study of their population ecology and key threats be undertaken as soon as possible (section 4.11.2).	Supported in principle, subject to availability of additional resources	Addressed in general terms by action 6.2
Recommendation 15: (High priority) Eradication of Black Rats and Feral Cats from Christmas Island be carried out as soon as possible in a coordinated project and research into rat eradication commence as soon as possible (sections 4.5.2.2 and 4.9.2).	Supported in principle, subject to availability of additional resources	Addressed by action 1.2

Expert Working Group Recommendation	Australian Government Response	How Addressed in Recovery Plan
Recommendation 16: (High Priority) A comprehensive program of invertebrate biodiversity research be undertaken resolved to a high taxonomic level and that the definitive collection of Christmas Island invertebrates be housed in a recognised public fauna collection with only non-critical voucher specimens retained on Christmas Island (sect 4.13).	Supported in principle, subject to availability of additional resources	Addressed in general terms by action 6.3
Recommendation 17: (Medium priority) Potential 'sleeper' species of both exotic plants and animals be identified and those species identified as being a high threat to the island's biodiversity be eradicated (section 4.5.1).	Supported in principle, subject to availability of additional resources	Addressed by actions 2.3, 3.1 and 5.4
Recommendation 18: (High priority) Sampling take place to establish baseline levels of prevalence of pathogens, disease and parasites in selected endemic animals and plants (section 4.5.4).	Supported (completed)	Addressed in part by action 6.1
Recommendation 19: (High priority) Sampling take place to establish disease (including parasite) levels in exotic plants and animals now present on Christmas Island (specifically including Black Rats, Feral Cats, Dogs, Tree Sparrows, Java Sparrows, House Geckos, Wolf Snakes and Giant African Land Snails) (section 4.5.4).	Supported (completed)	Addressed in part by action 6.1
Recommendation 20: (Medium priority) A program of regular and robust monitoring of these pathogen levels be developed (section 4.5.4) and **Recommendation 21: (Medium priority)** The development of a response protocol and framework associated with the monitoring program be undertaken (section 4.5.4).	Supported in principle	Addressed in part by action 6.1

Expert Working Group recommendations for management actions that can be taken immediately to prevent or slow biodiversity loss

Expert Working Group Recommendation	Australian Government Response	How Addressed in Recovery Plan
Recommendation 22 (High priority) A program for checking for the presence of the Pipistrelle be continued for the next two years, with a response protocol in place for implementation should a detection occur (Section 4.7).	Supported (being implemented)	Addressed by action 5.2
Recommendation 23 (High priority) All proposals for land clearance and resource extraction on the island be subject to rigorous assessment and amendment where necessary to prevent significant impact on Island biodiversity. Where land clearance and resource extraction is approved associated conditions should be locally monitored and enforced (section 4.5.6).	Supported	Not addressed (out of scope)
Recommendation 24: (High priority) The costs / benefits and need for a flying fox captive breeding program be considered, for establishment, if recommended, by December 2010 (section 4.10).	Supported in principle (longer timeframe required)	Addressed by actions 4.3 and 9.2
Recommendation 25: (High priority) Appropriate monitoring and targeted research be conducted to identify major threatening processes for the endemic flying fox (Section 4.10).	Supported in principle, subject to availability of existing resources	Addressed by actions 5.2 and 6.2
Recommendation 26: (High priority) Measures be implemented immediately to exclude Cats from Red-tailed Tropicbird nesting areas along the Settlement shoreline (section 4.9.2).	Supported, subject to availability of additional resources above those already committed	Addressed by action 1.2
Recommendation 27: (High priority) The recently established captive breeding program for the Blue-tailed Skink, Lister's Gecko and Forest Skink be continued (section 4.8).	Supported (being implemented)	Addressed by action 4.1
Recommendation 28: (High priority) Appropriate monitoring and/or targeted research be conducted to identify major threatening processes for endemic reptiles (section 4.8).	Supported, subject to availability of additional resources	Addressed by action 5.2
Recommendation 29: (High priority) Fundamental investigations continue and be augmented by adaptive management and aspects of Integrated Pest Control experimental work to develop cost-effective methods to break the scale insect—Yellow Crazy Ant mutualistic dependence (sections 4.4 and 4.5.3).	Supported	Addressed in general terms by action 1.1
Recommendation 30: (High priority) "Christmas Island and its surrounding seas" be considered for listing as a threatened ecological community under the Environment Protection and Biodiversity Conservation Act (section 5.1).	Not supported	Not addressed (not appropriate)
Recommendation 31: (High priority) An appropriate community communications program relating to the recovery of Christmas Island biodiversity and re-establishing key ecological relationships be planned and executed (sections 4.3.1 and 5.2).	Supported	Addressed by action 8.1

Findings with wider applicability

Expert Working Group Recommendation	Australian Government Response	How Addressed in Recovery Plan
Recommendation 32: (High priority for DSEWPAC as a whole) National recognition (and concomitant resourcing) of Australia's iconic islands, many of which have extraordinary conservation values and a high susceptibility to biodiversity loss. Long continuity in conservation management, with appropriate monitoring and adaptive capacity. Development and implementation of a management prioritisation framework. More systematic and streamlined processes for identification and review of threatening processes and lists of threatened species, including those in conservation reserves. The application of suitable conditions on developments to create additional resources to manage areas or matters of high biodiversity conservation importance. Development and maintenance of a secure funding stream for the conservation management of all biodiversity aspects of Parks Australia reserves. Development and maintenance of robust, integrated monitoring programs for Parks Australia reserves, including for threatened species, ecosystem health and other matters of particular conservation significance, the provision of annual reports on such monitoring and using monitoring as a basis for ongoing adaptive management. Improved monitoring and stronger incorporation of adaptive management into Recovery Plans. Development of explicit response protocols for intervention in recovery planning, including the option of precautionary establishment of captive breeding populations. Establishment of conservation reserves is a useful step towards biodiversity conservation, but must be accompanied by appropriate management for biodiversity conservation outcomes; this must include direct assessment of threats (especially by introduced biota), biodiversity condition and trends, and of management effectiveness.	Addressed in part via the aims of Australian Government strategies and programs	Not specifically addressed (largely out of scope) however recommended actions concerning recovery plans and recovery planning noted and taken into account (e.g. via action 9.2)

Appendix B—International Agreements relating to species on Christmas Island

Convention on Wetlands of International Importance (Ramsar Convention)

The Ramsar Convention is an international agreement which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. The convention aims to stop the world from losing wetlands and to conserve, through wise use and management, those that remain. There are now more than 150 contracting parties to the convention throughout the world.

Sites are selected for the List of Wetlands of International Importance under the Ramsar Convention because of ecological, botanical, zoological, limnological or hydrological importance. The Hosnies Spring site was listed in 1990 and The Dales was listed in 2002. Ecological Character Descriptions are available for both The Dales (Butcher and Hale 2010) and Hosnies Spring (Hale and Butcher 2010).

Wetlands included in the List of Wetlands of International Importance under the Ramsar Convention are considered 'declared Ramsar wetlands' under the EPBC Act. Australian Ramsar management principles are prescribed by the EPBC Regulations.

http://www.ramsar.org/

China–Australia Migratory Bird Agreement (CAMBA)

CAMBA provides for China and Australia to cooperate in the protection of migratory birds listed in the annex to the agreement and of their environment, and requires each country to take appropriate measures to preserve and enhance the environment of migratory bird species listed under the agreement.

http://www.environment.gov.au/biodiversity/migratory/waterbirds/bilateral.html

Japan–Australia Migratory Bird Agreement (JAMBA)

JAMBA provides for Japan and Australia to cooperate in taking measures for the management and protection of migratory birds, birds in danger of extinction, and the management and protection of their environments, and requires each country to take appropriate measures to preserve and enhance the environment of birds protected under the provisions of the agreement.

http://www.environment.gov.au/biodiversity/migratory/waterbirds/bilateral.html

Republic of Korea–Australia Migratory Bird Agreement (ROKAMBA)

ROKAMBA provides for the Republic of Korea and Australia to cooperate in taking measures for the management and protection of migratory birds and their habitat by providing a forum for the exchange of information, support for training activities and collaboration on migratory bird research and monitoring activities.

http://www.environment.gov.au/biodiversity/migratory/waterbirds/bilateral.html

Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)

The Bonn Convention aims to conserve terrestrial, marine and avian migratory species throughout their range. Parties to this convention work together to conserve migratory species and their habitat.

http://www.cms.int/

Species that are listed under the above migratory agreements and conventions are listed Migratory species the EPBC Act. Migratory species of Christmas Island are listed in Appendix D.

Convention on Biological Diversity

Australia ratified the Convention on Biological Diversity on 18 June 1993 and the Convention came into force in December 1993. The Convention's objectives are:

- the conservation of the world's biological diversity
- to promote the sustainable use of the components of biological diversity
- to provide for the fair and equitable sharing of benefits from the utilisation of genetic resources, including providing appropriate access to genetic resources and the appropriate transfer of relevant technologies taking into account all rights over those resources and technologies, and by appropriate funding.

Appendix C—Endemic vascular plants of Christmas Island

Species Name	Common Name	Abundance	Distribution
Abutilon listeri	lantern flower	common	coastal fringe and shore terraces
Arenga listeri	Christmas Island palm	abundant	most habitats; plateau and terraces
Asplenium listeri	Christmas Island spleenwort	rare	limestone rocks and cliffs in marginal forest
Asystasia alba	a herb	rare	coastal fringe and terrace forest
Brachypeza archytas	Ridley's orchid	abundant	terrace forest
Colubrina pedunculata	a shrub	common	terrace vegetation
Dendrocnide peltata var. *murrayana*	stinging tree	rare	tops of inland cliffs
Dicliptera maclearii	a herb	rare	lower terraces marginal forest
Flickingeria nativitatis	an epiphytic orchid	uncommon	evergreen tall closed forest, plateau
Grewia insularis	a tree	uncommon	terrace forest
Hoya aldrichii	hoya vine	abundant	forest canopy, plateau
Illigera elegans	a vine	rare	marginal forest
Ischaemum nativitatis	Christmas Island duck-beak	common	pinnacles behind sea cliffs
Pandanus christmatensis	pandanus, screw-pine	abundant	tops of shore and inland cliffs
Pandanus elatus	pandanus, screw-pine	abundant	forest understorey, plateau and terraces
Peperomia rossii[(a)]	an epiphytic herb	unknown	unknown
Phreatia listeri	an epiphytic orchid	abundant	tall plateau forest canopy
Zeuxine exilis[(b)]	Ridley's ground orchid	unknown	unknown

(a) Not collected since first recorded in 1900, possibly extinct

(b) Rediscovered in 2009 after not being collected since first recorded in 1904

Sources: Commonwealth of Australia 1993; Holmes & Holmes 2002; Parks Australia unpub. data

Appendix D—EPBC Act listed Christmas Island flora and fauna

Species Name	Common Name	EPBC Act Lists Status [(a)]	Migratory	Marine
VASCULAR PLANTS				
Asplenium listeri	Christmas Island spleenwort	CE		
Pneumatopteris truncata	a fern	CE		
Tectaria devexa var. *minor*	a fern	EN		
MAMMALS				
Crocidura trichura	Christmas Island shrew	EN		
Pipistrellus murrayi	Christmas Island pipistrelle	CE		
Pteropus melanotus natalis	Christmas Island flying-fox	CE		
Rattus macleari	Maclear's rat	EX		
Rattus nativitatis	bulldog rat	EX		
REPTILES				
Chelonia mydas	green turtle	VU	X	X
Cryptoblepharus egeriae	blue-tailed skink	CE		
Cyrtodactylus sadleiri	giant gecko	EN		
Emoia nativitatis	forest skink	CE		
Eretmochelys imbricata	hawksbill turtle	VU	X	X
Lepidodactylus listeri	Lister's gecko	CE		
Ramphotyphlops exocoeti	Christmas Island blind snake	VU		
FISHES				
Rhincodon typus	whale shark	VU	X	
BIRDS (excludes vagrant species)				
Accipiter hiogaster natalis	Christmas Island goshawk	EN		X
Actitis hypoleucos	common sandpiper		X	X
Anous stolidus	common noddy		X	X
Apus pacificus	fork-tailed swiftlet		X	X
Ardea alba	great egret		X	X
Arenaria interpres	ruddy turnstone		X	X
Bulweria bulwerii	Bulwer's petrel			X
Chalcophaps indica natalis	emerald dove (Christmas Island)	EN		
Charadrius leschenaultii	greater sand plover		X	X
Charadrius veredus	oriental plover		X	X
Chlidonias hybrida	whiskered tern			X
Cuculus saturatus	oriental cuckoo		X	X
Egretta sacra	eastern reef egret		X	X
Falco cenchroides	Australian kestrel			X
Fregata andrewsi	Christmas Island frigatebird	VU	X	X
Fregata ariel	lesser frigatebird		X	X

Species Name	Common Name	EPBC Act Lists		
		Status [(a)]	Migratory	Marine
BIRDS (excludes vagrant species)				
Fregata minor	great frigatebird		X	X
Gallinago stenura	pin-tailed snipe		X	X
Hirundo rustica	barn swallow		X	X
Motacilla cinerea	grey wagtail		X	X
Motacilla flava	yellow wagtail		X	X
Ninox natalis	Christmas Island hawk-owl	VU		
Papasula abbotti	Abbott's booby	EN	X	X
Phaethon lepturus fulvus	golden bosun, white-tailed tropicbird		X	X
Phaethon rubricauda	silver bosun, red-tailed tropicbird			X
Stiltia isabella	Australian pratincole			X
Sula leucogaster	brown booby		X	X
Sula sula	red-footed booby		X	X
Tringa glareola	wood sandpiper			X
Tringa nebularia	greenshank			X
Pluvialis fulva	Pacific golden plover		X	X
Turdus poliocephalus erythropleurus	Christmas Island thrush	EN		

(a) EX = extinct; CE = critically endangered; EN = endangered; VU = vulnerable

Appendix E—Non-endemic vascular plants of Christmas Island of possible conservation concern

Species Name	Common Name	Christmas Is Abundance	Christmas Is Distribution	Other Distribution
Abelmoschus manihot tetraphyllus	a shrub	rare	clearings, forest edges	Sumatra, Philippines
Amaracarpus pubescens	a shrub	rare	evergreen tall closed forest	South-east Asia, New Guinea
Balanophora abbreviata	a herb	rare	parasitic on roots of host trees in evergreen tall closed forest on plateau	Madagascar, Africa, Malesia, Philippines, New Guinea, Pacific
Blumea balsamifera	camphor bush	occasional	plateau in secondary growth	South east Asia
Blumea lanceolaria	a herb	rare	clearings and marginal forest	India, China, south-east Asia
Cinnamomum iners	wild cinnamon	rare	clearings, forest edges	India, south east Asia
Cleome gynandra	an annual herb	rare	disturbed areas	Africa, Asia
Commicarpus chinensis ssp. *chinensis*	a subshrub	rare	rock ledges at North West Point	India, China, south-east Asia, southern Africa
Cycas rumphii	cycad	rare	cliff lines and shore terrace	Malesia, Philippines, Pacific
Cynometra ramiflora	wrinklepod mangrove	rare	a single stand in evergreen tall closed forest south of Ross Hill	India, south-east Asia, Pacific
Didymoplexis pallens	an orchid	one record only	evergreen tall closed forest	India, south-east Asia, Polynesia, north Australia
Eria retusa	an epiphytic orchid	common	evergreen tall closed forest on plateau	Java
Ficus saxophila	a fig tree	frequent	terraces and cliffs island-wide	South-east Asia, Philippines, Java
Hibiscus vitifolius	a herb	two records only	shore terrace	Old World tropics
Jacquemontia paniculata	a twining herb	rare	disturbed sites	Madagascar, Africa, Asia, Malesia
Leptochilus decurrens	a fern	rare	evergreen tall closed forest on plateau	South-east Asia
Leucas zeylanica	a herb	rare	disturbed sites, forest margins	South-east Asia
Lycianthes biflora	a herb	unknown	clearings, rainforest edges	India, Asia, Malesia
Momordica charantia	an annual climber	unknown	disturbed sites, forest margins	Asia, Africa, Malesia, north Australia
Mucuna pruriens	velvet bean	occasional	disturbed sites, forest margins	Madagascar, Africa, Asia

Species Name	Common Name	Christmas Is Abundance	Christmas Is Distribution	Other Distribution
Muellerargia timorensis	a climber	rare	semi-deciduous closed forest	Malesia, north Australia
Peperomia laevifolia	an epiphytic herb	unknown	evergreen tall closed forest on plateau	Java, Sumatra, Borneo, Philippines, New Guinea
Phlegmariurus phlegmaria	common tassel fern	rare	evergreen tall closed forest on plateau	South-east Asia, north Australia, Polynesia
Pteridrys syrmatica	a fern	common	evergreen tall closed forest on plateau	Sri Lanka, India, south-east Asia, Philippines
Remusatia vivipara	an epiphytic herb	one record only	evergreen tall closed forest	Old World tropics
Selaginella alutacia	a fern-ally	one record only	limestone rocks near the shore	South-east Asia, Sumatra, Java
Setaria clivalis	a grass	one record only	near Flying Fish Cove	Malesia
Spermacoce mauritiana	an annual herb	rare	clearings, rainforest edges	Pantropical
Spondias cytherea	great hog plum	rare	semi-deciduous closed forest, only known from two natural sites	South-east Asia
Strongylodon lucidus	a climbing shrub	rare	plateau in semi-deciduous closed forest	Madagascar, Sri Lanka, Malesia, north-east Australia, Pacific
Taeniophyllum hasseltii	an epiphytic orchid	uncommon	evergreen tall closed forest on plateau	Malesia
Tectaria dissecta	a fern	uncommon	plateau and upper terraces	Taiwan, Philippines, Borneo, Java, New Guinea, Pacific
Thelasis capitata	an epiphytic orchid	uncommon	evergreen tall closed forest on plateau	Java, Sumatra, Sabah
Thrixspermum carinatifolium	an epiphytic orchid	abundant	evergreen tall closed forest on plateau	Malaya, Java, Sumatra
Triphasia trifolia	limeberry	rare	scree slope in marginal forest, only known from one site	South east Asia, Malesia
Triumfetta suffruticosa	a shrub	occasional	clearings and rainforest edges	Malay Islands, Polynesia
Vitis flexuosa	a climber	rare	disturbed or scrubby vegetation	India, China, Philippines, south-east Asia, Java
Zehneria mucronata[(a)]	a vine	unknown	shrubby margins or forest	North Australia

(a) Christmas Island population formerly considered to be endemic (as *Z. alba*)

Sources: Commonwealth of Australia 1993; Holmes & Holmes 2002; Parks Australia unpub. data

Appendix F—Birds of Christmas Island

Species Name	Common Name	Status	Abundance
RESIDENT FOREST BIRDS AND SHOREBIRDS			
Accipiter hiogaster natalis	Christmas Island goshawk	endemic	uncommon
Amaurornis phoenicurus	white-breasted water-hen	self-introduced	uncommon
Chalcophaps indica natalis	emerald dove (Christmas Island)	endemic	common
Collocalia linchi natalis	Christmas Island swiftlet, glossy swiftlet	endemic	abundant
Ducula whartoni	Christmas Island imperial pigeon	endemic	common
Egretta novaehollandiae	white-faced heron	self-introduced	rare
Egretta sacra	eastern reef egret	native	rare
Falco cenchroides	Australian kestrel	self-introduced	common
Gallus gallus	feral fowl	introduced	common
Ninox natalis	Christmas Island hawk-owl	endemic	uncommon
Lonchura oryzivora	java sparrow	introduced	uncommon
Passer montanus	tree sparrow	self-introduced	common
Turdus poliocephalus erythropleurus	Christmas Island thrush	endemic	common
Zosterops natalis	Christmas Island white-eye	endemic	abundant
BREEDING SEABIRDS			
Anous stolidus	common noddy	native	common
Fregata andrewsi	Christmas Island frigatebird	endemic	uncommon
Fregata ariel	lesser frigatebird	native	rare
Fregata minor	great frigatebird	native	common
Papasula abbotti	Abbott's booby	endemic	uncommon
Phaethon lepturus fulvus	golden bosun	endemic	common
Phaethon rubricauda	silver bosun	native	common
Sula leucogaster	brown booby	native	common
Sula sula	red-footed booby	native	common
REGULAR MIGRANTS AND OCCASIONAL VISITORS[(a)]			
Actitis hypoleucos	common sandpiper	regular migrant	
Apus pacificus	fork-tailed swiftet	regular visitor	
Ardea alba	great egret	occasional visitor	
Arenaria interpres	ruddy turnstone	regular migrant	
Bulweria bulwerii	bulwer's petrel	occasional visitor	
Charadrius leschenaultii	greater sand plover	rare migrant	
Charadrius veredus	oriental plover	rare migrant	
Chlidonias hybrida	whiskered tern	occasional visitor	
Cuculus saturatus	oriental cuckoo	rare migrant	
Gallinago stenura	pin-tailed snipe	occasional visitor	
Glareola maldivarum	oriental pratincole	rare migrant	
Gorsachius melanolophus	Malay night-heron	occasional visitor	
Hirundo rustica	barn swallow	common migrant	
Motacilla cinerea	grey wagtail	common migrant	
Motacilla flava	yellow wagtail	common migrant	
Pluvialis fulva	Pacific golden plover	regular migrant	
Stiltia isabella	Australian pratincole	occasional visitor	
Tringa glareola	wood sandpiper	rare migrant	
Tringa nebularia	greenshank	rare migrant	

(a) excludes vagrant species

Sources: Johnstone & Darnell 2004; Parks Australia unpub. data

Appendix G—Terrestrial mammals and reptiles of Christmas Island

Species Name	Common Name	Status	Abundance
MAMMALS			
Crocidura trichura	Christmas Island shrew	endemic	presumed extinct
Felis catus	feral cat	introduced	common
Mus musculus	house mouse	introduced	common
Pipistrellus murrayi	Christmas Island pipistrelle	endemic	presumed extinct
Pteropus melanotus natalis	Christmas Island flying-fox	endemic	declining
Rattus macleari	Maclear's rat	endemic	extinct
Rattus nativitatis	bulldog rat	endemic	extinct
Rattus rattus	black rat	introduced	common
REPTILES			
Cryptoblepharus egeriae	blue-tailed skink	endemic	possibly extinct in the wild[a]
Cyrtodactylus sadleiri	giant gecko	endemic	rare, declining
Emoia atrocostata	coastal skink	native	possibly extinct
Emoia nativitatis	forest skink	endemic	possibly extinct in the wild
Gehyra mutilata	Pacific gecko	introduced	common
Hemidactylus frenatus	Asian house gecko	introduced	common
Lepidodactylus listeri	Lister's gecko	endemic	very rare, declining[a]
Lycodon aulicus	wolf snake	introduced	abundant
Lygosoma bowringii	grass skink	introduced	common
Ramphotyphlops braminus	flowerpot snake	introduced	common
Ramphotyphlops exocoeti	Christmas Island blind snake	endemic	very rare, declining

(a) captive breeding populations maintained on-island and off-island

Sources: Cogger & Sadlier 2000; Parks Australia unpub. data

Appendix H—Land and shoreline crabs of Christmas Island

Species Name	Common Name	Status	Abundance and Distribution
Birgus latro	robber crab	native	common, widespread, arboreal and terrestrial
Chiromantes garfunkel	Christmas Island yellow-eyed crab	endemic	common, crevices high in seacliffs beyond tidal or salt spray, around coast
Coenobita brevimanus	purple hermit crab	native	common, beaches and shore terraces
Coenobita perlatus	red hermit crab	native	common, rubble beaches
Coenobita rugosus	tawny hermit crab	native	common, beaches and shore terraces
Cyclograpsus integer	sandy rubble crab	native	rare, restricted to rubble buried in sand at Greta and Ethel beaches
Discoplax celeste	Christmas Island blue crab	endemic	uncommon, moist areas with water seepages
Discoplax aff. *hirtipes*	orange-legged crab	native	uncommon, drier karstic environments
Discoplax rotunda	rugose land crab	native	rare, shore terrace near The Blowholes
Epigrapsus politus	brown crab	native	rare, beach sand/rubble boundary on forest soil, usually under rocks
Gecarcoidea humei	purple land crab	native	rare, distributed island-wide
Gecarcoidea lalandii	purple crab	native	rare, distributed island-wide
Gecarcoidea natalis	red crab	endemic[a]	abundant but declined due to impact of crazy ants, distributed island-wide
Geograpsus crinipes	yellow nipper	native	uncommon, lower terraces, seacliff and beaches
Geograpsus grayi	little nipper	native	common, distributed from shore terrace to plateau
Geograpsus stormi	red nipper	native	rare, under shoreline rocks and in crevices on the seacliff near water
Grapsus tenuicrustatus	grapsus crab	native	common all around coastline
Karstama jacksoni	Jackson's crab	endemic	rare, cool moist areas on lower terraces, in caves
Labuanium vitatum	white-striped crab	native	uncommon, terraces above Greta Beach, The Dales and West White Beach
Metasesarma obesum	mottled crab	native	rare, leaf litter above beaches
Ocypode ceratophthalmus	horn-eyed ghost crab	native	common, sandy beaches
Ocypode cordimanus	smooth-handed ghost crab	native	common, sandy beaches
Ocypode kuhlii	ghost crab	native	Rare, Greta Beach
Ocypode sinensis	Chinese ghost crab	native	Greta Beach
Ocypode sp.	horn-eyed ghost crab	native	sandy beaches
Orcovita hicksi	Hick's cave crab	endemic	unknown but restricted to anchialine cave systems
Orcovita orchardorum	Orchard's cave crab	endemic	unknown, less common than *O. hicksi*, currently known only from Runaway, Whip and Freshwater caves

(a) A very small, likely introduced population occurs on North Keeling Island

Sources: Hicks et al.1990; Orchard 2012, Ng & Davie 2012; Ng & Davie 2013

Appendix I—Threat risk assessment

During the development of this plan an analysis of the consequences of threats to significant Christmas Island species was attempted. This incorporated estimates of the intensity of the impact and extent of threatening processes potentially affecting each significant species. In many instances, the threats were found to be poorly understood for most species, with comments for each species ranging from the worst case 'no reliable information on threats' to, at best, 'some threats understood'.

The main conclusion from this process is that there is currently insufficient information, on both the impacts and likelihood of consequences of threats, to support a detailed rigorous threat risk analysis. An action to use a risk management framework to assess threats (Action 9.2) is therefore included in this plan, along with collecting data (Actions 1, 2, 3, 5 and 6) for use in a more detailed rigorous assessment. This is reflected in Sections 6.2 (Recommended Actions) and 7.1 (Priorities) which identify the need for an adaptive and risk management approach in relation to action prioritisation.

For the preparation of this plan, a simple process was used to identify major threats. This was based on the pervasiveness of a threat (number of significant species known or potentially affected) and impacts to species essential to the ecosystem (known threat to species considered as important in maintaining the island's ecosystem). Threats were classed as a 'major risk' to the biodiversity of Christmas Island if they met one (or both) of the following criteria:

1. A known or potential threat to more than five significant species (as defined in Part 3.2 of this plan).
2. A known threat to at least one species with a keystone role (as described in Part 3.2 of this plan).

This basic assessment does not take into account confounding factors, such as:

- the relative degree of impact of threats on species
- the potential for single threats to have multiple impacts (e.g. both predation and habitat change due to crazy ants)
- the interplay between threats (e.g. crazy ants changing forest dynamics and increasing potential for weed invasion)
- threats to other native species, in particular poorly known species (plants of possible conservation concern; freshwater, subterranean and terrestrial invertebrates)
- the varied conservation status of species
- the future risk from threats such as climate change, and existing introduced species which are currently not thought to be affecting significant species.

Threats identified as having major risk and the criteria they meet are:

- crazy ants (criteria 1 and 2)
- introduction of new terrestrial invasive species (criterion 1)
- cats (criteria 1 and 2)
- rats (criterion 1)
- habitat disturbance and loss (criterion 1)
- traffic-induced mortality (criterion 2).

Processes which are not considered threats or for which abatement actions are currently beyond the scope of this plan are not included. These comprise:

- processes with minimal consequences and/or highly unlikely, such as overfishing and hunting within the Territory of Christmas Island (see Part 4.3 of this plan)
- threats or potential threats currently beyond the Australian terrestrial range of threatened species, such as habitat clearing and hunting of Christmas Island frigatebirds and Abbott's booby in nearby countries
- marine threats which may affect terrestrial species, as this plan is restricted to terrestrial areas.

Appendix J—Review of existing recovery plans

SPECIES: CHRISTMAS ISLAND SHREW (*Crocidura trichura*)

Overall comment

Except for clarification of its taxonomy and opportunistic but non-target monitoring, the recovery plan was not/could not be specifically implemented as the species is likely to be extinct

Objectives

1. To clarify the taxonomic status from existing museum specimens.
2. To assess the current status and distribution through targeted surveys.
3. To control the abundance and spread of the crazy ant
4. To establish captive breeding populations from any extant populations, pending mitigation of all potential threats.
5. To effectively protect and manage any extant populations
6. To identify habitat critical to survival, including shelter, breeding and foraging habitat.
7. To determine threatening processes affecting the species.
8. To develop and implement a community awareness program to assist in the location of previously undetected populations.

Recovery criteria

1. Taxonomic status of the Christmas Island Shrew resolved.
2. Current conservation status and distribution determined.
3. Abundance and spread of crazy ant is less than at 2002 levels, with all high density supercolonies reduced by 99% of their original densities.
4. Captive breeding populations established with the aim of reintroduction once potential threat control has been achieved.
5. Any identified extant populations protected and population numbers increase.
6. Habitat critical to survival investigated and determined.
7. Threatening processes determined, and actions taken to control them.
8. Increased knowledge of the shrew amongst island residents, an enhanced ability amongst islanders to identify the species from other small mammals and guidelines on what to do if a shrew is found.

No.	Actions	Action status comments	Status	Recommendations
1	Investigate the taxonomic status of the shrew	In 2009 the Australian Museum conducted a study for DEWHA on the taxonomy of the Christmas Island shrew. Based on available evidence the study suggested the CI shrew should be regarded as a distinct species. The study also confirmed that the shrew specimens collected on Christmas Island in 1985 were authentic Christmas Island shrews and represent the same taxon last collected in 1899.	Complete	No further action recommended.

2	Investigate current status and distribution	No specific surveys were conducted. However, the Island Wide Survey has been conducted every two years since 2001 with approx. 900 waypoints surveyed. In addition intensive reptile and other biodiversity surveys have been conducted by Park staff. Although shrews were not specifically targeted, no shrews were sighted during these surveys and targeted surveys are unlikely to be more efficient at detecting this species. There have been no recent reports of reliable sightings from individuals/residents.	Not started	Ensure IWS and any other ecosystem wide monitoring programs use methods suitable for detecting the species.
3	Develop wildlife management program for potential habitat outside the Christmas Island National Park	A specific plan was not prepared. However, the Christmas Island regional recovery plan will cover this requirement.	Started	Include habitat management outside National Park in regional recovery plan.
4	Control abundance and spread of crazy ant	Management of crazy ants is ongoing and includes aerial baiting to reduce numbers in supercolonies, monitoring to assess success of and need for baiting, assessing off-target impacts, and research into alternative control methods.	Ongoing	Continue crazy ant management.
5	Implement community awareness program	No specific community awareness program has been conducted.	Not started	Consider publishing booklet of threatened species.
6	Establish captive breeding population	Could not be considered as shrew had not been sighted since 1985.	Not started	Consider if population/s are found and it is feasible and appropriate.
7	Effective management of populations	Could not be considered as shrew had not been sighted since 1985.	Not started	In absence of detectable population, continue to focus on ecosystem and broader species threat abatement activities (e.g. crazy ant and cat and rat management).
8	Identify and describe critical habitat	This was not progressed beyond what was stated in the recovery plan: "Until further information is obtained, by applying the precautionary principle to the EPBC Act criteria, all areas of primary plateau and terrace rainforest on the island should be considered as potential habitat critical to survival. If the shrew is found to be extant, identifying habitat requirements critical to survival is recommended".	Not started	Further define habitat if/when population/s are found.
9	Identify threatening processes	No specific studies were conducted. However, invasive species threats (particularly, disease, crazy ants and cats and rats) as well as previous habitat losses are likely to be a threat. Crazy ant, cat and rat management has occurred and needs to continue.	Not started	If/when population/s are found, the highest priority actions are surveys to determine population extent and habitat, and potentially captive breeding. If these actions occur, potential threats may be investigated.

SPECIES: CHRISTMAS ISLAND PIPISTRELLE (*Pipistrellus murrayi*)

Overall comment: Many of the actions were started and some were completed. However, these this did not prevent the rapid decline and likely extinction of the pipistrelle. However, captive breeding was likely to be the only action that could have prevented its likely extinction, but may not have resulted in release of populations back in the wild.

Objectives:

1. To assess current population and distribution trends of the Christmas Island Pipistrelle.
2. To determine the roosting requirements of the Christmas Island Pipistrelle, including seasonal and distributional differences.
3. To assess the potential for the Common Wolf Snake to prey on bats in roosts and if it is considered that they impact on pipistrelles, devise management actions to reduce predation.
4. To assess the impact of the Nankeen Kestrel and if found to predate on pipistrelles, devise management actions to reduce impact.
5. To identify primary foraging site characteristics in the dry and wet seasons, especially away from ecotones and roadways, within extensive tracts of evergreen tall closed forest.
6. To examine dietary specialisation as a contributing factor in the species decline.
7. To clarify the taxonomic status of the Christmas Island Pipistrelle.
8. To continue active management for the control of Yellow Crazy Ant supercolonies.
9. To increase protection of known and potential habitat outside the Christmas Island National Park.
10. To assess the potential impact on the Christmas Island Pipistrelle of phosphate stockpile removal within and abutting the Christmas Island National Park.
11. To establish guidelines to reduce vehicle-related mortality along roads passing through important foraging areas.
12. To review the conservation status of the species.

1. The current status of the population and distribution trends in the species are determined.
2. Roosting requirements are characterised, including maternity and non-breeding roosts. Roosting requirements in the core of the species range are compared with those at the eastern limit of the range, and the impact of Yellow Crazy Ant supercolonies on roosting habitat is determined.
3. The impact of the Common Wolf Snake on roosting bats is determined and management actions established to reduce such impacts where they occur.
4. The impact of the Nankeen Kestrel on pipistrelles is determined and management actions established to reduce such impacts where they occur.
5. Primary foraging habitat is identified away from forest ecotones and roadways.
6. The diet of the species is determined in both the wet and dry season and compared to prey availability.
7. Taxonomic status of the Christmas Island Pipistrelle is resolved.
8. All supercolonies of the Yellow Crazy Ant are eliminated and ongoing management undertaken to ensure no subsequent re-infestation.
9. Protection of known or potential habitat is increased outside the Christmas Island National Park.
10. An assessment of the impacts on the Christmas Island Pipistrelle of proposed phosphate stockpile removal within and abutting the Christmas Island National Park has been conducted.
11. Guidelines have been established and implemented to reduce vehicle related mortality.
12. The conservation status of the species has been reviewed.

No.	Actions	Action status comments	Status	Recommendations
1	Assess population and distribution trends in the Christmas Island Pipistrelle and establish long-term monitoring programs	Significant monitoring was conducted by Park staff, external researchers and by consultant(s) engaged by Christmas Island Phosphates using Anabat detectors and other methods (e.g. night vision goggles). The results of this monitoring showed that the pipistrelle had contracted to a few sites on the western part of the island. However, in 2009 an extensive monitoring program was conducted by members of the Australasian Bat Society as part of an attempted captive breeding program. Despite considerable efforts no bats were caught and only one was detected. The pipistrelle is likely to now be extinct.	Complete	Pipistrelle monitoring to be incorporated into island wide ecosystem monitoring.
2	Determine roosting requirements, investigating seasonal and distributional differences	Potential roost trees were searched for, including an intensive survey in 2009. Due to several factors, including low population numbers, roosting requirements could not be determined.	Started	If population/s are found, the highest priority actions are: surveys to determine population extent and habitat; and potential captive breeding. This may include identifying roosting requirements.
3	Determine the impact of the common wolf snake on roosts, and if considered to impact on pipistrelles, develop management actions to reduce the predation risk	Wolf snakes were detected on or near known roost trees or within the western end of the island. However, there was no evidence to show that it had a role in the decline of the pipistrelle.	Partially complete	If population/s are found and the highest priority actions occur, potential threats may be investigated.
4	Determine the impact of the nankeen kestrel, and if found to prey on pipistrelles, develop management actions to reduce the impact	Studies by Lumsden (et al.) in 2007 found that the nankeen kestrel largely predated on large grasshoppers but they were found in pipistrelle foraging areas near the start of the Winifred Beach track. Due to seasonal prey availability and the low density of pipistrelles in 2007 it is hard to conclusively determine what impact the nankeen kestrel may have had on the decline of the pipistrelle. However, its impact is considered to have been insignificant.	Complete	No further action
5	Identify primary foraging sites away from ecotones and roads	Surveys (by Lumsden, Richards and Parks Australia) showed that the pipistrelle continued to contract to the west of the island until its last detection in 2009. However, these surveys were aimed at detecting pipistrelles, not specifically at identifying foraging sites away from ecotones and roads.	Partially complete	If population/s are found, the highest priority actions include surveys to determine habitat. This may include identifying foraging sites.
6	Investigate dietary specialisation as a contributing factor to the current status of Christmas Island Pipistrelle)	In 2007 Lumsden et al. recommended that further investigations be carried out to determine if the pipistrelle was an opportunistic or specialised feeder. Although inconclusive Lumsden's analysis of the spatial and temporal distributions of crazy ant supercolonies and the pattern of decline in the pipistrelle did not correlate. Richards (2008) hypothesised a link between prey availability, influenced by crazy ants, and pipistrelle decline.	Started	No further action

No.	Actions	Action status comments	Status	Recommendations
7	Clarify the taxonomic status of the Christmas Island pipistrelle	An examination was carried out by the Australian Biological Resources Study in 2009, which determined that the pipistrelle is a discrete and endemic species.	Complete	No further action
8	Continue active management for the control of Yellow Crazy Ant supercolonies	Management of crazy ants is ongoing and includes aerial baiting to reduce numbers in supercolonies, monitoring to assess success of and need for baiting, assessing off-target impacts, and research into alternative control methods.	Ongoing	Continue crazy ant management program.
9	Increased protection of known and potential habitat outside the National Park	No additional protection of potential habitat was initiated. During the life of the recovery plan the distribution of the pipistrelle contracted to the western end of the island and was mostly detected in the national park. However, some calls were detected outside of the Park along the Winifred Beach track (which intersects mine fields 25 and 26). A survey of mine fields was also conducted by Richards in 2008, although no calls were detected.	Not started	Progress if species is detected in an area outside the National Park which requires additional protection.
10	Assess the impact of phosphate stockpile removal on the Christmas Island Pipistrelle	Pipistrelle surveys were conducted by Christmas Island Phosphates before the removal of stockpiles at fields on the north west of the island.	Complete	No further action
11	Guidelines to reduce vehicle-related mortality	No guidelines were prepared. However, due to the rapid decline of the pipistrelle vehicle impacts were not considered to be a factor in their decline.	Not started	No further action
12	Review the conservation status of the species	When the recovery plan was prepared in 2004 the pipistrelle was listed under the EPBC Act as endangered but was assessed and listed under the EPBC Act as critically endangered in 2006.	Complete	No further action

SPECIES: ABBOTT'S BOOBY (*Papasula abbotti*)

Overall comment: Many recovery actions were started/partially completed. Anecdotally it appears that the Abbott's booby populations may slowly be recovering but existing monitoring data do not provide a basis for drawing conclusions about the status of the Abbott's booby. Furthermore, if recovery is occurring it is difficult to attribute this to any specific recovery actions.

Objective 1	**Protect, restore and enhance the breeding habitat of Abbott's booby**
Recovery Criteria 1.1	• Removal of stockpiles proceeds in accordance with the CINPMP. • Breeding habitat is not compromised by removal of stockpiles.
Recovery Criteria 1.2	• Mining fields rehabilitated in accordance with priorities in CINPMP. • Extent to which mining fields are rehabilitated. • Breeding success and survival of Abbott's booby nesting adjacent to mining fields increased to levels observed in good (non-turbulent) habitat.
Recovery Criteria 1.3	• Extent to which the actions and priorities of the CI weed management are implemented.
Recovery Criteria 1.4	• Habitat critical to survival is mapped

No.	Actions	Action status comments	Status	Recommendations
1.1	Manage the removal/mining of phosphate stockpiles in and adjacent to the Park in accordance with the mining lease and *Third Christmas Island National Park Management Plan*, to ensure this activity does not have a significant environmental impact on breeding habitat.	No stockpiles were removed from Christmas Island National Park. Stockpiles outside of the park were removed in accordance with lease conditions.	Complete	Continue compliance monitoring through existing regulatory processes.
1.2	Implement the Christmas Island Rainforest Rehabilitation Program, giving priorities for to mining fields detailed in Table 2 of the *Third Christmas Island National Park Management Plan* (page 94) with consideration of land tenure and long term success of the rehabilitation.	With over 25% of the island cleared since settlement and most of this area being located on the plateau and former rainforest, not all sites are likely to be able to be rehabilitated. However, this action is considered Partially Complete as rehabilitation occurred to the extent possible with the current available financial and physical resources (e.g. soil).	Partially complete	Continue the rainforest rehabilitation program subject to continued annual funding allocations as per the rehabilitation program plan.

No.	Actions	Action status comments	Status	Recommendations
1.3	Continue to implement the Christmas Island weed management strategy.	A weed management plan 2005–2009 has been prepared and was updated in 2010 (for 2010–2015). Weed management occurred in the fields planted as part of the Christmas Island Mine-site to Forest Rehabilitation Program (CIMFR). This involved pre-planting clearing of weeds and follow up weed management in planted fields. Since 2006 a minimum of 250 hectares of weed control work was also conducted on other sites, primarily in plateau areas. Parthenium weed has been detected on Christmas Island and is being managed under a Service Delivery Agreement between the Territories Administration and WA DEC. However, except for weed management work associated with the CIMFR program it is difficult to determine the benefits of weed control work in terms of Abbott's booby recovery.	Partially complete	Continue weed management.
1.4	Accurately map critical breeding habitat inside and outside the Park. The wind turbulence model (Action 7) will help to determine and assess potential breeding habitat.	This action was not conducted and is not considered necessary. Existing knowledge of nesting requirements, as well as the IWS, aerial surveys and remote sensing data, combined with GIS mapping, provide a means of mapping critical habitat.	Not started	No further action
Objective 2		**Manage any threats posed by the crazy ant to ecosystem function in areas of infestation**		
Recovery Criteria 2.1		• Control program is maintained at, or increased above, current (2002) levels. • Crazy ants reduced to a level where ecosystem function is re-established in affected areas. • Crazy ant control has no negative impact on Abbott's booby.		
No.	**Actions**	**Action status comments**	**Status**	**Recommendations**
2.1	Continue control of crazy ants as a high priority action to preserve ecosystem integrity and hence protect breeding habitat.	Management of crazy ants is ongoing and includes aerial baiting to reduce numbers in supercolonies, monitoring to assess success of and need for baiting, assessing off-target impacts, and research into alternative control methods.	Ongoing	Continue crazy ant management.
Objective 3		**Ensure activities associated with construction and operation of Immigration Reception and Processing Centre do not impede recovery**		
Recovery Criteria 3.1		• Removal of vegetation on site is minimised. • Wherever possible, revegetation is undertaken on parts of the site. • Development of the Centre is contained within the site. • Breeding success and survival of Abbott's booby nesting adjacent to the Centre is not reduced.		
Recovery Criteria 3.2		• Wind-shear effects on nests along Murray's Road are not increased. • Breeding success and survival of Abbott's booby nesting along Murray's Road is not reduced.		
Recovery Criteria 3.3		• Breeding success and survival of boobies nesting adjacent to the Centre is not reduced as a result of routine operation of the facility.		
Recovery Criteria 3.4		• Monitoring program is established, preferably one that is integrated with the regular monitoring program (objective 7).		

No.	Actions	Action status comments	Status	Recommendations
3.1	Closely supervise construction of the IRPC to ensure environmental impacts are minimised, in particular, design and siting of the Centre to minimise: • wind-turbulence effects on adjacent Abbott's booby nests; and • removal of revegetation within the designated site. •	The building of the IRPC was considered a matter of national interest and was not subject to referral and assessment processes under the EPBC Act. However, as part of the construction of the IRPC, DOFA funded the Christmas Island Biodiversity Monitoring Program which included monitoring of Abbott's booby nesting sites adjacent to the IRPC. The monitoring did not detect any measurable change in the density and distribution of nest sites in the vicinity of the IRPC between 2004–2006 and no strong indication of any movement of nesting sites away from the IRPC. This is likely to have been because no clearing of tall evergreen rainforest (i.e. Abbott's booby nesting habitat) for the IRPC's construction occurred.	Complete	No further action
3.2	Closely supervise road upgrading and infrastructure construction along Murray's Road during development of the IRPC, to ensure environmental impacts are minimised. In particular: • rainforest clearing should be minimised if not prevented; • waste treatment and other services should be laid close together on the same side of the road; • minor road re-alignments should be considered to prevent destruction of nesting trees.	It is difficult to determine if impacts were minimised or avoided. Transect surveys along Murray Road may indicate a slight decrease in Abbott's booby numbers, which may be due to increased road dust and noise since the opening of the IRPC. However, more studies would need to be done in order to draw any conclusions as there is no clear baseline for comparisons.	Partially complete	Assess any future road upgrades in accordance with the assessment processes identified in the EPBC Act.
3.3	The day-to-day operational activities of the IRPC are managed to ensure that environmental impacts are minimised. In particular, breeding of Abbott's booby pairs nesting adjacent to the site should not be compromised by the Centre's operational activities.	Covers were placed on the lights of the IRPC but no other related measures, including monitoring, have been adopted as part of the on-going operation of the IRPC. However, any impacts are considered to be low or minimal when compared to other threats so this action is not considered necessary unless the centre expands considerably.	Started	No further action
3.4	Establish and implement a monitoring program for construction and operational activities of the IRPC which: • establishes baseline data; and • rapidly detects any adverse impacts on Abbott's booby (both short and long-term).	Some baseline data was collected as part of the DoFA funded Biodiversity Monitoring Program. However, no other specific measures, including specific IRPC site monitoring, are adopted as part of the on-going operation of the IRPC.	Started	See previous action

Objective 4		**Ensure activities associated with the construction and operation of the Asia Pacific Space Centre do not impede recovery**		
Recovery Criteria 4.1		• Monitoring program is established, preferably one that contributes to the regular monitoring program (objective 7).		
Recovery Criteria 4.2		• APSC activities suspended if an adverse impact identified. • APSC activities not resumed until the adverse situation has been rectified and Abbott's booby conservation assured.		
No.	**Actions**	**Action status comments**	**Status**	**Recommendations**
4.1	Establish a monitoring program of construction and operational activities of the APSC which: • collects baseline data for at least 3 years prior to the first launch; and • detects any significant impacts on Abbott's booby.	Not applicable as the APSC did not get off the ground	Not applicable	No further action
4.2	If a significant impact is detected, any satellite launch regime should be suspended immediately and a review conducted. Any detrimental activity should not re-commence until the cause of the impact has been rectified.	Not applicable as the APSC did not get off the ground	Not applicable	No further action
Objective 5		**Identify feeding habitat of adults and juveniles and develop appropriate management responses to any threats identified**		
Recovery Criteria 5.1		• Satellite telemetry studies completed. • Marine habitat critical to survival (if any), and potential threats to this habitat, identified.		
No.	**Actions**	**Action status comments**	**Status**	**Recommendations**
5.1	Investigate at-sea distribution of Abbott's booby through the use of satellite telemetry to: • determine foraging range and potential overlap with threatening processes e.g., fishing and hunting. Studies need to resolve at-sea range both spatially and temporally and account for sex, age class, season and breeding status; • resolve/define marine habitat critical to survival.	Monitoring has been conducted as part of a 2007 NHT funded project 'Investigation of the Foraging Ecology of the Endangered Abbott's booby' conducted in collaboration with Hamburg University. The results showed that Abbott's booby travel as far away as 550 km from Christmas Island and can cover 2200 km in a single journey and that they dominantly travel to the north, south and west.	Started	Investigate the at-sea distribution of Abbott's booby, including to detect any seasonal variation in foraging journeys, and ensure results are used during management of these areas.

Objective 6		Establish a population monitoring program		
Recovery Criteria 6.1		• Techniques for monitoring developed and trailed.		
Recovery Criteria 6.2		• A regular monitoring program is implemented within two years. • Results of the monitoring program are reported immediately to assist in management and recovery. • Results of the monitoring program used to evaluate and guide CIRRP.		
No.	**Actions**	**Action status comments**	**Status**	**Recommendations**
6.1	Develop and trial sampling techniques for use in monitoring program.	Methods for monitoring population demographics are established and being used. Ground survey methods through the Island Wide Survey are also being used and aerial surveys have also been used.	Complete	As needed further refine methods during future monitoring programs.
6.2	Develop and implement a cost-effective monitoring program for Abbott's booby to: • detect changes in population with high precision; • monitor effectiveness of mine site rehabilitation on adjacent nesting Abbott's boobies to ascertain whether population size, distribution and breeding success are increased; • estimate total population size with low to medium precision; and • where possible, allow monitoring of other potential threats, such as from APSC and IRPC.	In 2009 an aerial survey was conducted. However, the methods may need to be refined as population trends/counts are difficult to determine. Data collected needs to be analysed and correlated with ground surveys as it is difficult to estimate a population size from these surveys.	Started	Continue to monitor Abbott's booby. Analyse data already collected and correlate with ground surveys.
6.3	Upgrade existing monitoring data and ensure that the coding system is documented.	This action was not completed.	Not started	Ensure monitoring data and is effectively managed in GIS and other data systems.

Objective 7		**Develop a wind turbulence model to guide and evaluate the CIRRP in restoration of Abbott's booby breeding habitat**		
Recovery Criteria 7.1		• Refined wind turbulence model for Abbott's booby breeding habitat developed. • Effectiveness of existing mine rehabilitation in improving habitat assessed. • Rehabilitation priorities and prescriptions of CIRRP are re-evaluated.		
No.	**Actions**	**Action status comments**	**Status**	**Recommendations**
7.1	Appraise effectiveness of mine site rehabilitation in ameliorating wind turbulence upwind of breeding sites through use of GIS and computer modelling. Use model to determine at what stage wind turbulence upwind of clearings is ameliorated to an extent that breeding success and survival of Abbott's booby is not compromised, and to improve guidelines for rehabilitation, including stockpile removal, in consultation with DOTARS and PRL.	The model was not completed. However, it is not clear what the value of the model will be in terms of influencing rehabilitation works, as rehabilitation is already targeted at rainforest adjoining evergreen tall closed forest. Monitoring actual nesting sites adjacent to areas that have been rehabilitated is likely to be a more effective measure of rehabilitation success in the long-term, once revegetation is old enough.	Not started	No further action in short term. Monitor nesting sites in areas adjacent to revegetated areas to measure success of rehabilitation in long-term.
Objective 8		**Monitor and assess the likely impact of developing fisheries in the Christmas Island area**		
Recovery Criteria 8.1		• As necessary, assessment of risk and development of preventative procedures.		
No.	**Actions**	**Action status comments**	**Status**	**Recommendations**
8.1	In the event of a fishery developing in the area, ensure observer coverage to identify whether by catch is occurring; develop appropriate measures to eliminate any problem.	Currently there are no large scale commercial fisheries within the Territory of Christmas Island or surrounding Australian waters. This action is also relevant to a number of other seabird species.	Not applicable	If a fishery is considered, advise AFMA and other relevant agencies of potential fishing impacts on Abbott's booby (and other seabirds).
Objective 9		**Assess and revise the Recovery Plan as necessary**		
Recovery Criteria 9.1		• Recovery Team formed and plan implemented.		
Recovery Criteria 9.2		• Consistency across National and International threatened species lists.		
No.	**Actions**	**Action status comments**	**Status**	**Recommendations**
9.1	Form Recovery Team and implement Recovery Plan. Team should include experts and stakeholder representatives and communicate via email and telephone conferencing.	A recovery team was not formed. However, a working group has been developed to assist with the preparation of the Christmas Island regional recovery plan and a recovery team is proposed for the plan's implementation.	Started	Develop and maintain a recovery team.
9.2	Prepare and submit nomination to TSSC for listing as Critically Endangered.	A nomination was not prepared. However, as the population numbers are unclear it may be difficult to assess the Abbott's booby as being critically endangered.	Not started	No further action

SPECIES: CHRISTMAS ISLAND FRIGATEBIRD (*Fregata andrewsi*)

Overall comment: Some recovery actions were started or partially completed. However, existing monitoring data do not provide a basis for drawing conclusions about the status of the Christmas Island frigatebird populations and other than habitat disturbance, likely threats are not known.

Objective 1	**Maximising extent of occurrence and total population size.**
Recovery Criteria	• Breeding distribution of Christmas Island frigatebirds maintained or increased on Stokes (1988) levels. • Total population size not significantly less than 1620 breeding pairs. • Protection of all habitat critical to survival of the Christmas island frigatebird.

No.	Action	Action status comments	Status	Recommendations
1	Develop techniques to monitor the total breeding population size.	Monitoring techniques were developed and used as part of the Biodiversity Monitoring Program (BMP) to determine population trends and site occupation. However, there are limitations using these methods for locating other breeding colonies.	Complete	Continue to use and adapt methods to detect population trends and site occupation/colonies.
2	Monitor the total breeding population size.	Monitoring was conducted as part of the BMP (indicating that there were an estimated 100 breeding pairs near the phosphate dryers in 2005); genetic work is being initiated by Hamburg University and an opportunistic aerial survey was conducted in 2009. These may assist with monitoring the trends in the breeding population size but it may be difficult to determine a total population size. A total population estimate is not currently available.	Partially complete	Continue to monitor population trends.
3	Monitor and/or assist the recovery of the Dryers breeding colony.	Surveys in 2005 estimated 100 breeding pairs near the phosphate dryer's colony and surveys conducted in 2011 appear to indicate the colony and moved west of the initial site.	Partially complete	Monitor frigatebird colony at the Dryers area as part of monitoring known colonies.
4	Development and implementation of a wildlife management plan for frigatebird habitat outside the national park.	The Christmas Island regional recovery plan will incorporate actions for conserving the Christmas Island frigatebird.	Started	Include relevant actions in the regional recovery plan.
5	Ensure protection of habitat critical to survival outside the national park.	The crazy ant management program includes off-park area. However, threats such as weeds are not being managed and other threats are not fully understood. However, actions that may impact on its habitat require assessment under the EPBC Act.	Started	Continue to assess the impacts of proposed actions in accordance with the EPBC Act. Continue to implement island-wide ecosystem recovery actions such as weed and crazy ant management.

Objective 2		**Implementing threat abatement strategies.**		
Recovery Criteria		• Crazy Ants having an insignificant impact on Christmas Island frigatebirds. • Maintenance of effective quarantine against the introduction of avian diseases		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
6	Implement the Invasive Ants on Christmas Island Action Plan.	Management of crazy ants is ongoing and includes aerial baiting to reduce numbers in supercolonies, monitoring to assess success of and need for baiting, assessing off-target impacts, and research into alternative control methods.	Ongoing	Continue crazy ant management.
7	Maintenance [and regular review] of a quarantine barrier between Christmas Island and all other lands to minimise the risks of new avian diseases establishing on Christmas Island.	DAFF Biosecurity have been present on Christmas Island since 1994 and carry out their operations in accordance with the *Quarantine Act*. However, in 2009 the Minster for the Environment, Heritage and the Arts established an Expert Working Group (EWG) to advise the Minister on biodiversity conservation issues on Christmas Island. The EWG recommended quarantine management be upgraded to a standard consistent with the island's biodiversity values.	Partially complete	Increase/improve quarantine.
Objective 3		**Increasing community involvement in and awareness of the Frigatebird.**		
Recovery Criteria		• Demonstrated increase in community awareness and support for habitat protection		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
8	Conduct a community education program.	Several community education activities were conducted on Christmas Island's ecology and species but little was specifically focused on the frigatebird.	Not started	Consider publishing booklet of threatened species.
Objective 4		**To implement the Recovery Plan through a Recovery Team.**		
Recovery Criteria		Demonstrated successful operation of the Recovery Team over five years.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
9	Establish a recovery team which meets regularly	A recovery team was not formed. However, a recovery working group has been developed to assist with the preparation of the Christmas Island regional recovery plan and a recovery team is proposed for the plan's implementation.	Partially complete	Develop and maintain a recovery team.
10	Carry out a major review of the recovery plan.	This audit provides the review.	Complete	No further action

SPECIES: CHRISTMAS ISLAND GOSHAWK (*Accipiter hiogaster natalis*)

Overall comment: Most recovery actions were complete, started or partially completed including establishing a monitoring program. However, existing monitoring data do not provide conclusions about their population status and likely threats.				
Objective 1		**Determine taxonomic status**		
Recovery Criteria 1		• Taxonomic position of Christmas Island goshawk clarified.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
1	Investigate the taxonomic status of the Christmas Island goshawk.	No taxonomic investigations were carried out.	Not started	Conduct taxonomic investigations.
Objective 2		**Determine and maximise total population size and area of occupancy**		
Recovery Criteria		• Distribution of Christmas Island goshawks widespread on the island in all suitable habitats as demonstrated by population monitoring • Density of Christmas Island goshawks increased as demonstrated by population monitoring • Protection of all habitat critical outside the national park. • A continuing increase in suitable habitat through implementation Christmas Island Rainforest Rehabilitation program.		
2	Conduct detailed population survey.	In 2006–07 Holdsworth established a monitoring program; established a sightings database and conducted surveys. The goshawk was also monitored by Parks Australia in the 2009 Island Wide Survey and through the CIMFR program. A total population estimate is yet to be determined.	Partially complete	Analyse existing data and generate population figures for comparison with ongoing monitoring data.
3	On-going monitoring of the population.	Monitoring has been conducted over a number of years by Holdsworth and Parks Australia through the 2009 Island Wide Survey and the CIMFR program.	Partially complete	Continue monitoring population trends.
4	Develop and implement wildlife management plan outside the national park.	A regional recovery plan for Christmas Island is being prepared and will effectively be a wildlife management plan for a range of species inside and outside of the park.	Started	Complete the regional recovery plan.
5	Ensure protection of habitat critical outside the national park.	All new development proposals likely to have significant impact on matters of national significance must be referred under the EPBC Act. Threatening processes impacting on the goshawk are not conclusive, but are likely to be related to habitat loss and modification, weed impacts and invasive species.	Partially complete	Continue to assess the impacts of proposed actions in accordance with the EPBC Act. Continue to implement island wide ecosystem recovery actions such as weed and crazy ant management. Ensure consideration of impacts on the goshawk (e.g. prey relationships, toxin impacts) in any cat and rat management.

No.	Action	Action status comments	Status	Recommendations
6	Continue effective and long-term rainforest rehabilitation program managed by DOTARS & supported by PAN and the mining company.	Rehabilitation occurred to the extent possible with the current available financial and physical resources (e.g. soil). This activity will continue according to annual funding allocation.	Partially complete /ongoing	Continue the rainforest rehabilitation program.
Objective 3		**Implement threat abatement strategies**		
Recovery Criteria		• Crazy Ants have a negligible impact on Christmas Island goshawk • Maintenance of effective quarantine against the introduction of all avian diseases		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
7	Implement the Invasive Ants on Christmas Island Action Plan.	Management of crazy ants is ongoing and includes aerial baiting to reduce numbers in supercolonies, monitoring to assess success of and need for baiting, assessing off-target impacts, and research into alternative control methods.	Ongoing	Continue crazy ant management.
	Maintenance [and regular review] of a quarantine barrier between Christmas Island and all other lands which minimises the risks of new avian diseases establishing on Christmas Island.	DAFF Biosecurity have been present on Christmas Island since 1994 and carry out their operations in accordance with the *Quarantine Act.* However, in 2009 the Minster for the Environment, Heritage and the Arts established an Expert Working Group (EWG) to advise the Minister on biodiversity conservation issues on Christmas Island. The EWG recommended that quarantine management be upgraded to a standard consistent with the island's biodiversity values.	Partially complete	Increase/improve quarantine.
Objective 4		**Increase community involvement and awareness**		
Recovery Criteria		• Demonstrated increase in community awareness and support for habitat protection		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
9	A community education program to raise awareness and interest in the conservation of Christmas Island goshawks.	The goshawk has been included as a feature bird species as part of the annual Bird Week program for seabird groups. No other specific programs for the goshawk have been implemented.	Partially complete	Consider publishing booklet on recovery of the island's species.
Objective 5		**Implement the Recovery Plan through a Recovery Team**		
Recovery Criteria		• Demonstrated successful operation of the Recovery Team over five years		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
10	Establish a recovery team which meets regularly.	A recovery team was not formed. However, a recovery working group has been developed to assist with the preparation of the Christmas Island regional recovery plan and a recovery team is proposed for the plan's implementation.	Started	Develop and maintain a recovery team.
11	Carry out a major review of the recovery plan	This audit provides the review.	Complete	No further action

SPECIES: CHRISTMAS ISLAND HAWK-OWL (*Ninox natalis*)

Overall comment Recovery actions were complete, started or partially completed but monitoring was limited and existing data do not enable conclusions about their population status and likely threats to be determined.

Objective 1	**Maintain (or increase) extent of occurrence and total population size at 1994–96 levels.**
Recovery Criteria	• Total population size not less than 562 ± 105 occupied territories as measured by the monitoring program. • Owls widespread on the island in all suitable habitats as measured by the monitoring program. • Protection of all habitat critical to survival outside the national park. • A continuing increase in suitable habitat through implementation of the Christmas Island Rainforest Rehabilitation program.

No.	Action	Action status comments	Status	Recommendations
1	Monitor the Christmas Island hawk-owl population every two years to detect any significant change in the distribution or abundance.	Limited/incomplete monitoring of Hawk-owls occurred as part of the Biodiversity Monitoring Program (BMP) and a program was further developed and implemented in 2010 after completion of the BMP. These surveys were repeated in 2012 and indicate that the population trend may be stable. Surveys were also conducted by Christmas Island Phosphates for the preparation of a supplementary impact assessment for their application for new mining leases.	Partially complete	Analyse existing monitoring data. Continue the monitoring program.
2	Develop and implement a wildlife management plan for hawk-owl habitat outside the national park.	A regional recovery plan for Christmas Island is being prepared and will effectively be a wildlife management plan for a range of species inside and outside of the park.	Started	Complete the regional recovery plan.
3	Ensure protection of habitat critical to survival outside the national park.	All new development proposals are subject to referral and assessment processes outline under the EPBC Act. However, threatening processes impacting on the Hawk-owl are not conclusive but are likely to be related to habitat loss and modification, weed impacts and invasive species.	Partially complete	Continue to assess the impacts of proposed actions in accordance with the EPBC Act.
4	Continue an effective and long-term rainforest rehabilitation program managed by DOTARS and supported by other government departments, PAN and the mining company.	Rehabilitation occurred to the extent possible with the current available financial and physical resources (e.g. soil).	Partially complete/ ongoing	Continue the rainforest rehabilitation program

Objective 2		**Implement threat abatement strategies**		
Recovery Criteria		• Crazy Ants having a negligible impact on Christmas Island hawk-owls populations. • Maintenance of effective quarantine against the introduction of all avian diseases.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
5	Implement the Invasive Ants on Christmas Island Action Plan	Management of crazy ants is ongoing and includes aerial baiting to reduce numbers in supercolonies, monitoring to assess success of and need for baiting, assessing off-target impacts, and research into alternative control methods.	Ongoing	Continue crazy ant management.
6	Maintenance [and regular review] of a quarantine barrier between Christmas Island and all other lands which minimises the risks of new avian diseases establishing on Christmas Island.	DAFF Biosecurity have been present on Christmas Island since 1994 and carry out their operations in accordance with the *Quarantine Act*. However, in 2009 the Minster for the Environment, Heritage and the Arts established an Expert Working Group (EWG) to advise the Minister on biodiversity conservation issues on Christmas Island. The EWG recommended that quarantine management be upgraded to a standard consistent with the island's biodiversity values.	Partially complete	Increase/improve quarantine.
Objective 3		**Increase community involvement in and awareness**		
Recovery Criteria		• Demonstrated increase in community awareness and support for habitat protection.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
7	Community education program to raise awareness and interest in conservation of Christmas Island hawk-owls.	No specific program for the Hawk-owl was implemented.	Started	Consider publishing booklet on recovery of the island's species.
Objective 4		**Implement the Recovery Plan through a Recovery Team**		
Recovery Criteria		• Demonstrated successful operation of the Recovery Team over five years.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
8	Establish a recovery team which meets regularly.	A recovery team was not formed. However, a recovery working group has been developed to assist with the preparation of the Christmas Island regional recovery plan and a recovery team is proposed for the plan's implementation.	Started	Develop and maintain a recovery team.
9	Carry out a major review of the recovery plan.	This audit provides the review.	Complete	No further action

SPECIES: LISTER'S GECKO (*Lepidodactylus listeri*) and CHRISTMAS ISLAND BLIND SNAKE (*Ramphotyphlops exocoeti*)

Overall comment: Recovery actions were complete, started or partially completed. Intensive localised surveys were conducted for Lister's gecko leading to the rediscovery of the species and the Island Wide Survey resulted in the rediscovery of the CI blind snake. A captive breeding program, not identified in the original recovery plan, for native reptiles, including for Lister' gecko commenced in 2009. Investigation of likely threatening processes is being commenced, including disease and invasive species threats.

Objectives:

1. Find both species in the wild
2. Determine the likelihood that one or more potential threats are threatening the survival of the species
3. Continue present abatement strategies, or develop and implement new strategies, for potential threats such as crazy ants, predators, habitat fragmentation and unintended invasive species introductions (quarantine effectiveness).
4. Obtaining, following rediscovery of either or both species, sufficient knowledge of the biology and ecology of, and threats to, these species to guide an effective management program for increasing their numbers and spatial distribution.

Recovery Criteria:

1. Populations of both species are located within 2 years *or* surveys to locate both species continue (until species located) for the life of the Recovery Plan (5 years).
2. The possible role of the wolf snake, cats and black rats as threats, and potential for control programs, investigated.
3. Existing control program for the crazy ant maintained and/or improved within 2 years.
4. Quarantine regulations and protocols reviewed, and modified as necessary within 2 years.
5. Autecological studies are commissioned within 6 months of the rediscovery of either or both species.
6. Should populations of either species be rediscovered, then at the end of 5 years the current distribution, biology, demography (including estimates of population size) and ecology is sufficiently well documented as to enable development of a full recovery program, including identification and prioritisation of all threats, together with plans for their abatement.
7. Comprehensive information is compiled on both species to support reassessment of their conservation status under the EPBC Act after 2 years if the species are not located, or, if rediscovered, at the end of 5 years.

No.	Action	Action status comments	Status	Recommendations
1	Survey and monitor the endemic reptilian and other selected taxa of Christmas Island.	Considerable native reptile surveys have been conducted during the life of the recovery plan by Barker and Schultz (2008) and park staff surveys, including the Biodiversity Monitoring Program (BMP); Island Wide Surveys and targeted reptile-specific surveys. The results of these surveys were that Lister's gecko and the CI blind snake were rediscovered in 2009 (although only one blind snake was found) but that all six native reptile species were in serious decline. Recent surveys showed that all species (except for the blind snake and giant gecko) are restricted to Egeria Point.	Complete/ ongoing	Continue to monitor native reptiles.
2	Until Lister's gecko and the CI blind snake are rediscovered, have annual searches for both species.	See above	Complete/ ongoing	Continue to search for Lister's gecko and CI blind snake populations.

No.	Action	Action status comments	Status	Recommendations
3	Upon rediscovery of either or both species in the wild, conduct autecological studies to inform recovery actions.	Ecological studies, including disease threats, have been conducted or are being initiated in conjunction with: a captive breeding program for Lister's gecko and blue-tailed skink (with the aim of adaptively releasing them back into the wild) and monitoring to help determine threatening processes to inform recovery actions.	Started	Continue studies to investigate threatening processes. Continue the captive breeding program for Lister's gecko.
4	Identify the role of the introduced wolf snake as a potential threat to endemic reptiles.	The Biodiversity Monitoring Program (BMP) analysed prey data from the digestive tracts of wolf snakes. As cited by Shultz and Barker (2008) the BMP found reptiles comprised 96% of the diet by weight of 104 snakes examined. The predominant prey species were introduced species: the Asian wolf snake (37%, n=30), grass skink (30%, n=24), Asian house gecko (12%, n=10) and barking house gecko (11%, n=9). The blue-tailed skink comprised only a small dietary component (1%, n=1), but this is likely to be a reflection of the low relative abundance of this species compared to the more abundant introduced species. Although inconclusive this indicates wolf snakes are a threat to native reptiles but the level of threat is difficult to quantify. In 2010 the stomach contents of a wolf snake included blue-tailed skink.	Complete	Continue studies to investigate and if possible address threatening processes, including the wolf snake.
5	Review and maintain existing control program for crazy ants.	Management of crazy ants is ongoing and includes aerial baiting to reduce numbers in supercolonies, monitoring to assess success of and need for baiting, assessing off-target impacts, and research into alternative control methods.	Ongoing	Continue crazy ant management.
6	Identify the role of cats and rats as potential threats to endemic reptiles.	Previous cat gut content studies have shown cats predate on native reptiles. However, any current predation is likely to be low as reptile numbers are low. Due to the known and potential impacts of cats and rats on many Christmas Island species, the Shire of Christmas Island and Parks Australia coordinated the preparation of an island-wide cat and rat management plan (Algar and Johnston 2010). Implementation commenced in 2010 and is ongoing.	Started	Investigate impacts of rats on endemic reptiles. Continue to implement cat and as needed rat management.
7	Reassess conservation status in the absence of further records.	Species both detected in 2009. Nomination for revised status for Lister's gecko has been prepared.	Complete	No further action
8	Review quarantine protocols for all personnel and materiel entering Christmas Island.	DAFF Biosecurity have been present on Christmas Island since 1994 and carry out their operations in accordance with the *Quarantine Act*. However, in 2009 the Minster for the Environment, Heritage and the Arts established an Expert Working Group (EWG) to advise the Minister on biodiversity conservation issues on Christmas Island. The EWG recommended that quarantine management be upgraded to a standard consistent with the island's biodiversity values.	Partially complete	Increase/improve quarantine.

SPECIES: CHRISTMAS ISLAND SPLEENWORT (*Asplenium listeri*)

No.	Action	Action status comments	Status	Recommendations
Overall comment: Few recovery actions were complete, started or partially completed. There is little understanding of its biology and ecology and threats (other than weeds and direct human impacts like vegetation clearance) or if its populations are increasing from a low population base as it may be a recently evolved species. Some proposed actions were difficult to link with recovery.				
Objective 1		**To abate and avert threats to the species**		
Recovery Criteria 1		• No population of the species is impacted by a threatening process.		
1.1	Keep locations of populations confidential.	Confidentiality of sites was maintained however on Christmas Island illegal collection of plants is considered rare or not to occur.	Complete	No further action
1.2	Monitor visitor pressure and impact on Gannet Hill population.	Although a detailed monitoring program is not in place monitoring of track conditions and visitor infrastructure indicates that visitor impacts and pressures are low.	Partially complete	Maintain monitoring of visitor pressure and impacts.
1.3	Ensure inclusion of *Asplenium listeri* in all guidelines and specifications for environmental assessment and standards, particularly along the east coast.	*Asplenium listeri* has been considered in environmental assessments.	Partially complete	Continue to assess the impacts of proposed actions in accordance with the EPBC Act.
1.4	Pursue national park status for the Ross Hill Gardens area and around South Point, and other areas related to populations of *Asplenium listeri* that are located within the term of this plan.	The Christmas Island National Park management plan indicates that there may be an opportunity to expand the area of the park. Any consideration of boundary changes would seek to extend the area of the park to include other areas of high conservation value and recently rehabilitated minefield, and possibly remove areas of low conservation value. Any boundary changes must be approved by both houses of Parliament and boundary extensions are beyond the scope of recovery plans.	Not started	No further action for recovery plan
1.5	Consider need for listing on the EPBC Register of Critical Habitat to strengthen legal protection, with update as new populations are located.	Need was considered and listing not pursued. Due to the existing level of protection under other provisions of the EPBC Act, there would be no additional conservation benefit from listing reptile habitat on the EPBC Register of Critical Habitat.	Complete	No further action
1.6	Expand content about *Asplenium listeri* (and other listed plant species) in future national park management plans with specific reference to recovery plans and relevant threat abatement plans (keeping precise locations confidential).	Reference to *Asplenium listeri* was included in Christmas Island National Park Management Plan. However, except for raising some awareness and for impact assessments, the recovery benefits of doing this may be limited.	Complete	No further action

No.	Action	Action status comments	Status	Recommendations
1.7	For the population at The Dales, and if a population is located at Hosnies Spring, update the relevant Ramsar Information Sheet and description of ecological character to ensure the most robust protective framework under the EPBC Act.	Ramsar Ecological Character Descriptions (ECD) for The Dales and Hosnies Spring were prepared in 2010. The Dales ECD refers to the CI spleenwort. While it is valuable documenting its presence at The Dales the impact on recovery is likely to be limited.	Complete	No further action
Objective 2		**To improve knowledge of factors in the restricted distribution of the species**		
Recovery Criteria 2		• A comprehensive list of environmental factors (physical and biological) and/or a predictive model assist(s) location of additional populations.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
2.1	Survey all known occurrences of *Asplenium listeri* to compile a comprehensive list of environmental factors (physical and biological) and base data (including photographic) for population monitoring.	Surveys were conducted in 2002 by Holmes and Holmes but surveys have not been conducted in the life of the recovery plan. Environmental factors and base data for population monitoring have not been compiled.	Not started	Conduct population monitoring. Survey known sites to determine environmental factors affecting distribution.
2.2	Consider use of the above to develop predictive models to assist location of additional populations.	This action was not started .	Not started	Develop a model based on habitat survey results.
Objective 3		**To increase the number of known occurrences**		
Recovery Criteria 3		• At least one additional population (or an enlarged population) of the species has been located in the wild.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
3.1	Survey potential habitat for more populations, with focus on the east coast, including Hosnies Spring (following a wet season).	Surveys were conducted in 2002 by Holmes and Holmes but surveys have not been conducted in the life of the recovery plan.	Not started	Conduct surveys of potential habitat.
3.2	Examine the need for and potential of *ex situ* cultivation.	The potential for *ex situ* has been examined and scientific advice indicates it is feasible. The need has not been examined.	Partially complete	Determine triggers for implementing *ex situ* cultivation, monitor populations and implement *ex situ* actions if required.
3.3	Examine potential for (re)introduction of *Asplenium listeri* into additional east coast terrace clifftops.	This has not been examined.	Not started	Investigate potential re-introduction areas if *ex situ* cultivation is triggered.

SPECIES: The fern *Tectaria devexa* (a)

Overall comment: Most recovery actions were complete, started or partially completed. There is little understanding of its biology and ecology and threats but exotic species and direct human impacts like vegetation clearance are proposed. Some proposed actions were difficult to link with recovery. **Note: specific objectives and actions referring to Queensland populations are not included.**				
Objective 1		**To reduce the rate of decline in the species**		
Recovery Criteria 1		• Monitoring demonstrates no net decline in populations.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
1.1	Quantify and monitor populations in the Rockhampton area and on Christmas Island.	Limited surveys at one site were conducted (2004–05 and 2009) by Parks Australia. These surveys found additional individuals to those surveyed by Holmes and Holmes in 2002.	Started	Conduct population monitoring surveys, including through the IWS.
Objective 2		**To increase the number and area of occurrences**		
Recovery Criteria 2		• Systematic surveys to determine whether there are any additional populations have been completed.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
2.1	Survey potential habitat for more populations in the Rockhampton area and on Christmas Island.	Potential habitat not surveyed.	Not started	Conduct surveys of potential habitat.
2.2	Encourage reporting of new localities to assist on-going review of conservation status.	Active encouragement did not occur.	Not started	Consider publishing booklet on recovery of the island's species. Encourage involvement in regional recovery plan actions.
Objective 3		**To abate and avert threats to the species**		
Recovery Criteria 3		• No population of the species is significantly impacted by a threatening process.		
No.	**Action**	**Action status comments**	**Status**	**Recommendations**
3.1	Maintain confidentiality for precise locations in the Rockhampton area (other than Capricorn Caves) and on Christmas Island.	Confidentiality of sites was maintained however on Christmas Island illegal collection of plants is considered rare or not to occur.	Complete	No further action
3.5	Ensure inclusion of *Tectaria devexa* in all guidelines and specifications for environmental assessment and standards on Christmas Island, particularly on the central plateau.	*Tectaria devexa* has been considered in environmental assessments.	Partially complete	Continue to assess the impacts of proposed actions in accordance with the EPBC Act.

No.	Action	Action status comments	Status	Recommendations
3.7	Objectively examine differences in specialist opinion regarding the extent to which canopy gaps may be important to *Tectaria devexa* on Christmas Island.	No examination was conducted. This action is no longer considered essential to recovery, given it is not focused on addressing conservation threats or is likely to trigger a management response.	Not started	No further action
3.8	Update The Dales Ramsar Information Sheet and description of ecological character to note the population of *Tectaria devexa* near Sydney's Dale.	The Ramsar Ecological Character Description for The Dales (prepared in 2010) refers to *Tectaria devexa* being within the site. However, the recovery benefits of doing this are likely to be limited.	Complete	No further action
3.10	Expand content about *Tectaria devexa* (and other listed plant species) in future Christmas Island National Park management plans in line with recovery plans and relevant threat abatement plans.	Reference to *Tectaria devexa* is included in the Christmas Island National Park Management Plan.	Complete	No further action

Actions 3.2–4.3 and 3.9 were not applicable for the Christmas Island population.

Objective 4	**To improve knowledge of factors in the restricted distribution of the species**
Recovery Criteria 4	• A comprehensive list of habitat requirements (physical and biological) is developed to assist location of additional populations.

No.	Action	Action status comments	Status	Recommendations
4.1	Investigate all known occurrences of *Tectaria devexa* to compile a comprehensive list of habitat requirements (physical and biological) to assist location of additional populations.	Limited surveys at one site were conducted (2004–05 and 2009) by Parks Australia. However these surveys did not assess habitat requirements.	Not started	Survey known sites to determine environmental factors affecting distribution.

Objective 5		**To develop capability for enrichment planting or reintroduction of the species**		
Recovery Criteria 5		• The species (var. *devexa*) has been cultivated *ex situ* as a precaution against extinction in the wild in the Rockhampton area.		
5.1	Examine the need for, and potential risks of, *ex situ* cultivation of both varieties.	The potential for *ex situ* cultivation of var. *minor* has been examined and scientific advice indicates it is feasible. The need and risks have not been examined.	Partially complete	Determine triggers for implementing *ex situ* cultivation, monitor populations and implement *ex situ* actions if required.

Action 5.2 was not applicable for the Christmas Island population.

Objective 6	**To improve community awareness of the species and its conservation status**
Recovery Criteria 6	• There is active presentation, and heightened awareness of the status of the species and its role in illustrating regional (and continual) environmental change.

The action included under this objective was not applicable for the Christmas Island population.

(a) The *Tectaria devexa* recovery plan will remain in place under the EPBC Act, as it covers the Queensland population of this species

Appendix K—Species profiles

The following profiles provide information on species identified as significant (see Part 3.2 of this plan for definition).

The action numbers identified in the species profiles refer to the integrated actions described in Part 6 of this plan. The actions which are essential in order to achieve both the underpinning and biological objectives of this plan—Action 7 *Manage and analyse data*, Action 8 *Communicate with and engage the community and other stakeholders* and Action 9 *Coordinate biodiversity conservation plan implementation*—are not included within species profiles as these actions are relevant to all species.

Species		Page	Map
Vascular plants			
Asplenium listeri	Christmas Island spleenwort	138	1
Bruguiera gymnorhiza, B. sexangula	large-leafed and upriver orange mangroves	140	n.a.
Pneumatopteris truncata	a fern	141	2
Tectaria devexa var. *minor*	a fern	143	3
Seabirds			
Fregata andrewsi	Christmas Island frigatebird	145	4
Papasula abbotti	Abbott's booby	147	5
Phaethon lepturus fulvus	golden bosun (white-tailed tropicbird)	149	n.a.
Forest birds			
Accipiter hiogaster natalis	Christmas Island goshawk	150	6
Chalcophaps indica natalis	Christmas Island emerald dove	152	7
Collocalia linchi natalis	Christmas Island swiftlet	154	n.a.
Ducula whartoni	Christmas Island imperial pigeon	155	8
Ninox natalis	Christmas Island hawk-owl	157	9
Turdus poliocephalus erythropleurus	Christmas Island thrush	159	10
Zosterops natalis	Christmas Island white-eye	161	11
Mammals			
Crocidura trichura	Christmas Island shrew	163	12
Pipistrellus murrayi	Christmas Island pipistrelle	165	13
Pteropus melanotus natalis	Christmas Island flying-fox	167	14
Reptiles			
Cryptoblepharus egeriae	blue-tailed skink	169	15
Cyrtodactylus sadleiri	giant gecko	171	16
Emoia atrocostata	coastal skink	173	17
Emoia nativitatis	forest skink	175	18
Lepidodactylus listeri	Lister's gecko	177	19
Ramphotyphlops exocoeti	Christmas Island blind snake	179	20
Land crabs			
Birgus latro	robber crab	181	n.a.
Discoplax celeste	blue crab	182	21
Gecarcoidea natalis	red crab	184	22

Asplenium listeri | Christmas Island spleenwort

Family ASPLENIACEAE

Conservation Significance

Small rock-dwelling fern endemic to Christmas Island

EPBC Act Listing: Critically Endangered

Existing Conservation Measures

Monitoring through IWS and targeted surveys

Previous Recovery Plan

Butz 2004b

Distribution

Asplenium listeri is currently known from five separate sites across the island of which three are in the national park (Map 1). However, distribution is not well known and there is the possibility of undiscovered sites.

The sites are narrow cliff-top strips up to 15 m wide, between a very open aspect on the seaward side and a forest structure increasing up to 40 m high on the inland side (Reddell pers. comm. in Butz 2004b), situations which are well placed to interrupt and capture moist flow from south-easterly trade winds (Tranter pers. comm. in Butz 2004b).

Populations

There are five known populations, all restricted to Christmas Island. There is a further historical record from a site at Flying Fish Cove (Du Puy 1993a).

In 2002 a total of about 300 plants were recorded across the five known sites (Holmes & Holmes 2002). Sizes of populations are currently unknown, apart from a single estimate of 25–50 plants for one population (DNP unpub. data 2012).

All occurrences of the species, including any future populations found, are important populations, based on its endemic status, its highly restricted occurrence and the uncertainty surrounding the reasons for its rarity.

Habitat

A. listeri grows colonially on limestone rocks and cliffs in semi-deciduous closed forest, mainly beneath or near *Ficus microcarpa*, in partly shaded sites but sufficiently exposed for ventilation (Holmes & Holmes 2002).

Habitat critical to the survival of the species is:

- all limestone rock crevices in the vicinity of known occurrences (reflecting uncertainty regarding reasons for the extremely limited distribution of the species and potential threats to survival)
- tall vegetation on the inland side of cliff-tops with relatively open exposure to the coast.

Due to the uncertainty of current location information and limited knowledge on the ecology and specific habitat requirements, habitat critical to the survival of the species cannot be mapped.

Threats

The endemicity, very small population size, fragmented distribution and lack of accurate location data for this species make it vulnerable to a wide range of threats and to changes in its habitat.

Threats include:

- removal or modification of habitat through vegetation clearing and disturbance e.g. road construction, developments or mining
- invasive species e.g. weeds, giant African land snails and crazy ants (which reduce numbers of red crabs which prey on snails)
- introduction of new invasive species
- climatic events, such as drought and cyclones, and climate change.

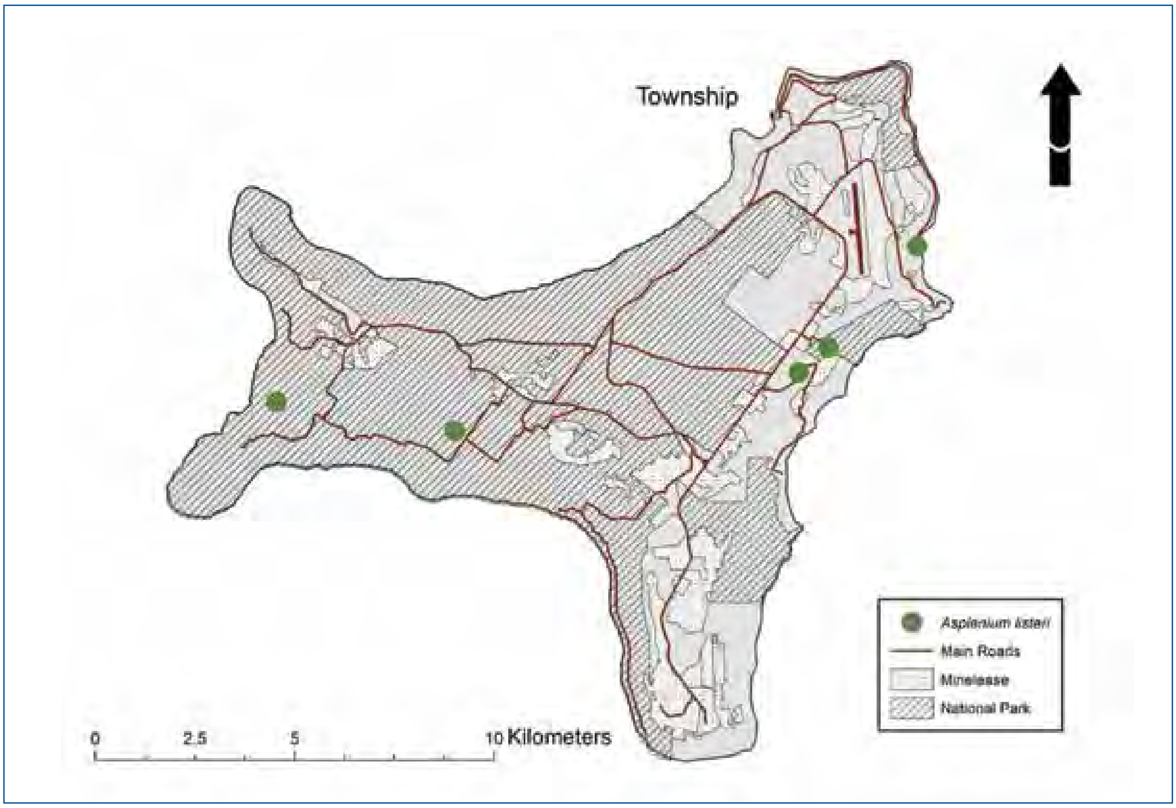
Most of these threats are widespread, occurring across the range of this species on Christmas Island. Vegetation disturbance through clearing is only a threat to populations located outside the national park.

Forest fires represent a potential threat if dry seasons become more severe as the climate changes.

Illegal collection is highly unlikely to occur so is not considered a threat.

Management Actions

- Conduct population surveys to determine sizes and locations, and collect additional habitat/site data, as well as targeted surveys for additional populations (Action 5.5).
- Monitor populations to detect any declines (including for possible *ex situ* action) (Action 5.2).
- Assess and identify physical and biological habitat requirements (Action 6.2).
- Monitor and avoid or mitigate threats and negative impacts to populations, including: invasive species, such as crazy ants (Action 1.1), weeds (Action 3.1) and giant African land snails (Action 3.4).
- Improve biosecurity to maintain effective quarantine against the introduction of invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Determine targets and thresholds for implementing *ex situ* cultivation (Action 9.2). Implement *ex situ* actions and investigate potential re-introduction areas if *ex situ* cultivation is triggered (Action 4.2).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).



Map 1: Known locations of *Asplenium listeri* on Christmas Island 2013 (Parks Australia)

Map caveats:

The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Bruguiera gymnorhiza	large-leafed orange mangrove
Bruguiera sexangula	upriver orange mangrove

Family RHIZOPHORACEAE

Conservation Significance

The dominant plant species and critical components for defining the ecological character of Hosnies Spring which is listed as a Wetland of International Importance under the Ramsar Convention (Hale & Butcher 2010).

The two species are treated together as they co-occur and are difficult to distinguish.

EPBC Act listing: none

Existing Conservation Measures

Not actively promoting visitor access to the site as board walks are not in place or proposed. No other specific conservation measures are currently in place

Hosnies Spring is a declared Ramsar wetland under the EPBC Act.

Distribution

On Christmas Island both species are restricted to the freshwater environment of Hosnies Spring which is located wholly within the national park (Figure 4).

Both species are widely distributed outside Christmas Island. *B. gymnorhiza* occurs in littoral mangrove forest from eastern Africa and south-east Asia through Malesia and New Guinea to northern Australia and the Pacific islands. *B. sexangula* is distributed from south-east Asia through Malesia to New Guinea, New Britain and northern Australia (Du Puy 1993b).

Populations

On Christmas Island these species only occur in the unusual freshwater mangrove stand at Hosnies Spring, which is on the north east coast of Christmas Island, located about 30 m above sea level and 120 m inland from the seaward cliff (see Figure 4).

Approximately 300 to 600 individuals of both species occur at this site, restricted to an area of about 0.33 hectares (Woodroffe 1988).

The single population is necessary for the long-term survival of both species on Christmas Island.

Habitat

Hosnies Spring (Figure 4) is near the base of the first inland cliff, where a junction between basalt and limestone rocks occurs at an altitude of about 15–25 m (Du Puy 1993b). The spring is habitat critical for both species.

The site is an example of a specific type of wetland unique to Christmas Island and perhaps unique worldwide. The mangroves are a relict population estimated to be 120,000 years old. They occur at an elevation not recorded anywhere else in the world.

Threats

There are no conceivable current threats (Holmes & Holmes 2002).

Potential threats, which may be exacerbated by small population size, include:

- stochastic events and landscape or habitat change such as cyclones and drought
- pervasive threats arising from changes to rainforest ecosystem dynamics from the introduced crazy ant and their interaction with the red crabs (may change the forest structure, floristic composition and dynamics and favour other invasive species including weeds and giant African land snails)
- crazy ant super colonies help develop or maintain heavy infestations of scale insects on foliage, with consequential increases in tree mortality
- competition from weeds
- changes to water flows and hydrology, for example from over extraction of groundwater
- visitor impacts on mangrove seedling regeneration.

Management Actions

- Conduct survey of mangrove community composition, extent, age classes and regeneration (Action 5.5) and density of mangrove trees and presence of seedlings and saplings (Action 5.4).
- Control and reduce the impacts of crazy ants (Action 1.1).
- Monitor and manage use of subterranean groundwater (Action 3.5).
- Control high risk weeds (Action 3.1).
- Monitor and minimise visitor impacts (Action 3.2)
- Determine targets and thresholds for implementing *ex situ* cultivation (Action 9.2) and implement relevant actions if *ex situ* cultivation is triggered (Action 4.2).

Pneumatopteris truncata	a fern
Family THELYPTERIDACEAE	

Conservation Significance

Only Australian occurrence is on Christmas Island

EPBC Act Listing: Critically Endangered

Existing Conservation Measures

Monitoring through targeted surveys

Previous Recovery Plan

This is the first recovery plan for this species

Distribution

The species has a fragmented distribution over Asia and Malesia (Du Puy 1993c). The Australian distribution is restricted to Christmas Island, where it is known from two localities on the south-west side of the island (Holmes & Holmes 2002; Du Puy 1993c) (Map 2). However, distribution is not well known and there is the possibility of undiscovered sites.

Populations

Two populations of this species were identified on Christmas Island in a survey in 2002 (Holmes & Holmes 2002). There are also two historical records, one with no precise locality and one from the Waterfall (Du Puy 1993c). Additional scattered occurrences have subsequently been located on former mining areas within the national park that have been rehabilitated (DNP upub. data 2012).

A total of 45 plants divided between two small localities (Hugh's Dale and the Blowholes) was recorded in the 2002 survey. Current total population size is unknown however more than 100 plants have been identified within rehabilitated areas; the population at Hugh's Dale may be declining (DNP unpub. data 2012).

All occurrences of the species, including any future populations found, are important populations, based on its highly restricted occurrence and the uncertainty surrounding the reasons for its rarity.

Habitat

P. truncata grows in colonies on permanently moist sites in semi-deciduous closed forest (Figure 3) between 50 and 140 m elevation (Holmes & Holmes 2002; Du Puy 1993c).

Data on the habitat requirements of this species are insufficient to define and locate habitat critical to survival.

Threats

The very small known population size, fragmented distribution and lack of accurate location data make the species vulnerable to a wide range of threats and to changes in its habitat.

Threats include:

- removal or modification of habitat through vegetation clearing and disturbance e.g. road construction, developments or mining
- invasive species e.g. weeds, giant African land snails and crazy ants (which reduce numbers of red crabs which prey on snails)
- the introduction of new invasive species
- climatic events, such as drought and cyclones, and climate change.

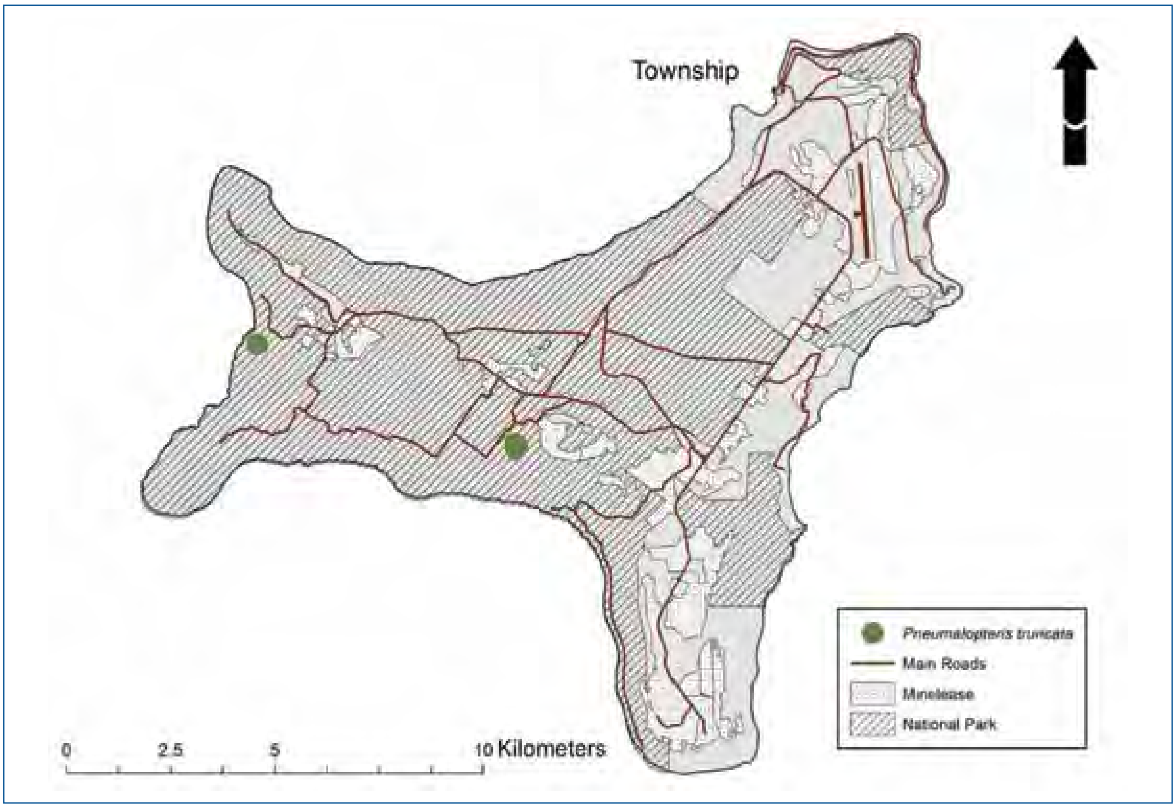
Most of these threats are widespread, occurring across the range of this species on Christmas Island. Vegetation disturbance through clearing is only a threat to populations located outside the national park.

Forest fires represent a potential threat if dry seasons become more severe as the climate changes.

Illegal collection is highly unlikely to occur and is not considered a threat.

Management Actions

- Conduct population surveys to determine size and location and collect additional habitat/site data as well as targeted surveys for additional populations (Action 5.5).
- Monitor populations to detect any declines (including for possible *ex situ* action) (Action 5.2).
- Assess and identify physical and biological habitat requirements (Action 6.2).
- Monitor and avoid or mitigate threats and negative impacts to populations, including invasive species, such as crazy ants (Action 1.1), weeds (Action 3.1) and giant African land snails (Action 3.4).
- Determine targets and thresholds for implementing *ex situ* cultivation (Action 9.2). Implement *ex situ* actions and investigate potential re-introduction areas if *ex situ* cultivation is triggered (Action 4.2).
- Improve biosecurity to maintain effective quarantine against the introduction of invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).



Map 2: Known locations of *Pneumatopteris truncata* on Christmas Island 2013 (Parks Australia)

Map caveats:

The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Tectaria devexa var. minor | a fern

Family TECTARIACEAE

Conservation Significance

EPBC Act Listing: Endangered (as part of *Tectaria devexa*)

Existing Conservation Measures

Monitoring through IWS and targeted surveys

Previous Recovery Plan

Butz 2004a (for *Tectaria devexa*)

Distribution

Tectaria devexa var. *minor* is found only on Christmas Island and Sri Lanka. *Tectaria devexa* var. *devexa* is known from southern Asia and central Queensland (Du Puy 1993d).

On Christmas Island *T. devexa* var. *minor* has a fragmented distribution on the plateau where it is currently known from nine locations (Du Puy 1993d; Holmes & Holmes 2002; Butz 2004a, DNP unpub. data 2012). Most known sites occur within the national park (Map 3). However, distribution is not well known and there is the possibility of undiscovered sites.

An historic record exists from a site that has since been developed (Du Puy 1993d).

Populations

The total number recorded on Christmas Island by Holmes & Holmes (2002) was just over 400 plants with 210 being confined to one locality, 170 to another and remaining plants distributed among small and scattered colonies. Recent decline has not been observed or inferred.

All occurrences of the species, including any future populations found, are important populations, based on its highly restricted occurrence and the uncertainty surrounding the reasons for its rarity.

Habitat

T. devexa var. *minor* grows in shaded positions in the evergreen tall closed forest on the plateau above 80 m elevation (Holmes & Holmes 2002), usually in areas of deep soil derived from limestone substrate, where it may be the only forest floor species (Du Puy 1993d). Records have been made of this species inhabiting drill line clearings (Butz 2004a) although subsequent searches highlighted there may have been confusion with the similar species *Tectaria dissecta* (Moloney pers. comm. 2012).

Data on the biophysical requirements of this species is insufficient to define, and identify the location and extent of, habitat critical to survival. Until this information is available, habitat critical to the survival of *T. devexa* var. *minor* is considered to include all areas within 50 m of the area occupied by the species.

Threats

The very small known population size, fragmented distribution and lack of accurate location data make the species vulnerable to a wide range of threats and to changes in its habitat.

Threats include:

- removal or modification of habitat through vegetation clearing (e.g. road construction, developments or mining)
- invasive species e.g. weeds, giant African land snails and crazy ants (which reduce numbers of red crabs which prey on snails)
- introduction of new invasive species
- climatic events, such as drought and cyclones, and climate change.

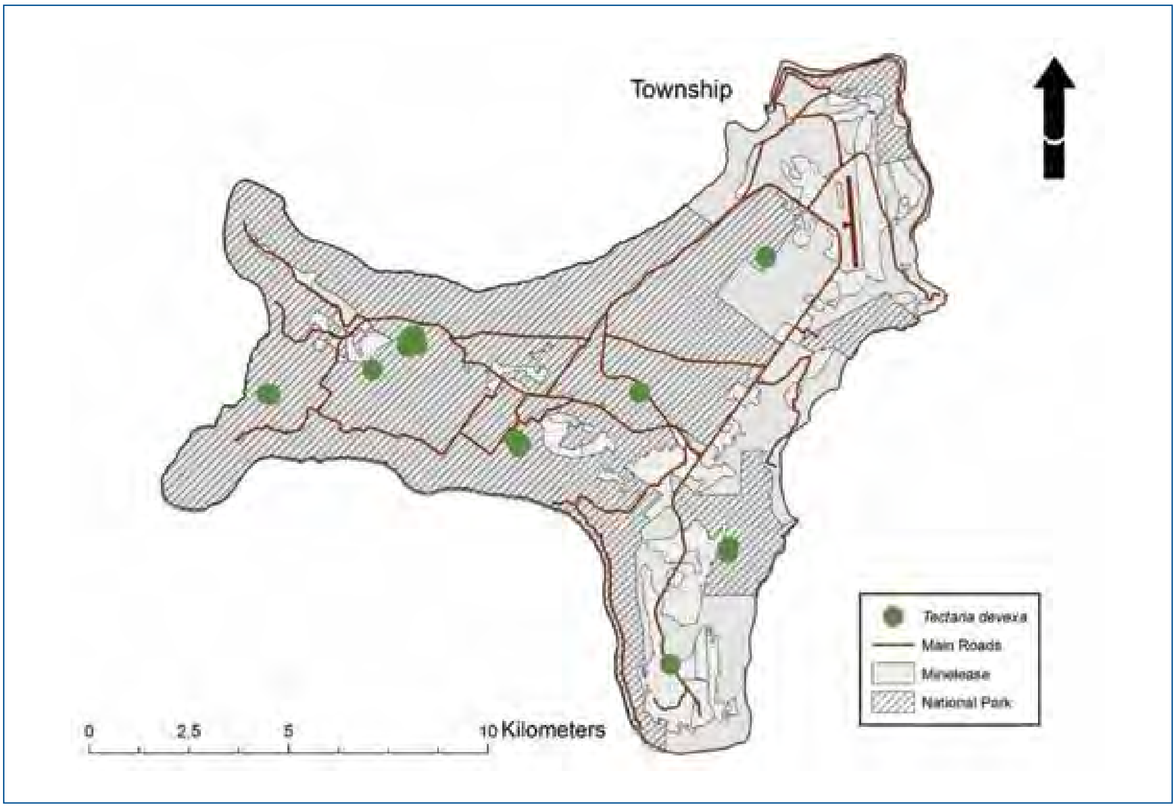
Most of these threats are widespread, occurring across the range of this species on Christmas Island. Vegetation disturbance through clearing is only a threat to populations located outside the national park.

Forest fires represent a potential threat if dry seasons become more severe as the climate changes.

Illegal collection is highly unlikely to occur so is not considered a threat.

Management Actions

- Conduct population surveys to determine sizes and locations, and collect additional habitat/site data, as well as targeted surveys for additional populations (Action 5.5).
- Monitor populations to detect any declines (including for possible *ex situ* action) (Action 5.2).
- Assess and identify physical and biological habitat requirements (Action 6.2).
- Monitor and avoid or mitigate threats and negative impacts to populations, including invasive species, such as crazy ants (Action 1.1), weeds (Action 3.1) and giant African land snails (Action 3.4).
- Improve biosecurity to maintain effective quarantine against the introduction of invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Determine targets and thresholds for implementing *ex situ* cultivation (Action 9.2). Implement *ex situ* actions and investigate potential re-introduction areas if *ex situ* cultivation is triggered (Action 4.2).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).



Map 3: Known locations of *Tectaria devexa* var. *minor* on Christmas Island 2013 (Parks Australia)

Map caveats:

The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Fregata andrewsi	Christmas Island frigatebird

Family FREGATIDAE

Conservation Significance

Breeds only on Christmas Island

EPBC Act Listing: Vulnerable (also marine and migratory)

IUCN Listing: Critically Endangered

Existing Conservation Measures

Monitoring of nesting success at known nesting colonies

Previous Recovery Plan

Hill & Dunn 2004

Distribution

The Christmas Island Frigatebird nests in a few small areas of terrace forests on the north-east of the island, located both in and outside the national park. James (2003) estimated the then four known breeding colonies to cover about 140 ha, a reduction from a previous report of 170 ha (Stokes 1988).

Breeding birds frequently forage hundreds and even thousands of kilometres over the Indian Ocean and throughout the Indo–Malay Archipelago. When not breeding the species ranges widely across the seas of south-east Asia to Indochina and south to northern Australia; its range to the west is less well known (Hill & Dunn 2004).

Populations

The total population size was estimated in 1984 as approximately 1620 pairs (Stokes 1984) and more recently was reported as 1100 breeding pairs (DNP 2008c). The current population size is unknown and, while it is not clear if the population has remained stable, decreased or increased, it is thought to be declining.

In 2004 there were four breeding colonies (Flying Fish Cove, Dryers, Golf Course and Cemetery with the latter two being within the national park—see Map 4). However, as at 2011 there is no longer a known colony at Flying Fish Cove (Garnett et al. 2011).

The single known population is considered important to the survival of the species.

Habitat

The frigatebird nests in tall forest trees, particularly *Terminalia catappa* and *Celtis timorensis*, which are sheltered from prevailing trade winds (Stokes 1988). The birds forage over relatively warm, low salinity waters (Marchant & Higgins 1990).

Given the limited data on habitat requirements, nesting habitat critical to the survival of the Christmas Island frigatebird is defined as the area occupied by all current and former nesting colonies.

Threats

Supercolonies of crazy ants potentially threaten individual breeding birds and their nestlings, through predation or disturbance at nest sites and habitat changes.

Three invasive weed species may threaten the species. The disturbed fringes of the Cemetery breeding colony may be at risk of being invaded by the coastal vine *Antigonon leptopus,* which may smother nest trees and restrict access. *Leucaena leucocephala* has formed monocultural stands around some edges, completely excluding recruitment of preferred native nest-tree species. The spread of *Clausena excavata* throughout the Cemetery breeding colony has the potential to form monocultures, out-competing preferred nest-tree species and preventing recruitment.

The introduction of new invasive species is a threat across the island.

There is risk of catastrophic destruction of breeding colonies by climatic events like cyclones.

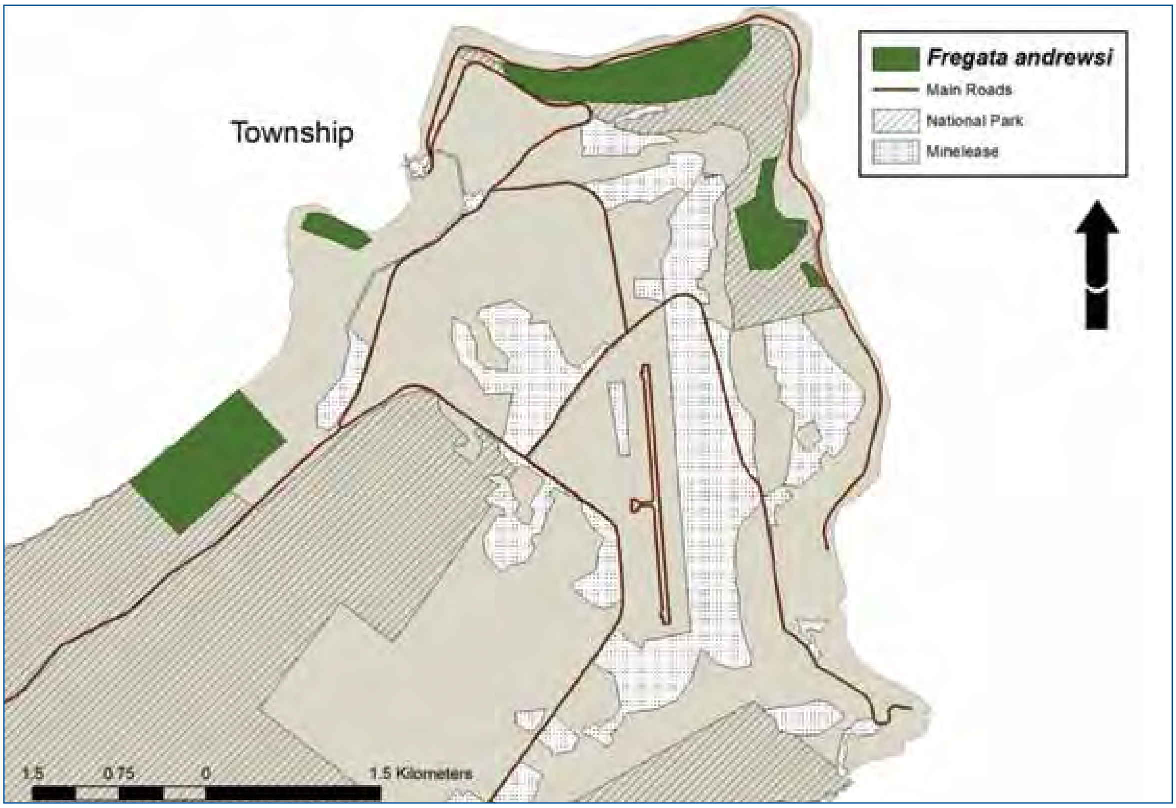
Much of the breeding area lies outside the national park and has no formal protection (Hill & Dunn 2004). Clearing of nesting sites could therefore pose a future threat.

Heavy metal poisoning (including from drinking at contaminated sites) is an unknown but potential threat.

Threats and potential threats in areas beyond the Christmas Island Territory include overfishing, marine pollution, changes to sea surface temperature affecting feeding or food availability, and off-island hunting, for example on non-breeding roost islands. Hunting is not a threat on Christmas Island.

Management Actions

- Control and reduce the impacts of crazy ants (Action 1.1).
- Control high risk weeds, especially those that impact on nesting sites (Action 3.1).
- Monitor population trends and site occupation (Action 5.2).
- Improve biosecurity to maintain effective quarantine against the introduction of invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Investigate the potential threat and risks of chemicals and toxins (Action 6.1).
- Protect nesting habitat from clearing or other disturbances. Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).
- Investigate at-sea distribution and habitat utilisation, using data loggers and satellite telemetry (Action 6.2) to determine:
  - foraging range, habitat and behaviour, both spatially and temporally, and accounting for sex, age class, season and breeding status
  - potential overlap of foraging behaviour and habitat with threatening processes, such as long-line fishing, marine pollution and hunting.



Map 4: Locations of Christmas Island frigatebird nesting colonies in 2004 (Parks Australia)

Map caveats: The data on this map represents areas where nesting colonies have been detected but does not represent all areas where the species or nesting colonies may exist and the map cannot be used for population estimate purposes.

Since 2011 the colony at Flying Fish Cove is not known to remain.

Papasula abbotti	Abbott's booby

Family SULIDAE

Conservation Significance

Breeds only on Christmas Island

EPBC Act Listing: Endangered (also marine and migratory)

IUCN Listing: Endangered

Existing Conservation Measures

Monitoring through IWS

Surveys of chick survival rates and breeding activity undertaken

Restoration of nesting sites through rainforest rehabilitation program

Previous Recovery Plan

Department of the Environment and Heritage 2004

Distribution

Abbott's booby formerly bred on many islands in the Indian and Pacific oceans but since the early 1900s only known to breed on Christmas Island. Most nests are situated on the central and western areas (tall plateau forest) but are also found along the north coast (upper terrace forest). Most nests are now between cleared land and coastal terraces (Garnett et al. 2011). Map 5 shows detection sites for the species across the island.

Although the at-sea distribution of Abbott's booby is poorly known (DEH 2004) it is thought foraging occurs over a wide area. However, chick-rearing individuals in tracking studies utilised only a small area of the eastern Indian Ocean close to the island (Hennicke 2007).

An adult female recorded in the Mariana Islands indicates extensive foraging range, another possible breeding colony, or vagrancy (see Pratt et al. 2009).

Populations

Accurate estimates of population size are not available due to the rugged terrain of preferred breeding sites, and the inherent difficulty in locating breeding sites high in the canopy.

Total breeding population size was estimated at around 2500 pairs in a 1991 ground-based survey (Yorkston & Green 1997). A 2002 helicopter survey recorded 1500 nests (Commonwealth of Australia 2004) which compared favourably with the 1991 estimate (noting the species breeds biennially) although the validity of that comparison is open to question due to the different techniques involved (DNP 2008b). Garnett et al. (2011) estimated the population at 7000 mature individuals, citing earlier population estimates.

Recent surveys of chick survival rates and nesting occupancy suggest the population is stable (DNP unpub. data 2012) which is supported by anecdotal evidence of long-term island residents.

Populations important for survival of the species include all breeding populations (currently the only known extant breeding population is on Christmas Island).

Habitat

Abbott's booby nests in tall rainforest trees, mostly in uneven canopy containing emergent trees (Stokes 1988). Nest sites are largely restricted to areas above 150 m, mostly on the sides of northwest facing slopes (Nelson 1978, Stokes 1988) that are not impacted by windshear (DEH 2004).

The sole breeding habitat, tall rainforest mostly above 150 m elevation in the western, central and northern portions of the island, is critical to the survival of Abbott's booby. Most suitable nesting habitat lies within the national park.

Abbott's booby forages at sea but is a poor diver (DEH 2004). The at-sea distribution of the species is poorly known but contains specific areas of foraging habitat that are critical to survival of the species.

Threats

Degradation and loss of critical breeding habitat from previous land clearing for mining and other settlement activities (e.g. road construction) have had an impact on the population. Although clearing of breeding habitat does not currently occur, it is a potential threat outside the national park.

The impact of crazy ants on the island's ecosystem poses a threat to the species, along with predation or disturbance at nest sites.

Three invasive weed species are a potential threat. The invasive vine *Mucuna albertisii* can form enormous vine towers in canopy gaps and forest edges; it occurs directly adjacent to existing nest sites and could exclude birds from any trees that it smothers. The woody weeds *Clausena excavata* and *Aleurites moluccana* have the ability to germinate in full shade under intact rainforest and are a potential threat to the survival of the bird's preferred nest-tree species (e.g. *Planchonella nitida*, *Syzygium nervosum*, *Celtis timorensis*).

The introduction of new invasive species is also a threat.

Unsustainable exploitation of sub-surface predatory fish (e.g. tuna, billfish) in marine habitat may impact negatively. Marine pollution is a potential threat, along with entanglement or persecution in fisheries beyond Christmas Island.

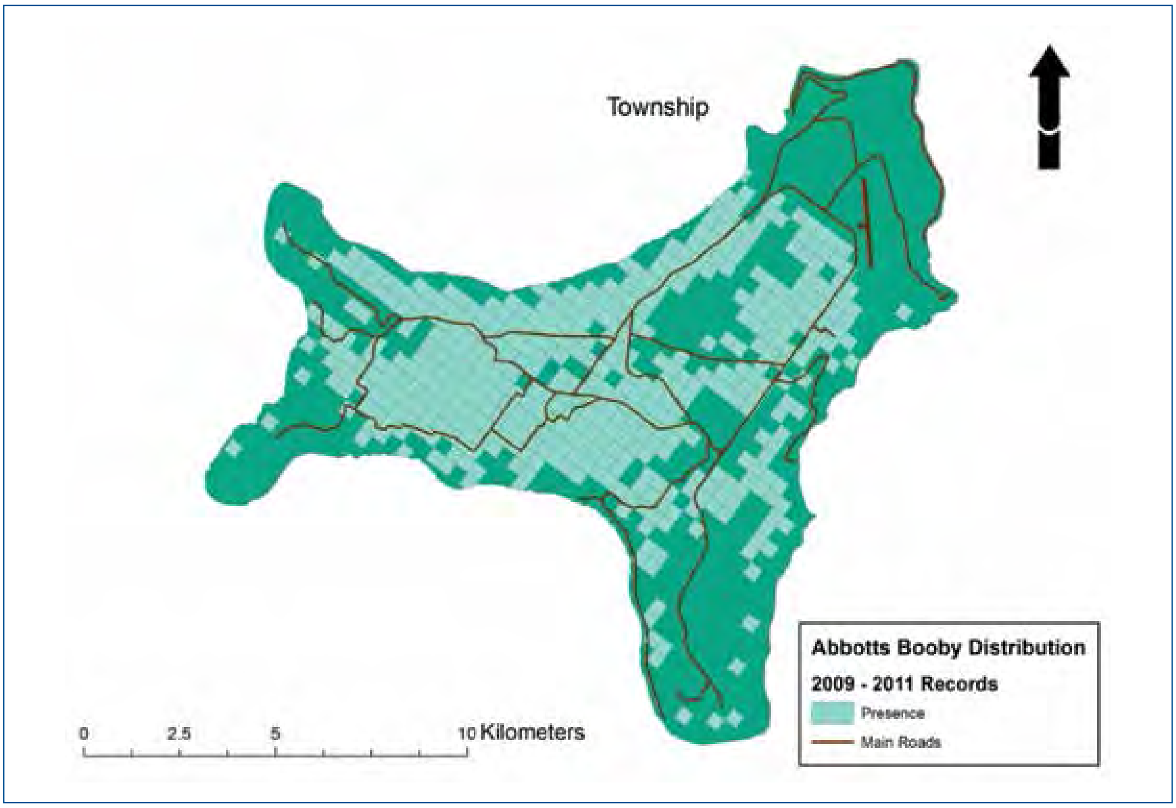
Climate change may result in changes to sea surface temperature, affecting feeding behaviour/food availability.

Potentially, harvest of the birds in other areas, such as Indonesia, might pose a threat (Hennicke 2012). Hunting on Christmas Island is not considered a threat.

Management Actions

- Monitor nest occupancy (Action 5.1), population demographics, breeding success and population trends (Action 5.2).
- Continue to implement the rainforest rehabilitation program (Action 3.3) and, in the long-term, monitor the use of these habitats to determine if and when they are used for nesting (not within the timeframe of this plan).

- Control high risk weeds (Action 3.1).
- Control and reduce the impacts of crazy ants (Action 1.1).
- Improve biosecurity to maintain effective quarantine against the introduction of native species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).
- Investigate potential threats (Action 6.1) and at-sea distribution and habitat utilisation, using data loggers and satellite telemetry (Action 6.2) to determine:
  - foraging range, habitat and behaviour, both spatially and temporally, and accounting for sex, age class, season and breeding status
  - potential overlap of foraging behaviour and habitat with threatening processes, such as long-line fishing and marine pollution.



Map 5: Sites at which Abbott's booby was detected from 2009 and 2011 Island Wide Surveys and 2009 Aerial Survey (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Phaethon lepturus fulvus	golden bosun, white-tailed tropicbird

Family PHAETHONTIDAE

Conservation Significance

Breeds only on Christmas Island

EPBC Act Listing: Listed as migratory and marine (nomination for listing as threatened in 2006 was unsuccessful)

Existing Conservation Measures

Feral cat and rat control

Distribution

This endemic subspecies is widespread across Christmas Island.

The species as a whole is widespread in tropical and sub-tropical seas throughout the world.

Populations

Population estimates on Christmas Island over the last 25 years vary from 6000 to 12 000 pairs but there have been no definitive estimates. Unpublished data suggest that numbers have declined substantially since 2000 (Garnett et al. 2011).

Habitat

The golden bosun breeds in tree hollows in rainforest, and in rock crevices on terraces (Stokes 1988). It forages in warm waters for fish and squid (Marchant & Higgins 1990). Individuals range very widely when foraging, up to 1660 km from Christmas Island (Dunlop et al. 2001).

(Note: No map or additional spatial information of distribution or habitat is available)

Threats

Chicks may be taken by feral cats and eggs and nestlings could be taken by rats.

The introduction of new invasive species and diseases to the island also poses a threat. Existing invasive species are a potential threat, such as honey bees usurping nesting hollows.

Supercolonies of crazy ants potentially threaten individual nesting adults and chicks through predation and/or disturbance, and changes to habitat.

These threats are widespread, occurring across the range of this subspecies on Christmas Island.

Unsustainable exploitation of sub-surface predatory fish (e.g. tuna, billfish) may impact negatively. Marine pollution is a potential threat, along with entanglement or persecution in fisheries beyond Christmas Island.

Potentially, harvest of the birds in other areas, such as Indonesia, might pose a threat (Hennicke 2012). Hunting on Christmas Island is not considered a threat.

Climate change may result in changes to sea surface temperature, affecting feeding behaviour/food availability.

Management Actions

- Monitor population demographics, breeding success, population trends and, if possible, assess total population size (Action 5.2).
- Control cats and rats (Action 1.2) particularly near nesting habitats, and control crazy ants (Action 1.1).
- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Investigate potential threats, including rats and honey bees (Action 6.1) and identify critical nesting habitat (Action 6.2).

Accipiter hiogaster natalis	Christmas Island goshawk

Family ACCIPITRIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act Listing: Endangered

Existing Conservation Measures

Monitoring through IWS

Restoration of habitat through rainforest rehabilitation program

Previous Recovery Plan

Hill 2004a

Distribution

Considered to be the rarest endemic bird on Christmas Island but it can occur across the entire island (Map 6).

Populations

There is a single population, restricted to Christmas Island. The population has probably declined in proportion to the areas of forest cleared since settlement.

Although there are no published data on adult or juvenile movements or population size estimates for the subspecies, the total population is thought to be very small (Hill 2004a). Ongoing banding studies initiated in 2004 suggest a total population size of fewer than 250 individuals but this estimate is very approximate (Hurley 2005). The population is possibly stable (Garnett et al. 2011).

The single population is considered necessary to the long-term survival of the subspecies.

The taxonomic affinities of the Christmas Island goshawk require clarification (Christidis & Boles 2008). It is currently variously treated as a subspecies of Variable goshawk *Accipiter hiogaster* or brown goshawk *A. fasciatus*. However, owing to on-going review of the *Accipiter* genus, further study including genetic analysis, may indicate the Christmas Island goshawk is more closely related to the grey goshawk (*A. novaehollandiae*), or a distinct species.

Habitat

Ranges from tall evergreen and semi-deciduous closed forests to suitable areas of secondary regrowth vegetation. Foraging can occur in any habitat type, including urban areas. Insects, centipedes and rats have been recorded in its diet (Hill 2004a). Goshawks are opportunistic hunters and are regularly observed taking Christmas Island white-eyes, thrush, emerald dove, feral chickens, booby nestlings and adult bosun birds (Holdsworth pers. comm. 2012).

Habitat critical to survival of the goshawk is not well known, however, all known nests are found within primary forest types (Garnett et al. 2011).

Applying a precautionary approach, habitat critical to the survival of the goshawk is defined as all evergreen tall closed forest and semi-deciduous closed forest (see Figure 3).

Threats

The decline of this subspecies has probably been the result of a combination of clearing of habitat since settlement, weeds, and crazy ants, either directly or through reduced prey availability or habitat changes. The small population size also increases vulnerability to a range of potential threats.

Protection of forest has reduced the risk of destruction of nest sites, however clearing of suitable nesting habitat would represent a threat.

Goshawks can nest close to road verges within forested areas. Clearing and other sustained road works close to nests at critical times may result in abandonment. The significant increased traffic associated with the operation of the Immigration Detention Centre has reduced the frequency of occurrence of goshawks along the road through the national park. It is not clear if this is due to increased disturbance, thus abandonment, or population reduction through road kill. Regardless, a significant area of foraging habitat is now not used to the same extent (Holdsworth pers. comm.).

The introduction of new invasive species and avian diseases to the island poses a threat. Previously introduced feral bird populations could form a reservoir for introduced avian disease.

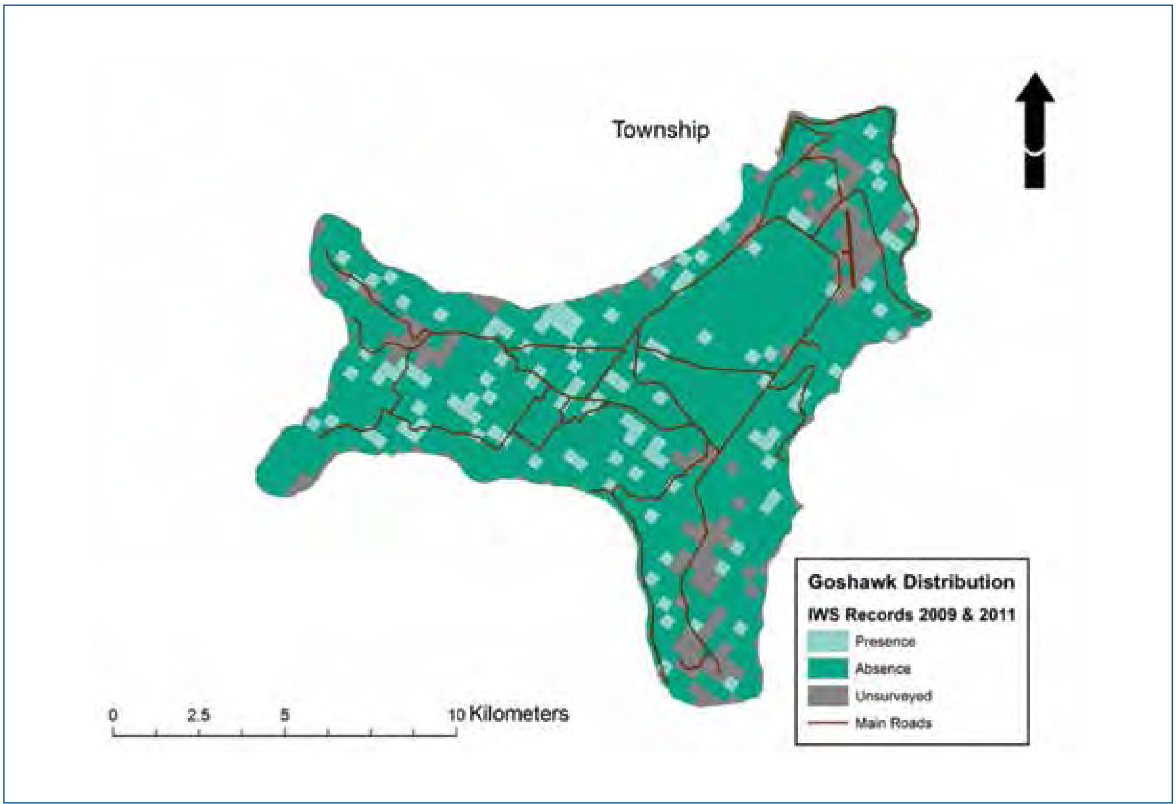
The indiscriminate use of second-generation rodent poisons poses a threat to the species through secondary poisoning. Changes to prey relationships across the island, as a result of cat and/or rat control, could also potentially affect goshawks.

Weeds may pose a potential threat by forming vine towers over nesting trees (Hill 2004a).

Management Actions

- Undertake research to determine foraging, nesting and breeding behaviour and habitat preferences. Conduct a taxonomic review to determine if a distinct species (Action 6.2).
- Undertake surveys to locate nest sites and gather data on breeding success (Action 5.2).
- Monitor presence, distribution and population trends and recruitment (Actions 5.1 and 5.2).
- Control and reduce the impacts of crazy ants including reducing off target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Minimise impacts on the goshawk (e.g. prey relationships, toxin impacts) in any cat and rat management program. (Action 1.2).
- Control high risk weeds as part of broader weed control programs (Action 3.1).
- Continue to implement the rainforest rehabilitation program (Action 3.3) and, in the long-term, monitor the use of these habitats to determine if and when they are used for nesting (not within the timeframe of this plan).

- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests, such as pigeons, that may enter and assessing the risk of threat (Action 2).
- Monitor deaths from vehicles and implement mitigation measures if vehicle deaths are identified as a threat (Action 1.3).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).



Map 6: Sites at which the Christmas Island goshawk was detected during 2009 and 2011 Island Wide Surveys (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Chalcophaps indica natalis	Christmas Island emerald dove

Family COLUMBIDAE

Conservation Significance

Endemic to Christmas Island

Important role in island's ecology as seed disperser

EPBC Act Listing: Endangered

Existing Conservation Measures

Monitoring through IWS

Recovery Plan

This is the first recovery plan for this subspecies

Distribution

Endemic to Christmas Island where it is widespread and common (Garnett et al. 2011) (Map 7).

Area of occupancy may have been reduced by due to human settlement, mining, introduced predators and possibly hunting, but the species remains frequently seen in most habitats (Stokes 1988) and over recent years there appears to be some recovery (DNP unpub. data 2011).

Populations

There is a single population, restricted to Christmas Island. The most recent population estimates are 900–3500 individuals and 1000 pairs in 2002 (Corbett et al. 2003) although these are considered to be unreliable (DNP 2008b). Doves were detected at 21 per cent of the 932 waypoints visited during the 2011 IWS, excluding repeat visits (DNP unpub. data 2011).

The single population is considered necessary to the long-term survival of the subspecies.

Habitat

The Christmas Island emerald dove occurs in most forested habitats. It is most common in tall closed evergreen rainforest and open semi-deciduous rainforest, especially on the terraces that surround the central plateau of the island, but is also regularly observed in deciduous scrub, disturbed vegetation such as thickets of weeds and secondary regrowth (including areas dominated by *Muntingia calabura*), settled areas (lawns, gardens and around houses) and on forest tracks.

The subspecies appears to be a habitat generalist so it is not possible to determine or locate specific habitat critical for its survival.

Threats

Habitat loss through previous clearing may have reduced the area of occupancy.

Predation by cats, and possibly rats, poses an ongoing threat although the dove has successfully withstood such predation since settlement due to its adaptability (Stokes 1988).

Supercolonies of crazy ants are known to prey directly on nestlings and are responsible for widespread ecological changes across the island which may threaten the dove's survival (Garnett et al. 2011). It is less numerous in areas with ants than those without (Davis et al. 2008). However, little evidence was found of a negative impact of high density crazy ant colonies on the dove's distribution in the 2011 IWS (Smith et al. 2011).

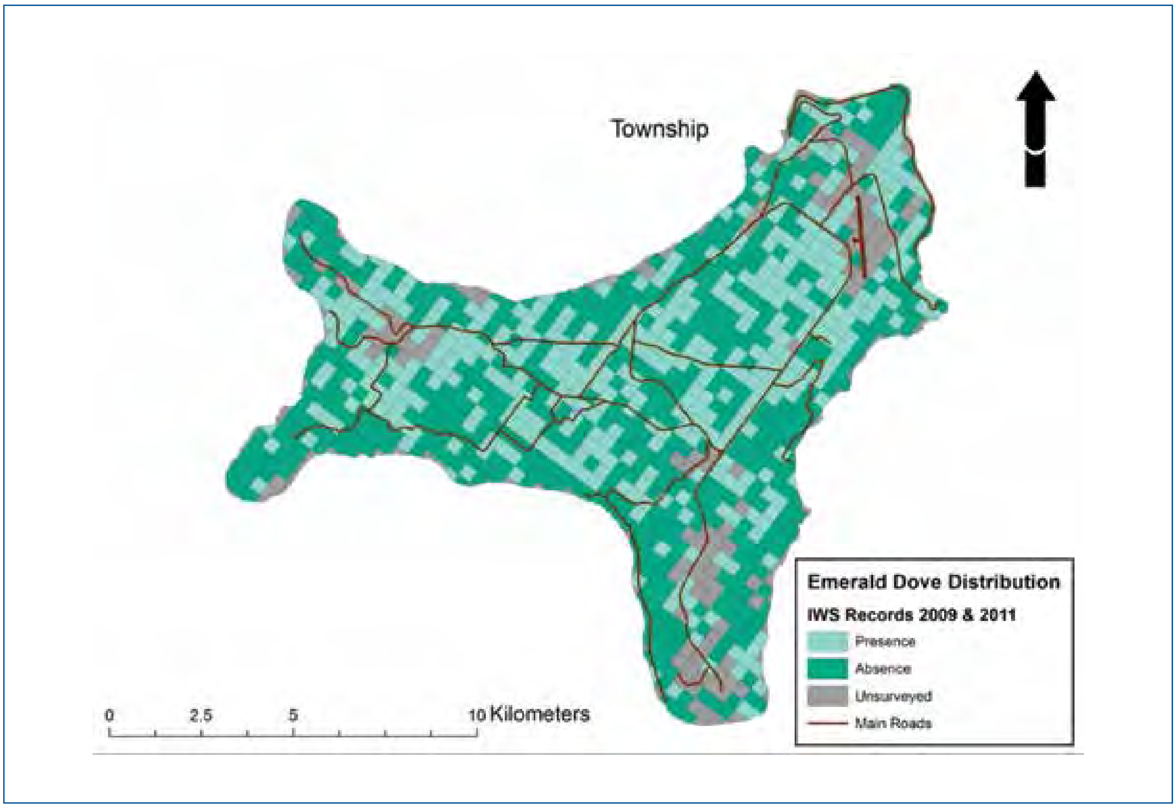
The introduction of new species and avian diseases to the island also poses a threat.

These threats can be considered to be widespread across the island.

Vehicle strike may be a threat in high-use road areas away from settlement.

Management Actions

- Continue to monitor population (Action 5.1).
- Control cats, rats and crazy ants (Actions 1.1 and 1.2).
- Conduct research on threats, including cats, rats and introduced ants (Action 6.1).
- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).
- Implement road management measures to reduce mortality (e.g. driver education, appropriate speed limits) (Action 1.3).



Map 7: Sites at which the Christmas Island emerald dove was detected during 2009 and 2011 Island Wide Surveys (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Collocalia linchi natalis — Christmas Island swiftlet

Family APODIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Listing: found not eligible for listing as threatened in 2006

Existing Conservation Measures

No specific measures

Distribution

Endemic to Christmas Island where it is widespread and abundant. Present numbers are probably little changed since settlement (Stokes 1988; DNP unpub. data 2011).

Populations

Swiftlets can occur across the entire island and are considered to be widespread. While reliable population estimates are not available, an early estimate put the population at 100 000 to 1 000 000 individuals (van Tets 1975).

The single population is necessary to the long-term survival of the subspecies.

Habitat

The Christmas Island swiftlet roosts and nests in caves and feeds over most habitats including settlements, forests and terraces, taking aerial prey (Stokes 1988).

Habitat critical to the survival of the species includes all cave systems on the island.

(Note: No map or additional spatial information of distribution or habitat is available)

Threats

There are no demonstrated threats although it is possible that changes in invertebrate composition and abundance due to the impact of crazy ants could affect the species (EWG 2010). Vehicle strike has also been detected as a potential threat in high use road areas away from settlement.

As the population appears stable, addressing island-wide threats, particularly cats, rats, crazy ants and new invasive species, is considered the most effective means of maintaining the subspecies.

Management Actions

- Monitor the population (Action 5.2).
- Control cats, rats and crazy ants (Actions 1.1 and 1.2).
- Implement road management measures to reduce mortality (e.g. driver education, appropriate speed limits) (Action 1.3).
- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).

Ducula whartoni	Christmas Island imperial pigeon

Family COLUMBIDAE

Conservation Significance

Endemic to Christmas Island

Important role in island's ecology as seed disperser

EPBC Listing: found not eligible for listing as threatened in 2006

Existing Conservation Measures

Monitoring through IWS

Distribution

Endemic to Christmas Island where it is widespread. The imperial pigeon can occur across the entire island. Pigeons were detected at 92 per cent of the 932 waypoints visited during the 2011 IWS, excluding repeat visits (DNP unpub. data 2011) (Map 8).

Populations

Present numbers have probably been reduced due to human settlement, mining and, in the past, hunting but the species remains abundant (Stokes 1988; DNP unpub. data 2011). There is no current estimate of population size.

The single population is necessary to the long-term survival of the species.

Habitat

The Christmas Island imperial pigeon occupies mainly primary forest and some secondary regrowth dominated by the introduced Japanese cherry on which it extensively feeds, along with a range of rainforest fruits, leaves and buds (Crome 1987, Stokes 1988). As such, it is considered to play a major role in seed dispersal of rainforest plants. It nests in the tops of rainforest trees and other dense vegetation (Hicks & Yorkston 1982).

Threats

The imperial pigeon may be potentially threatened by supercolonies of invasive ants which could prey directly on nestlings as well as being responsible for widespread ecological changes across the island. However, little evidence was found of a negative impact of high density crazy ant colonies on the pigeon's distribution in the 2011 IWS (Smith et al. 2011).

Feral cats may take some individuals. The introduction of new diseases to the island may also pose a threat to the species.

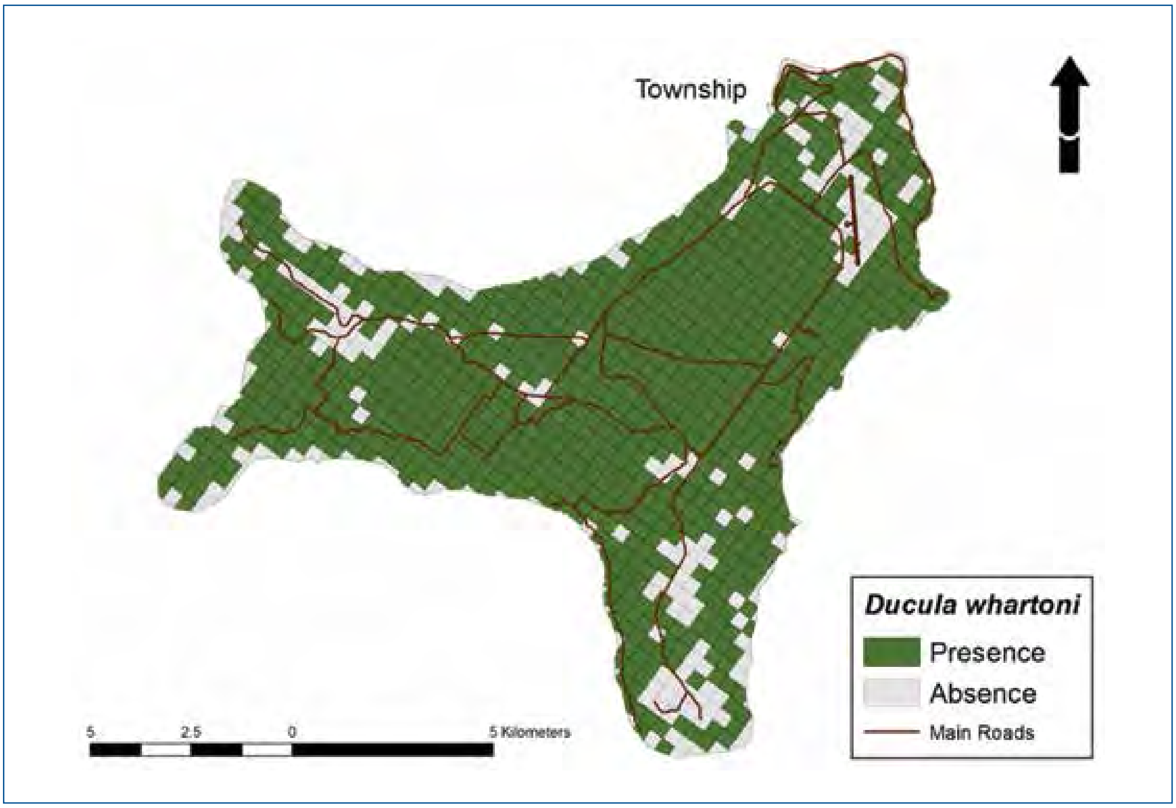
These threats can be considered to be widespread across the island.

Hunting occurred in the past but is no longer considered a threat.

As the population appears stable, addressing island-wide threats, particularly cats, rats, crazy ants and new invasive species, is considered the most effective means of maintaining the species.

Management Actions

- Continue to monitor the population (Action 5.1).
- Control cats, rats and crazy ants (Actions 1.1 and 1.2).
- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).



Map 8: Observation records of Christmas Island imperial pigeon in 2011 (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Ninox natalis	Christmas Island hawk-owl

Family STRIGIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act Listing: Vulnerable

IUCN Listing: Vulnerable

Existing Conservation Measures

Population monitoring (call surveys)

Survey of fixed sites on roads

Restoration of habitat through rainforest rehabilitation program

Previous Recovery Plan

Hill 2004b

Distribution

This species occurs across the entire island, primarily in primary rainforest (Map 9). It is absent from un-regenerated mine sites (Hill & Lill 1998a).

Populations

There is a single population, restricted to Christmas Island. The total population size was estimated at 820–1200 individuals in the mid 1990s (Hill & Lill 1998a). EWG (2010) reported anecdotal evidence suggesting the species may have declined abruptly over the last few years. However, surveys by the DNP in 2012 and 2013 (unpublished) indicate that the population appears to have been stable from 2006 to 2013.

Hill & Lill (1998a) estimated that prior to settlement the island had a carrying capacity in the order of 740 ± 135 owl territories. Between 1994 and 1996 the population was estimated to be 556 ± 101 occupied owl territories in evergreen tall closed forest, 6 ± 4 occupied owl territories in regrowth vegetation (a total population size of 562 ± 105 occupied territories). The total population has probably decreased by at least 25 per cent since settlement (Stokes 1988, Hill & Lill 1998a).

The single population is necessary to the long-term survival of the species.

Habitat

Occupy permanent territories in all forest types, with the highest densities in evergreen tall closed forest and lowest in regrowth (Hill & Lill 1998a). Prey is mainly insects but also small vertebrates including introduced rodents (Hill & Lill 1998b).

Based on the available information, habitat critical to the survival of the species cannot be precisely defined. However, as breeding is dependent on all evergreen tall closed forest and semi-deciduous closed forest, these areas should be considered habitat critical to survival. Figure 3 illustrates the location of this habitat across Christmas Island.

Threats

Threats are not fully understood. The main threats are believed to be the loss of vegetation since settlement from clearing and previous mining, degradation of habitat caused by supercolonies of crazy ants, and weed infestations. Crazy ant impacts may include predation on nestlings and eggs, changes to habitat and reduction in the prey base. However, there is no evidence of decline in the owl population where ants are present (Garnett et al. 2011). Usurpation of hollows by honey bees may also pose a threat.

Black rats and cats are also likely to kill birds and reduce nesting success (Garnett et al. 2011).

Second-generation rodent poison is a potential threat to the hawk-owl and other predatory species.

The introduction of new species and avian diseases to the island poses a threat.

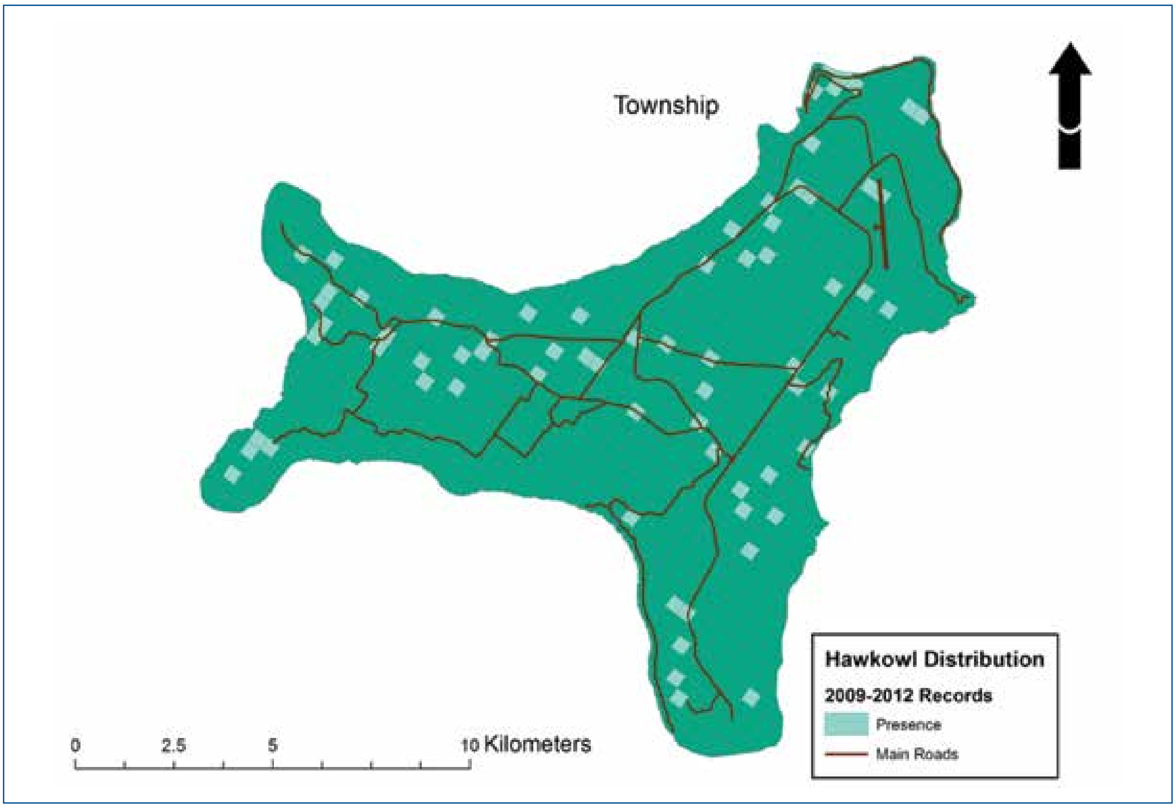
Inbreeding depression is also a risk, while natural catastrophes would also diminish an already small population.

These threats can be considered to be widespread across the island.

There have been previous reports of road mortalities (Hill 2004b); while the level of mortality is unknown it is not considered to be a significant threat.

Management Actions

- Monitor distribution and population trends (Action 5.2).
- Control cats and rats (Action 1.2).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Control high risk weeds as part of broader weed control programs (Action 3.1).
- Continue to implement the rainforest rehabilitation program (Action 3.3) and, in the long-term, monitor the use of these habitats to determine if and when they are used for nesting (not within the timeframe of this plan).
- Research threats, including rats and introduced ants, bees and chemical use (Action 6.1).
- Undertake research to determine foraging, nesting and breeding behaviour and habitat preferences (Action 6.2).
- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).



Map 9: Sites where the Christmas Island hawk-owl was detected 2009 to 2012 (Parks Australia)

Map caveats:

The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Turdus poliocephalus erythropleurus | Christmas Island thrush

Family TURDIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act Listing: Endangered

Existing Conservation Measures

Monitoring through IWS

Recovery Plan

This is the first recovery plan for this subspecies

Distribution

The species is widespread throughout south-east Asia and the south-west Pacific with many subspecies. The two other Australian subspecies (*T. p. poliocephalus* from Norfolk Island and *T. p .vinitinctus* from Lord Howe Island) are now extinct (Garnett et al. 2011).

This subspecies is endemic to Christmas Island where it is widespread (Map 10). It was introduced to the Cocos (Keeling) Islands between 1885 and 1900 but this population has since become extinct (Stokes 1988).

Populations

There is a single population, restricted to Christmas Island. The most recent estimate is 20 000–50 000 individuals (Corbett et al. 2003) although this is considered to be unreliable (DNP 2008b). Thrushes were detected at 83 per cent of the 932 waypoints visited during the 2011 IWS, excluding repeat visits (DNP unpub. data 2011).

The thrush is claimed to have undergone a moderate decline in numbers on Christmas Island in response to habitat alteration, predation by introduced animals and hunting by humans (Stokes 1988). However, it remains common.

The single population is considered necessary to the long-term survival of the subspecies.

Habitat

The thrush is found in most habitats, including tall closed evergreen rainforest, open semi-deciduous rainforest, secondary regrowth, thickets of weeds and semi-deciduous vines, settled areas (where it forages on lawns and nests on buildings) and on the Christmas Island golf course. It is most common in tall closed evergreen rainforest and open semi-deciduous rainforest on the coastal and higher terraces and plateau of Christmas Island. It is least common in disturbed habitats, such as regrowth and post-mining wasteland, and in suboptimal endemic vegetation such as *Pandanus* thickets and patches of low vegetation in coastal areas (Stokes 1988, DNP 2008b).

The subspecies appears to be a habitat generalist so it is not possible to determine or locate specific habitat critical for its survival.

Threats

The thrush is threatened by black rats, and potentially by supercolonies of crazy ants, which probably prey directly on nestlings. Nest success and the number of juveniles encountered are lower in areas with ants than without (Davis et al. 2008). However, little evidence was found of a negative impact of high density crazy ant colonies on the thrush's distribution in the 2011 IWS (Smith et al. 2011).

Ecological changes arising from the impact of crazy ants could favour the spread of black rats, which have been responsible for extinctions of island thrushes on other islands (Garnett et al. 2011).

Other threats include predation by feral cats, introduced bird diseases (Garnett et al. 2011) and, potentially, the introduction of new species and diseases.

These threats can be considered to be widespread across the island.

Management Actions

- Monitor population trends (Actions 5.1 and 5.2).
- Control cats and rats (Action 1.2).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Conduct research on threats, including rats and crazy ants (Action 6.1).
- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).

Map 10: Observation records of Christmas Island thrush in 2011 (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Zosterops natalis	Christmas Island white-eye

Family ZOSTEROPIDAE

Conservation Significance

Endemic to Christmas Island

Important role in the island's ecology as seed disperser

EPBC Listing: found not eligible for listing as threatened in 2006

Existing Conservation Measures

Monitoring through IWS

Distribution

Endemic to Christmas Island, widely distributed and can occur across the entire island (Map 11). Introduced to the Cocos (Keeling) Islands (Horsburgh Island).

Populations

Present numbers have probably been reduced due to human settlement and mining but the species remains abundant (Stokes 1988; DNP unpub. data 2011).

The population has been estimated at 100 000 to 1 000 000 (van Tets 1975) but current population estimates are not available. White-eyes were detected at 83 per cent of the 932 waypoints visited during the 2011 IWS, excluding repeat visits (DNP unpub. data 2011).

The single population is considered necessary to the long-term survival of the species.

Habitat

The white-eye occupies all forested habitats and feeds on insects, nectar and fruit throughout the forest strata, with little sign of a preferred feeding zone. The species may play a major role in the ecological function of the island's forests through seed dispersal especially of smaller-fruited plants, pollination and insect predation. The white-eye has no known avian competitor on the island (Stokes 1988) but introduced Java sparrows may compete in settled areas.

Threats

The species is potentially threatened by supercolonies of invasive ants which could prey directly on nestlings. However, little evidence was found of a negative impact of high density crazy ant colonies on the white-eye's distribution in the 2011 IWS (Smith et al. 2011).

Predation by feral cats sometimes occurs and ecological changes arising from the impact of crazy ants could favour the spread of black rats which have been responsible for extinctions of white-eye species on other islands, although there is no evidence that numbers are currently being affected (Garnett et al. 2011).

The introduction of new diseases to the island also poses a threat to the species.

The extent to which there is competition from introduced species is unknown, but may be a potential threat.

These threats can be considered to be widespread across the island.

Management Actions

- Continue to monitor population (Action 5.1).
- Control cats and rats (Action 1.2).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Improve biosecurity to maintain effective quarantine against the introduction of avian diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).

Map 11: Observation records of Christmas Island white-eye in 2011 (Parks Australia)

Map caveats:

The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Crocidura trichura | Christmas Island shrew

Family SORICIDAE

Conservation Significance

Endemic to Christmas Island

Only shrew species recorded in Australia

EPBC Act listing: Endangered (but likely to be extinct)

IUCN Listing: Critically Endangered

Existing Conservation Measures

Opportunistic monitoring through IWS and other fauna surveys

Targeted surveys previously undertaken

Previous Recovery Plan

Schulz 2004

Distribution

The Christmas Island shrew is endemic to Christmas Island. Previously considered to be a subspecies of the more widely spread grey shrew (*Crodicura attenuata*) recent molecular studies established it as a separate species (Eldridge et al. 2009). Current distribution is unknown and it is considered extremely rare and possibly extinct (Schulz 2004).

The shrew was widespread and abundant at the time of settlement, occurring in rainforest on the plateau and adjacent to the shoreline (Schulz 2004). It has not been recorded since 1985, when two separate individuals were accidentally found at the western edge of the island over a period of less than a month (Tranter pers. comm. cited in Schulz 2004) (Map 12).

Populations

If still extant, there is a single population, restricted to Christmas Island. There have been no confirmed records since 1985 despite subsequent targeted surveys (Tidemann 1989; Meek 2000) and ongoing biodiversity monitoring. Any individuals located would be regarded as part of an important population.

The shrew was once extremely common across the island, but declined rapidly following settlement. By 1908 it was thought to be extinct, until the 1985 records. Subsequently it was discovered that two specimens had been encountered in 1958 during rainforest clearing operations for phosphate mining near South Point (Powell pers. comm. cited in Meek 2000).

Habitat

The shrew was widespread in rainforest extending from shoreline to plateau. The 1985 records were from tall plateau forest in deep soils and terrace rainforest with shallow soils (Schulz 2004).

Until further information is obtained, by applying a precautionary approach, habitat critical to the survival of the shrew is defined as all evergreen tall closed forest and semi-deciduous closed forest (see Figure 3).

Threats

As knowledge of the shrew's ecology and conservation requirements is limited, no known threats have been documented. However, the dramatic decline which occurred within 20 years of human settlement suggests direct or indirect human threat (Schulz 2004) for example, through invasive species associated with settlement.

Potential threats include:

- disease, probably caused by the parasite *Trypanosoma* carried by black rats, is implicated in the dramatic decline recorded following human settlement (Meek 2000)
- predation and/or competition by invasive species such as cats and rats (no instances of predation have been recorded however)
- direct and indirect effects of crazy ants (shrew declines occurred well before crazy ants were introduced however)
- habitat alteration and loss through past clearing
- introduction of new diseases and invasive species.

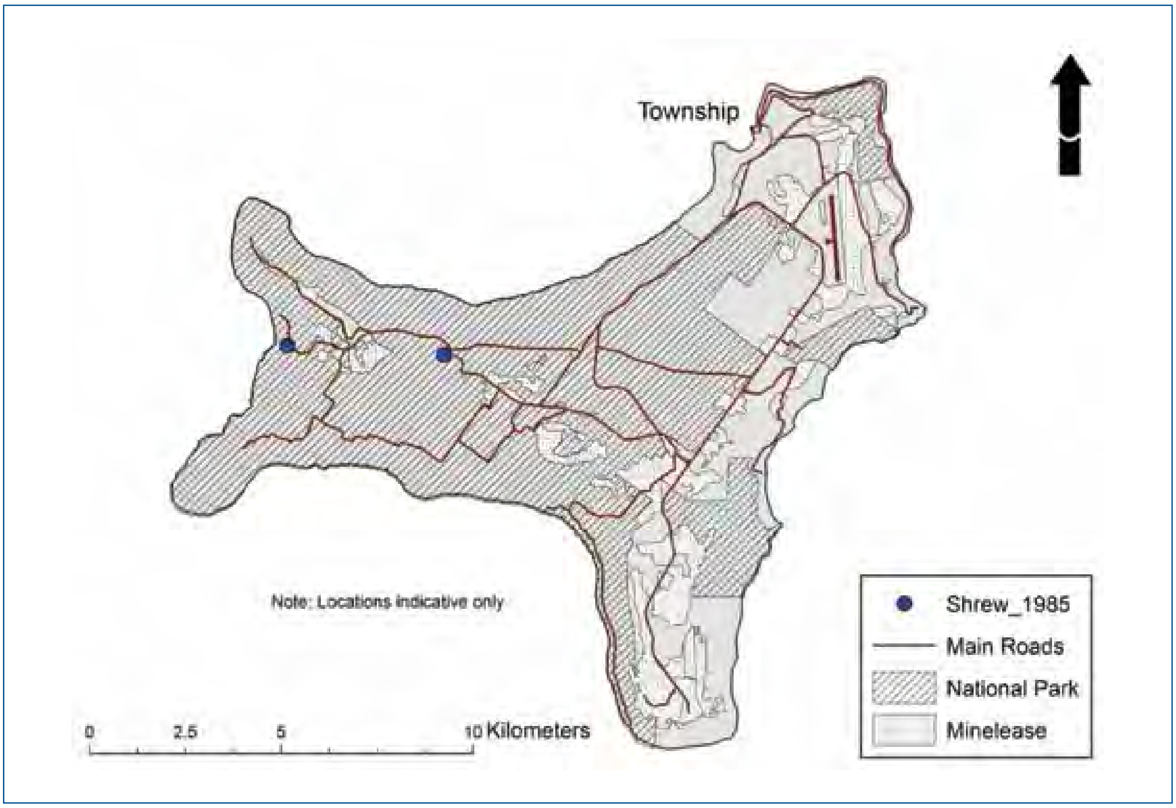
Apart from clearing, these potential threats can be considered to be widespread across the island.

Management Actions

- Collect data on opportunistic sightings through monitoring (Action 5).
- Control cats, rats and crazy ants (Actions 1.1 and 1.2).
- Conduct research on potential threats, including rats, crazy ants and *Trypanosoma* parasites (Action 6.1).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).

If individuals or populations are found the following actions should apply:

- Seek immediate scientific advice on the feasibility of a captive breeding program and implement if feasible (Action 4.3).
- Conduct surveys to determine population extent and habitats (Action 5.2).
- Seek scientific advice on the need for specific additional *in situ* threat management options, and, if required, develop and implement (Action 4.5).



Map 12: Location of two 1985 sightings of the Christmas Island shrew (Parks Australia)

Map caveats:
The data on this map represents areas where the species was last detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Pipistrellus murrayi	Christmas Island pipistrelle

Family VESPERTILIONIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act listing: Critically Endangered (but likely to be extinct)

IUCN listing: Critically Endangered

Existing Conservation Measures

Intensive visual and acoustic monitoring of roosting and foraging habitat commenced in 1998 (since 2009 restricted to intermittent acoustic monitoring).

Artificial roosts erected in 2006 in response to shrinking population size and roost protection measures also installed; strict conditions in place since 2008 on clearing of vegetation for mining at the last known site.

Expert Working Group appointed in 2009 to advise on emergency conservation measures (EWG 2010); led to an unsuccessful attempt to establish a captive breeding population in 2009 by the Australasian Bat Society and supported by the DNP (no bats could be captured due to lack of detection).

Previous Recovery Plan

Schulz & Lumsden 2004

Distribution

Endemic to Christmas Island. This species was formerly widespread and common in primary and secondary rainforest (Tidemann 1985). In the 1990s targeted surveys indicated a marked reduction in abundance and a westward range contraction had occurred. The last individuals were detected in the far western section of the Island in Sydney's Dale (Lumsden & Schulz 2009) (Map 13).

Populations

Analysis established the pipistrelle was taxonomically distinct although closely related to other Indo–Australian *Pipistrellus* species (Helgen et al. 2009).

No individuals have been recorded since August 2009 (Lumsden et al. 2010). The species is likely to be extinct but if any individuals are located they would be regarded as part of an important population.

Habitat

An edge specialist which favoured vegetation ecotones, tracks and other small gaps within evergreen tall closed forest where its insectivorous prey was taken in flight. Foraging or commuting individuals also ranged into adjacent habitats including regrowth forest, minefield rehabilitation sites and formerly the Settlement area (Lumsden & Schulz 2004).

The pipstrelle roosted under exfoliating bark on dead trees, under loose dead fronds of palm and pandanus trees, in hollows in large live trees and under strangler figs (Lumsden et al. 1999).

Little information is available on the relative importance of various habitat types for roosting, foraging, commuting and maternity sites during all seasons of the year. Until such information is available, habitat critical to survival of the Christmas Island pipistrelle is defined as: areas of evergreen tall closed forest and areas of regenerating rainforest regrowth (of all ages) especially in the western part of the island.

Threats

The factors responsible for the likely extinction of the pipistrelle are not clearly known. The EWG (2010) presented a plausible but speculative 'ecological cascade' scenario involving a complex interaction of multiple factors including predation and habitat change arising from the impact of crazy ant supercolonies.

Introduced species (e.g. black rats, honey bees, giant centipedes and supercolonies of crazy ants) have been implicated in their decline (Lumsden et al. 2007). Those potential threats can be considered to be widespread across the island.

There were previous reports of road mortalities (Tidemann 1985) however the level was unknown and is not considered to have been a significant threat.

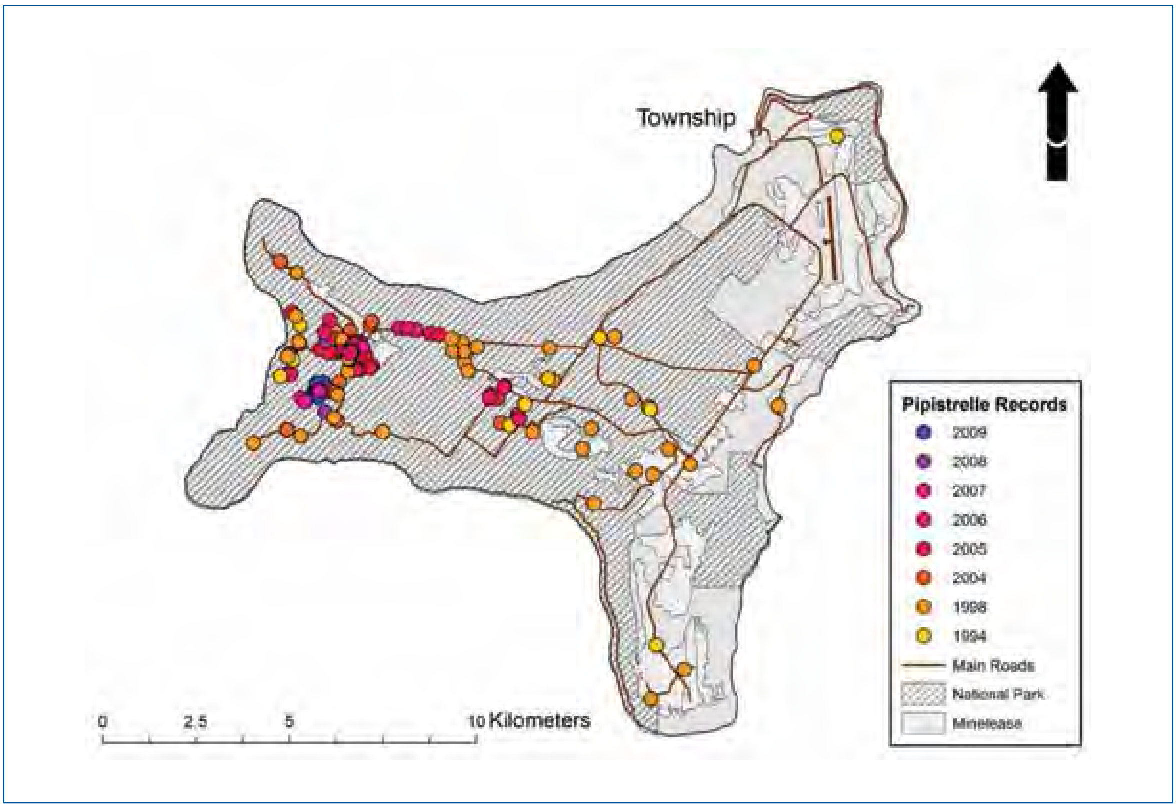
Neither habitat loss nor reduction in prey items appear to have been a threat (Lumsden et al. 2007) although the EWG (2010) did not accept the argument that the persistence of insectivorous diurnal birds was convincing argument against shortage of prey. No evidence that disease posed a threat was found but it cannot be ruled out (Lumsden et al. 2007, EWG 2010).

Management Actions

- Collect data on opportunistic sightings through monitoring (Action 5).
- Control cats, rats (Action 1.2) and crazy ants (Action 1.1).
- Conduct research on potential threats that also impact on other species, including wolf snake, black rat, honey bee, giant centipede and crazy ants (Action 6.1).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).

If individuals or populations are found the following actions should apply:

- Seek immediate scientific advice on the feasibility of a captive breeding program and implement if feasible (Action 4.3).
- Conduct surveys to determine population extent and habitats (Action 5.2).
- Seek scientific advice on the need for specific additional *in situ* threat management options, and, if required, develop and implement (Action 4.5).



Map 13: Compilation dataset of pipistrelle records from surveys occurring between 1994 and 2009—presence data only (Parks Australia and external researchers)

Map caveats:

The data on this map represents areas where the species was last detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Pteropus melanotus natalis	Christmas Island flying-fox

Family PTEROPODIDAE

Conservation Significance

Endemic to Christmas Island

Important role in the island's ecology as pollinator and seed disperser

EPBC Act Listing: Critically Endangered

IUCN listing: species *Pteropus melanotus* listed as Vulnerable

Existing Conservation Measures

Monitoring through biennial IWS and targeted surveys in 2012 and 2013

Expert-based conservation workshop in 2012

Genetic and disease studies

Distribution

Endemic to Christmas Island, where it forages across the entire island. Congregates in distinct roost sites ('camps') of varying size and location, similar to other flying-foxes. Three of six historically known major roost sites are no longer occupied (DNP 2008b).

The three remaining major roost sites are at Hosnies Spring, McMicken Point (Dolly Beach) and Greta Beach totalling ca. 10 ha; a small roost site is also currently known from the golf course. However, there may be additional roost sites.

Map 14 shows 2013 survey results.

Populations

There is one population, restricted to Christmas Island. The total population was estimated in 2006 at about 1500 individuals, a dramatic decline since 1984 (DNP 2008b). A targeted survey in 2012 recorded a 35–39 per cent decline in detection at fixed survey points, which indicates a population decline since 2006. A similar incidence of detection was recorded in the 2013 survey, implying a similar population level. The population is estimated to be at least 1000.

The single population is considered necessary to the long-term survival of the subspecies. There are only a few breeding colonies which should constitute the pivotal conservation focus.

While currently considered a subspecies of a more widely distributed species, the taxonomic status of the flying-fox is poorly resolved. Genetic studies to date have not been sufficient to determine genetic distinctiveness, though a relatively high level of genetic diversity is indicated (Phalen et al. 2012).

Habitat

The flying-fox feeds on fruits found in most of the vegetation types present on the island and especially fond of introduced fruits, contributing to their wide dispersal (Gray 1995). It is a primary seed disperser and pollinator for many rainforest trees and other plants and is considered to be an important component of the island's rainforest ecosystem (Tidemann 1985).

All recorded campsites have been located on the coastal terrace or around the first land cliff and semi-deciduous forest, although the actual structure of sites varies. Four of the six historical sites are on the east coast of the island and one each on the north and south of the island. The seasonal variation of campsite usage is poorly understood (DNP 2008b).

Due to its declining population and because the species uses a range of rainforest vegetation types for feeding and roosting, all previously uncleared native vegetation is considered critical habitat. The flying-fox will also use urban and some mined areas for feeding but these are not critical habitats.

Threats

Threats to the species are not precisely known and it is possible that a combination of factors and threats is responsible for declining numbers.

Most likely threats include:

- supercolonies of crazy ants which cause widespread ecological changes across the island and possible disturbance at roost/maternity sites
- predation by cats which has been recorded through cat stomach content analysis (Tidemann 1985).

Potential threats include:

- habitat decline and loss through past clearing
- climatic events, such as severe storms and cyclones
- introduction of other or new invasive species, diseases, parasites and pathogens
- chemicals and toxins.

Apart from clearing, each of these threats is widespread and can be considered to be a threat across the entire island. Potential threats require investigation.

The diet of the flying-fox now includes a considerable proportion of fruits and nectar from introduced species. It is possible these provide less nutrition than native species (as reported for Pacific Island flying-foxes by Nelson et al. 2000) but there is no primary evidence for this for the Christmas Island flying-fox.

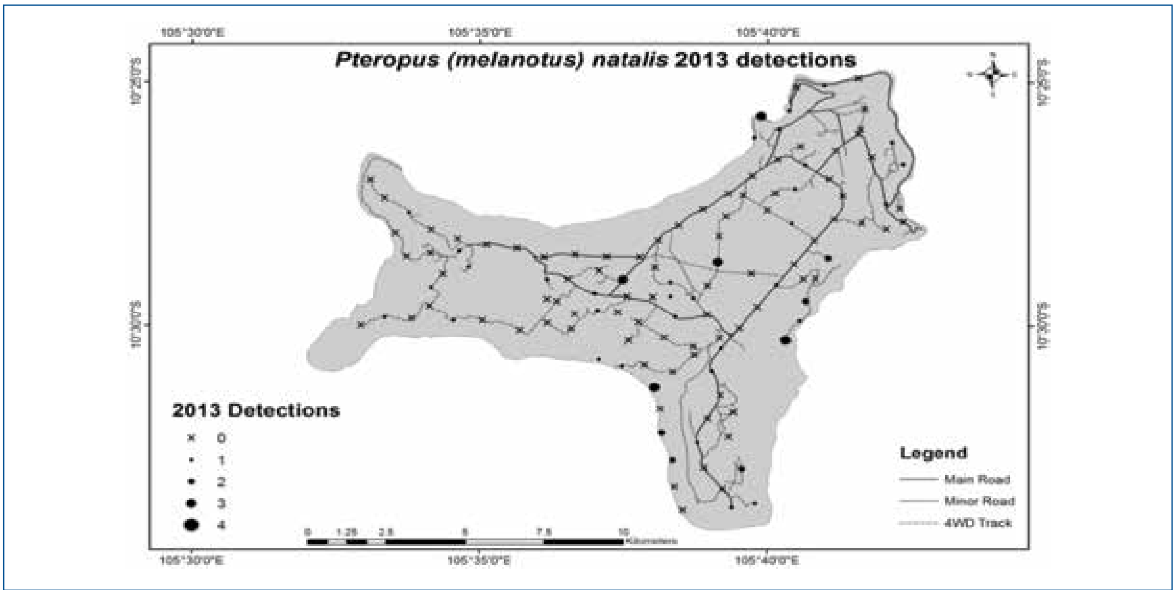
Heavy metal poisoning (including from drinking at contaminated sites) is an unknown but potential threat.

Hunting occurred in the past but is no longer a threat.

Management Actions

- Monitor population including searches for any additional camps (Actions 5.1 and 5.2).
- Conduct ecological and biological studies to inform recovery actions (Action 6.2).
- Investigate threatening processes including; crazy ants causing habitat decline and disturbance at roost/ maternity sites, cats, diseases, pathogens and parasites (Action 6.1).

- Control cats (Action 1.2) and crazy ants (Action 1.1).
- Determine targets and thresholds for criteria and for management intervention (Action 9.2). If a decision is made that intervention is required, assess the need for, and feasibility of, establishing a captive breeding program, and implement if feasible (Action 4.3).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases, parasites, pathogens and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Investigate the potential threat and risks of chemicals and toxins (Action 6.1).
- Rehabilitate mine sites (Action 3.3).
- Continue to assess the environmental impacts of proposals in accordance with relevant legislation (Action 1.4).



Map 14: Sites where flying-foxes were detected during a 2013 survey (Parks Australia)

Map caveats:
The data on this map represents areas where the species was last detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes..

Cryptoblepharus egeriae	blue-tailed skink

Family SCINCIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act Listing: Critically Endangered

Existing Conservation Measures

Monitoring through IWS (but insufficiently powerful design) and dedicated native reptile survey (2012 and 2013).

Captive breeding population established on and off island.

Crazy ant control measures and disease studies

Distribution

Endemic to Christmas Island. Formerly common and widespread across the island (Map 15), the blue-tailed skink is now possibly extinct in the wild.

A 1979 reptile survey found it abundant with a sparse and widely-scattered distribution. A decline in numbers first recorded by Rumpff (1992) coincided with spread of the introduced wolf snake. A second survey in 1998 revealed a considerable contraction in non-coastal areas while island-wide biodiversity monitoring from 2004–06 found further decline (Cogger & Sadlier 2000, DNP 2008b).

Extensive surveying in 2008 (Schulz & Barker 2008) recorded this species from only two areas (Egeria Point and North West Point). Subsequent surveys by Parks Australia (Smith et al. 2012) have confirmed its disappearance from North West Point (mid–2008) and suggest disappearance from Egeria Point (mid–2010).

Extensive surveys undertaken in 2012 to locate native reptiles (including sites where the species had been previously recorded as well as previously unsurveyed areas) did not detect this species (DNP unpub. data 2012).

Populations

Since 2009, a captive breeding population has been established in holding cages at Christmas Island and at Taronga Zoo. The captive population is important for survival of the species.

If any individual or population is found in the wild, this would be considered a population necessary for the long-term survival of the species.

Habitat

The blue-tailed skink formerly occurred across all habitats; tall primary rainforest, deciduous thickets, coastal thickets, and settlement areas, including areas scarred and left un-rehabilitated by previous mining. In 1979, it was abundant in household gardens, brick walls and roadside vegetation (Cogger et al. 1983). It was less common in tall primary rainforest, being recorded more frequently at their edges and in canopy gaps (Cogger & Sadlier 2000). It was also found commonly foraging on the bare faces of coastal cliffs, often within the splash zone, retreating to fringing ground cover when disturbed (DNP 2012b).

Given the broad habitats used, lack of records and the profound habitat changes that have occurred over the past 20 years, it is not possible to define or map habitat critical to the survival of this species.

Threats

Threats to the species are not precisely known, however the most likely factor of decline is predation by one or more exotic species. The most likely predators include the wolf snake, giant centipede and crazy ants. The first two of these have been confirmed to prey on this species and their distribution and abundance have increased in correlation with the species' decline (DNP 2012b). Feral cats have also been implicated in their decline.

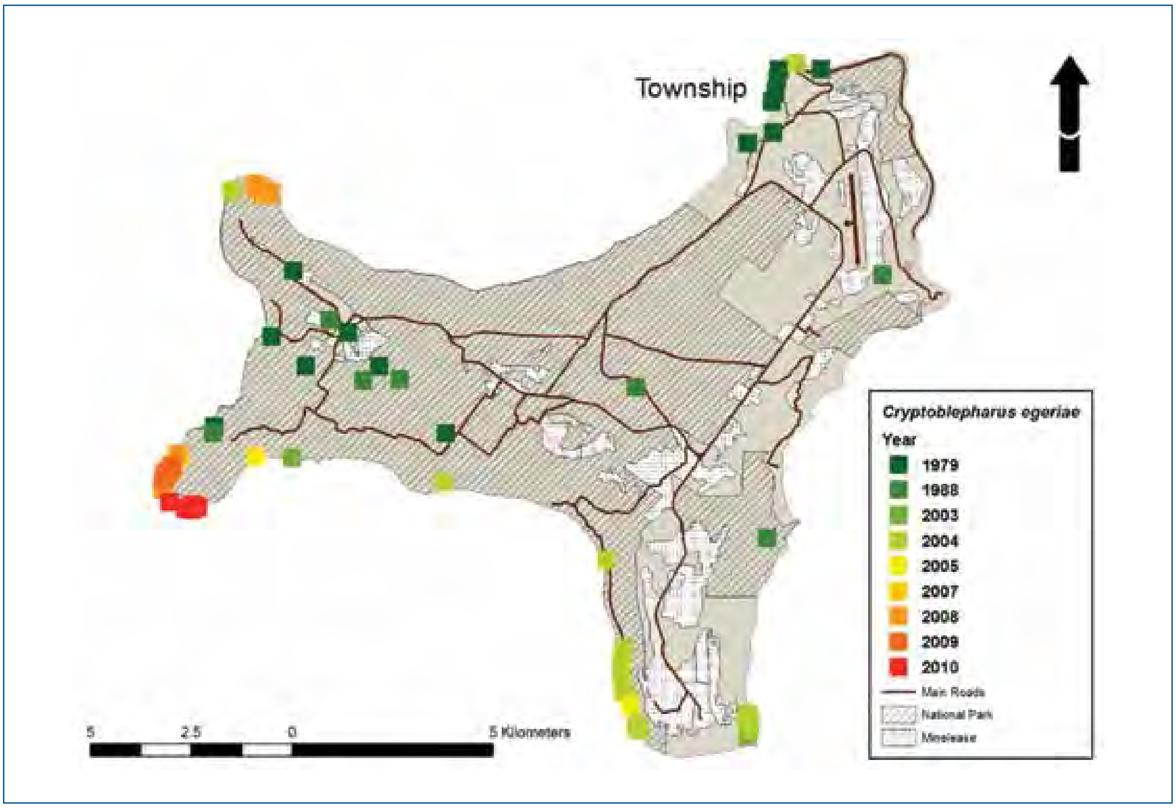
Potential threats include:

- other potential predators such as the black rat and (self-introduced) nankeen kestrel
- exotic reptiles, through predation, competition and/or spreading introduced disease (unlikely to have been the primary cause of decline however)
- supercolonies of crazy ants, through reduction in habitat suitability and/or food availability
- introduction of new diseases or invasive species.

These threats can be considered to be widespread across the island.

Management Actions

- Continue captive breeding programs, including adaptive release trials (Action 4.1).
- Monitor the extent and habitats of wild and/or reintroduced captive populations (Action 5.2).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Control cats and rats (Action 1.2).
- Investigate the feasibility of reducing the impacts of wolf snakes and centipedes and trial management (Action 3.4).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Investigate threatening processes including invasive species, pathogens, diseases and parasites (Action 6.1).



Map 15: Last recorded detections of the blue-tailed skink (Parks Australia)

Map caveats:
The data on this map represents areas where the species was last detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Cyrtodactylus sadleiri	giant gecko

Family GEKKONIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act Listing: Endangered

Existing Conservation Measures

Monitoring through IWS (but insufficiently powerful design to record declines)

Opportunistic monitoring as part of other monitoring programs and targeted monitoring (with other reptiles) in 2012 and 2013

Crazy ant control measures

Distribution

The current area of occupancy is uncertain, but the giant gecko probably persists across most of Christmas Island other than disturbed areas lacking woody regrowth (DNP 2012c) (Map 16).

Recorded as extremely abundant and widespread in a 1979 reptile survey (Cogger et al. 1983) and confirmed as common in subsequent surveys (Cogger & Sadlier 2000, DNP 2008b).

Following an extensive survey of Christmas Island reptiles in 2008, Schulz and Barker (2008) considered that it had "declined markedly, particularly in terrace rainforests and primary plateau rainforests in the western half of the island". In this sampling, they also reported no giant geckoes from several sites where it was formerly abundant (DNP 2012c).

Populations

There are no data on the number of populations and no estimates of total population size. Future reduction in population size may be inferred given the recent catastrophic decline of the four other native lizards on Christmas Island (DNP 2012c).

Populations necessary to the long-term recovery and/or survival of the species are those located in primary forest on the central plateau, and any captive population established.

Habitat

The giant gecko is found in all island habitats except for areas lacking trees and shrubs, including formerly mined areas with dense regrowth. The species is most commonly encountered in primary forest on the central plateau (Cogger et al. 1983).

Habitat critical to survival of this species comprises evergreen-tall closed forest (Figure 3).

Threats

Threats to the species are not precisely known, however the most likely cause of population decline is predation by one or more exotic species. The most likely predators include the wolf snake, giant centipede and crazy ants. The first two of these have been confirmed to prey on the gecko and their distribution and abundance has increased in correlation with the decline of the gecko (DNP 2012c). The gecko is regularly found in areas with high densities of crazy ants and may be able to tolerate ant outbreaks (Cogger & Sadlier 2000). Feral cats are also implicated in their decline.

Potential threats include:

- other potential predators such as the black rat and (self-introduced) nankeen kestrel
- exotic reptiles, through disease, predation and competition, though this is unlikely to be the primary cause of decline
- supercolonies of crazy ants, through reduction in habitat suitability and/or food availability
- introduction of new diseases or invasive species.

These threats can be considered to be widespread across the island.

Management Actions

- Conduct surveys to determine the presence, and the extent, trends and habitats of populations (Action 5.2).
- Based on population monitoring, identify thresholds (Action 9.2) and methods for initiating captive breeding, including husbandry trials (Action 4.1).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Control cats and rats (Action 1.2).
- Investigate the feasibility of reducing the impacts of wolf snakes and centipedes and trail management (Action 3.4).
- Investigate reasons for the gecko's persistence despite the more rapid decline of other native reptile species (Action 6.2).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Investigate threatening processes including invasive species, pathogens, diseases and parasites (Action 6.1).

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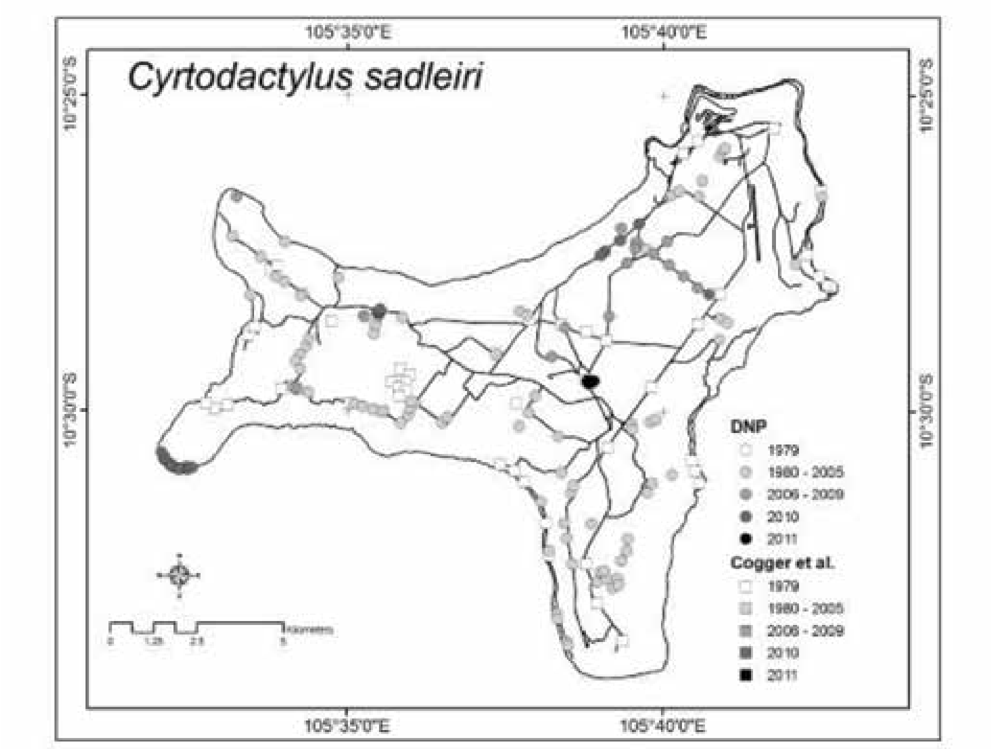


Map 16: Giant gecko records (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Emoia atrocostata	coastal skink

Family SCINCIDAE

Conservation Significance

EPBC Act Listing: none

Existing Conservation Measures

Monitoring through IWS (but insufficiently powerful design to record declines)

Dedicated native reptile survey (2012 and 2013)

Crazy ant control measures

Distribution

The coastal skink is found throughout South-east Asia and islands of the Pacific and Indian Oceans in littoral habitats. In Australia, it occurs on Christmas Island, some Torres Strait islands and the northern tip of Cape York Peninsula.

On Christmas Island, it is restricted to rocky coastal terraces in the intertidal zone (Map 17). Surveys in 1979 and 1998 suggest the species was common and widely distributed around all the island's foreshores (Cogger et al. 1983, Cogger & Sadlier 2000).

Very few sightings were made during island-wide biodiversity monitoring from 2004–06 and during targeted searches, including in all sites where it had been previously recorded (Schulz & Barker 2008).

The last sighting of the coastal skink was in 2010 (Smith et al. 2012). Extensive surveys undertaken in 2012 and 2013 to locate native reptiles (including sites where the species had been previously recorded as well as previously unsurveyed areas) did not detect this species (DNP unpub. data 2012 and 2013).

Populations

At best this species may now only occur in a few small populations scattered around the island's perimeter. It may not be extant (DNP 2012d).

Any populations or individuals in the wild or captive population established would be regarded as necessary for the long-term survival of this species.

While the species is relatively widespread, the Christmas Island population is isolated and studies have not been undertaken to determine its genetic distinctiveness compared with other populations.

Habitat

On Christmas Island, the coastal skink "is confined to the intertidal zone where it forages at low tide, and extends inland only a few metres beyond the bare rocky foreshore, where the limestone rock is lightly covered by vines. The heavily eroded limestone contains numerous crevices and holes, in which *E. atrocostata* shelter when not actively foraging" (Cogger et al. 1983).

Habitat critical to survival includes coastal terraces but is difficult to determine and locate.

Threats

Not precisely known, however the most likely factor of population decline is predation by one or more exotic species. If extant, the population is now extremely small making the species more vulnerable to threats.

The most likely predators include the wolf snake, giant centipede and crazy ants. The first two of these have been confirmed to prey on native lizards and their distribution and abundance has increased in correlation with the decline of the coastal skink (DNP 2012d). Feral cats may also be implicated in the decline of the skink, as there is evidence of predation on other native reptiles on Christmas Island.

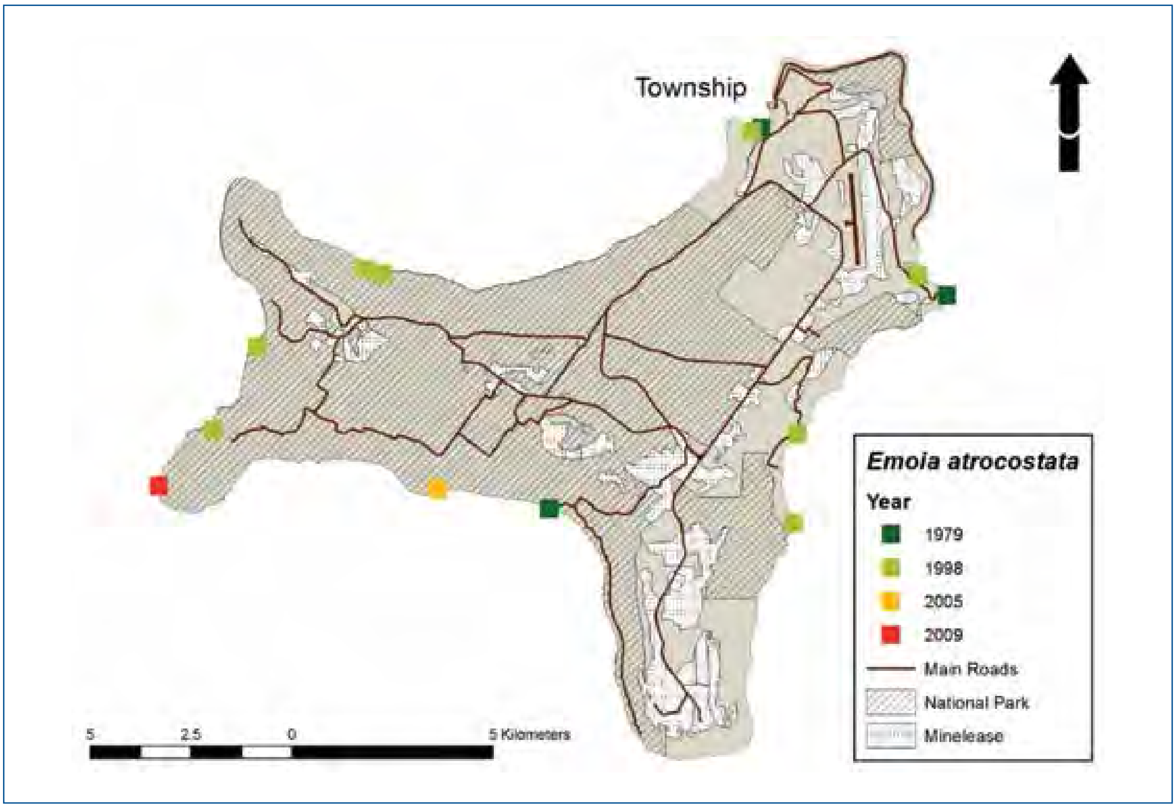
Potential threats include:

- other potential predators such as the black rat and (self-introduced) nankeen kestrel
- exotic reptiles, through competition, predation and/or introduced disease, (though this is unlikely to have been the primary cause of decline)
- supercolonies of crazy ants, through reduction in habitat suitability and/or food availability
- introduction of new diseases or invasive species.

These threats can be considered to be widespread across the island.

Management Actions

- Conduct surveys to determine presence, extent and habitats of any populations found (Action 5.2).
- If a sufficient number of individuals are found, add this species to the captive breeding program (Action 4.1).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Control cats and rats (Action 1.2).
- Investigate the feasibility of reducing the impacts of wolf snakes and centipedes and trial management (Action 3.4).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).



Map 17: Last recorded detections of the coastal skink (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Emoia nativitatis	forest skink

Family SCINCIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act Listing: Critically Endangered

IUCN listing: Critically Endangered

Existing Conservation Measures

Monitoring through IWS (but insufficiently powerful design to record declines) and dedicated reptile survey (2012 & 2013)

Crazy ant control measures

Distribution

Endemic to Christmas Island. Cogger and Sadlier (1981) reported it to be widespread in 1979 ("the most abundant and wide-ranging of the diurnal lizards"). They re-sampled the island in 1998 and "found no evidence that *Emoia nativitatis* had declined in either geographic range or numbers … although our small sample sizes in 1998 made our estimates of relative abundance very unreliable." (Cogger & Sadlier 2000).

The species has subsequently become far less common and contracted severely in range. A biodiversity monitoring program from 2003 to 2005 sampled 320 sites across the Island for reptiles and reported that the forest skink "has declined severely….. now confined to scattered, localised pockets in remote areas of the coastal terraces and first inland cliff" (DNP 2008b).

Further decline was evident in subsequent targeted searches by Schulz & Barker (2008) who reported it from only one site. The current distribution is considered extremely restricted (DNP 2012e).

The last sighting of the forest skink was in 2010 (Smith et al. 2012). Extensive surveys undertaken in 2012 (including sites where the species had been previously recorded as well as previously unsurveyed areas) did not detect this species (DNP unpub. data 2012).

Map 18 shows forest skink record locations.

Populations

The current population size is uncertain. The species may no longer be extant, based on 2012 and 2013 surveys.

Between 2009 and 2011 three individuals were held in enclosures on Christmas Island but no breeding occurred as all three were female.

Any individual or population found to exist in the wild, and any captive breeding population established, would be considered necessary for the long-term survival of the species.

Habitat

The forest skink "is primarily a forest-clearing species largely restricted to the litter of the forest floor, but will climb about on low vegetation and among the buttress roots of rainforest trees when foraging… this species appears to be as abundant on the plateau as it is on the terraces and in the low forest backing the rocky coastline" (Cogger & Sadlier 1981).

Habitat critical to survival is difficult to determine as it has not been detected in the wild since 2010. If extant, it is likely to include coastal terraces including Egeria Point.

Threats

Threats are not precisely known, however the most likely cause of population decline is predation by one or more exotic species. The most likely predators include the wolf snake, giant centipede and crazy ants. The first two are confirmed as preying on native lizards and their distribution and abundance has increased in correlation with forest skink decline (DNP 2012e). Feral cats may also be implicated in declines, as there is evidence they prey on other native lizards on Christmas Island.

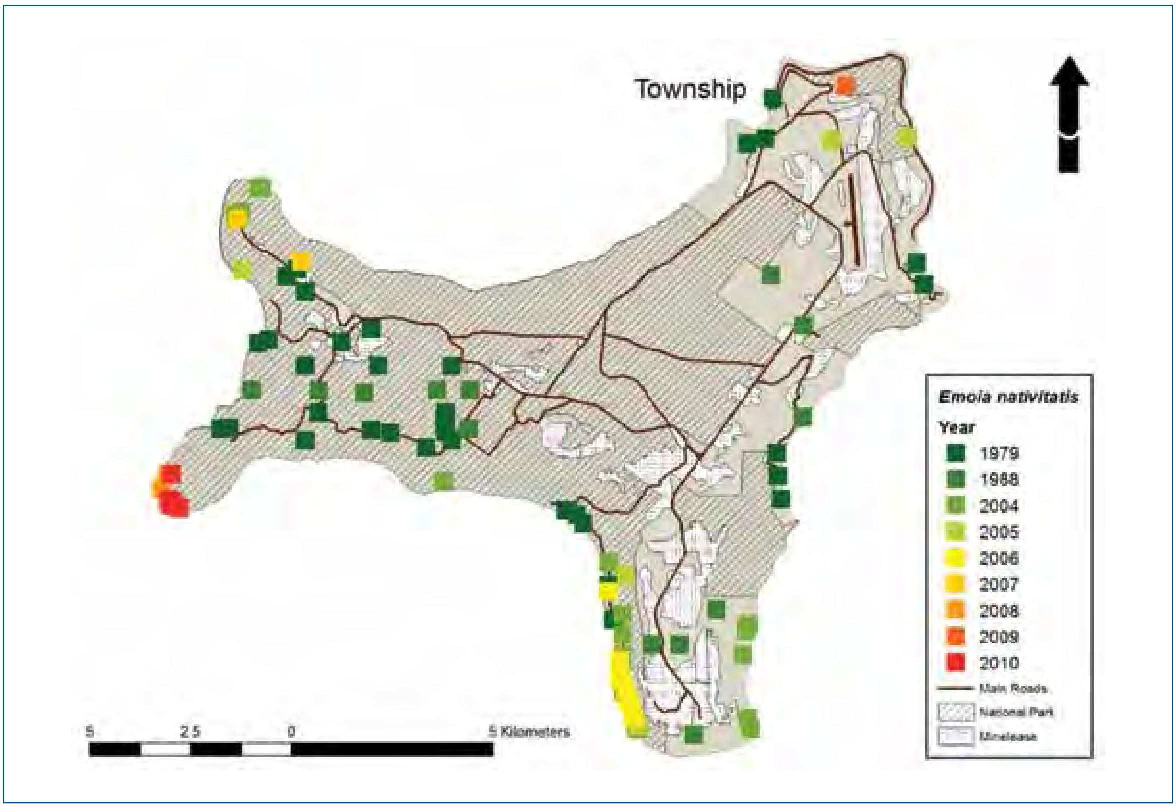
Potential threats include:

- other predators like the black rat and (self-introduced) nankeen kestrel
- exotic reptiles, through competition and/or introduced disease (though unlikely to have been the primary cause of decline)
- supercolonies of crazy ants, through reduction in habitat suitability and/or food availability
- introduction of new diseases or invasive species.

These threats can be considered to be widespread across the island.

Management Actions

- Conduct surveys to determine the presence, and the extent and habitats of any populations found (Action 5.2).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Control cats and rats (Action 1.2).
- Investigate feasibility of reducing the impacts of wolf snakes and centipedes and trial management (Action 3.4).
- Conduct ecological and biological studies to inform recovery (Action 6.2).
- Determine targets and thresholds for management intervention (Action 9.2). If intervention is decided, and a sufficient number of individuals are found, add this species to the captive reptile breeding program (Action 4.1).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Investigate threatening processes including invasive species, pathogens, diseases and parasites (Action 6.1).



Map 18: Last recorded detections of the forest skink (Parks Australia)

Map caveats:

The data on this map represents areas where the species was last detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Lepidodactylus listeri	Lister's gecko

Family GEKKONIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act listing: Critically Endangered

IUCN listing: Vulnerable

Existing Conservation Measures

Monitoring through IWS (but insufficiently powerful design to record declines)

Specific monitoring program maintained at Egeria Point plus dedicated native reptile survey (2012 and 2013)

Captive breeding population established on and off island

Crazy ant control measures

Previous Recovery Plan

Cogger 2006

Distribution

Endemic to Christmas Island where it is now only known from two small sites. The population may be declining in a southerly direction (Smith et al. 2012). The species was originally widely distributed across the island (Cogger 2005) (Map 19).

Populations

The most recent records were in October 2012 (four individuals at Egeria Point and one individual at North West Point) during extensive surveys undertaken to locate native reptiles (DNP unpub. data 2012).

Since 2009 a captive breeding population has been established in holding cages at Christmas Island and at Taronga Zoo.

All wild and captive populations of this species are regarded as important for its survival.

Habitat

Historically the species was most abundant in evergreen tall closed forest, less abundant on lower terraces and absent from mined areas. It appears to be entirely arboreal, sheltering during the day under the bark of living or dead trees and active at night on tree trunks (Cogger 2006).

However, more recent studies at Egeria Point detected it most frequently within the foliage of *Pandanus* spp. and *Scaevola taccada* in the coastal spray zone and less frequently, on the trunks and branches of *Barringtonia racemosa* and *Terminalia catappa* in the shore terrace forest. Some individuals were captured on large pinnacles/boulders covered with salt damaged vines (few leaves) found on the coastal vegetation/rock margin (DNP 2012f).

Until more populations are detected, evergreen tall closed rainforest on the plateau (Figure 3) and the shore terraces of Egeria Point and North West Point should be regarded as habitat critical to the species' survival.

Threats

No specific threatening processes have yet been proven as the cause of decline. However, invasive species are the most significant threat. The key factors in the decline are the timing, pace and extent, suggesting a newly-arrived predator, disease, or island-wide rapid habitat change (Smith et al. 2012) which may also be exacerbating the impacts of other invasive species.

Likely threats include:

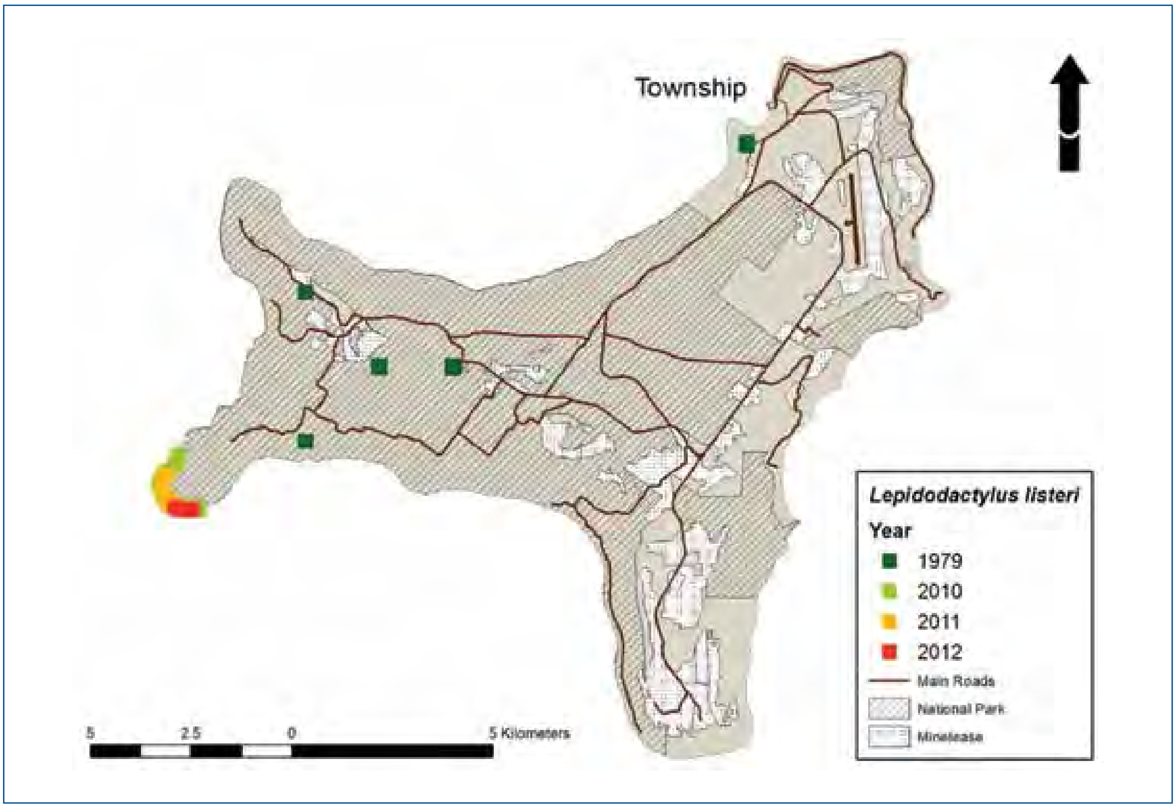
- introduced predators particularly the wolf snake and giant centipede (both confirmed predators of Lister's gecko) as well as crazy ants, black rats and cats
- competition from introduced geckoes
- habitat degradation, particularly from the impacts of crazy ants
- new introduced species and diseases (Hall et al. 2011 found no evidence of current disease threats).

The closely related *L. lugubris* occurs on the Cocos (Keeling) Islands (and many other islands in the region) and may represent a further threat through competition should it colonise the island.

All of these potential threats can be considered to be widespread across the island.

Management Actions

- Continue captive reptile breeding programs, including adaptive release trials such as through the use of exclosures (Action 4.1).
- Monitor the extent and habitats of wild and/or reintroduced captive populations (Action 5.2).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Control cats and rats (Action 1.2).
- Investigate the feasibility of reducing the impacts of wolf snakes and centipedes and trial management (Action 3.4).
- Conduct ecological and biological studies to inform recovery actions (Action 6.2).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Investigate threatening processes including invasive species, pathogens, diseases and parasites (Action 6.1).



Map 19: Last recorded detections of Lister's gecko (Parks Australia)

Map caveats:
The data on this map represents areas where the species was last detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Ramphotyphlops exocoeti | Christmas Island blind snake

Family TYPHLOPIDAE

Conservation Significance

Endemic to Christmas Island

EPBC Act listing: Vulnerable

IUCN listing: Vulnerable

Existing Conservation Measures

Monitoring through IWS (but detection difficult and insufficiently powerful design to record declines)

Dedicated native reptile survey (2012 and 2013)

Crazy ant control measures

Previous Recovery Plan

Cogger 2006

Distribution

Endemic to Christmas Island. Despite targeted surveys the species was not recorded from 1986 until 2009, when an individual was recorded at the western end of the island at Powell's Hill (Maple et al. 2013). Map 20 shows records for the species which can be located accurately.

Cogger (2005) collated a total of 22 records since settlement, some of which may be misidentifications of the introduced flowerpot snake which is very similar. These records reveal no clear pattern of distribution although it was likely to have originally occurred across the entire island (Cogger 2005).

Populations

The number of populations and total number of remaining individuals are unknown.

The 2009 sighting remains the only recent record. Extensive surveys undertaken in 2012 and 2013 to locate native reptiles (including sites where the species had been previously recorded as well as previously unsurveyed areas) did not detect this species although prevailing dry conditions may have hindered detection in 2012 (DNP unpub. data 2012).

Should any individuals be located, they would be regarded as part of an important population.

Habitat

The few available records suggest the species occurs in evergreen tall closed forest on deeper soils in the island's central plateau where it occupies the sub-surface and litter layer of the forest floor (Cogger 2006).

The 2009 specimen was found in evergreen tall closed forest typical of the central plateau, under a small piece of rotting wood at the periphery of a yellow crazy ant colony and at 361 m altitude, the island's maximum elevation (Maple et al. 2013). The understorey vegetation was *Pandanus elatus* and the dominant canopy was *Inocarpus fagifer* and the emergent *Syzygium nervosum* was also present.

Until knowledge of the population size and ecological requirement of the Christmas Island blind snake is available and understood, all forested parts of the island should be regarded as potential critical habitat. These areas are included in Figure 3 as evergreen tall closed forest and semi-deciduous closed forest.

Threats

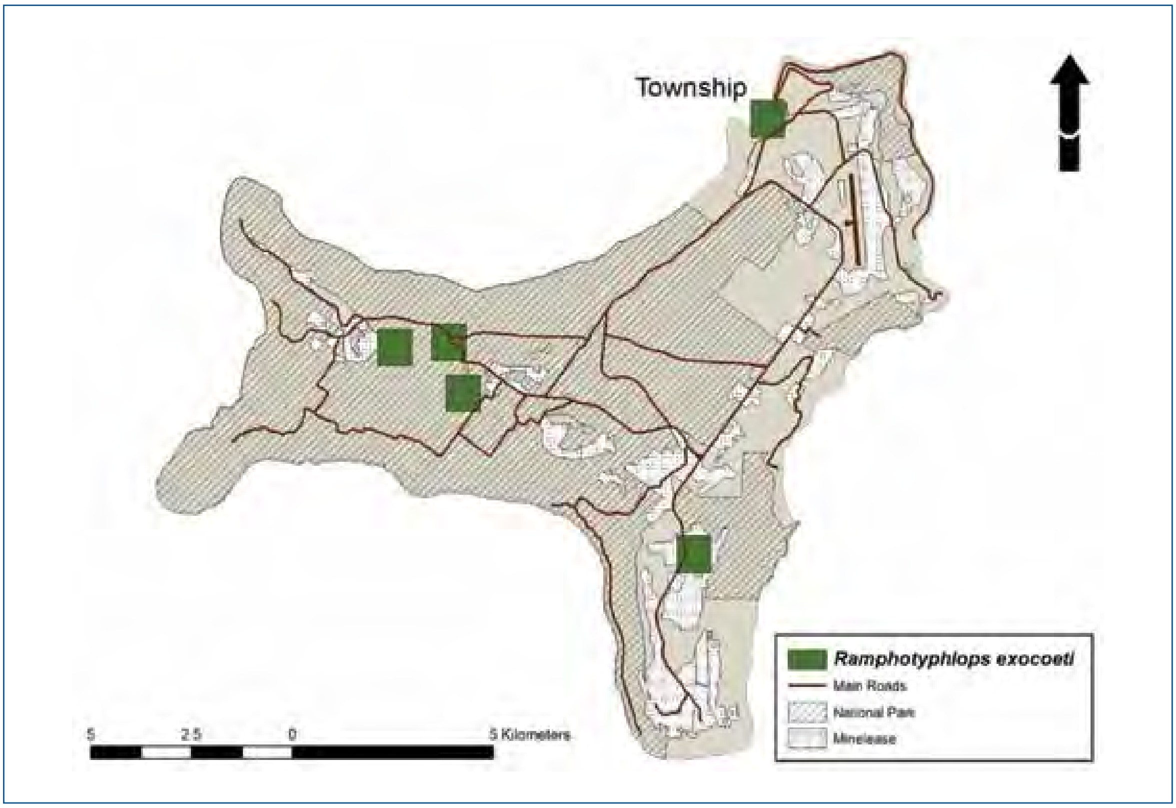
No specific threats have been demonstrated due to lack of ecological studies. Potential threats include:

- introduced predators including the black rat, giant centipede, wolf snake, cats and crazy ants
- impacts of crazy ant supercolonies, including through habitat degradation. This species is known to eat ant larvae but the interactions between the two species are unknown (Cogger 2006). However, the 2009 specimen was found in the presence of crazy ants (Maple et al. 2013). Crazy ants may also deplete prey
- introduction of new diseases or other species, which could further exacerbate existing threats
- competition from the introduced flowerpot snake.

These threats can be considered to be widespread across the island.

Management Actions

- Collect data on opportunistic sightings (Action 5). If individuals are detected, conduct surveys to determine the extent and habitats of populations (Action 5.2) and conduct relevant research (Action 6.2).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Control cats and rats (Action 1.2).
- Assess and manage the impacts of the wolf snake, giant centipede and flowerpot snake (Actions 3.4 and 6.1).
- Improve biosecurity to maintain effective quarantine against the introduction of diseases and invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).



Map 20: Last recorded detections of the Christmas Island blind snake (Parks Australia)

Map caveats:
The data on this map represents areas where the species was last detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Birgus latro	robber crab

Family COENOBITIDAE

Conservation Significance

Largest terrestrial crustacean in the world

Largest known population in the world inhabits Christmas Island

EPBC Act Listing: none

IUCN listing: Data Deficient

Existing Conservation Measures

The EPBC Regulations apply similar protection measures to robber crabs outside the national park as apply within the national park (other than for limited harvesting for personal consumption in certain circumstances).

The crazy ant control program aids robber crabs as they are threatened by crazy ant supercolonies; strategies are adopted during baiting to reduce potential deaths of robber crabs (Boland et al. 2011).

Monitoring of monthly road mortality provides a basis for education and road management activities to reduce mortality from vehicle impacts.

Distribution

The robber crab is widespread on islands of the Pacific and Indian oceans, where it is also known as the coconut crab, but scarce and secretive on inhabited islands due to extensive hunting for food (Buden 2012).

Christmas Island now represents one of the species' major sanctuaries (Hicks et al. 1990). It remains common and widely distributed across the island. However, population sampling undertaken as part of island-wide monitoring in 2004–06 identified a skewed sex ratio in favour of males and found smaller crabs rare which may have conservation management implications for the species (DNP 2008b).

Populations

There is a single population on Christmas Island which is important for the survival of the species, both on Christmas Island and globally. The size of the Christmas Island population is unknown but may be over 500 000 (Drew pers. comm. 2012) and is one of the largest known worldwide.

Habitat

Christmas Island is an internationally significant habitat for this species where it inhabits a wide range of habitats, including forest areas and sometimes disturbed areas. Robber crabs are omnivorous, feeding on ripening and falling fruits, coconuts, carrion and other crabs; occasionally climbs trees in search of food (Hicks et al. 1990). They moult deep inside burrows (Drew et al. 2010).

As a habitat generalist, all areas of previously uncleared rainforest vegetation can be considered critical habitat.

(Note: No map or additional spatial information of distribution or habitat is available)

Threats

Threats include:

- supercolonies of crazy ants via predation and habitat changes
- Fipronil bait used to control crazy ants (toxic to robber crabs however food lures are used to entice robber crabs away from supercolonies before baiting occurs)
- road traffic mortality
- chemicals used to control rats and cats may also pose a threat
- the introduction of new invasive species which poses a high risk.

These threats are found, or impact, across the island.

Significant mortality due to traffic occurs when visibility is low, during times of rain/wet season, and in the evening and at night, when the crabs are feeding on land crabs killed on the road during the day (Ng & Orchard unpub. data). Surveys showed that at least 854 (in 2010), 667 (in 2011) and 677 (in 2012) robber crabs were killed by vehicles (DNP unpub. data).

Changes to marine habitat e.g. sea temperature, current, may result in sustained mortality of immature stages.

Limited harvesting for food which occurs in restricted areas outside the national park may have a minor impact on numbers (Ng & Orchard unpub. data) but is not currently considered a threat.

Critical knowledge of habitat, ecological role, population demographics and structure for this species is absent. This information is vital in determining the need for and timing of management actions.

Management Actions

- Monitor for presence at The Dales and Hosnies Spring and population trends (Action 5.4).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Reduce impacts on robber crabs from cat and rat baiting (e.g. by elevating baits and using robber crab proof bait stations) (Action 1.2).
- Reduce vehicle impacts on robber crabs including education and awareness raising programs (Action 1.3).
- Improve biosecurity to maintain effective quarantine against the introduction of invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).
- Complete a study of robber crab ecology and population dynamics (Action 6.2) with the aim of identifying:
  - habitat needs and their ecological role
  - population demographics and structures
  - population abundance or trends.

Discoplax celeste	**blue crab**
Family GECARCINIDAE	

Conservation Significance

Endemic to Christmas Island

Characterises a significant ecosystem

EPBC Act Listing: none

Existing Conservation Measures

The EPBC Regulations apply similar protection measures to blue crabs outside the national park as apply within the national park.

The crazy ant control program aids blue crabs as they are threatened by crazy ant supercolonies.

Distribution

Endemic to Christmas Island. The species was previously confused with *D. hirtipes* which occurs from the northern Indian Ocean to the central Pacific Ocean but was described as distinct in 2012 (Ng & Davie 2012).

The blue crab has a restricted distribution in perennially wet/moist areas and seepages, including The Dales and Hosnies Spring where it is locally common (Hicks et al. 1990) (Map 21).

Populations

There are five known populations of which the largest is located at The Dales; populations at other springs areas of equal importance to the long term viability of the species (Hicks et al. 1990, Turner et al. 2011).

All occurrences of the species, including any future populations found, are important populations, based on its endemic status and its highly restricted occurrence.

Little is known about population dynamics (but see Turner et al. 2011).

Habitat

The blue crab prefers moist areas near freshwater seepages (Hicks et al. 1990) including swampy areas, streams and springs; it burrows in soft earth.

All springs and wetland areas on Christmas Island are considered habitat critical to the survival of the blue crab, in particular those located at The Dales, as well as other wetlands including Hosnies Spring (Figure 4). Blue crabs need freshwater to maintain respiratory function so are restricted to the springs and wetland areas in the drier months. In the wet season there is sufficient moisture in the forests to enable them to range over large areas (Hicks et al. 1990).

Threats

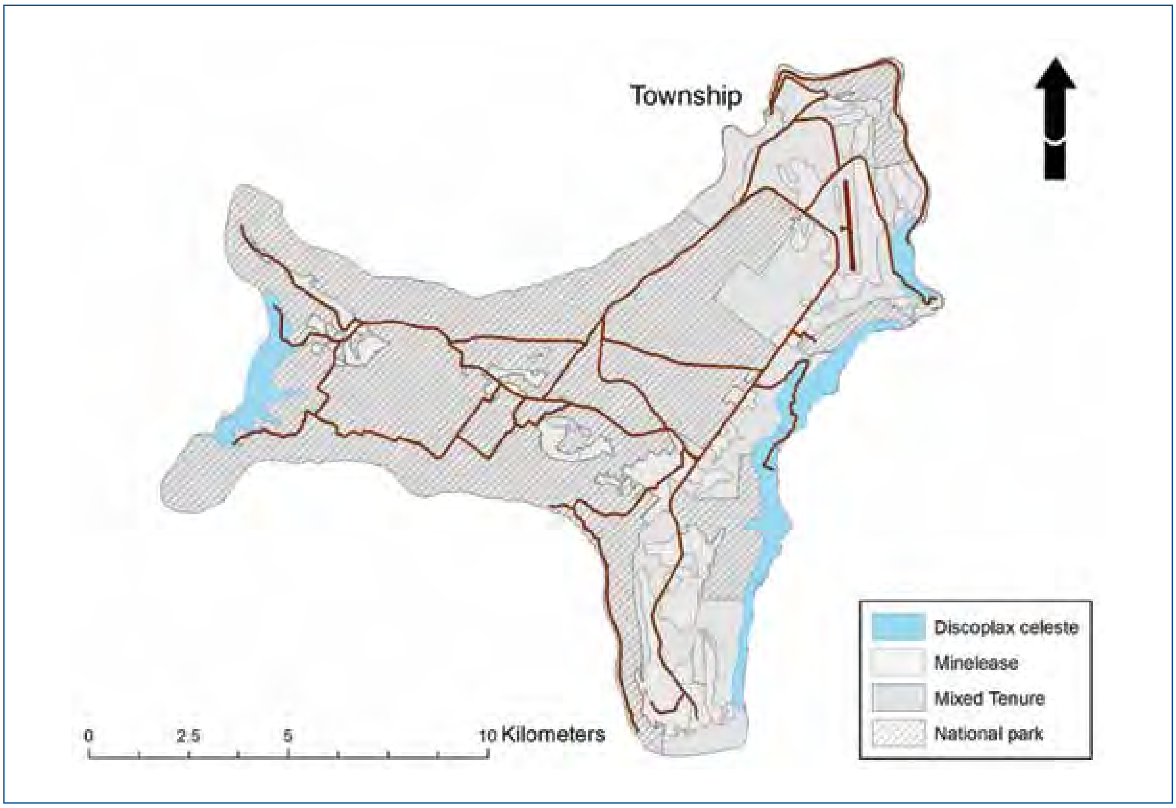
Supercolonies of crazy ants are a threat via predation and habitat changes. The introduction of new invasive species poses a high risk. These threats are found, or impact, across the island.

Loss, diversion and/or decreased water flows at spring sites, for instance due to anthropogenic influences like island water supply, natural variations and/or climate changes is currently a major risk (Ng unpub. data).

Changes to marine habitat e.g. sea temperature, current, may result in sustained mortality of immature stages.

Management Actions

- Monitor for presence at The Dales and Hosnies Spring and population trends (Action 5.4).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Monitor and manage use of subterranean groundwater (Action 3.5).
- Conduct studies of population dynamics and juvenile dispersal (Action 6.2).
- Improve biosecurity to maintain effective quarantine against the introduction of invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).



Map 21: Estimated peak blue crab distribution (wet season) (Parks Australia)

Map caveats:

The data on this map represents areas where the species may or is likely to be detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Gecarcoidea natalis	red crab
Family GECARCINIDAE	

Conservation Significance

Endemic to Christmas Island

Keystone species for the island's forests

Internationally iconic species with a unique lifecycle/breeding migration, which characterises the island's natural environment

EPBC Act Listing: none

Existing Conservation Measures

Monitoring through biennial Island Wide Survey (IWS) (burrow counts).

Crazy ant control program largely focused on conservation of red crabs

Roads are managed to protect red crabs from traffic impacts (via installation of crab crossings and use of road closures, as well as through public education activities, including promotion of slower driving speeds).

The EPBC Regulations apply similar protection measures to red crabs outside the national park as apply within the national park.

Distribution

Endemic to Christmas Island, apart from a small population on North Keeling Island where it is very rare and may have been accidentally introduced in the early 1900s (Tweedie 1950).

Widespread across the island (Map 22) and abundant.

Populations

There is a single population on Christmas Island. The original population size is not known but was previously estimated at 120 million (Hicks et al. 1990). A major population reduction occurred following the establishment of crazy ant supercolonies. The 2011 IWS results suggest a population (based on burrow counts) of about 45 million. However, small crabs (e.g. 3–4 years of age) will not have burrowed so this may underestimate actual population size.

Population sampling undertaken as part of island-wide monitoring in 2004–06 identified a skewed sex ratio in favour of males which may have conservation management implications for the species (DNP 2008b). Returns from the sea, and the implications on the age-structure and recruitment, have not been investigated in detail.

The single genetic population on Christmas Island has no apparent spatial genetic structure or restricted gene flow between sampled locations. Further, red crabs from North Keeling Island are not genetically distinct and are likely to be recent immigrants from Christmas Island.

The effective population size has likely remained large and stable on Christmas Island throughout its evolutionary history with relatively moderate to high levels of genetic diversity.

The single population is important for the survival of the species.

Habitat

Adult red crabs are fully terrestrial but depend on the sea for breeding. Red crabs live in burrows and karst areas in forest and shaded areas, with highest densities in evergreen tall closed forest (Hicks et al. 1990).

Habitat critical to survival occurs across the whole island (except for areas of land devoid of vegetation and/or soil such as bare mine fields and houses/buildings) and particularly includes previously uncleared rainforest vegetation. However, crabs may migrate through areas such as roads (but not generally open areas like cleared mine fields) during their annual breeding migration.

Red crabs are considered to have a major role in the ecological functioning of the island's forests. Red crabs are omnivorous, and a main portion of their diet is fruits, seeds, and seedlings as well as leaf litter. Crabs also prey on the invasive giant African land snail. Where red crabs have been removed by crazy ants there has been a significant impact on the forest ecology.

Threats

Supercolonies of crazy ants across the island pose the primary and most significant threat, as red crabs do not survive near supercolonies (O'Dowd et al. 1999, 2003). Although baiting crazy ants with Fipronil may affect red crabs, only the supercolonies are baited so this threat is minimal.

During the breeding migration, significant mortality due to traffic may occur on roads which are open and have no crab barriers.

Climate change may impact on the species through favouring conditions for crazy ants.

The introduction of new invasive species poses a high risk.

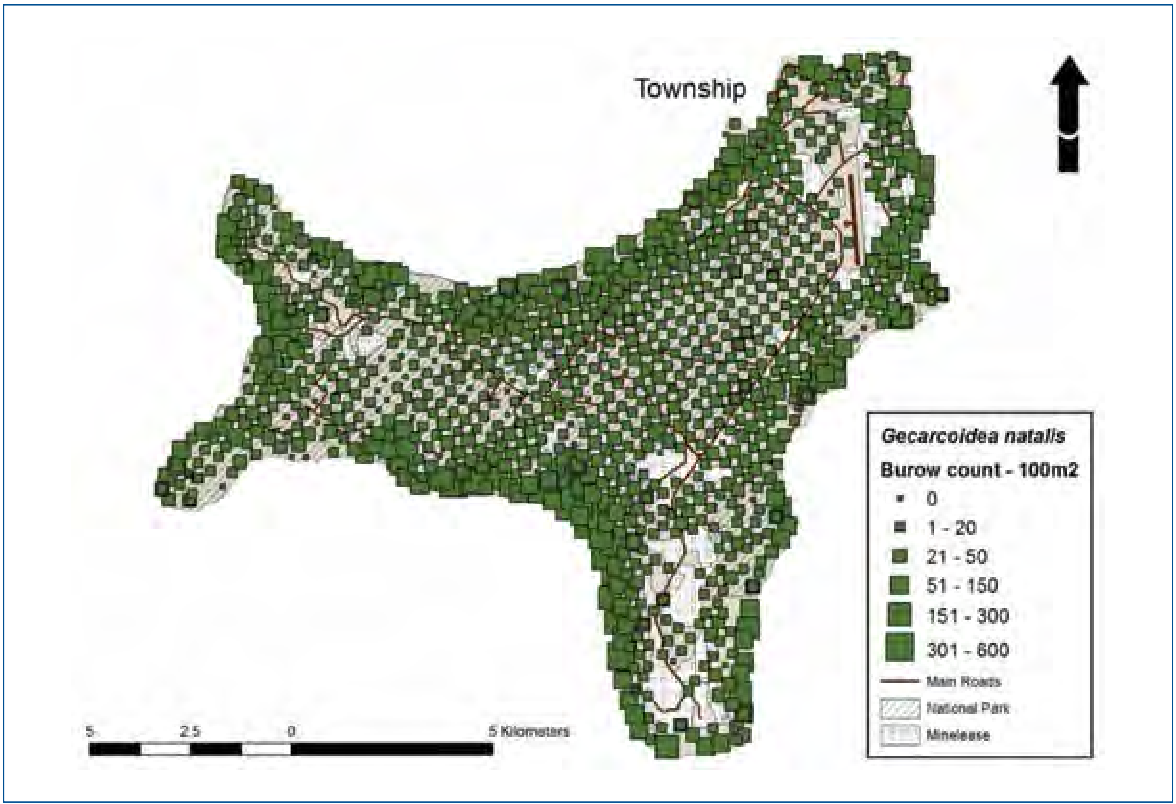
Habitat loss and clearing, especially previously uncleared rainforest vegetation, could also impact on population size.

Crabs may also be vulnerable during their at-sea life cycle (e.g. due to changing sea swell conditions, currents, temperature) which may affect the return of crabs.

Management Actions

- Reduce vehicle impacts on red crabs, for example through education and awareness raising programs (Action 1.3).
- Control and reduce the impacts of crazy ants including reducing off-target baiting impacts and by investigating alternative control methods, particularly biological control and lower off-target baits and baiting methods (Action 1.1).
- Monitor burrow abundance and distribution trends, and presence at wetlands (Actions 5.1 and 5.2).
- Reduce impacts from cat and rat baiting, such as by elevating baits and using red crab proof bait stations (Action 1.2).

- Investigate migration patterns including at sea life cycles and returns (Action 6.2).
- Monitor the annual red crab migration (Action 5.3).
- Trial the re-establishment of red crabs (Action 4.4).
- Rehabilitate previously mined areas (Action 3.3).
- Improve biosecurity to maintain effective quarantine against the introduction of invasive species. This includes rapidly controlling pests that may enter and assessing the risk of threat (Action 2).



Map 22: Red crab burrow density 2011 (Parks Australia)

Map caveats:
The data on this map represents areas where the species has been detected but does not represent all areas where the species may exist and the map cannot be used for population estimate purposes.

Page no.	Image credits
Front cover	Red crab eating. Photo credit: Parks Australia
xiv	Rainforest is the dominant vegetation type on Christmas Island. Photo credit: Parks Australia
12	Each year, most of Christmas Island's adult red crabs spawn (lay their eggs) in the sea. On the years when ocean conditions are favourable, there is a spectacular return migration as the young crabs make their way from the ocean to the forests. Photo credit: Parks Australia, Caitlyn Pink
16	Hugh's Dale waterfall is spring fed and flows all year round. The Dales—a series of seven picturesque watercourses on the western coastline—is listed as a Wetland of International Importance under the Ramsar Convention. Photo credit: Christmas Island Tourism Association
21	The tall evergreen rainforest on Christmas Island provides habitat for species such as the Abbott's booby and the flying fox which are both found nowhere else in the world. Photo credit: Parks Australia
29	The tall evergreen rainforest on Christmas Island is the last remaining nesting habitat for the Abbott's booby. Photo credit: Parks Australia
33	Christmas Island is home to tens of millions of red crabs. Their annual migration to the sea—usually between November and January—coincides with the beginning of the monsoon rains and the correct phase of the moon. Photo credit: Parks Australia, Samantha Flakus
36	Yellow crazy ants are a major threat to Christmas Island's biodiversity, and are a particular problem for red crabs. The national park has used recurring aerial baiting to keep ant super colonies at bay. As a long term solution, the park is working with LaTrobe University to explore the potential to control the ants via indirect biological control of scale insects (a major food source for the ants). Photo credit: Parks Australia
49	The whole Christmas Island community works together to protect migrating red crabs from vehicle traffic. Crossings like this crab bridge help keep crabs safe as they march across the island, including over roads. Other protection measures include road underpasses and temporary road closures. Photo credit: Parks Australia
51	When the red crabs begin their annual migration, nothing stops them—least of all roads! Specially designed underpasses channel the marching crabs away from the wheels of passing traffic. Photo credit: Parks Australia
56	Every two years, staff from Christmas Island National Park conduct an island-wide biodiversity survey. The aim is to gauge the health of the island's ecosystems, by estimating red crab populations and the area of crazy ant super-colonies. The survey also collects data on the status of other native and invasive species. Photo credit: Parks Australia
58	Robber crabs are the largest living land crab in the world. They are extremely slow-growing and research suggests that they can live to more than 70 years old. Christmas Island provides habitat for one the largest remaining populations of robber crabs in the world. Photo credit: Parks Australia
Back cover	Red crab. Photo credit: Parks Australia

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FOI 170312
Document 09

Commonwealth of Australia

Exemption under section 158 of the
Environment Protection and Biodiversity Conservation Act 1999

I, **David Alistair Kemp,** Minister for the Environment and Heritage, being satisfied that it is in the national interest to do so, hereby exempt, under s 158 of the *Environment Protection and Biodiversity Conservation Act 1999,* the persons specified in the Schedule from the application of all of the provisions of Part 3 of the *Environment Protection and Biodiversity Conservation Act 1999* in relation to the action specified in the Schedule, on and after the date of this notice.

Schedule

Specified persons

- the Commonwealth; and
- all Commonwealth agencies, within the meaning of that term in s.528 of the *Environment Protection and Biodiversity Conservation Act 1999*; and
- all persons acting on behalf of the Commonwealth; and
- all persons providing services or carrying out activities for the purposes of or in connection with the action specified in this Schedule.

Specified action

Establishment and ongoing operation of an Immigration Reception and Processing Centre, together with associated services and infrastructure, on the Territory of Christmas Island comprising:

- Design, construction and operation of an Immigration Reception and Processing Centre (IRPC) on that area of land shown as ML 138 and ML 139 on Map 94/068 produced by the Australian Surveying and Land Information Group.
- Construction of additional housing and associated infrastructure for staff and other persons associated with the IRPC, located within or immediately adjacent to the existing residential settlement in the north east corner of Christmas Island.
- Works associated with laying and operation of cables, pipes and other infrastructure within the currently cleared corridor along the road that commences as Murray road and proceeds from near the power station to the Central Area Workshop site and then to the IRPC site to enable the supply of power, water and other services to the IRPC.
- Construction and operation of a temporary construction camp on the area of land immediately north of the existing cricket ground, situated between Irvine Hill and Phosphate Hill and shown on Map 94/068 produced by the Australian Surveying and Land Information Group and delineated by Australian Surveying and Land Information Group Christmas Island 85 grid coordinates (24504, 66783)(24739, 66747)(24756, 66658)(24778, 66588)(24706, 66573)(24681, 66597)(24636, 66603)(24555, 66581)

David Kemp
Minister for the Environment and Heritage

Dated this Third day of April 2002

FOI 170312
Document 10

STATEMENT OF REASONS FOR DECISION UNDER SECTION 158 OF THE *ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999*

I, DAVID ALISTAIR KEMP, Minister for the Environment and Heritage, provide this statement of reasons under subsection 158(7) of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) for my decision under subsection 158(3) to exempt the Commonwealth and certain other specified persons from the application of the provisions of Part 3 of the EPBC Act in relation to the following action:

Establishment and ongoing operation of an Immigration Reception and Processing Centre (IRPC), together with associated services and infrastructure, on the Territory of Christmas Island comprising:

- Design, construction and operation of an IRPC on that area of land shown as ML 138 and ML 139 on Map 94/068 produced by the Australian Surveying and Land Information Group.
- Construction of additional housing and associated infrastructure for staff and other persons associated with the IRPC, located within or immediately adjacent to the existing residential settlement in the north east corner of Christmas Island.
- Works associated with laying and operation of cables, pipes and other infrastructure within the currently cleared corridor along the road that commences as Murray road and proceeds from near the power station to the Central Area Workshop site and then to the IRPC site to enable the supply of power, water and other services to the IRPC.
- Construction and operation of a temporary construction camp on the area of land immediately north of the existing cricket ground, situated between Irvine Hill and Phosphate Hill and shown on Map 94/068 produced by the Australian Surveying and Land Information Group and delineated by Australian Surveying and Land Information Group Christmas Island 85 grid coordinates (24504,66783)(24739,66747)(24756,66658) (24778, 66588)(24706,66573)(24681,66597)(24636, 66603)(24555,66581).

Legislation

1. Section 158 of the EPBC Act provides:

158 Exemptions from Part 3 and this Chapter

(1) A person proposing to take a controlled action, or the designated proponent of an action, may apply in writing to the Minister for an exemption from a specified provision of Part 3 or of this Chapter.

(2) The Minister must decide within 20 business days of receiving the application whether or not to grant the exemption.

(3) The Minister may, by written notice, exempt a specified person

from the application of a specified provision of Part 3 or of this Chapter in relation to a specified action.

(4) The Minister may do so only if he or she is satisfied that it is in the national interest that the provision not apply in relation to the person or the action.

(5) In determining the national interest, the Minister may consider Australia's defence or security or a national emergency. This does not limit the matters the Minister may consider.

(6) A provision specified in the notice does not apply in relation to the specified person or action on or after the day specified in the notice. The Minister must not specify a day earlier than the day the notice is made.

(7) Within 10 business days after making the notice, the Minister must:

(a) publish a copy of the notice and his or her reasons for granting the exemption in accordance with the regulations; and

(b) give a copy of the notice to the person specified in the notice.

Background

2. On 20 March 2002, the Hon. Philip Ruddock MP, Minister for Immigration and Multicultural and Indigenous Affairs, and the Hon. Wilson Tuckey MP, Minister for Regional Services, Territories and Local Government, applied for exemptions under sections 158 and 303A of the EPBC Act in relation to a proposal to establish an IRPC, and associated infrastructure, on Christmas Island.

3. On 3 April 2002, I decided, in accordance with section 158 of the EPBC Act, to exempt the Commonwealth and other specified persons from the application of the provisions of Part 3 in relation to the action involved in that proposal.

Evidence or other material on which the decision-maker's findings were based

4. The evidence and other material on which my findings were based is listed below:

- a brief from the Department of the Environment and Heritage, dated 28 March 2002, which included the following attachments:
  - a copy of the application from Ministers Ruddock and Tuckey for an exemption under section 158 of the EPBC Act in relation to the proposed IRPC and associated infrastructure;
  - a copy of section 158 of the EPBC Act;

- a summary of communications from the Department of Immigration and Multicultural and Indigenous Affairs providing further information regarding the application for the exemption; and
- a copy of a brief from the Department of the Environment and Heritage, dated 21 March 2002.

Findings on material questions of fact

5. I found that the Government has a policy of mandatory detention of asylum seekers who enter or seek to enter Australia without authorisation. I found that the Cabinet is committed to the retention of that policy, and to the establishment and maintenance of appropriate detention infrastructure to give effect to it, including establishment and operation of an IRPC on Christmas Island.

6. I found that it is expected that there will continue to be arrivals of asylum seekers towards north-west Australia.

7. I found that the existing temporary accommodation on Christmas Island would not be adequate or suitable for accommodating asylum seekers on Christmas Island, particularly during the monsoon season.

8. I found that the monsoon season in Christmas Island usually commences in October/November, but can commence as early as September.

9. I found that the first stage of the proposed Christmas Island IRPC would need to be constructed and commissioned within the next six months if adequate accommodation for further arrivals of asylum seekers is to be available on Christmas Island, particularly after the onset of the monsoon season.

10. I found that the statutory time frames under the EPBC Act, particularly those relating to public consultation, would have meant that the first stage of construction could not be completed within six months if the provisions of Part 3 applied in relation to the actions involved in the proposal.

11. I found that Ministers Ruddock and Tuckey undertook to ensure that best practice environmental management measures would be implemented in relation to the establishment and ongoing operation of the proposed Christmas Island IRPC and associated infrastructure, including:

    - the development of an environmental management plan for the construction and operation of the IRPC and associated infrastructure;

    - the appointment of a suitably qualified environmental manager;

- monitoring for protected species, and the application of mitigation measures should the action prove to have adverse impacts on those species.

12. I found that these measures will be undertaken in consultation with Environment Australia.

13. I found that any works that affect the Christmas Island National Park will need to be consistent with the management plan for the Park and that the *Environment Protection and Biodiversity Conservation Regulations 2000* will apply to the proposed Christmas Island IRPC and associated infrastructure in relation to the protection of biodiversity in areas of Christmas Island outside the Park.

Reasons for decision

14. I decided to give the exemption under subsection 158(3) because I was satisfied that:

    - it was in the national interest that all of the provisions of Part 3 of the EPBC Act not apply in relation to the activities involved in the establishment and ongoing operation of the proposed IRPC on Christmas Island, together with associated services and infrastructure described above in this Statement of Reasons; and
    - environmental management measures will be implemented for the purpose of ensuring that best practice management will be employed in relation to those activities were the exemption to be given.

15. In making my decision, I took into account that the Cabinet is committed to the retention of the Government's current policy on mandatory detention of asylum seekers who enter or seek to enter Australia without authorisation, and to the establishment and maintenance of appropriate detention infrastructure to give effect to it, including establishment and operation of an IRPC on Christmas Island. I considered that:

    - an IRPC on Christmas Island is a central element of the infrastructure necessary to maintain the Government's current policies in relation to mandatory detention and processing of asylum seekers; and
    - the establishment and ongoing operation of the proposed Christmas Island IRPC is also integral to the effective implementation of a strategy to protect the security of Australia's borders, including the determination of who can and cannot enter Australia.

16. In making my decision, I also considered that, without establishment and ongoing operation of the proposed Christmas Island IRPC, the accommodation for any asylum seekers arriving towards north-west Australia in the future would continue to be unsuitable and would not facilitate their effective processing. This would particularly be the case

during the monsoon season (which may begin as early as September in any year). I considered that the first stage of the proposed Christmas Island IRPC therefore needed to be completed within the next six months. In particular, this would ensure adequate accommodation was available before the next monsoon season.

17. I was also of the view that, in the absence of exemption from the provisions of Part 3 of the EPBC Act, the statutory time frames under that Act, and particularly those related to public consultation, would have meant that the first stage of the establishment and ongoing operation of the proposed Christmas IRPC could not occur within the next six months.

18. In the light of these considerations and the findings referred to above in this Statement of Reasons, I therefore concluded that it was in the national interest that all of the provisions of Part 3 of the EPBC Act not apply in relation to the actions described above in this Statement.

19. In making my decision, I also took into account the undertaking made by Ministers Ruddock and Tuckey in their application for the exemption referred to above in this Statement that best practice environmental management measures would be implemented in relation to the proposed Christmas Island IRPC. I took into account that these measures will be undertaken in consultation with Environment Australia. Further, I considered that the management plan for the Christmas Island National Park will provide adequate protection for the Park and the *Environment Protection and Biodiversity Conservation Regulations 2000* will provide adequate protection for biodiversity outside of the Park.

David Kemp

MINISTER FOR THE ENVIRONMENT AND HERITAGE

16 / 4 /2002

FOI 170312
Document 11

Commonwealth of Australia

Exemption under section 303A of the
Environment Protection and Biodiversity Conservation Act 1999

I, **David Alistair Kemp,** Minister for the Environment and Heritage, being satisfied that it is in the national interest to do so, hereby exempt, under s 303A of the *Environment Protection and Biodiversity Conservation Act 1999,* the persons specified in the Schedule from the application of all of the provisions of Part 13 of the *Environment Protection and Biodiversity Conservation Act 1999* in relation to the action specified in the Schedule, on and after the date of this notice.

Schedule

Specified persons

- the Commonwealth; and
- all Commonwealth agencies, within the meaning of that term in s.528 of the *Environment Protection and Biodiversity Conservation Act 1999*; and
- all persons acting on behalf of the Commonwealth; and
- all persons providing services or carrying out activities for the purposes of or in connection with the action specified in this Schedule.

Specified action

Establishment and ongoing operation of an Immigration Reception and Processing Centre, together with associated services and infrastructure, on the Territory of Christmas Island comprising:

- Design, construction and operation of an Immigration Reception and Processing Centre (IRPC) on that area of land shown as ML 138 and ML 139 on Map 94/068 produced by the Australian Surveying and Land Information Group.
- Construction of additional housing and associated infrastructure for staff and other persons associated with the IRPC, located within or immediately adjacent to the existing residential settlement in the north east corner of Christmas Island.
- Works associated with laying and operation of cables, pipes and other infrastructure within the currently cleared corridor along the road that commences as Murray road and proceeds from near the power station to the Central Area Workshop site and then to the IRPC site to enable the supply of power, water and other services to the IRPC.
- Construction and operation of a temporary construction camp on the area of land immediately north of the existing cricket ground, situated between Irvine Hill and Phosphate Hill and shown on Map 94/068 produced by the Australian Surveying and Land Information Group and delineated by Australian Surveying and Land Information Group Christmas Island 85 grid coordinates (24504, 66783)(24739, 66747)(24756, 66658)(24778, 66588)(24706, 66573)(24681, 66597)(24636, 66603)(24555, 66581)

David Kemp

Minister for the Environment and Heritage

Dated this Third day of April 2002

FOI 170312
Document 12

STATEMENT OF REASONS FOR DECISION UNDER SECTION 303A OF THE *ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999*

I, DAVID ALISTAIR KEMP, Minister for the Environment and Heritage, provide this statement of reasons under subsection 303A(7) of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) for my decision under subsection 303A(3) to exempt the Commonwealth and certain other specified persons from the application of the provisions of Part 13 of the EPBC Act in relation to the following action:

Establishment and ongoing operation of an Immigration Reception and Processing Centre (IRPC), together with associated services and infrastructure, on the Territory of Christmas Island comprising:

- Design, construction and operation of an IRPC on that area of land shown as ML 138 and ML 139 on Map 94/068 produced by the Australian Surveying and Land Information Group.
- Construction of additional housing and associated infrastructure for staff and other persons associated with the IRPC, located within or immediately adjacent to the existing residential settlement in the north east corner of Christmas Island.
- Works associated with laying and operation of cables, pipes and other infrastructure within the currently cleared corridor along the road that commences as Murray road and proceeds from near the power station to the Central Area Workshop site and then to the IRPC site to enable the supply of power, water and other services to the IRPC.
- Construction and operation of a temporary construction camp on the area of land immediately north of the existing cricket ground, situated between Irvine Hill and Phosphate Hill and shown on Map 94/068 produced by the Australian Surveying and Land Information Group and delineated by Australian Surveying and Land Information Group Christmas Island 85 grid coordinates (24504,66783)(24739,66747)(24756,66658) (24778, 66588)(24706,66573)(24681,66597)(24636, 66603)(24555,66581).

Legislation

1. Section 303A of the EPBC Act provides:

303A Exemptions from this Part

(1) A person proposing to take an action that would contravene a provision of this Part apart from this section may apply in writing to the Minister for an exemption from the provision.

(2) The Minister must decide within 20 business days of receiving the application whether or not to grant the exemption.

(3) The Minister may, by written notice, exempt a specified person

from the application of a specified provision of this Part in relation to a specified action.

(4) The Minister may do so only if he or she is satisfied that it is in the national interest that the provision not apply in relation to the person or the action.

(5) In determining the national interest, the Minister may consider Australia's defence or security or a national emergency. This does not limit the matters the Minister may consider.

(6) A provision specified in the notice does not apply in relation to the specified person or action on or after the day specified in the notice. The Minister must not specify a day earlier than the day the notice is made.

(7) Within 10 business days after making the notice, the Minister must:

(a) publish a copy of the notice and his or her reasons for granting the exemption in accordance with the regulations; and

(b) give a copy of the notice to the person specified in the notice.

Background

2. On 20 March 2002, the Hon. Philip Ruddock MP, Minister for Immigration and Multicultural and Indigenous Affairs, and the Hon. Wilson Tuckey MP, Minister for Regional Services, Territories and Local Government, applied for exemptions under sections 158 and 303A of the EPBC Act in relation to a proposal to establish an IRPC, and associated infrastructure, on Christmas Island.

3. On 3 April 2002, I decided, in accordance with section 303A of the EPBC Act, to exempt the Commonwealth and other specified persons from the application of the provisions of Part 13 in relation to the action involved in that proposal.

Evidence or other material on which the decision-maker's findings were based

4. The evidence and other material on which my findings were based is listed below:

- a brief from the Department of the Environment and Heritage, dated 28 March 2002, which included the following attachments:
  - a copy of the application from Ministers Ruddock and Tuckey for an exemption under section 303A of the EPBC Act in relation to the proposed IRPC and associated infrastructure;
  - a copy of section 303A of the EPBC Act;

- a summary of communications from the Department of Immigration and Multicultural and Indigenous Affairs providing further information regarding the application for the exemption; and
- a copy of a brief from the Department of the Environment and Heritage, dated 21 March 2002.

Findings on material questions of fact

5. I found that the Government has a policy of mandatory detention of asylum seekers who enter or seek to enter Australia without authorisation. I found that the Cabinet is committed to the retention of that policy, and to the establishment and maintenance of appropriate detention infrastructure to give effect to it, including establishment and operation of an IRPC on Christmas Island.

6. I found that it is expected that there will continue to be arrivals of asylum seekers towards north-west Australia.

7. I found that the existing temporary accommodation on Christmas Island would not be adequate or suitable for accommodating asylum seekers on Christmas Island, particularly during the monsoon season.

8. I found that the monsoon season in Christmas Island usually commences in October/November, but can commence as early as September.

9. I found that the first stage of the proposed Christmas Island IRPC would need to be constructed and commissioned within the next six months if adequate accommodation for further arrivals of asylum seekers is to be available on Christmas Island, particularly after the onset of the monsoon season.

10. I found that, if the provisions of Part 13 of the EPBC Act applied in relation to the actions involved in the proposal, the permit requirements under that Part could have had the effect of preventing completion of the first stage of construction of the proposed IRPC within six months.

11. I found that Ministers Ruddock and Tuckey undertook to ensure that best practice environmental management measures would be implemented in relation to the establishment and ongoing operation of the proposed Christmas Island IRPC and associated infrastructure, including:

    - the development of an environmental management plan for the construction and operation of the IRPC and associated infrastructure;

    - the appointment of a suitably qualified environmental manager;

- monitoring for protected species, and the application of mitigation measures should the action prove to have adverse impacts on those species.

12. I found that these measures will be undertaken in consultation with Environment Australia.

13. I found that any works that affect the Christmas Island National Park will need to be consistent with the management plan for the Park and that the *Environment Protection and Biodiversity Conservation Regulations 2000* will apply to the proposed Christmas Island IRPC and associated infrastructure in relation to the protection of biodiversity in areas of Christmas Island outside the Park.

Reasons for decision

14. I decided to give the exemption under subsection 303A(3) because I was satisfied that:

    - it was in the national interest that all of the provisions of Part 13 of the EPBC Act not apply in relation to the activities involved in the establishment and ongoing operation of the proposed IRPC on Christmas Island, together with associated services and infrastructure described above in this Statement of Reasons; and
    - environmental management measures will be implemented for the purpose of ensuring that best practice management will be employed in relation to those activities were the exemption to be given.

15. In making my decision, I took into account that the Cabinet is committed to the retention of the Government's current policy on mandatory detention of asylum seekers who enter or seek to enter Australia without authorisation, and to the establishment and maintenance of appropriate detention infrastructure to give effect to it, including establishment and operation of an IRPC on Christmas Island. I considered that:

    - an IRPC on Christmas Island is a central element of the infrastructure necessary to maintain the Government's current policies in relation to mandatory detention and processing of asylum seekers; and
    - the establishment and ongoing operation of the proposed Christmas Island IRPC is also integral to the effective implementation of a strategy to protect the security of Australia's borders, including the determination of who can and cannot enter Australia.

16. In making my decision, I also considered that, without establishment and ongoing operation of the proposed Christmas Island IRPC, the accommodation for any asylum seekers arriving towards north-west Australia in the future would continue to be unsuitable and would not

facilitate their effective processing. This would particularly be the case during the monsoon season (which may begin as early as September in any year). I considered that the first stage of the proposed Christmas Island IRPC therefore needed to be completed within the next six months. In particular, this would ensure adequate accommodation was available before the next monsoon season.

17. I was also of the view that, in the absence of exemption from the provisions of Part 13 of the EPBC Act, the permit requirements under that Part could have had the effect that the first stage of the establishment and ongoing operation of the proposed Christmas IRPC would not occur within the next six months.

18. In the light of these considerations and the findings referred to above in this Statement of Reasons, I therefore concluded that it was in the national interest that all of the provisions of Part 13 of the EPBC Act not apply in relation to the actions described above in this Statement.

19. In making my decision, I also took into account the undertaking made by Ministers Ruddock and Tuckey in their application for the exemption referred to above in this Statement that best practice environmental management measures would be implemented in relation to the proposed Christmas Island IRPC. I took into account that these measures will be undertaken in consultation with Environment Australia. Further, I considered that the management plan for the Christmas Island National Park will provide adequate protection for the Park and the *Environment Protection and Biodiversity Conservation Regulations 2000* will provide adequate protection for biodiversity outside of the Park.

David Kemp

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MINISTER FOR THE ENVIRONMENT AND HERITAGE

16 / 4 /2002