Australian Government

Department of Sustainability, Environment,
Water, Population and Communities

The Dales
Ramsar Site

Ecological Character Description

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Department of Sustainability, Environment, Water, Population and Communities

- Parks Australia, Planning, Tourism and National Landscapes Section
- Parks Australia, Christmas Island National Park
- Water Reform Division, Wetlands Section

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Glossary

Definitions of words associated with ecological character descriptions (DEWHA 2008 and references cited within).

Benefits	Benefits/services are defined in accordance with the Millennium Ecosystem Assessment definition of ecosystem services as "the benefits that people receive from ecosystems (Ramsar Convention 2005, Resolution IX.1 Annex A). See also “Ecosystem Services”.
Biogeographic region	A scientifically rigorous determination of regions as established using biological and physical parameters such as climate, soil type, vegetation cover, etc (Ramsar Convention 2005).
Biological diversity	The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species (genetic diversity), between species (species diversity), of ecosystems (ecosystem diversity), and of ecological processes. This definition is largely based on the one contained in Article 2 of the Convention on Biological Diversity (Ramsar Convention 2005).
Change in ecological character	Defined as the human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service (Ramsar Convention 2005, Resolution IX.1 Annex A).
Community	An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another (ANZECC and ARMCANZ 2000).
Community Composition	All the types of taxa present in a community (ANZECC and ARMCANZ 2000).
Conceptual model	Wetland conceptual models express ideas about components and processes deemed important for wetland ecosystems (Gross 2003).
Contracting Parties	Countries that are Member States to the Ramsar Convention on Wetlands; 159 as at March 2010. Membership in the Convention is open to all states that are members of the United Nations, one of the UN specialized agencies, or the International Atomic Energy Agency, or is a Party to the Statute of the International Court of Justice.
Critical stage	Meaning stage of the life cycle of wetland-dependent species. Critical stages being those activities (breeding, migration stopovers, moulting etc.) which if interrupted or prevented from occurring may threaten long-term conservation of the species. (Ramsar Convention 2005).
Ecological character	The combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time.
Ecosystems	The complex of living communities (including human communities) and non-living environment (Ecosystem Components) interacting (through Ecological Processes) as a functional unit which provides inter alia a variety of benefits to people (Ecosystem Services). (Millennium Ecosystem Assessment 2005).
Ecosystem components	Include the physical, chemical and biological parts of a wetland (from large scale to very small scale, e.g. habitat, species and genes) (Millennium Ecosystem Assessment 2005).
Ecosystem processes	The changes or reactions which occur naturally within wetland systems. They may be physical, chemical or biological. (Ramsar Convention 1996, Resolution VI.1 Annex A). They include all those processes that occur between organisms and within and between populations and communities, including interactions with the non-living environment, that result in existing ecosystems and bring about changes in ecosystems over time (Australian Heritage Commission 2002).
Ecosystem services	The benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (e.g. food and water), regulating (e.g. flood control), cultural (e.g. spiritual, recreational), and supporting (e.g nutrient cycling, ecological value). (Millennium Ecosystem Assessment 2005). See also “Benefits”.
Essential elements	A component or process that has an essential influence on the critical CPS of the wetland. Should the essential element cease, reduce, or is lost, it

	would result in a detrimental impact on one or more critical CPS. Critical CPS may depend in part or fully on essential elements, but an essential element is not in itself critical for defining the ecological character of the site.
Fluvial geomorphology	The study of water-shaped landforms (Gordon et al. 1999).
Geomorphology	The study of the evolution and configuration of landforms.
Indigenous species	A species that originates and occurs naturally in a particular country (Ramsar Convention 2005).
Limits of Acceptable Change	The variation that is considered acceptable in a particular component or process of the ecological character of the wetland without indicating change in ecological character which may lead to a reduction or loss of the criteria for which the site was Ramsar listed' (modified from definition adopted by Phillips 2006).
List of Wetlands of International Importance ("the Ramsar List")	The list of wetlands which have been designated by the Ramsar Contracting Party in which they reside as internationally important, according to one or more of the criteria that have been adopted by the Conference of the Parties.
Monodominant forest	One tree species dominates the canopy.
Ramsar	City in Iran, on the shores of the Caspian Sea, where the Convention on Wetlands was signed on 2 February 1971; thus the Convention's short title, "Ramsar Convention on Wetlands".
Ramsar Criteria	Criteria for Identifying Wetlands of International Importance, used by Contracting Parties and advisory bodies to identify wetlands as qualifying for the Ramsar List on the basis of representativeness or uniqueness or of biodiversity values.
Ramsar Convention	Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar (Iran), 2 February 1971. UN Treaty Series No. 14583. As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987. The abbreviated names "Convention on Wetlands (Ramsar, Iran, 1971)" or "Ramsar Convention" are more commonly used.
Ramsar Information Sheet (RIS)	The form upon which Contracting Parties record relevant data on proposed Wetlands of International Importance for inclusion in the Ramsar Database; covers identifying details like geographical coordinates and surface area, criteria for inclusion in the Ramsar List and wetland types present, hydrological, ecological, and socioeconomic issues among others, ownership and jurisdictions, and conservation measures taken and needed.
Ramsar List	The List of Wetlands of International Importance.
Ramsar Sites	Wetlands designated by the Contracting Parties for inclusion in the List of Wetlands of International Importance because they meet one or more of the Ramsar Criteria.
Waterbirds	"birds ecologically dependent on wetlands" (Article 1.2). This definition thus includes any wetland bird species. However, at the broad level of taxonomic order, it includes especially: • penguins: *Sphenisciformes*. • divers: *Gaviiformes*; • grebes: *Podicipediformes*; • wetland related pelicans, cormorants, darters and allies: *Pelecaniformes*; • herons, bitterns, storks, ibises and spoonbills: *Ciconiiformes*; • flamingos: *Phoenicopteriformes*: • screamers, swans, geese and ducks (wildfowl): *Anseriformes*; • wetland related raptors: *Accipitriformes* and *Falconiformes*; • wetland related cranes, rails and allies: *Gruiformes*; • Hoatzin: *Opisthocomiformes*; • wetland related jacanas, waders (or shorebirds), gulls, skimmers and terns: *Charadriiformes;* • coucals*: Cuculiformes;* and • wetland related owls: *Strigiformes*.
Wetlands	Are areas of marsh, fen, peatland or water, whether natural or artificial,

	permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar Convention 1987).
Wetland types	As defined by the Ramsar Convention's wetland classification system [http://www.ramsar.org/ris/key_ris.htm#type].

List of Abbreviations

CAMBA	China Australia Migratory Bird Agreement.
CEPA	Communication, Education, Participation and Awareness.
CMS	Bonn Convention on Migratory Species.
CPS	Components, processes and services.
DEWHA	Department of the Environment, Water, Heritage and the Arts (Commonwealth).
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities (formerly DEWHA)
DIWA	Directory of Important Wetlands in Australia.
ECD	Ecological Character Description.
EPBC Act	Environment Protection and Biodiversity Conservation Act, 1999 (Commonwealth).
IUCN	International Union for Conservation of Nature.
JAMBA	Japan Australia Migratory Bird Agreement.
LAC	Limits of Acceptable Change.
RIS	Ramsar Information Sheet.
ROKAMBA	Republic of Korea Australia Migratory Bird Agreement.

Executive Summary

The Dales, Christmas Island Ramsar site (hereafter referred to as The Dales) is located on Christmas Island in the Indian Ocean approximately 2800 kilometres west of Darwin, 2600 kilometres north-west of Perth, Australia, 900 kilometres northeast of the Cocos Islands and approximately 360 kilometres south of the western head of Java. The Dales Ramsar site is located entirely within the Christmas Island National Park, in the west of the island, with the western boundary of the site extending to 50 metres seaward from the low water mark (Figure E1). The site was listed as a Ramsar site in 2002. The Dales Ramsar site comprises a system of seven watercourses collectively known as "The Dales". Three of the Dales support permanent springs, No. 1 Dale, Hugh's Dale (No. 2 Dale) and Anderson Dale (No, 5 Dale). Darling Dale (No. 3 Dale), No. 4 Dale, Sydney's Dale (No. 6 Dale) and No. 7 Dale all support intermittent streams during the wet season.

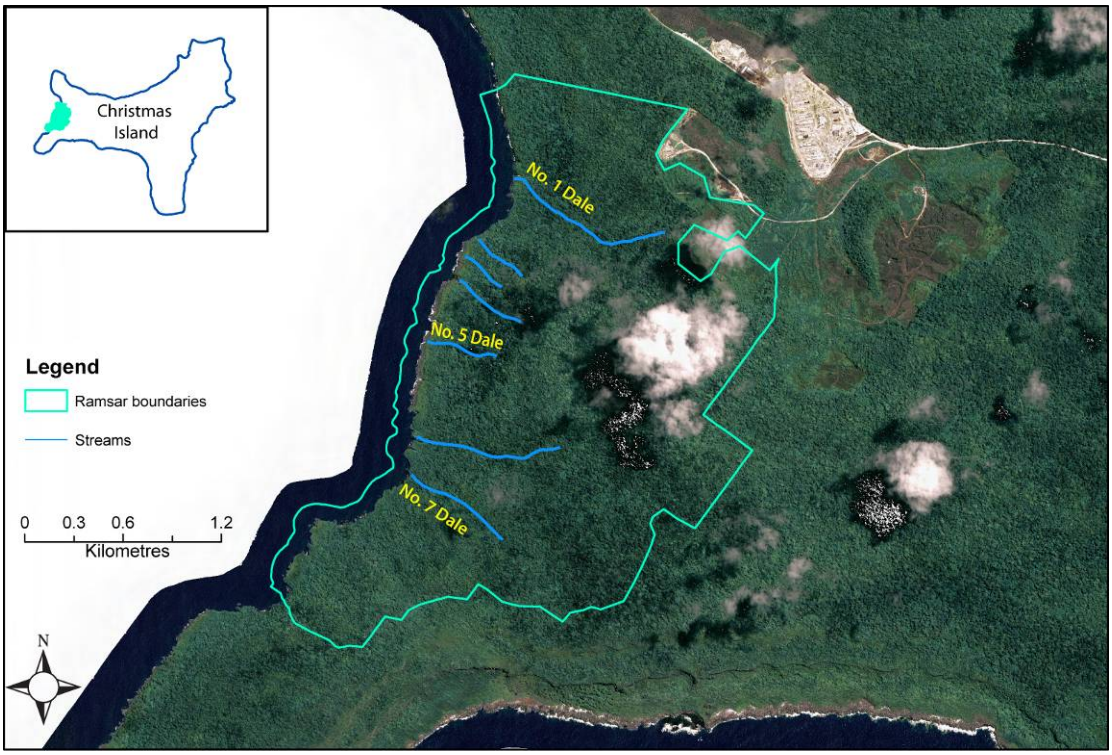


Figure E1: Location of The Dales Ramsar site (data supplied by DSEWPaC).

The Dales Ramsar site meets the following Ramsar criteria:

Criterion 1: Christmas Island represents the only land mass within the bioregion and the wetlands associated with The Dales, particularly the karst system are unique in a bioregional context.

Criterion 2: There are two threatened species supported by the wetlands within The Dales Ramsar site that contribute to the site meeting this criterion:

- Abbott's booby (*Papasula abbotti*) listed as endangered under the EPBC Act occurs within the Ramsar site (DEH 2004); and
- Christmas Island frigatebird (*Fregata andrewsi*) listed as vulnerable under the EPBC Act has been recorded in the Ramsar site (Birds Australia unpublished).

Criterion 3: Christmas Island is recognised for its high conservation values and is specifically identified as an area for biodiversity conservation under Part 9 of the EPBC Regulations 2000. All native species on the island, as detailed in Schedule 12 of the Act, are considered protected. Of particular note is the land crab diversity, with Christmas Island supporting the

greatest diversity of land crabs on an oceanic island in the world. All 20 species of land crab found on the island occur within the Ramsar site, with the site particularly important for the blue crab (*Discoplax hirtipes)*. In addition The Dales support a 10 hectare monodominant stand of Tahitian chestnut (*Inocarpus fagifer*), which is unique in the bioregion. The Dales include most of the habitat types present within the bioregion within the boundary of the site.

Criterion 4: The Dales is a significant migratory route for red crabs (*Gecarcoidea natalis*), blue crabs (*Discoplax hirtipes*) and robber crabs (*Birgus latro*). The freshwater streams provide critical habitat for the blue crabs as the larvae emerge from the ocean and return inland. In addition the site provides important habitat for land crab spawning, with all 20 species which occur in the site, migrating to the ocean to spawn with their larval stages being marine. The red crab is the most numerous of the land crabs with current estimates of 40-50 million crabs on the island. Within the Ramsar site all the Dales are important migration pathways, but especially Sydney's Dale and No. 1 Dale.

Criteria 8: The mass spawning and development of the larvae of red crabs corresponds to the arrival and aggregation of juvenile whale sharks off shore of Christmas Island. Meekan et al. (2009) confirmed whale sharks are feeding on the immature stages of red crabs. The offshore waters are believed to provide an important habitat and feeding area for the whale sharks.

A summary of the components and processes which contribute to the sites ecological character is provided in Table E1. This includes those that are considered critical to the ecological character of the site, as well as a number of components and processes that were considered essential elements of the sites character, but not necessarily critical. Critical components and processes and essential elements were selected on the basis of their role in maintaining the ecological character of the site, the ecosystem services they support (Table E2) and the Ramsar criteria for which the site is listed.

Table E1: Summary of components and processes important for maintaining the ecological character of The Dales Ramsar site.

Component / process	Description
Essential components and processes	
Climate.	Warm tropical climatic zone. High rainfall (2000 millimetres per year); warm to hot year round.
Geomorphic setting.	Site is located within the shore terrace on an area of gravel overlying phosphoric soils. Springs are situated at the base of the inland cliffs where spring water flows over a limestone flowstone.
Water quality.	Limited site specific data – information from one survey in 2003 for Hugh's Dale may provide baseline data for time of listing. Water quality is good, with higher concentrations of some trace metals and major ions compared to upstream reference sites, due to the presence of volcanic rocks and significant crab populations.
Terrestrial vegetation.	Limited site specific data; descriptions of the vegetation are limited. General descriptions provided by Mitchell (1985) and Du Puy (1993) for vegetation associations indicate five major associations, with tall rainforest the dominant type.
Coral reef.	The coral reef is limited and dominated by abiotic and hard corals of low diversity.
Fish.	• Community predominantly of Indo-Pacific origin. • Endemism is low, but a number of species are at the western extent of their range at Christmas Island and there is evidence of hybridisation. One endemic freshwater species recorded from the site.
Invertebrates (non crab fauna).	The site supports a low diversity of benthic marine invertebrates, but may also support anchialine fauna although no site specific data has been sourced to confirm this.

Component / process	Description
Critical components and processes	
Geomorphic setting.	The island is a karstic landscape with key geomorphic features including the terrace formations, sea cliffs, and caves and other karst features such as tufa at Hugh's Dale.
Hydrology.	Karstic drainage system of groundwater and surface ephemeral stream flow post heavy rainfall events during the wet season. Spring outflow of groundwater at three of the Dales is permanent.
Land crabs.	All 20 species of land crab occur within the boundary of the site. The Dales provide a major migration pathway for crabs to and from the ocean during spawning. The site is important for blue crabs in particular.
Waterbirds.	Eleven waterbirds, including nine endemic species, one nationally listed vulnerable and one endangered species are found at the site. The site supports breeding seabirds including Abbott's booby and red-footed booby.

Table E2: Summary of the benefits and services of The Dales Ramsar site (critical services are shaded).

Category	Description
Cultural services	
Recreation and Tourism.	The Dales is a popular recreational area for both tourists and locals. Two timber board walks have been installed at No. 1 Dale and Hugh's Dale. The Dales is the most popular sight seeing destination on the island with the waterfall at Hugh's Dale being the greatest attraction.
Science and education.	Parks Australia undertakes and supports a range of research programs across the National Park, many of which are directly relevant to The Dales. For example research investigations include impacts of the yellow crazy ant, land crab ecology and Abbott's booby.
Supporting services	
Food webs.	Crab spawning provides a rich food supply to marine biota including whale sharks. In addition the land crabs play a significant role in the energy dynamics of the forest affecting seedling recruitment and ultimately the structure of the forest. The invasion of the yellow crazy ant has significantly affected trophic relationships on Christmas Island.
Provides physical habitat (for breeding waterbirds).	Terrestrial vegetation provides roosting and breeding sites for several species of waterbirds.
Biodiversity.	Supports a variety of wetland species, communities and habitats including marine, terrestrial and freshwater dependent species.
Special ecological, physical or geomorphic features.	Provides critical habitat for the blue crabs and freshwater crabs, provides examples of karst features such as tufa deposits at the Hugh's Dale waterfall, and possibly anchialine cave communities.
Distinct or unique wetland species.	Red crabs are considered keystone species on the island.
Threatened wetland species, habitats and ecosystems.	The Dales Ramsar site supports nesting sites for the endangered Abbott's booby. The Christmas Island frigatebird has also been recorded from the site.
Priority wetland species.	Christmas Island supports a number of vagrant species listed under various international agreements.

Category	Description
Supports near-natural wetland types.	Springs and karst systems are representative of the bioregion and considered in near natural condition at the time of listing.
Ecological connectivity.	The streams of The Dales provide critical migration pathways for downward migration of red, blue and robber crabs and return pathways for juvenile blue crabs in particular.

The relationship between essential and critical components, processes and services and how they relate to the listing criteria are shown conceptually in Figure E2.

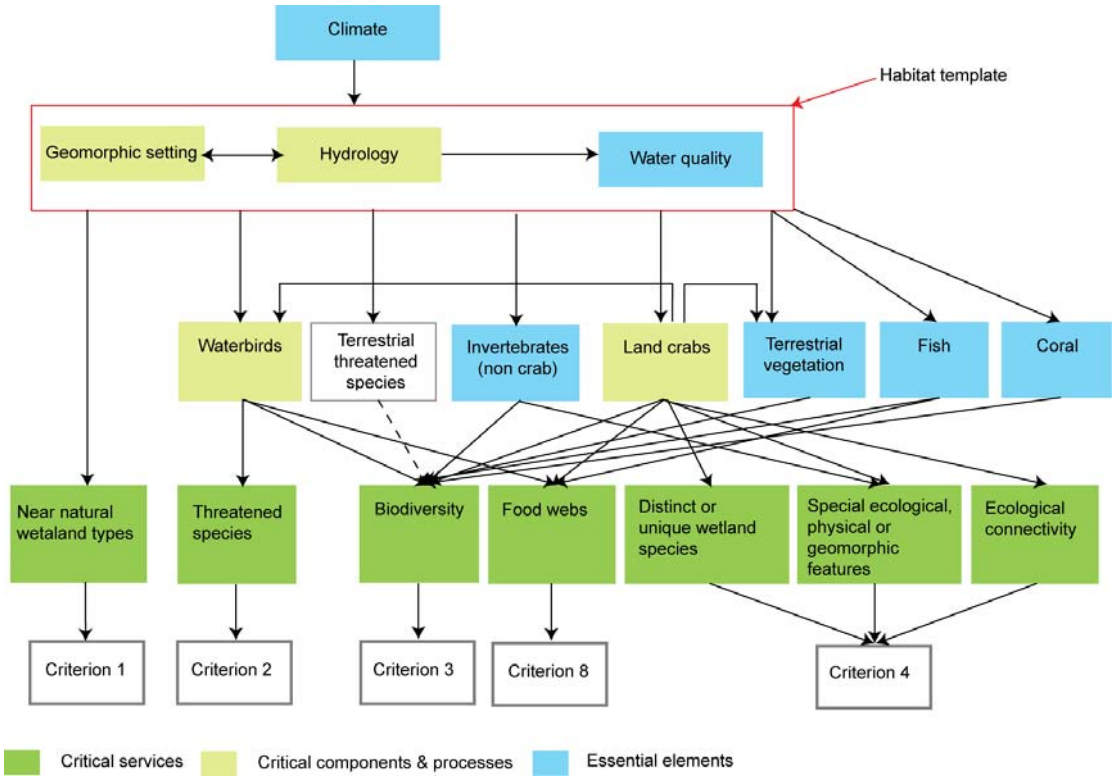


Figure E2: Relationships between components and processes; benefits and services and the listing criteria which the site meets.

"Limits of acceptable change" (LAC) are used to describe the range of variation which key aspects of the ecology of the site can vary without representing a change in the ecological character. If a LAC is breeched this represents the point at which a potential change in the ecological character of a site has occurred. Limits of acceptable change for The Dales have been proposed for critical components, processes and benefits and services based on existing data and guidelines and are summarised in Table E3.

Table E3: Proposed LAC for The Dales Ramsar site.

Component / Process/Service	Limit of Acceptable Change
Component • Geomorphic setting. **Services** • Near natural wetland type; • Special ecological, physical or geomorphic features; • Ecological connectivity.	• No loss of wetland types and maintenance of seven Dales. • Wetland extent - Data deficient, baseline must be determined before quantitative limits can be refined.

Component / Process/Service	Limit of Acceptable Change
Component • Hydrology. **Services** • Near natural wetland type; • Special ecological physical or geomorphic features; • Biodiversity; • Ecological connectivity.	• No loss of surface water connection to the sea at No. 1 Dale, Hugh's Dale and Anderson Dale.
Component • Land crabs. **Services** • Food webs; • Distinct wetland species; • Biodiversity.	• Blue crabs present at the site during the dry season. Red crabs and robber crabs present at the site for at least part of their lifecycle. • Data deficient, baseline must be determined before quantitative limits can be set.
Component • Waterbirds. **Services** • Threatened species; • Biodiversity.	• Minimum of three species of seabirds breeding within the site, including Abbott's booby. • Data deficient, baseline must be determined before quantitative limits can be set with regard to numbers of breeding pairs within the site.

There are a number of potential and actual threats that may impact on the ecological character of The Dales Ramsar site. A summary of each of these threats is provided in Table E4.

Table E4: Summary of threats to the ecological character of the Ramsar site.

Actual or likely threat	Potential impact(s) to wetland components, processes and/or service	Likelihood	Timing
Groundwater extraction.	Decrease in flow and loss of permanent surface water. This could result in a change in wetland type and a loss of blue crabs.	Medium	Current
Invasive species: yellow crazy ants.	Predation on crabs, resulting in alteration to the forest ecosystems and consequent increase in other invasive species.	Certain	Current.
Recreation.	Increased visitor impacts leading to physical disturbance of the site	Certain	Current
Climate change – altered rainfall patterns.	Reduced/altered recharge of aquifer and loss of freshwater. Corresponding loss of habitat for blue crabs.	Medium	Medium to long term
Climate change – increased intensity of storms.	Direct physical damage to waterbird breeding habitat.	Medium	Medium to long term
Climate change – increased temperature.	Increased incidence of coral bleaching and disease.	Certain (for coral bleaching)	Current (disease outbreak summer 2007-2008; coral bleaching 1997-1998 and 2010).

There is no evidence that there has been any change to any of the critical components, processes or services since the site was listed. The threats of groundwater extraction and yellow crazy ants, whilst deemed the most serious and ongoing threats, were present at the time of listing and there is no evidence that there have been significant changes since listing. The Dales Ramsar site still retains its essential ecological character as per when it was listed in 2002.

Knowledge gaps have been identified (Table E5) and monitoring to address knowledge gaps and assess against LAC recommended (Table E6).

Table E5: Knowledge gaps relevant to the ecological character of The Dales Ramsar site.

Component / process	Knowledge Gap	Recommended Action
Geomorphic setting.	Number and extent of wetland types, particularly sea caves, within the boundary of the site.	Mapping of wetland types including karst features within the site.
Hydrology.	• Flow rates at the three springs including seasonal variability. • Extent and duration of inundation at the site. Relative importance of Dales which have intermittent surface water.	• Monitoring of flow rates at the permanent springs on a monthly basis. • Measures of the extent and depth of inundation in wet and dry season.
	• Connectivity between groundwater source for The Dales and the groundwater resources used for human consumption. • Relative relationship and contribution of basal versus perched aquifers to the springs at The Dales.	Ongoing groundwater monitoring and investigations. An assessment of the sustainable extraction volumes from groundwater.
Water quality.	Effect of altered water quality in groundwater, in particular organic and nutrient loads, on receiving waters in The Dales. This would have an effect on tufa deposits at Hugh's Dale.	Water quality monitoring of groundwater.
Land crabs.	• Quantitative information on crab densities and the importance of the site for different crab species (including breeding migrations). • Recovery of crabs in response to baiting programs against yellow crazy ant.	Survey of crab burrow densities within the Ramsar site. Mapping of recovering infested areas post baiting for yellow crazy ants.
Waterbirds.	• Number of breeding pairs of Abbott's booby within the site. • Number of breeding pairs of other species including the brown booby which breed or on sea cliffs and shore terrace within the site.	Surveys of waterbirds within the site, including the sea cliffs. Mapping of nesting sites.
Marine environment.	There is very limited site specific information on marine features in the site: fish species and abundance, benthic invertebrates.	Expanded surveys of marine habitat and fauna, within the Ramsar site boundary.
	Baseline description of anchialine communities present within the site.	Survey of sea caves within the site and collection of invertebrate samples.

Table E6: Recommended monitoring for The Dales Ramsar site.

Component/ Process	Purpose	Indicator	Locations	Frequency	Priority
Hydrology.	Set baseline.	Flow.	Dales 1, 2, 5.	Monthly.	High.
	Set baseline.	Extent and duration of inundation.	All Dales.	Seasonally.	High.
Land crabs.	Establishment of variability detection of change, refinement of LAC.	Crab burrow density – blue crab.	Immediate vicinity of Dales 1, 2 and 5.	Every two years.	Medium.
	Establishment of variability detection of change, assessment of threats (yellow crazy ants) refinement of LAC.	Crab burrow density – red crabs.	Entire Ramsar site.	Every two years.	Medium.
Yellow crazy ants.	Assessment of threat.	Super colony presence and location.	Entire Ramsar site.	Every two years.	High.
Marine environment.	Establish baseline of anchialine communities.	Survey of sea caves and associated communities.	Marine portion of the site.	Once off	Medium.
	Establishment of baseline, informing the development of LAC, detection of change.	Benthic habitat, fish and invertebrate diversity and abundance. Monitor threats (coral beaching + coral disease).	Marine portion of the site.	Every two – five years.	Medium.
Waterbirds.	Establishment of baseline.	Survey of all habitats types to establish patterns of usage.	Entire Ramsar site.	Every two – five years.	Low.
	Establishment of baseline informing the development of LAC, detection of change.	Number of breeding pairs for key species.	Nesting sites.	Every two – five years.	High.

1. Introduction

1.1 Site details

The Dales, Christmas Island Ramsar site (hereafter referred to as The Dales) comprises a system of seven watercourses collectively known as “The Dales” in the Australian territory of Christmas Island, approximately 2600 kilometres northwest of Perth in the Indian Ocean. It was originally nominated as a “Wetland of International Importance” under the Ramsar Convention in 2002. The original RIS description listed the area of the site as being 57 hectares; however this appears to have been a calculation error. The area of the boundary in the original nomination covers an area of approximately 580 hectares. Specific information on the exact area and boundary of the site are available in the most recent RIS. Further site details for this Ramsar wetland are provided in Table 1.

Table 1: Site details for The Dales Ramsar site taken from the Ramsar Information Sheet (1999).

Site Name	The Dales Christmas Island.
Location in coordinates	Latitude: 10° 28' S to 10° 29' Longitude: 105° 32' E to 105° 34
General location of the site	The Dales Ramsar site is located in the Australian Territory of Christmas Island in the Indian Ocean. The site is 2800 km west of Darwin (Northern Territory) and 2600 km northwest of Perth (Western Australia); within the Christmas Island National Park. The site also lies within the marine bioregion, Christmas Island Province (Commonwealth of Australia 2006).
Area	580 hectares.
Date of Ramsar site designation	Designated on 21 October 2002.
Ramsar/DIWA Criteria met by wetland	Ramsar criteria 1, 2, 3, 4, 8.
Management authority for the site	The Dales is situated in the Australian External Territory of Christmas Island which is under the jurisdiction of the Commonwealth of Australia and is administered under the Christmas Island Act 1958. The site is located wholly within the Christmas Island National Park which is managed by Parks Australia.
Date the ECD applies	2002.
Status of Description	This represents the first ECD for the site.
Date of Compilation	May 2010.
Name(s) of compiler(s)	Rhonda Butcher and Jennifer Hale on behalf of the Australian Government Department of Sustainability, Environment, Water, Population and Communities.

References to the Ramsar Information Sheet (RIS)	"The Dales" Christmas Island Ramsar Site RIS compiled by Parks Australia in 2002. Updated by Rhonda Butcher on behalf of the Australian Government Department of Sustainability, Environment, Water, Population and Communities 2010.
References to Management Plan(s)	Christmas Island National Park Management Plan, Director of National Parks, 2002.

1.2 Statement of purpose

The act of designating a wetland as a Ramsar site carries with it certain obligations, including managing the site to retain its 'ecological character' and to have procedures in place to detect if any threatening processes are likely to, or have altered the 'ecological character'. Thus, understanding and describing the 'ecological character' of a Ramsar site is a fundamental management tool for signatories and local site managers which should form the baseline or benchmark for management planning and action, including site monitoring to detect negative impacts.

The Ramsar Convention has defined "ecological character" and "change in ecological character" as (Ramsar 2005):

"Ecological character is the combination of the ecosystem components, processes and benefits/services that characterise the wetlands at a given point in time"

And

"…change in ecological character is the human induced adverse alteration of any ecosystem component, process and or ecosystem benefit/service."

In order to detect change it is necessary to establish a benchmark for management and planning purposes. Ecological character descriptions (ECD) form the foundation on which a site management plan and associated monitoring and evaluation activities are based. The legal framework for ensuring the ecological character of all Australian Ramsar sites is maintained is the Environment Protection and Biodiversity Conservation Act, 1999 (the EPBC Act) (Figure 1). A Ramsar Information Sheet is prepared at the time of designation. However whilst there is some link between the data used for listing a site (based on the various criteria) the information in an RIS does not provide sufficient detail on the interactions between ecological components, processes and functions to constitute a comprehensive description of ecological character. To assist in the management of Ramsar sites in the face of insufficient detail, the Australian and state/territory governments have developed a *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands. Module 2 of Australian National Guidelines for Ramsar Wetlands – Implementing the Ramsar Convention in Australia* (DEWHA 2008).

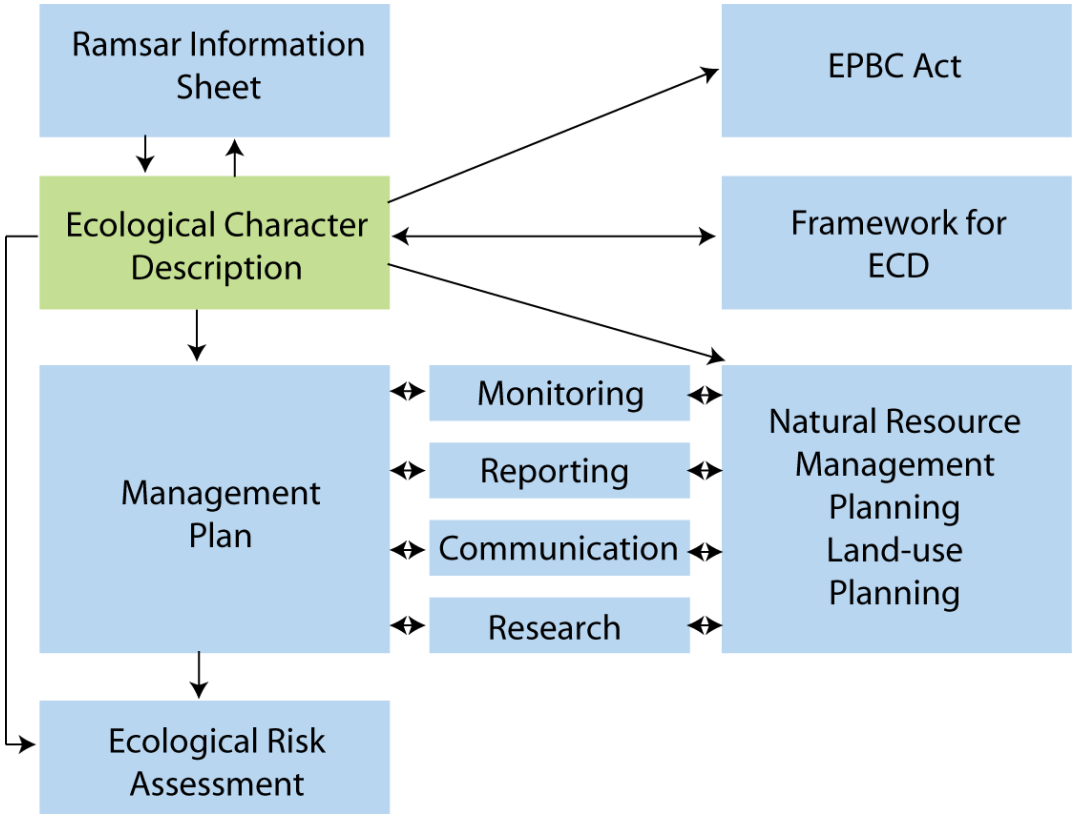


Figure 1: The ecological character description in the context of other requirements for the management of Ramsar sites (adapted from DEWHA 2008).

The framework emphasises the importance of describing and quantifying the ecosystem components, processes and benefits/services of the wetland and the relationship between them. It is also important that information is provided on the benchmarks or ecologically significant limits of acceptable change that would indicate when the ecological character has or is likely to change.

McGrath (2006) detailed the general aims of an ECD as follows:

1. To assist in implementing Australia's obligations under the Ramsar Convention, as stated in Schedule 6 (Managing wetlands of international importance) of the *Environment Protection and Biodiversity Conservation Regulations* 2000 (Commonwealth):
    a) To describe and maintain the ecological character of declared Ramsar wetlands in Australia; and
    b) To formulate and implement planning that promotes:
        i) Conservation of the wetland; and
        ii) Wise and sustainable use of the wetland for the benefit of humanity in a way that is compatible with maintenance of the natural properties of the ecosystem.
2. To assist in fulfilling Australia's obligation under the Ramsar Convention to arrange to be informed at the earliest possible time if the ecological character of any wetland in its territory and included in the Ramsar List has changed, is changing or is likely to change as the result of technological developments, pollution or other human interference.
3. To supplement the description of the ecological character contained in the Ramsar Information Sheet submitted under the Ramsar Convention for each listed wetland and, collectively, form an official record of the ecological character of the site.
4. To assist the administration of the EPBC Act, particularly:

a) To determine whether an action has, will have or is likely to have a significant impact on a declared Ramsar wetland in contravention of sections 16 and 17B of the EPBC Act; or

b) To assess the impacts that actions referred to the Minister under Part 7 of the EPBC Act have had, will have or are likely to have on a declared Ramsar wetland.

5. To assist any person considering taking an action that may impact on a declared Ramsar wetland whether to refer the action to the Minister under Part 7 of the EPBC Act for assessment and approval.

6. To inform members of the public who are interested generally in declared Ramsar wetlands to understand and value the wetlands.

1.3 Relevant treaties, legislation and regulations

This section provides a brief listing of the legislation and policy that is relevant to the description of the ecological character of the Ramsar site.

International

Ramsar Convention

The Convention on Wetlands of International Importance, otherwise known as the Ramsar Convention, was signed in Ramsar Iran in 1971 and came into force in 1975. It provides the framework for local, regional and national actions, and international cooperation, for the conservation and wise use of wetlands. Wetlands of International Importance are selected on the basis of their international significance in terms of ecology, botany, zoology, limnology and or hydrology

Migratory bird bilateral agreements and conventions

Australia is party to a number of bilateral agreements, initiatives and conventions for the conservation of migratory birds, which are relevant to The Dales Ramsar site. The bilateral agreements are:

- *JAMBA (Japan Australia Migratory Bird Agreement)* – The agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment, 1974;
- *CAMBA (China Australia Migratory Bird Agreement)* - 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 1986;
- *ROKAMBA (Republic of Korea Australia Migratory Bird Agreement)* - The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds and their Environment, 2006; and
- *The Bonn Convention on Migratory Species (CMS)* - The Bonn Convention adopts a framework in which countries with jurisdiction over any part of the range of a particular species co-operate to prevent migratory species becoming endangered. For Australian purposes, many of the species are migratory birds.

National legislation

Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)

The EPBC Act regulates actions that will have or are likely to have a significant impact on any matter of national environmental significance, which includes the ecological character of a Ramsar wetland (EPBC Act 1999 s16(1)). An action that will have or is likely to have a significant impact on a Ramsar wetland will require an environmental assessment and approval under the EPBC Act. An 'action' includes a project, a development, an undertaking or an activity or series of activities (http://www.environment.gov.au/epbc/index.html).

The EPBC Act establishes a framework for managing Ramsar wetlands, through the Australian Ramsar Management Principles (EPBC Act 1999 s335), which are set out in Schedule 6 of the *Environment Protection and Biodiversity Conservation Act Regulations 2000*. These principles are intended to promote national standards of management, planning, environmental impact assessment, community involvement, and monitoring, for all of Australia's Ramsar wetlands in a way that is consistent with Australia's obligations under the

Ramsar Convention. Some matters protected under the EPBC Act are not protected under local or state/territory legislation, and as such, many migratory birds are not specifically protected under some State legislation. Species listed under international treaties (JAMBA, CAMBA and CMS) have been included in the List of Migratory species under the Act. Threatened species and communities listed under the EPBC Act may also occur, or have habitat in the Ramsar site; some species listed under State legislation as threatened are not listed under the EPBC Act as threatened, usually because they are not threatened at the national (often equivalent to whole-of-population) level. The Regulations also cover matters relevant to the preparation of management plans, environmental assessment of actions that may affect the site, and the community consultation process.

The Christmas Island National Park is managed under Part 15 of the EPBC Act and was declared for:

a. the preservation of the area in its natural condition; and
b. the encouragement and regulation of the appropriate use, appreciation and enjoyment of the area by the public.

Administration and management of Commonwealth reserves are a function of the Director of National Parks under the EPBC Act (s.514B).

1.4 Preparing the ECD

The method used to develop the ecological character description for The Dales Ramsar site is based on the twelve-step approach provided in the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEWHA 2008) illustrated in Figure 2. A more detailed description of each of the steps and outputs required is provided in the source document.

This ECD was developed primarily through a desktop assessment and is based on existing data and information. A stakeholder advisory group was formed to provide input and comment on the ECD. Details of members of this group and more details of the method are provided in Appendix A.

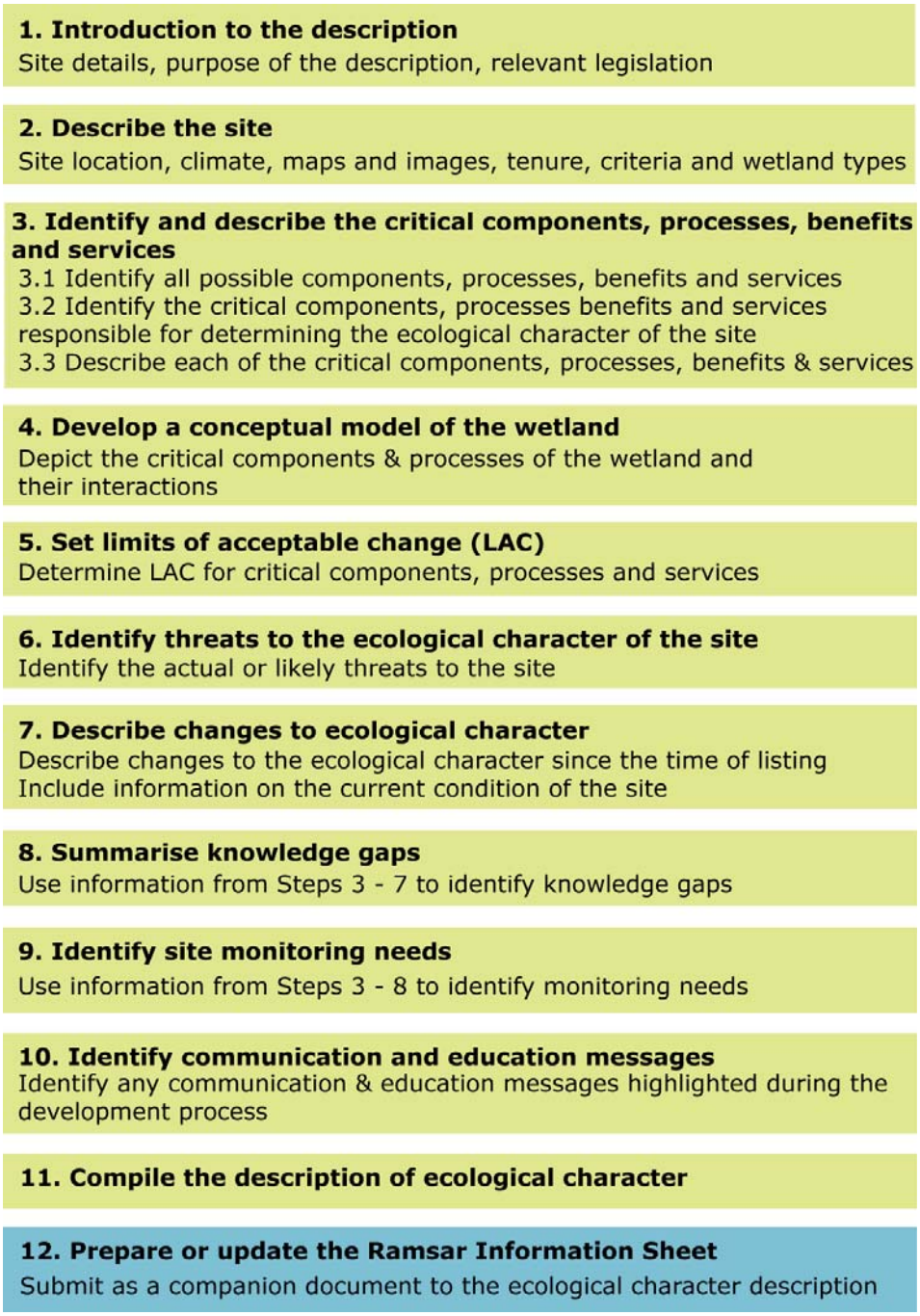


Figure 2: Twelve step process for developing an ECD (adapted from DEWHA 2008).

2. General Description of The Dales Ramsar Site

2.1 Location

The Dales Ramsar site is located on Christmas Island in the Indian Ocean approximately 2800 kilometres west of Darwin, 2600 kilometres north-west of Perth, Australia, 900 kilometres northeast of the Cocos Islands and approximately 360 kilometres south of the western head of Java. The nearest point of the Australian mainland is Northwest Cape which lies approximately 1565 kilometres to the south-east. Christmas Island is 135 000 hectares with approximately 8500 hectares proclaimed National Park (Figure 3).

The Dales Ramsar site is located entirely within the Christmas Island National Park in the west of the island with the western boundary of the site extending to 50 metres seaward from the low water mark (Figure 3 and Figure 4) (RIS 2002, Attorney General's Department 2009). The population of the Christmas Island was 1351 in 2006 (Attorney General's Department 2009) and the Shire of Christmas Island is the local government Authority. The main area of human settlement is Flying Fish Cove, which is located on the north-eastern coast of the island. Just north of The Dales is the main Christmas Island Detention Facility, approximately 17 kilometres from Flying Fish Cove. The Dales Ramsar site corresponds with The Dales management unit of the Christmas Island National Park and is roughly bounded Winifred Beach Track on the east and south, along the coast from Winifred Beach to Martin Point and then across to Winifred Beach Track – Dales Road intersection on the northern boundary.

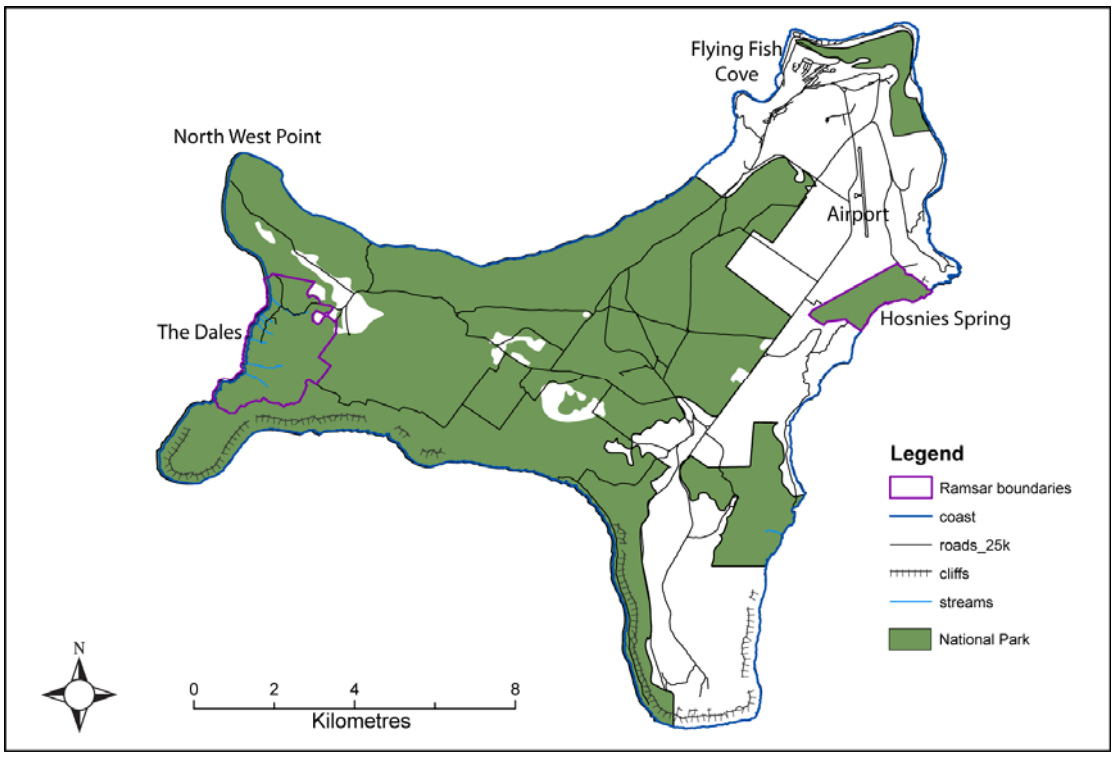


Figure 3: Land tenure on Christmas Island.

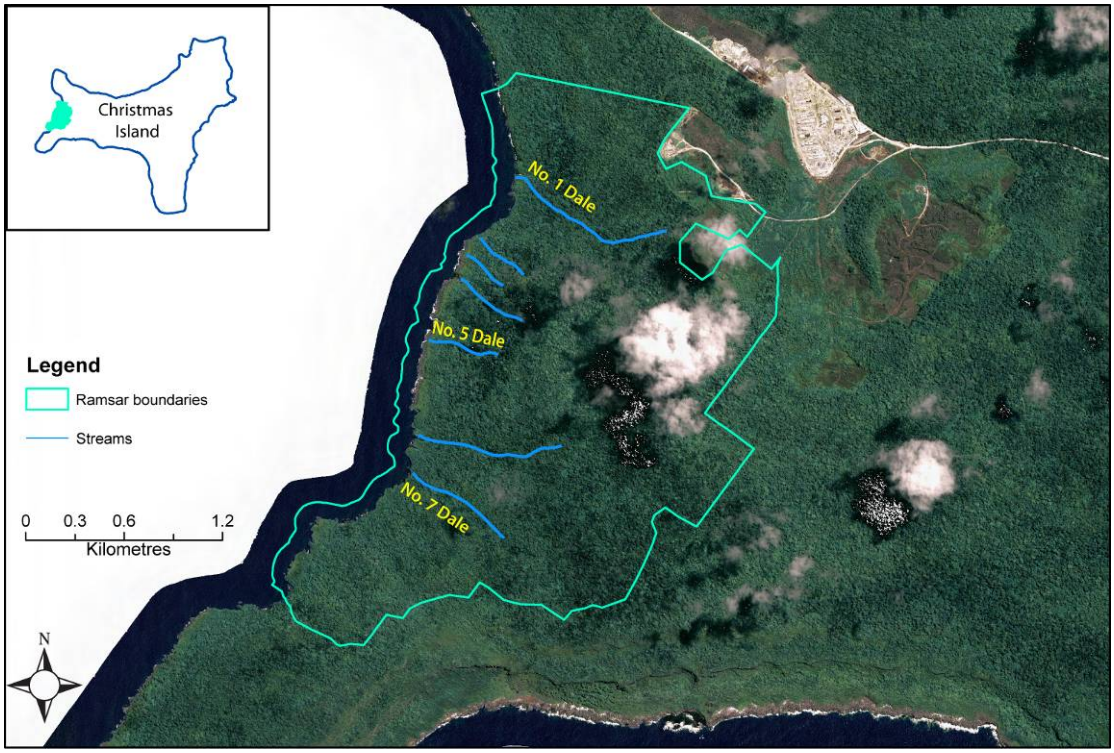


Figure 4: Location of The Dales Ramsar site (data supplied by DSEWPAC and Parks Australia).

2.2 Overview of the site

The Dales Ramsar site includes a series of seven Dales, three of which support permanent springs and four support intermittent streams. The Dales are named as follows:

- No. 1 Dale
- Hugh's Dale (No. 2 Dale)
- Darling Dale (No. 3 Dale)
- No. 4 Dale
- Anderson Dale (No.5 Dale)
- Sydney's Dale (No.6 Dale)
- No. 7 Dale

The Dales are surrounded predominantly by semi-deciduous forest. On the seaward side at the edge of the shore terrace there 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, sloping reef. Mixed amongst the terrestrial and marine environments are a range of karst features, highly representative of the environment of Christmas Island. The combination of this variety of habitats and the presence of permanent surface water provide the physical habitat template which supports a wide diversity of endemic and threatened species. The site plays host to the annual mass migration and spawning of red crabs (*Gecarcoiodea natalis*) as well as providing critical habitat for the blue crab (*Discoplax hirtipes*). In total 20 species of land crab are found within the site, all migrating to the ocean to spawn.

The Dales Ramsar site supports a diverse community of tree species and epiphytes. At Hugh's Dale, both above and below the waterfall, and in parts of Anderson Dale and Sydney's Dale are monodominant stands of Tahitian chestnut (*Inocarpus fagifer)* and the rare epiphytic ribbon fern (*Ophioglossum pendulum)* (RIS 2002). The endemic arenga palm (*Arenga listeri)* and endemic Ridley's orchid (*Brachypeza archytas*) are common in The Dales. *Terminalia catappa* grows to an unusual size on Christmas Island and several large specimens occur in The Dales (RIS 2002).

Christmas Island is renowned for its birdlife, with a large number of seabirds and migratory species utilising the habitats of the island for roosting and breeding, many of which occur in The Dales. Of particular note are the large breeding colonies of seabirds, including the last extant colony for Abbott's booby (*Papasula abotti*) which is listed as endangered under the EBPC Act. Another threatened wetland dependent listed species also occurs within the site, the Christmas Island frigatebird (*Fregata andrewsi*), which is listed as vulnerable. Data from the Bird Atlas (Birds Australia unpublished) puts the number of species on the island at 42, with 20 of these species occurring within The Dales Ramsar site. Other sources put the number of bird species on the island as much higher as a large number of vagrant species (104 vagrants - Parks Australia 2008, 76 vagrants - Director of National Parks 2002) have been sighted on the island.

A number of terrestrial EPBC Act listed species occur within The Dales including the Christmas Island hawk-owl (*Ninox natalis*) (vulnerable), Christmas Island thrush (*Turdus poliocephalus*) (endangered), Christmas Island brown goshawk (*Accipiter fasciatus natalis*) (endangered), Christmas Island shrew (*Crocidura attenuate trichura*) (endangered), Christmas Island gecko (*Lepidodactylus listeri*) (vulnerable) and Christmas Island blind snake (*Ramphotyphlops exocoeti*) (vulnerable) (RIS 2002). Whilst these species are not wetland dependent and therefore do not contribute to the listing of the site as a Wetland of International Importance, they do contribute to the sties general biodiversity values. The endemic freshwater fish, the brown gudgeon (*Eleotris fusca*) has also been recently sighted within The Dales.

The endemic Christmas Island pipistrelle (*Pipistrellus murrayi*), a small insectivorous bat, is now considered to be extinct and a large part of its roosting habitat was within The Dales (Lumsden and Schulz 2009).

Christmas Island is also known as an internationally significant cave fauna region and supports both terrestrial and anchialine systems. The cave fauna is a major element of the islands biodiversity, however specific details as to communities within The Dales Ramsar site are lacking.

2.3 Land tenure

The entire Ramsar site is within a declared Commonwealth Reserve under the control of the Director of National Parks. The Dale Ramsar site is adjacent to small areas of cleared land used for various activities including the main Christmas Island Detention Facility (Figure 3 above). Phosphate mining occurs on the island and whilst The Dales are predominantly surrounded by National Park, there is a mining area (Mining Lease 140) adjacent to the site boundary to the east and north-east (RIS 2002).

2.4 Wetland types

Classification of wetlands into discrete types is a difficult exercise and an inexact science. Clear boundaries are difficult to define or delineate and multiple wetland types could be considered to apply to the same wetland. For example at three of the Dales, springs (type Y) express groundwater which flows to the sea, with the flowing sections of these wetlands being classed as perennial streams (type M). Many of the Dales have been described as having multiple wetland types along their lengths (RIS 2002) with a total of nine Ramsar wetland types being found within the site (Table 2:). In the RIS (2002) Ramsar wetland types Tp and Ts were listed as occurring at The Dales, however these marsh and pool areas were not felt to be distinct from the permanent and intermittent streams and as such have been combined under type M and N. Further discussion of the wetland types is provided in section 4.3.1

Table 2: Wetland types present within The Dales Ramsar site (RIS 2002).

Ramsar wetland type	Description on site
C - Coral reefs.	The western boundary of the site extends 50 metres seaward from the low water mark (Gilligan et al. 2008) and includes significant areas of fringing coral reef.
D - Rocky marine shores; includes rocky offshore islands, sea cliffs (applies to areas of rocky outcrops along the western and southern shores).	Rocky marine shore is inter dispersed along the site coastal edge between patches of sandy beach and includes areas of intertidal rock platforms such as at the end of Sydney's Dale and No. 7 Dale.
E - Sand, shingle or pebble shores; includes sand bars, spits and sandy islets; includes dune systems and humid dune slacks.	The main area of this wetland type within the site occurs at Merial Beach immediately north of No. 1 Dale. It is a small area of sandy beach at the mouth of a gorge.
Zk(a) - Karst and other subterranean hydrological systems, marine/coastal.	Karst features which occur in the coastal zone of the site include areas of phytokarst which occur along the Shore Terrace, small blowholes (No. 4 Dale), sea caves and surface karst such as tufa deposits.
M – Permanent rivers/streams/creeks.	There are three springs which provide perennial streams at No. 1 Dale, Hugh's Dale, and Anderson Dale. At Hugh's Dale and Anderson Dale these streams include areas of marsh/pools and swamps with emergent vegetation which are water logged for part of the year.
N – Seasonal/intermittent/irregular rivers/streams/creeks.	Seasonal intermittent stream flows occurs at Darling Dale, No. 4 Dale, Sydney's Dale and No. 7 Dale during the wet season and after heavy rains. Associated cease to flow conditions in the intermittent streams of Darling Dale, No. 4 Dale, Sydney's Dale and No. 7 Dale result in seasonal freshwater pools.
Xf - Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils.	Hugh's Dale supports a monodominant stand of Tahitian chestnut.
Y - Freshwater springs; oases.	Three major springs arise within the site at No. 1 Dale, Hugh's Dale and Anderson Dale.
ZK(b) - Karst and other subterranean hydrological systems, inland.	Inland subterranean karst has not been identified within the site, however Grimes (2001) describes several surface karstic features. These include the three springs mentioned above, tufa deposits, the narrow ravines which the spring water has carved through the limestone, and phytokarst mentioned above).

2.5 Ramsar criteria

2.5.1 Criteria under which the site was designated

At the time that The Dales site was first nominated as a Wetland of International Importance (2002), there were eight criteria for identifying Wetlands of International Importance, of which the site was considered to meet five (Table 3).

Table 3: Criteria for Identifying Wetlands of International Importance as at listing date, 2002. Criteria for which The Dales Ramsar site has been listed are shaded.

Number	Basis	Description
Group A. Sites containing representative, rare or unique wetland types		
Criterion 1.		A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
Group B. Sites of international importance for conserving biological diversity		
Criterion 2.	Species and ecological communities.	A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
Criterion 3.	Species and ecological communities.	A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.
Criterion 4.	Species and ecological communities.	A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.
Criterion 5.	Waterbirds.	A wetland should be considered internationally important if it regularly supports 20 000 or more waterbirds.
Criterion 6.	Waterbirds.	A wetland should be considered internationally important if it regularly supports one percent of the individuals in a population of one species or subspecies of waterbird.
Criterion 7.	Fish.	A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.
Criterion 8.	Fish.	A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.
Criterion 9.	Other taxa.	A wetland should be considered internationally important if it regularly supports one percent of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species.

2.5.2 Assessment based on current information and Ramsar criteria

There have been a few developments since the site was nominated in 2002 that influence the application of the Ramsar criteria to wetland sites this includes:

- Refinements and revisions of the Ramsar criteria: a ninth criterion was added at the ninth Conference of the Contracting Parties to the Ramsar Conference in Uganda in 2005.

- Revision of population estimates for waterbirds (Wetlands International 2006; Bamford et al. 2008), which influences the application of criterion six.

- A decision with respect to the appropriate bioregionalisation for aquatic systems in Australia, which for inland systems are now based on drainage divisions and for marine systems the interim marine classification and regionalisation for Australia (IMCRA). This affects the application of criteria one and three.

- Updating of threatened species listings, which affects criterion two.

However, for the most part the criteria met by The Dales, as applied in 2002 still apply today. An assessment against each of the criteria for The Dales Ramsar site is as follows:

Criterion 1: The application of this criterion must be considered in the context of the Bioregion within which the site is located. As this site includes marine elements, the appropriate bioregionalisation is the IMCRA v4.0 (Commonwealth of Australia 2006). The corresponding bioregion is the Christmas Island Province, which encompasses 277 180 square kilometres of the Indian Ocean surrounding Christmas Island (Heap et al. 2005).

Christmas Island represents the only land mass within the bioregion and the wetlands associated with The Dales, particularly the karst system are unique in a bioregional context. As such The Dales Ramsar site met this criterion at the time of listing and continues to do so.

Criterion 2: In the Australian context, it is recommended that this criterion should only be applied with respect to nationally threatened species/communities, listed under the EPBC Act or the International Union for Conservation of Nature (IUCN) Red List. A number of threatened species listed at the national and / or international level have been recorded within the boundary of The Dales Ramsar site. However, central to the application of this criterion are the words “a wetland” and “supports”. Guidance from Ramsar (Ramsar 2005) in applying the criteria indicates that the wetland must provide habitat for the species concerned. For this reason, vagrant species; such as the observations of passing whales have not been considered to contribute to the meeting of this criterion; nor have purely terrestrial species that are not reliant on aquatic habitats as a primary foraging ground, reproduction or other key part of their lifecycle.

There are two threatened species supported by the wetlands within The Dales Ramsar site that contribute to the site meeting this criterion:

- Abbott’s booby (*Papasula abbotti*) listed as endangered under the EPBC Act occurs within the Ramsar site (DEH 2004); and
- Christmas Island frigatebird (*Fregata andrewsi*) listed as vulnerable under the EPBC Act has been recorded in the Ramsar site (Birds Australia unpublished).

This criterion was met at the time of listing and continues to be met.

Criterion 3: Like criterion one, application of this criterion must be taken in the context of the appropriate bioregion, in this instance the IMCRA (v4) Christmas Island Province. Guidance from the Convention indicates that this criteria should be applied to "hotspots" of biological diversity, centres of endemism, sites that contain the range of biological diversity (including habitat types) occurring in a region; and/or support particular elements of biological diversity that are rare or particularly characteristic of the biogeographic region.

Christmas Island is recognised for its high conservation values and is specifically identified as an area for biodiversity conservation under Part 9 of the EPBC Act Regulations 2000. All native species on the island, as detailed in Schedule 12 of the Act, are considered protected.

Of particular note is the land crab diversity, with Christmas Island supporting the greatest diversity of land crabs on an oceanic island in the world. All of the 20 species of land crab found on the island occur within the site, with the site particularly important for the blue crab

(*Discoplax hirtipes)*. In addition The Dales support a 10 hectare monodominant stand of Tahitian chestnut (*Inocarpus fagifer*), which is unique in the bioregion.

This criterion was met at the time of listing and continues to be met.

Criterion 4: The basic description of this criterion implies a number of common functions/roles that wetlands provide including supporting fauna during migration and supporting breeding. The Dales is a significant migratory route for red crabs (*Gecarcoidea natalis*), blue crabs (*Discoplax hirtipes*) and robber crabs (*Birgus latro*). The freshwater streams provide critical habitat for the blue crabs as the larvae emerge from the ocean and return inland. In addition the site provides important habitat for land crab spawning, with all 20 species which occur in the site, migrating to the ocean to spawn with their larval stages being marine. The red crab is the most numerous of the land crabs with estimates of 40-50 million crabs on the island. Within the Ramsar sites all the Dales are important migration pathways, but especially Sydney's Dale and No. 1 Dale.

A large number of migratory or vagrant waterbird have been recorded from the island, although the usage at The Dales is not documented, it can be assumed that some species utilise the site as a staging point during migration and a landfall for vagrant species outside their accustomed range (RIS 2002).

This criterion was met at the time of listing and continues to be met.

Criteria 5 and 6: These criteria were not included in the original nomination document, and there is no data available against which to assess them. It is possible that the site may meet criterion 6. However, currently these criteria are not considered to be met.

Criteria 7: Guidance from the Ramsar Convention (Ramsar Convention 2009) on the application of this criterion indicates that in order to meet this criterion, a site should have a high degree of endemism or biodisparity in fish communities. This criterion is very difficult to apply. A site can potentially qualify based on the proportion of fish species present that are endemic to the site (must be greater than 10 per cent) or by having a high degree of biodisparity in the fish community.

The fish population of Christmas Island is unusual and has a high degree of hybridisation (Hobbs et al. 2009). However, this is not unique to The Dales Ramsar site.

This criterion is not considered to be met either at listing or currently.

Criteria 8: The Dales was listed as meeting this criterion, however this criterion specifically relates to fish species and maintenance of fish stocks and has been misapplied. The justification in the RIS (2002) focused on the spawning of land crabs and providing critical habitat for the blue crab. These aspects of the site are better accounted for under criterion 4. Whilst the spawning of red crabs may provide a food source for some pelagic reef fish the majority of fish species recorded in The Dales rely on other food types. In general there are no data to suggest that fish, or fish stocks, are dependent on The Dales as a feeding area.

A possible exception is whale sharks (*Rhincodon typus*). Christmas Island is a significant area for whale sharks (*Rhincodon typus*) because the mass spawning and development of the larvae of red crabs corresponds to the arrival and aggregation of juveniles off shore of Christmas Island (Hobbs et al. 2009b). Meekan et al. (2009) confirmed whale sharks are feeding on the immature stages of red crabs through analysis of faecal matter from a single shark. Whale sharks have been observed feeding close to shore around most of the island in shallow waters (J-P Hobbs, James Cook University, pers. comm.) and almost certainly feed within the boundary of the Ramsar site. The whale sharks persist in the waters off Christmas Island for several months after the red crab larvae have left the water and therefore are not solely reliant on them as a food source. It has been postulated that other crab species spawning events and coral spawning also provide food for the sharks (J.P. Hobbs, James Cook University, pers. comm.).

This criterion was met at the time of listing and continues to be met.

Criteria 9: The application of this criterion relies on estimates of the total population of non-avian wetland dependent species. In the case of The Dales Ramsar site this would require estimates of red crab and blue crab numbers as a proportion of the populations on the island. This criterion cannot be assessed based on current information. Both of these species are covered under other criteria.

This criterion is not considered to be met either at listing or currently.

3. Critical Components and Processes

3.1 Identifying critical components and processes

Ecological Character Descriptions (ECDs) identify, describe and where possible, quantify the critical components, processes and services of the site which determine the wetland's character and ultimately allow detection and monitoring of change in that character. These are the aspects of the ecology of the wetland, which, if they were to be significantly altered, would result in a significant change in the system.

DEWHA (2008) suggest the minimum components, processes, benefits and services, which should be included in an ECD are those:

1. that are important determinants of the sites unique character;
2. that are important for supporting the Ramsar or DIWA criteria under which the site was listed;
3. for which change is reasonably likely to occur over short to medium time scales (less than 100 years); and/or
4. that will cause significant negative consequences if change occurs.

The role that components and processes play in the provision of critical ecosystem services should also be considered in the selection of critical components and processes. The linkages between components, processes, benefits and services and the criteria under which the site was listed are illustrated conceptually in Figure 5. This simple conceptual model for The Dales Ramsar site shows not only the components, processes and services that are critical to the ecological character of the site, but also but also the essential elements which are important in supporting the critical components, processes and services the site provides.

It is difficult to separate components (physical, chemical and biological parts) and processes (reactions and changes). For example, aspects of hydrology such as rainfall and water regime may be considered as components, while other aspects of hydrology such as groundwater flow and connectivity could be considered processes. Similarly the species composition of crabs at a site may be considered a component, but breeding and migration are processes. In the context of this ECD a separation of the ecology of wetlands into nouns (components) and verbs (processes) is an artificial boundary and does not add clarity to the description. As such components and processes are considered together.

Each of the identified critical components and processes meet the four criteria provided by DEWHA (2008) in that they are central to the character of the site, are directly linked to the Ramsar criteria for which the site was listed, could potentially change in the next 100 years and for which change would result in negative consequences and a change in the ecological character of the site.

The remaining components and process identified in Figure 5, although important in supporting the critical components and processes, benefits and services are not considered critical as a change in these components and process, in isolation (that is without a corresponding biological response) would not result in a change in the ecological character of the site. Nevertheless, these supporting components and processes (termed essential elements) are important in managing the site to maintain ecological character and some may provide early warning indicators of change. As such, this ECD includes a description of the following essential elements that are important in supporting the ecological character of the site:

- Climate
- Water quality
- Terrestrial vegetation (in the context of habitat for nesting birds)
- Coral
- Fish, and
- Invertebrates (non crab).

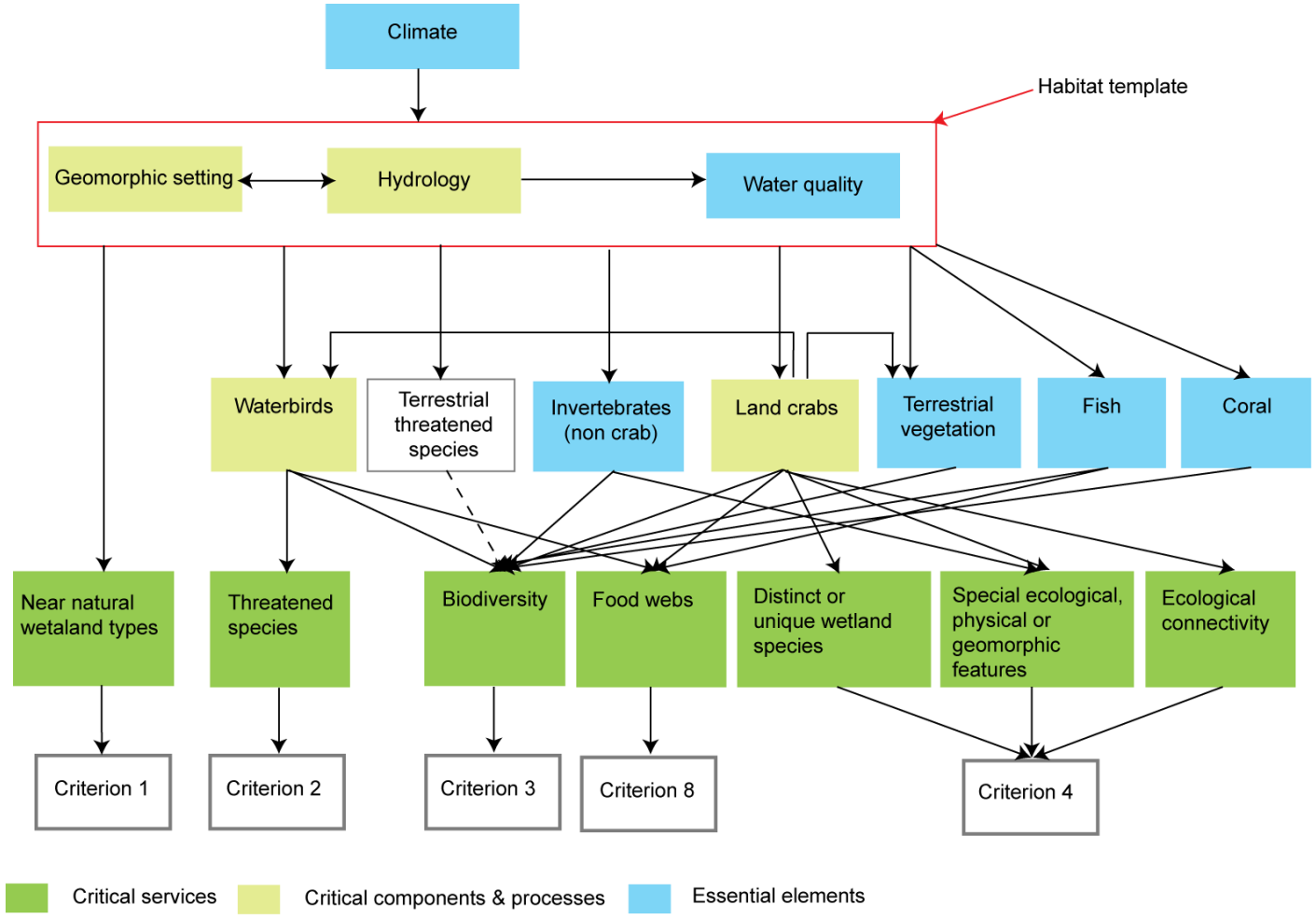


Figure 5: Simple conceptual model showing the key relationships between components and processes; benefits and services and the reasons for the site being listed as a Wetland of International Importance.

3.2 Essential elements

The components and processes of The Dales Ramsar site that are considered important in supporting the critical components, processes, benefits and services of the site (and hence termed "essential elements") are described briefly below and summarised in Table 4.

Table 4: Summary of supporting components and processes within The Dales Ramsar site.

Component / process	Description
Climate.	Warm tropical climatic zone. High rainfall (2000 millimetres per year); warm to hot year round.
Water quality.	Limited site specific data – information from one survey in 2003 for Hugh's Dale may provide baseline data for time of listing. Water quality is good, with higher concentrations of some trace metals and major ions compared to upstream reference sites, due to the presence of volcanic rocks and significant crab populations.
Terrestrial vegetation.	Limited site specific data; descriptions of the vegetation are limited. General descriptions provided by Mitchell (1985) and Du Puy (1993) for vegetation associations indicate five major associations, with tall rainforest the dominant type.
Coral.	The coral reef is limited and dominated by abiotic habitat and hard corals of low diversity.
Fish.	Community predominantly of Indo-Pacific origin. Seven endemic or near endemic species or sub-species (Allen et al. 2007). Christmas Island represents a unique biogeographic border for marine fishes (Hobbs and Salmon, 2008) and the intermixing of Indian and Pacific Ocean fishes has created an abundance of hybrids (Hobbs et al. 2009) One endemic freshwater species recorded from the site.
Invertebrates (non crab fauna).	The site supports a low diversity of benthic marine invertebrates, but may also support anchialine fauna although no site specific data has been sourced to confirm this.

3.2.1 Climate

Christmas Island lies within the moist tropical climatic zone of the Indian Ocean. The general climatic pattern is warm to hot temperatures and high rainfall occurring year round. The nearest weather station to The Dales Ramsar site is located at the Christmas Island airport (approximately 15 kilometres west).

Rainfall, on average, occurs year round with highest monthly average rainfall in February (345 millimetres) and lowest in August (44 millimetres). There is some degree of variability in rainfall as evidenced by the 10th and 90th percentiles, which range from less than one millimetre per month to greater than 550 millimetres per month (Figure 6). However, this is considerably more stable than rainfall in arid zones within Australia (Bureau of Meteorology 2009a).

Annual average rainfall at Christmas Island is in the order of 2000 millimetres per year. Once again, although there is some degree of variability in annual rainfall (ranging from less than 1250 millimetres to greater than 3700 millimetres in 30 years of records from this site) (Figure 7) this is relatively low compared to areas in mainland Australia.

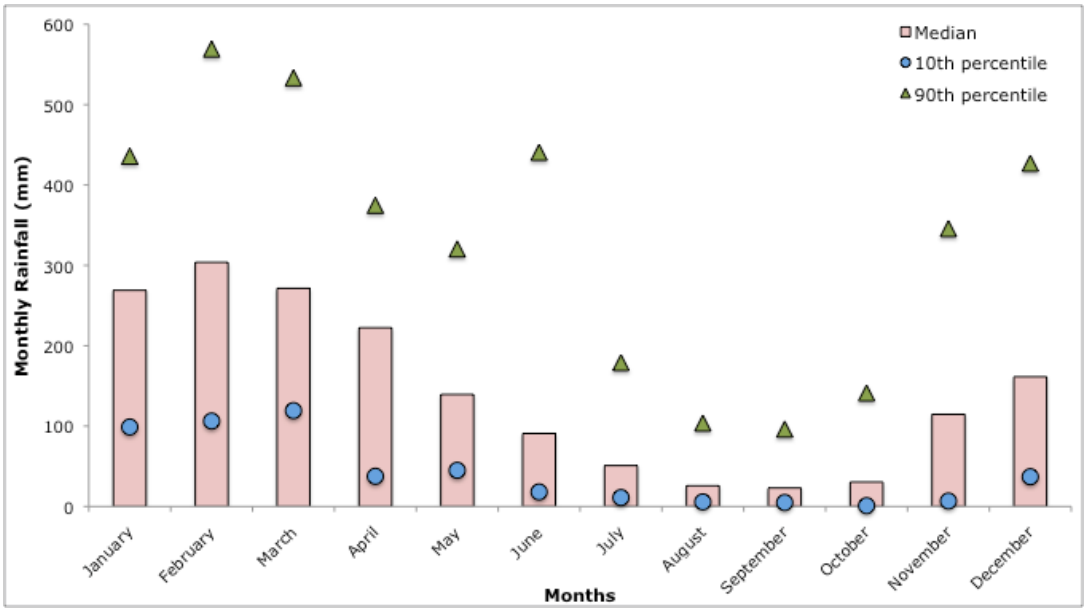


Figure 6: Median (10th and 90th percentile) monthly rainfall at Christmas Island Airport (1973 – 2009; Bureau of Meteorology 2009a).

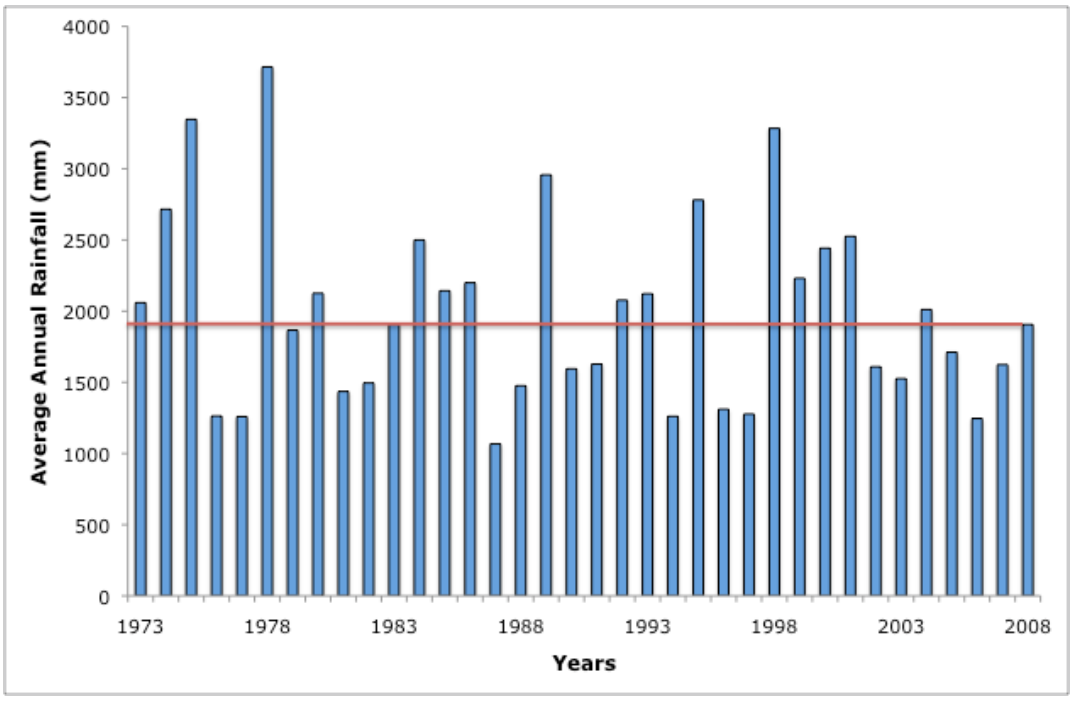


Figure 7: Average annual rainfall at Christmas Island Airport (1973 – 2006; Bureau of Meteorology 2009a). Note horizontal line shows long term average.

Temperatures are warm to hot year round (Figure 8), with little seasonal variation. Maximum monthly temperatures are between 26 and 28 degrees Celsius and average minimum temperatures between 22 and 24 degrees Celsius.

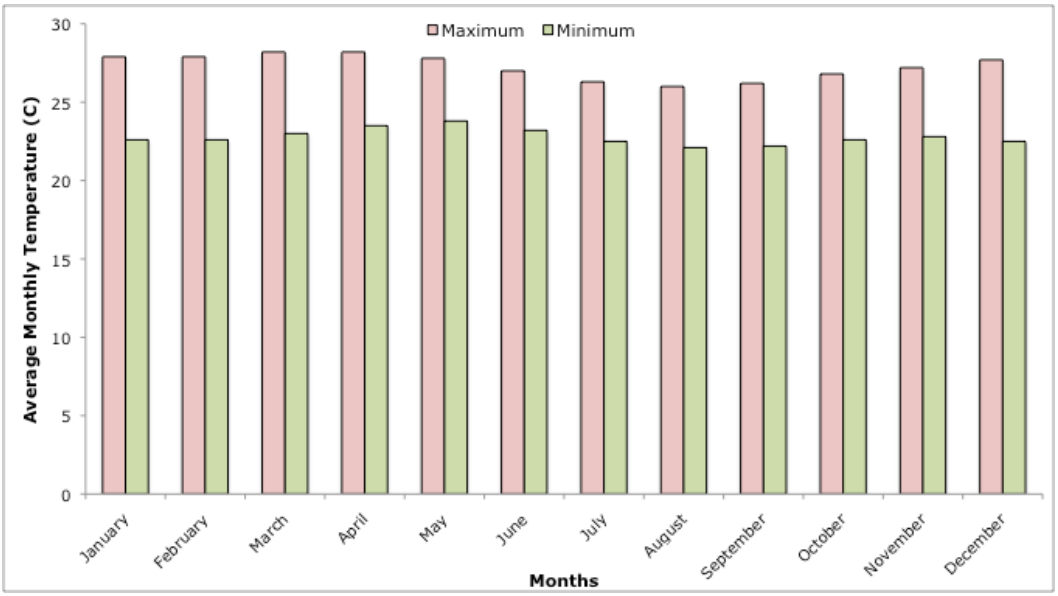


Figure 8: Average monthly maximum and minimum temperatures at Christmas Island Airport (1973 – 2009; Bureau of Meteorology 2009a).

Christmas Island is located in an area subject to tropical cyclones. Thirteen tropical cyclones were recorded in the vicinity of Christmas Island between 1972 and 2005. On average this equates to a tropical cyclone every five years. However, in the 20 years of wind records, there has only been one severe gust recorded of at least 90 kilometres per hour. That was 107 kilometres per hour in December 1980 during tropical cyclone Dan (Bureau of Meteorology 2009b).

3.2.2 Water Quality

Water quality is important for maintaining shallow reef communities; however there is no data for the marine areas of the Ramsar site.

Very limited data exists for the groundwater and surface water within the site. In 2003 water quality was sampled at Hugh's Dale as part of a wider investigation into springs and caves downstream of historic mining fields. Hugh's Dale is approximately 3.4 kilometres downstream of a mining field which operated in the 1970's (EWL Sciences and Tallegalla 2005). Results included higher concentrations of some trace metals and major ions compared to upstream reference sites, believed to attributable to the presence of volcanic rocks and significant crab populations. The data for Hugh's Dale for standard water quality variables are presented below in Table 5.

Table 5: Water quality measurements Hugh's Dale wet season 2003 (extracted from Puhalovich et al. 2003).

Parameter	February 2003	May 2003
pH.	7.81	8.3
EC (micro siemens per centimetre).	364	380
Turbidity NTU.	11	14
Total Suspended Solids (micrograms per litre).	28	Less than 5
$N\text{-}NO_3$ (milligrams per litre).	1.2-1.4	1.5-1.7
Total Kjeldahl Nitrogen .	0.3	Less than 0.2
Total Nitrogen (milligrams per litre).	1.5	1.7
Phosphorous (milligrams per litre).	Below detection limits.	Below detection limits.
Calcium (milligrams per litre).	69.2	68.82

Without significant anthropogenic disturbance within the catchment for The Dales the water quality of the intermittent streams should be high. For groundwater flow from the springs, activities outside of the site's boundary may have an impact on the water quality. This remains a knowledge gap.

3.2.3 Vegetation

The terrestrial vegetation, and other biota, of Christmas Island are derived from species colonisation and show little affinity with the Australian mainland. The isolation of the island and the randomness of the colonisation process have resulted in a unique flora and fauna (Expert Working Group 2009). The major types of rainforest on the island are dominated by plants which are pan-tropical species most likely from South East Asia (Expert Working Group 2009).

There are approximately 420 species of vascular plants on Christmas Island, however a floristic survey specific to The Dales has not been undertaken and so the discussion presented relates generally to the island as a whole unless otherwise stated. Of the 420 species, 242 are indigenous and 177 are naturalised since human occupation (Claussen 2005; EWL Sciences and Tallegalla Consultants 2005). The island has eighteen endemic species (see Appendix D), three of which are listed under the EPBC Act. These include a lithophytic fern *Asplenium listeri*, two ground ferns *Pneumatopteris truncate* and *Tectaria devexa* var *minor*.

There are a number of classifications of the vegetation of Christmas Island available (Parks Australia 2008) (see Table 6).

Table 6: Comparison of vegetation classifications applied to Christmas Island (from Parks Australia 2008).

Mitchell 1985	Du Puy 1993	Reddell and Zimmermann 2003	Claussen 2005
Tall closed forest, deep soil phase.	Primary (plateau) rainforest.	Complex mesophyll vine forest, tall emergents.	Evergreen closed forest.
		Complex mesophyll vine forest.	
Closed forest, shallow soil phase.		Mesophyll vine forest (a)	
		Mesophyll vine forest with Ficus.	
Closed forest, freshwater seepage.	Areas with surface water.	Mesophyll vine forest (a)	
Closed forest, scree and pinnacle phase.	Marginal (terrace) rainforest.	Semi-deciduous mesophyll vine forest.	Semi-deciduous closed forest.
Open forest and vine woodland.	Open forest, scrubby forest, vine forest.	Deciduous vine thicket.	Deciduous scrub.
	Inland cliffs.		
Heath, shrubland and low closed woodland.	Coastal fringe.	Sclerophyllous shrublands and heathlands.	Herbland.
	Shore cliffs and spray zone		
Seral vegetation.	Mined areas.	Cleared land.	n.a.

(a) areas with surface water were considered a special case of mesophyll vine forest by Reddell and Zimmermann (2003).

The dominant vegetation types present on Christmas Island include plateau/primary rainforest, marginal rainforest, and scrub forest (also referred to as open forest and vine

forest). Other minor community types include coastal fringe forest (also referred to as shore cliff and spray zone vegetation), and areas with surface water such as The Dales and Hosnies Spring. Each of the vegetation types found within boundary of the site (see Figure 9) is briefly described below.

Evergreen tall closed forest/ Plateau rainforest (86.41 hectares): characterised by deeper soils with rainforest species reaching 30 – 45 metres tall with emergent trees reaching up to 50 metres (Mitchell 1985). Usually restricted to elevations above 160 metres (Mitchell 1985). The canopy supports a number of epiphytic ferns, orchids and other climbers. *Syzgium nervosum, Planchonella nitida, Macaranga tanarius* and *Hermandia ovigera* are typical species found in the primary rainforest. Dominant canopy species include *Inocarpus fagifer, Barringtonia racemosa, Cryptocarya nitens, Dysoxylum gaudichaudianum* and *Tristiropsis acutangula.* The under canopy contains *Leea angulata, Ochrosia ackeringae, Pisonia umbellifera* and two common, endemic species: the Christmas Island palm, *Arenga listeri*, and *Pandanus elatus*, a tree-like pandanus. The composition of the forest canopy is influenced by the soil substrate. *Tristiropsis acutangula, Dendrocnide sinuata* and *Procris pedunculata* are more frequently found thinner soils (Du Puy 1993).

Within this association at three areas on the island which are perennially wet, a distinctive vegetation community of 'closed forest, freshwater seepage' occurs. The largest area is at Hugh's Dale which includes the 10 hectare monodominant stand of Tahitian chestnut *Inocarpus* fagifer. GIS data supplied (Figure 9) does not show this vegetation association within The Dales; however it is obviously a key component of the sites vegetation (see section 4.3.3).

The forest floor is predominantly bare of a shrub and herb understorey due largely to the activities of the land crabs (see section 4.3.4) and also the shading of sunlight by the canopy species (Du Puy 1993).

Semi deciduous closed forest/ Marginal rainforest (438.19 hectares): characterised by a more open forest than the plateau rainforest, on thinner soils on the lower terraces, at elevations predominantly above 130 metres (Mitchell 1985). Canopy height reaches 20 to 30 metres. This rainforest type has higher species diversity, including salt tolerant species (*Pandanus sp*. thickets and heaths) found along the coastline, vine thickets and open forests on the shore terrace, and forests of evergreen and deciduous species including *Terminalia catappa*, *Macaranga tenarius* and stands of the endemic palm *Arenga listeri* on the middle and upper terraces (SKM 2000). Species found in the marginal rainforest are more tolerant of dry conditions and include *Pisonia grandis*, *Gyrocarpus americanus* and *Erythrina variegata* which have thick trunks in which to retain water, and the deciduous *Terminalia catappa* and *Celtis timorensis* (Du Puy 1993).

The marginal rainforest floor is also almost devoid of a herb and shrub layer.

Coastal fringe shrubland and herbland/ Coastal fringe forest (11.15 hectares): as the name suggests this vegetation type is a narrow strip along the coastline between the sea cliffs and edge of the marginal forest, dominated by low stature sclerophyllus species which have their stature affected by exposure to wind and sea spray (Mitchell 1985, Parks Australia 2008). It is characterised by dense shrubs, including *Pandanus christmatensis* and Christmas Island abutilon *Abutilon listeri*, *Cordia subcordata, Pemphis acidula, Argusia argentea* and *Scaevola taccada* plus a number of herbs and ferns (Du Puy 1993 cited SKM 2000).

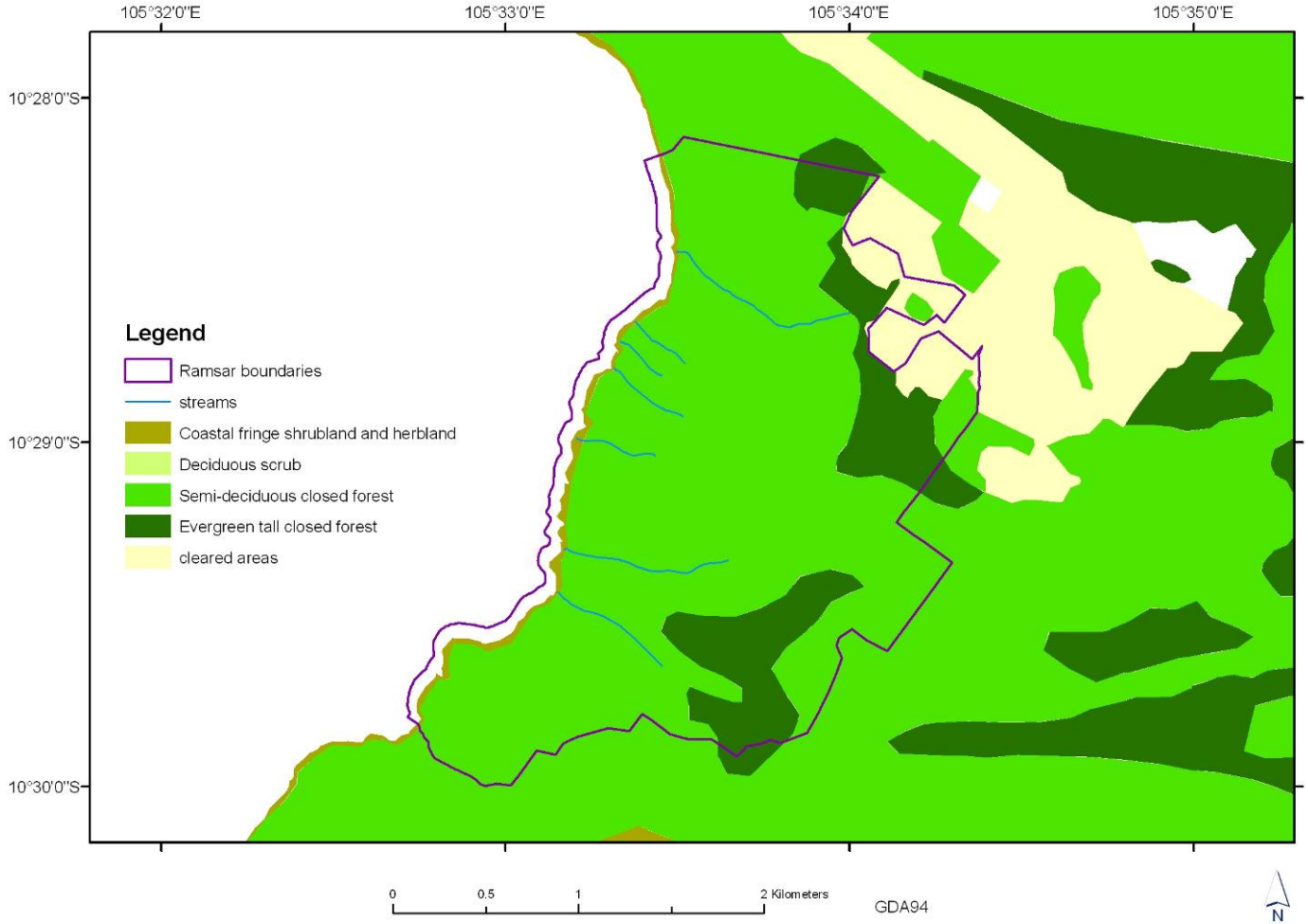


Figure 9: Vegetation types within The Dales (data provided by Parks Australia).

3.2.4 Coral reef

Although Christmas Island is completely surrounded by coral reef, the extent of this habitat is limited (Gray and Clarke 1995). At the seaward edge, reef is limited by a steep drop off some 20 to 100 metres from shore, where the underwater terraces descend steeply. At the landward edge, reef is limited by the exposed coastline and high impact of waves and consequently only extends to the intertidal zone in sheltered locations (Gray and Clarke 1995). Gilligan et al. (2008) measured the extent of reef platform at several locations around the Island and determined an average extent of 79 metres. Unfortunately although monitoring included a site within The Dales, the weather prevented measurement of reef extent at this location. Despite this, available data indicates that the reef habitat at Christmas Island is spatially limited and it is likely that the marine area of The Dales Ramsar site contains a significant proportion of the adjacent reef.

There is very limited information on the marine environment at The Dales Ramsar site and site specific information is limited to a single sampling survey in May 2005 (Gilligan et al. 2008). While this provides an indication of components and processes within the sub-tidal areas in The Dales Ramsar site, it cannot be considered to be a complete description and the ecological character of the marine portions of the site remain a knowledge gap.

The reef at The Dales was dominated by hard corals, with low amounts of soft coral and an absence of encrusting algae or sponges (Figure 10). Total live coral cover at The Dales site was 42 percent, which is less than the mean for the entire island (51.5 percent) and considered “fair” condition according to the reef health index of Gomez et al. (1991, in Gilligan et al. 2008); but higher than most other comparable oceanic reef systems in the indo-pacific (Gilligan et al. 2008).

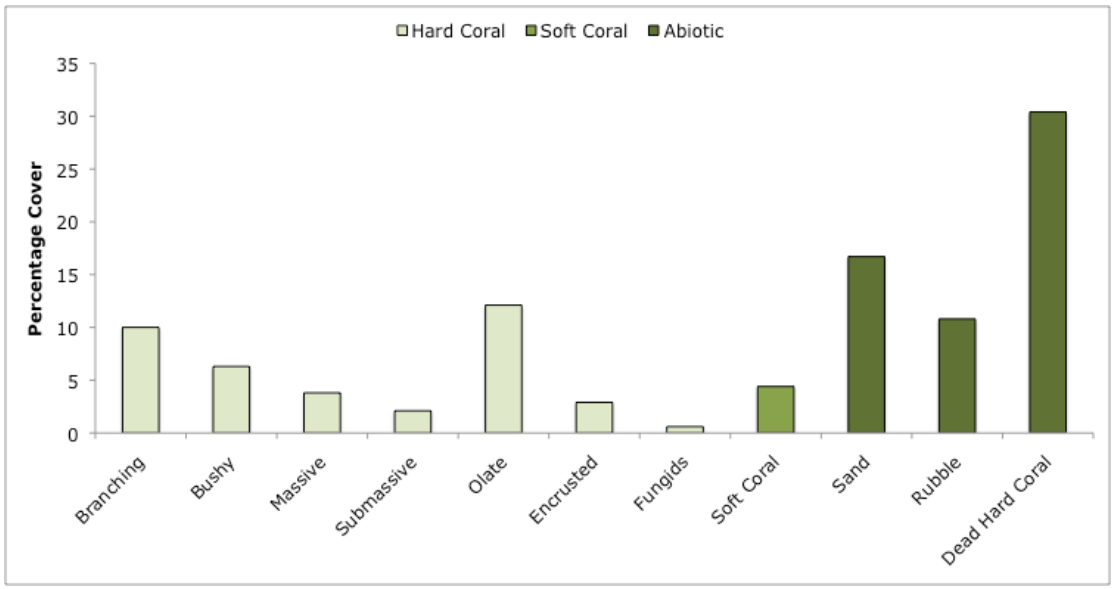


Figure 10: Benthic cover at the Dales (Data from Gilligan et al. 2008).

3.2.5 Fish

Marine fish

Six hundred and seven marine fish species have been recorded in the reefs of Christmas Island (Hobbs et al. 2008), of which 32 have been recorded within the Ramsar site boundary (Hobbs et al. 2008; Gilligan et al. 2008; Appendix C). The list includes species of Indo-Pacific, Pacific Ocean and Indian Ocean origins and Christmas Island is considered as an important “stepping-stone” in the dispersal of species between the Indian and Pacific Oceans (Hobbs et al. in press). The marine community at Christmas Island is globally unique because the island is located on a marine biogeogaphic border where Indian and Pacific Ocean fishes intermix

(Hobbs and Salmond 2008). Consequently, there are more hybridising reef fishes recorded at Christmas Island than anywhere else in the world (Hobbs et al. 2009a).

The Christmas Island fish community includes seven endemic or near-endemic species or sub-species (*Eviota natalis, Pseudochromis viridis, Praealticus natalis, Aseraggodes crypticus, Centropyge joculator, Centropyge flavissima, Stegastes insularis*). The Cocos angelfish (*Centropyge joculator*), which is restricted to Christmas Island and the Cocos Islands, is abundant in deep water and the endemic damselfish (*Stegastes insularis*), is locally abundant in shallow waters (Gilligan et al. 2008). Two of the endemic angelfishes (*C. joculator and C. flavissima)* have high local abundance and generalist patterns of resource-use (Hobbs et al. 2010).

Christmas Island is also a globally significant area for whale sharks (*Rhincodon typus*) because juveniles aggregate at the Island in summer to feed on the larvae of red crabs (Hobbs et al. 2009b). They have been observed along the east coast of the island within 50 metres of the shoreline (Jean-Paul Hobbs, pers. comm.) and so potentially could occur at times within the Ramsar site. Whale sharks are the largest fish in the world and travel throughout the tropics. At certain times of the year, whale sharks migrate to specific locations to aggregate and feed on the mass spawning of other organisms. There are only a small number of these feeding locations and they represent important habitat for the long-term conservation of these “vulnerable” species.

Freshwater fish

There are records of six species of freshwater fish occurring on Christmas Island with only limited information available regarding their presence within The Dales. The species are all considered introduced species except the brown gudgeon (*Eleotris fusca*) (Director of National Parks 2002). Recent investigations into introduced freshwater fish on Christmas Island found guppies (*Poecilia reticulata*) from upstream and downstream of the waterfall at Hugh’s Dale. Three brown gudgeon were reported from Anderson Dale as well as a single eel (*Anguilla marmoratus*) (D. Morgan, Murdoch University, pers. comm.). An understanding the freshwater fish ecology and potential impact from introduced species in The Dales is a knowledge gap.

3.2.6 Invertebrates (non crab fauna)

Anchialine community

A notable feature of Christmas Island is that it supports a broad band of caverns and associated crevicular habitat from above the surface of the ocean to a depth of over 100 metres (Humphreys et al. 2009) that support anchialine fauna. Anchialine systems are essentially interfaces between marine and inland waters, described by Humphreys and Danielopol (2006) as groundwater estuaries (see section 4.3.1). There is only one other anchialine system in Australia, the Cape Range/Barrow Island area (Humphreys and Eberhard 2001).

Anchialine systems may support diverse crustacean assemblages and most of their members represent biogeographic and/or phylogenetic relicts and as such are of widespread conservation interest (Humphreys and Danielopol 2006). Two distinct types of anchialine fauna have been identified, each with an often predictable species assemblage: the Remipede and Procaridid Types (Humphreys and Danielopol 2006). The Procaridid Type is usually restricted to seamount islands such as Christmas Island and typically contains typically comprises procaridid, alpheid, hippolytid, and atyid shrimps (Humphreys and Danielopol 2006).

The stygofauna is considered a significant component of the biodiversity values of the island and a significant cave fauna province on an international scale (Humphreys and Eberhard 2001). Anchialine systems are considered to be vulnerable to even slight organic pollution (Humphreys and Eberhard 2001) and so groundwater pollution could have an impact on the fauna of the island.

It is not known if anchialine communities are present within The Dales Ramsar site, however as there is at least one sea cave (see section 4.3.1) it is likely. This remains a knowledge gap for the site.

Marine benthic invertebrates

As discussed above in section 3.2.4 the shallow reef resources of Christmas Island are limited by a number of factors, notably a relatively small area and diversity of habitat. The narrow reef fringing the island is the only suitable shallow-water habitat for benthic invertebrates as seaward of this platform the reef drops quickly into deeper waters (Gilligan et al. 2008). The exposed nature of the reef and a lack of seagrass, sandy patches, or mangrove habitat combined with the isolation of the island relative to other seeding reefs, all contribute to the observed low diversity of invertebrates present at the site (Gilligan et al. 2008).

Survey work at Sydney's Dale included searches for sea urchins, sea cucumbers, clams, trochus shell, and crown-of-thorns starfish. No crown-of-thorns starfish (*Acanthaster plancii*) were recorded, and only three other taxa were identified in the underwater visual assessment: *Thelenota ananas* (sea cucumber), *Tridacna* sp. (clam) and *Diadema* sp. (sea urchin) Gilligan et al. 2008).

3.3 Critical components and processes

The attributes and characteristics of each of the critical components and processes of The Dales Ramsar site are described below (sections 3.3.1 to 3.3.5). Where possible, quantitative information is included in the description of each component or process. However, as with many ecological character descriptions, there are significant knowledge gaps relating to the key characteristics of this site (see section 8). A summary of the critical components and processes within The Dales Ramsar site is provided in Table 7.

Table 7: Summary of critical components and processes within The Dales Ramsar site.

Component / process	Description
Geomorphic setting.	The island is a karstic landscape with key geomorphic features including the terrace formations, sea cliffs, and caves and other karst features.
Hydrology.	Karstic drainage system of groundwater and surface ephemeral stream flow post heavy rainfall events during the wet season. Spring outflow of groundwater at three of the Dales is permanent.
Land Crabs.	All 20 species of land crab occur within the boundary of the site. The Dales provide a major migration pathway for crabs to and from the ocean during spawning. The site is important for blue crabs in particular.
Waterbirds.	Eleven waterbirds, including nine endemic species, one nationally listed vulnerable and one endangered species are found at the site. The site supports breeding seabirds including Abbott's booby and red-footed booby.

3.3.1 Geology and geomorphological setting

Christmas Island is a seamount island which rises above the 5500 metre deep abyssal area of the Western Australian Basin. The island has a basaltic volcanic core overlain with Tertiary to Recent limestone (EWL Sciences and Tallegalla Consultants 2005). The basalt volcanic rocks are found at variable depths and as exposed outcrops in several coastal areas including The Dales. Rising in several stages the island is characterised by a series of stepped terraces. Uplift events are believed to have commenced in the Tertiary period and have produced a series of cliffs or slopes with terraces between. The characteristic terraces were formed by the combined effects of the fringing reef development and subsequent erosion (Rivereau 1965; Director of National Parks 2002). On the surficial layer of the

terraces phosphate has been deposited. The terraces rise from the coast to a plateau in the centre of the island, with four terraces comprising the inland cliffs and three contributing to the inland plateau. In some places terraces are difficult to distinguish. The interior plateau region rises from 160 to 360 metres. Soils on the plateau and upper terraces are deeper, becoming progressively thinner and drier in the lower terraces.

Almost completely encircling the island are the sea cliffs, behind which lies the shore terrace (Figure 11). The shore terrace occurs at approximately 15 metres above sea level. The width of the shore terrace is variable extending 50 – 200 metres landward of the sea cliffs (EWL Sciences and Tallegalla Consultants 2005).

Christmas Island is dominated by a karstic landscape and drainage system with significant karst features both on the surface and underground. Cave formations typically occur at the basalt and limestone and sea and freshwater interfaces (Humphreys and Eberhard 2001). Anchialine caves at the current and ancient shoreline levels, formed by erosion from sea wave action, can extend considerable distances inland (see section 4.3.1 and 4.3.3 for more detail). Anchialine karst caves begin at the coast where the groundwater meets the sea, but the formation of the cave goes upwards along the groundwater drainage line, thus often extending inland beyond the influence of the sea.

Other karst features include surface dolines or sink holes formed by collapses of cavity roofs (SKM 2000). The Dales contain flowstone formations which are more typically found underground (SKM 2000). The islands water drainage system is karstic, with rainfall percolating into the limestone then forming underground aquifers and drainage lines along the basalt. Short spring fed surface streams occur on the margins of the island where limestone and basalt interface leading to surface expression of the groundwater (see section 3.3.2 for more detail on hydrology). The Dales support three such springs.

Grimes (2001) describes The Dales as narrow ravines, some with springs, occurring at volcanic outcrops forming streams which become deep fissures closer to the coastline. Considered surface karst features themselves, the other karst features at The Dales include springs and tufa deposits (Grimes 2001). Tufa deposits occur at waterfalls below the springs and have large vertical tufa deposits (Grimes 2001). Tufa is the calcareous and siliceous rock deposits which come from springs and groundwater. See section 4.3.1 and 4.3.3 for more detail on karst features of The Dales.

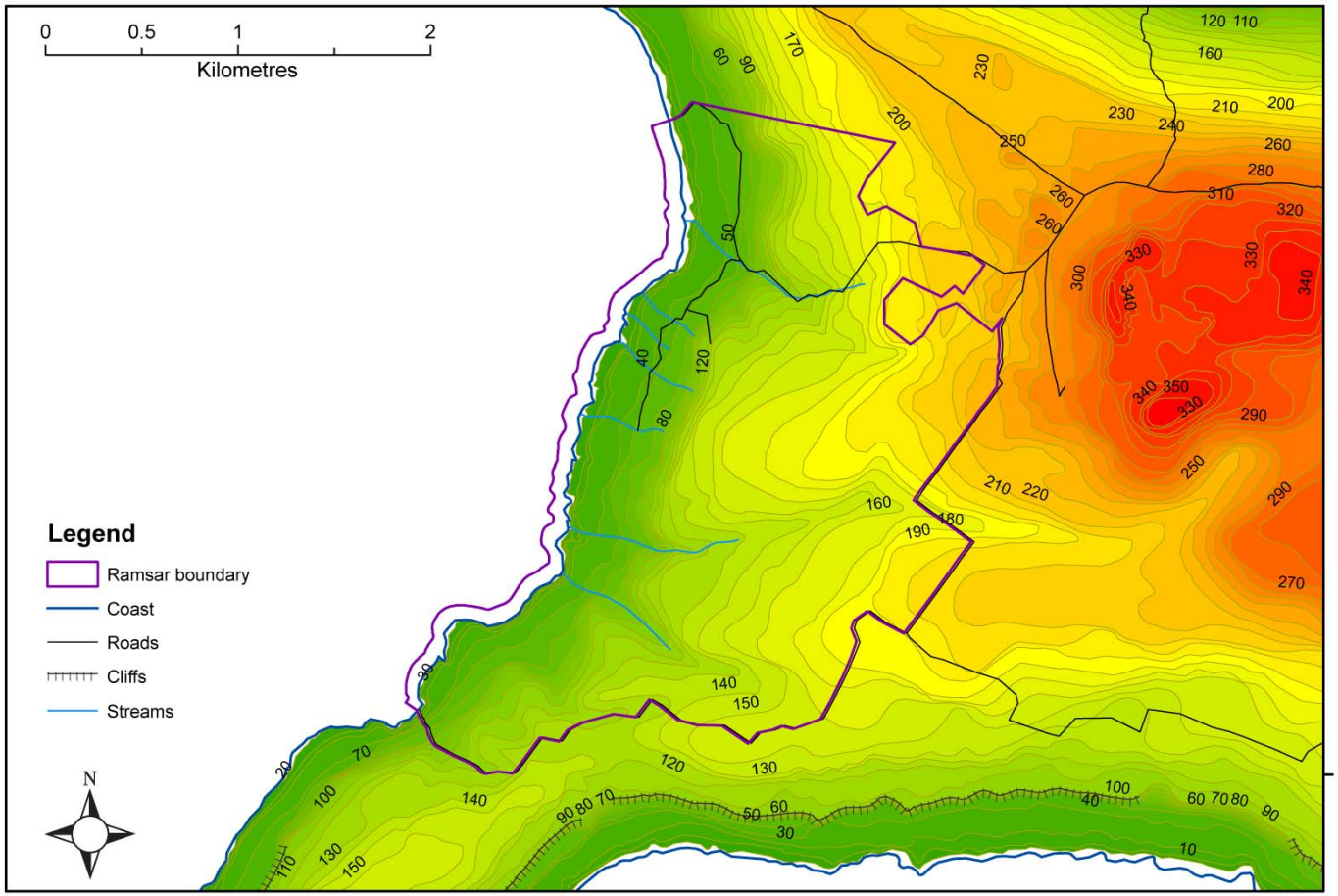


Figure 11: Topographic map of The Dales Ramsar site (data supplied by Parks Australia). The dark green shading corresponds to the shore terrace.

3.3.2 Hydrology

As mentioned above the island has a karst drainage system with surface water restricted to a few springs, and intermittent systems which flow after significant rainfall events in the wet season, but last only for short periods of time (SKM 2000; Grimes 2001). Springs are fed from recharge areas on the plateau (Puhalovich et al. 2003). An accurate water balance for the island is lacking. Grimes (2001) states evapotranspiration is high having been estimated to be approximately 70 per cent, known/measured discharges account for a further five per cent and the remainder is assumed to be discharged by coastal and offshore springs. Puhalovich et al. (2003) state that approximately half of incident rainfall passes through the soil zone to recharge the aquifers, with recharge occurring rapidly once soils are saturated. Recharge also occurs through dissolution features including dolines and sinkholes (Puhalovich et al. 2003).

Rain infiltrates the land surface and contributes to soil water storage, being taken up by plants or moving to recharge the groundwater. Water either flows along the interface or down fractures in the volcanic rock and contributes to basal and perched aquifers (SKM 2000). Higher permeability of the limestone on the margin of the island results in the water table being just above sea level (SKM 2000; Grimes 2001).

Puhalovich et al. (2003) identified two hydrological units and assigned hydrological processes to each to form the key elements of a conceptual hydrological model for the island (see Table 8 and Figure 12).

Table 8: Key elements of conceptual hydrological model (Puhalovich et al. 2003).

Hydrological unit	Processes
Soil zone.	• Rainfall recharge (inflow). • Evaporation (outflow). • Transpiration (outflow). • Leakage to underlying aquifers (outflow).
Weathered/fractured rock aquifers.	• Leakage from overlying soil zone (inflow). • Spring discharge (outflow). • Ocean discharge (outflow).

No data exist for long-term seasonal or daily monitoring of stream flow (Puhalovich et al. 2003). Grimes (2001) reports outflows measured at The Dales as six litres per second. The basal aquifer at The Dales is reported as brackish (RIS 2002), however information in Puhalovich et al. (2003) suggest there may also be a perched freshwater aquifer within the site (Figure 13). No other site specific information on hydrology of The Dales is available.

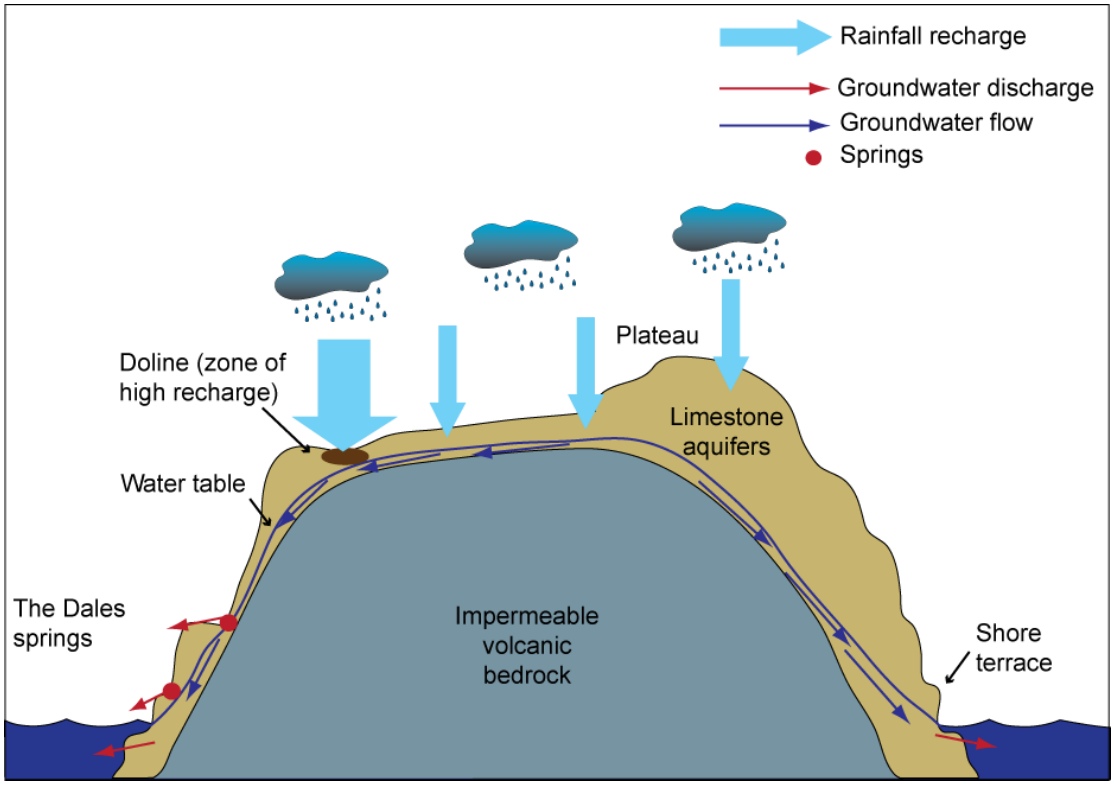


Figure 12: Diagrammatic cross section of Christmas Island showing karst drainage system (after Grimes 2001) (not to scale).

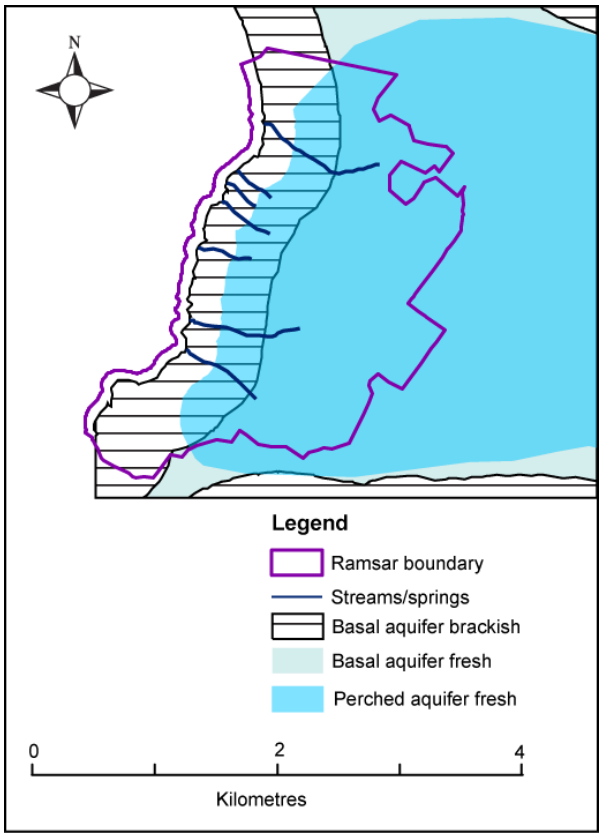


Figure 13: Aquifers within The Dales Ramsar site (data supplied by Parks Australia).

3.3.3 Crab fauna

This section provides information on the diversity and species of crabs found within the Ramsar site. Important biological processes such as spawning and migration are covered in section on critical services provided by the site (section 4.3). Christmas Island is famous for its land crabs, with the migration of the red crabs (*Gecarcoidea natalis*) (Figure 14) considered one of the natural wonders of the world. Their dominance of the fauna on the island has significant influence on the ecology of the island as a whole, with the crabs playing critical roles in the recycling of nutrients; bioengineering of soils and ultimately on forest structure (see section 4.3.5).

Figure 14: Male red crab *Gecarcoidea natalis*, Christmas Island (© Director of National Parks, photograph by Max Orchard, Parks Australia).

Figure 15: Robber crab *Birgus latro* (photograph by Daniel Simon).

Twenty species of land crabs have been recorded on Christmas Island (Table 9) all of which occur within the boundary of the site. Jackson's crab (*Sesarma jacksoni*) is endemic to Christmas Island. The red crab is thought to be endemic, but it also occurs in the Cocos (Keeling) Islands (Green 2009). The blue form of the blue crab (*Discoplax hirtipes*) only occurs on Christmas Island. The most common and largest species, the red crab, blue crab and robber crab (*Birgus latro*) (Figure 15), all feed mainly on fallen leaves and fruit of the rainforest (Hicks et al. 1984). The dominant species within The Dales, however, is the blue crab. There are neither quantitative data on the numbers of crabs within The Dales, nor any indication of population variability either seasonally or inter-annually.

Table 9: Land crabs present in The Dales (from Green 2009).

Common name	Scientific name	Habitat	Local range	Abundance
Family Coenobitidae				
Purple hermit crab.	*Coenobita brevimana*	ST,SL	R	C
Red hermit crab.	*Coenobita perlata*	SL	R	C
Robber crab.	*Birgus latro*	RF	W	A
Tawny hermit crab.	*Coenobita rugosa*	SL	R	R
Family Gecarcinidae				
Blue crab.	*Discoplax hirtipes*	FS	R	C
Brown crab.	*Epigrapsus politus*	SL	R	R
Purple crab.	*Gecarcoidea lalandii*	RF	W	R
Red crab (e).	*Gecarcoidea natalis*	RF	W	A
Family Grapsidae				
Freshwater crab.	*Ptychognathus pusillus*	FS	R	R
Grapsus.	*Grapsus tenuicrustatus*	SL	W	A

Common name	Scientific name	Habitat	Local range	Abundance
Jackson's crab*.	*Sesarma jacksoni*	ST	R	R
Little nipper.	*Geograpsus grayi*	RF	W	C
Mottled crab.	*Metasesarma rousseauxi*	SL	R	C
Red nipper.	*Geograpsus stormi*	SL	W	R
Sandy rubble crab.	*Cyclograpsus integer*	SL	R	R
White stripe crab.	*Labuanium rotundatum*	ST	R	R
Yellow nipper.	*Geograpsus crinipes*	ST,SL	W	C
Yellow-eyed crab.	*Sesarma obtusifrons*	SL	W	C
Family Ocypodidae				
Horn-eyed ghost crab.	*Ocypode ceratophthalma*	SL	R	C
Smooth-handed ghost crab.	*Ocypode cordimana*	SL	R	C

(e) = species and subspecies endemic to the island. * Jackson's crab has not been recorded elsewhere and may be endemic. For habitat: FS = freshwater stream or seepage, RF = rain forest, ST = shore terrace, SL = shoreline. For range: W = widespread, and R = restricted. For abundance: A = abundant, C = common, and R = rare.

Blue crabs

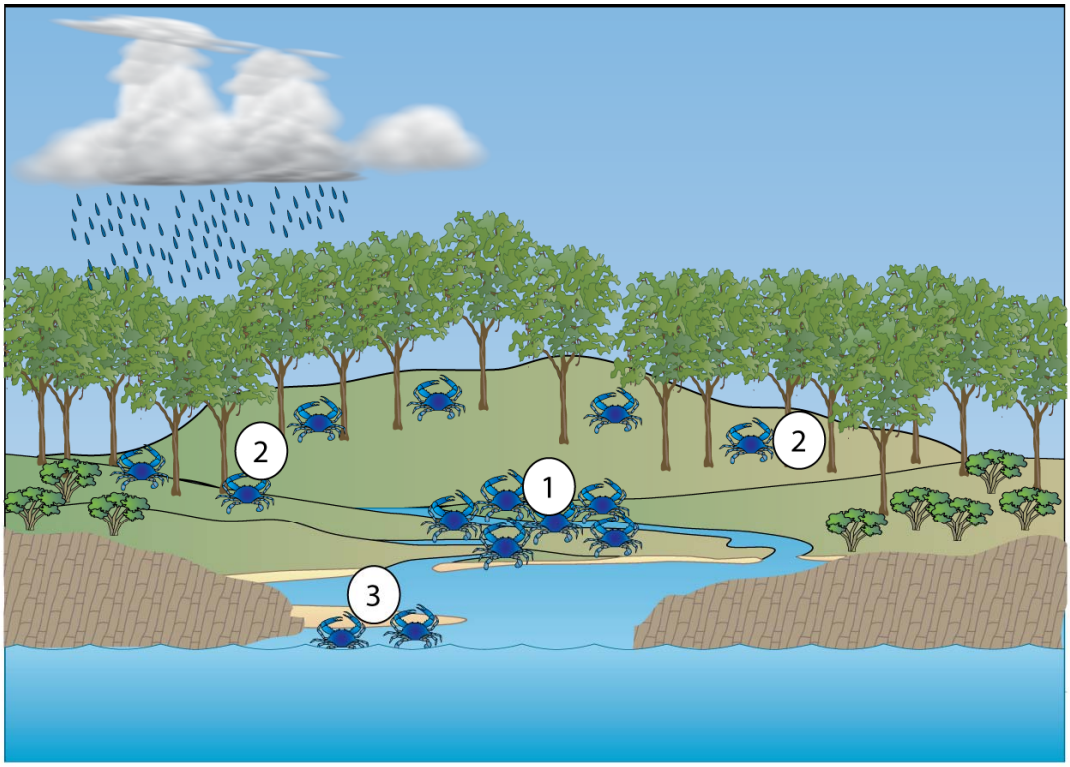
Blue crabs (Figure 16) although often referred to as land crabs are in fact amphibious as they can only exist in areas where their burrows can reach the water table (Greenaway 1989). Whilst derived from marine origins, and retaining a marine larval stage, this species is reliant on freshwater (Greenaway 1989). Little is known about blue crab reproduction, juvenile recruitment and inland dispersal. Hicks et al. (1984) suggest that blue crabs require a freshwater connection to the sea to facilitate juvenile migration, having observed tens of thousands of megalopae swim up the freshwater streams of The Dales to settle and undergo their first moult. Juvenile blue crabs have been observed to live in and around adult burrows, occasionally building their own burrows (Hicks et al. 1984).

Blue crabs exhibit a dichotomous distribution in response to rainfall (Morris 2005, Turner et al. 2009). In the dry season blue crabs are restricted to seepage areas and springs, but in the wet season can disperse away from the permanent freshwater sources (Hicks et al. 1984; Turner 2007; Turner et al. 2009). As such, The Dales represent a strong hold for the species on the island.

The ecology and behaviour of the blue crabs is dictated by the seasonally variable rainfall and is linked to mechanisms of ionic and osmotic regulation (Morris 2005; Turner et al. 2009). Blue crabs (similar to all land crabs of the Gecarcinidae family) have both gills and lungs for respiration. The former do not require surface water, but gills need to be kept moist to function properly. Urine is passed over the gills to maintain moister levels for respiratory function and for the renal (kidney) function of removing salts (Greenaway 1989). It has been suggested that while gas exchange could be maintained in the absence of surface water, blue crabs need to immerse in freshwater at least once a week to remove excess nitrogen from gill surfaces (Turner 2007; Turner et al. 2009).

Figure 16: Blue crab *Discoplax hirtipes* (photograph by Daniel Simon).

During the wet season there is sufficient surface water in forests to maintain gill functioning in blue crabs and they can range over large areas of Christmas Island. However, during the dry season they are restricted to permanent freshwater sources, such as that provided at The Dales (Hicks et al. 1984; RIS 2002). The Dales are considered critical habitat for the larvae of the blue crab as they move emerge from the ocean, and when the species moults (RIS 2002). The movements of the blue crabs in response to seasonal variability in rainfall are illustrated in Figure 17.



1 Dry season (April-October) crabs are concentrated around springs and seepage areas where they have access to either surface water or their burrows intersect the water table. High densities lead to little to no leaf litter being present on the forest floor, crabs prefer freshly fallen leaves and fruit.

2 Early/onset of wet season crabs disperse throughout the forest and overlap with the red crabs, competing for resources.

3 Mid to late wet season (January-February) the blue crabs begin their breeding migration, with females spawning in the ocean.

Figure 17: Conceptual model of blue crab movements within The Dales.

Red crabs

The annual red crab migration is a biological wonder, with tens of millions of crabs moving across the island during their breeding migration. Estimates of the number of red crabs on the island vary considerably. The first comprehensive study of crab abundance was done as part of the first Island Wide Survey in 2001, by which time yellow crazy ant supercolonies had already had a significant impact. Using data on crab density in uninvaded forest (75 percent of survey records), and extrapolating to the whole island, the number of adult crabs immediately before widespread invasion by yellow crazy ant was tens of millions. Present estimates put numbers at about 40-50 million (P. Green, Latrobe University pers. comm.). This represents a significant decline in numbers across the island, due to the impacts of the yellow crazy ant (*Anoplolepis gracilipes*) (see section 5). Due to its dominance in numbers and biomass the red crab plays a highly influential role in the ecology of the island.

As mentioned above, red crabs are one of the larger species found on the island with individual weights of 500 grams or more (Green 1997). The primary habitat for the red crab is the rain forest where densities can range from 0.4 – 1.8 crabs per metre squared with biomass estimates of up to 1519 kilogram per hectare (O'Dowd and Lake 1991; Green 1997). They feed on fallen leaf litter, fruit and seeds removing large amounts of litter from the forest floor, removing between 39 and 87 percent of the annual fall from the forest floor (Green et al. 1999). In some places the forest floor can appear completely clear of plant matter (O'Dowd and Lake 1989, 1991) which has been attributed to their high biomass compared to other litter invertebrates (Green et al. 1999). The red crab is considered a keystone species on the

island for its role as an ecosystem engineer and consumer (Green et al. 1999; Green et al. 2008) (see section 4.3.5 and 4.3.7 for more detail). Red crabs not only consume leaf litter, they also redistribute it across with the forest floor, moving leaf litter into and around their burrows resulting in areas with localised higher concentrations of organic matter and nutrients (O'Dowd and Lake 1989). The presence of litter around and in burrows may be a means of sequestering food and also modifying the microenvironment of the burrow, potentially increasing or maintaining humidity (O'Dowd and Lake 1989; Green 1997, 2004).

Red crabs are susceptible to desiccation and show clear relationships between activity, rainfall and humidity (Green 1997). Levels of activity are highly seasonal, with most activity occurring in the wet season into the early dry season and periods of daily rainfall, with low activity corresponding to periods of low relative humidity, ambient temperature and rainfall (Green 1997). Peak densities of active crabs correspond to the breeding migration of the crab, with lower densities of active crabs being recorded during moulting, when crabs stay in their burrows (Green 1997). Activity patterns are also predictable on a daily basis with a diel activity pattern exhibited by the red crabs, feeding mainly throughout the day and being inactive at night (Green 1997).

Quantitative data for red crab burrow density from the 2009 island wide survey (Figure 18) illustrates that occupied burrows occur at a greater density in the northern half of the site, in the vicinity of No. 1 Dale and Hugh's Dale which are permanently flowing systems. Continued monitoring of this type (50 metre transects) in future surveys could inform against change in character.

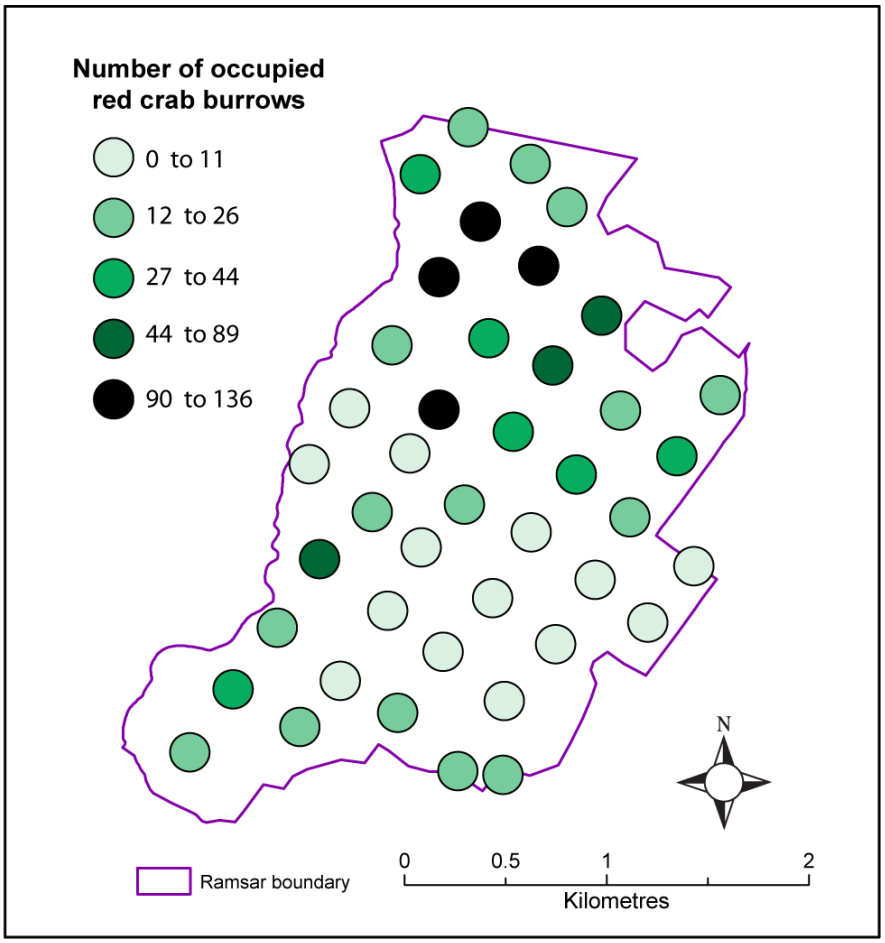


Figure 18: Red crab burrow density per 50 metre transect within The Dales Ramsar site (2009 island wide survey, data provided by Parks Australia).

3.3.4 Waterbirds

A total of 11 species of waterbird have been recorded within the Ramsar site which contributes to the sites listing as a Wetland of International Importance (Appendix B). This includes six species that are listed under international migratory agreements CAMBA (5), JAMBA (4) and ROKAMBA (1). Nine species are listed as marine under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). There are two species that are considered threatened at the national and international scales; the Abbott's booby (Endangered) and the Christmas Island frigatebird (Vulnerable) (see section 4.3.4). Significantly, of the 20 species recorded in the site, nine are endemic species.

The majority of birds on Christmas Island are seabirds that live predominantly out at sea, utilising the island for breeding. Abbott's booby breeds within the site (see section 4.3.4) as do red-footed booby (*Sula sula*) (Figure 19) and the brown booby (*Sula leucogaster plotus*). The red-footed booby is the most common breeding seabird on Christmas Island, nesting along the shore terrace around the whole island, including The Dales (RIS 2002; EWL Sciences and Tallegalla Consultants 2005). Red-footed boobies, the smallest of the boobies, build their nest in trees making nests from sticks and branches, lay a single egg per season and often feed at night in groups. The feeding behaviour is a possible defence against prey theft by frigatebirds. Kleptoparasitism, meaning parasitism by theft, involves the stealing of resources such as food, nesting material, or other resources from another species. Frigatebirds are known to exhibit this behaviour, harassing and stealing food from other seabirds.

The brown-footed booby nest on the ground in the coastal terrace, on the sea cliffs and inland cliffs (RIS 2002; Director of National Parks 2002). Brown boobies nest in colonies, typically building nests in open areas using grass, branches, and other debris to build their nests. They are the only booby to build their nests on the ground. Brown boobies lay two eggs, however siblicide, where one chick kills the other, is common.

The great frigatebird (*Fregata minor minor*) nests in colonies in trees on the shore terraces all around the island and the common noddy (*Anous stolidus pileatus*) nests on ledges along the seacliff and in trees along the shore terrace. The red-tailed tropicbird (Figure 19) or silver bosun (*Phaethon rubricauda westralis*) nests in depressions along the coastal and inland cliffs while the endemic sub-species of white-tailed tropicbird, the golden bosun (*Phaethon lepturus fulvus*) (see front cover), uses tree and cliff hollows all over the island (http://www.environment.gov.au/parks/christmas/nature-science/fauna/birds.html) .

Data on numbers of birds and breeding specific to the site are not available and as such there are insufficient data to determine levels of variability or mean numbers of birds. This is a key knowledge gap for the site.

Figure 19: Red-footed booby *Sula sula* (left) and red-tailed tropicbird (right) Christmas Island. © I. Montgomery, Birdway.

4 Critical Ecosystem Services

4.1 Overview of benefits and services

Ecosystem benefits and services are defined under the Millennium Ecosystem Assessment definition of ecosystem services as "the benefits that people receive from ecosystems" (Ramsar Convention 2005, Resolution IX.1 Annex A). This includes benefits that directly affect people such as the provision of food or water resources as well as indirect ecological benefits. The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005) defines four main categories of ecosystem services:

1. **Provisioning services** - the products obtained from the ecosystem such as food, fuel and fresh water;
2. **Regulating services** – the benefits obtained from the regulation of ecosystem processes such as climate regulation, water regulation and natural hazard regulation;
3. **Cultural services** – the benefits people obtain through spiritual enrichment, recreation, education and aesthetics; and
4. **Supporting services** – the services necessary for the production of all other ecosystem services such as water cycling, nutrient cycling and habitat for biota. These services will generally have an indirect benefit to humans or a direct benefit over a long period of time.

There is no evidence to substantiate a case for provisioning or regulating services within The Dales Ramsar site. The site is wholly contained within a national park and the site is protected from resource harvesting. In addition, the small size of the site and its remote location makes it unlikely to play a substantial role in regulating the surrounding environment. The cultural and supporting ecosystem benefits and services of The Dales Ramsar site are outlined in Table 10 below.

4.2 Identifying critical ecosystem services and benefits

The critical ecologically based ecosystem services and benefits of the Ramsar site have been identified using the same criteria provided by DEWHA (2008) for selecting critical components and services. These are services that:

1. are important determinants of the site's unique character;
2. are important for supporting the Ramsar or DIWA criteria under which the site was listed;
3. for which change is reasonably likely to occur over short or medium time scales (less than 100 years); and/or
4. that will cause significant negative consequences if change occurs.

Using these criteria it was considered that the majority of the supporting services (i.e. those that are ecologically based) could be considered "critical" (see Table 10). The site was initially thought to provide a drought refuge, however on consultation with expert ecologists familiar with the site it was judged that this was not a critical service for the site.

Supporting priority wetland species is not considered a critical service as the majority of JAMBA/CAMBA/ROKAMBA listed species (Appendix B) that occur on the island have not been shown to preferentially use the site. Physical habitat for supporting waterbird breeding could be considered an essential service, but not critical. The main waterbird of note within the site is the Abbott's booby, and this species and its habitat requirements are covered under the service of supporting threatened wetland species. Physical habitat is described in section 3.2.3, 3.3.1, 3.3.2 and 4.3.1.

Recreation and tourism were not considered critical to the ecological character of the site, despite being one of the main recreational destinations on the island. While the site is undoubtedly beneficial in terms of providing opportunities for scientific research this was not considered a "critical" service in that a reduction in research interest would not necessarily indicate a change in ecological character. However whilst not critical, cultural services are considered important for The Dales Ramsar site and so have been briefly described in section 4.4.

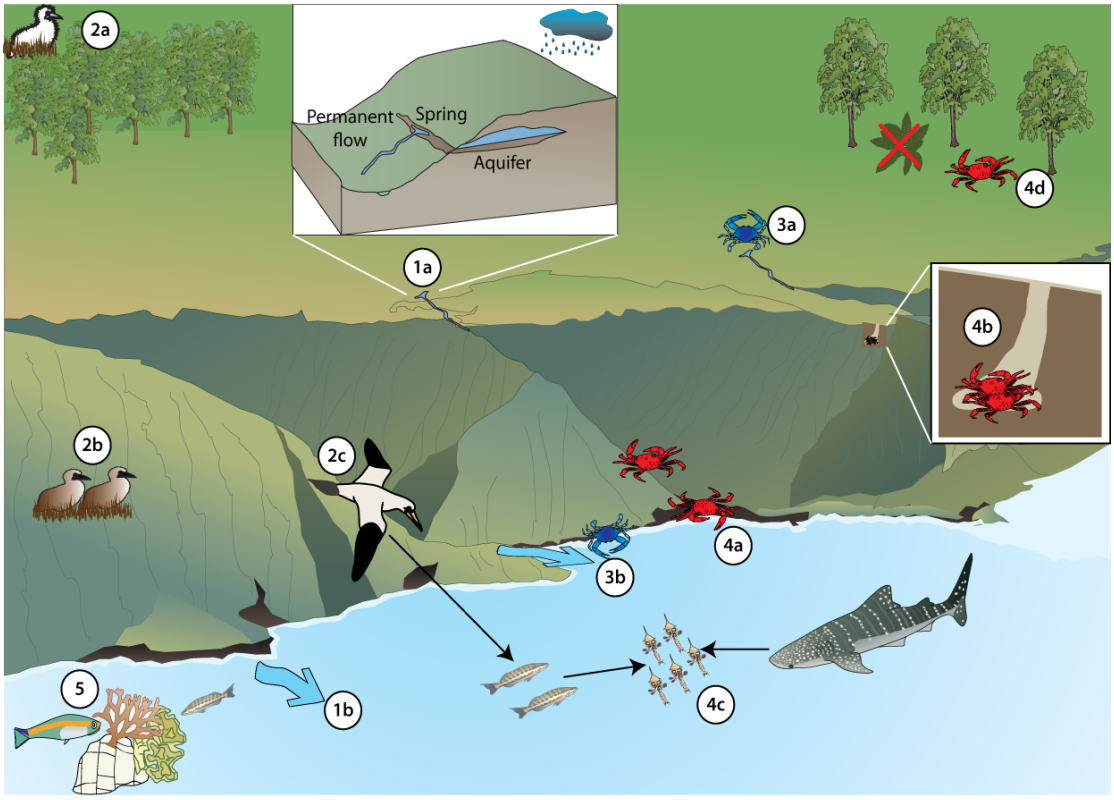
Table 10: Ecosystem services and benefits provided by The Dales Ramsar site at the time of listing. Shaded services indicate those considered critical to the ecological character of the site.

Category	Description
Cultural services	
Recreation and Tourism.	The Dales is a popular recreational area for both tourists and locals. Two timber board walks have been installed at No. 1 Dale and Hugh's Dale. The Dales is the most popular sight seeing destination on the island with the waterfall at Hugh's Dale being the greatest attraction.
Science and education.	Parks Australia undertakes and supports a range of research programs across the National Park, many of which are directly relevant to The Dales. For example research investigations include impacts of the yellow crazy ant, land crab ecology and the Abbott's booby.
Supporting services	
Food webs.	Crab spawning provides a rich food supply to marine biota including whale sharks. In addition the land crabs play a significant role in the energy dynamics of the forest affecting seedling recruitment and ultimately the structure of the forest. The invasion of the yellow crazy ant has significantly affected trophic relationships on Christmas Island.
Provides physical habitat (for breeding waterbirds).	Terrestrial vegetation provides roosting and breeding sites for several species of waterbirds.
Biodiversity.	Supports a variety of wetland species, communities and habitats including marine, terrestrial and freshwater dependent species.
Special ecological, physical or geomorphic features.	Provides critical habitat for the blue crabs and freshwater crabs, provides examples of karst features such as tufa deposits at the Hugh's Dale waterfall, and possibly anchialine cave communities.
Distinct or unique wetland species.	Red crabs are considered keystone species on the island.
Threatened wetland species, habitats and ecosystems.	The Dales Ramsar site supports nesting sites for the endangered Abbott's booby. The Christmas Island frigatebird has also been recorded from the site.
Priority wetland species.	Christmas Island supports a number of vagrant species listed under various international agreements.
Supports near-natural wetland types.	Springs and karst systems are representative of the bioregion and considered in near natural condition at the time of listing.
Ecological connectivity.	The streams of The Dales provide critical migration pathways for downward migration of red, blue and robber crabs and return pathways for juvenile blue crabs in particular.

4.3 Critical supporting services

This section documents the critical supporting ecosystem services and how they interact (often overlap) with the critical components and processes found at The Dales. The Dales, and Christmas Island in general, are renowned for their biodiversity and the diversity of habitat present, a direct consequence of the unusual geomorphic setting and hydrology of the site. The habitat template along with the biogeography of the island creates the foundation from which many of the services are derived. It is important to note that in many instances the

services equate to functions or processes, a separation that is often difficult to make. For example the red crabs are a critical component, are involved in critical processes (food webs, keystone consumer) and in critical services (keystone consumer, migration/ecological connectivity) – the boundaries between these elements are not always clear cut. The simple conceptual model (Figure 20) shows the key elements which make The Dales a truly unique wetland system.



1. Hydrology
a. Groundwater is recharged during the wet season resulting in permanent flow at spring fed Dales.
b. Groundwater discharge under the sea surface in anchialine systems.

2. Seabirds
a. Abbott's booby nest in the trees on the plateau.
b. Common noddy nest in colonies on the seacliffs.
c. Seabirds feed in the rich waters off the coast.

3. Blue crabs
a. Are restricted to vicinity of the permanent freshwater streams in the dry season.
b. Use the Dales as a migratory route to the shore to breed.

4. Red crabs
a. Use the Dales as a migratory route to the shore to breed.
b. Mate in burrows on the shore terrace.
c. Large biomass of red crab larvae are a food resource for whale sharks and other fish.
d. Red crabs control forest structure on the shore terrace and the plateau, feeding on seeds, fruits, seedlings and litter; maintaining low cover in the understorey.

5. Coral communities
High degree of diversity, endemism and hybridisation in marine fish communities.

Figure 20: Conceptual model showing key elements of the ecological character of The Dales Ramsar site.

4.3.1 Natural or near natural wetland ecosystems

As detailed in section 2.5, The Dales Ramsar site contains a number of wetland types that by virtue of the remote location, limited access, terrain and protected status of the site can be considered in near natural condition. The wetland types present in the site are brought about

predominantly by interactions between geomorphology/geology and hydrology. Very little data is available to describe the inland aquatic wetland types found at The Dales, and general ecological theory has been used to detail potential linkages between wetland type and critical components and processes. This ecosystem service is closely linked with all other services as it represents the physical habitat template or the variety of wetland types, which support the critical components, processes and other ecosystem services.

Marine wetland types

Four marine wetland types are found within the site, coral reefs (type C), rocky marine shores including sea cliffs (type D), sandy beach areas (type E) and marine/coastal karst (type Zk(a)). The karst wetland type is discussed in a separate section below.

Fringing Christmas Island is a narrow, sloping, coral reef which extends 20 – 100 metres from the shoreline (an average width of 79 metres) reaching up to 20 metres deep. Beyond the shallow water the reef drops quickly to depths of greater than 4000 metres (Gilligan et al. 2008; Hobbs et al. 2008). The site boundary of the Ramsar site extends to 50 metres on the seaward side of the mean low water mark and therefore incorporates part of this sloping reef within the boundary of the site. Data on the reef structure is limited however data from a transect at Sydney's Dale indicates a composition of approximately 37 percent hard corals (seven types) four percent soft coral, 58 percent abiotic cover including approximately 30 percent dead hard coral (Gilligan et al. 2008) (see section 3.2.4 for more detail).

Rocky marine shores, rocky platforms and sea cliffs are characteristic of the coastal zone for Christmas Island including The Dales. Within the Ramsar site there is only a small area of sandy beach, Merial Beach, north of No. 1 Dale and a sandy area at the mouth of Darling Dale (RIS 2002). Rocky platforms are identified as important habitat and safe spawning sites for several of the land crabs, most notably the red and blue crabs (RIS 2002).

Sea cliffs are a distinctive habitat on the island, averaging 10 - 20 metres high (RIS 2002). They are exposed and harsh environments with vegetation adapted to salt spray, and provide nesting habitat for a number of species of birds (see section 4.3.3). The rocky marine shores include areas of karren or phytokarst (see below).

Inland wetland types

The inland wetland types present are either dependent on the karst drainage systems (groundwater dependent) or rainfall dependent systems. The groundwater dependent wetlands include No. 1 Dale, Hugh's Dale, and Anderson Dale springs (type Y), perennial streams (type M) with associated permanent freshwater pools, and freshwater seasonally flooded forest (type Xf) at Hugh's Dale which supports a monodominant stand of Tahitian chestnut. Hugh's Dale waterfall has a 10 metre drop and is a popular tourist attraction at the site. The stand of Tahitian chestnut trees is below the falls. The springs all occur in the Shore Terrace at the juncture of exposed basalt rock.

Darling Dale, No. 4 Dale, Sydney's Dale and No. 7 Dale are intermittent systems reliant on seasonal rainfall and local runoff, only flowing after heavy rainfall events. These Dales include seasonal intermittent streams (type N) with associated remnant freshwater pools when they cease to flow. These systems typically have surface water for days to weeks depending on the intensity of rainfall events, only remaining on the surface where the streams run over basalt and percolating underground where they go over limestone (RIS 2002).

Karst wetlands

The geology and geomorphology of The Dales, and Christmas Island in general, is presented in section 3.3.1 above. To recap, the island is a limestone covered basaltic volcano which rises 4.5 kilometres from the sea floor. Due to the steady uplift of the island (Grimes 2001) a series of emergent marine terraces have been formed (Humphreys and Eberhard 2001). Within the two lower terraces that anchialine systems appear.

Anchialine systems are variably defined (e.g. Grimes 2001; Expert Working Group 2009; Culvern and Pipan 2007), but are essentially interfaces between marine and inland waters, described by Humphreys and Danielopol (2006) as groundwater estuaries. They are coastal

systems, with the word anchialine literally meaning *near the sea*. Many coastal caves on Christmas Island are anchialine, although not all. Within The Dales a rift and a large sea cave entrance in Sydney's Dale has been identified (Humphreys and Eberhard 2001; K. Grimes pers. comm.). There are several submerged and open sea caves on the west coast near The Dales.

Grimes (2001) described surface, subsurface, inland and coastal karst features in his paper on the karst of Christmas Island. The springs found at The Dales (and elsewhere on the island – see above) are classified as surface karst features (Grimes 2001). Other surface karst features found within The Dales are the tufa deposits below the Hugh's Dale waterfall, and karren (or phytokarst) along the coastline. Grimes (2001) describe The Dales themselves as karst features, being narrow ravines cut into the shore terrace which form deep fissures close to the coast. Drivers Cave, located within The Dales is a small fissure or cleft down the side of rock and may be an abandoned relic of an old cave system in the side of the Dale (K. Grimes, pers. comm.). Spate and Webb (1998) mention several other small caves as being accessed from the track to The Dales, including a small cave near Anderson Dale.

4.3.2 Biodiversity

Island biodiversity values are quite different to mainland biodiversity values with the biogeography of isolated oceanic islands playing an important role. Key features of island biodiversity exhibited on Christmas Island are summarised in (Table 11).

Table 11: Biodiversity characteristics of Christmas Island (modified from EWL Sciences and Tallegalla 2005)

Island biodiversity characteristics	Examples from Christmas Island (list not exhaustive)
The biota is usually relatively simple and species depauperate compared to corresponding areas on continental or 'island-chain' landmasses.	Flora and fauna are depauperate reflecting isolation from potential sources of colonists.
Endemic species are more abundant and often comprise a greater proportion of the total biota.	Island wide the plant endemic species is not as high (18 species of 242) but may reflect a stable environment. However, vertebrate endemism is very high. Endemism in the invertebrate fauna is not known.
Many species and species groups fill atypical ecological roles and or occupy habitats that would be dominated by very different groups of organisms on larger more interconnected landmasses.	Mangrove stand at Hosnies Spring. Red crabs are keystone consumers.
Individual species may dominate a trophic level that elsewhere would be occupied by many species.	Red crabs as keystone consumers.
Biological invasions are a pervasive feature and represent a fundamental long-term change in the dynamics and population structure of the biota.	Yellow crazy ant – scale insect infestations leading to supercolonies; giant African land snail, wolf snake. Introduced plant species constitute 42 percent of plant species.
Island species, especially endemics, are more vulnerable to extinction as a consequence of biological invasions and anthropogenic changes than are the more 'resilient' populations of biota of continental and interconnected landmasses.	Endemic species are particularly vulnerable as there is no possibility of immigration. The Christmas Island pipistrelle (*Pipistrellus melanotis*) is a prime example.

Christmas Island, incorporating The Dales, biodiversity value does not arise from high species richness, but rather from a unique combination of species and ecosystems, in particular the crab – forest community (Expert Working Group 2009). The habitat template for

the island, and The Dales, is complex ranging from terrestrial rain forest, freshwater wetlands, karst habitats, including inland surface, subterranean and aquatic systems, through to fringing coral reefs. This diversity of habitat sets the stage for some truly unique associations and biodiversity values. For example there are a high number of endemic species present on the island, unusual associations such as supporting eight seabird species which breed on the island, a unique stygofauna, the marine bioregion may be a potential centre of hybridisation for fish species, and the island is home to the world renowned migration of the red crab.

It has been postulated that given the high level of endemism in the higher taxa that it is probably that there is also a high level of endemism in the lower fauna of the island as well (Expert Working Group 2009).

4.3.3 Special ecological, physical or geomorphic features

Anchialine fauna

It is possible that The Dales supports this unique element of biodiversity at the site; however no site specific information is available. Section 3.2.6 describes the basic elements of the stygofauna.

Tufa deposits

One of the most visited sites on Christmas Island is the waterfall at Hugh's Dale where significant tufa has formed. Tufa is chemical sedimentary rock composed of calcium carbonate precipitated from the freshwater springs (Onton and Forbes 2009), and is considered a surface karst feature by Grimes (2001). Tufa is formed through both biochemical (precipitation of calcium carbonate) and biological processes including growth and metabolic activity of a range of microbial organisms, including cyanobacteria, diatoms and other algal (Onton and Forbes 2009). Tufa are unusual in that they are formed under flowing water but do not erode, but rather grow or undergo agrradation (Ford and Pedley 1996). Potential threats to the tufa include damage from increased recreational activities, changes to hydrological regime and altered water quality including alkalinity, pH and nutrients. The tufa at Hugh's Dale is a perched springline formation or slope system (Ford and Pedley 1996). These types of tufa formations typically include lobate or multilobate, convex to flat surfaced deposits which thicken away from the source. On the steeper faces of such formations, where tufa growth is the fastest, there are often microterraces, gutter cascades and gullies (Ford and Pedley 1996) (Figure 21).

Tahitian chestnut stand – Hugh's Dale

Monodominant stands of Tahitian chestnut *Inocarpus fagifer* which occur at Hugh's Dale and south of Dolly Beach on the east coast of the island are considered unique in the bioregion. Monodominance is the exception rather than the rule for this species, making the 'core' of The Dales Ramsar site even more unusual. In its range across the Pacific this species is predominantly found along banks of freshwater streams and in brackish swampy areas. It is usually a minor component of the canopy with only one other study describing the same degree of monodominance found in The Dales (Wiser et al. 2002) (P. Green, La Trobe University, pers. comm.).

Figure 21: Tufa deposits at Hugh's Dale waterfall (photograph by Daniel Simon).

4.3.4 Supports threatened species

Two listed species occur within The Dales, the Abbott's booby (*Papasula abbotti)* (Figure 22Figure 22) is listed as endangered, marine and migratory under the EPBC Act. The second species is the Christmas Island frigatebird (*Fregata andrewsi*) (Figure 22) which is the rarest endemic seabird on Christmas Island and is listed as vulnerable, marine and migratory under the EPBC Act as well.

Figure 22: Abbot's booby (*Papasula abbotti*) (left) Christmas Island frigatebird (*Fregata andrewsi*) (right), © Ian Montgomery, Birdway.

Abbott's booby

Abbott's booby is also listed as endangered on the IUCN Red List (IUCN 2009) and is considered one of the most endangered seabirds in the world, with an estimated population of only 5000 (Wetlands International 2006; Hennicke 2007). Being a marine species the seabird, Abbott's booby only comes ashore to nest and breed. Christmas Island is the only extant breeding colony, and the first proclamation of national park in 1980 on Christmas Island was to protect the Abbott's booby (Director of National Parks 2008).

The species nests in the canopy of the tall emergent rainforest trees in the western, central and northern portions of the island (Reville et al. 1990; DEH 2004). Within The Dales the nesting sites occur in the vicinity of the eastern and north eastern boundaries. Nest trees are typically associated with rough terrain and influenced by topography and the nature of the canopy, mainly occurring at elevations above 150 metres on the northwest sides of slopes (DEH 2004). Tree species favoured for nesting include *Syzygium nervosum* and *Planchonella nitida* which form irregular canopies (Yorkston and Green 1997), particularly on the south western areas of the island which are protected from the southeast trade winds which blow throughout the dry season. Yorkston and Green (1997) recorded nesting sites in four other tree species including *Celtis timorensis*, *Tristiropsis acutangula, Ficus microcarpa* and *Pongamia pinnata.* Abbott's booby show distinct preferences for sheltered sites locating their nests in the northwestern sector of the canopy of trees (Reville et al. 1990; Yorkston and Green 1997).

Abbott's booby form long term pairings and exhibit high fidelity to a nest site, returning to the same nest each breeding event. Nesting densities are typically less than five pairs per hectare, with each pair occupying its own tree, however several pairs have been observed in the one nesting tree (Commonwealth of Australia 2001). Breeding commences in March with eggs being laid between April and October, with most pairs laying between May and July. Pairs typically breed once every three years or longer, with 80 percent of successful breeders following this pattern (Yorkston and Green 1997); however a small number will successfully breed in the second year providing young from the first year are independent in June or July (Commonwealth of Australia 2001). Unsuccessful breeding events can lead to a nesting site being moved (Reville et al. 1990). If sites are moved, they are generally not far from the

original site, and as such it may take a number of years for a breeding pair to move away from an area of disturbance (Reville et al. 1990; Commonwealth of Australia 2001).

Young hatch between June and November and are brooded by the adults on the top of the webs of the feet, taking food directly from their parent's mouth (Commonwealth of Australia 2001). Down appears at six to seven weeks and the hatchling stays at the nest site for approximately five months and a further seven and a half months in post-fledging dependency. During this time the fledglings will return to the nest to be fed once or twice a week by both parents (Commonwealth of Australia 2001). The breeding cycle, from hatching to independence takes approximately 16 months to complete (Yorkston and Green 1997; Commonwealth of Australia 2001). Overall breeding success is low with less than 50 percent breeding attempts resulting in a fledgling entering the population (Commonwealth of Australia 2001).

Abbott's booby is predominantly a pelagic feeder similar to other sulid seabirds, however recent research has shown that during the early reproductive phases foraging is often restricted to the waters immediately surrounding Christmas Island. Foraging behaviour is different to other seabirds, even closely related species (Hennicke 2007). Whilst rearing chicks adult birds have been shown to utilise only a small area of eastern Indian Ocean, with foraging trips lasting on average, 4.1 hours, with an average radial distance from Christmas Island of 36 kilometres (Hennicke 2007). Fish prey are non commercial, however the seabirds often take advantage of large predatory fish, such as tuna and billfish, driving their prey closer to the surface. Unsustainable fishing of these predatory species may have impacts on the foraging success of Abbott's boobies (Hennicke 2007). Foraging behaviour is summarised in Figure 23.

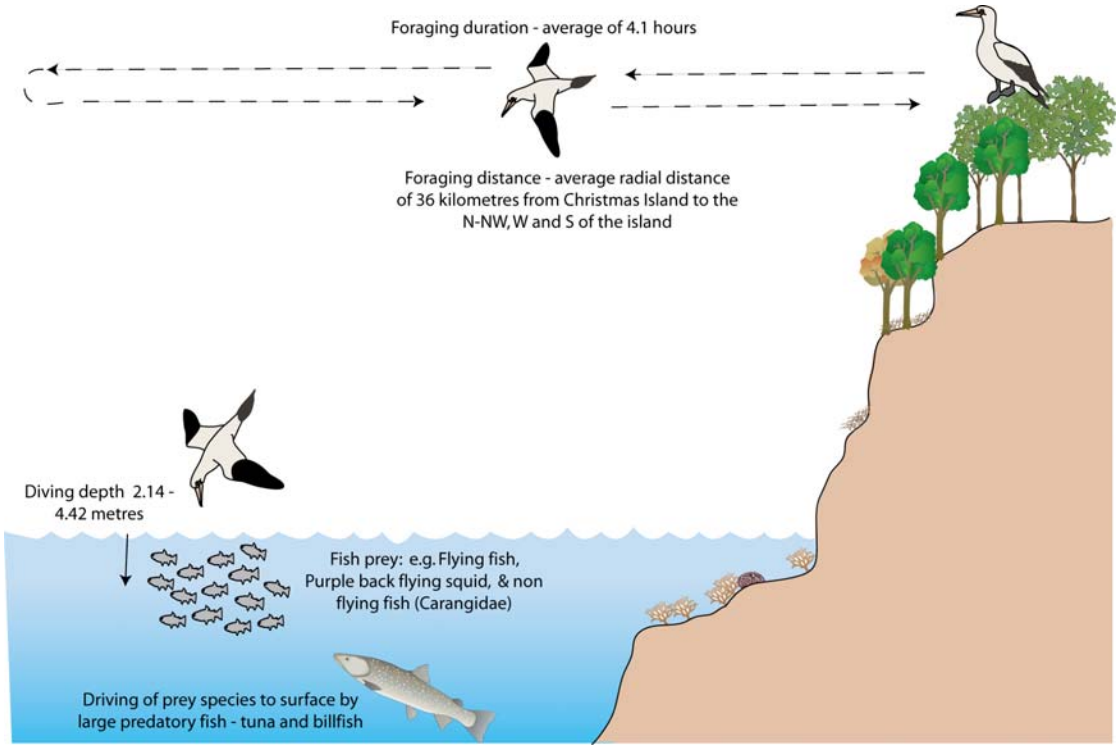


Figure 23: Foraging behaviour of Abbott's booby during reproductive cycle (based on information extracted from Hennicke 2007).

The critical components and processes that are important for sustaining the Abbott's booby are therefore, intact terrestrial vegetation communities with protected emergent canopy of six key species of trees (nesting habitat); the fringing marine zone of up to 36 kilomtres (foraging habitat) and the interaction between seabirds, and primary / secondary production which provide adequate food resources for the population (Figure 23).

Christmas Island frigatebird

The Christmas Island frigatebird (*Fregata andrewsi*) (see Figure 22 above) is the rarest endemic seabird on Christmas Island and is listed under JAMBA and CAMBA and as Vulnerable under the EPBC Act. It is the smallest of the three frigatebirds found on Christmas Island and breeds in three locations on the opposite side of the island to The Dales (Hill and Dunn 2004). However the species has been recorded at The Dales, although the relative importance of the Ramsar site to the species is unknown.

Frigatebirds are seabirds with morphologically adaptations for a highly specialised type of aerial feeding which affects their entire breeding ecology and behaviour, with all species having extremely prolonged breeding cycles (Hill and Dunn 2004). Foraging behaviour includes scooping up marine organisms or offal floating on the surface of the ocean or by harassing other seabirds, notably boobies, to disgorge or release their catches (Hill and Dunn 2004).

4.3.5 Distinct or unique wetland species – red crabs as keystone species

The red crab is considered a keystone consumer which regulates seedling recruitment across the island, independent of forest type and plant species composition. Red crabs are ubiquitous across the island and their impacts override all other factors influencing seedling abundance such as variation in light environment, microclimate and topography, litter and soil characteristics (Green et al. 2008). Exclusion experiments over a six year period clearly displayed the transformation of forest devoid of seedlings to one dominated by numerous seedlings, saplings and a persistent layer of litter (Green et al. 2008). The effects illustrated by exclusion of red crabs by researchers have been duplicated at the landscape scale through the impacts of yellow crazy ant (*Anoplolepis gracilipes*). Areas where supercolonies have eliminated the red crabs have undergone transformation with seedling recruitment, establishment of saplings and litter (see Figure 24).

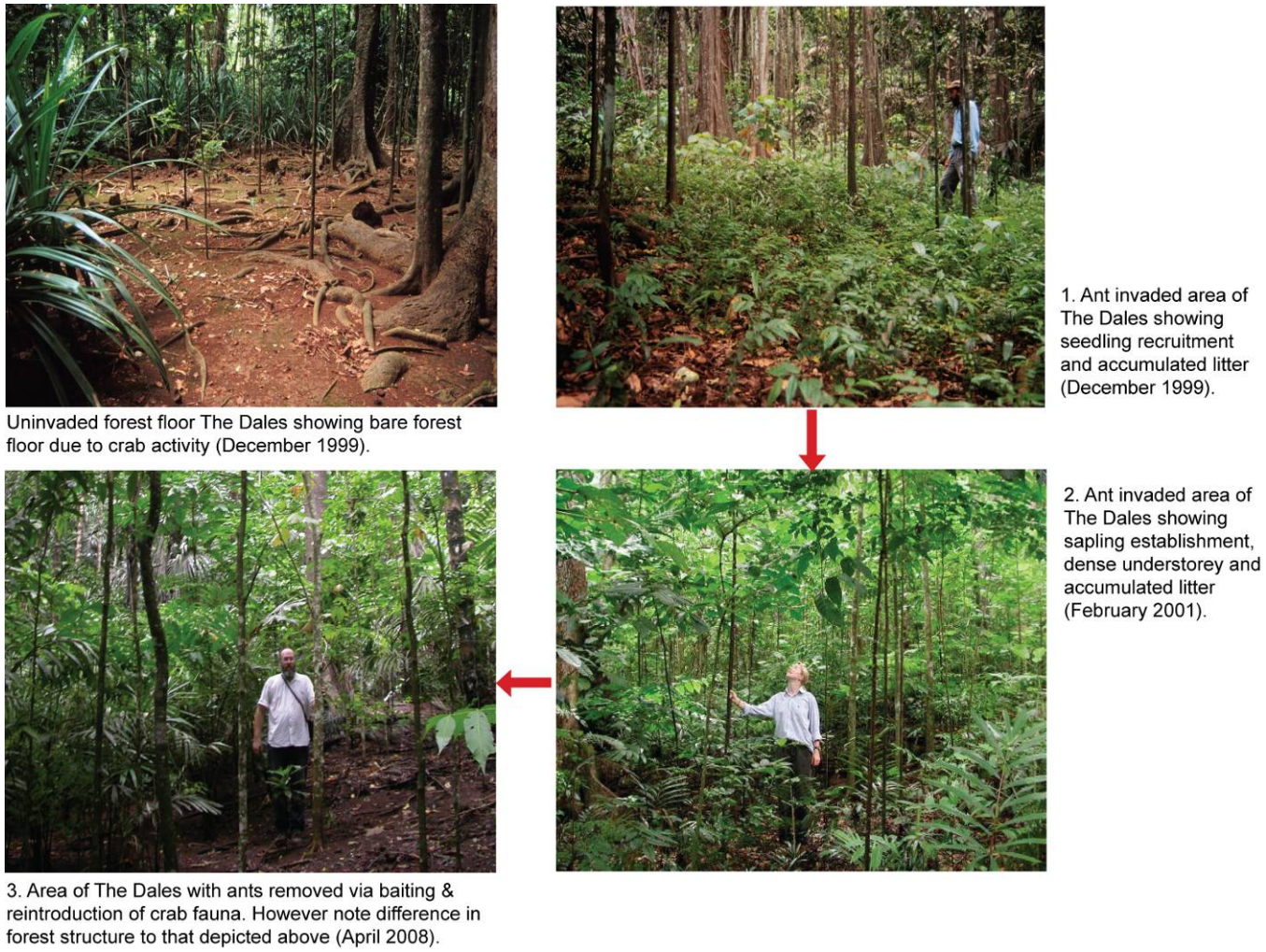


Figure 24: Loss of keystone species, red crabs, via yellow crazy ant predation in The Dales leading to changes in forest floor structure and composition. Diagram courtesy Peter Green LaTrobe University.

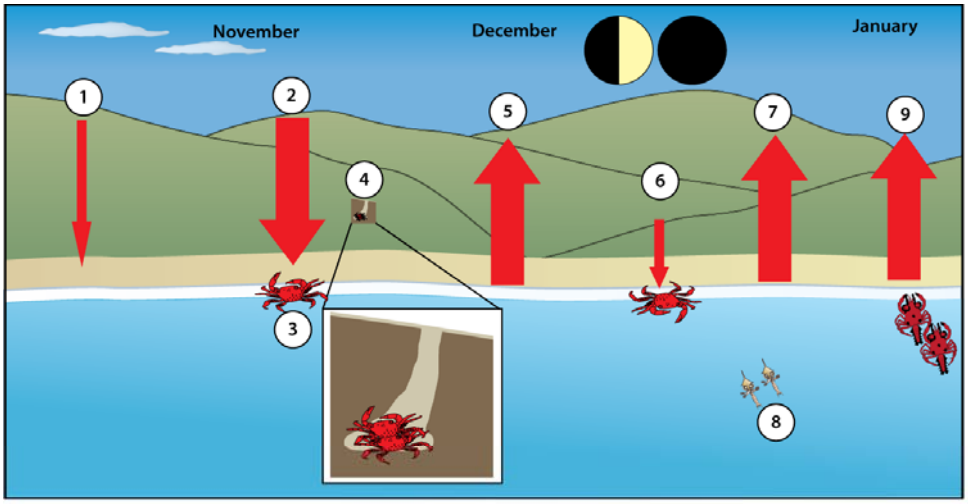
4.3.6 Ecological connectivity – crab migration

Migrating crabs may use the same pathways annually (Adamczewska and Morris 2001), with The Dales providing a major migration pathway for the red crabs moving from the plateau to the ocean during their downward and return legs on the western side of the island (RIS 2002). As discussed above the site is also critical in that it provides the connectivity between ocean freshwater and land for the blue crabs migration (Hicks et al. 1984). The red crab migration is a world renowned phenomenon which is well documented anecdotally (for example Hicks et al. 1984); however no quantitative data is available specific to The Dales. The key phases of the migration are presented below and illustrated in Figure 25.

The breeding season lasts between three to six weeks, is usually synchronised island wide, with adult red crabs entering the migration once they reach three or more years of age and moving en masse from the forest to the ocean. Males depart first followed by the females. Early onset of the rainy season can act as a trigger for early migration; however the actual spawning is set by the lunar phase (Adamczewska and Morris 2001). On arrival at the coast both sexes dip in the ocean with large males arriving first followed by smaller males and females two to three days later. By day four to five, females outnumber the males on the shorelines (Hicks 1985). After dipping males retreat back to the shore terrace to excavate burrows for mating. Dipping also occurs before the males return to the higher terraces and prior to the females returning inland after spawning (Hicks 1985). Fighting over burrows occurs in the shore terrace. After mating the males return to the higher terraces, whilst the females retreat to the burrow to produce the eggs.

The females produce eggs within three days of mating and remain in the breeding burrows for 12 to 13 days while the eggs develop. A single female can brood up to 100 000 eggs. Spawning is tied to the lunar phase and corresponds to a low volume neap tide with females releasing their eggs toward dawn (see Figure 26), around the turn of the high tide. Release of eggs may occur on five to six consecutive nights during the main breeding migration. After the first two days, eggless females may be seen crossing plateau roads, kilometres from the shore (http://www.environment.gov.au/parks/christmas/nature-science/fauna/red-crabs.html).

Eggs hatch into megalopae on release into the ocean and are carried off by the tide, returning after 17 to 28 days. Megalopae accumulate at the tide line for several days before during which time they metamorphose into baby crabs. The baby crabs then begin their migration inland, joining the adult population after three years.



1. Early onset of the wet season can result in early downward migration of red crabs
2. Main migration starts in mid to late November when the wet season has commenced
3. Crabs "dip" in the ocean to take in water
4. Crabs retreat to the shore terrace to dig burrows, where they mate
5. Males return to the plateau following mating, and often another "dip" in the ocean
6. Females travel to the shore and release their eggs into the ocean, this occurs between the last quarter and new moon in December
7. Females return to the plateau following release of eggs
8. Eggs hatch at sea and pass through several larval stages (17 to 30 days)
9. In years of successful reproduction, baby crabs (megalopae) return and migrate up from the ocean in late January

Figure 25: Conceptual model of red crab migration at The Dales (modified from Hicks et al. 1984).

Figure 26: Female red crab releasing eggs into the ocean (photograph by Daniel Simon).

4.3.7 Food webs

There are two major food webs are of critical importance to the character of The Dales Ramsar site: the terrestrial food web dominated by the crab – forest energy pathway, and the marine food web which has two key pathways, the crab spawning and waterbird/fish pathway.

Terrestrial crab-forest food web

Red crabs are the dominant consumers on the rainforest floor with abundances of 0.4–1.8 crabs meter square and 758–1519 kilograms per hectare (Green 1997; Green et al. 2008). As discussed in above, the red crab is the dominant consumer of fruits, seeds, seedlings, and leaf litter on the forest floor (O'Dowd and Lake 1989, 1990, 1991; Green et al. 1997, 1999, 2008). The red crab is around 50 times more common than the next most abundant species of land crab, the robber crab *Birgus latro* (Green 1997; Green et al. 2008).

In areas where blue and red crabs overlap, their habits and dietary preferences appear to utilise different components of the litter fall in the forest, an example of resource partitioning. Blue crabs prefer green, fresh fallen leaves and fruit whereas brown and rotting leaf litter make up the majority of the diet of red crabs (Greenaway and Raghaven 1998). For blue crabs, this may be in part due to their requirement to stay in close proximity to freshwater along seepage areas, which are frequently bare of litter, thus restricting their 'preference' to freshly fallen litter (Greenaway and Raghaven 1998).

Crabs play a central role in redistributing litter in and around burrows (section 3.3.3) (O'Dowd and Lake 1989) thus facilitating nutrient cycling. In plateau forests red crabs turn over less than one percent of surface soils annually (Green 2004) but on the shore terrace during the migration there is near complete turnover of soils annually (Green et al. 2008).

Whilst decomposition of plant material has been shown to be a major nutrient pathway in the forest ecosystem the role of fungi and microorganisms in facilitating nutrient breakdown has not been investigated and is considered a knowledge gap (Expert Working Group 2009).

Marine coastal food web

Seabirds are at the highest trophic level in coastal food webs and can have a significant role in transfer or marine derived nutrients into terrestrial food webs (for example through guano, and via predation and carrion scavenging by terrestrial consumers such as the land crabs). The Christmas Island coastal food web is interesting as it has a strong temporal component linked to the mass spawning of the red crabs. As each mature female red crab can brood up to 100 000 eggs, billions of eggs are released each spawning event. This provides an enormous food resource for marine consumers. Juvenile whale sharks have been reported aggregating offshore in December to March which coincides with the red crab spawning in December, leading to speculation that the species is feeding on the crab larvae (Hobbs et al. 2009). The presence of the whale sharks in the waters immediately off Christmas Island beyond the return of the red crab larvae to land, suggests other food sources are utilised as well (Hobbs et al. 2009). Faecal analysis from a whale shark confirmed that they consume immature crab stages (Meekan et al. 2009). Meekan et al. (2009) suggest that as the whale shark arrival at the island typically lags the actual spawning event that the whale sharks may be preferentially feeding on the older larvae rather than the eggs or newly hatched stages.

4.4 Cultural services

Recreation and tourism were not considered critical to the ecological character of the site, despite being one of the main recreational destinations on the island. While the site is undoubtedly beneficial in terms of providing opportunities for scientific research this was not considered a "critical" service in that a reduction in research interest would not necessarily indicate a change in ecological character. However whilst not critical, cultural services are considered important for The Dales Ramsar site and so have been briefly described in below.

4.4.1 Recreation and tourism

A major attraction of Christmas Island is its natural environment, especially the red crab migration. The National Park, including The Dales, plays a key role in the economic

development of the island as an eco-tourism destination (Director of National Parks 2002). Recreational activities within The Dales include, walking, sightseeing, and the enjoyment of wildlife (Director of National Parks 2002). Since human settlement in 1888 members of the Malay and Chinese communities, in particular, have fished for food and they consider fishing to be part of their cultural lifestyle rather than a recreational pursuit (Director of National Parks 2002). Overall visitor numbers are low and so the pressure from recreation and tourism is considered low. There is, however, increasing use of the site due to recent population increases on the island and potential impacts from recreational activities needs to be monitored.

4.5.2 Scientific research

Considerable research has been undertaken on Christmas Island, with much of the contemporary work beginning in the 1970's. Four research themes are of note (Expert Working Group 2009):

- assessment of the complex ecological relationships and dynamics of the island, focusing particularly on the ecology and ecological role of the red crab;
- assessment of the status of threatened species;
- assessment of non-native pest species and their control; and
- inventory studies that have assessed the impacts of current or proposed developments.

Some of this work has been continued over decades and contributes to the establishment of long term data sets which will ultimately help management of the natural environment on the island. Much of the research has been commissioned, directed, and undertaken by the Parks Australia in collaboration with researchers both from Australia and overseas.

5. Threats to Ecological Character

Island biotas are often naturally-simple systems that can be subject to significant perturbations in short time frames from natural events, exotic species invasions or more complex interactions of an ecological nature (Expert Working Group 2009). From a species perspective oceanic islands have few if any geographic refuges, and as a consequence any major natural perturbation or significant threat that affects populations is likely have a significant impact, as there is little possibility of recovery through re-colonisation (Expert Working Group 2009).

Wetlands are complex systems and an understanding of components and processes and the interactions or linkages between them is necessary to describe ecological character. Similarly threats to ecological character need to be described not just in terms of their potential effects, but the interactions between them. One mechanism for exploring these relationships is the use of stressor models (Gross 2003). The use of stressor models in ecological character descriptions has been suggested by a number of authors to describe ecological character (for example Phillips and Muller, 2006; Hale and Butcher 2008) and to aid in the determination of limits of acceptable change (Davis and Brock 2008).

Stressors are defined as (Barrett et al. 1976):

"*physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level*"

In evaluating threats it is useful (in terms of management) to separate the threatening activity from the stressor. In this manner, the causes of impacts to natural assets are made clear, which provides clarity for the management of natural resources by focussing management actions on tangible threatening activities.

There are a number of potential and actual threats that may impact on the ecological character of The Dales Ramsar site. The stressor model (Figure 27) only illustrates the major threatening activities (boxes), stressors (ellipses) and resulting ecological effects (diamonds) on the components processes and services (hexagons) in The Dales Ramsar site. A description of these major threats is provided below. Note not all threats are described in detail, only those considered likely to have an impact on the ecological character of the site.

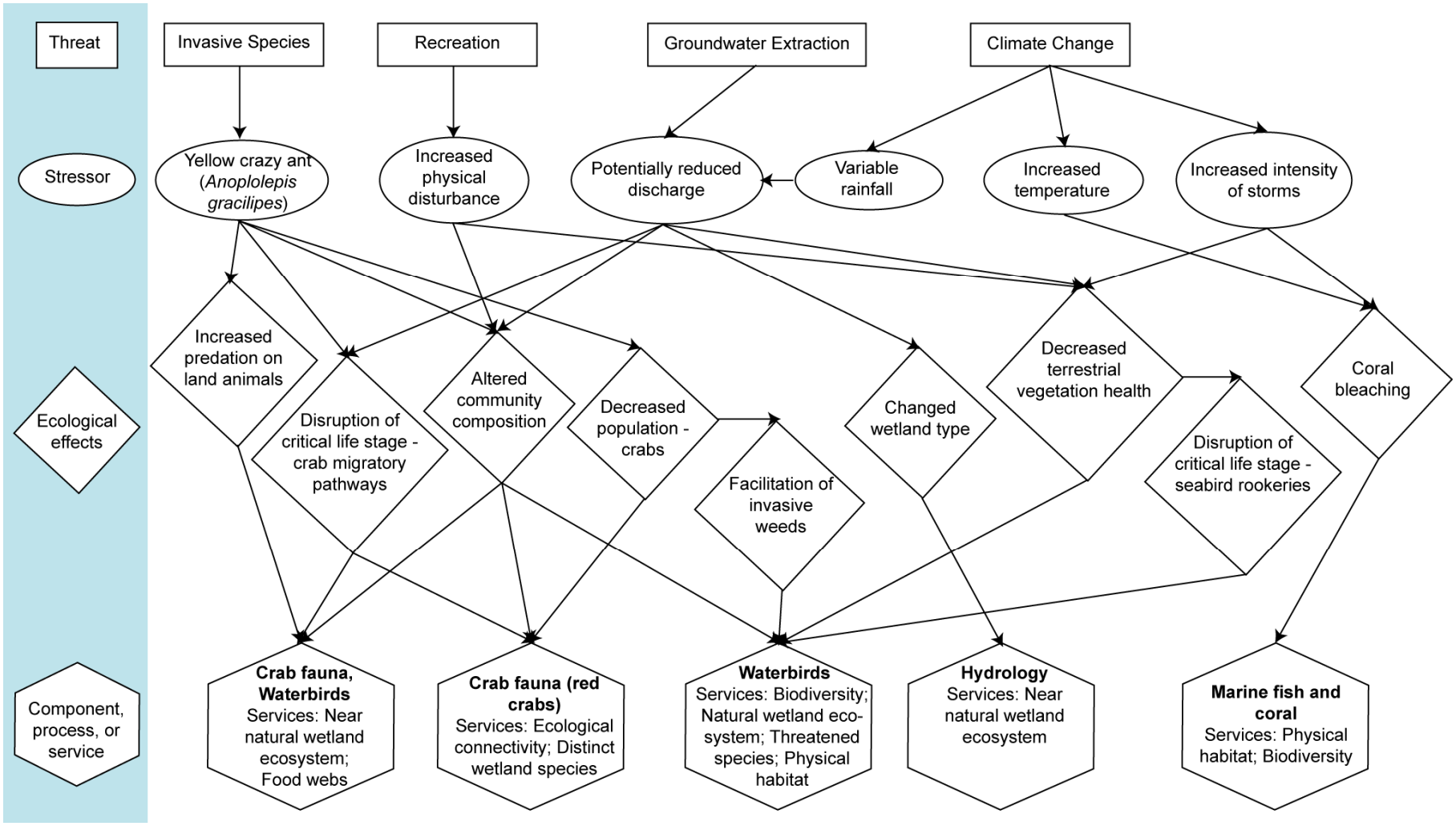


Figure 27: Stressor model of major threats to ecological character of The Dales Ramsar site (after Gross 2003 and Davis and Brock 2008).

5.1 Invasive species (yellow crazy ants)

Yellow crazy ants (*Anoplolepis gracilipes*) are thought to have been introduced to Christmas Island between 1915 and 1934 (O'Dowd et al. 1999). Listed as one of the top 100 worst invasive alien species in the world by the Global Invasive Species Database (2009), they have caused wide scale impacts to tropical ecosystems on Christmas Island, Hawaii and the Seychelles. Yellow crazy ants forage over a large range of habitats, including forest floor and canopy and are scavengers feeding on a range of invertebrates. They also form mutualistic associations with scale insects, harvesting carbohydrate rich honeydew. On Christmas Island the relationship between yellow crazy ants and high densities of scale insects has resulted in the formation of multi-queen "super colonies" which result in high population densities (Abbott 2005). There are nine species of scale insects on Christmas Island (Abbott and Green 2007), however only two main species were involved with the advent of the super colonies, the lac scale**,** *Tachardina aurantiaca* (Kerriidae), and *Coccus celatus* (Coccidae) (Hemiptera, Homoptera, Coccoidea) (Abbott 2003; O'Dowd 2003).

The spread of the scale insects have been influenced by positive interactions with the yellow crazy ant, as indicated by experiments where crashes in scale densities corresponded with the exclusion of the yellow crazy ant (Abbott and Green 2007). Boundaries of supercolonies exhibit abrupt declines in ant densities over tens of metres, declines which are matched by in scale density on understory saplings over the same distance (Abbott and Green 2007). Whilst this association between supercolonies and high scale densities is most obvious on the forest floor, large numbers of ants also move into the canopy of the rainforest indicating that most of the ant-scale interaction occurs in the canopy (Abbott and Green 2007). In the forest canopy the ant-scale interactions leads to the development of honeydew dependent sooty moulds, declines in shoot growth, and canopy dieback (O'Dowd et al. 2003). Canopy trees appear to be variable in their susceptibility to scale infestations, with *Inocarpus fagifer* being especially hard hit by the lac scale *Tachardina aurantiaca*, leading to lower rates of seed production in adult trees, slower rates of growth in adult and juvenile trees, and higher rates of mortality in all size classes (O'Dowd et al 2003; P. Green, LaTrobe University, pers. comm.). The monodominant stands of *Inocarpus fagifer* in The Dales appears to be less susceptible than trees elsewhere in the forest, although the reason for this is unclear at present (P. Green, LaTrobe University, pers. comm.).

It has been suggested that the ants could cause chick death in nesting Abbott's booby, but there has been no observations of this occurring (Commonwealth of Australia 2001), however some evidence exists that shows no detectable impact on the number or success of breeding pairs in areas with supercolonies (P. Green unpublished data). Christmas Island frigatebirds are considered to be especially at risk from yellow crazy ants as they have limited nesting sites which all occur within the shore terrace, the forest type in which the majority of supercolonies are found (Hill and Dunn 2004). Davis et al. (2008) also noted declines in two endemic landbirds reflecting direct interference by ants and altered resource availability and habitat structure caused indirectly by ant invasion. The ants have a severe impact on all ground dwelling fauna including reptiles and invertebrates including the red, blue and robber crabs.

In invaded areas, yellow crazy ants swarm over all surfaces; and in addition to harvesting honey dew they kill and feed on, amongst other things, large numbers of red crabs. The ants have a severe impact on all ground dwelling fauna, however the most notable is the impact on the red crabs. It is estimated that 10 – 15 million red crabs (over one-third of the entire population) have been killed by the yellow crazy ant (O'Dowd et al. 2003). Crazy ants spray formic acid in the eyes and mouth parts of the crabs, killing them within 48 hours. The super colonies then spread occupying red crab burrows, consuming resident crabs and using the burrows as nest sites (O'Dowd et al. 2003).

The red crab is considered a keystone species on the island (see section 4.3.5) playing an important role in maintaining forest structure. The foraging of red crabs on seedlings and leaf litter results in open understorey structure and bare soils with littler leaf litter. In areas where yellow crazy ants have invaded, and red crab numbers are diminished, forest structure is changed with dense seedling cover and a thick layer of leaf litter (O'Dowd et al. 2003). There

is evidence that this has a further effect in facilitating the increase in the populations of two additional introduced species the giant African land snail (*Achatina fulica*) and the giant centipede (*Scolopendra morsitans*). The increased litter on the forest floor provides habitat for these invasive invertebrates, which coupled by a lack of predation by red crabs, results in increased populations of both invasive species (O'Dowd and Green 2010). These processes are illustrated conceptually in Figure 28.

Results of island wide surveys and other research (Parks Australia unpublished; Abbott 2006) indicate that yellow crazy ant super colonies have been present within The Dales Ramsar site since prior to listing, with supercolonies being first detected in The Dales in 1997 (P. Green, Latrobe University, pers. comm.).

5.2 Climate change

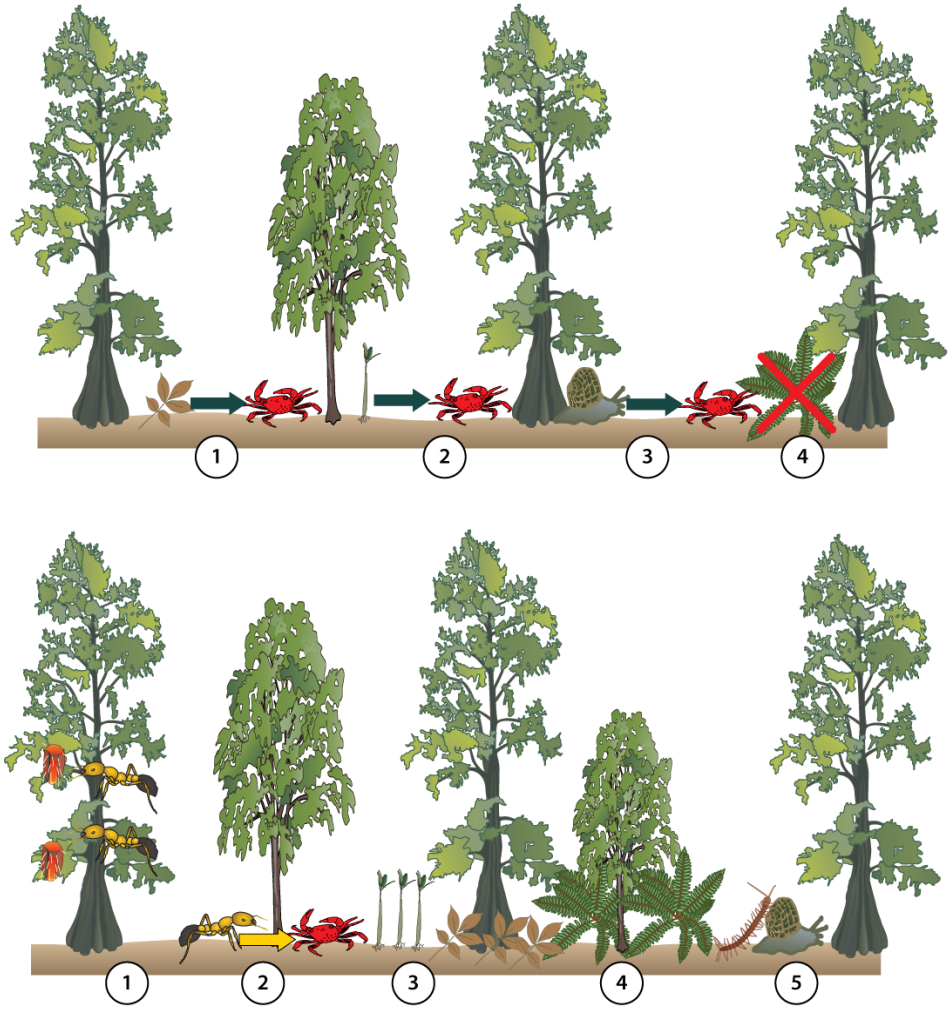
There are a variety of climate change predictions for Christmas Island (McInnes et al. 2008); those of direct relevance to The Dales are related to rainfall and tropical cyclones. There is uncertainty in the predicted change in climate for Christmas Island, but in general it is thought that rainfall could decrease and that the intensity of tropical cyclones could increase (McInnes et al. 2008).

Recent modelling is not clear on if rainfall will change due to greenhouse effects, however McInnes et al. (2008) suggest that rainfall decreases are more likely than increases in the driest seasons of the year, winter and spring, and in the annual average rainfall total, which is likely to change by -10 to +3 percent by 2030 and by -28 to +9 percent by 2070 (McInnes et al. 2008).

The Dales is part of a karst drainage system which is reliant on annual recharge during the wet season (see section 3.3.2 above). A significant reduction in rainfall coupled with increase groundwater extraction could result in reduced groundwater flow and a reduction in the extent and duration of surface water at the site. Loss of permanent water would affect the survival of the blue crab, which is reliant on freshwater springs to survive during the dry season (Hick et al. 1984) and potentially change other aspects of the wetlands.

Tropical cyclones occur about once every two years in the vicinity of Christmas Island and Cocos Islands (McInnes et al. 2008), with 66 cyclones occurring near Christmas Island since 1960. Recent modelling indicates a decrease in the observed 66 tropical cyclones (1.7 tropical cyclones per year) to 53 events in 2030 (1.3 tropical cyclones per year) and 18 events in 2070 (0.5 tropical cyclones per year). However, the modelling suggests an increase in the number of intense (Category 4 and 5 storms) (McInnes et al. 2008). Increased intensity in tropical storm events could lead to disturbance of the seabird rookies including damage to breeding habitat. Cyclones produce large waves that cause significant damage to shallow coral reefs. This was evident on 22nd of April, 2008 when Cyclone Rosie hit Christmas Island causing widespread coral mortality, particularly on the north coast (Hobbs unpublished data).

The recent warming of annual average sea surface temperatures in the vicinity of Christmas Island is likely to continue and accelerate in the future (McInnes et al. 2008). Annual average sea surface temperatures are likely to increase by 0.4 to 0.9 degrees Celsius by 2030 and by 1.7 to 2.5 degrees Celsius by 2070, with increases across all seasons of a similar magnitude of warming (McInnes et al. 2008). The predicted increases in sea temperature are likely to impact on the marine communities of Christmas Island in a number of ways. Firstly, outbreaks of coral disease, particularly White Syndrome, have been linked to increased water temperatures. There was an outbreak of this destructive disease at Christmas Island in February 2008 when water temperatures were high. This outbreak was specific to plate corals and infected 13 percent of these corals around the island and up to 43 percent at some locations (Hobbs and Frisch 2010). The disease resulted in widespread mortality of plate corals, and the loss of this habitat and food source caused significant declines in abundance of some fishes (Hobbs unpublished data).



Model 1: Absence of Yellow crazy ants

1. Red crabs consume live and dead leaf and plant material resulting in low levels of litter and other detritivores
2. Red crabs consume seeds and seedlings reducing recruitment
3. Red crabs consume invertebrates including introduced species such as the African land snail
4. The result of red crab feeding is a simple forest structure with sparse understorey and ground cover.

Model 2: Yellow crazy ant super colonies

1. Yellow crazy ants feed on secretions from scale insects and form super colonies
2. Yellow crazy ants feed on red crabs and reduce the population
3. In the absence of crab predation, plant recruitment and leaf litter increase
4. Increased recruitment results in increased understorey and groundcover.
5. Increased habitat and food, together with decreased predation, increases numbers of other introduced species such as the African land snail and giant centipede

Figure 28: Conceptual diagram of effects of yellow crazy ants on red crabs and vegetation.

Arguably the biggest threat to coral reefs from increasing sea temperature is coral bleaching. The heat-induced stress causes a breakdown in the relationship between corals and their symbiotic algae that can lead to widespread coral mortality. In 1998, elevated sea temperatures resulted in mass bleaching leading to destruction of 16 percent of the world's coral reefs, with 99 percent coral mortality on some Indian Ocean reefs (Wilkinson 2004). Coral bleaching caused significant mortality at Christmas Island in 1997-1998 and also currently occurred in March and April 2010 (see Figure 29). Initial surveys of the 2010 event indicate eight percent of corals have bleached so far, with 29 percent affected in some locations. In addition, 70 percent of *Cryptodendrum adhaesivum* anemones have bleached so far and this threatens the future of the anemone fish (*Amphiprion clarkii*) that relies on its host anemone. Species that rely on specific habitats will be affected the most by changes in coral reefs associated with warming oceans. This is already evident at Christmas Island, where the longnose filefish (*Oxymonacanthus longirostris*) appears to have significantly declined due to the loss of its habitat (Hobbs et al. 2010). Fishes and many calcareous organisms (for example corals) will also be negatively affected by the increasing acidity of the oceans associated with global warming (Hoegh-Guldberg et al. 2007; Munday et al. 2008)

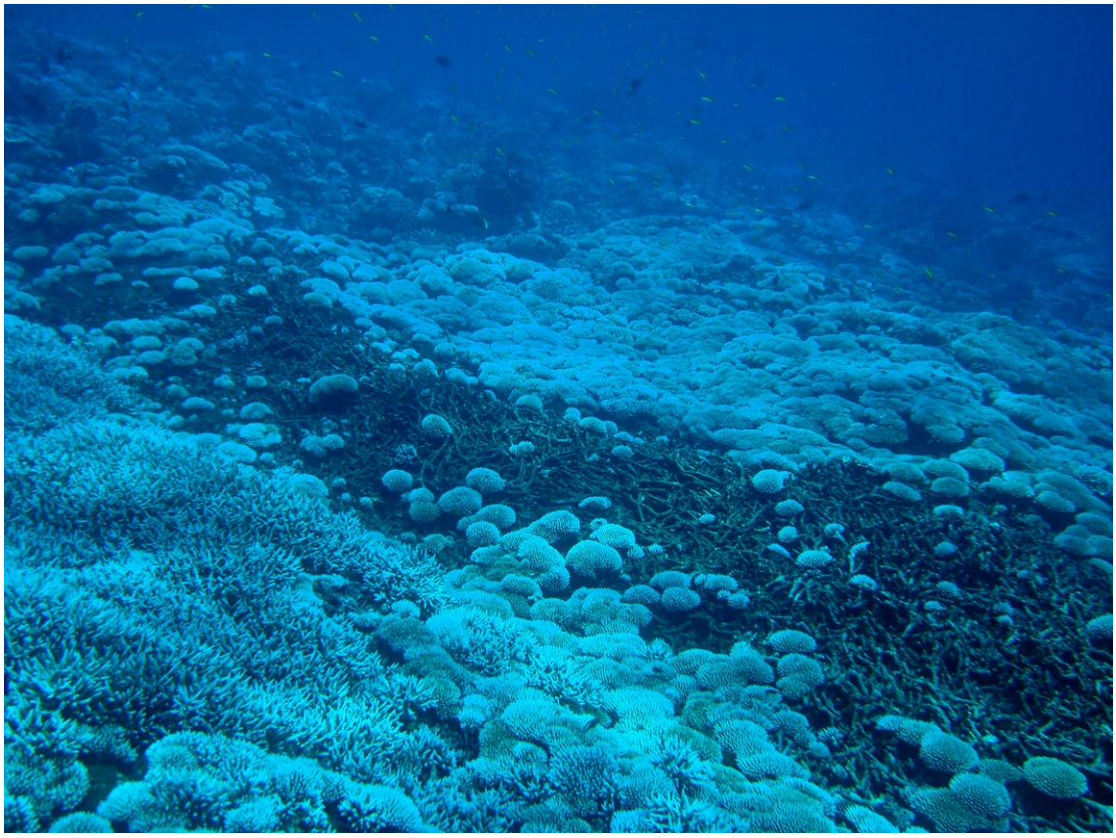


Figure 29: Coral bleaching at Christmas Island (Image courtesy J-P Hobbs, James Cook University).

5.3 Natural system modification - groundwater extraction

There is little permanent surface water on Christmas Island, and water for consumptive uses is extracted from the unconfined aquifers. The main water supply for the settlement is from the Grant's Well Karst system. However at any one time, water could be sourced from a variety of sites including Jedda Cave, Jane-up, Waterfall Spring and Ross Hill Gardens Spring (EWL Sciences and Tallegalla Consultants 2005). The system of pipe lines and storages that runs across the eastern side of the island (Figure 30) indicates the spatial extent of water resource utilisation on Christmas Island.

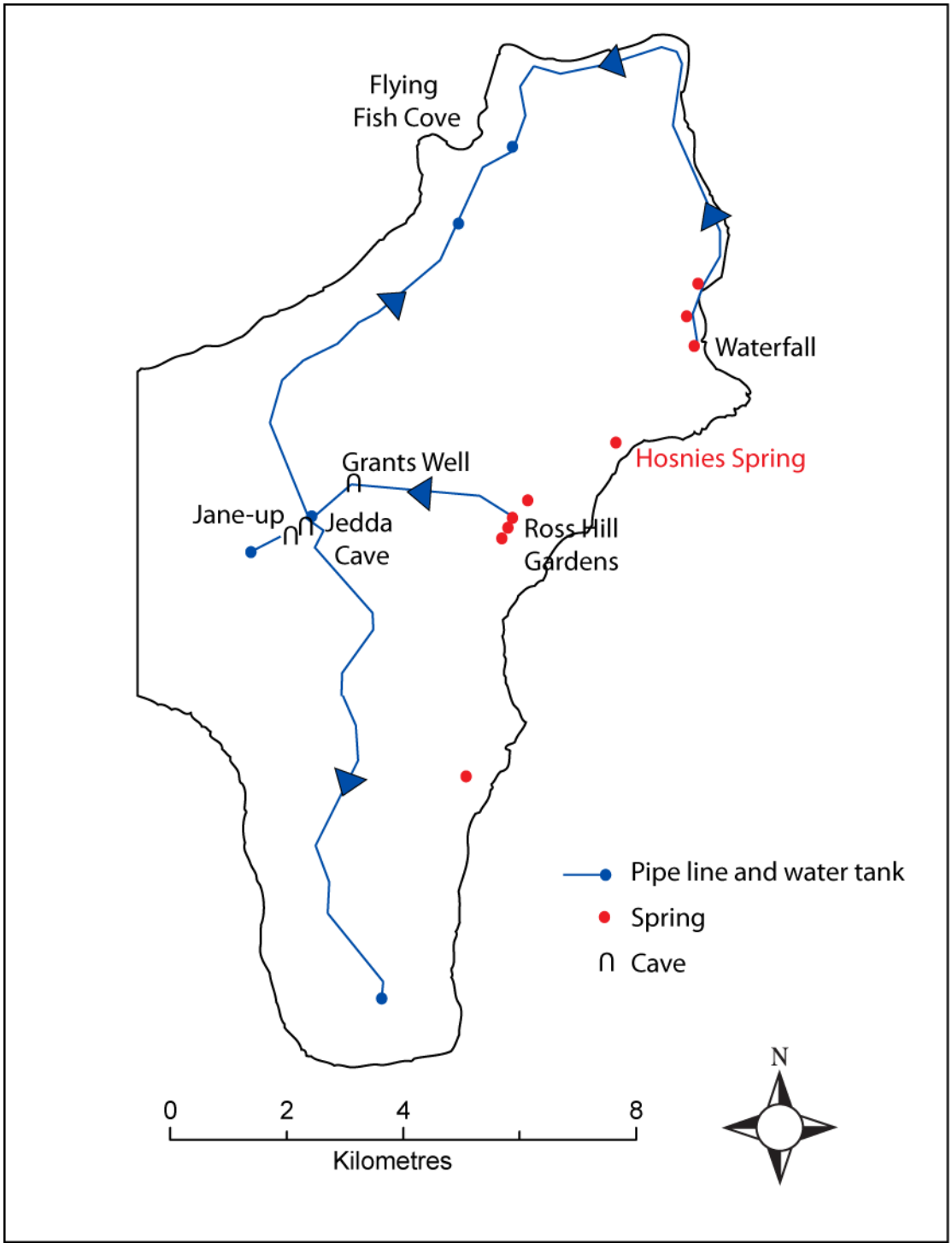


Figure 30: Water sources and pipelines on Christmas Island (Barrett 2001).

There is no information on the quantity of water extracted for consumptive purposes. However, trends in water use can be considered in terms of population fluctuations and major industrial uses on the island.

The population on Christmas Island fluctuates in response to construction and mining activities, but in 2009, was considered to be close to that at the time of listing (Figure 31). However, it should be noted that the population figures do not include fly-in fly-out workers, nor do they include residents at the detention centre, which has the capacity to accommodate over 1000 people; effectively doubling the resident population (ACIL Tasman 2009). In addition, water is utilised in phosphate mining operations on the island.

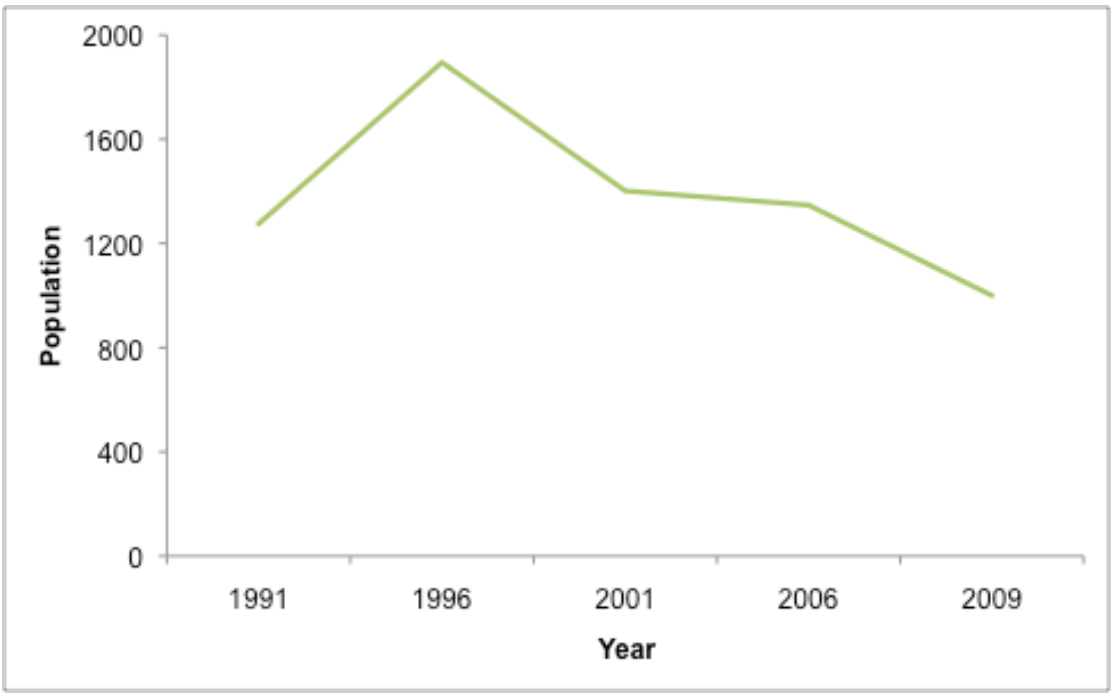


Figure 31: Resident population of Christmas Island (ACIL Tasman 2009).

Although water is not extracted from The Dales directly, Grimes (2001) described the groundwater resources of the island as interconnected. This suggests that extraction from water on the plateau at Grants Well or Jane-up, could impact on the discharge volumes and rates at coastal springs on the shore terrace. A significant reduction in flow, or a loss of permanent water at The Dales Ramsar site has the potential to result in dramatic effects to the ecological character of the site, with the potential loss of one of the strong holds for the blue crab, changes to the tufa formations at Hugh's Dale and potentially influence migration patterns of the red crab.

However, the connectivity between springs at The Dales and the aquifers from which groundwater is extracted is not understood. In addition, there is neither quantitative information on flows at the Ramsar site, nor any indication if groundwater extraction on the plateau is having or could effects on hydrology in the Ramsar site. This remains a significant knowledge gap.

5.4 Recreation

The Dales is one of the main recreation and tourism destinations on Christmas Island. Parks Australia's policy towards tourism is to preserve the natural character of the landscape whilst providing opportunities for the enjoyment of the island's environmental and cultural attributes (Director of National Parks 2002). At The Dales, to help maintain the natural state of the site, there are defined walking track access and interpretation boards. The increase in the population of Christmas Island has resulted in more people seeking recreational activities during non-work hours. Unmanaged site visitation by large numbers of visitors has the potential to negatively impact on The Dales through physical disturbance and trampling of vegetation and seedlings.

5.5 Summary of threats

Although a risk assessment is beyond the scope of an ECD, the DEWHA (2008) framework states that an indication of the impacts of threats to ecological character, likelihood and timing of threats should be included. The major threats considered in the previous sections have

been summarised for each location within the Ramsar site in accordance with the DEWHA (2008) framework
Table 12.

Table 12: Summary of the main threats to the The Dales Ramsar site.

Actual or likely threat	Potential impact(s) to wetland components, processes and/or service	Likelihood[1]	Timing
Groundwater extraction.	Decrease in flow and loss of permanent surface water. This could result in a change in wetland type and a loss of blue crabs. Tahitian chestnut stand at Hugh' Dale may be affected.	Medium.	Current.
Invasive species: yellow crazy ants.	Predation on crabs, resulting in alteration to the forest ecosystems and consequent increase in other invasive species.	Certain.	Current.
Recreation.	Increased visitor impacts leading to physical disturbance of the site.	Certain.	Current.
Climate change – altered rainfall patterns.	Reduced/altered recharge of aquifer and loss of freshwater. Corresponding loss of habitat blue crabs.	Medium.	Medium to long term.
Climate change – increased intensity of storms.	Direct physical damage to waterbird breeding habitat.	Medium.	Medium to long term.
Climate change – increased temperature.	Increased incidence of coral bleaching and disease.	Certain (for coral bleaching).	Current (disease outbreak summer 2007-2008; coral bleaching 1997-1998 and 2010).

[1] Where Certain is defined as known to occur at the site or has occurred in the past; Medium is defined as not known from the site but occurs at similar sites; and Low is defined as theoretically possible, but not recorded at this or similar sites.

6. Limits of Acceptable Change

6.1 Process for setting Limits of Acceptable Change (LAC)

Limits of acceptable change are defined by Phillips (2006) as:

"…the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. This may include population measures, hectares covered by a particular wetland type, the range of certain water quality parameter, etc. The inference is that if the particular measure or parameter moves outside the 'limits of acceptable change' this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed. In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed".

LAC and the natural variability in the parameters for which limits are set are inextricably linked. Phillips (2006) suggested that LAC should be beyond the levels of natural variation. Setting limits in consideration with natural variability is an important, but complex concept. Wetlands are complex systems and there is both spatial and temporal variability associated with all components and processes. Defining this variability such that trends away from "natural" can be reliably detected is far from straight forward.

Hale and Butcher (2008) considered that it is not sufficient to simply define the extreme measures of a given parameter and to set LAC beyond those limits. What is required is a method of detecting change in pattern and setting limits that indicate a distinct shift from natural variability (be that positive or negative). This may mean accounting for changes in the frequency and magnitude of extreme events, changes in the temporal or seasonal patterns and changes in spatial variability as well as changes in the mean or median conditions.

It should be noted that LAC are not synonymous with management values or "trigger levels". The LAC described here represents what would be considered a change in ecological character at the site in absolute terms with no regard for detecting change prior to irrevocable changes in wetland ecology. Detecting change with sufficient time to instigate management actions to prevent an irrevocable change in ecological character is the role of wetland management and the management plan for a site must develop and implement a set of management triggers with this aim.

LAC have been set for The Dales Ramsar site based on conditions at the time of listing (Table 13). It is preferable to use site specific information to statistically determine LAC. However, in the absence of sufficient site specific data, LAC are based on recognised standards or information in the scientific literature that are relevant to the site. In these cases, the source of the information upon which the LAC has been determined is provided. For The Dales there is very limited site specific data for most of the critical components, processes and services, therefore qualitative LAC based on the precautionary principle are recommended and will require careful review with increased information gained from future monitoring.

The columns in Table 13 contain the following information:

Primary Component / Process for the LAC.	The component or processes for which the LAC is a direct measure.
Baseline / supporting evidence.	Relevant baseline information (relevant to the time of listing) and any additional supporting evidence from the scientific literature and / or local knowledge.
Limit of Acceptable Change.	The LAC stated as it is to be assessed against.
Confidence level.	The degree to which the authors are confident that the LAC represents the point at which a change in character has occurred. Assigned as follows:

	High – Quantitative site specific data; good understanding linking the indicator to the ecological character of the site; LAC is objectively measurable. **Medium** – Some site specific data or strong evidence for similar systems elsewhere derived from the scientific literature; or informed expert opinion; LAC is objectively measurable. **Low** – no site specific data or reliable evidence from the scientific literature or expert opinion, LAC may not be objectively measurable and / or the importance of the indicator to the ecological character of the site is unknown.
Secondary critical Components/ Processes/ Services addressed by LAC.	These are other critical components, processes or services that are protected indirectly by the LAC.

Table 13: Proposed Limit of Acceptable Change (LAC) for The Dales Ramsar site.

Primary Component / Process for the LAC	Baseline/Supporting Evidence	Limit of Acceptable Change	Confidence level	Secondary critical Components / Processes/ Services addressed by LAC
Geomorphic setting.	No baseline mapping exists for the wetland types found within the site. Descriptions of the karst features are provided in Grimes (2001), descriptions of the wetland types is based on information in the RIS (2002).	No loss of wetland types and maintenance of seven Dales.	Medium.	**Services** • Near natural wetland type; • Special ecological, physical or geomorphic features; and • Ecological connectivity.
		Wetland extent - Data deficient, baseline must be determined before quantitative limits can be refined.	Low.	
Hydrology.	Three of the Dales (No. 1 Dale, Hugh's and Anderson Dales) are land based spring discharge points for groundwater, resulting in permanent surface water flows. No. 4, 7, Darling and Sydney's Dales only flow following heavy rain events in the wet season. Literature detailing dependence of blue crabs, in particular, on surface water includes Greenaway (1989) and Hicks et al. (1984).	No loss of surface water connection to the sea at No. 1 Dale, Hugh's Dale and Anderson Dale.	Medium.	**Component** • Land crabs (particularly blue crabs). **Services** • Near natural wetland type; • Special ecological, physical or geomorphic features; • Biodiversity; and • Ecological connectivity.
Land crabs.	Supports all 20 species of land crab (RIS 2002) including: • Red crabs (*Gecarcoidea natalis*); • Robber crabs (*Birgus latro*); and • Blue crabs (*Discoplax hirtipes*) No quantitative data available for the site.	Blue crabs present at the site during the dry season. Red crabs and robber crabs present at the site for at least part of their lifecycle. Data deficient, baseline must be	Low.	**Services** • Food webs; • Distinct wetland species; and • Biodiversity.

Primary Component / Process for the LAC	Baseline/Supporting Evidence	Limit of Acceptable Change	Confidence level	Secondary critical Components / Processes/ Services addressed by LAC
		determined before quantitative limits can be set.		
Waterbirds.	Supports breeding seabirds, however number of species which breed within the site is not known. Number of breeding pairs of Abbott's booby that nest within the site is not known. No quantitative data is available at the site.	Minimum of three species of seabirds breeding within the site, including Abbott's booby. Data deficient, baseline must be determined before quantitative limits can be set with regard to numbers of breeding pairs within the site.	Low.	**Services** • Threatened species; • Biodiversity.

7. Current Ecological Character and Changes since Designation

Change in ecological character is defined as the human-induced adverse alteration of any ecosystem component, process and/or ecosystem benefit or service (Ramsar Convention 2005, Resolution IX.1 Annex A). Changes to the ecological character of the wetland outside natural variations may signal that uses of the site or externally derived impacts on the site are unsustainable and may lead to the degradation of natural processes and thus the ultimate breakdown of the ecological, biological and hydrological functioning of the wetland (Ramsar Convention 1996, Resolution VI.1). Guidance from the Australian Government indicates that positive change to ecological character should also be documented. Change should be established against the ecological character at the time a site was listed as a Ramsar site.

There is no evidence that there has been any negative change to the hydrology, geomorphic setting or biota at The Dales since listing. The threats of groundwater extraction and yellow crazy ants were present at the time of listing and there is no evidence that there have been significant negative changes since 2002. However it should be noted that prior to listing the site had undergone negative change from the impacts of the yellow crazy ants. There is insufficient site specific information to assess against the LAC contained in Table 13, but anecdotally there has been no change in ecological character at the site since listing (P. Green, LaTrobe University, pers. comm.).

The ecological character of the site has not changed and the site continues to meet the five criteria for which it was listed in 2002 (see section 2.5).

8. Knowledge Gaps

Throughout the Ecological Character Description for The Dales Ramsar site, mention has been made of knowledge gaps and data deficiencies for the site. While it is tempting to produce an infinite list of research and monitoring needs for this wetland system, it is important to focus on the purpose of an ecological character description and identify and prioritise knowledge gaps that are important for describing and maintaining the ecological character of the system.

Knowledge gaps that are required to be addressed so as to fully describe the ecological character of this site and enable rigorous and defensible limits of acceptable change to be met are relatively few (Table 14). Collection of information at The Dales Ramsar site is difficult due to the remote location and difficulty of access. In recognition of this, recommended actions are aimed at developing indicators of ecological character that could fill knowledge gaps and help in the design of on-going monitoring.

Table 14: Knowledge gaps for The Dales Ramsar site

Component / process	Knowledge Gap	Recommended Action
Geomorphic setting.	Number and extent of wetland types, particularly sea caves, within the boundary of the site.	Mapping of wetland types including karst features within the site.
Hydrology.	• Flow rates at the three springs including seasonal variability. • Extent and duration of inundation at the site. Relative importance of Dales which have intermittent surface water.	• Monitoring of flow rates at the permanent springs on a monthly basis. • Measures of the extent and depth of inundation in wet and dry season.
	• Connectivity between groundwater source for The Dales and the groundwater resources used for human consumption. • Relative relationship and contribution of basal versus perched aquifers to the springs at The Dales.	Ongoing groundwater monitoring and investigations. An assessment of the sustainable extraction volumes from groundwater.
Water quality.	Affect of altered water quality in groundwater, in particular organic and nutrient loads, on receiving waters in The Dales. This would have an effect on tufa deposits at Hugh's Dale.	Water quality monitoring of groundwater.
Land crabs.	• Quantitative information on crab densities and the importance of the site for different crab species (including breeding migrations). • Recovery of crabs in response to baiting programs against yellow crazy ant.	Survey of crab burrow densities within the Ramsar site. Mapping of recovering infested areas post baiting for yellow crazy ants.
Waterbirds.	Number of breeding pairs of Abbott's booby within the site. Number of breeding pairs of other species including the brown booby which breed or on sea cliffs and shore terrace within the site.	Surveys of waterbirds within the site, including the sea cliffs. Mapping of nesting sites.
Marine environment.	There is very limited site specific	Expanded surveys of marine

Component / process	Knowledge Gap	Recommended Action
	information on marine features in the site: fish species and abundance, benthic invertebrates.	habitat and fauna, within the Ramsar site boundary.
	Baseline description of anchialine communities present within the site.	Survey of sea caves within the site and collection of invertebrate samples.

9. Monitoring needs

As a signatory to the Ramsar Convention, Australia has made a commitment to protect the ecological character of its Wetlands of International Importance. Under Part 3 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) a person must not take an action that has, will have or is likely to have a significant impact on the ecological character of a declared Ramsar wetland. While there is no explicit requirement for monitoring the site, in order to ascertain if the ecological character of the wetland site is being protected a monitoring program is required.

A comprehensive monitoring program is beyond the scope of an ECD. What is provided is an identification of monitoring needs required to both set baselines for key components and processes and to assess against limits of acceptable change. It should be noted that the focus of the monitoring recommended in an ECD is an assessment against LAC and determination of changes in ecological character. This monitoring is not designed as an early warning system whereby trends in data are assessed to detect changes in components and processes prior to a change in ecological character of the site. This must be included in the management plan for the site.

The recommended monitoring to meet the obligations under Ramsar and the EPBC Act with respect to The Dales Ramsar site are provided in Table 15. There are a number of existing monitoring programs within The Dales Ramsar site and some of the monitoring recommended may already be contained in these existing programs.

Table 15: Monitoring needs for The Dales Ramsar site.

Component/ Process	Purpose	Indicator	Locations	Frequency	Priority
Hydrology.	Set baseline.	Flow.	Dales 1, 2, 5.	Monthly.	High.
	Set baseline.	Extent and duration of inundation.	All Dales.	Seasonally.	High.
Land crabs.	Establishment of variability detection of change, refinement of LAC.	Crab burrow density – blue crab.	Immediate vicinity of Dales 1, 2 and 5.	Every two years.	Medium.
	Establishment of variability detection of change, assessment of threats (yellow crazy ants) refinement of LAC.	Crab burrow density – red crabs.	Entire Ramsar site	Annual.	Medium.
Yellow crazy ants.	Assessment of threat.	Super colony presence and location.	Entire Ramsar site.	Every two years.	High.
Marine environment.	Establish baseline of anchialine communities.	Survey of sea caves and associated communities.	Marine portion of the site.	Once off.	Medium.
	Establishment of baseline, informing the development of LAC, detection of change.	Benthic habitat, fish and invertebrate diversity and abundance. Monitor threats (coral beaching + coral disease).	Marine portion of the site.	Every two – five years.	Medium.
Waterbirds.	Establishment of baseline.	Survey of all habitats types to establish patterns of usage.	Entire Ramsar site.	Every two – five years.	Low.
	Establishment of baseline informing the development of LAC, detection of change.	Number of breeding pairs for key species.	Nesting sites.	Every two – five years.	High.

10. Communication and Education Messages

Under the Ramsar Convention a Program of Communication, Education, Participation and Awareness (CEPA) was established to help raise awareness of wetland values and functions. At the Conference of Contracting Parties in Korea in 2008, a resolution was made to continue the CEPA program in its third iteration for the next two triennia (2009 – 2015).

The vision of the Ramsar Convention's CEPA Program is: "People taking action for the wise use of wetlands." To achieve this vision, three guiding principles have been developed:

a) The CEPA Program offers tools to help people understand the values of wetlands so that they are motivated to become advocates for wetland conservation and wise use and may act to become involved in relevant policy formulation, planning and management.
b) The CEPA Program fosters the production of effective CEPA tools and expertise to engage major stakeholders' participation in the wise use of wetlands and to convey appropriate messages in order to promote the wise use principle throughout society.
c) The Ramsar Convention believes that CEPA should form a central part of implementing the Convention by each Contracting Party. Investment in CEPA will increase the number of informed advocates, actors and networks involved in wetland issues and build an informed decision-making and public constituency.

The Ramsar Convention encourages that communication, education, participation and awareness are used effectively at all levels, from local to international, to promote the value of wetlands.

A comprehensive CEPA program for an individual Ramsar site is beyond the scope of an ECD, but key communication messages and CEPA actions, such as a community education program, can be used as a component of a management plan.

The management plan for the Christmas Island National Park contains a number of key communication messages and a program for implementing community education. Key CEPA messages for The Dales Ramsar site arising from this ECD, which should be promoted through this program, include:

- The fragility of The Dales and the importance of maintaining the sites ecological character;
- The danger of introducing exotic species to an island ecosystem and how past introductions threaten the natural environment, tourism and recreational activities;
- The connectivity between groundwater resources on the island and the potential effects of over extraction on the flora and fauna dependant on freshwater at the site;
- The dependence of the blue crab on this freshwater resources; and
- The importance of low impact tourist activities at this remote site.

References

Abbott, K.L., 2005, Supercolonies of the invasive yellow crazy ant, *Anteplolepis gracilipes*, on an oceanic island: Forager patterns, density and biomass, Insectes Sociaux 52: 266–273.

Abbott, K.L., 2006, Spatial dynamics of supercolonies of the invasive yellow crazy ant, *Anoplolepis gracilipes*, on Christmas Island, Indian Ocean. Diversity and Distributions,12: 101–110.

Abbott, K.L., and Green, P.T., 2007, Collapse of an ant-scale mutualism in a rainforest on Christmas Island. Oikos. 116: 1238-1246.

ACIL Tasman, 2009, The Economic Impact of Christmas Island Phosphates: The impact of Christmas Island Phosphates on the economy of Christmas Island, Report to Christmas Island Phosphates.

Adamczewska, A.M., and Morris, S., 2001, Ecology and behaviour of *Gecarcoidea natalis*, the Christmas Island red crab, during the annual breeding migration. The Biological Bulletin 200: 305-320.

Allen, G.R., Steene, R., and Orchard, M., 2007. *Fishes of Christmas Island, Second Edition*. Christmas Island Natural History Association, Christmas Island, Indian Ocean, Australia.

ANZECC and ARMCANZ, 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality National Water Quality Management Strategy Paper no. 4.Australian and New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand.

Attorney General's Department 2009; Christmas Island http://www.ag.gov.au/www/agd/agd.nsf/Page/Territories_of_AustraliaChristmas_Island accessed December 2009.

Australian Heritage Commission, 2002, Australian Natural Heritage Charter for conservation of places of natural heritage significance. Second Edition. Australian Heritage Commission. Canberra.

Bamford, M, D. Watkins, W. Bancroft, G. Tischler and J. Wahl. 2008, Migratory Shorebirds of the East Asian - Australasian Flyway; Population Estimates and Internationally Important Sites. Wetlands International Oceania. Canberra, Australia.

Barrett, G.W., Van Dyne, G.M. and Odum, E. P., 1976. Stress ecology. BioScience 26:192-194.

Birds Australia, unpublished, Australian Bird Atlas data extracted May 2009.

Bureau of Meteorology, 2009a, Climate data online, downloaded from http://www.bom.gov.au/climate/averages/ December 2009.

Bureau of Meteorology, 2009b, Australian tropical cyclones, downloaded from http://www.bom.gov.au/weather/cyclone/tc-history.shtml December 2009.

Claussen, J. 2005. *Native Plants of Christmas Island.* Flora of Australia Supplementary Series Number 22. Department of the Environment and Heritage, Canberra.

Commonwealth of Australia, 2001, Background Information for the Abbott's Booby, *Papasula abbotti* Recovery Plan. Department of the Environment and Heritage, Canberra.

Commonwealth of Australia, 2006, A guide to The Integrated Marine and Coastal Regionalisation of Australia - version 4.0 June 2006 (IMCRA v4.0).

Culvern, D.C., and Pipan, T., 2007, Subterranean ecosystems. *Encyclopaedia of Biodiversity*. Elsevier Inc.

Davis, J. and Brock, M. 2008, Detecting unacceptable change in the ecological character of Ramsar wetlands, Ecological Management and Restoration, 9: 26-32.

Davis, N.E., O'Downd, D.J., Green, P.T., and MacNally R., 2008, Effects of an alien ant invasion on abundance, behavior, and reproductive success of endemic island birds. Conservation Biology. 22: 1165–1176.

DEH (Department of the Environment and Heritage), 2004, National Recovery Plan for the Abbott's Booby *Papasula abbotti*. Department of the Environment and Heritage, Canberra.

DEWHA (Department of the Environment, Water, Heritage and the Arts), 2008, National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands. Module 2 of Australian National Guidelines for Ramsar Wetlands – Implementing the Ramsar Convention in Australia.

Director of National Parks, 2002, Third Christmas Island National Park Management Plan.

Director of National Parks, 2008, Christmas Island Biodiversity Monitoring Program: December 2003 to April 2007. Report to the Department of Finance and Deregulation from the Director of National Parks.

Du Puy, D.J., 1993, Christmas Island. *in* Commonwealth of Australia 1993. *Flora of Australia Volume 50 Oceanic Islands 2*, Australian Government Publishing Service, Canberra.

EWL Sciences and Tallegalla Consultants, 2005, Draft Environmental Impact Statement for the Proposed Christmas Island Phosphate Mines (9 Sites)(EPBC 2001/487). Unpublished Report for Phosphate Resources Limited, Christmas Island, Indian Ocean.

Expert Working Group, 2009, Revised interim report Christmas Island expert working group to Minister for Environment, Heritage and the Arts. June 2009.

Ford, T.D., and Pedley, H.M, 1996, A review of tufa and travertine deposits of the world. Earth-Science Reviews. 41: 117-175.

Gilligan, J., Hender, J., Hobbs, JP., Neilson, J., and McDonald, C., 2008, Coral reef surveys and stock size estimates of shallow water (0-20m) marine resources at Christmas Island, Indian Ocean. Report to Parks Australia North.

Global Invasive Species Database, 2009, (http://www.issg.org/database) accessed October 4, 2009.

Gomez E.D., Alcala, A.C. and San Diego, A.C., 1991, States of Phillipine coral reefs. Proceedings of the 4th International Coral Reef Symposium. 275-282pp.

Gordon, N.D., McMahon, T.A., and Finlayson, B.L., 1999, *Stream hydrology: An introduction for ecologists*. John Wiley & Sons Ltd, Chichester, England.

Gray, H.S. and Clarke, R., 1995, Christmas Island Naturally, Second Edition, National Library of Australia.

Green, P.T., 1997, Red crabs in rain forest on Christmas Island, Indian Ocean: Activity patterns, density and biomass. Journal of Tropical Ecology, 13:17-38.

Green, P.T., 2004, Burrow dynamics of the red land crab *Gecarcoidea natalis* (Brachyura, Gecarcinidae) in rain forest on Christmas Island (Indian Ocean). Journal of Crustacean Biology, 24: 340–349.

Green, P.T., 2009, Land crabs on Christmas Island. Pp 532-535 in R.G. Gillespie and D.A. Clague (eds). *Encyclopedia of Islands*. University of California Press.

Green, P.T., Lake, P.S., and O'Dowd, D.J., 1999, Monopolization of litter processing by a dominant land crab on a tropical oceanic island. Oecologia, 119: 435-444.

Green, P.T., O'Dowd, D.J., and Lake, P.S., 1997, Control of seedling recruitment by land crabs in rain forest on a remote oceanic island. Ecology 78:2474–2486.

Green, P.T., O'Dowd, D.J., and Lake, P.S., 2008, Recruitment dynamics in a rainforest seedling community: context-independent impact of a keystone consumer. Oecologia, 156: 373-385.

Greenaway, P., 1989, Sodium balance and adaptation to freshwater in the amphibious crab *Cardisoma hirtipes.* Physiological Zoolology, 62:639-653.

Greenaway, P., and Raghaven, S. 1998, Digestive strategies in two species of leaf-eating land crabs (Brachyura: Gecarcinidae) in a rain forest. Physiological Zoology, 71(1): 36-44.

Grimes, K., 2001, Karst features of Christmas Island (Indian Ocean). Helictite 37: 41-58.

Gross, J., 2003, Developing Conceptual Models for Monitoring Programs http://science.nature.nps.gov/im/monitor/docs/Conceptual_Modelling.pdf

Hale, J., and Butcher, R., 2008, Ecological Character Description of the Peel-Yalgorup Ramsar site. A report to the Department of the Environment and Conservation and Peel Harvey Catchment Council.

Heap, A.D., Harris, P.T., Hinde, A. and Woods, M., 2005, Report to the National Oceans Office on the Development of a National Benthic Marine Bioregionalisation in support of Regional Marine Planning, GeoScience Australia, Canberra.

Hennicke, J., 2007, Investigation of the foraging ecology of the endangered Abbott's booby. NHT Project ID 52588. In partnership with Parks Australia North, Christmas Island.

Hicks, J., Rumpff, H., and Yorkston, H. 1984, *Christmas Crabs.* (Christmas Island Natural History Association).

Hicks, J.W., 1985, The breeding behaviour and migrations of the terrestrial crab *Gecarcoidea natalis* (Decapoda: Brachyura). Australian Journal of Zoology. 33:127-142.

Hill, R., and Dunn A., 2004, National recovery plan for the Christmas Island frigatebird *Fregata andrewsi*. Commonwealth of Australia, Canberra.

Hobbs, J-P.A., Ayling, A.M., Choat, J.H., Gilligan, J.J, McDonald, C.A., Neilson, J., and Newman, S.J., 2010. New records of marine fishes illustrate the biogeographic importance of Christmas Island, Indian Ocean. Zootaxa 2422:63-68.

Hobbs, J-P.A., and Frisch, A.J., 2010. Coral disease in the Indian Ocean: prevalence and distribution of white syndrome on remote coral reefs. Diseases of Aquatic Organisms 89:1-8.

Hobbs, J-P.A., Frisch A.J., Allen, G.R., and van Herwerden, L. 2009a. Marine hybrid hotspot at Indo-Pacific biogeographic border. *Biology Letters* 5:258-261.

Hobbs, J-P.A., Frisch, A.J., Hamanaka, T., McDonald, C.A., Gilligan, J.J., and Neilson, J., 2009b, Seasonal aggregation of juvenile whale sharks (*Rhincodon typus*) at Christmas Island, Indian Ocean. Coral Reefs 28:577.

Hobbs, J-P.A., Gilligan, J.J., Hender, J., McDonald, C.A., and Neilson, J., 2008, New fish records for Christmas Island, Indian Ocean (2002-2008). Report to Parks Australia Christmas Island, May 2008.

Hobbs, J-P.A., and Salmond, J.K., 2008, Cohabitation of Indian and Pacific Ocean species at Christmas and Cocos (Keeling) Islands. Coral Reefs, 27:933

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., and Hatziolos, M.E. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318: 1737-1742.

Humphreys, W.F., and Danielopol, D.L., 2006, *Danielopolina* (Ostracoda, Thaumatocyprididae) on Christmas Island, Indian Ocean, a sea mount island. Crustaceana 78: 1339-1352.

Humphreys, W.F. and Eberhard, S.M., 2001, Subterranean Fauna of Christmas Island, Indian Ocean. Helictite, 37: 59-74.

Humphreys, W.F., Kornicker, L.S., and Danielopol, D.L., 2009, On the origin of *Danielopolina baltanasi* sp. n. (Ostracoda, Thaumatocypridoidea) from three anchialine caves on Christmas Island, a seamount in the Indian Ocean. Crustaceana. 82: 1177-1203.

IUCN, 2009, IUCN Red List of Threatened Species. Version 2009.2. <www.iucnredlist.org>. Downloaded on 06 January 2010.

Lumsden, L. and Schulz, M., 2009, Captive breeding and future in-situ management of the Christmas Island Pipistrelle *Pipistrellus murrayi.* Unpublished report. Arthur Rylah Institute. Victoria.

McGrath, C. 2006, unpublished Legal review of the framework for describing the ecological character of Ramsar wetlands to support implementation of the EPBC Act. Report to the Department of the Environment and Heritage, Unpublished.

McInnes, K.L., Macadam, I., Hemer, M., Abbs, D., White, N., Church, J., and Bathois, J., 2008, Recent and future climate conditions for Cocos and Christmas Islands. CSIRO Marine and Atmospheric Research. Undertaken for Maunsell Pt. Ltd. Draft report.

Meekan, M.G., Jarman, S.N., McLen C., and Schulz, m.B. 2009, DNA evidence of whale sharks (*Rhincodon typus*) feeding on red crab *Gecarcoidea natalis*) larvae at Christmas Island, Australia. Marine and Freshwater Research, 60: 607-609.

Millennium Ecosystem Assessment, 2005, Ecosystem Services and Human Well-Being: Wetlands and Water: Synthesis. 2005. Millennium Ecosystem Assessment report to the Ramsar Convention: World Resources Institute, Washington D.C.

Mitchell, B., 1985. A vegetation survey of Christmas Island, Indian Ocean. Unpublished report to the Australian National Parks and Wildlife Service.

Morris, S., 2005, Respiratory and acid–base responses during migration and to exercise by the terrestrial crab *Discoplax (Cardisoma) hirtipes*, with regard to season, humidity and behaviour. The Journal of Experimental Biology 208: 4333-4343.

Munday, P.L., Jones, G.P., Pratchett, M.S., and Williams, A.J., 2008. Climate change and the future for coral reef fishes. Fish and Fisheries 9:261–285.

O'Dowd, D.J. and Green, P.T., 2010, Invasional meltdown: do invasive ants facilitate secondary invasions? Pp 271-272 in L. Lach, C. Parr and K. L. Abbott (eds). *Ant Ecology*. Oxford University Press.

O'Dowd, D.J., Green, P.T. and Lake, P.S. 1999. Status, impact, and recommendations for research and management of exotic invasive ants in Christmas Island National Park. Unpublished report to Environment Australia.

O'Dowd, D.J., Green, P.T., and Lake, P.S., 2003, Invasional "meltdown" on an oceanic island. Ecology Letters 6:812–817.

O'Dowd, D.J., and Lake, P.S., 1989 Red crabs in rain forest, Christmas Island: removal and relocation of leaf- fall.: Journal of Tropical Ecology, 5: 337-348.

O'Dowd, D.J., and Lake, P.S., 1990, Red crabs in rain forest, Christmas Island: differential herbivory of seedlings. Oikos 58:289–292.

O'Dowd, D.J., and Lake, P.S., 1991, Red crabs in rain forest, Christmas Island: removal and fate of fruits and seeds. Journal of Tropical Ecology 7:113-122.

Onton, K., and Forbes, M., 2009, Augusta Microbial Threatened Ecological Community Monitoring Report 2009, South West Region, Department of the Environment and Conservation, Bunbury, Western Australia.

Parks Australia 2008, Issue paper: Conservation status and threats to the flora and fauna of the Christmas Island Region. Draft for comment.

Phillips, B., 2006, Critique of the Framework for describing the ecological character of Ramsar Wetlands (Department of Sustainability and Environment, Victoria, 2005) based on its application at three Ramsar sites: Ashmore Reed National Nature Reserve, the Coral Sea Reserves (Coringa-Herald and Lihou Reeds and Cays), and Elizabeth and Middleton Reeds Marine National Nature Reserve. Mainstream Environmental Consulting Pty Ltd, Waramanga ACT.

Phillips, B. and Muller, K., 2006, Ecological Character Description of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance, Department of the Environment and Heritage, Adelaide, South Australia.

Puhalovich, A., Jocobsen, N., and Overall, R.,A. 2003, Surface water and groundwater hydrology in relation to proposed new mining leases, Christmas Island, Indian Ocean. Report for Phosphate Resources Limited by EWL Sciences Pty. Ltd.

Ramsar Convention, 1987, Convention on Wetlands of International Importance especially as Waterfowl Habitat.

Ramsar Convention, 1996, Resolution VI.1. Annex to Resolution VI.1. Working Definitions, Guidelines for Describing and Maintaining Ecological Character of Listed Sites, and Guidelines for Operation on the Montreux Record.

Ramsar Convention 2005, Resolution IX.1 Annex A. A Conceptual Framework for the wise use of wetlands and the maintenance of their ecological character.
http://www.ramsar.org/res/key_res_ix_01_annexa_e.htm

Ramsar Convention, 2009, Strategic Framework for the List of Wetlands of International Importance, Third edition, as adopted by Resolution VII.11 (COP7, 1999) and amended by Resolutions VII.13 (1999), VIII.11 and VIII.33 (COP8, 2002), IX.1 Annexes A and B (COP9, 2005), and X.20 (COP10, 2008).
http://ramsar.rgis.ch/dev/ramsar/display/main/main.jsp?zn=ramsar&cp=1-31-105^20823_4000_0__

Reddell, P. and Zimmermann, A., 2003, Terrestrial Flora of the Proposed Phosphate Mine Leases on Christmas Island and an Assessment of Feasible Rehabilitation Options following Mining. *in* Phosphate Resources Ltd 2005. *Draft Environmental Impact Statement for the*

Proposed Christmas Island Phosphate Mines. Technical Appendices Vol 1. Phosphate Resources Ltd.

Reville, B. J., Tranter, J.D., and Yorkston, H. D., 1990, Impact of forest clearing on endangered seabird *Sula abbotti*. Biological Conservation 51: 23-38.

RIS (Ramsar Information Sheet), 2002, "The Dales", Christmas Island http://www.environment.gov.au/water/topics/wetlands/database/pubs/61-ris.pdf

Rivereau, J.C. 1965, Notes on a geomorphological study of Christmas Island Indian Ocean. Bureau of Mineral Resources Australia Record 1965/116.

SKM 2000, Christmas Island satellite launch facility: final environmental impact statement. Report prepared for APSC Asia Pacific Space Centre.

Spate, A.P., and Webb, R., 1998, Management options for cave use on Christmas Island. Unpublished report to Parks Australia North by the Australian Cave and Karst Management Association Inc. 82 pp.

Turner, L., 2007, Regulation of kidney-like function in freshwater land crabs, http://www.bio.bris.ac.uk/research/morlab/blue-crab_student.htm accessed February 9, 2010

Turner, L., Webster, S.G., and Morris, S., 2009, A role for CHH in the regulation of kidney-like function in freshwater land-crabs: A study of the Christmas Island blue crab, *Discoplax hirtipes*. Comparative Biochemistry and Physiology, Part A 153 (2009) S96.

Yorkston, H. D., and Green, P.T. 1997, The breeding distribution and status of Abbott's Booby (Sullidae: *Papasula abbotti*) on Christmas Island, Indian Ocean. Biological Conservation 79: 293-301.

Wetlands International, 2006, Waterbird Population Estimates, fourth edition.

Wilkinson, C., 2004. Status of coral reefs of the world. Townsville: Australian Institute of Marine Science.

Wiser, S.K., Drake, D.R., Burrows, L.E., and Sykes, W.R., 2002, The potential for long-term persistence of forest fragments on Tongatapu, a large island in western Polynesia. Journal Biogeography 29:767-787.

Appendix A: Methods

A.1 Approach

The method for compiling this ECD comprised of the following tasks:

Project Inception:
Consultant team leader Jennifer Hale met with the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) project manager to confirm the scope of works and timelines as well as identifying relevant stakeholders that would be consulted.

Task 1: Review and compilation of available data
The consultant team undertook a thorough desktop review of existing information on the ecology of The Dales Ramsar site. In addition, data was provided by Parks Australia, Peter Green (Latrobe University), Ken Grimes, and Jean-Paul Hobbs (James Cook University).

Task 2: Stakeholder engagement and consultation
A Steering Committee was formed for the preparation of The Dales Ramsar site ECD. This group was comprised of stakeholders with an interest in the ECD and management planning process, and included representatives of the following organisations:

Department of Sustainability, Environment, Water, Population and Communities
- Parks Australia, Planning, Tourism and National Landscapes Section
- Parks Australia, Christmas Island National Park
- Water Reform Division, Wetlands Section

Members of the Steering Committee provided verbal and written comments on drafts of the ECD.

Task 3: Development of a draft ECD
Consistent with the national guidance and framework (2008) the following steps were undertaken to describe the ecological character of The Dales Ramsar site.

Steps from the national draft (2008) framework	Activities
1. Document introductory details.	Prepare basic details: site details, purpose, legislation.
2. Describe the site.	Based on the Ramsar RIS and the above literature review describe the site in terms of: location, land tenure, Ramsar criteria, wetland types (using Ramsar classification).
3. Identify and describe the critical components, processes and services.	Identify all possible components, services and benefits. Identify and describe the critical components, services and benefits responsible for determining ecological character.
4. Develop a conceptual model of the system.	Two types of models were developed for the system: • A series of control models that describe important aspects of the ecology of the site, including feedback loops. Aiding in the understanding of the system and its ecological functions. • A stressor model that highlights the threats and their effects on ecological components and processes. Aiding in understanding management of the system.
5. Set Limits of Acceptable Change.	For each critical component process and service, establish the limits of acceptable change.
6. Identify threats to the site.	This process identified both actual and potential future threats to the ecological character of the wetland system.
7. Describe changes to ecological character since the	This section describes in quantitative terms (where possible) changes to the wetlands since the initial listing in

Steps from the national draft (2008) framework	Activities
time of listing.	2002.
8. Summarise knowledge gaps.	This identifies the knowledge gaps for not only the ecological character description, but also for its management.
9. Identify site monitoring needs.	Based on the identification of knowledge gaps above, recommendations for future monitoring are described.
10. Identify communication, education and public awareness messages.	Following the identification of threats, management actions and incorporating stakeholder comments, a general description of the broad communication / education messages are described.

Task 4: Revision of the Ramsar Information Sheet (RIS)
The information collated during Task 1, together with the draft Ecological Character Description was used to produce a revised RIS in the standard format provided by Ramsar.

Task 5 Finalising the ECD and RIS
The draft ECD and RIS were submitted to DSEWPaC, and the Steering Committee for review. Comments from agencies and stakeholders were incorporated to produce revised ECD and RIS documents.

A.2 Consultant Team

Jennifer Hale (team leader)
Jennifer has over twenty years experience in the water industry having started her career with the State Water Laboratory in Victoria. Jennifer is an aquatic ecologist with expertise in freshwater, estuarine and near-shore marine systems. She is qualified with a Bachelor of Science (Natural Resource Management) and a Masters of Business Administration. Jennifer is an aquatic ecologist with specialist fields of expertise including phytoplankton dynamics, aquatic macrophytes, sediment water interactions and nutrient dynamics. She has a broad understanding of the ecology of aquatic macrophytes, fish, waterbirds, macroinvertebrates and floodplain vegetation as well as geomorphic processes. She has a solid knowledge of the development of ecological character descriptions and has been involved in the development of ECDs for Port Phillip Bay and Bellarine Peninsula, the Peel-Yalgorup, the Ord River Floodplain, Eighty-mile Beach, the Coorong and Lakes Alexandrina and Albert, Lake MacLeod, Elizabeth and Middleton Reefs, Ashmore Reef and the Coral Seas Ramsar sites.

Rhonda Butcher
Rhonda is considered an expert in wetland ecology and assessment. She has a BSc (hons) and a PhD in Wetland Ecology together with over twenty years of experience in the field of aquatic science. She has extensive experience in biological monitoring, biodiversity assessment, invertebrate ecology as well as wetland and river ecology having worked for CSIRO/Murray Darling Freshwater Research Centre, Monash University/CRC for Freshwater Ecology, Museum of Victoria, Victorian EPA and the State Water Laboratories of Victoria. Rhonda has worked on numerous Ramsar related projects over the past eight years, including the first pilot studies into describing ecological character. She has subsequently co-authored, provided technical input, and peer reviewed a number of Ecological Character Descriptions. She project managed the preparation of Ramsar nomination documents for Piccaninnie Ponds Karst Wetlands in South Australia, which included preparation of the ECD, RIS and Ramsar Management Plan, and the preparation of the ECD for Banrock Station Wetland Complex. Other ECD project's Rhonda has had technical input to include the Coorong and Lakes Alexandrina and Albert, Lake MacLeod, Peel-Yalgorup, Eighty-mile Beach, Port Phillip Bay. Rhonda is currently project managing the Ramsar Rolling Review developing a framework for reporting the status of ecological character at all 65 Ramsar sites in Australia.

Halina Kobryn

Dr Halina Kobryn has over fifteen years of experience in applications of GIS and remote sensing in environmental applications. She is a GIS and remote sensing expert, specialising in natural resource assessment. Dr Kobryn has a BSc in Physical Geography and Cartography, Graduate Diploma in Surveying and Mapping and a PhD which explored impacts of stormwater on an urban wetland and explored GIS methods for such applications. She has worked at a university as a lecturer for over 15 years and taught many subjects including GIS, remote sensing, environmental monitoring and management of aquatic systems. She has developed the first course in Australia (at a graduate level) on Environmental Monitoring. She has been involved in many research and consulting projects and her cv outlines the breadth of her expertise. She has also supervised over 20 research students (honours, Masters and PhD). She has worked in Indonesia, Malaysia (Sarawak) and East Timor on projects related to water quality and river health.

Peter Green
Dr Peter Green is an ecologist with a broad range of interests, including forest ecology, plant-animal interactions, seed and seedling ecology, invasion biology, and the ecological strategies of plants. Peter is a senior lecturer in the Department of Botany at Latrobe University. Peter has been involved in the study of red land crabs, invasive yellow crazy ants and scale insects as biotic filters to the local assembly of rainforest seedling communities on Christmas Island for over a decade. During this time he has acquired an in depth understanding of the ecology of Christmas Island which will be invaluable to the development of the ECDs in general and the conceptual models in particular.

Jean-Paul Hobbs
Jean-Paul is a marine ecologists specialising in the ecology of tropical coral reefs and in particular isolated island systems. He is a member of the ARC Centre of Excellence for Coral Reef Studies and a lecturer at James Cook University in Queensland. He has undertaken extensive surveys and research into the marine environments at Christmas Island and Cocos Island. He is currently finishing a report to Parks Australia on the status of Pulu Keeling National Park Ramsar site in the Cocos Islands and the loss of marine diversity and local extinctions that have recently occurred in this wetland following the closure of the lagoon. He brings technical expertise and invaluable local, recent knowledge to the team.

Bill Humphreys
Dr Humphreys is currently Senior Curator at the Western Australian Museum. He has experience of marine, freshwater and terrestrial fauna, both as a researcher and teacher, and has published widely on both invertebrate and vertebrate taxa. To date, he has edited 4 books, and authored 36 chapters, over 100 peer-reviewed papers, 36 consultancy reports and in excess of 40 other publications. Dr Humphreys is a board member of the Centre for Groundwater Studies and serves on the Editorial Board of the Records of the Western Australian Museum and the international journal Subterranean Biology. He is also Vice-President of the International Society of Subterranean Biology. Dr Humphreys is currently a member of the Western Australian Scientific Advisory Committee for Threatened Ecological Communities and also serves on a number of other Western Australian-based advisory groups and recovery teams.

Appendix B: Wetland birds recorded in The Dales Ramsar Site

Species list compiled from Birds Australia Bird Atlas (Birds Australia unpublished).

Scientific Name	Common Name	EPBC Act Listing
Amaurornis phoenicurus	White-breasted water-hen	
Egretta novaehollandiae	White-faced heron	
Egretta sacra	Eastern reef egret	Marine; Migratory (CAMBA)
Fregata andrewsi	Christmas Island frigatebird	Vulnerable; Marine; Migratory (CAMBA)
Fregata ariel	Lesser frigatebird	Marine; Migratory (CAMBA, JAMBA, ROKAMBA)
Fregata minor	Greater frigatebird	Marine; Migratory (CAMBA, JAMBA)
Nycticorax caledonicus	Nankeen night heron	Marine
Papasula abbotti	Abbott's booby	Endangered; Marine, Migratory (JAMBA)
Phaethon lepturus fulvus	White-tailed tropicbird	Marine
Phaethon rubricauda	Red-tailed tropicbird	Marine
Sula sula	Red-footed booby	Marine; Migratory (CAMBA, JAMBA)

Appendix C: Marine fish

Species list specific to The Dales Ramsar site (Gilligan et al. 2008; Hobbs et al. 2008).

Family and common name	Species	Distribution
Haemulidae - grunter	*Plectorhinchus vittatus*	Indo-West Pacific
Holocentridae - squirrelfish	*Sargocentron caudimaculatum*	Indo-Pacific
Serranidae – sea bass	*Cephalopholis argus*	Indo-Pacific
	Variola louti	Indo-Pacific
Lutjanidae - snapper	*Aphareus furca*	Indo-Pacific
	Lutjanus bohar	Indo-Pacific
	Macolor macularis	Indo-Pacific
Mullidae - goatfish	*Parupeneus trifasciatus*	Indo-Pacific
	P. cyclostomus	Indo-Pacific
Kyphosidae - rudderfish	*Kyphosus sp.*	Indo-Pacific
Chaetodontidae - butterflyfish	*Chaetodon auriga*	Indo-Pacific
	C. citrinellus	Indo-Pacific
	C. guttatissimus	Indian Ocean
	C. lunula	Indo-Pacific
	C. meyeri	Indo-Pacific
	C. ornatissimus	Indo-Pacific
	C. trifascialis	Indo-Pacific
	C. unimaculatus	Indo-Pacific
	Forcipiger flavissimus	Indo-Pacific
	Forcipiger longirostris	West Pacific
Pomacanthidae - angelfish	*Apolemichthys trimaculatus*	Indo-Pacific
	Centropyge flavissimus	Indo-Pacific
	C.bicolor	Indo-Pacific
	Pomacentrus alleni	Indo-Pacific
	Pygoplites diacanthus	Indo-Pacific
Pomacentridae - damselfish	*Stegastes insularis*	Endemic
Labridae – wrasses and parrotfish	*Bodianus bilunulatus*	Indo-Pacific
	Scarus rubroviolaceus	Indo-Pacific
Acanthuridae – surgeonfishes and unicornfishes	*Acanthurus leucosternon*	Indo-Pacific
	A. tristis	Indo-Pacific
	Naso unicornis	Indo-Pacific
Zanclidae - moorish idols	*Zanclus cornutus*	Indo-Pacific

Appendix D: Endemic Flora (vascular)

Species names from EWL Sciences and Tallegalla (2005) common names from Director of National Parks (2002).

Family	Species	Life form	Habitat	Common name
Malvaceae	*Abuliton listeri*	Shrub	Coast and shore terrace	Lantern flower
Arecaceae	*Arenga listeri*	Palm	Closed forests	Arenga palm, Christmas Island palm
Aspleniaceae	*Asplenium listeri*	Fern	Exposed limestone outcrops	Spleenwort
Acanthaceae	*Asystasia alba*	Herb	Terrace forest	
Orchidaceae	*Brachypeza archytas*	Epiphytic orchid	Terrace and plateau forests	
Rhamnaceae	*Colubrina pendunculata*	Shrub/ small tree	Terrace shrubland	
Urticaceae	*Dendrocnide peltata var. murrayana*	Small tree	Inland cliffs	Stinging tree
	Dicliptera maclearii	Herb	Terrace vegetation	
	Flickingeria nativitatis	Epiphytic orchid	Plateau forests	
Tiliaceae	*Grewia insularis*	Small tree	Terrace forest	
Asclepidaceae	*Hoya aldrichii*	Vine	Closed forests	Hoya vine
Poaceae	*Ischaemum nativitatis*	Grass	Seacliffs	Christmas Island duck beak
Pandanaceae	*Pandanus christmatensis*	Shrub	Shore and inland cliffs	Pandanus, screw pine
	Pandanus elatus	Shrub/small tree	Forest understorey	Pandanus, screw pine
Piperaceae	*Perperomia rossii*	Epiphytic herb	Plateau	
	Phreatia listeri	Epiphytic orchid	Plateau forests	
Cucurbitaceae	*Zehneria alba*	Vvine	Forest margins	
	Zeuxine exilis	Epiphytic orchid	Plateau forests	