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ECOLOGICAL CHARACTER DESCRIPTION FOR
ROEBUCK BAY

Bennelongia Environmental Consultants

DHI

Wetland Research & Management

ECOLOGICAL CHARACTER DESCRIPTION FOR ROEBUCK BAY

Report prepared for the Department of Environment and Conservation

by

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EXECUTIVE SUMMARY

Roebuck Bay was designated a "Wetland of International Importance" under the Ramsar Convention in June 1990. The Convention (*The Convention on Wetlands of International Importance, especially as Waterfowl Habitat*) is an intergovernmental multilateral treaty on the wise use of wetlands generally and, specifically, the conservation of designated Wetlands of International Importance.

Signatory countries to the Ramsar Convention are required to formulate and implement planning to promote wise use and conservation of the nation's wetlands and to inform the Ramsar Secretariat at the earliest possible time if the "ecological character" of any Ramsar listed wetland has changed, or is likely to change as a result of human activity.

Describing the "ecological character" of a Ramsar wetland is a fundamental step towards documenting its baseline condition so that any changes in ecological character may be identified. Ecological character is defined under the Ramsar Convention (2005) as "the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time".

The methodology used to compile a description of the ecological character of Roebuck Bay is that proposed in the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* DEWHA (2008). There were six specific objectives of the ecological character description:

- Describe the critical components, processes and benefits/services of the Roebuck Bay Ramsar site at the time of Ramsar listing.
- Develop a conceptual model for Roebuck Bay that shows how the components, processes and benefits/services relate to each other to create the Bay's ecological character.
- Identify gaps in the knowledge of the critical components, processes and benefits/services of the site.
- Identify likely threats to the ecological components, processes or services of the site.
- Quantify the limits of acceptable change for the key components, processes and benefits/services.
- Develop a framework for monitoring key values of Roebuck Bay that incorporates limits of acceptable change.

The Roebuck Bay Ramsar site comprises 34,119 hectares, mostly occupied by intertidal mudflats. Waters more than 6 m deep at low tide are excluded from the site, which stretches from Campsite (a location on the northern shore of Roebuck Bay) east of the town of Broome, to south of Sandy Point (***Figure 2***). The soft bottom intertidal mudflats of the northern and eastern shores of Roebuck Bay, and high tide roosts at Bush and Sandy Points are the most biologically significant parts of the site, which was listed for several reasons including, most notably, outstanding shorebird values.

Roebuck Bay is one of less than twenty soft bottomed intertidal mudflats worldwide that support very large numbers of migratory shorebirds and comprise the primary staging and over-wintering areas for Palaearctic shorebirds on their annual southwards migrations. The high biomass of benthic invertebrates at Roebuck Bay (for a tropical mudflat) is a key characteristic that makes it such an important shorebird habitat. The maximum count of waterbirds in Roebuck Bay was 170,915 in October 1983 and it is used by up to 300,000 shorebirds annually. It is estimated to support between 300 - 500 species of benthic invertebrates.

The formal criteria under which Roebuck Bay was listed as a Ramsar site are:

Criterion 1: *Wetland values*. The site is a superb example of a tropical marine embayment within the Northwest (IMCRA) bioregion. It is one of only a dozen intertidal flats worldwide where benthic food sources are found in sufficient densities that they regularly support internationally significant numbers of waders.

Criterion 2: *Threatened species/communities*. Loggerhead Turtles *Caretta caretta* (nationally endangered) and Green Turtles *Chelonia mydas* (nationally vulnerable) regularly use the site as a seasonal feeding area and as a transit area on migration. Flatback Turtles *Natator depressus* (nationally vulnerable) regularly nest in small numbers around Cape Villaret during the summer months. Sawfish *Pristis clavata* (nationally endangered) regularly use the tidal creeks and mangrove areas for breeding and refuge.

Criterion 3: *Regional biodiversity*. The site supports a significant component of the regional (Northwest IMCRA bioregion) intertidal and shallow marine biodiversity in terms of the marine mammals (Dugong, turtles and dolphin), marine invertebrate infauna, and avian fauna across the site. The total density of macrobenthic animals (1,287 individuals/m^2) is high by global standards for a tropical mudflat and species richness is very high (estimated to be between 300 - 500 species).

Criterion 4: *Key habitat in life cycle*. The site is one of the most important migration stopover areas for shorebirds in Australia and globally. It is the arrival and departure point for large proportions of the Australian populations of several shorebird species, notably Bar-tailed Godwit *Limosa lapponica* and Great Knot *Calidris tenuirostris*. The site provides essential energy replenishment for many migrating species, some of which fly non-stop between continental East Asia and Australia.

Criterion 5: *Supports >20,000 waterbirds*. The site regularly supports over 100,000 waterbirds. The highest number of shorebirds counted at the site was 170,915 in October 1983 and allowing for turnover, the total number of shorebirds using the site may exceed 300,000 annually. It is the fourth most important site for waders in Australia in terms of absolute numbers and the most important in terms of the number of species it supports in internationally significant numbers (see Criterion 6).

Criterion 6: The site regularly supports ≥1% of the population of at least 22 wader species (20 migratory and 2 resident species).

Criterion 8: The site is important as a nursery and/or breeding and/or feeding ground for at least five species of fish and for mudcrabs and prawns. The site's mangal system is particularly important as a nursery area for marine fishes and prawns.

Criteria 7 and 9 for Ramsar listing were not met with existing information.

Under the Ramsar classification system there are numerous categories of “wetland” ranging from shallow areas of ocean to inland freshwater lakes and to man-made waterbodies. The Roebuck Bay Ramsar site contains four different marine or coastal wetland types:

1. Marine subtidal aquatic beds - sea-grass beds;

2. Intertidal mud and sand flats;

Oldmeadow (2007) refers to three main sediment provinces in the intertidal zone of Roebuck Bay:

- Northern sands province;
- Eastern silt and clay province;
- Southern sands province.

3. Intertidal forested wetlands - mangrove swamps;

4. Intertidal marshes - samphire and saline grasslands.

The fundamental drivers of the ecology of Roebuck Bay are climate, geomorphology, hydrology and oceanography, which control wetland type, and biogeography, which controls the pool of available organisms to colonise the Bay. Biogeochemical and biotic features then determine exactly which animals and plants live within the resultant wetland environment and the finer scale distribution of these plants and animals.

Many physical, chemical and biological processes or wetland components are important at Roebuck Bay but it is considered that the most critical are:

- Sediment characteristics;
- Benthic plants (seagrass and macroalgae);
- Stands of mangroves;
- Benthic invertebrates on the mudflats;
- Shorebirds.

Conceptual models are presented at three levels. The first model shows how the ecological character of Roebuck Bay is shaped by climatic, oceanographic, geomorphic and biogeographic factors. These control the biochemical processes occurring in sediments and water and the biological organisms that may potentially use the area. The second shows how the situation created by broad drivers of ecological character may be affected by anthropogenic changes (termed drivers) that change the biochemical processes and biological values of the Bay and, in turn, alter the ecosystem services it provides. Thirdly, two finer scale models are presented to illustrate the connectivity between the terrestrial and marine ecosystems at Roebuck Bay, with groundwater and surface water flow after monsoonal rain (as well as marine production) supplying the system with energy and nutrients. The second of these models focuses on the importance of tidal movement in sustaining mangrove and salt marsh communities, which provide nursery habitats for invertebrates and fish, as well as roosting sites for shorebirds.

The ecological character description addresses what are likely to be the limits of acceptable change for each of the important processes and biological components at the Bay but knowledge gaps mean that the limits of acceptable change proposed are interim limits and will need to be revised as more data become available. Monitoring programs are proposed for each of the above attributes to provide data to assess compliance with interims limits of acceptable change and enable refinement of the limits over time.

In considering the ecology of Roebuck Bay, two issues emerge very strongly. Global populations of 44% of shorebird species have declined over the last 20 years and recent developments along the Australasian East-Asian Flyway, of which Roebuck Bay is part, are placing considerable pressure on the capacity of shorebirds to complete their annual migration. Maintenance of the capacity of Australian staging points, such as Roebuck Bay, in first class condition is critical for global conservation of shorebirds.

The attributes of Roebuck Bay that make it such an important shorebird conservation site are the soft silty sediments of much of the Bay and the consequential high biomass of benthic invertebrates on the mudflats. Maintaining Roebuck Bay in first class condition means ensuring that the physical characteristics of the mudflats and the energy sources driving productivity on the mudflats (mudflat diatoms, planktonic algae brought in by tides, mangrove detritus) continue in their current state. These attributes are critical to maintaining invertebrate biomass and, therefore, Roebuck Bay as an outstanding migratory shorebird site.

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1. INTRODUCTION

1.1 CONTEXT / SITE DETAILS

Much of the intertidal zone and some adjoining areas of Roebuck Bay were designated a “Wetland of International Importance” under the Ramsar Convention in June 1990. The Convention (*The Convention on Wetlands of International Importance, especially as Waterfowl Habitat*) is an intergovernmental multilateral treaty on the wise use of wetlands generally and, specifically, the conservation of designated Wetlands of International Importance. There are presently 158 Contracting Parties to the Convention worldwide, including Australia and 1831 listed wetlands under the Ramsar Convention totalling 170 million hectares.

Contracting Parties to the Ramsar Convention have a number of responsibilities. Prominent among these are commitments to formulate and implement planning so as to promote wise use and conservation of the nation’s wetlands, and to arrange to inform the Secretariat at the earliest possible time if the “ecological character” of any listed wetland has changed, or is likely to change as a result of human activity (Convention Articles 3.1 and 3.2). Describing the “ecological character” of a Ramsar site is a fundamental step to documenting its baseline condition so that any changes in ecological character may be identified. Roebuck Bay was originally listed as being one of only a dozen intertidal flats worldwide where benthic food sources support huge numbers of shorebirds, as well as a superb example of a tropical marine embayment. Over time, the site has been deemed to meet additional listing criteria (***Table 1***).

Roebuck Bay remains one of the most important sites for shorebird conservation in the East-Asian Australasian Flyway. It is internationally important for at least 20 species of migratory shorebirds with total numbers of waders using the site each year estimated at over 300,000. By global standards, it supports high biomass of benthic invertebrates for a tropical mudflat, including many species believed to be new to science. Nationally endangered Loggerhead Turtles (*Caretta caretta*) and the nationally vulnerable Green Turtle (*Chelonia mydas*) regularly use the area as a seasonal feeding ground and as a transit area during migration (Lambert and Elix 2006).

Research data gathered from this site have been important in the study of the biology and behaviour of many shorebird species. Such work has major implications for shorebird conservation, not only in Australia but also along the migratory flyway in Asia. Protected migratory mammal species such as the

Dugong (*Dugong dugon*) and an as yet undescribed species of dolphin (previously thought to be *Orcaella brevirostris*) frequent the Bay. The site is also of high social and cultural value. The Bay provides the only deep-water port in the Kimberley. It supports tourism, commercial fishing and pearling, and a diversity of recreational activities such as bird-watching, fishing, crabbing, water skiing, kayaking and sight-seeing tours by hovercraft.

In addition, the Bay area contains a substantial number of Aboriginal heritage sites, and remains a place of Aboriginal cultural, spiritual, social and economic significance (Lambert and Elix 2004). Dinosaur footprints in the Broome sandstone at Fall Point date from the Cretaceous period and are of considerable scientific interest.

Major threats to the values of Roebuck Bay largely relate to rapidly increasing population and increased tourism that will lead to greater numbers of people in and around the Ramsar site – more vehicles, boats, dogs, litter, waste water, fishing, boating and development of an international airport. Furthermore, increased mining in the region and development of Broome as a base for North-west Shelf gas exploration and supply are likely to lead to an expansion of Broome port facilities (Lambert and Elix 2004). The Shire of Broome is already the region's largest population centre with more than 40% of the regional population. Oil is currently shipped out of Broome port and exploration permits for petroleum are held over the wetland area of the Bay. Pressure to develop petroleum reserves within the Bay would increase the risk of an oil spill, and a spill at the time of mass migration could be globally catastrophic for shorebirds (ANCA 1996).

The Ramsar site does not extend over the entire Roebuck Bay wetland ecosystem. Most of the extensive grasslands east of the Bay referred to as Roebuck Plains are excluded from the Roebuck Bay Ramsar site, even though they are contiguous with the Bay and hydrologically connected. The western boundary of the Ramsar site along the northern shore stops short of the Dampier Creek system. For the purpose of this report, it was often not possible to separate the values of the Ramsar site from those of coastally influenced parts of Roebuck Plains.

1.2 PURPOSE OF ECOLOGICAL CHARACTER DESCRIPTIONS

'Ecological character' is defined under the Ramsar Convention (2005) as "the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time". Change in ecological character is considered under Ramsar as "the human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service". The legal framework ensuring the ecological character of all Australian Ramsar sites is maintained is the *Environment Protection and Biodiversity Conservation Act* 1999 (*EPBC Act*). The relationship between the *EPBC Act*, the ECD and the management of Ramsar sites is summarised in ***Figure 1***.

Table 1. Site details for the Roebuck Bay Ramsar site.

Site Name	Roebuck Bay, Western Australia.
Location in coordinates	Latitude: 17°58' S to 18°16' S. Longitude: 122°08' E to 122°27' E.
General location of the site	Roebuck Bay is located in the Shire of Broome (local authority) in the State of Western Australia (population ca 2.13 million in 2006). Roebuck Bay Ramsar site extends from the location "Campsite" , east of the town of Broome (population ca. 14,500 in 2006), to south of Sandy Point.
Area	34,119 ha.
Date of Ramsar site designation	Originally nominated in June 1990. Criteria for listing were updated in October 2003 and December 2008.
Ramsar/DIWA criteria met by wetland	Ramsar criteria 1, 2, 3, 4, 5, 6, and 8.
Management authority	Territorial: The State Government of Western Australia. Functional: The Conservation Commission of Western Australia (vesting of reserves) and the Department of Environment and Conservation (DEC). Management authority: Department of Environment and Conservation.
Date the ecological character description applies	June 1990 to current.
Status of Description	This is the first ecological character description for the site.
Date of Compilation	April 2009
Name(s) of compiler(s)	*Bennelongia* Pty Ltd on behalf of DEC, all enquires to Michael Coote, DEC, 17 Dick Perry Ave, Technology Park, Kensington, WA 6983, Australia, (Tel: +61-8-9219-8714; Fax: +61-8-9219-8750; email: Michael.Coote@dec.wa.gov.au).
References to the Ramsar Information Sheet	Roebuck Bay, Western Australia – Ramsar site no. 479. RIS compiled by the Department of Conservation and Land Management (DCLM) in 1990; updated in 2003, and by *Bennelongia* Pty Ltd on behalf of DEC in 2009.
References to the Management Plan(s)	Roebuck Bay Interim Management Guidelines, prepared for the Roebuck Bay Working Group and WWF Australia (Lambert & Elix 2006).

The Government of Western Australia has jurisdiction over marine areas within the Roebuck Bay Ramsar site. The landward sections of the site are Unallocated Crown Land, except for a small reserve gazetted for the purpose of a Bird Observatory. The Department of Planning and Infrastructure has ultimate management responsibility for Unallocated Crown Land, but DEC is responsible for management of the Ramsar site and has control over flora and fauna. The Department of Fisheries is responsible for areas below the low tide mark and for ensuring sustainable recreational and commercial harvesting of fish populations. A diversity of private leaseholders are responsible for the day-to-day management of activities such as pearling and aquaculture leases, commercial fishing leases, tour boat operations (including hovercraft) and the Broome Bird Observatory lease (Lambert and Elix 2006).

In order to detect a change in ecological character, baseline condition must first be identified. Once the baseline is quantified, limits of acceptable change may be set. Management intervention should be triggered if ecological character moves outside these limits. The methodology used for the Roebuck Bay ECD is that proposed in the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEWHA 2008). One of the outcomes is a site-specific monitoring program for Roebuck Bay.

The overall goal of any ECD is to detail current understanding of the wetland ecosystem, including all components and processes related to the criteria for which it was listed. A set of high level objectives for

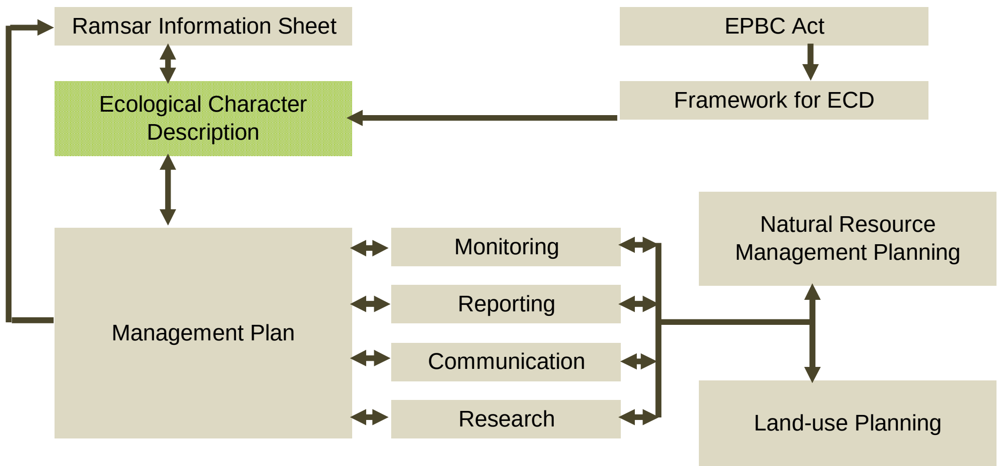


Figure 1. The ecological character description in the context of other requirements for the management of Ramsar sites (adapted from DEWHA 2008 and Hale & Butcher 2007).

ECDs, principally aimed at benefits to the Commonwealth Government, have been outlined by McGrath (2006) 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:

   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.

This Roebuck Bay ECD synthesizes existing scientific information on the natural values of Roebuck Bay to describe its ecological character. A monitoring program to measure the state of key biological and physical attributes related to listing criteria is proposed, together with estimates of the limits of acceptable change in the attributes monitored. The monitoring program focuses on what are regarded as the most important values of Roebuck Bay and does attempt to be comprehensive. While potential threats to key values are identified, the ECD does not address management responses.

1.3 MANAGEMENT PLANS AND INITIATIVES

Interim Management Guidelines for Roebuck Bay were developed in 2006 by the Roebuck Bay Working Group (RBWG), in collaboration with Traditional Owners, other Indigenous representatives, government agencies, industry groups, community organisations and local government. The guidelines are a step towards a management plan that will "protect, restore and maintain the natural and cultural values of the Bay, while still sustaining the economic and social uses of the area" (Lambert and Elix 2006). The guidelines are based on, and incorporate results of, the 2004 Values Mapping project (Lambert and Elix

2004) and associated Aboriginal consultation, scientific studies of benthic animals and shorebirds, an RBWG Issues Paper and stakeholder workshops.

Other initiatives that will assist in management of the Ramsar site are:

- Coastal Park Management Plan 1999;
- Shire of Broome stormwater management 2003;
- Community Seagrass Monitoring Project;
- RBWG sub-committee on *Lyngbya*;
- Aboriginal Ranger/Heritage Officer program;
- Cultural mapping projects in the area through the Native Title initiative;
- National Plan for Shorebird Conservation in Australia 1993;
- National Wildlife Conservation Plan for Migratory Shorebirds 2006;
- Recovery Plan for marine turtles in Australia.

1.4 OBJECTIVES OF THE ROEBUCK BAY ECOLOGICAL CHARACTER DESCRIPTION

The specific objectives of the ecological character description for Roebuck Bay may be summarised as follows:

1. Describe the critical components, processes and benefits/services of the Roebuck Bay Ramsar site at the time of Ramsar listing.
2. Develop a conceptual model for Roebuck Bay that shows how the components, processes and benefits/services relate to each other to create the Bay's ecological character.
3. Identify gaps in the knowledge of the critical components, processes and benefits/services of the site.
4. Identify likely threats to the ecological components, processes or services of the site.
5. Quantify the limits of acceptable change for the key components, processes and benefits/services. Further change represents loss of ecological character.
6. Develop a framework for monitoring key values of Roebuck Bay that incorporates limits of acceptable change.

The stages leading to the ecological character description for Roebuck Bay and ultimately a management plan are illustrated in ***Table 2***.

1.5 RELEVANT LEGISLATION AND POLICIES

There are numerous international, national and state legislation and policy that apply either directly or indirectly to the management of the Roebuck Bay Ramsar site (***Table 3***). The most relevant of these are briefly described below. Legislation and policy will be more fully documented in the management plan for the site.

International Treaties

Ramsar Convention

The Ramsar Convention (*The Convention on Wetlands of International Importance, especially as Waterfowl Habitat 1971*) is an intergovernmental multilateral treaty on the conservation of designated wetlands of international importance and the wise use of wetlands generally. The Convention was signed by representatives of eighteen nations in Ramsar, Iran in 1971 and brought into force in 1975. The Convention is overseen by the Ramsar Convention Secretariat which is based in Gland, Switzerland.

Table 2. Progress toward a management plan for the Roebuck Bay Ramsar site (adapted from Hale & Butcher 2007).

TIME LINE	MILESTONE	ACTION	RESPONSIBILITY
1975	Ramsar Convention introduced in Australia requiring a national approach	Australia will nominate wetlands for the Ramsar list of Wetlands of International Importance	Commonwealth and State Governments
1990	Australia designates Roebuck Bay as a Ramsar Site.	Obligation to maintain the ecological character of Roebuck Bay	Commonwealth and Western Australian Governments
1999	Commonwealth *Environment Protection and Biodiversity Conservation Act* (*EPBC Act*) enacted	This Act enshrines in Commonwealth law the requirements to maintain ecological character of Ramsar Sites	Australian governments are required to prepare management plans for Ramsar sites based on the Australian Ramsar Management Principles
2006	Interim Management Guidelines for Roebuck Bay	Guidance for conservation and wise use until such time as a detailed management plan is implemented	Roebuck Bay Working Group
2008	ECD for the Roebuck Bay Ramsar site	Description of character of the site at the time of listing (1990) and current conditions (2009).	DEC
Future	Management Plan for the Roebuck Bay Ramsar Site and Environs	Use the ECD for guidance on maintaining the ecological character of Roebuck Bay	DEC, community

Sites may be nominated for listing based on "their international significance in terms of ecology, botany, zoology, limnology or hydrology" and contracting parties are to "formulate and implement their planning so as to promote the conservation of the wetlands included in the List" (Ramsar Convention 1987). Further information on the Convention is available online at www.ramsar.org.

Agreements and Conventions on Migratory Species

Australia is party to a number of agreements, initiatives and conventions for the conservation of migratory birds and other animals (*e.g.* dolphins, dugongs, turtles) which are relevant to the Roebuck Bay Ramsar site. Bilateral agreements include:

Table 3. Agencies governing land tenure at Roebuck Bay (adapted from Lambert & Elix 2006).

ORGANISATION	RESPONSIBILITIES & ENABLING LEGISLATION
Australian Government Department of the Environment and Heritage	Protection and wise use of Ramsar sites, under provisions of Ramsar Convention and the *EPBC Act* 1999 and related regulations. Responsible for protection of endangered and vulnerable species listed under the *EPBC Act 1999,* and for conservation planning for shorebirds listed under international Agreements. Responsible for protection of both non-Indigenous and Aboriginal and Torres Strait Islander heritage.
Department of Environment and Conservation	Responsible for protection of native flora and fauna and pollution control under the provisions of the *Wildlife Conservation Act* 1950 and *Environment Protection Act* 1986. Responsibility for management of Ramsar sites at the State level..
Department of Water	Responsible for licensing, regulation, protection of water quality and preparation of policies and plans ensuring safe and sustainable surface and ground water supplies. Legislation includes the *Water Boards Act 1904*, *Water Services Licensing Act 1995* and the *Water Agencies (Powers) Act 1984*.
Department of Fisheries	Responsible for the sustainable development and management of the State's fisheries. Principal legislation is the *Fish Resource Management Act* 1994 and the *Pearling Act* 1990.
Department for Planning & Infrastructure	Responsible for a diversity of land use and planning activities relating to maritime facilities, boat harbours, recreational boating, sea freight, and pastoral leases. Relevant legislation includes the *Land Administration Act* 1997, *Port Authorities Act* 1999 and *WA Marine Act* 1982.
Environmental Protection Authority	An independent Authority providing advice to the Minister on a broad range of issues affecting protection of the environment, including State Environmental Protection Policies, assessment of development proposals, and management plans such as the recent Coastal Water Quality Improvement Plan. Legislation is *Environmental Protection Act* 1986
Department of Indigenous Affairs	Responsible, under *Aboriginal Heritage Act 1972*, for protection of all Aboriginal sites, whether registered or not.
Shire of Broome	Responsible under the provisions of the *Local Government Act 1995* for providing civic leadership, strategic direction and management for the area, through planning processes and development approvals. Coastal management planning responsibilities consistent with WA Coastal Management Policy.
Broome Port Authority	Controlling maritime activities and services, including de-ballasting, and planning for the future development of the port including its land area, consistent with the provisions of the *Port Authorities Act 1999.*
Rubibi / Prescribed Body Corporate	Based on Native Title determination (April 2006) – see below.
Indigenous Land Corporation	Established under the *Land Fund and Indigenous Land Corporation Act 1995*, the ILC's role is to redress the dispossession of Aboriginal peoples and Torres Strait Islanders by assisting them to acquire, own and manage their land in a way that enhances their social, cultural, economic and

ORGANISATION	RESPONSIBILITIES & ENABLING LEGISLATION
	environmental well-being. The ILC owns Roebuck Plains Station which adjoins Roebuck Bay.

JAMBA – *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*, February 1974;

CAMBA – *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*, October 1986;

ROKAMBA – *The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds and their Environment*, July 2007.

Multilateral agreements include:

CMS or Bonn Convention – *Convention on the Conservation of Migratory Species of Wild Animals 1979*. The CMS was first signed in Bonn in 1979 and came into force in 1983. It seeks to protect all migratory species, including waterbirds throughout their range. There are 108 Contracting Parties (as of March 2008) from Africa, Central and South America, Asia, Europe and Oceania. The CMS is coordinated by a Secretariat under the auspices of the United Nations Environment Program (UNEP) concerned with the conservation of wildlife and habitats on a global scale. The Secretariat is based in Bonn, Germany.

National Legislation

***The Environment Protection and Biodiversity Conservation Act* 1999 (*EPBC Act*)**

The *EPBC Act* regulates actions that will, 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)].

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 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 State legislation (though they are in Western Australia). All species listed under international treaties JAMBA, CAMBA, ROKAMBA and CMS are covered by the Act. Threatened species and communities listed under the *EPBC Act* may also occur, or have habitat in, the Ramsar site. 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 (http://www.environment.gov.au/epbc/matters/ramsar.html).

Australian Heritage Council Act 2003

The *Australian Heritage Council Act* 2003 protects places of National and Commonwealth significance. Under the Act, Roebuck Bay (including Roebuck Plains and Lake Edna) was placed on the Register of the National Estate in 1996. As such, all development proposals must be referred to the Heritage Commission.

Native Title Act 1993

Native title describes the rights and interests of Aboriginal and Torres Strait Islander people in land and waters, according to their traditional laws and customs that are recognised under Australian law.

The *Native Title Act* 1993 set up the National Native Title Tribunal as an independent body to process native title applications. Aboriginal and Torres Strait Islander people can apply to the courts to have their native title rights recognised under Australian law. Native title holders have the right to be compensated if governments acquire their land or waters for future developments.

In April 2006, the Federal Court handed down a National Native Title Tribunal Determination giving the Yawuru people exclusive possession rights to about 5,000 km^2 surrounding the Bay. The determination also included non-exclusive use rights to “waterways, coastal waters, beaches” and other areas in common public use, which included much of the mudflats of Roebuck Bay.

Aboriginal and Torres Strait Islander Heritage Protection Act 1984

Protection of places of significance to Indigenous Australians is provided through the *Aboriginal and Torres Strait Islander Heritage Protection Act* 1984, which is administered by the Indigenous Heritage Section of the Department of the Environment, Water, Heritage and the Arts. The Act offers protection for significant places or objects through ministerial decision. Aboriginal people who believe that a place or object is threatened and believe that state government processes offer inadequate protection can apply to the Australian Government Environment Minister to protect the place or object.

Western Australian Legislation

Environmental Protection Act 1986 (*EP Act*)

The aim of the Western Australian *EP Act* is “to create an Environmental Protection Authority (EPA), for the prevention, control and abatement of environmental pollution, for the conservation, preservation, protection, enhancement and management of the environment". The EPA administers environmental impact assessments and makes recommendations to the Minister of the Environment concerning approvals. It also develops statutory environmental protection policies. Regulations made under that Act include the clearing of native vegetation, administered by the Department of Environment and Conservation (DEC).

Regulatory responsibilities for protection, conservation, sustainable use and enjoyment of marine and terrestrial flora and fauna are achieved under the *EP Act*, *Wildlife Conservation Act* 1950 and *Conservation and Land Management Act* 1984.

Wildlife Conservation Act 1950

This Act provides for the conservation and protection of wildlife, establishes licensing frameworks for the taking and possession of protected native flora and fauna and establishes offences and penalties for unauthorised taking of native flora and fauna. All native fauna in Western Australia is protected (unless deemed to be not protected, including an open season to take certain species such as kangaroos) and protected native flora cannot be taken on Crown land without a licence issued under this Act. The Act is administered by DEC.

Conservation and Land Management Act 1984

The *CALM Act* established DEC, the Conservation Commission of WA and the Marine Parks and Reserves Authority and specifies the functions of these bodies. The Act defines different categories of *CALM Act* land and their management objectives (*e.g.* nature reserve, national park, marine park) and stipulates management planning processes for that land. There is capacity for prosecution for damage to the values of vested land. The *CALM Act* is almost entirely related to *CALM Act* lands and waters whereas the *Wildlife Conservation Act 1950* applies across all vestings in Western Australia.

Fish Resources Management Act 1994 and *Pearling Act* 1990

These Acts were created to conserve fisheries and to protect their environment as well as achieving optimal economic, social and other benefits from the use of fisheries resources. The Department of Fisheries is responsible administering the Acts and for the sustainable management of fish species.

Aboriginal Heritage Act 1972

The *Aboriginal Heritage Act* 1972 recognises Aboriginal peoples' strong relationships with the land and provides automatic protection for all places and objects (and storage areas for objects) that may have sacred, ceremonial or of ritual significance in connection with Aboriginal culture. These places and objects are referred to as Aboriginal sites. The Department of Indigenous Affairs maintains a Register of Aboriginal Sites as a record of places and objects of significance to which the Act applies.

***Local Government Act* 1995**

Under this Act, the Shire of Broome is responsible for providing civic strategic direction and management of urban, suburban, and rural lands within the Roebuck Bay area, through planning processes and development approvals consistent with the principles of sustainability. The Shire is also responsible for coastal management planning consistent with Western Australian Coastal Management Policy.

Water Quality, Supply and Protection Acts

Various legislation and policy under the *Water Boards Act* 1904, *Water Services Licensing Act* 1995 and the *Water Agencies (Powers) Act* 1984, administered by the Department of Water, govern water extraction and protection of water quality.

***Port Authorities Act* 1999**

Broome Port Authority controls maritime activities and services within its land area, which extends east to Fall Point, under the *Port Authorities Act* 1999. Management of the port-controlled area must be consistent with an approved Environmental Management Plan.

Land Administration Act 1997

The *Land Administration Act* 1997 is the main statute governing the administration of State land in Western Australia. It covers most of the land in the Ramsar site south-east of Fall Point.

1.6 COMPILING THE ECOLOGICAL CHARACTER DESCRIPTION

The national framework for describing the ECDs (DEWHA 2008) was the methodology adopted at Roebuck Bay. It consists of a twelve-step approach for the development of the ecological character of a Ramsar wetland (***Table 4***).

The twelve steps were approached through:

Desktop Study

Most of the Roebuck Bay Ramsar Site ECD was prepared using existing information obtained through literature review and correspondence with experts. Some raw data were compiled and analysed.

Site visit

The authors have up to 25 years first-hand experience of the area from undertaking a considerable amount of shorebird and mudflat research in the Bay. In addition, Pearson and Chiffings undertook a two day site visit to check that all important ecosystem components, processes, benefits and services of the site were considered during preparation of the ECD.

Consultation

Pearson and Chiffings also consulted and liaised with a wide range of stakeholders, including various community group and State Government Department representatives, to seek local input and ensure people were adequately briefed on the aims of the ECD. There was also extensive interaction with the team developing RBWG's Crab Creek Management Plan. After submission of the draft ECD, Halse travelled to Broome to give a Powerpoint presentation of the main issues in the ECD and discussed responses with local stakeholders and members of the Technical Advisory Group assembled by DEC.

ECD Preparation

The ECD was developed in accordance with the requirements detailed in DEWHA (2008).

Final Documents

Two draft versions of the ECD and RIS were submitted to DEC and the Department of Environment, Water, Heritage and the Arts (DEWHA) for review. The final ECD and RIS documents were prepared after incorporating the comments from DEC, TAG, local stakeholders TAG and DEWHA.

Table 4. The 12 step process for describing the ecological character of a Ramsar wetland (adapted from DEWHA 2008)

1. Introduction to the description Site details, purpose of the description and relevant legislation
2. Describe the site Site location, climate, maps and images, tenure, wetland criteria and types
3. Identify and describe the critical components, processes and services 1. Identify all possible components, processes and benefits 2. Of these, identify the critical components, processes and benefits responsible for determining the ecological character of the site 3. Describe each of the critical components, processes and benefits
4. Develop a conceptual model for the wetland Depict the critical components and processes of the wetland (*e.g.* hydrology, biogeochemical processes, biota and vegetation, and their relationships)
5. Set limits of acceptable change Determine limits of acceptable change for critical components, processes and services of the site
6. Identify threats to the ecological character of the site Use information from Steps 3–5 and other information to identify the actual or likely threats to the site
7. Describe changes to ecological character Describe any changes to the ecological character of the site since the time of listing; include information on the current condition of the site
8. Summarise the knowledge gaps Use information from Steps 3–7 to identify the knowledge gaps
9. Identify site monitoring needs

Use information from steps 3–8 to identify monitoring needs
10. Identify communication and education messages Identify any communication and education messages highlighted during the development of the description
11. Compile the description of ecological character
12. Prepare or update the Ramsar Information Sheet Submit as a companion document to the ecological character description

2. OVERVIEW OF THE ROEBUCK BAY RAMSAR SITE

2.1 LOCATION

Roebuck Bay is located within the Northwest (IMCRA) bioregion and the Timor Sea Australian Drainage Division. The Roebuck Bay Ramsar site is located at the southern end of Dampier Peninsula within Roebuck Bay, a large 360 km^2 embayment of the Indian Ocean. The Bay lies within the Shire of Broome, in the coastal dry tropics of the Kimberley region, Western Australia. It forms part of the Pindanland subregion of the Dampierland bioregion that covers approximately 52,000 km^2. The Bay is bounded to the north-west and far south-east by low sand ridges and to the east and north by coastal flats of Holocene marine sediment. The coastal flats support mangal, samphire, hummock grasslands and paperbark swamps. Behind these, vast grasslands that are contiguous with the Bay occur on black soils of the Roebuck Plains (Graham 2002).

The Ramsar site itself comprises 34,119 hectares, mostly occupied by intertidal mudflats. Waters more than 6 m deep at low tide are excluded from the site, which stretches from immediately east of the town of Broome at a location on the northern shore of Roebuck Bay referred to as "Campsite" by shorebird researchers, to south of Sandy Point (***Figure 2***). The soft bottom intertidal mudflats of the northern and eastern shores of Roebuck Bay, and high tide roosts at Bush and Sandy Points are the most biologically significant parts of the site, which was listed for several reasons including, most notably, outstanding shorebird values. The northern part of the site encompasses the mouths of two major creeks – Dampier Creek and Crab Creek. A similar sized tidal system - Yardoogarra Creek is located at the southern part of the site. A long red cliff, 2-6 m in height, of pindan soil, overlying yellowish-red Broome Sandstone of Cretaceous age dominates the northern shore of the Bay. At the base of the cliff, and just outside the boundary of the Ramsar site, occasional dinosaur footprints are preserved in sandstone (Thulborn *et al*. 1994).

The extensive mudflat system of Roebuck Bay and the vast wetland plains to the east are the product of a palaeoriver that drained out of the Canning Basin during the early Miocene when Australian climates were much wetter (Van de Graaf et al. 1977). The approximate location of the palaeochannel is identified in Vogwill (2003).

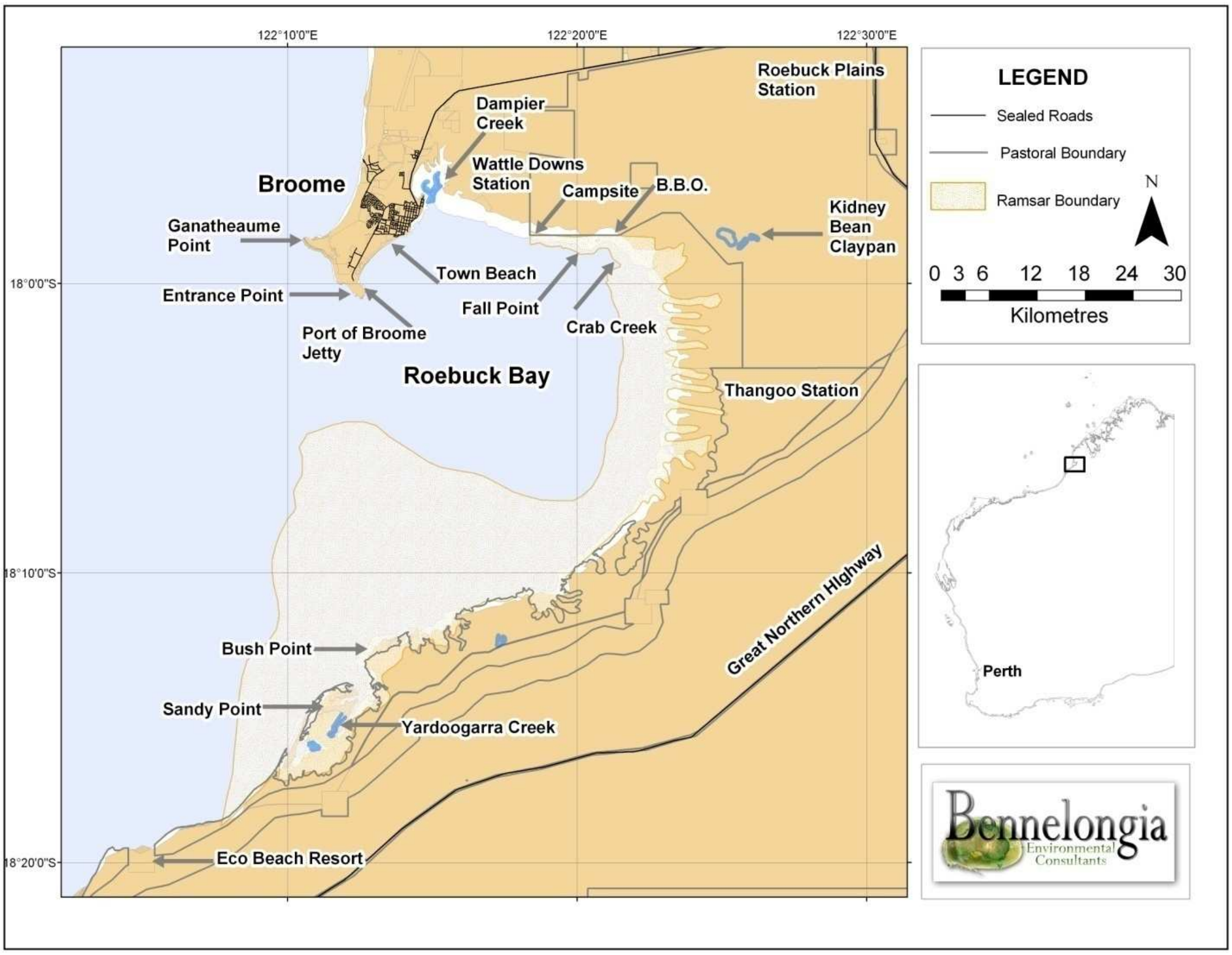


Figure 2. Roebuck Bay Ramsar site showing site boundary and key locations mentioned in text

2.2 CLIMATE

Temperature and Rainfall

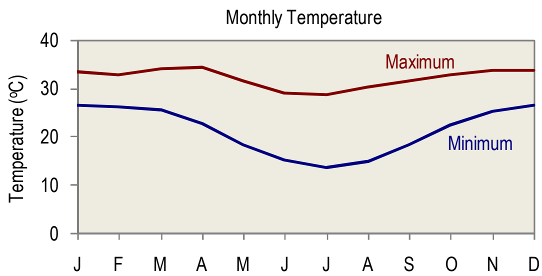


Figure 3. Mean maximum and minimum monthly temperatures at Broome Airport 1941-2007.

The climate of the region is semi-arid monsoonal with hot, wet summers and warm, dry winters. Mean monthly temperature ranges from a maximum of approximately 35°C to a minimum of 13.6°C (*Figure 3*), and average daily sunshine is ca. 15 hours. The highest temperature ever recorded was 44.8°C in December 1951, however maximum temperatures are typically less than 40°C. Winters are mild, with overnight temperatures rarely falling below 5°C. Median and mean annual rainfall at Broome are 533 mm and 601 mm, respectively, mostly falling in December-March; annual evaporation is ca. 3,050 mm. Variability in total annual and total monthly rainfall over the last 65 years or more is shown in Figures 4 and 5. There is emerging trend of increasing summer rainfall and a slight decline in winter falls, although this should probably be viewed as a pattern within a longer term cycle rather than a trend. Summer monthly rainfall totals were higher for the period 2001-2007 than for earlier periods 1941-1974 and 1975-2000.

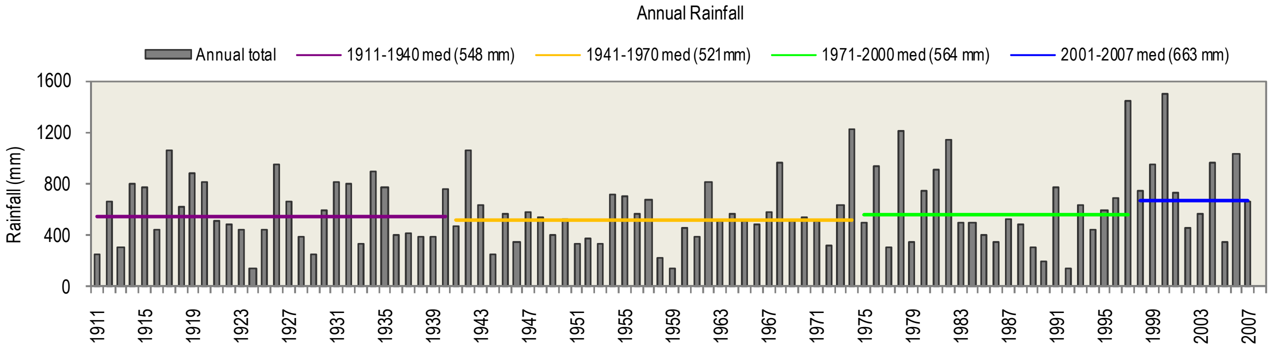


Figure 4. Annual rainfall data for Broome Airport 1941-2007 together with median rainfall for differing time periods

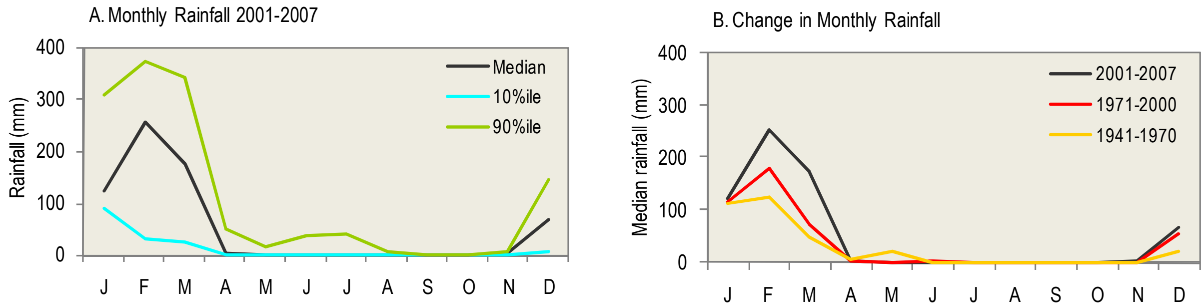


Figure 5. A: Median 10th and 90th percentile monthly rainfall for Broome Airport 1998-2007; B: Median monthly rainfall for Broome Airport for the periods 1941-1970, 1971-2000 and 2001-2007.

Cyclones

The north-west of Western Australia is subjected to annual cyclonic events and associated rainfall totals in excess of 100 mm are common. The Bureau of Meteorology report 22 cyclones causing gale force winds at Broome since 1910. The cyclone season typically lasts from late November to April and cyclonic events can have a significant impact on the ecology of Roebuck Bay and the hinterland of Roebuck Plains.

Table 5. Tidal levels for the Port of Broome, Western Australia (source Pepping et al. 1999

Tidal level	Height in metres above Broome Tidal Datum
Highest Astronomical Tide (HAT)	9.6
Mean High Water Spring (MHWS)	8.5
Mean High Water neap (MHWN)	5.6
Mean Sea level (MSL)	4.5
Mean Low Water Neap (MLWN)	3.5
Mean Low Water Spring (MLWS)	0.3
Lowest Astronomical Tide (LAT)	-0.9

2.3 TIDES

Roebuck Bay is subjected to semi-diurnal tides with an amplitude up to 10 m (***Table 5***, Pepping *et al*. 1999). Spring tides occur every fortnight. These flood low lying salt marshes behind the mangrove woodlands fringing the Bay at high tide and expose about 190 km^2 of mudflat (45% of the Bay area) at low tide. The twice daily tidal flushing across the mudflat is a driving factor in the ecology of most life forms in the extensive intertidal zone of the Bay. The role of tides in the distribution of sediments around Roebuck Bay is considerable.

2.4 LAND TENURE

The Government of Western Australia has jurisdiction over marine areas within the Roebuck Bay Ramsar site. The landward sections of the site are Unallocated Crown Land, except for a small reserve gazetted for the purpose of a Bird Observatory. The Department of Planning and Infrastructure has ultimate management responsibility for Unallocated Crown Land, but DEC is responsible for management of the Ramsar site and has control over flora and fauna. The Department of Fisheries is responsible for areas below the low tide mark and for ensuring sustainable recreational and commercial harvesting of fish populations. A range of private leaseholders are responsible for the day-to-day management of

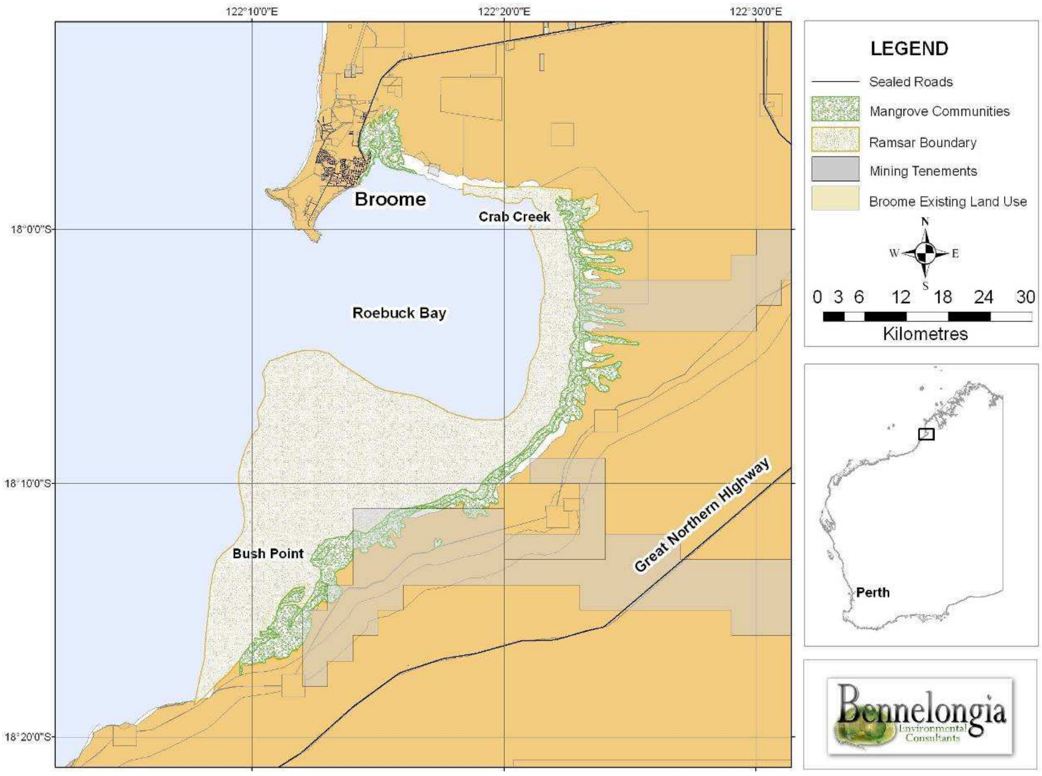


Figure 6. Map of land tenure for Roebuck Bay (data supplied by DEC)

activities such as pearling and aquaculture leases, commercial fishing leases, tour boat operations (including hovercraft) and the Broome Bird Observatory lease (Lambert and Elix 2006).

Outside the boundary of the Ramsar site, pastoral leases surround most of the Bay. The exceptions are the north-western part of the Bay, where Broome townsite is located, and Fall Point, where the Broome Bird Observatory is located.

In April 2006, the Federal Court handed down a National Native Title Tribunal Determination giving the Yawuru people exclusive possession rights to about 5,000 km^2 surrounding the Bay. The determination also included non-exclusive use rights to "waterways, coastal waters, beaches" and other areas in common public use, which included much of the mudflats of Roebuck Bay. A right to take and use natural resources in the area was granted "for personal, domestic or non-commercial communal needs". The State Government is continuing negotiations with Rubibi (Yawuru) for a practical resolution of outstanding native title and cultural heritage matters in and around Broome.

Land-Use

There is recreational use of the northern part of the Roebuck Bay Ramsar site, principally for fishing and bird watching. There is also commercial fishing, pearling and port use of the Ramsar site or adjacent areas. Crude oil from the Blina Oilfield, 300 km north-east of Broome, is exported from Broome Port by tankers, which also deliver refined fuel products from Kwinana Refinery, south of Perth. Exploration permits for petroleum are held over the Ramsar site and a mining exploration permit for Kaolin on Thangoo Station to the east of Roebuck Bay was withdrawn in 2002 (Environs Kimberley Bulletin 24) A diamond mining tenement is reported around Bush Point by Lambert and Elix 2006.

The most intensive land use in the vicinity of the Ramsar site is urban/industrial in Broome, where the human population is ca. 14,500. During peak tourist season (June to August) numbers swell to over 45,000 visitors per month. The estimated annual visitor number for the Shire of Broome is 240,000.

A small amount of gravel mining occurs in the western part of pindan cliffs, outside the boundary of the Ramsar site, and commercial cattle grazing occurs on pastoral leases to the east of the Bay on Roebuck Plains (Roebuck Plains and Thangoo Stations). There are also tentative proposals for intensive irrigated agriculture (*e.g.* cotton) on Roebuck Plains.

2.5 RAMSAR CRITERIA

When Roebuck Bay was originally nominated for inclusion as a Ramsar Site, there were only six qualifying criteria. Roebuck Bay met three of them (see Anon 1990):

Criterion 1a: It is a particularly good example of a specific type of wetland, characteristic of its region.

Criterion 3a: It regularly supports 20,000 waterfowl.

Criterion 3c: It regularly supports 1% of the individuals in a population of one species or a subspecies of waterfowl.

In 1998, the qualifying criteria were further developed and re-numbered by a Ramsar Conference of the Contracting Parties, and two new criteria (Criteria 7 & 8) were adopted (***Table 7***). In 2003, the Ramsar Information Sheet for the Roebuck Bay site was updated by DEC and it was proposed that the site qualified against all eight criteria. In 2005, the Contracting Parties added a ninth criterion (***Table 7***). The RIS was revised during preparation of the ECD and the justifications for listing have been updated from the 2003 RIS where required, except for criteria 7-9. It is currently proposed that the Bay meets seven criteria:

Criterion 1: *Wetland values*. The site is a superb example of a tropical marine embayment within the Northwest (IMCRA) bioregion. It is one of only a dozen intertidal flats worldwide where benthic food sources are found in sufficient densities that they regularly support internationally significant numbers of waders.

Criterion 2: *Threatened species/communities*. Loggerhead Turtles *Caretta caretta* (nationally endangered) and Green Turtles *Chelonia mydas* (nationally vulnerable) regularly use the site as a seasonal feeding area and as a transit area on migration. Flatback Turtles *Natator depressus* (nationally vulnerable) regularly nest in small numbers around Cape Villaret during the summer months. Sawfish *Pristis clavata* (nationally endangered) regularly use the tidal creeks and mangrove areas for breeding and refuge.

Criterion 3: *Regional biodiversity*. The site supports a significant component of the regional (Northwest IMCRA bioregion) intertidal and shallow marine biodiversity in terms of the marine mammals (Dugong, turtles and dolphin), marine invertebrate infauna, and avian fauna across the site. The total density of macrobenthic animals (1,287 individuals/m^2) is high by global standards for a tropical mudflat and species richness is very high (estimated to be between 300 - 500 species).

Criterion 4: *Key habitat in life cycle*. The site is one of the most important migration stopover areas for shorebirds both in Australia and globally. It is the arrival and departure point for large proportions of the Australian populations of several shorebird species, notably Bar-tailed Godwit *Limosa lapponica* and Great Knot *Calidris tenuirostris*. The site provides essential energy replenishment for many migrating species, some of which fly non-stop between continental East Asia and Australia.

Criterion 5: *Supports >20,000 waterbirds*. The site regularly supports over 100,000 waterbirds (***Table 6***, ***Figure 7***). The highest number of shorebirds counted at the site was 170,915 in October 1983 and allowing for turnover, the total number of shorebirds using the site may exceed 300,000 annually. It is the fourth most important site for waders in Australia in terms of absolute numbers and the most

Table 6. Definition of regularly in the application of Criteria 5 and 6 (as adopted by the 7th (1999) and modified by the 9th (2005) Meetings of the Conference of the Contracting Parties.

A wetland **regularly** supports a population of a given size if:
i) The requisite number of birds is known to have occurred in two-thirds of the seasons for which adequate data are available, the number of seasons being not less than three, or
ii) The mean of the maxima of those seasons in which the site is internationally important, taken over at least five years, amounts to the required level

Table 7. Ramsar Criteria for identifying Wetlands of International Importance (adopted by the 7th (1999) and 9th (2005) Meetings of the Conference of the Contracting Parties.

CRITERIA	BASIS	DESCRIPTION
GROUP A. SITES CONTAINING REPRESENTATIVE, RARE OR UNIQUE WETLAND TYPES		
Criterion 1	Wetland	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	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 1% 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 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species.

important in terms of the number of species it supports in internationally significant numbers (see Criterion 6).

Criterion 6: *Supports >1% of waterbird species*. The site regularly supports ≥1% of the population of at least 22 wader species (20 migratory and 2 resident species):

Large Sand Plover *Charadrius leschenaultii*,
Oriental Plover *C. veredus*,
Mongolian Plover *C. mongolus*,
Red-capped Plover *C. ruficapillus* (resident),
Grey Plover *Pluvialis squatarola*,
Bar-tailed Godwit *Limosa lapponica*,
Black-tailed Godwit *L. limosa*,
Red Knot *Calidris canutus*,
Great Knot *C. tenuirostris*,
Red-necked Stint *C. ruficollis*,
Curlew Sandpiper *C. ferruginea*,
Sanderling *C. alba*,
Eastern Curlew *Numenius madagascariensis*,
Little Curlew *N. minutus*,
Whimbrel *N. phaeopus*,
Greenshank *Tringa nebularia*,
Common Redshank *T. totanus*,
Grey-tailed Tattler *T. brevipes*,
Terek Sandpiper *T. terek*,
Ruddy Turnstone *Arenaria interpres*,
Asian Dowitcher *Limnodromus semipalmatus,* and
Pied Oystercatcher *Haematopus longirostris* (resident).

Criterion 7: *Significant for indigenous fish*. The 2003 RIS stated that criterion 7 was met on the basis of benthic invertebrate occurrence. This is considered to be mis-applying the criterion. The currently documented values of the Bay for indigenous fish species do not appear to make it outstanding or different from other parts of the Kimberley region.

Criterion 8: *Key habitat in fish life cycle*. The site is important as a nursery and/or breeding and/or feeding ground for at least five species of fish and for mudcrabs and prawns. The site's mangal system is particularly important as a nursery area for marine fishes and prawns.

Criterion 9: *Supports >1% of non avian species*. Insufficient information for assessment.

2.6 WETLAND TYPES

Under the Ramsar classification system there are numerous categories of “wetland” ranging from shallow areas of ocean to inland freshwater lakes and to man-made waterbodies. The Roebuck Bay Ramsar site contains four different wetland types and all are marine or coastal:

Marine subtidal aquatic beds - sea-grass beds;

Intertidal mud and sand flats;

Intertidal forested wetlands - mangrove swamps;

Intertidal marshes - samphire and saline grasslands.

It can be seen by comparing Figures 6 and 8 that that there is also a strong connection between the inter-tidal area of the Ramsar wetland and the more inland areas of Roebuck Plains.

Marine Subtidal Aquatic Beds – Seagrass Beds

Extensive seagrass beds occur in Roebuck Bay and are dominated by *Halophila ovalis* and *Halodule uninervis* (Prince 1986). The most vigorous stands grow in areas that are exposed for less than two hours at low tide. These meadows are important feeding grounds for Dugong and Green Turtle.

Intertidal Mud and Sand Flats

The dominant wetland type within the Ramsar site is the intertidal mud and sand flats that cover approximately 45% of the total Bay area. The sediments of these flats grade from silty muds in the north-east to fine or very fine sands in the north-west and to coarse sands in the south of the Bay (***Figure 9***). Near the mouth of Crab Creek the flats comprise waterlogged and thixotropic (gel-like) muds that are more than knee-deep (Pepping *et al.* 1999). The mud and sand flats are among the widest in Western Australia: the intertidal flats extend up to 13 km offshore at the south-western end of the Bay where sandbanks are common, offering an important roost for shorebirds.

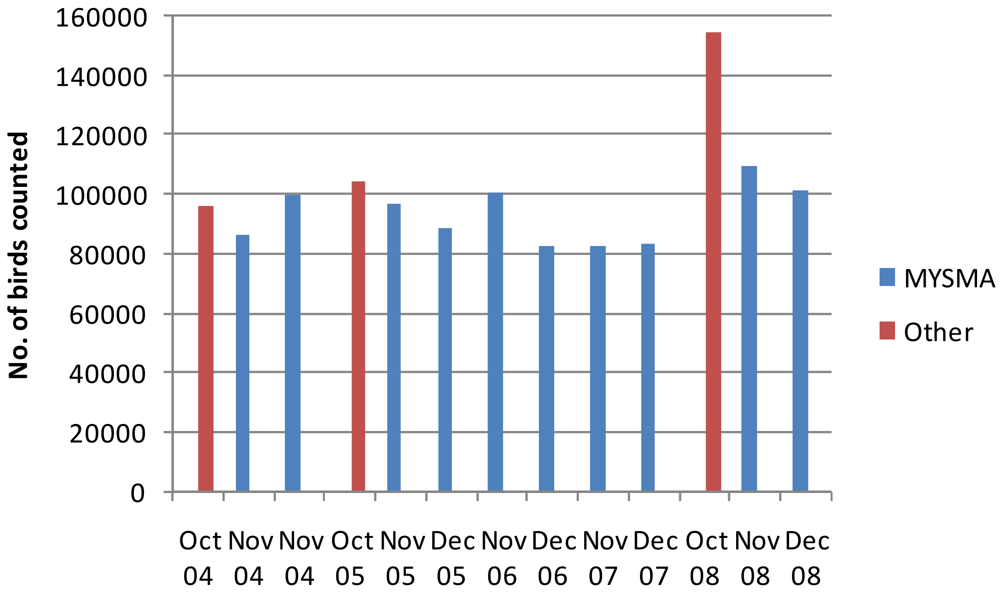


Figure 7. Summer counts of shorebirds and waterbirds at Roebuck Bay, 2004-08. Data from AWSG MYSMA Project, except for October counts from AWSG ad hoc counting and National Waterbirds Survey, National Water Commission (2008).

Figure 8. Landsat TM (Bands 3,2,1) image (taken July 1997) showing geomorphic relationships between Roebuck Bay, Roebuck Plains and surrounding areas on a low neap tide.

Most of the intertidal mudflat area is inundated each high tide, and at times, spring tides and/or cyclones may cause the adjoining coastal flats to become inundated, flooding the samphire and saline grasslands.

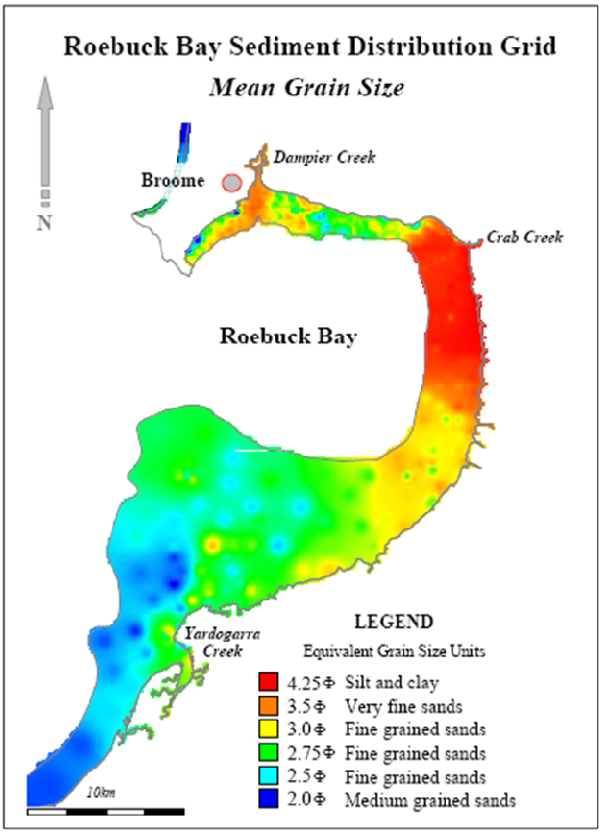


Figure 9. Sediment distribution in Roebuck Bay intertidal zone

Intertidal Forested Wetlands – Mangrove Swamps

Intertidal forested wetlands are widespread at Roebuck Bay. They comprise mangroves in low closed-forest to open-scrub in narrow arrangement along the shore in the east and south of the Bay. More extensive areas occur around the main tidal creeks, with about 6 km^2 of mangroves around Dampier Creek. Eleven mangrove species are known to occur in the Bay (Semeniuk *et al.* 1978).

Within Roebuck Bay, Johnstone (1990) divides the mangroves into a northern and southern section. The northern section consists of a low open to closed forest. The common species on the landward and seaward edge of the mangroves is *Avicennia marina*. The southern section contains narrow linear stands fringing the shoreline in the Thangoo area.

The mangroves have highest species diversity and tallest trees around Dampier and Crab Creeks and in Yardoogarra Creek, the inlet between Bush Point and Sandy Point. In these areas there is distinct zonation of the mangroves. The typical sequence of species in landward direction is *Avicennia*, *Rhizophora* and *Ceriops* (Chalmers and Woods 1987).

Landward of the mangroves are areas of bare salt flats that are inundated on high spring tides. The hyper-salinity of the soil in these areas inhibits the establishment of vegetation.

Intertidal Marshes – Samphire and Saline Grasslands

Samphire flats and saline grasslands occur landward from the edge of the bare salt flats behind the mangal (Chalmers and Woods 1987). The saline grass plains occur at slightly higher in elevation than the samphire flats where the soil has a lower salinity. The dominant grass species is Saltwater Couch *Sporobolus virginicus*, which forms dense grassland 15-20 cm tall. These grasslands may be inundated by some high tides. Towards the edge of the grass plains, at the interface with pindan soils at higher elevation, low woodlands or thickets of *Melaleuca acacioides* grow up to 10 m in height. These woodlands mark the inland boundary of the grasslands

2.7 SYSTEM BENEFITS AND SERVICES

Ecosystem services are “the benefits that people receive from ecosystems” (Ramsar Convention 2005, Resolution IX.1 Annex A). This includes indirect ecological benefits as well as benefits that directly affect people, such as the provision of food or water resources. Four main categories of ecosystem services are defined:

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;
4. Supporting services – the services necessary for the production of all other ecosystem services such as water cycling, nutrient cycling and habitat for biota.

The Roebuck Bay Ramsar site is economically and culturally significant. The critical ecosystem benefits and services of the Roebuck Bay Ramsar site are outlined in ***Table 8*** and a brief description of the cultural and economic significance is provided in section 2.8. The relationships between ecological components and processes and these benefits and services are discussed in section 5.

2.8 CULTURAL, ECONOMIC AND SOCIAL SERVICES AND BENEFITS

Commercial Fishing and Pearling

Roebuck Bay supports both recreational and commercial fisheries. Commercial fishing activities include net fishing for table fish, shell collection, aquarium stocking and collection of hermit crabs for pet store supplies. Principal commercial fish species include Giant Threadfin Salmon (*Polydactylus macrochir*), Blue Threadfin Salmon (*Eleutheronema tetradactylum*), Barramundi (*Lates calcarifer*) and Tripletail Perch (*Lobotes surinamensis*).

Roebuck Bay is considered an important breeding area for prawns and the Ramsar listed intertidal flats and mangrove areas are an important feeding area for juvenile prawns. Prawn trawling does not take place within the Bay but five boats with 16 crew are licensed to operate in the prawn fishery. Targeted species are Western King Prawns (*Penaeus latisulcatus*) and coral prawns (a combined category of small penaeid species).

Table 8. Ecosystem benefits and services of the Roebuck Bay Ramsar site

CATEGORY	DESCRIPTION
PROVISIONING SERVICES - PRODUCTS OBTAINED FROM THE ECOSYSTEM SUCH AS FOOD, FUEL AND FRESH WATER	
Wetland products	Commercial and recreational fisheries for a number of species of fish, prawns and crabs.
	Aboriginal people continue to make extensive use of the Bay's natural resources.
REGULATING SERVICES - BENEFITS OBTAINED FROM THE REGULATION OF ECOSYSTEM PROCESSES SUCH AS CLIMATE REGULATION, WATER REGULATION AND NATURAL HAZARD REGULATION	
Pollution control and detoxification	No data.
Climate regulation	No data.
CULTURAL SERVICES - BENEFITS PEOPLE OBTAIN THROUGH SPIRITUAL ENRICHMENT, RECREATION, EDUCATION AND AESTHETICS	
Recreation and tourism	Major tourism and bird-watching venue. Broome is an important destination for national and international tourism
	Active recreational fishing and crabbing activities, boating, hovercraft.
Spiritual and inspirational	The site has inspirational and aesthetic values that are both regional and nationally recognized through travel to Broome.
	Roebuck Bay is spiritually significant to Aboriginal people belonging to the Yawuru and Jukun groups and contains a number of specific culturally significant sites.
Scientific and educational	Many scientific research programs, especially on shorebirds and mudflat invertebrates, have been based at Roebuck Bay. They have often involved Broome Bird Observatory, near Fall Point.
SUPPORTING SERVICES - 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	
Biodiversity	Key location in global flyway for migratory waders Nursery values for prawns and fish Seagrass beds for Dugong

The pearling industry has been established at Broome since the 1880s, initially for mother-of-pearl and, since 1956, for high value cultured pearls. Pearling is based primarily on Silver-lipped Oyster (*Pinctada maxim*). The industry employs around 1,000 people and generates approximately $200 million annually. It is the major industry within Broome. There are currently 12 pearl farms operating 16 licences to fish and farm pearls on a quota basis. There are no pearl farm leases within the boundary of the Ramsar site (***Figure 10***) and Roebuck Bay contributes only a small percentage of total production. Divers harvest the pearls within the Bay by hand and they are of extremely high grade. Broome's pearling history has contributed greatly to its multicultural character, bringing together Aboriginal, European and Asian (notably Japanese, Chinese, Filipino and Malay) peoples. The principal cultural event in the Broome calendar is Shinju Matsuri or Festival of the Pearl, held in July-August.

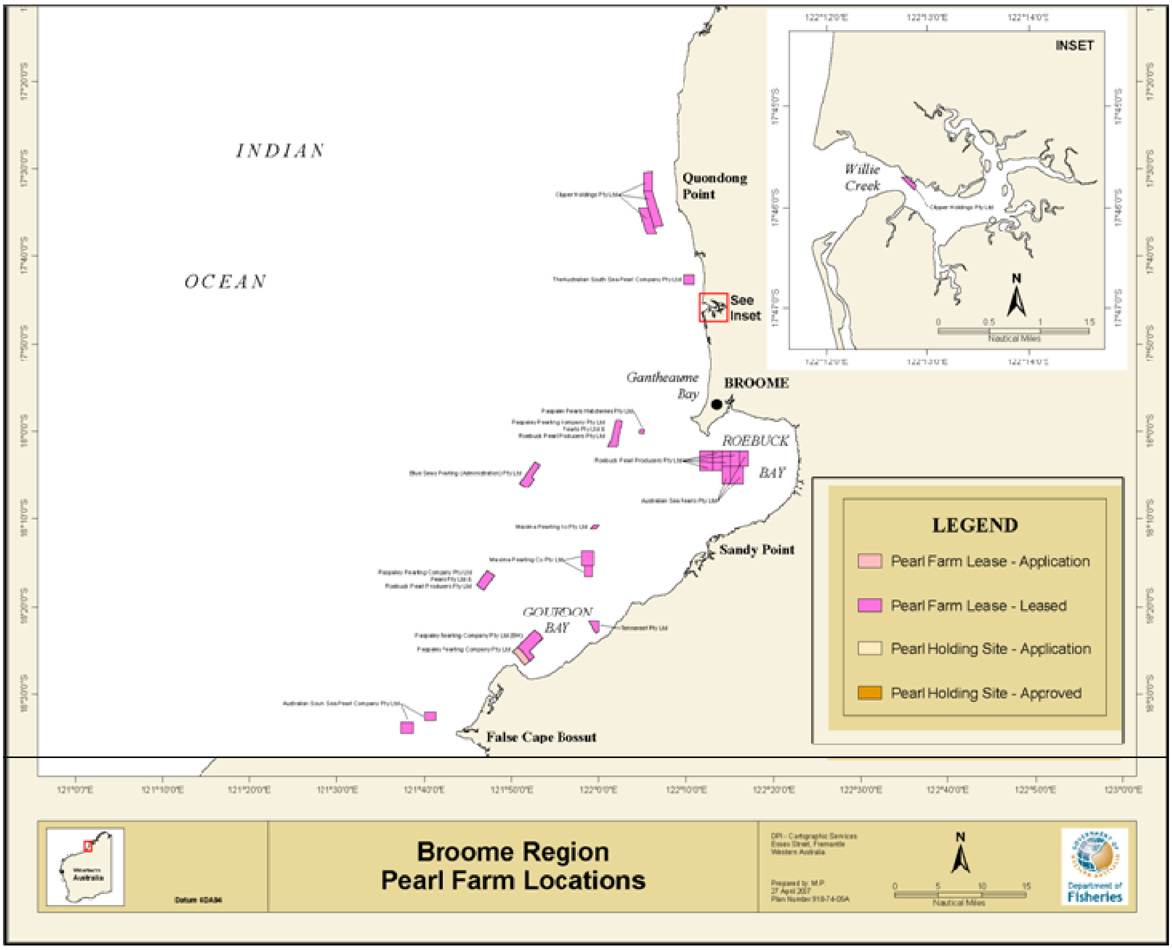


Figure 10. Location of pearl farm tenements in and around Roebuck Bay (map extracted from a regional map provided by the Department of Fisheries)

Recreation and Tourism

Roebuck Bay provides an important recreational and tourism destination. Tourism, both domestic and international, around Broome generates significant income for the region. Broome International Airport recorded 380,000 passenger arrivals in 2006/2008, with passenger numbers growing an average of 15% per year since 2001. The most popular recreational and tourism activities associated with the Ramsar site include: birdwatching, sightseeing, bushwalking, camping, fishing, boating, crabbing, kayaking and swimming. One commercial hovercraft company has operated scenic tours in there since 1990. Along with growing tourism there is growing interest in the Ramsar values of Roebuck Bay, particularly during the cooler months of the dry season (May to September).

Recreational fishing occurs within the Bay, particularly close to Broome and along the Fall Point coast, and there are several boat launching sites in both areas. Much of the shoreline along the eastern side of the Bay is inaccessible, other than by boat at high tide. Lambert and Elix (2004) identified the most utilized recreational sites:

- Crab Creek – fishing, crabbing and other activities;
- Dampier Creek – fishing, water skiing and other boating activities (hovercraft at low tide), eco-tourism;
- Fishermen's Bend (and other places on the northern beaches) – birdwatching, walking, fishing and general enjoyment of the area and its scenery;
- Bush Point – birdwatching, hovercraft, eco-tourism.

Low cliffs offer a panoramic view across the northern Bay and the contrast of pale blue sea, dark green mangroves and red cliffs is particularly appealing. The cliffs and Crab Creek area offer one of the best places in the world for viewing shorebirds, because of the unique combination of accessibility, high species richness, very high densities and numbers.

Scientific and Educational

Broome Bird Observatory near Fall Point was opened in 1988 on 2 hectares of land leased from DEC. It is operated by Birds Australia (formerly the Royal Australasian Ornithologists Union), has full-time wardens and is used as an educational, research and recreation facility focusing on Roebuck Bay and its environs. The Observatory has several walk-trails and interpretive displays, which are open to visitors. Planning has commenced for a dedicated Visitor Centre to be constructed.

The wardens and local volunteers undertake wader banding on a monthly basis. Since 1981, the Australasian Wader Studies Group has conducted, more or less, annual large scale banding of shorebirds in the Bay. Many international participants have been involved, including Asian researchers (most sponsored by Environment Australia and DEC) seeking training in shorebird studies.

A large number of other studies have been conducted on the behaviour and ecophysiology of migratory waders in the Bay, including shorebird roost choice, heat avoidance behaviour and preparation for migration (Tulp and DeGeoij 1994, Rogers *et al.* 2000b,c, 2006a,b, 2007; Piersma *et al.* 2003, 2008).

There has been extensive mapping of benthic invertebrate biodiversity in the mudflats of Roebuck Bay (Hickey *et al*. 1998, 2000, 2003; Pepping *et al.* 1999; Piersma *et al.* 2002, 2003; Honkoop *et al.* 2006; Compton *et al.* 2007). Two recent postgraduate studies focused on the hydrogeology and deep geology of the Broome region (Vogwill 2003) and distribution of sediments and surficial geology in Roebuck Bay (Oldmeadow 2007). Broome Bird Observatory in collaboration with DEC is continuing research into the sediments and benthos of the Bay at four sites within the Ramsar boundary.

Indigenous Values

The Roebuck Bay Ramsar site lies within the traditional estate of the Yawuru and Jukun language groups. The site has great cultural significance for Aboriginal people and provides a range of benefits and services for them (DEC 2003). Both the land and the sea are an integral part of the cultural, spiritual, social and economic life of Aboriginal people. In the Yawuru language, the Bay is named Nalen Nalena (DEC 2003)

As of July 2008, the Register of Aboriginal Sites listed at least 65 heritage locations in the vicinity of the Ramsar site, 17 of which lie within or immediately adjacent to the Ramsar site, principally in the Fall Point, Thangoo and Cape Villaret areas (***Figure 11*** (http://www.dia.wa.gov.au/Heritage--Culture/Heritage-management/Register-of-Aboriginal-sites/).

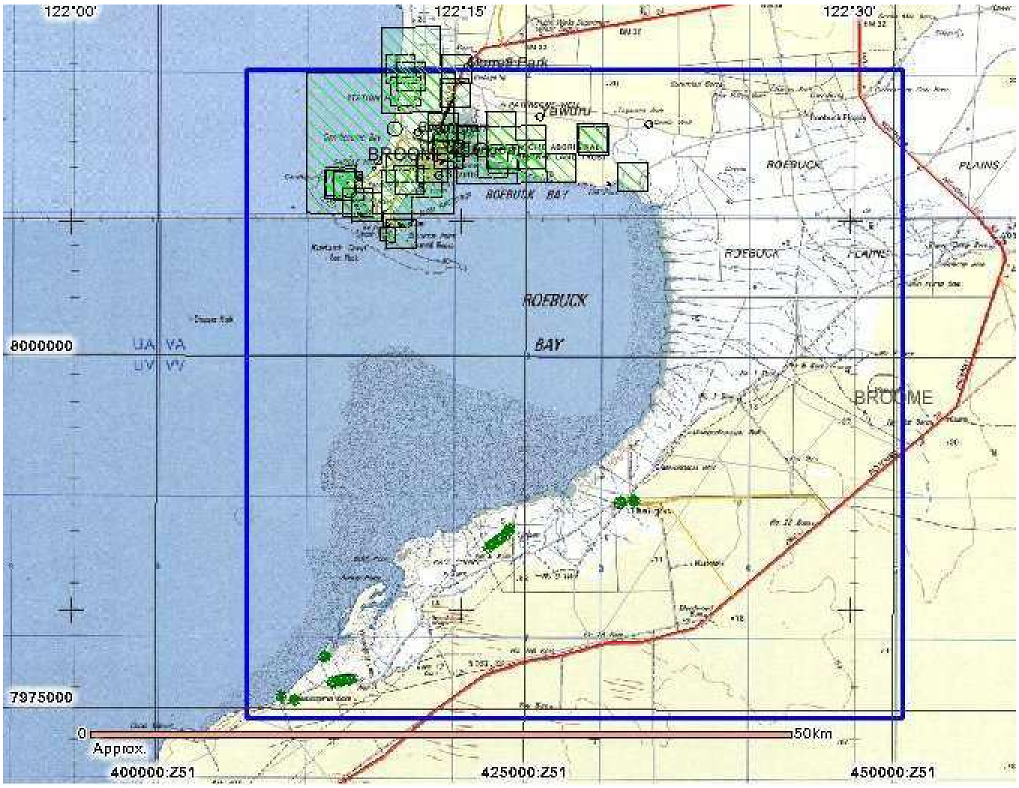


Figure 11. Locations of Aboriginal sites in and around the Roebuck Bay Ramsar site (DIA website http:/www.dia.wa.gov.au/ downloaded July 2008). Aboriginal sites are marked in green. Extent of the search area is denoted by the blue rectangle. Details of Aboriginal sites are provided in Appendix B.

The strength of connection Aboriginal people have had with Roebuck Bay is well illustrated by the numerous shellfish middens along the northern coastline of the Bay. Comprised mostly of thousands of relic shells of the Blood Cockle *Anadara granosa*, it is clear this food resource was an important component of the diet and social behaviour of Roebuck Bay people. One of the more substantial middens is Kennedy Hill, located adjacent to the Mangrove Hotel in Broome.

A Values Mapping project completed in 2004 further outlined the importance of Roebuck Bay to Aboriginal people. Though no longer dependent on the Bay for survival, Aboriginal people continue to use it extensively, gathering shellfish, fishing and hunting Dugong and turtles (Lambert and Elix 2006).

3. WHAT COMPRISED ROEBUCK BAY IN 1990

'Ecological character' is defined under the Ramsar Convention (2005) as "the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time". A description of the ecological character of a wetland such as Roebuck Bay requires, where possible, the quantification of critical components and processes. The principal aim of this document is to describe the features that determined the character of the site at the time of listing.

The ecological components and processes of a wetland as complex as Roebuck Bay are unlikely to be adequately described in a single document. Therefore, this document focuses on critical aspects of the ecology of Roebuck Bay which, if significantly altered, will cause a significant change in the nature of the system. In focussing on critical aspects of ecology, there has been little effort made to explicitly distinguish between wetland components and processes. In general terms, components constitute the building blocks of the wetland (physical structure and species), whereas processes are the connections between the components. However, there is considerable overlap in what are viewed as components and processes with, for example, the National Framework (DEHWA 2008) classifying water temperature as a component and climate temperature as a process.

3.1 DRIVERS OF WETLAND ECOLOGY

An extensive range of physical and biological factors influence the ecology of a wetland but its hydrological regime, and setting within the landscape, are primary determinants of its ecology. However, at a higher level of conceptualisation, the hydrological regime is a function of climate, hydrology and oceanography, while landscape setting is a function of geomorphology. Thus, the fundamental drivers of the ecology of Roebuck Bay can be regarded as climate, geomorphology, hydrology and oceanography controlling wetland type, and biogeography controlling the pool of available organisms to colonise a particular wetland (***Figure 12***). Biogeochemical and biotic tolerances then determine exactly which animals and plants live within the resultant wetland environment and their finer scale distribution (Brearley 2005).

3.2 ECOLOGICAL CHARACTER OF ROEBUCK BAY

Critical ecosystem components and processes of the Bay at the time of listing (1990) are summarised in ***Table 9*** and detailed in the following sub-sections.

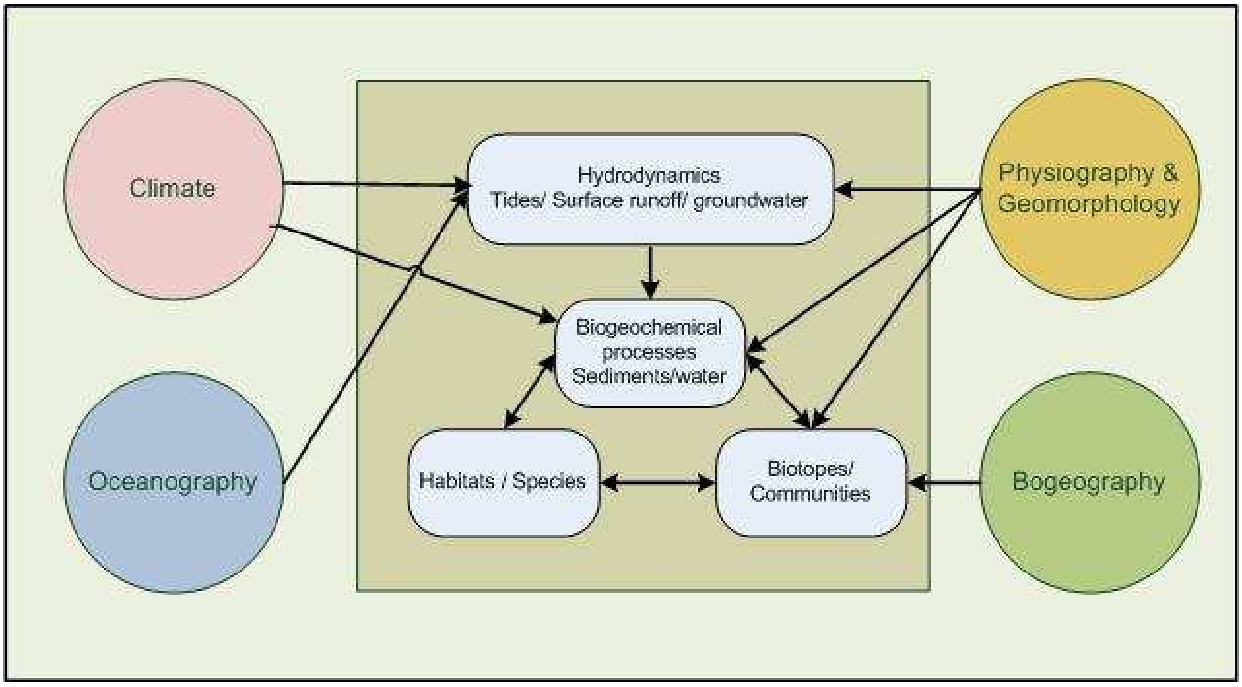


Figure 12. Conceptual model showing the relationship between critical ecosystem compartments and the principal drivers for Roebuck Bay

3.2.1 GEOMORPHOLOGY

The geomorphology of Roebuck Bay and Roebuck Plains reflects a complex tectonic and depositional geological history that is partially explained by their location within the onshore Canning Basin (***Figure 13***). Two-thirds of the 550,000 km^2 basin is onshore and the remaining one-third occurs offshore. The oldest outcropping rock at Roebuck Bay is the Broome sandstone, which was deposited as the sea retreated in the Late Jurassic - Early Cretaceous. The lithology is fine to very coarse sandstone with some mudstone and minor conglomerate. Ripple marks, cross-bedding and intensive bio-turbation are indicative of its shallow marine origin (Pepping *et al*. 1999). It is generally an upward fining sequence of sediments and can be separated into an upper fluvio-deltaic and lower fluvial facies based on sediment type and texture Vogwill (2003). The upper fluvio-deltaic facies has a limited vertical connectivity and may locally partially confine groundwater (Vogwill 2003).

The Broome Sandstone contains abundant plant and trace fossils and has the greatest number and variety of dinosaur footprints of any area in the world (Kenneally *et al.* 1996). Widely distributed though poorly exposed, the best outcrops of Broome Sandstone are at Gantheaume Point in the north-west of the Bay which is famous for footprints of the large therapod *Megalsauropus broomensis* from the early Cretaceous (ca. 110-120 my BP). The maximum currently exposed thickness of the Broome Sandstone is 12 m, but its overall depth in the Broome area is almost 290 m. All the other exposed facies in the area are recent Quaternary deposits (Oldmeadow 2007).

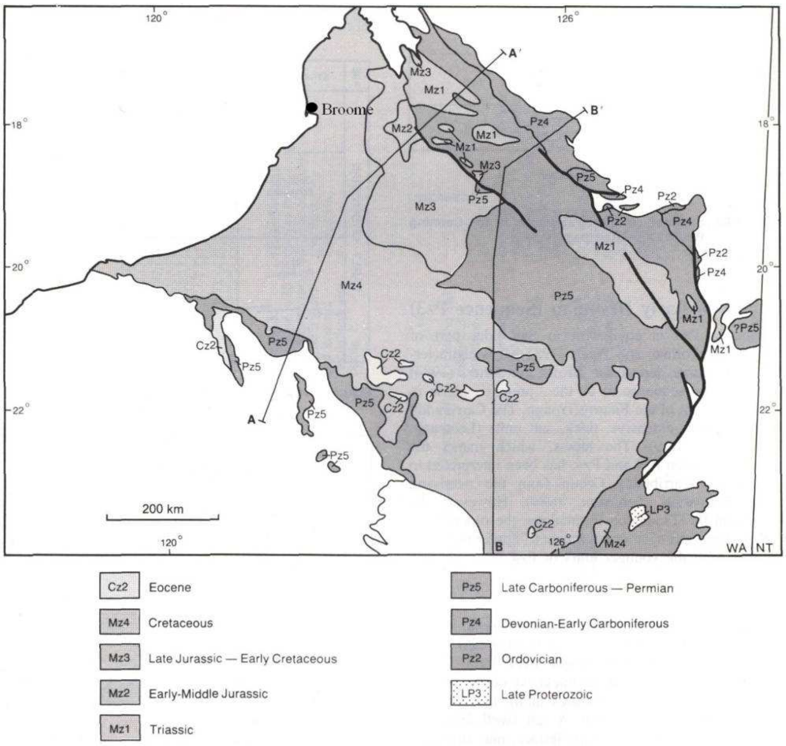


Figure 13. Age of Canning Basin components (from Middleton 1990).

Five different physiographic units can be distinguished in the Bay. They influence the ecological character of the Bay chiefly through their role in provision of habitat. Their sediment characteristics often control the distribution of animals within them, especially for mudflats (Pepping *et al*. 1999). The units are:

- Tidal Flats and Mangrove Swamps;
- Supratidal Zone;
- The Bossut Formation;
- Coastal Aeolian Dunes;
- Aeolian Seif Dunes and Sand Sheets.

Tidal Flats and Mangrove Swamps

Roebuck Bay is characterised by an extensive system of intertidal flats. The sediments of these flats are of biogenic and terrigenic origin, ranging in grain size from silty clay to coarse sand depending on the sorting due to the origin of the sediments and different current velocities across the Bay. There is a trend from finer in the northern parts of the bay to coarser sediments in the southern flats (Pepping *et al*. 1999; Oldmeadow 2007) (***Figure 9***). The eastern and northern shores of the Bay support mangrove communities around Dampier Creek and Crab Creek that contain black anoxic muds rich in organic material.

Table 9. Critical ecosystem components and processes of Roebuck Bay

COMPONENT	SUMMARY DESCRIPTION
Climate (cyclones, flooding)	The climate of the Broome region is semi-arid, monsoonal with a distinct wet (October to February) and dry season (March to September). Cyclonic flooding during the summer wet season results in periodic inundation of Roebuck Plains and drainage of freshwater off the Plains and through the mangroves.
Ocean currents	The Indonesian Flowthrough flows westwards from the Pacific to the Indian Ocean. This in turn provides a mass of warm water to the Leeuwin current off Western Australia as it sweeps south along the west coast and east along the south coast.
Tidal variation	Tides in the vicinity of Broome have a very large range (9.5 m), thus exchange through the Bay is high, tidal velocities are relatively high and large mudflats have developed.
Geomorphology	A megascale irregular curved embayment that contains a wide expanse of intertidal mud and sand flats indented by microscale linear tidal creeks.
Sediment structure	Three main sediment provinces have been identified: northern sands province, eastern silt and clay province and southern sands province.
Hydrology	The Broome Sandstone contains the most utilised (Broome water supply) and hence most threatened groundwater resource in the Canning Basin. The Broome Sandstone is generally an unconfined aquifer recharged by direct infiltration from rainfall. The Broome sandstone will be discharging groundwater to the surface or subsurface at the margins of the Roebuck plains and tidal creek systems. There will also be deep submarine groundwater discharge occurring at or below the low tide mark and within Roebuck deeps. The Broome Sandstone will be discharging groundwater to the coupled Roebuck Bay/Roebuck Plains system from all landward directions. This may create freshwater dependant ecological niches which could be threatened by regional water use or pollution. Roebuck Plains produces large amounts of sheetwash into the bay after large cyclonic events or prolonged wet season rains. This will be an important vector for nutrients, organic carbon and freshwater into the bay.
Water quality	Water quality appears poor, with TP levels, although there is limited information available from similar marine systems for comparison. Consideration has been given to the impact of urban run-off into the marine ecosystem. Agricultural activities may influence water quality from rangeland run-off during flood events.
Littoral vegetation	Along the sea edge there are mangrove communities. Mangrove detritus is a major source of energy for animals in the mangal and, perhaps, some mudflat species. Behind the mangal is an extensive plain of saline grassland that rises to the pindan plains typical of the western desert. Samphire occurs in the wetter zones. On beach dunes spinifex dominates.
Plankton and diatoms	Stable isotopes of carbon and nitrogen have shown that plankton and diatoms are a major source of

COMPONENT	SUMMARY DESCRIPTION
	energy for shellfish in the Bay.
Benthic invertebrates	Roebuck Bay has one of the most diverse arrays of benthic invertebrate infauna for any intertidal ecosystem. Species numbers are dominated by polychaetes. There is a rich assemblage of bivalves that provide an important source of accessible food for shorebirds. The average density of macrobenthic fauna is around 1287 animals per square metre.
Birds	The bay provides important food resources and refuge for migrating arctic shorebirds. A total of 43 species of waterbirds are recorded for the Bay including 22 species listed in migratory bird agreements.
Fish	The mudflats and mangrove creeks are nurseries for at least 4 fish species, for commercial prawn species and for mudcrabs
Marine fauna	Dugongs have been regular and important inhabitants of Roebuck Bay. Earlier records show evidence of Dugongs feeding on extensive seagrass beds in 1986. Loggerhead Turtles and Green Turtles regularly use the Ramsar site as a seasonal feeding area and as a transit area on migration. Flatback Turtles regularly nest in small numbers around Cape Villaret during the summer months.

Supratidal Zone

The second physiographic unit is a supratidal zone that extends landwards from the mangrove belt for a distance of around 30 km. Characterised by the rich alluvial grasslands that form Roebuck Plains, it is thought to have been structurally laid out by the Fitzroy River before it changed its course following uplift in the Miocene and Pliocene (Pepping *et al*. 1999). More recently, sea level changes have significantly affected sediment structure on Roebuck Plains, with sediments with a high level of organic carbonate forming when the sea covered much of the Plains about 6000 BP.

Bossut Formation

Between Dampier Creek and Fall Point on the northern shores of Roebuck Bay there are cliffs and beach ridges comprised of coarse calcareous and quartzoose sandstone. Referred to as Bossut Formation, these ridges represent the third physiographic unit. They contain fossilized gastropods, bivalves and foraminferans, which are evidence of the marine origins of this rock (Pepping *et al*.1999).

Coastal Aeolian Dunes

The white sands of Cable Beach, outside the Ramsar boundary, are an example of the fourth physiographic unit. There are small examples of this sand dune landform within the Ramsar site between Fall Point and Crab Creek. Most of the dunes are now stabilised and vegetated.

Aeolian Seif Dunes and Sand Sheets

Aeolian seif dunes and sand sheets occur over most of the land around the Bay as fine to medium red sands and give the Pindan soil its characteristic red colour as a result of the high concentrations of iron (Pepping *et al*. 1999).

3.2.2 SEDIMENTOLOGY

In sedimentary environments, such as the sand and mudflats of the intertidal zone at Roebuck Bay, the characteristics of the sediments define the system. Oldmeadow (2007) refers to three main sediment provinces in the intertidal zone of Roebuck Bay:

i. Northern sands province;
ii. Eastern silt and clay province;
iii. Southern sands province.

Northern Sands Province

The northern sands province, comprising most of the shores between Fall Point and Dampier Creek, is poor in carbonate. The high cliffs that border the northern beaches in this region erode and contribute Quaternary and Pleistocene terrigenous red pindan sands that may be seen infiltrating the mudflat sediments close to the base of the cliffs.

Eastern Silt and Clay Province

Carbonate rich sediments occur in the eastern province between Crab Creek and the junction of the southern sands province. This low energy environment is dominated by silt sized carbonates with small amounts of silica, kaolinite and illite. There is considerable bio-turbation that accelerates the break down and homogenization of the biogenic material (Oldmeadow 2007).

Southern Sands Province

The most expansive province in the Bay is the southern sands province. The sediments are comprised mostly of quartz-dominated sands with varying amounts (20-50%) of biogenic skeletal fragments. Such sands are typical of higher energy beaches between Cape Keraudren, at the southern boundary of Eighty Mile Beach and Roebuck Bay. The role of these high carbonate content sediments in the benthic productivity of shorebird sites such as Eighty Mile Beach and Roebuck Bay is uncertain.

3.2.3 SEDIMENT COHESIVENESS

The cohesiveness of sediments may exert a strong influence on the distribution of benthic fauna and the productivity of a mudflat (Compton 2007). Cohesiveness is probably best described to the layperson as firmness of the sediment and is affected by several bio-physical processes, including the size and chemical nature of the particles, the way they behave under different concentrations of dissolved salts and the occurrence on the sediment of mucus membranes made of polysaccharides excreted by bacteria and diatoms (Oldmeadow 2007). The occurrence of these polysaccharide mucus membranes can be localised and may be the cause of higher cohesiveness in areas such as Crab Creek (Oldmeadow 2007). Seagrasses have also been found to increase cohesiveness.

To a juvenile bivalve or other invertebrate, the structure of the sediments in which it lodges matters a great deal. Success of settlement can be determined by whether it finds itself on relatively coarse sands or sitting in very fine-grained mud. Not surprisingly, there appears to be a close relationship between biological diversity, abundance and sediment cohesiveness in Roebuck Bay. Benthic invertebrate surveys since 1997 suggest the highest abundance and greatest diversity of benthic fauna occurs in the two finer grained provinces. Species distributional overlap (Compton 2007) and species richness (de Goeij *et al*. 2003) is greatest in fine-grained sediment types.

Sediment characteristics affect the ability of people to access intertidal flats. During benthic mapping surveys from 1997 to 2006, workers routinely recorded the depth of the footsteps in different parts of the mudflats, calling the measure ‘penetrability’. Independent investigations suggest penetrability and grain size are correlated (Pepping *et al.* 1999, see also Oldmeadow 2007) ***Figure 14*** shows how penetrability

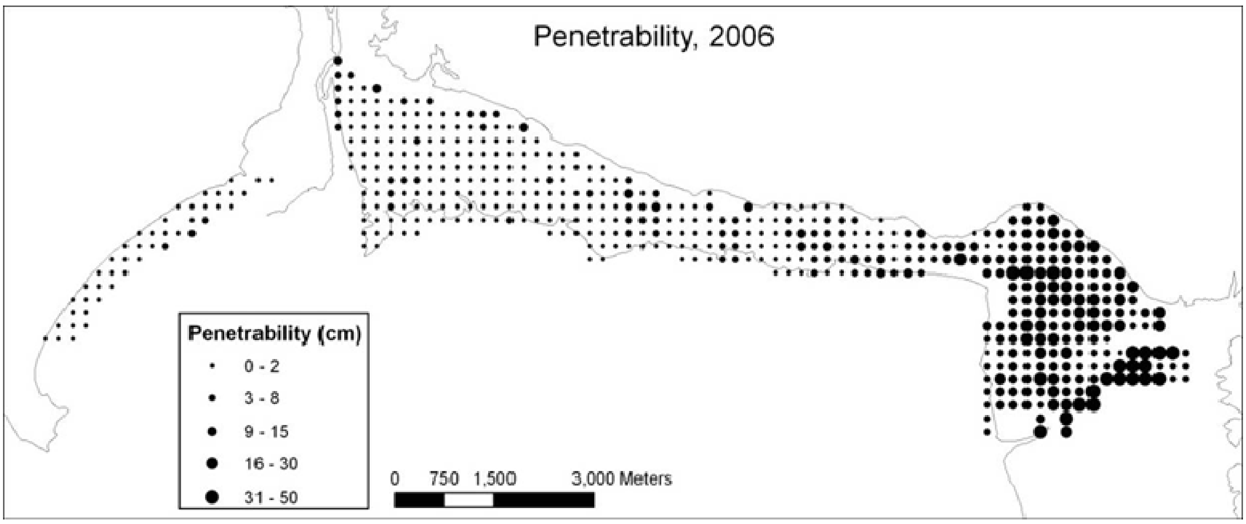


Figure 14. Depths to which participants of benthic mapping surveys sank in the mud in June 2006 on the northern intertidal areas of Roebuck Bay (Piersma et al. 2006).

values are distributed over the northern shores. The deep inshore mud between the Broome Bird Observatory foreshore and Crab Creek stands out as an area of soft sediments where people sank to considerable depths. Town Beach, and most of the northern foreshore, is firmer with a higher proportion of sand in the sediment structure.

3.2.4 HYDROGEOLOGY

The hydrogeology of the Canning Basin is dominated by extensive sandstone aquifers, which vary in salinity from fresh to 50,000 mg/L (Laws 1991b; Vogwill 2003). Detailed groundwater studies in the Basin are available in the immediate vicinity of Broome (Laws 1987, Vogwill 2003), and in the south-west of the Basin (Leech 1979). The La Grange sub-basin, to the east and south of Roebuck Bay, is fed by direct recharge from rainfall on the outcrop area of Broome Sandstone. Vogwill (2003) reports the Broome Sandstone will be discharging groundwater to the coupled Roebuck Bay/Roebuck Plains system from all landward directions. This may create freshwater dependant ecological niches which could be threatened by regional water use or pollution.

The influence of groundwater discharge on Roebuck Bay intertidal and supratidal areas can be observed at a number of localities, such as the surface expressions of fresh water in the Roebuck Plains, north of Crab Creek. In addition to their ecological values, these springs have cultural values for traditional owners and commercial value for graziers.

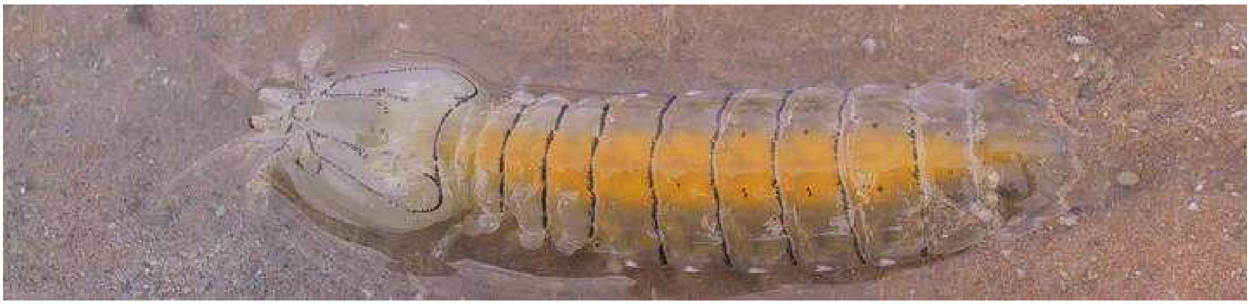
3.2.5 FRESHWATER INFLOWS

While there are a large number of ill defined drainage lines across Roebuck Plains there are no clearly defined creeks or streams that collect flow from across the Plains and feed into the Bay (***Figure 15*** and ***Figure 16***). Freshwater inflow to the Bay after summer cyclonic rain occurs as sheet flow and is unquantified, albeit probably substantial. The only known estimate is 450 GL per year across an area of 22,952 km^2 for the entire Cape Leveque Coast Basin (http://www.anra.gov.au/index.html).

With development of the Broome regional population centre, a system of urban drainage has been put in place. While there are no known measurements of the outflow volume from these drains into Roebuck Bay, some preliminary estimates of TN and TP concentrations have been obtained.

3.2.6 TIDAL CHANGES

Roebuck Bay is subject to semi-diurnal tides with amplitudes that vary from less than a metre at neap to 9.5 m at spring tides (***Figure 17***). Average tidal levels for Broome are given in ***Table 5***. The movement of the semi-diurnal tides that occur in Roebuck Bay is based on a lunar day, *i.e.* approximately 24 hours and 50 minutes (Pepping *et al.* 1999). As a result, the time of maximum and minimum tide varies daily.



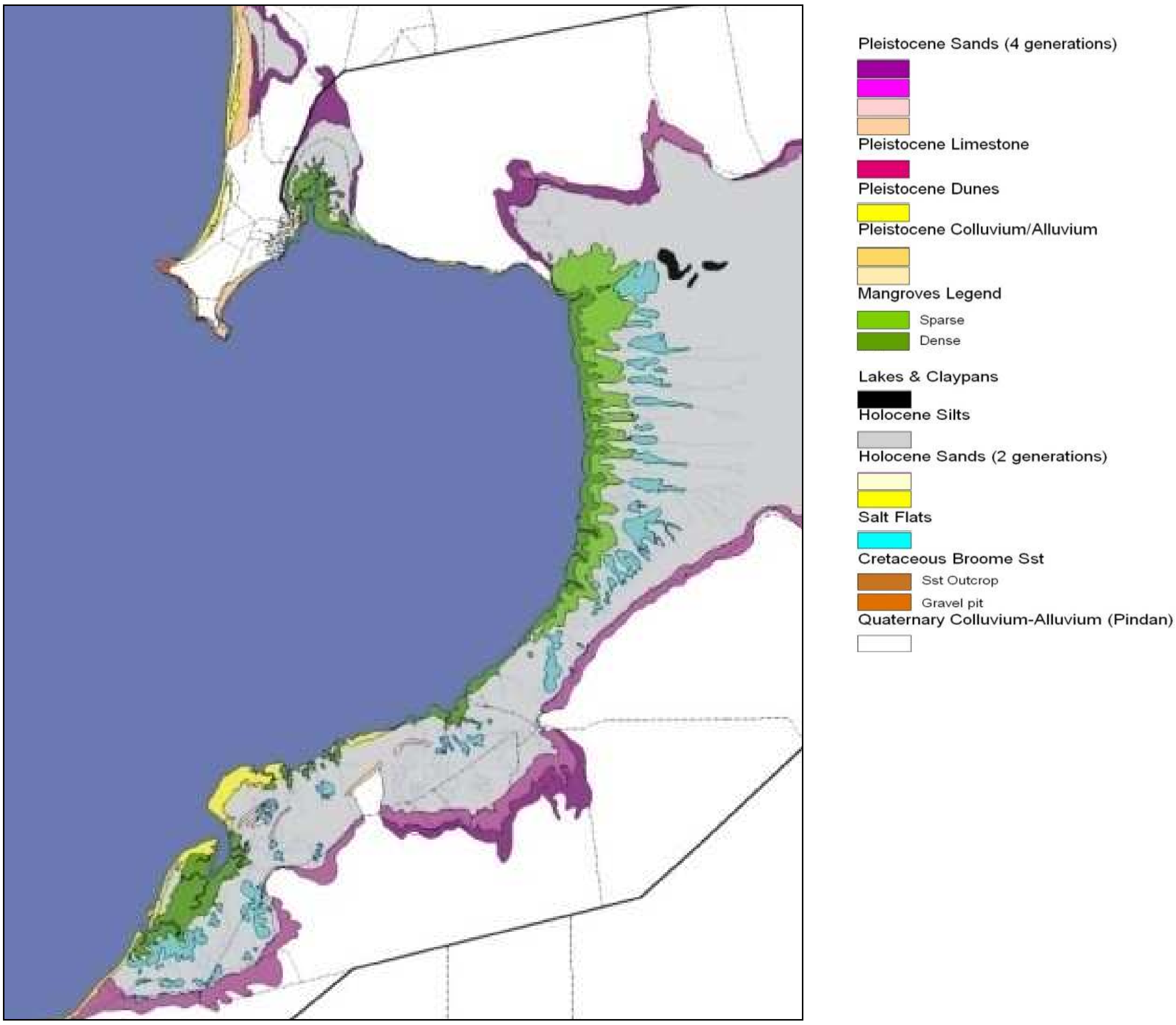


Figure 15. Physiography and surficial geology of Roebuck Bay and Roebuck Plains (from Vogwill 2003)

Semeniuk (1983) indicates that the transition between mangroves and the salt flats occurs at mean high water spring (MHWS) in north-west Western Australia. Tides that exceed MHWS flood the low lying salt flats and marshes behind the mangrove woodlands fringing the Bay for approximately 50% of the time.

Similarly such spring tides expose around 190 km^2 of mudflat at low tide. Hickey *et al*. (1998) developed a GIS based model of this movement allowing the derivation of mean inundation times. The model can be used to look at the extent of exposure or inundation in system process studies.

Figure 16. Topographic map of the Roebuck Plains showing the numerous defined drainage lines (blue) (from the Broome and Lagrange 1:250,000 scale series Geoscience Australia Natmap series).

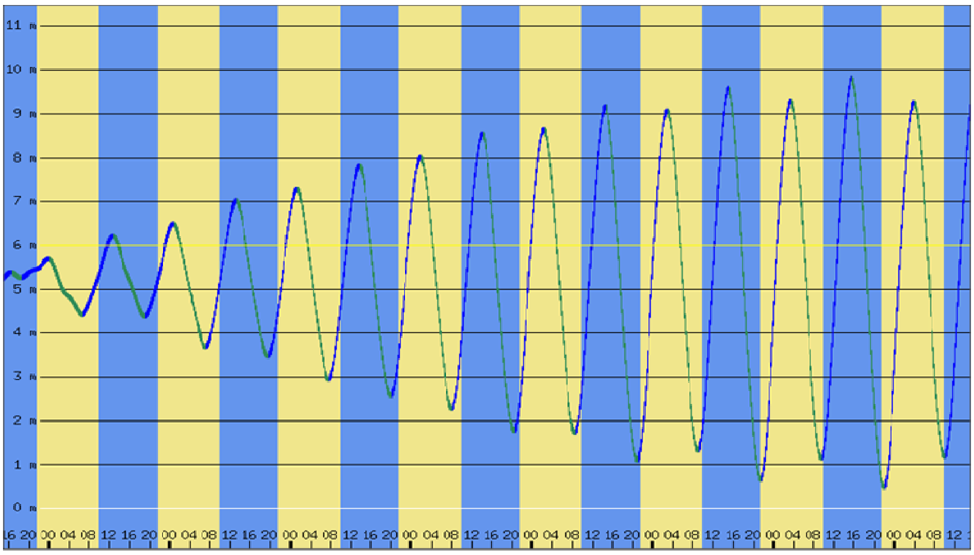


Figure 17. Graph of predicted tides for Broome from the 10th-17th October 2008 showing the change in diurnal amplitude from neap to spring tides (http://www.wtides.com/).

3.2.7 WATER QUALITY

Only limited water quality data exist for Roebuck Bay. Rose *et al*. (1990) collected water samples from the Broome jetty, west of the Ramsar site, between April 1986 and April 1989. The water samples were analysed for nutrients and chlorophyll *a* (a measure of phytoplankton concentrations). Results are expected to be broadly representative of conditions in the Bay, although anthropogenic influences may be higher and the effect of suspended sediment less than in most of the Ramsar site. The Department of Fisheries has continued sampling since 2005 (usually at 8.00 am on the third Wednesday of the month) as part of a quality assurance program for water supplied to the Aquaculture Facility). Summary statistics for both datasets are shown in ***Table 10***.

There appears to have been a major increase in total phosphorus (TP), total nitrogen (TN) and nitrates/nitrites (NO_x) between 1986-89 and 2005-08. However, this may be an artefact of differences in the way the two sets of samples were collected and analysed. For example, if sampled on the outgoing tide then water collected would essentially represent Bay water, but if sampled on the incoming tide, it would essentially represent ocean water. Higher nutrients would be expected in Bay water.

Irrespective of whether there has been an increase in nutrients over the past 20 years, Bay water quality appears to be poor. The values reported for 2005-08 are well in excess of current water quality guidelines for both marine inshore and estuarine waters. Average TP concentration was particularly high, being 6 times higher than the guideline for marine inshore waters and 4.5 times higher than the guideline for estuaries.

High nutrient and phytoplankton concentrations in coastal waters are frequently associated with adverse impacts on amenity and ecosystem functions. For this reason, the lack of long-term water quality data for the Bay is a concern.

3.2.8 SEDIMENT NUTRIENTS - CARBON

The sediments of Roebuck Bay undergo changes along a gradient from the southernmost extent of the Bay to the northern shores around Dampier Creek. Towards the south the sediments are mostly coarse sand with a grain size >300 µm (Piersma *et al*. 2002). The coarse sands become infiltrated with silt along the eastern shore until about 10 km south of Crab Creek the sediments are entirely fine silt <63 µm (Pepping *et al*. 1999). These very fine silts are indicative of a low energy environment present in the northern parts of the Bay. There is a very sharp gradient between the silty sediments of Crab Creek and the adjoining north-central area near Fall Point (Pepping *et al.* 1999). In the northern parts of the Bay, the sediments are mostly made up of fine to very fine sands. They consist mainly of quartz and shell fragments with small amounts of mica or dark minerals. The median grain size is between 63 and 250 µm.

Table 10. A comparison of nutrient concentration recorded at the Broome Jetty between 1986-89 and 2005-08, together with current water quality guideline trigger values (data up to August 2008).

BROOME JETTY SURFACE WATER NUTRIENTS										
ANALYTE	**FRP (µg/L)**		**TP (µg/L)**		**NH_4 (µg/L)**		**NO_x (µg/L)**		**TN (µg/L)**	
Sample period	86-89	05-08	86-89	05-08	86-89	05-08	86-89	05-08	86-89	05-08
Mean	6.2	4.0	16.2	90.0	10.3	18.5	2.8	32.5	181	352.2
Std Dev	3.8	1.9	6.8	132.3	9.3	20.8	1.4	57.1	72	289.0
Range	1 – 24	2 - 8	2 - 35	11 - 770	2 - 52	5- 120	1 -6	2 - 262	48. - 314	27.6- 723

ANZECC/ARMCANZ (2000) GUIDELINE TRIGGER VALUES [A]					
ANALYTE	**FRP (µg/L)**	**TP (µg/L)**	**NH_4 (µg/L)**	**NO_x (µg/L)**	**TN (µg/L)**
Estuaries [B]	5	20	15	30	250
Marine inshore	5	15	10	8	100

[A] ANZECC/ARMCANZ (2000) default trigger values for protection of slightly disturbed ecosystems in inshore marine and estuarine waters including north-west Western Australia.

[B] No data available for tropical WA estuaries. A precautionary approach should be adopted when applying default trigger values to these systems.

Carbon analysis of sediment samples collected in 1997 indicates the concentration of total carbon differed strikingly between samples, and that carbon content was significantly correlated with the proportion of silt (Pepping *et al.* 1999). Figures for total carbon ranged from 0.4% in the very sandy regions to 10.6% in the muddy regions to the east. The content of organic carbon in tropical mudflats is generally very low and rarely exceeds 1% of the dry mass (Alongi 1988). Most of the total carbon is in the form of inorganic carbonates. Hence it is likely that silt in the Bay is rich in carbonate.

In the sandy parts of the Bay, where wave energy is higher, only the coarse shell fragments are deposited. These contribute very little to the overall carbonate content of the otherwise mostly siliclastic sediments. Sediments along the northern shore also contain relatively high levels of iron as a result of the input of pindan sediments (Pepping *et al.* 1999).

3.2.9 PLANKTONIC ALGAE AND DIATOMS

Planktonic algae and diatoms are significant drivers of the energy cycles of the intertidal biota. Studies by Compton *et al.* (2008) indicate that oceanic planktonic algae and benthic diatoms, in combination with mangrove detrital material, are an important dietary component for bivalves resident in tidal flats in Roebuck Bay. The bivalves constitute a large proportion of the total biomass of the intertidal benthic invertebrate fauna and are an important part of the food chain for shorebirds such as the Great Knot and the Red Knot. The relative importance of plankton and diatoms in the food chain is unlikely to have changed significantly since the time of Ramsar listing in 1990, although energy cycles within the Bay are poorly documented.

Other than Compton *et al.* (2008) there has been little research conducted on planktonic algae of Roebuck Bay. As mentioned in section 3.2.7, Rose *et al.* (1990) recorded chlorophyll *a* values as part of water quality investigations at Broome Jetty in the late 1980s but the species of phytoplankton present were not recorded. Mean chlorophyll *a* concentration was 0.7 ± 0.4 µg/L. This is a low value and characteristic of oligotrophic waters.

3.2.10 BENTHIC PLANTS

The distribution of benthic plants in Roebuck Bay is not well documented. Walker and Prince (1987) reported the occurrence of two species of seagrass *Halophila ovalis* and *Halodule uninervis* in the Bay. In addition, Oldmeadow (2007) described the majority of the sub-tidal environment within Roebuck Bay as shallow, moderately undulating to flat bottomed, consisting of biogenic carbonate shoals covered by calcareous corals and sponges, and seagrass meadows dominated by *Halophila* sp. and *Halodule* sp.

Seagrasses have been included in the benthic monitoring projects (see section 3.2.12) and were reported from the lower intertidal zone, together with some species of macroalgae. Macroalgae were identified at 136 sites in the 1997 sampling undertaken in the northern section of the intertidal zone, with nearly 50% of these occurring in the fine sand province of the northern shores. A further 17% occurred in the silt/clay province. However, algal species were not documented. Of the 267 sites that recorded seagrass (either *H. ovalis* or *H. uninervis*), 156 (58%) hosted *H. uninervis* and 111 (42%) hosted *H. ovalis*. Most of the seagrass records occurred in fine sand or silt/clay provinces that represent the most biologically diverse sediments in the Bay.

Seagrass beds are the principle food source for both the Green Turtle and Dugong in Roebuck Bay.

3.2.11 LITTORAL VEGETATION

Pindan

The Ramsar boundary extends 40 m north of MHWM along the northern shore of Roebuck Bay above the pindan cliffs that fringe the Bay between Fall Point and Campsite. This thin strip of the Ramsar site is largely pindan landform. In general the land surface in the vicinity of Broome is covered by a thin veneer of Quaternary red clayey, silty sands (Laws 1991a) formed by a combination of aeolian processes and alluvial-sheetwashing during periodic flooding. The soil contains much clay, which gives it its red-earthy colour, both as coatings on grains and as bridging material in the matrix, bonding the particles together. This soil is locally known as “pindan” but the term is also used in relation to the vegetation of the area, which consists of a sparse upper story of trees and middle story of dense acacia thickets over dense grasslands (Laws 1991a). Seif dunes have formed in the pindan to the south and east of Roebuck Plains and are very similar to those formed in the Great Sandy Desert to the south. Although pindan is typical of the northern section of Roebuck Bay, and often features in photographs, it supports terrestrial vegetation and covers an extremely small part of the Ramsar site.

Salt Marsh

In Roebuck Bay, the extensive mangrove communities along the eastern edge of the Bay and around Dampier and Crab Creeks are fringed by terrestrial halophyte systems that are, at times, extensive. The plants of these salt marshes occupy specialized ecological niches that enable them to survive prolonged dry periods when soil moisture becomes hypersaline, intermittent inundation by tidal sea water and persistent flooding of fresh water from the rains of seasonal cyclones.

Plant species in the Roebuck Bay marshes include a range of succulents, including samphires such as *Tecticornia* and *Sarcocornia*, sedges, and grasses such as *Spirobolus*. Salt marshes provide habitat for many waterbirds, including Little Curlew, Pacific Golden Plover and Sharp-tailed Sandpiper (Rogers *et al*. 2004b), and several terrestrial birds closely associated with marshlands, such as Yellow Chat.

The Roebuck Bay salt marshes bind the soil during periods of flood and also help reduce wind erosion along the coastline. Salt marsh plants contribute some energy to the Bay in the form of organic carbon as well as small quantities of phosphorous.

Mangroves

The coastal areas of Roebuck Bay are dominated by a combination of aeolian dunes and mangroves fringing tidal creeks and swamps. Mangrove stands in the Bay vary in width from a few trees in the north-west and parts of the south-east shore to more than 1 km along the eastern shoreline. Mangroves extend as far south as Bush Point and Sandy Point where there is a system of small tidal creeks, the largest of which is Yardoogarra Creek.

In biogeographical terms, Roebuck Bay is located in the south-west Kimberley mangrove region that extends from Cape Leveque to the northern end of the Eighty Mile Beach (Johnstone 1990). Semeniuk *et al.* (1978) identified eleven mangrove species within the Bay and distinguished between the community in the north and that around Thangoo Station in the south. The 640 ha northern section comprises low open to closed forest of *Avicennia marina*, *Aegiceras corniculatum*, *Campostemon schutzii* and *Rhizophora stylosa* with *Aegialitis annulata* understorey. The 200 ha southern section is described as mixed woodland (to 5m) of *Avicennia marina*, *Brugeira exaristata*, *Osbornia octodonta* and *Camptostemon schultzii*. There is a closed thicket of *Teriops tagal* on the landward side with some *Excoecaria agallocha*.

Mangroves have the highest species diversity and tallest trees in Dampier, Crab and Yardoogarra Creeks. In these areas there is distinct zonation of the mangroves. The typical sequence of species in a landward direction is *Avicennia*, *Rhizophora*, *Ceriops* and samphire or salt flats (Chalmers and Woods 1987). Mangroves are most commonly found on muddy substrates in Roebuck Bay.

Mangroves provide shelter and food for a diverse fauna that includes specialized bivalves such as Shipworms *Teredo* spp., Mangrove Whelks and other smaller molluscs. The presence of high numbers of crabs in the mangrove forests around Roebuck Bay is typical of tropical mangroves where crabs are important feeders of seeds of *Avicennia*. They also have an important role in the maintenance of the mangrove stands as bio-turbators of leaf litter. By burying and eating most of the leaves that fall from the trees they preserve essential nutrients, in particular nitrogen, within the mangrove sediments. This is then used in the maintenance of the mangal community. Leaves and detritus from the mangroves are also an important dietary component of bivalves in Roebuck Bay, constituting around 24% of dietary requirements for suspension feeding species (Compton *et al.* 2008).

Mangroves are used sometimes as roosting sites by waterbirds during spring high tides and species such as Whimbrel make extensive use of this habitat. Several species of terrestrial birds are dependent upon mangroves (***Table 11***).

The Dampier Creek mangroves are a regular roost for large colonies of fruit bats. Two species of flying fox (*Pteropus alecto* and *Pteropus scapulatus*) and one blossom bat (*Macroglossus lagochilus*) occur in the Bay. Insectivorous bats of the mangroves at Crab Creek have been studied as part of a larger study of the bat guilds in the Kimberley mangroves (McKenzie and Rolfe 1986). The species recorded were: *Taphozous flaviventris*, *Chaerephon jobensis*, *Mormopterus* nov. sp., *Chalinolobus gouldii*, *Nycticeius greyi*, *Pipistrellus westralis* and *Nyctophilus arnhemenis*.

3.2.12 BENTHIC INVERTEBRATES

Roebuck Bay is one of fewer than 20 soft bottom intertidal mudflats worldwide that support very large numbers of migratory shorebirds (Piersma *et al*. 2002). It is a key staging and over-wintering area for Palaearctic shorebirds, which use the intertidal foreshore as their feeding area. The relatively high biomass of benthic invertebrates, for a tropical mudflat, is a major component of the ecological character of Roebuck Bay through enabling it to meet the physiological demands of migrating shorebirds. Long-distance migration flights are an intense period of starvation for birds when metabolic processes are maintained by stored fat deposits (Battley *et al*. 2001). Suitable habitats for recovery from, and preparation for, migration are a critical element of global flyways. Various studies have been undertaken since 1988 to quantify the benthic invertebrate biomass of the Roebuck Bay mudflats and the role it provides as a food source for shorebirds.

Table 11. Habitat affiliations of some terrestrial birds at Roebuck Bay.

TERRESTRIAL BIRDS	HABITAT USAGE					
	Mudflat	Mangroves	Shallows	Grassland	Samphire	Plains
* Lemon-bellied Flycatcher		X				
Mangrove Golden Whistler		X				
Mangrove Grey Fantail		X				
Red-backed Button Quail				X		X
Red-headed Honeyeater		X				
Richard's Pipit		X	X		X	X
Sacred Kingfisher	X	X				
Tawny Grassbird						X
White-breasted Whistler		X				
White-breasted Wood Swallow		X				
Yellow Chat				X	X	X
Yellow Wagtail				X	X	X

The first index of the food availability was developed in 1989 using ash-free zoobenthic biomass in the top 30 cm of sediment (Tulp and de Goeij 1994). Estimates of biomass near Crab Creek averaged 13.9 g/m^2 ash-free dry weight. More recent surveys of the mudflats have shown that the fauna is also very diverse. Pepping *et al.* (1999) recorded 161 taxa from quantitative samples from the northern shores of Roebuck Bay, with another 30 taxa recorded opportunistically (Appendix C). Piersma *et al*. (2002) recorded 205 taxa from quantitative samples from the whole intertidal zone of Roebuck Bay, with at least 60 additional taxa recorded opportunistically. Approximately 50 taxa had not been recorded previously and the total number of benthic invertebrate on the mudflat is likely to exceed 500 species. Some of the species of invertebrate identified in the mudflat are new to science (Piersma *et al*. 2006).

Biomass of mudflats at Roebuck Bay is much higher than the mudflats at nearby King Sound (Pepping *et al.* 1999), which supports few migratory shorebirds. Part of the reason for the greater biomass (and diversity) of benthic invertebrates at Roebuck Bay compared with King Sound lies in the structure and chemical composition of the sediments at the two sites. The presence of foraminifera in Roebuck Bay sediments suggests they are partly of marine origin. However it is likely that the saline grasslands of Roebuck Plains have also contributed silt to the mudflats of the Bay.

3.2.13 FISH

Other than for commercial and recreational species, there is little information about composition and abundance of fish in Roebuck Bay at the time the Ramsar site was listed. The Department of Fisheries regularly monitor abundance of commercial fish and crustacean species through the use of CPUE (Catch Per Unit Effort) and length-frequency data recorded by commercial fishers and charter boat operators, who are required to keep daily log books of fishing activities and catches. The data are used by the fisheries researchers to monitor the status of the stocks but are not generally available. Published data tend to be for the region as a whole and not reported separately for Roebuck Bay.

Commercial and Recreational Species

Department of Fisheries data show a commercial catch of 82.4 tonnes of fish of indeterminate species in 2007 for Roebuck Bay (State of the Fisheries Report 2007/2008). The recreational catch for all fin-fish species for the Pilbara-Kimberley region is estimated at about one tenth of the commercial catch (State of the Fisheries Report 2007/2008).

The main commercial fish species include Barramundi (*Lates calcarifer*), Giant Threadfin Salmon (*Polydactylis macrochir*), Blue Threadfin Salmon (*Eleutheronema tetradactylum).* Popular recreational fish species are Giant and Blue Threadfin Salmon, Tripletail Perch, Mulloway (*Argyrosomus japonicus*), Barramundi, mudcrabs (*Scylla* sp.) and molluscs. Dampier Creek and Crab Creek are favoured locations for fishers operating from small boats using drop nets or wading in soft mud with metal hooks.

Roebuck Bay, and in particular the near shore sand and mud flats within the Ramsar boundary, are reported as major nursery grounds for a range of marine fishes and crustaceans including Blue and Giant Threadfin Salmon and commercial prawn species. The intertidal mudflats, mangrove areas and interconnecting system of soft sediment creeks also provide habitat for both adult and juvenile Mudcrabs. (RIS 2003)

Protected Species

The tidal creeks, mangroves and adjacent mudflats within Roebuck Bay are nursery areas and refuges for Sawfish (*Pristis clavata*). Sawfish are listed as Totally Protected under the Western Australian *Fish Resources Management Act* 1994 (FRMA). They are also listed as Critically Endangered on the IUCN Red List (IUCN 2008). There are no published data on population numbers at the time of Ramsar listing or on distribution and movement of Sawfish within the Bay. Most records of occurrence in Roebuck Bay are from by-catch data provided by commercial gillnet fishers.

3.2.14 BIRDS

Waterbirds have an important role in wetland ecosystem function, principally as top order predators, through shifting nutrients and energy across the landscape and as vectors for dispersal of plants and invertebrates (Green and Figuerola 2005). They are important culturally, socially and scientifically. Changes in the abundance of various functional waterbird groups can be used to indicate disturbance to less easily observed aquatic biodiversity.

The Roebuck Bay Ramsar site is an internationally important staging (or refuelling) site for shorebirds migrating within the East-Asian Australasian Flyway. Many shorebirds also spend the austral summer there (i.e. October to March) and a significant proportion of young birds that remain in Australia during their first year use it in winter (i.e. April to September). Roebuck Bay meets waterbird criteria for Ramsar listing because of the high number of shorebirds present. No other waterbirds (ducks, ibis, herons, gulls, cormorants *etc.*) occur in sufficient numbers to justify inclusion in the Ramsar criteria. It is appropriate, therefore, to refer to the Roebuck Bay Ramsar site primarily in terms of its value to shorebirds.

A total of 122 species of waterbirds (Birds Australia Atlas data) have been recorded for the whole of Roebuck Bay, including adjacent wetlands such as parts of Roebuck Plains, Kidney Bean Claypan and Dampier Creek. Of the waterbirds recorded at Roebuck Bay, 43 species are migratory (including 28 shorebirds), 7 species are resident shorebirds, 14 species are gulls and terns, 46 species are waterfowl and 5 species are raptors that are defined as waterbirds for the purpose of this report.

It is possible to tease out an approximate number of shorebirds recorded within the Ramsar site (as opposed to the whole Bay) using various counts and records since 1981. An indicative species list for the Ramsar site derived from these records is presented in Appendix D, together with a comprehensive list of waterbirds recorded for the whole of Roebuck Bay. In the context of a description of ecological character of the Bay, waterbird data have been used from all of Roebuck Bay and coastally influenced wetlands as far east as Kidney Bean Claypan.

Waterbirds can be divided into a series of guilds, based principally on family level taxonomy, which are listed in ***Table 12*** together with a brief description of the habitat preferences and the number of waterbird species belonging to each guild recorded at Roebuck Bay.

Distribution within the Bay

Most of the Ramsar site is comprised of intertidal mud and sand flats. These occur as a narrow strip of sand/silt substrates along the northern shore, to wider flats of softer silts from Crab Creek south for some distance along the eastern shore and an extensive area of sand flats over much of the southern area near Bush and Sandy Points. Granulometric work undertaken on sediment samples collected in 1997

show a very sharp gradient between the muddy parts of the eastern end of the Bay near Crab Creek and the adjoining north-central area near Fall Point (Pepping *et al.* 1999). Sediment distribution influences the occurrence of benthic invertebrates and, consequently, distribution of feeding shorebirds.

Table 12. Waterbird guilds based on habitat usage and number of guild species recorded for the Roebuck Bay Ramsar site.

WATERBIRD GUILD	ECOLOGICAL NICHE WITHIN ROEBUCK BAY RAMSAR SITE	NUMBER OF SPECIES (TOTAL= 84)
Crakes, Rails	Coots forage in open water, others in shallow margins or rushes, salt marsh. Omnivores including aquatic plants, small fish and insects.	3
Grebes	Diving birds mainly associated with standing fresh or saline water. Feed on insects, zooplankton, small fish, molluscs and vegetation.	2
Petrels, Shearwaters	Mainly feed in open ocean, occasional or opportunistic visitors to the Bay.	1
Cormorants, Darter, Pelican	Mainly open water, occasionally in tidal creeks, intertidal flats (Pelican). Feed mainly on fish, shrimps. Breed away from the Bay, nomadic, opportunistic .	7
Terns and Gulls	Fish-eating and scavenging, also take insects. Terns feed on fish by hunting/diving over open water. Some are occasional visitors.	10
Shorebirds	Intertidal mudflats, shallows, salt marsh. Opportunistic feeding on benthic invertebrates, airborne insects and fish. Migratory or nomadic. Most breed in Arctic or sub-Arctic.	35
Ibis, Egrets, Spoonbills, Herons	Shallow water, intertidal zone. Feed mainly on invertebrates, small fish. Some may breed within the Bay in mangroves. Mostly nomadic.	15
Geese, Swan, Ducks	Open water (shallow or deep) foragers or grazers on shorelines and in meadows. Vegetarian or omnivorous, opportunistic breeders, nomadic, uncommon in the Bay.	7
Harriers, Eagle, Osprey	Forage for fish over open water and shallows or for invertebrates, small animals in grassland. Some may breed within the Bay.	4
Passerines - Little Grassbird	Insectivorous in grasslands and woodlands.	0

An extensive mangal occurs around Crab Creek and much of the eastern shore. Along the southern shore the mangroves are interspersed by a complex of tidal creeks and sand dunes that eventually form the elevated dunes of Bush Point and Sandy Point and delineate the southern boundary of the Ramsar site. This expanse of sand flats is less important as feeding habitat for shorebirds but provides important high tide roost sites (***Figure 18***).

The largest number of waterbirds recorded at Roebuck Bay is 170,915 in October 1983. As the wetland regularly supports more than 100,000 birds (in the sense that 100,000 birds can be counted on one day – far more pass through in a season) it is recognised as the fourth most important shorebird site in

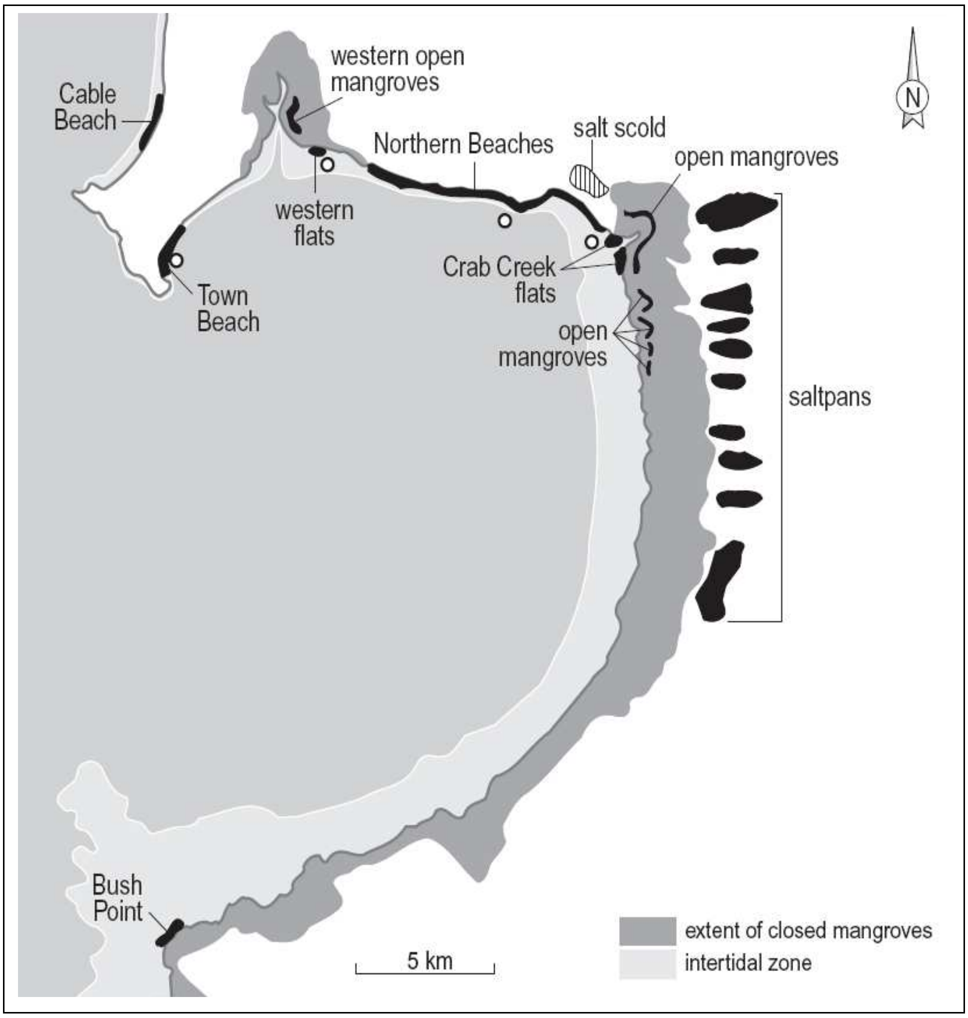


Figure 18. Map of the Roebuck Bay shorebird roosts, based on aerial photographs. The roosting habitats are shown in black shading (adapted from Rogers et al. 2006d). Roost sites are:

- *Cable Beach: white sand beach backed by unvegetated white dunes;*
- *Crab Creek flats: raised mudflats at the mouth of Crab Creek;*
- *Western flats: smaller raised mudflats, closer to tall cover;*
- *Northern Beaches: red sand beaches backed by dines or low cliffs; rocky points occasionally used as roosts;*
- *Town Beach: broader sandy beach backed by vegetated dunes;*
- *Open mangroves: clearings (ca. 100 m in diameter) in the Crab Creek and Dampier Creek mangrove forests;*
- *saltpans: large unvegetated claypans, surrounded by salt marsh;*
- *Bush Point: white beaches and sandbar.*

Australia and the most important in terms of the number of species it supports in internationally significant numbers (Rogers 2006d). The highest numbers of shorebirds are recorded between late October and early March. The period November to early March is considered to be the most stable for shorebird numbers, after birds moving farther south or east have moved on so that the Bay supports mostly those birds that will remain in the north-west. In the austral winter, shorebird numbers in Roebuck Bay have declined to as low as 50,000 juvenile or non-breeding birds (Rogers *et al*. 2006d). Juveniles of many species do not return to their breeding grounds for two years.

Within the currently defined Ramsar site boundary (***Figure 2***), 84 species of waterbirds have been recorded with 22 species occurring in numbers >1% of global populations (***Table 13***). Shorebirds are represented by 35 species. Many of these are molluscivores attracted by the high biomass of bivalves present in the intertidal zone (Piersma *et al.* 2006).

Population Trends

Delaney and Scott (2006) define a population as “a distinct assemblage of individuals which does not experience significant emigration or immigration”. Thus, populations of migratory species are defined in terms of numbers of birds in the Flyway while those of resident species can be defined in terms of numbers of birds in Australia.

Population changes are usually the result of changes in either recruitment or survival rate. The only practical way at present of determining annual reproduction rates of wader populations in the Australasian East-Asian Flyway, especially on a long-term basis, is measuring the proportion of first year birds in catches in non-breeding areas in Australia (*e.g.* Minton *et al*. 2007). However, a series of sampling and behavioural issues (aggregation of same-age birds, age-related habitat selection) are likely lead to errors in estimates of reproduction rate unless sampling programs are large and well designed (McCaffery *et al*. 2006).

Survival rates also are most easily measured in non-breeding areas. Recent improvements in mathematical models allow efficient estimates from re-sightings of live birds (White and Burnham 1999). However, the long-term banding datasets that might provide data on changes in survival over time are usually difficult to analyse (Bearhop *et al*. 2003).

World-wide, 44% of shorebird populations have declined markedly over the last 20 years and only 13% have increased (Delaney 2003). Recent developments along the Australasian East-Asian Flyway, such as the South Korean Saemangeum reclamation project and other habitat losses at Asian migratory stopovers (Moores 2006), have placed considerable pressure on shorebirds’ capacity to migrate and, therefore, on annual survival rates. Nevertheless, Roebuck Bay has supported substantially more than 20,000 waterbirds each year since nomination and is expected to continue doing so.

Breeding

The Roebuck Bay Ramsar site is not considered a stronghold of many species of breeding waterbirds. Indeed there are few records of significant breeding attempts by waterbirds in the Ramsar site and in the grasslands to the east. Known breeding waterbirds are:

Roebuck Bay Ramsar site

- Striated Heron *Butorides striatus*;
- Black-necked Stork *Xenorhynchus asiaticus*. Sometimes breeds in taller mangroves south of Crab Creek);
- Osprey *Pandion haliaetus*;
- Brahminy Kite *Haliastur indus*;
- Little Tern *Sterna albifrons*. In November 1999, 29 nests with one to three egg clutches were noted on the sand-spit at the mouth of “Jack’s Creek”, just south of Yardoogarra Creek. Nearby, Bush Point is an important roost for this species, with a flock of 1200 recorded there in April 1996 (Collins and Jessop 1997).

Feeding

Shorebird species at Roebuck Bay feed on shellfish, or benthic organisms, and therefore shorebirds can be used as indicators of the health of food webs in mudflat ecosystems. Harvestable prey must be available, profitable and ingestible or shorebird abundance will decline and species composition may change (Geering et. al. 2007). In Roebuck Bay, the diversity of benthic bivalves provides a platform for a high abundance and diversity of shorebird species, ranging from the world’s largest shorebird, the Eastern Curlew *Numenius madagascariensis*, to one of the smallest, the Red-necked Stint.

Recent studies have used distribution and abundance of benthic bivalves as a proxy for determining potential feeding distributions of shorebirds in Roebuck Bay. The basis for these studies is the fact that the abundance of shellfish is highest in fine sediment types (Compton et al. unpubl. data) so that, if birds are maximizing energy intake per unit foraging effort, they will concentrate in areas of fine sediment. There are, however, other constraints such as a species’ morphology, foraging method and prey choice that also influence where birds feed (***Table 14***).

Table 13. Species with maximum counts at Roebuck exceeding 1% population levels.

SPECIES	DESCRIPTION	COUNT	AUTHORITY	% OF POPN
Greater Sand Plover	International migrant, feeds on exposed mudflats at low tide, breeds in Mongolia.	26,900	Watkins1993	27
Oriental Plover	International migrant, feeds on exposed mudflats at low tide, breeds in Northern China and Mongolia.	8,700	Watkins1993	12

Lesser Sand Plover	International migrant, feeds on exposed mudflats at low tide, breeds in Siberia.	1,057	Watkins1993	2.6
Grey Plover	International migrant, feeds on exposed mudflats at low tide, breeds in high arctic tundra.	1,300	Watkins1993	1.0
Bar-tailed Godwit	International migrant, feeds on exposed mudflats at low tide, breeds in Siberia.	65,000	Watkins1993	38
Black-tailed Godwit	International migrant, feeds on exposed mudflats at low tide, breeds in high arctic tundra.	7,374	Watkins1993	4.6
Red Knot	International migrant, feeds on exposed mudflats at low tide, breeds NE Russia.	11,200	Watkins1993	5.1
Great Knot	International migrant, feeds on exposed mudflats at low tide, breeds NE Russia.	22,600	Watkins1993	5.9
Red-necked Stint	International migrant, feeds on exposed mudflats at low tide, breeds NE Russia.	19,800	Watkins1993	6.3
Curlew Sandpiper	International migrant, feeds on exposed mudflats at low tide, breeds NE Russia.	6,000	Watkins1993	3.3
Sanderling	International migrant, feeds on exposed mudflats at low tide, breeds in high arctic tundra.	1,510	Watkins1993	6.9
Far Eastern Curlew	International migrant, feeds on exposed mudflats at low tide, breeds in northern Mongolia, China, East Siberia.	603	Rogers *et al.* 2006a	1.6
Little Curlew	International migrant, feeds on exposed mudflats at low tide, breeds North Russia.	5,000	Watkins1993	2.8
Whimbrel	International migrant, feeds on exposed mudflats at low tide, breeds central and East Siberia.	1,020	Watkins1993	1.85
Common Greenshank	International migrant, feeds on exposed mudflats at low tide, breeds Central Asia, Central and East Siberia.	1,000	Watkins1993	1.7
Grey-tailed Tattler	International migrant, feeds on exposed mudflats at low tide, breeds North Central and North East Siberia.	3,180	Watkins1993a	8.0
Ruddy Turnstone	International migrant, feeds on exposed mudflats at low tide, breeds in high arctic tundra.	1,092	Rogers *et al.* 2006a	3.1
Asian Dowitcher	International migrant, feeds on exposed mudflats at low tide, breeds in Central and East Siberia and North East China.	414	Rogers *et al.* 2006a	1.7
Pied Oystercatcher	Australian resident shorebird, breeds along Australian coast.	416	Rogers *et al.* 2006a	3.8
Broad-billed Sandpiper	International migrant, feeds on exposed mudflats at low tide, breeds North East Siberia.	383	Watkins 1993	0.8-1.5
Red-capped Plover	Australian resident shorebird occurs in a variety of mostly saline wetland habitats. Breeds opportunistically.	3,300	Watkins 1993	3.5
Little Tern	Nomadic resident tern, breeds along Australian coast.	1200	C. Hassell, unpubl.	>1%

Table 14. Some waterbird feeding guilds based on prey choice and foraging method recorded for the Roebuck Bay Ramsar site (Rogers 1999a). Guilds are listed in order of abundance within the site (adapted from RIS 2003).

FEEDING GUILD	SPECIES	DISTRIBUTION WITHIN THE RAMSAR SITE
Tactile hunters of macrobenthos	Great Knot, Red Knot, Bar-tailed Godwit, Black-tailed Godwit, Asian Dowitcher	Feeding mainly in sea-edge flocks
Tactile hunters of smaller benthos	Curlew Sandpiper, Red-necked Stint, Broad-billed Sandpiper, Marsh Sandpiper, Sharp-tailed Sandpiper	Feeding mainly along sandy sea-edges or near tidal creeks
Visual hunters of slow surface-dwelling prey	Common Sandpiper, Sooty Oystercatcher, Pied Oystercatcher, Silver Gull, Ruddy Turnstone	Feeding mainly on reefs or mangrove fringes
Visual hunters of small fast prey	Grey Plover, Red-capped Plover, Greater Sand Plover, Lesser Sand Plover, Grey-tailed Tattler, Terek Sandpiper	Mainly occurring in the sandier western parts of Roebuck Bay, often near-shore
Visual hunters of fast large prey	Eastern Curlew, Whimbrel, Greenshank, Striated Heron and Black-necked Stork	Mostly favouring soft mudflats in north-east Roebuck Bay
Kleptoparasites	Gull-billed Tern	Rob large crabs from Whimbrels

Waterbirds in general and shorebirds in particular that possess different feeding strategies can occupy the same patch by targeting different prey. Length of time actually feeding can also vary and, in the case of shorebirds, the period spent feeding is inversely proportional to the size of the bird (Geering et al. 2007). This specialised feeding behaviour results in different shorebird species having different feeding distributions on intertidal mudflats within the Ramsar Site and reflects spatial variation in prey abundance (Piersma *et al*. 2006). A conceptual model of shorebird feeding strategies is given in ***Figure 19***.

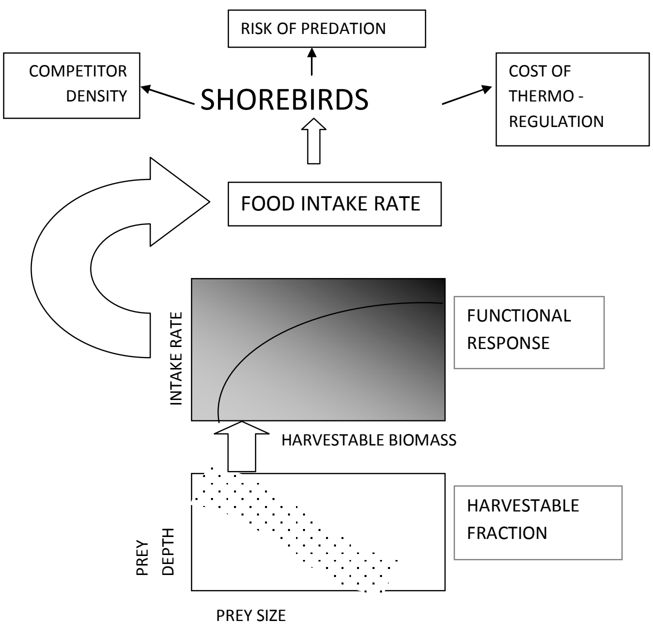


Figure 19. Conceptual model of shorebird feeding strategies (adapted from Piersma 1994).

Migration

In September 2007, a Bar-tailed Godwit fitted with a satellite tracking device completed an 11,000 km non-stop southern migration flight as a part of a 29,000 km round trip from Alaskan breeding grounds to wintering grounds in New Zealand (Gill 2008). This epic migration requires a level of endurance and energy use that is difficult to conceptualise.

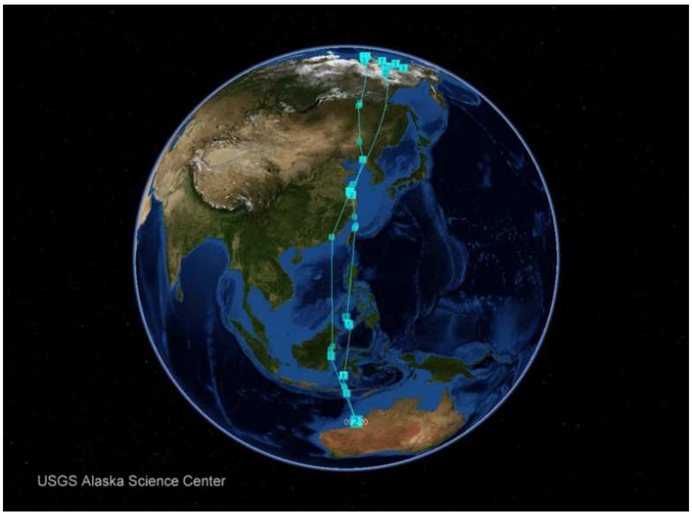


Figure 20. Part of the migratory route of Bar-tailed Godwits tagged in Broome (image courtesy USGS).

Shorebirds that migrate to and from Roebuck Bay undergo similar long distance migrations along the Australasian East-Asian Flyway (***Figure 20***). The energy budgets for their long distance migration, place stringent demands on a shorebird's capacity to choose the right habitat to refuel efficiently and in sufficient time to maintain their migratory prerogative. Few places in the world can satisfy these demands and migration staging points may provide the primary constraint on the size of shorebird populations.

With the exception of one species, which does not occur at Roebuck Bay, all Palaearctic shorebirds migrate to temperate or tropical regions during their non-breeding season (Battley *et al*. 2003). For many shorebirds, Roebuck Bay is the first Australian landfall on the East Asian Australasian Flyway. Most birds arrive between August and November and disperse to disparate regions of Australia and even New Zealand. The northern migration begins around March for some larger species and continues into May for others (Battley *et al*. 2003).

Roosting

Energy budgets imposed by their migratory lifestyle compel shorebirds to seek roost sites with a number of important qualities that minimise energy expenditure during periods of high tide. Shorebirds in Roebuck Bay choose roost sites that offer protection from predators, are close to feeding sites and provide some relief from tropical climate imposed heat stress. Roebuck Bay shorebird roosts are shown in ***Figure 18***. At spring high tide, the roosts along the northern shores contract, forcing many shorebirds to alternative roost sites east of the mangrove community on the eastern shore of the Bay. These roost sites are outside of the Ramsar site boundary.

Roost sites are an important habitat. They are often located on a narrow strip of beach just above high tide and susceptible to disturbance from anthropogenic impacts and from predators. The availability of roosting sites often determines the distribution of shorebirds within the feeding zones (Piersma 2006).

3.2.15 MARINE FAUNA

Turtles

Three species of turtle frequent Roebuck Bay, including the Loggerhead Turtle (*Caretta caretta*), Green Turtle (*Chelonia mydas*) and Flatback Turtle (*Natator depressus*), which regularly nests in summer months around Cape Villaret near the southern end of Roebuck Bay. The Loggerhead Turtle is currently listed nationally under the *EPBC Act* as endangered with the Green and Flatback turtles listed as vulnerable under the same Act. The Commonwealth *EPBC Act* (1999) provides special protection for nationally threatened species. There are no published data on turtle populations within Roebuck Bay or their movements within the Ramsar site.

Dugongs

A 1984 report on numbers of Dugong (*Dugong dugon)* of the northern waters of Western Australia (Prince 1986) estimated that 50-100 Dugong was a likely population for Roebuck Bay, with the animals occurring in groups of six to eight. The population in Roebuck Bay was recorded feeding on seagrass beds in the northern areas of Roebuck Bay, often within the intertidal zone close to the township of Broome. The Commonwealth *EPBC Act* (1999) provides special protection for Dugong as a migratory species of national environmental significance.

It was reported there was active Aboriginal exploitation of the Dugong and, in the context of the estimated population of 50-100, the 1984 rates of exploitation were considered unsustainable (Prince 1986).

Dolphins

Dolphins, previously identified as the Irrawaddy Dolphin (*Orcaella brevirostris*) have been reported to occur in Roebuck Bay. These dolphins are now thought to be a species recently described from the Northern Territory as *Orcaella heinsohni* (Beasley *et al*. 2005). The Commonwealth *EPBC Act* (1999) provides special protection for this dolphin as a migratory species of national environmental significance. There are no published data on dolphin populations within Roebuck Bay or their movements within the Ramsar site.

4. CHANGES IN ECOLOGICAL CHARACTER OF ROEBUCK BAY

Roebuck Bay was first listed as a Ramsar site in 1990. Since that time there have been a number of changes in the surrounding landscape and wetland that may have affected shorebird populations, and other aspects of the ecological character, of the Bay. A summary of known and potential change in ecological character of the Ramsar site is presented in ***Table 15***.

Over the past 20 years, the population of Broome has increased by 55% to over 14,500 in 2008. However this figure is swelled by 45,000 visitors per month during the winter tourist season. The population is likely to grow further in response to more development of oil and gas fields north-west of the town. Development of the Browse Gas Basin is likely to contribute 30,000 additional people before 2050 (Broome Shire Council pers.com). Tourist numbers are also expected to increase as Broome develops a reputation for high quality short-term accommodation. Both of these impacts will impose additional pressure on resources and conservation values of Roebuck Bay through disturbance and inappropriate activities, increased groundwater use through increased pumping, and pollution of groundwater with both waste water and other contaminants.

4.1 GROUNDWATER HYDROLOGY

There is little published information on changes to hydrology in Roebuck Bay. Vogwill (2003) presents evidence of groundwater pumping in the hinterland causing declines in the watertable and salt water incursion and upwelling. The implication is that significant groundwater pumping on Roebuck Plains will affect the location and quantities of discharge of fresh groundwater into the Roebuck Bay ecosystem. It is likely that the hydrology of inland areas north of the Bay has changed because of increased groundwater pumping for urban and horticultural needs, especially in the past 10 years, but the implications for Roebuck Bay itself are unknown. Potentially acid sulphate soils exist in the modern and palaeo mudflats of the Bay and dewatering/disturbance could generate increased acidity and liberate metal contaminants.

4.1.1 LA GRANGE GROUNDWATER RESOURCES

The La Grange groundwater resource, south of Broome, is divided into two subareas, the La Grange North subarea and the La Grange South subarea. Both subareas form the groundwater resources of the Broome Sandstone aquifer and the Wallal Sandstone aquifer (***Figure 21***). Five principles for management

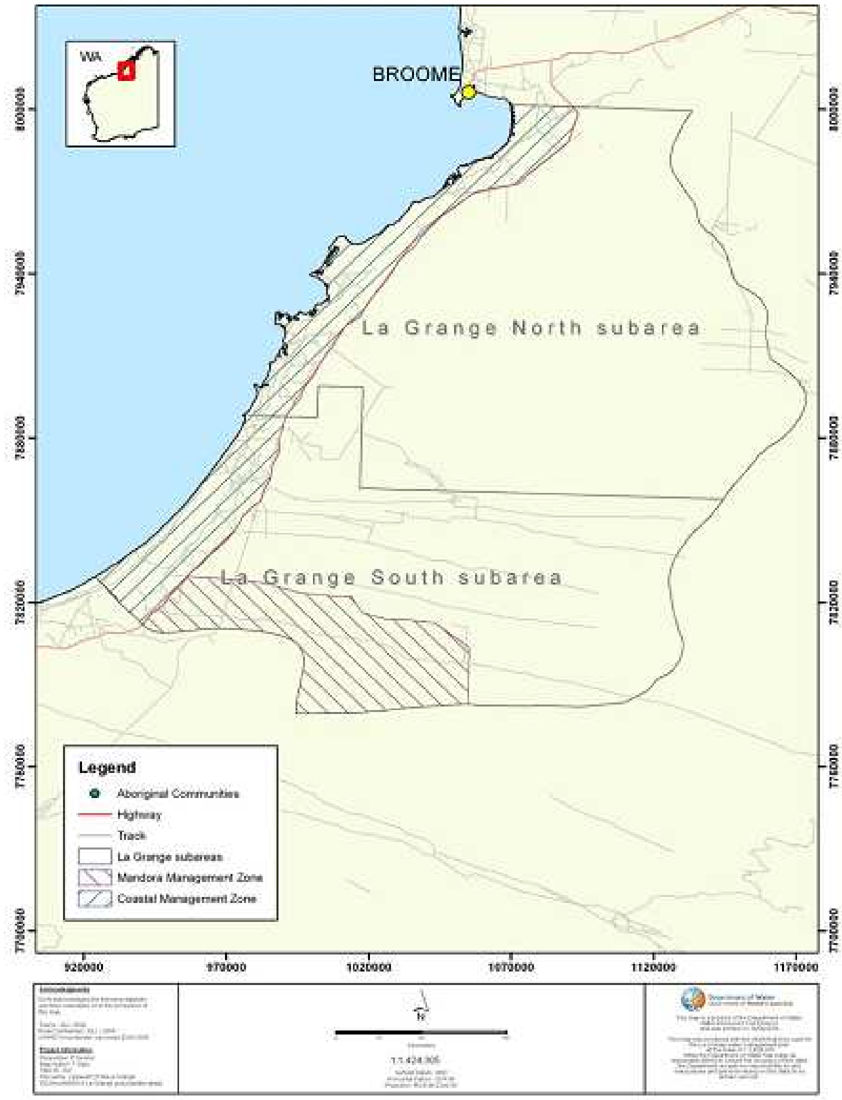


Figure 21. La Grange Groundwater sub -areas (adapted from Department of Water 2008 La Grange Ground Water Plan)

of water allocations in the La Grange Groundwater subareas have been developed to guide operational policies and were submitted for public review in September 2008. The principles included recognition of Ramsar sites and wetlands of national importance in the process of licensing decisions in the La Grange groundwater subareas.

4.2 TIDES AND GLOBAL WARMING

No change in tidal regime has been recorded for Roebuck Bay but there is the potential for changes to the inland extent of tidal movement and changed pattern of inundation in the different habitats in the Bay as a result of global warming. This will lead to a landward migration of the habitats to match the new flooding regime. Tidal behaviour plays a large part in shaping the ecosystems of the Bay.

4.3 WATER QUALITY, SEDIMENT NUTRIENTS AND *LYNGBYA*

Lyngbya majuscula was identified in Roebuck Bay in 2005 and has since become an issue of some concern. *Lyngbya* is a naturally occurring cyanophyte that grows on the surface of the sediment of shallow waterbodies. It is characterised by dark green to blackish mats that form an often slimy coating on the surface of the sediment. It can also produce individual tufts or extensive filamentous mats that are fixed to other plants such as seagrass. *Lyngbya* can be toxic and can severely impact upon biodiversity of shallow wetlands. There is evidence that *Lyngbya* can reduce seagrass cover by excluding light and through the production of toxins. It can be toxic to humans and poses a significant human health hazard.

Table 15. Summary of known and potential change in the ecological character of the Roebuck Bay Ramsar site.

ECOLOGICAL CHARACTER	DESCRIPTION OF CHANGE
Climate (cyclones, flooding)	None.
Geomorphology	None.
Hydrology	Possible changes to subterranean water inflow through urban drawdown. Potential for impact from drawdown for horticulture/agriculture in the east.
Tidal variation and global warming	None recorded but potential for changes to inundation period and tidal amplitude with global warming. Data deficient.
Water quality	Potential for change to nutrient levels of subterranean water supplies through urban impacts. Possible increased nutrients in waters off Broome Jetty, but data deficient. *Lyngbya majuscula* blooms recorded since 2005 may be related to increased nutrients in surface waters but data deficient.
Sediment structure and nutrient content	Changes have been recorded in the structure of sediments around Crab Creek that may be due to anthropogenic factors. Elevated TN and TP recorded in sediments at Town Beach but data deficient.
Littoral vegetation	Over-grazing in pastoral areas east of the Ramsar site has been reported in some areas. Impacts on samphire and mangroves unknown.
Benthic invertebrates	Declines in some benthic invertebrate infauna in the northern part of the Bay (de Goeij 2008) likely to represent natural fluctuations. Decline in abundance and distribution of the bivalve *Anadara granosa* (Piersma *et al*. 2006).
Fish	Anecdotal evidence of decline in recreational fishing catch for iconic species including Threadfin Salmon and Mudcrabs. Status of nursery stocks unknown. Data deficient.
Birds	No significant changes in overall waterbird numbers have been recorded within Roebuck Bay but data deficient at species level. Declines have been recorded for many species globally that may impact upon shorebird numbers in Roebuck Bay.
Marine fauna	Anecdotal evidence suggests Dugong numbers have declined.

Sustained growth and reproduction of *Lyngbya* is temperature dependant and has manifested in Roebuck Bay since November 2005. The production of hormogonia spores can occur in response to a combination of increased temperatures and nutrient levels. Monitoring of nutrient levels in sediments between Town Beach and the Port indicated elevated levels of N and P in some sites that may sustain recent algal blooms (Pearson *et al.* 2008).

The extent of distribution of *Lyngbya* in Roebuck Bay has not been determined. Anecdotal reports suggest it is concentrated mostly at Town Beach (which is outside the Ramsar site) with occurrences along the northern shores and the southern shores (K. Miller, pers. com.). It has been alleged the catalyst for the emergence of *Lyngbya* in Roebuck Bay was a sewage spill into the Bay from the Broome Wastewater Treatment Plant in 1999. Other than the data being collected at the Broome Jetty (see section 3.3.7) there are no data available with which to assess changes in water quality in the Bay. Although *Lyngbya* is believed to be a naturally occurring organism and possibly has been present in Roebuck Bay for some time there may be a link between the increased abundance recognised in 2005 and anthropogenic influences.

The RBWG established a sub-group in 2006 to investigate the extent and history of *Lyngbya* in Roebuck Bay. They found:

1. There are 23 uncontrolled drains carrying storm water into the Bay;
2. The history of *Lyngbya* in the Bay is unknown;
3. There may be potential for the nutrients P and N to enter the Bay via subterranean seepages from the waste water treatment plant (although P may be bound by soil);
4. The extent to which the nutrients P and N may act as drivers of the *Lyngbya* in Roebuck Bay and the extent to which P may reside in sediments within the intertidal zone is unknown.

As part of an overall plan to determine the drivers of the *Lyngbya* infestation at Roebuck Bay, 60 sediment samples along the Town Beach intertidal foreshore were collected on 21 February 2008 and analysed for TP and TN. Several sediment TP and TN values appear to be high but the lack of baseline information makes interpretation of the data difficult. The averages were 0.024% TN and 165 mg/kg TP. Neither of these figures appears sufficiently high enough to cause concern. However there is spatial variation in P, with values ranging up to 200-250 mg/L TP, perhaps as a result of point discharges (***Figure 22***).

4.4 BENTHIC PLANTS

Seagrass beds in Roebuck Bay have shown substantial fluctuations in density and distribution over recent years (***Figure 23***). Cyclonic weather events such as cyclone Rosita in 2000 may be the primary influence on seagrass occurrence. Environs Kimberley has been funded to monitor seagrass.

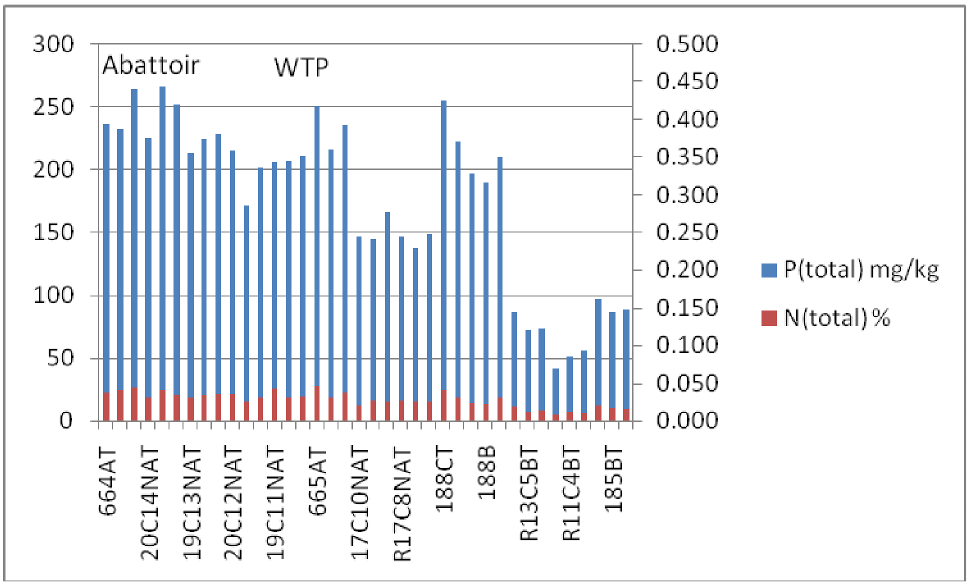


Figure 22. Nutrient levels from sediment samples from Town Beach. Sites are aligned from north to south with the approximate positions of the former abattoir and the WTP indicated.

4.5 LITTORAL VEGETATION

Littoral vegetation may be affected by grazing. Pastoral activities have changed from sheep to cattle grazing since early settlement. Over-grazing in pastoral areas adjacent to the Ramsar site has been reported in some areas but there are no empirical data and there is little documented evidence of changes to cattle stocking rates since 1990. Fire mostly affects the hinterland vegetation rather than wetland vegetation.

Mangrove communities appear to have shown little change since 1990. Broome TAFE has carried out experimental mapping of density and health of mangroves along a stretch of coast near the Town Beach but the data are not available; nor is it understood how results may relate to areas of mangrove within the Ramsar wetland.

4.6 BENTHIC INVERTEBRATES

Mapping studies undertaken since 1997 provide detailed data on spatial and temporal changes occurring in the intertidal zone of the whole Bay over the past 10 years (Piersma *et al.* 1997, 2002, 2006; Pearson *et al.* 2003).

Regular benthic sampling has been undertaken monthly by the Broome Bird Observatory at four sites since 1996 and reported twice (de Goeij *et al.* 2003, 2008). At two sites, more than 50% of species showed a decline in abundance over the period 1996 - 2001. Approximately 25% of species showed a marginal increase in abundance. Numbers appeared to stabilise between 2001 and 2005. Distribution patterns appear to have remained stable even though densities have changed.

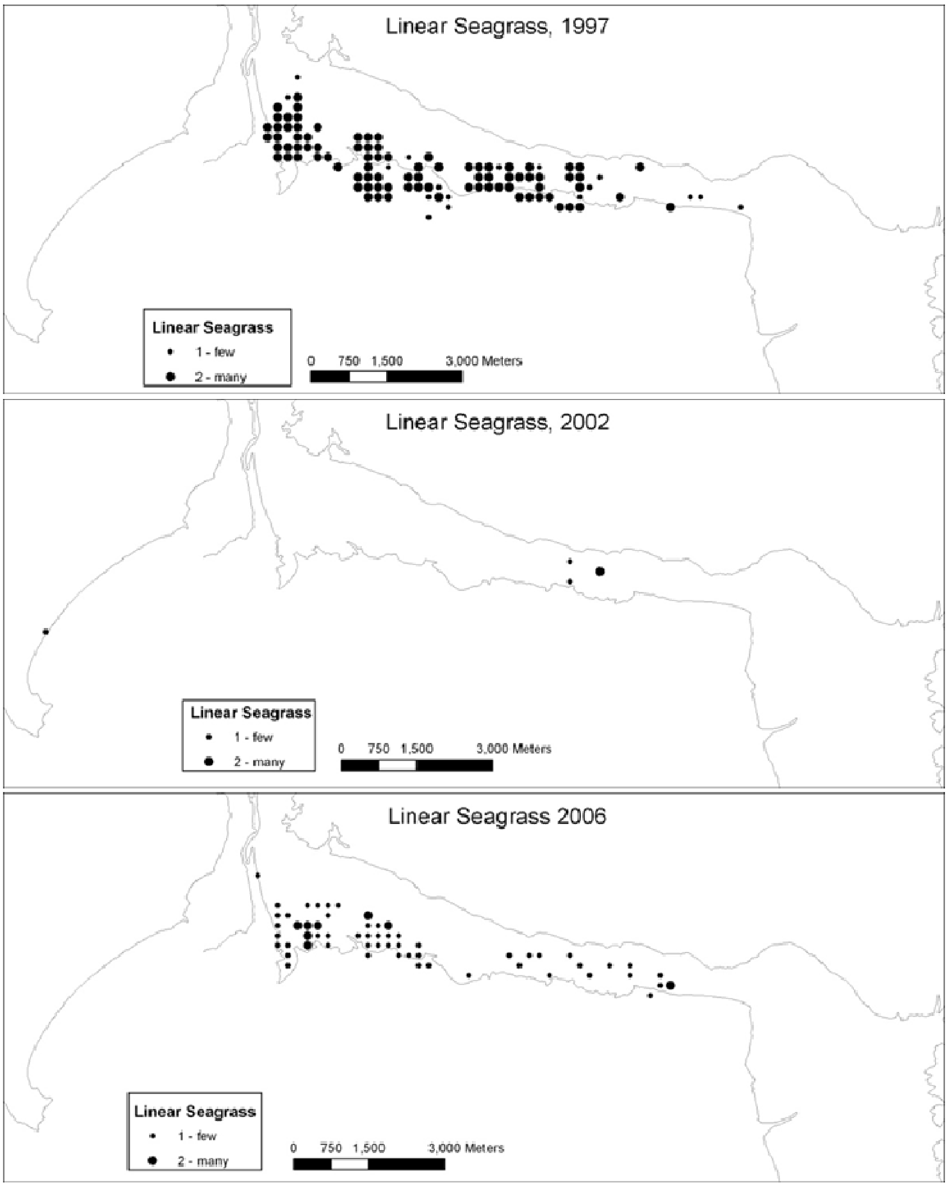


Figure 23. Extent to which linear seagrass was encountered on the northern shores of Roebuck Bay in June 1997, June 2002 and June 2006 (from Piersma et al. 2006).

The intertidal benthic mapping projects in Roebuck Bay recorded some decline in the abundance and distribution of the bivalve *Anadara granosa* (Piersma *et al.* 2006). This may be the result of natural cyclic changes in abundance at decadal time scales rather than anthropogenic disturbance. The decline in Roebuck Bay is consistent with anecdotal accounts of decline at Cape Preston in recent years (W. Boona pers. com.) and the fluctuations in abundance reported at Weipa by Morrison (2003). Harrison (in press) also suggests that *Anadara granosa* beds do not have long-term stability and that there may be shifts between *Anadara* and the Dog Whelk *Terrabralia palustris*.

4.7 FISH

There is anecdotal evidence of decline in recreational fishing catch for iconic species such as Threadfin Salmon. The Department of Fisheries set an annual target catch and monitor catch of commercial species. However, no formal assessment of Threadfin Salmon results has been undertaken. A 2002 stock assessment indicated that the Barramundi stocks were declining in the Broome sector, particularly the spawning biomass (Dept. of Fisheries 2007).

4.8 BIRDS

4.8.1 ROEBUCK BAY

Shorebird numbers have been reported and monitored at Roebuck Bay since 1980 through *ad hoc* counts. In 2005, Birds Australia undertook to carry out regular counts of shorebirds at a discrete number of sites in Roebuck Bay in an endeavour to provide robust datasets that would provide a baseline for management options for the Bay.

Most bird counts of Roebuck Bay are partial counts undertaken at different times of the year (*i.e*. migratory and non-migratory periods) with different sectors of the Bay being counted. Therefore, it is not possible to derive standard counts over time that show, at species level, whether shorebird abundance has changed since listing in 1990. However, overall waterbird numbers appear to have remained unchanged (see section 7.2)

Only two counts of individual shorebird species in the greater Roebuck Bay area can be reliably adopted as ‘whole of Bay’ counts. Other counts may be useful in providing records of incidental occurrences of species in the Bay but the absence of a species does not necessarily indicate its absence from the Bay. ***Table 16*** provides counts of the key shorebirds in Roebuck Bay in 2004 and 2005. The counts occurred at the end of the southwards migration period, between mid-November and mid-December, when all migrating shorebirds should have arrived in Australia. This period should reflect stable shorebird populations in the Bay, particularly as wet season rains are unlikely to occur before mid-December so that inland floodplains remain dry.

Table 16. Whole of Bay counts for 2004 and 2005 for key shorebird species.

SPECIES	2004	2005
Bar-tailed Godwit	11592	9909
Black-tailed Godwit	1076	1611
Eastern Curlew	453	363
Great Knot	14697	11648
Grey-tailed Tattler	361	433
Lesser Sand Plover	141	78
Pied Oystercatcher	54	45
Red Capped Plover	1157	1145
Red Knot	1266	1220
Sooty Oyster catcher	22	23
Whimbrel	415	437

4.8.2 GLOBALLY

Global declines have been recorded for many shorebird species (Gosbell and Clemens 2006) that may impact upon shorebird numbers in Roebuck Bay. Gosbell and Clemens 2006 report "(that) for populations with known trends:

- 44% appear to be decreasing, 13% increasing, 39% stable and 4% extinct (Delany 2003);
- In the East Asian–Australasian Flyway, a disproportionate number of shorebird species have been classified as threatened (AWSG 2003), and the shorebirds using this flyway are under increasing threat from habitat destruction and loss (Minton *et al*. 2005c);
- Over 80% of wetlands in east and south-east Asia are classified as threatened, with over half under serious threat (Barter *et al*. 2002)."

The main implication of these data for Roebuck Bay is that declines in numbers of shorebirds, and other waterbirds, observed in the Bay may be the result of external factors rather than local degradation. It has recently been shown that shorebird numbers in eastern Australia have declined 73% over the past 20 years, although in this case much of the decline is the result of habitat changes within eastern Australia (Nebel *et al*. 2008).

4.9 MARINE FAUNA

Earlier records show evidence of Dugong feeding on extensive seagrass beds in 1984 but anecdotal evidence suggests numbers have declined. There are no recorded data on changes in the populations of Dugong or other marine mammals or turtles between 1990 and present.

5. HOW THE ROEBUCK BAY SYSTEM WORKS

5.1 THE INTERACTIONS BETWEEN DRIVERS, COMPONENTS, PROCESSES AND SERVICES

The Roebuck Bay Ramsar site is strongly connected to the surrounding landscape through critical ecological components and processes. Similarly the Ramsar site has a great deal of internal complexity in how it functions. Understanding these connections and how they impact on the ecological character of the site is important for management. This section provides a conceptualisation of the interactions, pointing to the nature of the complexities in time and space.

Our overall understanding of the ecological character of the Ramsar site at this time is poorly developed and largely underpinned by knowledge of generic processes rather than by detailed scientific study of the Bay itself. The exceptions are the past strong focus on sedimentary processes, migratory shorebirds and their association with benthic invertebrates and other aspects of bird biology. As a consequence of the gaps in knowledge, the OzCoasts approach to conceptualising coastal ecosystems has been adopted here (http://www.ozcoasts.org.au/conceptual_ mods/cm_build.jsp). This approach looks at the physical underpinning of biological processes, and the stressors to them. The ecological character description of the Coorong, Lakes Alexandrina and Albert Ramsar site has been used as the basis for much of what is presented (Phillips and Muller 2006).

Key terms adopted in this approach to address ecosystem attributes are defined in ***Table 17***. This table has been adapted from that used in the Coorong and Lakes Alexandrina and Albert Ramsar Site ECD.

5.2 ECOSYSTEM DRIVERS, LEVERS, COMPONENTS, PROCESSES AND SERVICES

Central to understanding the ecological character of a wetland such as Roebuck Bay is a description of the drivers that shape the landscape and the levers that interact with the critical drivers to influence ecosystem component and processes. Anthropomorphic benefits and services are then a product of the

Table 17. Definitions of key terms used in this report compared with those defined by the Ramsar Convention.

TERM	RAMSAR'S INTERPRETATION	HOW USED IN THIS ECD
Components	Physical, chemical and biological components of the system, with the latter being defined as habitats, species and genes.	As defined by the Ramsar Convention
Processes	Interactions between the components that in turn supply benefits or services to humans.	Ecological processes being the dynamic biotic and abiotic interactions within an ecosystem such as primary production, decomposition, carbon and nutrient cycling. These may or may not provide direct benefits or services to humans.
Benefits/Services	'*…ecosystem benefits*' are defined in accordance with the Millennium Ecosystem Assessments definition of ecosystem series as '*…the benefits that people receive from ecosystems*'. Section 2.7 of this report provides a summary of these for this site.	When used in this report the definition of '*benefits and services'* is the same as that within the Ramsar Convention.
Drivers	Either indirect (economics, science cultural, religious) or direct (land uses, invasive species, water abstraction) drivers of change within the wetland. This is derived from the Millennium Ecosystem Assessment and focuses on predominantly anthropogenic activities which lead to change in the wetland ecosystem.	Fundamental natural processes that define the ecological character of the system within the landscape within which it occurs, namely climate, physiography and geomorphology, hydrodynamic and biogeographics. The intention is to define the underpinning natural factors critical to the ECD, not the influence of anthropomorphic factors.
Levers	The Ramsar Convention does not use the term 'levers'.	Factors of anthropogenic origin that alter ecosystem components or processes and as a result are key to management intervention. These may be the result of catchment-based activities (such as discharges to water from land-based activities or changes in hydrology) or direct manipulation at the site (such as increased tourist pressure from fishing, quad-bike use on the mudflats).
Biotope	The Ramsar Convention does not use the term 'biotopes'.	Each major biogeographical area within the wetland that is uniform in its physical, chemical and biological components including populations of animals and plants that provide a functional habitat area. This definition is based on that of Basson *et al.* (1977) and while 'biotope' may be thought of as synonymous with the term "habitat", the focus is not on a species or a population, but rather the biological community.
Biogeographic	The glossary to the Ramsar Convention on wetlands provides the following definition of 'biogeographic region' in relation to wetland management: *'a scientifically rigorous determination of regions as established using biological and physical parameters such as climate, soil type, vegetation cover,* etc'.	Naturally occurring small scale (large area) patterns of global distribution of species Global biogeographic regions have evolved as a consequence of processes such as continental drift and climate change that have influenced both the evolution and the distribution of species.

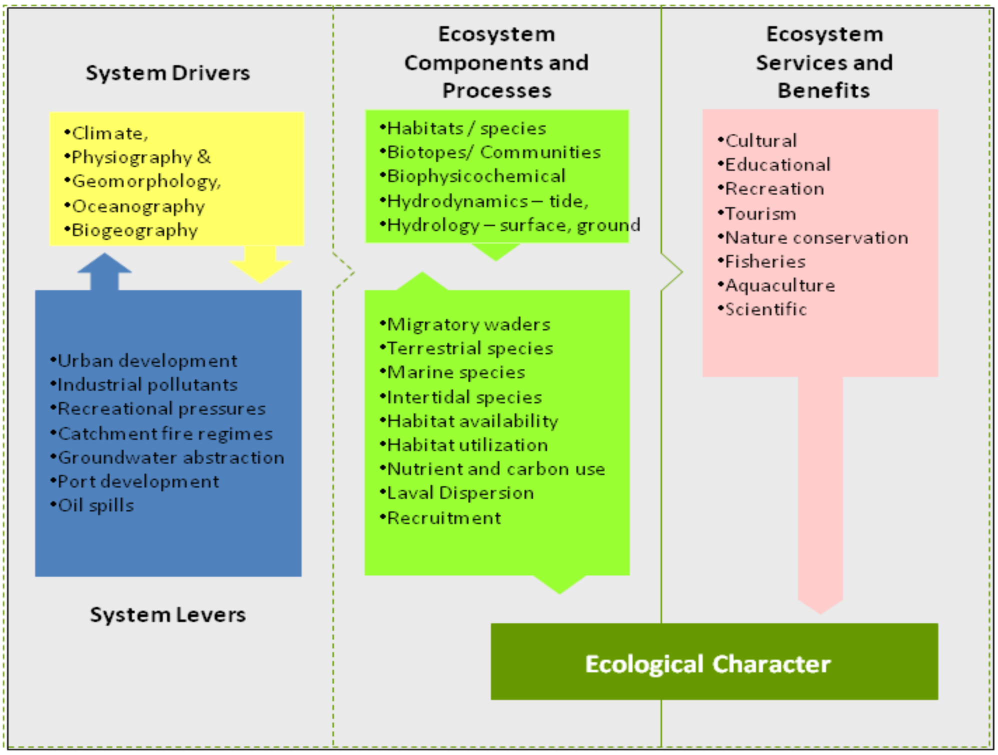


Figure 24. Ecosystem drivers, levers, components and processes that determine the ecological character of Roebuck Bay and the Ramsar site and the services and benefits that are received as a result.

components and processes. ***Figure 24*** shows conceptually the relationships between these aspects in defining the ecological character of the Roebuck Bay wetland.

5.3 DRIVERS

A number of factors, both past and present, determine the location and underpinning functioning of a wetland in the landscape. These factors are predominantly physical as they reflect the past and prevailing energy sources that have interacted with the prevailing geology to shape the landscape. The global distribution of biotic species and the way they have interacted with this changing landscape is also a major driver of the ecological character that has evolved over time. For the Ramsar site these drivers are:

- climate;
- physiographic attributes and geomorphic processes;
- marine and terrestrial hydrodynamics and hydrology;
- global biogeographic distributions of species.

It is clear that there are strong linkages across these processes in the way critical interactions between energy inputs and processes occur. Each will be described briefly in turn.

5.3.1 CLIMATE

Climate and climate variability across annual, decadal and greater timescales influence the nature of a wetland. Critical factors include precipitation, solar radiation, light and wind. Precipitation patterns, and consequent land-based runoff and ground water flows, have a strong influence through a range of processes including the transport of dissolved and particulate materials. This leads to changes in nutrient regimes, the supply of carbon, salinity and acidity, and the impacts of water as an erosion and transport medium.

Long term patterns in solar radiation affect temperatures in the landscape. Temperature is critical to the nature and rates of biochemical processes operating in sediments and the water column as well as dictating, in part, organism behaviour. These biochemical processes can control species niches and competitive interactions with other organisms. In a similar way, diurnal and seasonal patterns in wind strongly influences the suitability of specific locations as habitat.

Light quantity and quality is also critical to the type and rates of photosynthetic processes possible within a system and hence frequently dictates the limits for gross primary production at a system level. Not only are there daily and seasonal patterns in light, but the quality of available light can vary as a result of atmospheric and water column conditions.

In the case of the Roebuck Bay Ramsar site, the prevailing climate (section 2.2) sees strong seasonal patterns in rainfall, temperatures, available light and winds.

5.3.2 PHYSIOGRAPHY AND GEOMORPHOLOGY

Physiography (physical features) and geomorphology (processes shaping changes in these features) are critical driving forces in ecology. The shape and behaviour of a landscape is usually a product of the underlying geology and its interaction with key sources of energy. This leads to the prevailing physiographic attributes and associated biological interactions that define the biotopes identified within the wetland. These processes for the Ramsar site have been described in detail in section 4 and elaborated upon in greater detail in Oldmeadow (2007). The net effect of these processes with respect to Roebuck Bay is the occurrence of a complex array of well sorted sediment types in a relatively shallow topographic gradient that exposes them to both oceanic and land based movement of water.

5.3.3 HYDROLOGY

Oceanic Hydrology

Oceanic hydrodynamics dictate a range of spatial and temporal characteristics of Roebuck Bay and the associated Ramsar site. Horizontal and vertical water movement are key drivers dictating the nature of most marine and coastal systems and the diurnal changes in tide, control water circulation through the Bay, water exchange through the mangrove systems and periodic inundation of the supra-tidal areas. Other lunar monthly, seasonal and inter-annul changes lead to further water movement.

Another important influence on the Bay is the Indonesian Flowthrough that flows westwards from the Pacific to the Indian Ocean through the Indonesian archipelago to join water flowing out of the Indian Ocean before moving south to contribute a mass of warm water to the Leeuwin current off Western Australia. The nature of the water exchanged between the ocean and Roebuck Bay is strongly influenced by these processes. Water movements not only influence the regional climate but also such key characteristics as nutrient supply and pelagic species, including the movement of larvae of many subtidal and intertidal species that is so important to annual recruitment.

Land-based Hydrology

Seawards flow of surface and ground water are thought to have strong influences on the ecological character of Roebuck Bay. This is a result of the changes in salinity that affect the distribution of species such as mangroves, and the transport of dissolved and particulate chemicals such as nutrients and carbon from the terrestrial systems into the marine environment. In addition, freshwater runoff from the landscapes that surround the Bay may strongly influence water quality parameters such as turbidity, and nutrient concentrations.

5.3.4 BIOGEOGRAPHIC CONTEXT

Prevailing biotopes, their species composition and interactions are driven in part by the biogeographic context that dictates what species are “available” to occupy ecological niches. The biogeography of a region is a product of past and, sometimes, prevailing opportunities for evolutionary change as well as invasion from other regions and changes in physical and biological barriers through time. Barriers and environmental conditions may lead to speciation. More often they lead to ecological adaptation and the outwards movement of the new variants from their points of origin into other areas, plays a major role in species occurrence.

Wells and Walker (2003) describe the shallow water marine environments northwards of North West Cape as part of the vast tropical Indo-West Pacific biotic region which extends across the entire coastline of northern Australia to the southern extent of the Great Barrier Reef in Queensland. They propose that there are no major biogeographical limits along the north coast of Western Australia, but do note that there are differences in biota between the eastern and western sides of Cape York, Queensland. This is the Tropical Australia Province, sometimes referred to as the Dampierian province (Womersley 1990, as cited by Wells and Walker 2003). Roebuck Bay sits within this Dampierian province. In addition, a special biogeographic attribute of the Roebuck Bay Ramsar site is that it is a part of the global flyway for a range of bird species that are dependent on the physiographic and biological attributes of the Bay and its surrounds for their very survival (East Asian-Australasian Flyway).

From a terrestrial point of view, the Australian Natural Resources Atlas Biodiversity Assessment describes Roebuck Bay as a palaeoriver system within the southern subregion of Dampierland biogeographic region - the Pindanland subregion (DL2). This subregion is described as the "…coastal, semi-arid, north-western margin of the Canning Basin and with a semi-arid, hot, tropical climate with summer rainfall. Quaternary sandplains mantle Jurassic and Mesozoic sandstones and support Pindan vegetation on the plains and hummock grasslands on hills. Quaternary marine deposits on coastal plains support mangal, samphire, *Sporobolus* grasslands, *Melaleuca acacioides* low forests, and Spinifex-Crotalaria strand communities" - see http://www.anra.gov.au/topics/vegetation/assessment/wa/ibra-dampierland.html#intro.

5.3.5 LEVERS

The levers that can be changed to influence the ecology of Roebuck Bay may be summarized as:

- Urban runoff;
- Industrial pollutants;
- Recreational activities – land based;
- Recreational activities – water based;
- Agricultural activities;
- Groundwater extraction;
- Port development and dredging;
- Oil spills.

Each of these levers on the system is thought to be exerting only a relatively small influence on Roebuck Bay at this point in time. This is reflected in the assessment made by Paul Sattler and Colin Creighton (2002) in preparing the Australian Terrestrial Biodiversity Assessment for the National Land and Water Resources Audit. They concluded that the wetlands of Pindanland Subregion may be considered to be "good" in that recovery can occur in the short term with minimum intervention. The national estuary audit considered Roebuck Bay to be "near pristine" with sections "largely unmodified".

This situation is not likely to remain the case for long and, as is described below, evidence is already accumulating that major changes are taking place. Urban and industrial growth in response to oil and gas infrastructure development and the rising popularity of tourism is leading to increasing leverage on the Bay. The occurrence of *Lyngbya* near Broome since 2005 and the concentrations of pollutants in sediments reported by Oldmeadow (2007) are indicators that the Bay is being impacted.

An interesting footnote is the repeatedly heard belief of Broome residents that the very large tidal range protects the Bay from impacts. While it is true that tides in the Bay lead to movement of both dissolved and suspended material, it is likely that an increased amount of sedimentary material is being deposited in the Bay. The Bay is considered to be a net accumulator of sedimentary material as evidenced by accumulations of fine muds and clays within the intertidal. Otherwise, this material would have been progressively eroded out of the Bay over time.

5.3.6 COMPONENTS

It is the interactions between the critical system drivers that have shaped Roebuck Bay as we know it today. Oldmeadow (2007) makes the point that there is a strong relationship between vegetation, geology, and hydrogeochemistry in Roebuck Bay and as a result the transitions between vegetation types are frequently indicative of boundaries between sedimentological and geomorphic systems. This relationship has led to distinct but interconnected ecosystem components along a land-sea gradient as shown in the conceptual transect in ***Figure 25***.

Under an outgoing tide, sediments become exposed and are available to a range of both terrestrial and marine foragers. In the case of Roebuck Bay, the foragers are most notably migratory shorebirds but crustaceans, such as crabs, and some mollusc species are also important (***Figure 26***). Under an incoming tide, predation pressures change as a range of fish and crustaceans move in to forage across the flats and in the mangroves, driving many of their prey species back into the sediments for protection (***Figure 26***). Evidence for this process is the foraging behaviour of many rays where they disturb the sediments looking for prey and leaving the very characteristic hollows in the flats that retain water as the tide runs out.

This tidal inundation is critical to the net production of the flats and other ecological attributes including larval dispersion and recruitment. It is therefore a critical aspect in conceptualising how the system works as a whole, rather than focussing only on individual elements (such as shorebirds) in isolation. An example of inter-relationships is that changes in fishing pressure on predator species could conceivably change the pressure on benthic invertebrates and, as a result, affect the abundance and type of species available to different avian species.

The readily defined biotopes within Roebuck Bay are the beaches, cliffs, dunes (and adjacent terrestrial areas); the supratidal flats; the mangrove areas; the intertidal flats; and the subtidal areas of the Bay. These biotopes align with the wetland types described in section 2.6. The respective area of each biotope is given in ***Table 18***.

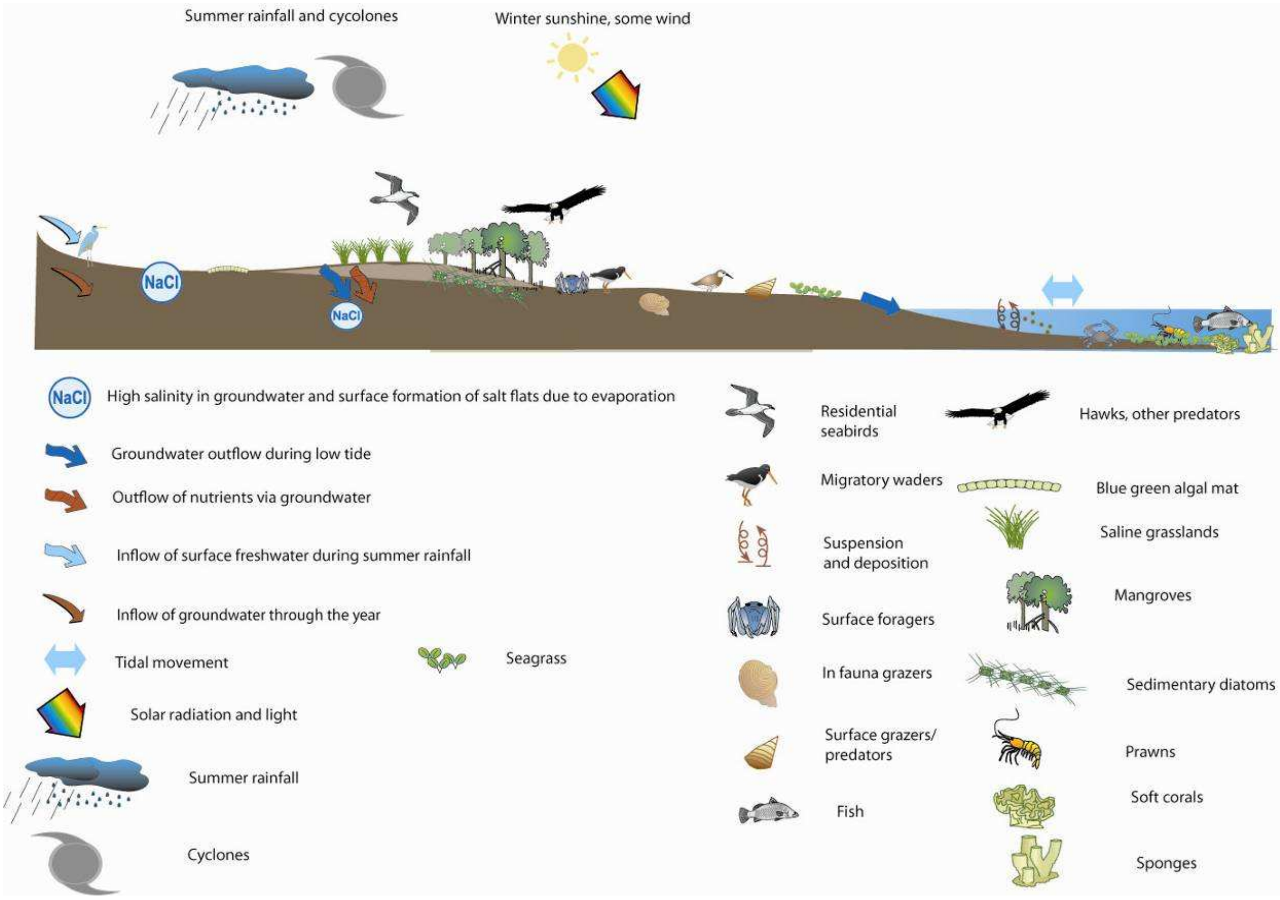


Figure 25. Conceptual model of a transect across the sea land margin of Roebuck Bay at low tide showing critical ecosystem components.

These are in sequential progression from the land to the sea; the individual elements are described in the diagram and are based on the description provided by Oldmeadow (2007).

Table 18. The areas of each major ecosystem component or biotope within Roebuck Bay.

ROEBUCK BAY	AREAS	PER CENT[3]
Subtidal zone of Roebuck Bay[1]	27 km^2	23 %
Intertidal zone of Roebuck Bay	67 km^2	60 %
Fringing mangroves	19 km^2	17 %
Beaches, cliffs and dunes	Not calculated	-
Supratidal zone on Roebuck Plains[2]	Not calculated	-

[1] all figures derived from Google Earth

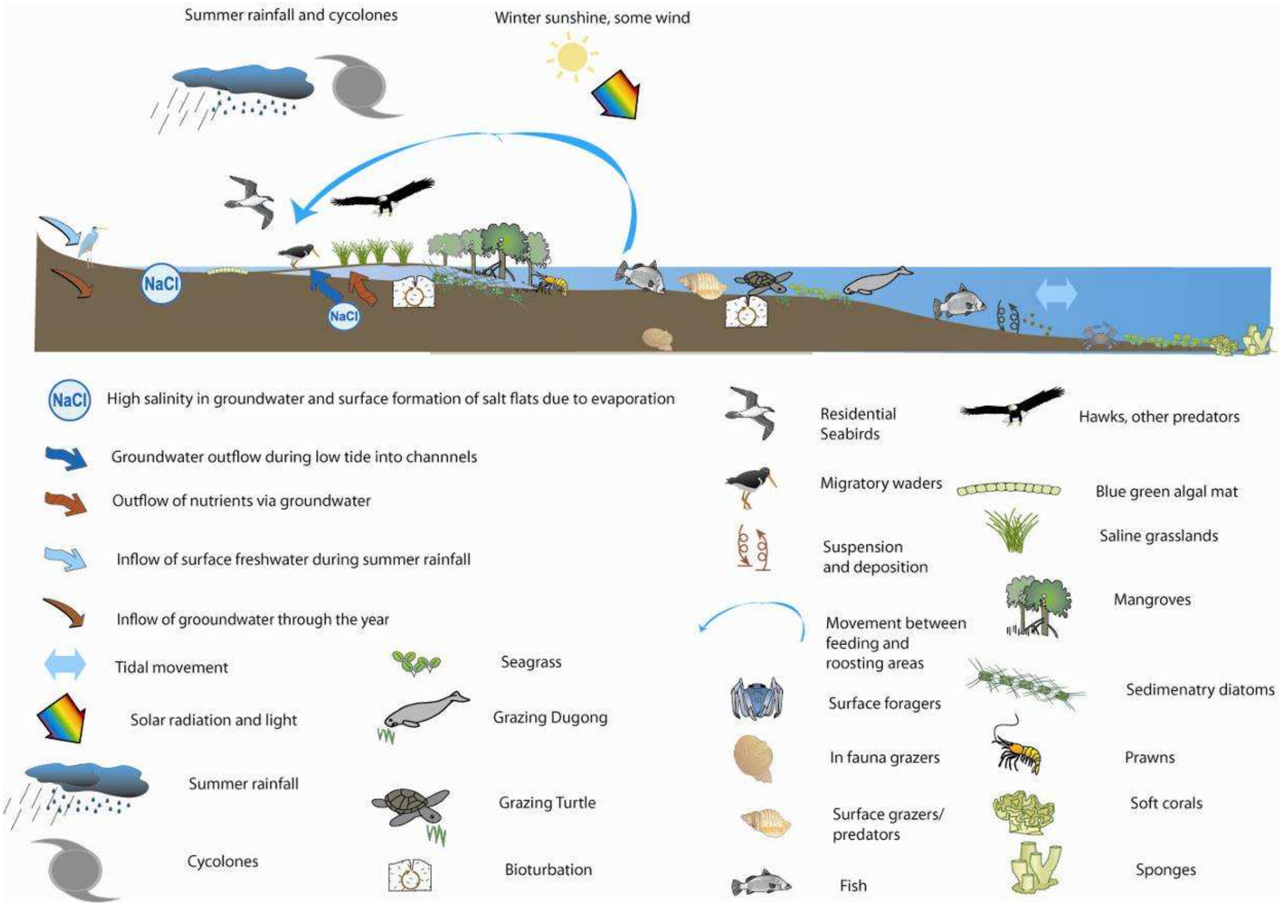


Figure 26. A second conceptual model. The influence of tide leads to a major partitioning of the mangroves and intertidal flats.

Under both inundated and exposed conditions these areas represent either a change of habitat conditions to which some species have adapted e.g. molluscs and crabs or extension of habitat for other species e.g. fish, insects and birds.

5.4 PRIMARY DETERMINANTS OF ECOLOGICAL CHARACTER

The key components of Roebuck Bay are linked through several sets of processes that are primarily determined by geomorphology, energy regimes and water movement, both fresh and marine. These processes are best conceptualised around geomorphological processes that influence the physical movement of materials, nutrient processes that influence the primary production within the system, and associated physical attributes such as salinity and temperature that are critical to species habitats/gradients.

5.4.1 SEDIMENTARY AND GEOMORPHIC PROCESSES

Despite the extensive tidal movement of water in and out of the Bay on a daily basis, Roebuck Bay is considered to be a low energy environment with respect to sedimentary processes and is in fact most likely to be a net depositional environment (Oldmeadow 2007). Short (2006) described the beaches of Roebuck Bay as low energy because of the limited fetch and wide tidal flats.

Under a changed sediment regime leading to greater sediment loads to the Bay, such as increases in urban runoff, greater input from rural catchments or dredging activity, a large proportion of this particulate material would be deposited within the Bay leading to changes in the characteristics of subtidal and intertidal sediments, the accumulation of nutrients or other chemicals of concern and a potential for re-suspension into the water column leading to change in water quality.

The faunal changes that would accompany sedimentation are not clear at this stage but the general comment can be made that bivalve diversity and abundance decreases as sediments become coarser (Compton *et al*. 2007). Changes to abundance of bivalves (and other invertebrates) would most likely affect feeding opportunities for birds and other animals.

Oldmeadow (2007) provides a comprehensive account of the geomorphology and sedimentary process of the Bay system and concluded the area can be divided into the five generic geomorphic provinces (see *Figure 8*). He also recognized five dominant facies within the intertidal sediments of the Bay. While the broad distributions of the facies are probably reasonably stable, there is no doubt that changes occur over annual time scales, as documented at one of the two benthic invertebrate monitoring sites assessed monthly by the Broome Bird Observatory, which is reported to becoming increasingly firm in its sediment composition (de Goeij 2008). There is no immediately obvious explanation for this but it is well recognised that such geomorphological changes in coastal systems can be the product of re-adjustments following major events on an annual basis, with some adjustments still taking place after hundreds of years (*e.g*. Eberhardt 1979). Tropical Cyclone Rosita, which passed across the coast some 40 km south of Broome in June 2000, was accompanied by a 2 m storm surge that accelerated erosion of coastal features such as cliff faces and removed near shore dunes (Oldmeadow 2007). Similarly Lavaleye *et al*. (1998) referred to Little Crab Creek being completely filled with sediment by a cyclone in 1998 and then re-establishing itself.

5.4.2 NUTRIENT PROCESSES AND CARBON SUPPLY

Inter-tidal environments are more complex than first appears because of the three-dimensional distribution of water, sediments and animals. Areas such as mangroves have added complexity (***Figure 27***). The key to understanding the nature of aquatic ecosystems often lies in documenting the sources, losses (sinks) and internal pathways and process rates of the plant nutrients nitrogen and phosphorus. While nitrogen and phosphorus are not the only nutrients critical to the growth of marine plants they are frequently the most important because their biological availability limits rates of growth. In near shore coastal environments it is the availability of dissolved inorganic nitrogen that is considered to be the most limiting, although mangrove systems may be phosphorus limited (Alongi 1998).

Both nitrogen and phosphorus exist in marine systems in particulate and dissolved forms with a considerable amount of the particulate form being organically bound. While the dissolved fraction can exist as both inorganic and organic forms, the most common fraction is organic and it is this fraction that is available to plants. Gross nutrient availability in coastal systems is a balance between new nutrients entering the system from water exchange or particulate movement, and loss or export as a result of water movement and sequestering in sediments. In the case of nitrogen, conversion by bacterial processes to nitrogen gas is also an important source of loss from the system.

Availability of nutrients, rather than the quantity in the system, is usually controlled by recycling processes. These processes are strongly linked to the availability of oxygen or some other form of electron acceptor and the decomposition of organic carbon as well as the chemical transformation of iron and sulphur in the sediments. The rates of a number of these processes are temperature dependent.

There are probably several sources of carbon supply to the intertidal flats of Roebuck Bay, namely *in situ* fixation by microalgae, phytoplankton deposits during flooding tides, detritus from adjacent mangrove systems, and some transport of macro-algal and seagrass material. There may also be input of terrestrial carbon, particularly after major rainfall events following the passage of cyclones. Crompton *et al.* (2007), in discussion of carbon isotope measurements made with respect to bivalve feeding, concluded that endosymbiotic bacteria, phytoplankton and microphytobenthic diatoms were the major food sources and that mangrove detritus was less important. Nutrient supplies are probably similarly sourced.

Tropical phytoplankton concentrations are usually reasonably low and this would appear to be the case for Roebuck Bay, where Rose *et al.* (1990) reported an average chlorophyll *a* concentration of 0.7 µg/L for samples from the Broome jetty taken at monthly intervals between April 1986 and April 1989. Therefore, despite the results from isotopic studies of feeding bivalves, it is considered to be unlikely that phytoplankton contribute significantly to the net productivity of the intertidal systems of the Bay as a whole. It is more likely that the intertidal areas of Roebuck Bay are benthic driven systems, with high primary production occurring *in situ*, both from diatoms on the flats and from mangroves. Mangrove systems usually provide somewhere between 20 – 40 % of carbon equivalent material to adjacent systems (Wolanski 2007).

Extensive studies have been undertaken of benthic driven intertidal systems elsewhere, such as the northeast of eastern Australia. Roebuck Bay has a much greater tidal range that presumably reduces residence times in the intertidal areas, although this has not been determined. It has been estimated that one hectare of tropical mangrove forest supports 100 - 1000 kg per year of marine fish and prawn catch

(Wolanski 2007) but the relative importance of mangroves to the net production of Roebuck Bay has not been quantified.

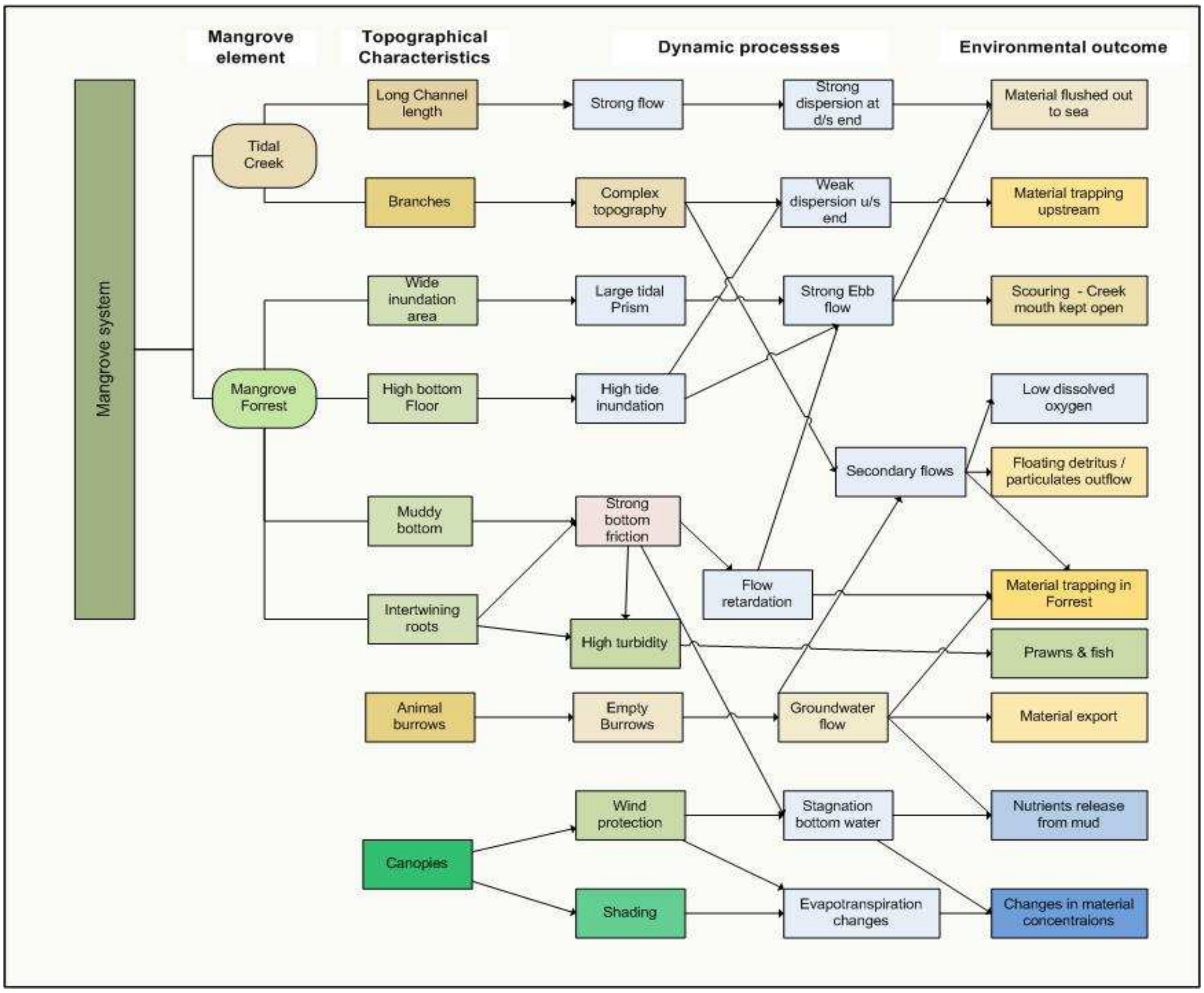


Figure 27. Links between physical, chemical and biological processes in mangrove systems (adapted from Wolanski 2007).

Alongi (1998), in discussing critical features of intertidal mud flats, points to a number of general attributes, namely:

i. The systems vary in the extent to which they are open or closed with respect to energy transfer and the movement of nutrients.
ii. Microalgae are the dominant primary producers. Bacteria, both as secondary producers and consumers, may dominate the system as a whole.
iii. While bacteria are thought to mineralise the bulk of the organic material the extent to which they are grazed represents only a small proportion of the standing stock. *In situ* primary production (most likely microalgae) must be relatively high to support the relatively abundant benthic invertebrate fauna that are critical to feeding of large populations of shorebirds.

iv. At this time it can only be assumed that nutrient fluxes are driven by extensive recycling with the net losses from denitrification, sequestering and export being low as it is anticipated that nutrient imports are also low.

The quantification of the processes listed above requires an ecohydrological study, together with the use of integrated or coupled hydrodynamic and ecological process models such as that proposed for Darwin Harbour by Wolanski *et al*. (2006) (***Figure 28***).

5.4.3 GROUNDWATER MOVEMENTS

In near shore coastal environments groundwater influx can be considerable and have a strong influence on ecology. This is even more so with respect to mangrove systems as the balance between tidal flow and groundwater input dictates the residual groundwater salinity and hence the distribution of both plants and animals. The only available measurements of the relationship between groundwater and the costal systems of Roebuck Bay are from Vogwill (2003) who used a series of piezometers to record changes in groundwater levels in mudflats behind Crab Creek and Dampier Creek. Groundwater levels in both systems were affected by tidal movement and rainfall, with each being dominant close to the coast and hinterland respectively.

5.4.4 TIDES AND WATER EXCHANGE

The daily ebb and flow of the tides in Roebuck Bay is a significant factor in determining the ecological character of the Bay, as are the lunar and annual tidal regimes. While it is possible to refer in general terms to the influence of tides and the associated water movement on the Bay, the only study of tidal movements was undertaken by Hickey *et al*. (2000), who developed a method of deriving inundation times as isohalines across a Digital Elevation Model as an aid to intertidal research planning.

No estimates have been made of water circulation within the Bay, rates of ingress and egress from the mangrove system, nor such important ecological factors as residence times. As a result, it is not possible to quantify the influence of either water exchange or tidal movement on the ecological character of the Bay with respect to the movement of nutrients and invertebrate larvae, although water-borne movement is critical in the recruitment of many marine species. It should be noted that other factors besides tides will contribute to water movement within and out of the Bay: namely, wind, waves and long period swells. The role of salinity and its effects on buoyancy movements remains unknown.

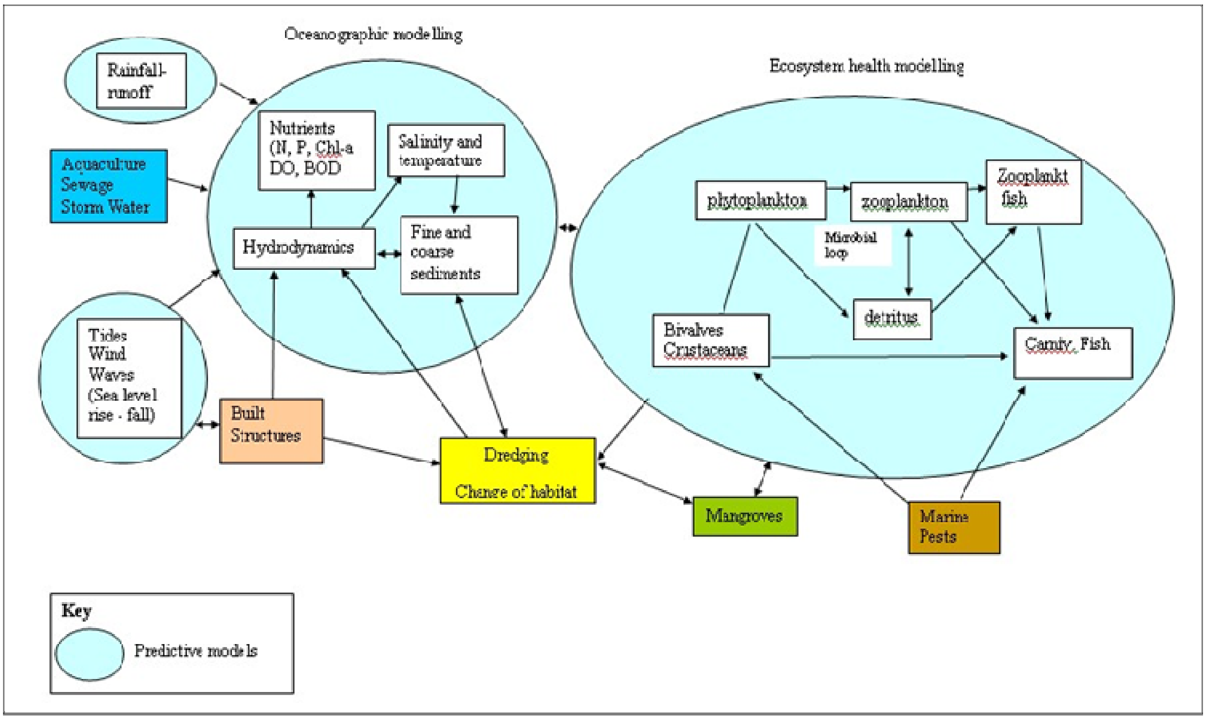


Figure 28. Draft of proposed ecohydrology model for Darwin Harbour - Roebuck Bay has the same critical drivers and levers as well as extensive intertidal flats backed by mangroves (after D. Williams, unpublished).

5.4.5 INTRINSIC ECOLOGICAL FACTORS

Within a systems approach to describing the ecological character of a geographical area, there is a need to include those intrinsic ecological factors such as recruitment, trophic structure, resources depletion and other attributes of habitat utilization. It is not possible to describe all of the intrinsic attributes of Roebuck Bay here as many of them are species specific and not documented. Many such elements have been documented for migratory shorebirds and a representative conceptual model is provided by Piersma *et al.* (1994) (***Figure 19***) that shows the relationship between food sources and other habitat attributes within the biotopes of the Bay. This is an important conceptual model of the balance that needs to be maintained between shorebirds and the intertidal fauna so as to provide a food source for shorebirds and to ensure a net accumulation of body mass by individual birds.

5.5 CONCEPTUAL MODELS OF ROEBUCK BAY – A SUMMARY

The relationship and key components making up the ecosystem drivers, levers, components, processes and benefits are shown in ***Figure 24***. A critical concept linking all of these processes is the gradient that occurs from the marine side of the subtidal zone to the upper inland limit of the supratidal and then

Table 19. Relationships between the services and benefits of the Roebuck Bay Ramsar site and key ecosystem components and processes.

BENEFIT / SERVICE	LOCATION	DIRECT COMPONENTS	INFLUENCING BIOTIC COMPONENTS	ABIOTIC COMPONENTS	THREATS / THREATENING ACTIVITIES
Tourism	Roebuck Bay intertidal zone	Migratory shorebirds at roost and feeding	Benthic invertebrate food resource	Sediment	Disturbance, reduced feeding, interruption to shorebird migration behaviour
Recreation: ▪ Fishing ▪ Leisure activities	Roebuck Bay; Crab Creek, Dampier Creek, northern beach	Fish, mangroves	Mangrove as nursery habitat and as stands, benthic invertebrate food resource	Sediment, dune formations, groundwater interactions with mangroves	Actions threatening mangroves and amenity of Ramsar site, over-fishing
Cultural services: ▪ Spiritual and inspirational ▪ Sustenance and cultural	Roebuck Bay system	Cultural sites, traditional food species, landscape health	Mangrove as nursery habitat and as stands, fish, dugongs and turtles	Drivers of ecological condition	Loss of natural landscape, noise pollution (hovercraft, power-boats), erosion of shoreline, over-fishing, decline of food species
Scientific and educational	Roebuck Bay system	Migratory shorebirds, benthic invertebrates, mangroves etc.	Ecological character of site	Subtidal and intertidal zones, dunes	N/A
Ecological services: ▪ Critical component of global flyway ▪ Fish nursery ▪ Benthic invertebrate biodiversity	Roebuck Bay system	Shorebirds, fish, benthic invertebrates	Benthic invertebrates (biomass), mangroves, organisms maintaining mudflat productivity	Sediment structure, hydrology	Loss of ecological character (pollution, habitat degradation, disturbance, over-exploitation)

beyond into terrestrial biotopes. The other important concept is that there is resource partitioning between those organisms that can access the mudflats when they are tidally inundated and those that access the mudflats when they are dry during low tide.

Physical processes driving water exchange, biogeochemical processes driving nutrient fluxes and intrinsic biological factors such as larval dispersion and species recruitment are also important elements of the Bay's ecological character that need to be conceptualized.

5.6 SERVICES AND BENEFITS

The relationships between the services and benefits provided by the Roebuck Bay site and the key components and processes that drive the Bay have been explored to aid in the identification of the primary determinants of ecological character for the site (***Table 19***).

6. THREATS TO THE ECOLOGICAL CHARACTER

6.1 INTERIM MANAGEMENT GUIDELINES

Through a community consultation process of workshop and engagement of interest groups and the wider community, the RBWG produced a document entitled *The Roebuck Bay Interim Management Guidelines* (Lambert and Elix 2006) that aimed to provide a manual for conservation at, and wise use of, Roebuck Bay until detailed management plans can be developed. The document identified a number of issues that are likely to affect the conservation values of Roebuck Bay and require active management from a "whole of catchment" context. Although the issues were identified in relation to all of Roebuck Bay, including the town of Broome, and are not confined to the Roebuck Bay Ramsar site, it is appropriate to consider them. The identified threatening processes raised were:

- Habitat loss and species decline;
- Habitat disturbance;
- Decline in water quality;
- Change in water regimes;
- Introduction of invasive species;
- Economic use pressures;
- Human visitation and recreational pressures;
- Pressures on cultural heritage.

To this list could be added:

- Impact of international pressure on shorebird habitat within the Australasian East Asian Flyway;
- Climate change;
- Loss of aesthetic amenity.

This document sets out only to identify the specific threats to the ecological character of the Roebuck Bay Ramsar site and the activities that contribute to the threats. Linkages are illustrated in ***Figure 29***.

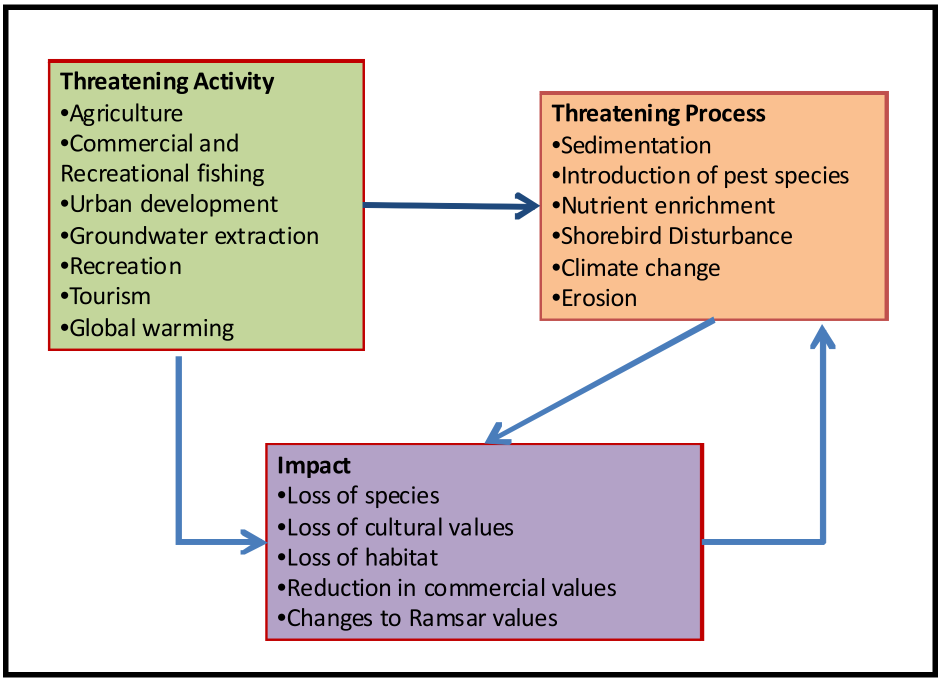


Figure 29. The relationships between threatening activities, threatening processes and impacts (adapted from Hale 2007).

Table 20. Potential threats to the Ramsar site's ecological character

	Issues	Severity
Agriculture	Weeds, erosion, nutrients	Weeds moderate, other minor
Water abstraction	Seawater intrusion, changes to mangroves	Minor
Urban development	Pollution of Bay through drainage, encroachment on Bay habitat, increased disturbance	Significant for Bay, minor for Ramsar site but indirect effects moderate
Lyngbya	Toxicity of this stage which accumulates along shore	Minor in most circumstances
Fishing	Over-fishing, especially if high conservative value species	Unknown
Recreation and tourism	Disturbance	Minor at present

There are a number of key activities that can be described as threatening activities with potential to alter wetland characteristics and thus influence the ecological characters for which the Ramsar site was originally established (***Table 20***).

6.2 AGRICULTURE

The Kimberley Region supports around 170 agricultural establishments covering 23 million hectares and representing around half of the Region's total land mass (Kimberley Development Commission 2006). A large proportion of this activity, particularly the horticultural component, takes place in the East Kimberley – Ord River Irrigation Area. However, cattle grazing is widespread throughout the Region and represents the principal form of land use in the West Kimberley Region and, more specifically, areas adjacent to the Roebuck Bay Ramsar site.

Roebuck Plains Station, at 294,000 ha, is the largest holding in the vicinity of Roebuck Bay. Its southern boundary adjoins the northern shores of the Bay. It is flanked on the eastern boundary by the 200,000 ha Thangoo Station, which extends to the southern shores of the Bay. Wattle Downs is a relatively smaller holding located adjacent to the Crab Creek Road to the west and the Broome-Derby Road to the north. It extends east to the boundary with Roebuck Plains Station

6.2.1 IMPACTS

The major threats posed by pastoralism and agricultural development around the Ramsar site are:

- Spread of weeds;
- Increased erosion (leading to silting and turbidity in the Bay);
- Increased nutrient and contaminant runoff.

Weeds

The major weed is Buffel Grass (*Cenchrus ciliaris*), which was introduced as cattle fodder and has had a significant impact on the native grasses that occurred on the floodplains prior to the introduction of cattle. Small areas of Rubbervine are also present around the Ramsar site . One small area of Lion's Tail Grass (*Leonotis nepetifolia*), which forms dense spiky stands and displaces native vegetation, has also been identified. Several grasses have the potential to be problems should they be introduced to the region, including Para (*Brachiaria mutica*), Grader (*Themeda quadrivalvis*), Mission (*Pennisetum polystachion*) and Gamba (*Andropogon gayanus*) grasses. These grasses would, however, have most impact east of the Ramsar area.

Erosion, Silting and Turbidity

Heavy erosion due to road runoff can impact upon mangrove survival and regeneration and affect the stability of cliffs and beaches. Over-grazing in pastoral country can increase erosion, perhaps leading to increased sediment loads in Roebuck Bay. This can affect ecosystem productivity and nutrient balance.

Nutrient and Contaminant Runoff

Until 1994 an abattoir operated at Broome, with effluent being disposed into the Bay. Phosphorus levels were above background levels in some sediment samples collected in 2008 along the intertidal zone in front of the former abattoir site (Pearson *et al.* 2008) and may reflect pollution effects 15 years on.

While there are no data suggesting run-off occurs, other potential sources of nutrient are the cattle-holding yard north of the townsite (between the Derby-Broome road and Dampier Creek) and a small intensive horticulture industry. The expansion of horticultural production east of the Ramsar site has been the subject of discussion between promoters of broad acre schemes (such as cotton production) and conservationists since 1996. The currently identified site for expansion of horticulture is 12 Mile, where there is a series of small holdings identified for horticultural pursuits. Located sufficiently far from Roebuck Bay to minimize impacts such as the leaching of contaminants into the groundwater, it is unlikely these small holding could influence ecosystems of the Ramsar site.

There is little information on water flow patterns into Roebuck Bay from Roebuck Plains. Consequently the fate of nutrients entering the system through flooding events on the Plains is unknown.

6.3 WATER USE AND GROUNDWATER EXTRACTION

Water supplies for the urban population of the town of Broome are largely derived from groundwater in the Broome Sandstone north east of the town and current use of this aquifer is unlikely to affect Roebuck Bay. It is unclear whether expansion of pumping from this aquifer to meet the demands of further urban and industrial development will impact on the Ramsar site. However, it seems highly likely that pumping of large volumes from under Roebuck Plains to supply broadscale horticulture will reverse flow of groundwater into the intertidal zone of the Bay and allow seawater to flow inland into the aquifer (*Figure 29*). Vogwill (2003) commented "… groundwater levels decreased from 1985 to 1987 with an accompanying increase in groundwater TDS content, probably associated with groundwater over-abstraction, minor amounts of salt-water incursion (near Roebuck Plains, Dampier and Crab Creeks) and up-coning of higher TDS content water from the base of the aquifer. The groundwater levels in the vicinity of the northern boundary of the Roebuck Bay/Plains system decreased 5m from 1985 to 1987, while the TDS increased from about 2000 to 5500 ppm. Such a large decrease in groundwater levels and the large increase in groundwater TDS content, in only two years, suggest that the amount of groundwater that was abstracted from the aquifer was too large to be sustainable". Dewatering or large scale regional groundwater level declines in the vicinity of the Bay/Plains system could also cause the oxidation of potential acid sulphate soils. This would cause changes in discharge and possibly salt water ingress (as described above) but also may generate increased acidity and metal contamination.

The aquifer is 200-250m thick in the vicinity of the Water Supply Borefield, while the water supply bores are 50-100m deep. Any saltwater incursion into the aquifer will generally occur at the base of the aquifer (due to the greater density of sea water) where the partially penetrating bores do not reach. However ***Figure 30*** shows how over pumping may cause seawater and saline water incursion to occur at the top of the aquifer as was identified in Vogwill (2003). The upper part of ***Figure 30*** represents the "natural" or undisturbed hydrogeological regime and the lower part of ***Figure 30*** represents the hydrogeological regime after over pumping. Note the reversal of flow directions in the lower figure, which is indicative of the potential for saltwater incursion and up-coning (Vogwill 2003). Interface up-coning occurs when a deep aquifer bore abstracts to much water and the saltwater freshwater interface is drawn upwards towards the bore. This is unlikely to have as many implications for the Ramsar site as for water potability through increased TDS (R. Vogwill pers. com.).

Local pastoral stations currently draw water from shallow bores in the Roebuck Plains aquifer as part of their stock husbandry requirements. However, the volumes of water used are small and unlikely to affect groundwater levels or groundwater flow into the Bay in anything other than a very local sense.

6.4 URBAN DEVELOPMENT

The rapid expansion of Broome has placed considerable strain on urban facilities, especially the management of surface run-off and sewage treatment. Waste water from domestic, industry and commercial sources is generated at the rate of 200 litres per person per day and treated at the Broome South wastewater treatment plant (Water Corporation data). A second wastewater treatment plant has been planned for a new site east of Broome at the head of Dampier Creek. The location of this

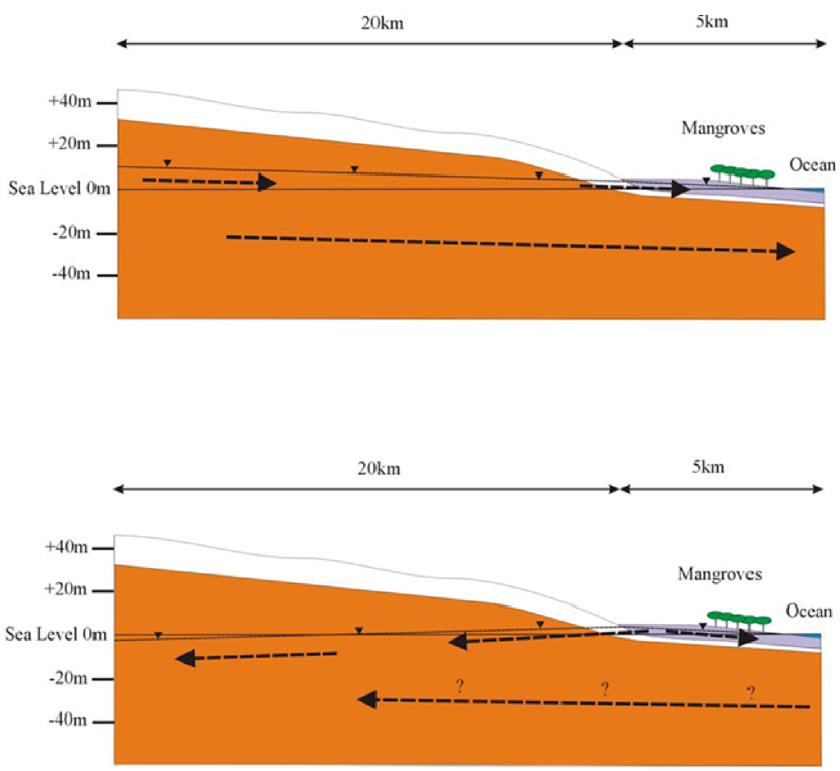


Figure 30. Schematic hygrogeological cross-sections showing the Holocene Mud Flat System and the Broome Sandstone/Pindan System (from Vogwill 2003).

Arrows indicate direction of water flow; upper graph shows undisturbed condition, lower shows effect of groundwater pumping (Vogwill 2003) facility upstream (in the context of groundwater flow) of the Ramsar site may present a potential risk to the hydrological processes in Roebuck Bay.

Any future drainage and landfill for urban development of floodplain waterbodies close to the Ramsar site should be viewed as potentially harmful because it may reduce feeding and roosting habitat for waterbirds and shorebirds. Houses and roads built adjacent to the Bay and associated increased urban activity, traffic and lighting are likely to disturb nesting, roosting and feeding waterbirds.

Pollution of the Ramsar site by heavy metals, tributyl tin, hydrocarbons and toxicants from road run-off and urban drains has the potential to affect birds, either directly or through lethal and sub-lethal effects on invertebrate prey. Sub-lethal effects of contamination may take a number of years to become apparent.

Increased pesticide/larvacide use for control of mosquitoes and midges around commercial and residential centres may have detrimental effects on non-target species either as a result of water-borne or air-borne contamination. Larvacides for mosquito control may reduce non-target mudflat invertebrate species that are an important food resource for birds. A number of overseas studies of larvacides have found lethal and sub-lethal effects on a number of fish and freshwater crustaceans.

6.5 LYNGBYA

The occurrence of this cyanophyte in great abundance since 2005 may have impacts on fish, Dugong, turtles and seagrass within the Ramsar site and Roebuck Bay generally, as well as presenting a potential health risk to people using the beaches where *Lyngbya* occurs as wrack (see section 8.3) .

6.6 COMMERCIAL USE AND RECREATIONAL FISHING

There are several commercial fishing operations within and around Roebuck Bay but few within the Ramsar site. The Department of Fisheries believes commercial fishing is having only a minimal effect on fish biomass in the Kimberley ecosystem as a whole (Dept. of Fisheries 2007). Despite this, the Department has reported declines in Barramundi spawning biomass. The impact on fish populations frequenting Roebuck Bay and the Ramsar site has not been specifically assessed.

Stevens *et al.* (2008) have noted that the impact of low intensity and sparsely distributed fishing operations on local populations of rarer species such as sawfish cannot be assumed benign. Sawfish in particular appear to have a very limited range of only a few square kilometres within the coastal fringe (Stevens *et al.* 2008).

A cultured pearl fishery occurs as a complex of pearl farms along the Kimberley coast, including Roebuck Bay. Although outside the Ramsar site boundary, the Roebuck Bay pearl farms are an important industry in the Bay. It is not considered likely to have major effects on the ecology of the Bay.

6.7 RECREATION AND TOURISM

Recreation is a multi-faceted and underpinning aspect of Broome's economy, lifestyle and industry. A high proportion of the respondents to a questionnaire on management concerns for Roebuck Bay focussed in some way on the impact of increasing levels of tourism, recreation and recreational activities of visitors and residents on the conservation values of Roebuck Bay (Lambert and Elix 2004). Paradoxically, tourism and the development of recreational pursuits appear to be high on the agenda of most of the residents.

The Interim Management Guidelines list increases in vehicle pressures, fishing and boating activities, land development, littering and waste pressures, and inappropriate use of the foreshore as threats to the Bay. Increased lighting, noise and other disturbance (including that during infrastructure construction) associated with tourism and recreational developments may disturb feeding, breeding and roosting waterbirds. Other specific threats include intrusion and trampling of nests (both by people and dogs). Discarded fishing gear and other rubbish (*e.g.* plastic rings, cigarette butts and other debris) can be ingested by birds or otherwise interfere with feeding and roosting behaviours.

As peak shorebird activity occurs during the traditional tourist off-season, some level of protection from anthropomorphic disturbance is recognised. Broome's tourism industry is largely seasonal with peak visitor activity between April and October each year with most visitors originating from interstate and other regions inside Western Australia. The estimated annual visitor numbers for the Shire of Broome is 239,000 (Source Tourism Research Australia International Visitor Survey 7 National Visitor Survey).

6.8 CLIMATE CHANGE

It is widely accepted that there have been changes to the climate in Western Australia in the past 50 years as a result of anthropogenic impacts as well as natural climatic cycles. However, future climates are poorly understood and predictions are accompanied by considerable uncertainty.

Aspects of climate change that have been reported in detail by various government agencies including DEC (Climate change and biodiversity in Western Australia DEC website 2008) are:

1. Changes in temperature -

   a. Temperatures throughout Western Australia have risen during the twentieth century. This rise has been mainly due to warmer nights rather than hotter days.

   b. Temperatures have increased by 0.8℃ since 1910. Most of this warming has occurred since 1950 (0.14℃ increase per decade since 1950). Clim ate projections recently published by CSIRO indicate that average annual temperatures are likely to continue to rise in Western Australia.

Table 21. Potential impacts of climate change. Likely effects on different habitats are shown.
A: strong impact; B: possible impact; C: type of impact dependent upon location;

	Flood and duration	Erosion	Sedimentation	Salinity	Boundary changes
Pindan		A			
Intertidal marshes – samphire and saline grasslands	A	A		B	A
Intertidal mud and sand flats	A		A		A
Intertidal forested wetlands – mangrove swamps	A		A		A
Marine subtidal aquatic beds					B

2. Changes in rainfall patterns -

   a. Since the 1970s, rainfall in parts of south-west Western Australia has fallen significantly mostly in the late autumn and winter months. Recent Indian Ocean Climate Initiative (IOCI) research indicates that by 2030 rainfall may decline by as much as 20% relative to the 1960 - 1990 level. This means that the number of winter rain days may decrease by up to 17%, and the runoff into south-west Western Australian catchments may consequently decrease by 5 - 40%.

   b. By about 2085, these changes may further increase, with a predicted 5 - 34% decline in rainfall, and a 30% decrease in the number of winter rain days. Conversely parts of the Northwest Western Australia have become wetter over recent decades.

   c. Cyclonic activity changes.

3. Other Changes -

   a. These fundamental climate changes have had a 'knock on effect' on other important atmospheric and earth processes. These include changes to sea temperatures, evaporation rates, atmospheric circulation, variability of the Leeuwin Current, river flows and groundwater levels. Further information about these changes can be found in the comprehensive "How has our Climate Changed" series produced by the Indian Ocean Climate Initiative in 2005.

The National Land and Water Resources Audit (2002) assessed 979 estuaries and coastal waterways in Australia and found that nearly one third were classified as wave dominated, and some 55% tide dominated. Roebuck Bay could be included in this group that are described in the report as potentially affected by mean sea level rise, storm surges and changes in wave energy, salinity changes in ephemeral or seasonal wetlands adjoining the Ramsar site, erosion and sedimentation and changes to inundation periods on intertidal zones (***Table 21***).

Climate change is not an issue that can be addressed at the local scale but increased knowledge and education of the potential impacts to Roebuck Bay may assist with future management protocols that can be applied to mitigate impacts of climate change.

7. LIMITS OF ACCEPTABLE CHANGE

7.1 UNDERLYING CONCEPT

Management and monitoring require that a baseline or benchmark condition be set, against which changes in the wetland ecosystem can be assessed. Changes may be either detrimental or beneficial. Limits of acceptable change are typically used to describe the benchmark condition outside of which detrimental change occurs. Phillips (2006) defines limits of acceptable change as:

"*…the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland*".

In order to set limits of acceptable change, the typical state of a parameter must be documented, including its natural variability. The limit of acceptable change is usually set as the point outside the typical/natural variability at which there is unacceptable reduction or loss of values. Care must be taken that the limit of acceptable change is not so wide that irrevocable change occurs before management intervenes (Hale and Butcher 2007). DEWHA (2008) states that wherever possible, limits of acceptable change should be based on:

"*…quantitative information from relevant monitoring programs, scientific papers, technical reports and other publications or documented information on the wetland (including oral histories).*"

Variability in ecosystem parameters typically at a range of time scales. To adequately quantify the variability, measurement should include not only the maxima and minima for the given time period, but also the frequency and duration of different values (***Figure 31***). For example in Roebuck Bay, fewer than 1,000 migratory Sanderling may not be uncommon in some years, *i.e.* may not be outside the natural range in numbers encountered. However, fewer than 1,000 migratory Sanderling every year may signal an unacceptable decline in the population. Thus setting a limit of acceptable change at a minimum 1,000 birds may not sufficiently protect the species unless their frequency of occurrence is taken into account. Duration should also be considered, *i.e.* the number of days that the birds are present on the mudflats each year and the time of year they are present. Spatial variation can further complicate matters.

Sanderling may not be equally abundant in all parts of the Ramsar site, but use different parts of the Bay at different times of day or month dependent on factors such as tide. Therefore, few Sanderling in one area may not necessarily indicate a decline; it may merely indicate the birds are utilising some other habitat either within or adjacent to the Ramsar site. Spatial variability means that limits of acceptable change for any particular parameter in one wetland type may need to be quite different to those in another wetland type.

It is important to understand, as far as possible, all patterns and extremes of natural variability. Another example might be an increase in the numbers of one particular bird species. On first consideration, this may not seem an unacceptable change. However it may indicate that food or habitat resources have changed and while benefitting one particular species, may be at the expense of others. Such complex (and likely numerous) interactions between ecosystem components can be problematic when attempting to define suitable limits of acceptable change.

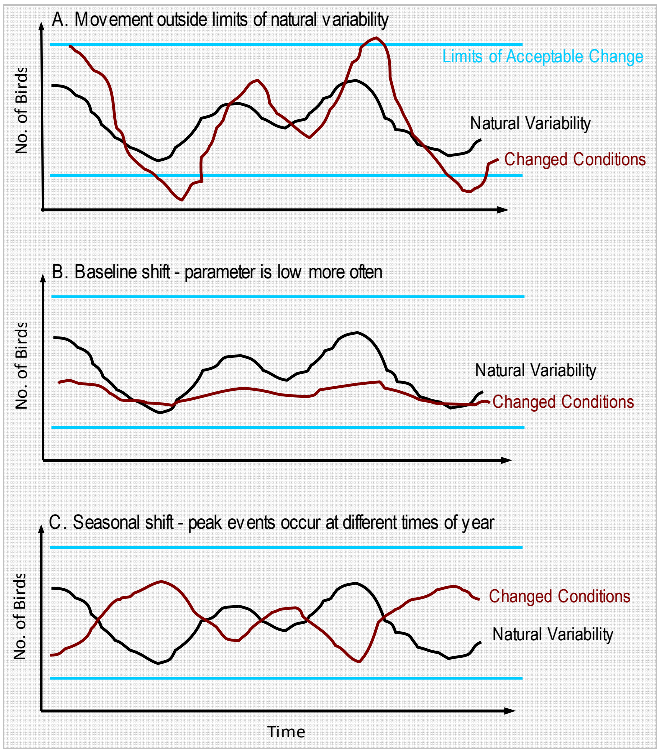


Figure 31. Representation of some of the issues to be considered when setting limits of acceptable change: (A) limits set outside the extremes of natural variability may only capture a change in maximum or minimum values;

(B) shifts in baseline values and (C) seasonal shifts may not be captured if measures of frequency and duration are not included (adapted from Hale & Butcher 2007).

7.2 ROEBUCK BAY RAMSAR SITE

In theory, limits should be set that cover most components (*e.g.* species abundance and diversity, water quality *etc*) and processes (*e.g.* primary production, carbon cycling) of the ecosystem. In reality, it is often more effective to set limits that address specific management objectives, can be readily measured and are not unduly expensive to monitor. Therefore, in establishing limits of acceptable change for the Roebuck Bay Ramsar site, the current study focused on those components and processes that are:

- key Ramsar values of the site;
- the primary determinants of ecological character;
- easy to monitor.

Although hydrological change has been identified as a potential threat the Ramsar site, it is not regarded as a higher level threat at present and considerable investigation will be required before quantified limits of acceptable change can be set. The environmental assessment associated with any increase in water abstraction should provide the necessary information.

A summary of limits of acceptable change for the Roebuck Bay Ramsar site is given in ***Table 22***. Where insufficient knowledge exists, interim limits have been set as a 'stop-gap' until adequate quantifiable baseline data can be gathered and more informed limits established. The interim limits have been formulated by supplementing site specific information with general guidelines for Australian ecosystems. For water quality, the ANZECC/ARMCANZ (2000) guideline "trigger" values for estuarine inshore waters have been applied in the absence of locally derived data for the Ramsar site. Limits of acceptable change should continue to be refined as more scientific data are collected for the site and as general scientific knowledge of Australian ecosystems improves. This will require regular analysis of monitoring data for the site as well as keeping up to date with the latest scientific developments in general wetland ecology.

Climate change and external factors that affect migratory species, present obvious difficulties in defining limits of acceptable change for on-going monitoring and management. It has not been possible to directly incorporate these factors into the limits of acceptable change. One of the goals of future monitoring should be an improved understanding of the links between external factors and the variability in critical ecological features within the wetland. This would help ensure that any future management activities do not unwittingly facilitate unfavourable change.

Benthic Invertebrates

In recognition of the high diversity, abundance and standing biomass of benthic fauna in Roebuck Bay, and the importance of this fauna as a food source for resident and migratory shorebirds, a benthic fauna monitoring program was initiated in 1996 with the aim of determining changes in the composition and density of the benthic fauna over time, and to provide data for the study of growth and recruitment patterns of the fauna of this tropical intertidal mudflat. The program involves sampling at two sites, one near Fall Point on the northern shore of Roebuck Bay, characterised by sandy/silty sediments, and the second at One Tree, at the eastern end of the Bay near the entrance to Crab Creek, characterised by deep grey soft silt sediments typical of that part of the Bay.

Table 22. Limits of acceptable change for Roebuck Bay.

COMPONENT	BASELINE / SUPPORTING EVIDENCE	LIMIT OF ACCEPTABLE CHANGE
ABIOTIC COMPONENTS		Values should remain:
Water Quality - Nutrients	Insufficient data for most of the Bay with the exception of Dept of Fisheries monitoring at Broome Jetty. Guideline limits have been set by ANZECC/ARMCANZ (2000).	TN - median concentration < 250 µg/L NO_x - median concentration < 30 µg/L NH_4 - median concentration < 15 µg/L TP - median concentration < 20 µg/L FRP - median concentration < 5 µg/L
Sediment Structure	Penetrability data from 2002	Crab Creek > 30 cm Fall Point > 8 cm Dampier Creek > 13 cm
Sediment Nutrients	TN and TP have been recorded around Town Beach. Levels may be associated with anthropogenic factors.	Baseline must be identified before limits can be set
	Baseline data indicate sediment carbon content is correlated with invertebrate species numbers and other benthic biodiversity estimates. Insufficient information to set baseline.	Baseline must be identified before limits can be set
SUPPORTING SPECIES AND COMMUNITIES		
Lyngbya	*Lyngbya majuscula* blooms first reported in 2005 but link with anthropogenic factors is unknown.	Baseline (historical occurrence pattern) must be identified before limits can be set.
Benthic Plants	Insufficient information to set baseline. Seagrass and macroalgae	Seagrass loss < 5% (allow 3 years after cyclone for re-establishment). Interim guidance only.
Mangal	Current extent of mangal communities is 47 km^2. It is proposed that 5% reduction represents the limit of acceptable change, although the loss associated with cyclones is unknown and proposed limit will need to be revised as further data are collected.	Mangal – spatial extent through the Ramsar site ≥ 44 km^2.
KEY SPECIES AND COMMUNITIES		
Invertebrates	Based on monitoring of de Goeiij (2008), results per sample from a station. Data are available but not currently worked up in this format.	Annual average taxa richness – 80^{th} – 120^{th} percentile of 1996 – 2006 data. Annual average biomass – 80^{th} – 120^{th} percentile of 1996 – 2006 data. Four sites, annual or bi-annual monitoring.
Shorebirds	Existing total counts of waterbirds in late spring/summer in Roebuck Bay used to set limits (most of the waterbirds present are shorebirds).	Total waterbird abundance in early November - >99,400 (i.e. > 75% of mean of November counts, dependent on counting technique).

At each site two stations, 150 m and 250 m from the shore, are sampled monthly. To date the project has identified 29,500 macrozoobenthic animals, comprising at least 144 taxa, including 45 species of bivalve, 30 species of gastropods, 3 species of scaphopods, 7 echinoderms and 17 species of crab (de Goeij 2008). Data indicate that species richness is higher at Fall Point than One Tree, and there is little difference between the inner and the outer stations at each site. The sandy sediments at Fall Point are richer than the deep soft sediments at One Tree. Bivalves are the most numerically dominant taxa.

In contrast to the regular seasonal patterns in abundance usually observed on temperate mudflats, the fauna of Roebuck Bay show a variety of patterns that bear little relation to circannual cycles (de Goeij *et al*. 2008). Examples of patterns are:

- The Blood cockle *Anadara granosa* recorded high densities from early to mid 1997 and has since declined.
- *Siliqua pulchella*, a razorclam-like bivalve peaked in abundance in mid 1997 and then declined until 2002 when numbers increased.
- Numbers of the bivalve *Tellina piratica* were highly variable, peaking five times over the ten year period of the study.
- Several polychaete worms and crab species show variable abundances since commencement of the program in 1996 and present no clear trends.
- The brittle star *Amphiuris tenuis* showed an increase in the first five years, declined and then recovered in 2004/05.

As summarised by de Goeij *et al*. (2008), more than half the species declined in abundance at both sites between 1996 and 2005. Approximately 25% of the species increased but with the exception of seven species that were found in very high numbers over the whole period, the increases were marginal. De Goeij *et al*. (2008) goes on to comment that, of the species that were abundant in 1996 and subsequently declined, most of these species have not declined further since May 2001, and some have shown a slight increase.

Although yet to be demonstrated, it is likely that during a period of stability, when there are no cyclones or other severe disturbances, the benthic fauna may reach a climax state, with particular species dominating. However, following infrequent, but excessive physical disturbance such as by a cyclone, the fauna may undergo rapid and dramatic changes as some species decline and others increase.

Until more is known of the natural cycles, suggested interim limits of acceptable change are that mean annual taxa richness and total abundance should remain within the 80^{th} – 120^{th} percentile range of the 1996 to 2006 data. Future monitoring should include at least four sites (Camp Site, Bush Point, Fall Point, Crab Creek). Frequency of monitoring could be reduced to once or twice a year.

Shorebirds

In the absence of a suitable existing shorebird dataset from Roebuck Bay, data from Corner Inlet, Victoria, were selected as a robust analogue dataset to indicate possible limits of acceptable change in shorebird numbers. The Corner Inlet dataset covers 28 years (1981 - 2008), with standard count methods, providing data for a range of the key shorebirds that are also found at Roebuck Bay. Corner Inlet is considered to be in relatively good condition, with comparatively stable shorebird populations, and therefore should provide rough estimates of the expected inter-annual variation at Roebuck Bay.

Relevant facts to emerge from the Corner Inlet analysis were:

- Bar-tailed Godwit, Eastern Curlew, Pied and Sooty Oystercatcher occurred in all years of record (1981 - 2008), whereas Great Knot, Red Knot, Whimbrel and Grey-tailed Tattler occurred in less than 50% of years (*i.e.* <14 of the 28 years of record). The Great Knot and Red Knot were not recorded for up to 10 years at a time, before being recorded again. Such low frequency of occurrence makes setting limits of acceptable change problematic when based on frequency of occurrence, with criteria such as 'must occur in 1 of every 10 years' potentially allowing major declines to occur before alarm bells sound.
- Even the most abundant, common species at Roebuck Bay show high variability in abundances at Corner Inlet. The numbers of Bar-tailed Godwit varied from 2,065 to 17 in summer and 1,150 to zero in winter, with coefficients of variation (CV) of 74% and 139%, respectively. Eastern Curlew ranged from 1,033 to 40 in summer and 191 to 2 in winter, with CVs of 74% and 76%, respectively. The other abundant species recorded at Roebuck Bay, the Great Knot and Red Knot had CVs of 516% and 490% and 244% and 254% in summer and winter, respectively, at Corner Inlet. The high CVs reflected high abundances in some years and absence in other years.
- The lowest CVs for Corner Inlet were for total shorebird counts. Although not providing species-specific data, the total count does indicate the overall suitability of the site for shorebirds in general. CVs for total shorebird counts for Corner Inlet for summer and winter were 48% and 55% respectively.

Given that there is some structured within-season movement of birds in and out of Corner Inlet and that counting error at Corner Inlet may be greater than in programmed monitoring at Roebuck Bay, it is not

Table 23. Total waterbird counts at Roebuck Bay since 1983.

DATE	COUNT	COMMENTS
Feb 1983	144,300	? Shorebirds only
October 1983	170,915	All waterbirds
Feb 1984	146,200	? Shorebirds only
Oct 2004	96,486	Shorebirds, terns
Oct 2005	104,306	Shorebirds, terns
October 2008	154,643	All waterbirds

surprising that the CV for available total counts in late spring/summer at Roebuck Bay is relatively small at 21% (see ***Table 23***). It is suggested that the interim limit for acceptable change in total waterbird abundance for Roebuck Bay should be > 75% of the average number of birds counted (i.e. 99,400 birds). The above approach is intended to monitor whether habitat in Roebuck Bay remains suitable for waterbirds and assumes that numbers in the global Flyway will remain constant. Monitoring data will need to be interpreted in relation to global trends as well as survey efficiency (note that the AWSG MYSMA surveys appear to produce lower counts than ad-hoc counting and the National Waterbird Survey, perhaps because of less complete coverage (see ***Figure 7***). Corner Inlet results show that abundance and frequency of occurrence of individual species are likely to be too variable to use in monitoring the adequacy of habitat at the Bay and, rather than reflecting carrying capacity of the habitat, will be largely determined by species-related issues.

8. MONITORING AND RESEARCH NEEDS

As discussed in the preceding chapters, a number of monitoring programs for individual components of the Bay already exist:

- MONROEB – monthly monitoring of invertebrate biomass at four locations in the Ramsar site;
- Australasian Wader Study Group – regular monitoring of shorebird numbers in the Ramsar site;
- Seagrass Monitoring Program – Run by Environs Kimberley in collaboration with DEC at locations in Roebuck Bay outside the Ramsar boundary;
- Water quality monitoring by TAFE and the Department of Fisheries outside the Ramsar site.

However, there is at present no comprehensive management and monitoring program for the Roebuck Bay Ramsar site.

A key finding of this ecological character description is the need for the collection of systematic data on waterbird numbers, benthic invertebrate abundance and richness, sediment particle size (or analogues), mangrove spatial extent and seagrass and macrophyte spatial extent. Currently available information is not sufficient to fully describe the ecological character of the site nor, in most cases, is it statistically robust enough to evaluate future change or even change since time of listing.

A cost-effective monitoring program for the Bay, with a subsidiary research program, should be established as a matter of urgency. The aim of the programs should be to define benchmark conditions for all critical components and processes of the ecosystem so that there is a basis for assessing any future change in condition. The content and level of sophistication of such programs are often hotly debated but the guiding principle when designing them should be to focus on achieving the minimum necessary information for decision-making.

As noted by Phillips and Muller (2006), monitoring is of little value if it is not linked to management actions. The recommended monitoring to meet the obligations under Ramsar and the *EPBC Act* (1999) with respect to the Roebuck Bay Ramsar site are summarised in ***Table 24*** together with research to fill some important information gaps. Wherever possible, recommended monitoring makes use of or builds upon existing programs in order that all relevant historical data can be incorporated. Collection of a minimum 4 years of baseline data is recommended to help identify which parts of the Bay are most in need of management intervention and where management intervention is likely to be of most benefit.

Table 24. Monitoring and research summary. Priorities shown in red.

COMPONENT/PROCESS	KNOWLEDGE GAP	RECOMMENDED ACTION
Hydrology	Ground and surface water inflows to Roebuck Bay and the Ramsar site	Targeted study to construct water balance model.
Water Quality	Spatial and seasonal bioavailability of dissolved inorganic nutrients (NO_x, NH_4, PO_4). Nutrient loads and residence times. Relative contribution of various point and diffuse sources to nutrient loads.	Investigation into the actual and potential threat posed by nutrient enrichment. Determine likely 'hot spots' for eutrophication.
Sediments structure and nutrient content	Extent of change in sediment characteristics. Sediment nutrient stores (TOC, TN, TP), recycling and denitrification rates. Relative contribution of various point and diffuse sources to nutrient loads.	Penetrability surveys Investigation into the threat posed by nutrient enrichment. Determine likely 'hot spots' for eutrophication.
Lyngbya	History, current extent, frequency, duration and distribution of blooms.	Mapping of extent, frequency and species composition.
Benthic plants	Current extent, biomass and health of seagrass and macroalgal communities.	Mapping (aerial) and condition assessment (on-ground). Build on existing monitoring program.
Littoral vegetation	Current extent, biomass and health of mangrove communities.	Mapping (aerial) and condition assessment (on-ground).
Benthic invertebrates	Monitoring at two locations for the past 10 years. The number of sites needs to be increased to 4 to develop a more robust data set.	Build on existing monitoring program but reduce sampling frequency to annual.
Fish	Insufficient information to set a baseline for most fish species. Unfortunately although CPUE is collected for commercial fish in Roebuck Bay (*e.g.* Threadfin Salmon, Barramundi) this information is not reported publicly and so can not be used to establish baseline values	Surveys to establish baseline condition of high conservation value fish species.
Shorebirds	Monitor total waterbird numbers in the Bay. Insufficient information to set a reliable baseline for most species. Extend surveys to provide species information.	Annual aerial monitoring count of the whole of Roebuck Bay. Annual monitoring ground count of species west of Crab Creek.

8.1 WATER QUALITY

Water quality data for Roebuck Bay are limited to those collected from Broome Jetty by Rose *et al.* (1990) between 1986 and 1989 and by Department of Fisheries from 2005 until present. The data suggest a trend of increasing phosphorus and nitrogen concentration in surface waters of the Bay. Mean monthly values for TN and TP for the period 2005 - 2008 were well in excess of ANZECC/ ARMCANZ (2000) guideline trigger values[1] for both inshore marine and estuarine waters.

It is recommended that the present monitoring program be continued and expanded to target likely 'hotspots' around the Bay. 'Hotspots' should include all urban and agricultural drain inflows as well as any points of entry for potentially nutrient-rich groundwater or overland flow (*e.g.* the wastewater treatment plant). Sampling should be undertaken two-monthly, increasing to fortnightly between October and April for areas affected by *Lyngbya* blooms. In addition, there should be a more thorough interrogation of existing water quality data collected pre and post 1980s to establish if differences reflect a real change in the water quality of the Bay or are merely an artefact of differences in collection/analysis techniques between the two periods.

Prior to monitoring, it is recommended that a water balance model be constructed for the Bay. This will help target points of inflow for potential contaminants.

8.2 SEDIMENT STRUCTURE AND NUTRIENT CONTENT

Sediment characteristics are a defining element of the extensive intertidal sand and mudflats of Roebuck Bay (Oldmeadow 2007). There is a close relationship between biological diversity, abundance and sediment characteristics such as grain size, cohesiveness and carbon content (Compton 2007). Furthermore, the RBWG sub-group investigating occurrence of *Lyngbya majuscula* in the Bay concluded there is a need to determine the extent to which phosphorous and nitrogen nutrients in groundwaters and intertidal sediments act as drivers of *Lyngbya* blooms in Roebuck Bay (see section 8.3).

An observed increase in sediment cohesiveness in the Crab Creek silt/clay province may also be related to increased bacterial and algal (diatom) growth driven by nutrients in sediment stores. Information on sediment structure and nutrients (total organic carbon, nitrogen and phosphorus) could be readily gathered in conjunction with core sampling for an ongoing benthic invertebrate mapping program. It is recommended that sediments taken from the replicate, quantitative benthic cores be used to monitor changes in grain size and concentration of TOC, TN and TP. Methods for determining grain size and carbon content should be standardised with those of previous surveys (see Pepping *et al.* 1999,

[1] ANZECC/ARMCANZ (2000) default trigger values for protection of slightly disturbed ecosystems in inshore marine and estuarine waters including north-west Western Australia.

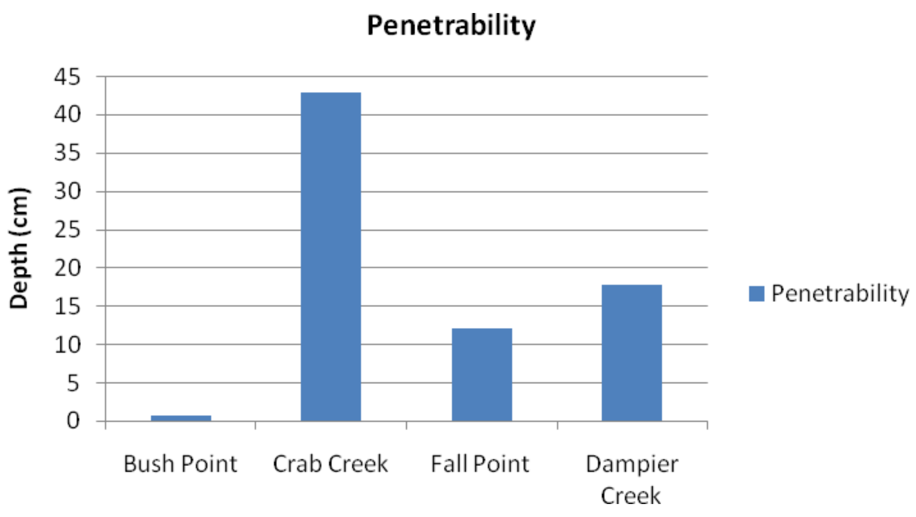


Figure 32. Mean penetrability in 2002 at selected transects in four areas of Roebuck Bay (G.B. Pearson unpublished data). Standard errors are small.

Piersma *et al.* 2002, 2003) so that any future change can be compared against data collected in 1997, 2000, 2002 and 2006. Where budgetary or personnel constraints limit the area to be sampled, 'penetrability' (*i.e.* depth of footsteps on the sands and muds) should be used as a surrogate measure of grain size at all benthic invertebrate sampling sites (***Figure 32***).

8.3 LYNGBYA

Severe *Lyngbya* blooms can be toxic to other life forms and can severely impact upon biodiversity of shallow wetlands. As recommended by the RBWG, further baseline research is required to establish the possible link between *Lyngbya majuscula* blooms in Roebuck Bay and anthropogenic nutrient sources.

It is recommended that random quadrat sampling be used to establish the existing variability in *Lyngbya* biomass, occurrence and frequency of blooms. Sampling should be conducted weekly between October and April, reduced to fortnightly or monthly for the rest of the year. Concurrent sampling for nutrients in surface waters where *Lyngbya* occurs is also required to determine if fluxes in nutrients are correlated with bloom formation.

8.4 BENTHIC PLANTS

Seagrass meadows within the Roebuck Bay Ramsar site provide important feeding grounds for protected migratory Dugongs and Green Turtles. Seagrass monitoring is currently undertaken by Environs Kimberley. It is recommended that this program be continued and expanded to include annual macroalgae surveys. Satellite or aerial photography together with ground truthing, in the form of repeatable replicated transect sampling, should be used to set benchmarks for species composition, percentage cover and biomass within the Bay. At present, cyclonic weather events are thought to be the major influence driving changes in distribution and density of benthic plants. However there is anecdotal evidence that *Lyngbya* blooms have led to localised reductions in seagrass cover.

8.5 MANGROVES

It is recommended that satellite imagery together with ground truthing, in the form of repeatable replicated transect sampling, be used to set benchmarks for species composition, percentage cover, and condition / health. Data gathered should be compared with existing archival satellite imagery to investigate any recent change in aerial extent of the mangal. To monitor future change, it is recommended that surveys be repeated once every 3 - 5 years.

8.6 BENTHIC INVERTEBRATES

Existing invertebrate monitoring should be expanded to four sites (Camp Site, Bush Point, Fall Point, Crab Creek) and annual changes in biomass and species richness should be measured to provide information on any change in the condition of mudflats, the availability of shorebird food and the biodiversity of benthic invertebrates.

There is likely to be very high variability in the occurrence and abundance of individual species that will be unrelated to trends of natural and anthropogenic change in the Bay, so that individual species are not an appropriate unit for monitoring (although long-term rolling averages of species occurrence may contain useful information). Community based parameters, such as species richness and the abundance of all animals in a sample are more stable parameters and, thus, more amenable to monitoring than data from individual species. Information on community parameters is not provided in the existing monitoring reports (de Goeij *et al*. 2005, 2008) but exist in accessible electronic format to estimate the limits of acceptable change for future monitoring.

8.7 SHOREBIRDS

Future monitoring of the carrying capacity of the Bay as a staging point for migratory shorebirds should be based on whole of Bay waterbird counts. These should be conducted in early November (and perhaps again in February) when populations are at their most stable.

Counts should consist of an aerial survey to count the total number of waterbirds in the Bay and a ground survey to count numbers of individual species of shorebirds. The survey should be conducted along the northern side of the Ramsar wetland, west of Crab Creek, using prominent landmarks to ensure the same area is counted on each occasion of survey. Data from Corner Inlet in Victoria suggest there will be high variability in these counts and that there will be a biased representation of the Bay as a whole. Nevertheless, over time (perhaps with a 5-year rolling averages) it should be possible to detect any declines in individual species.

9. COMMUNICATION, EDUCATION AND PUBLIC AWARENESS

A program of Communication, Education and Public Awareness 2003-2008 has been established under the Ramsar Convention. The program is designed to generate coordinated international and national campaigns that help raise public awareness of the value of wetlands and foster wise use and management. More or less at the same time, Australia established the Wetland Communication, Education and Public Awareness (CEPA) National Action Plan 2001-2005. This plan requires that a description of key communication, education and/or public awareness activities is included in the ECD of all Ramsar sites.

Management planning of Roebuck Bay is in a preliminary stage and will include CEPA activities.

Issues involving Ramsar values that would benefit from more community awareness are:

- The susceptibility of shorebirds to most kinds of disturbance, especially movement of people and vehicles on beaches when the birds are roosting or feeding nearby;
- The high level of erosion of pindan associated with tracks from the cliff-top onto the beach.

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GLOSSARY

Administrative Authority	The agency within each Contracting Party charged by the national government with implementation of the Ramsar Convention within its territory. http://www.ramsar.org/about/about_glossary.htm
Adverse conditions	Ecological conditions unusually hostile to the survival of plant or animal species, such as prolonged drought, flooding, cold, *etc* (Ramsar Convention 2005)
Aeolian	Refers to the process of erosion and deposition of sediments by wind (Phillips & Muller 2006)
Attributes of wetlands	Include biological diversity and unique cultural and heritage features. These attributes may lead to certain uses or the derivation of particular products, but they may also have intrinsic, unquantifiable importance (Ramsar Convention 1996, Resolution VI.1). This term has been replaced by Ecosystem Components in the ECD and there is focus on biological attributes
Baseline	Condition at a starting point, usually the time of listing under the Ramsar Convention (Lambert & Elix 2006)
Benchmark	This can be either a point of reference for condition (ANZECC & ARMCANZ 2000) or a pre-determined state (based on the values which are sought to be protected, Lambert & Elix 2006)
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”
Benthic	Species that occur in sediments at the bottom of a water body (Phillips & Muller 2006)
Biogeographic region	A region defined by relatively constant biological and physical parameters such as climate, soil type, plant communities, *etc* (Ramsar Convention 2005).
Biological diversity	The variability among living organisms from all sources including 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)
Bioturbation	Stirring or mixing of sediments by resident biota, particularly burrowing or boring animals. Bioturbation can play a major role in nutrient and carbon re-cycling through re-suspension of sediments. It also enhances organic decomposition and redistribution of organic material, and enables deeper penetration of oxygenated waters into the microscopic spaces in the soil
CAMBA	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. www.environment.gov.au/biodiversity/migratory/waterbirds/index.html

Catchment	The total area of land draining into a river, reservoir, or other body of water (ANZECC & ARMCANZ 2000)
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	A distinctive combination of species occupying a common environment and interacting with one another (ANZECC & ARMCANZ 2000)
Community composition	All the species present in a community (ANZECC & ARMCANZ 2000)
Community structure	The relative abundances of all the species present in a community (ANZECC & ARMCANZ 2000)
Conceptual model	Wetland conceptual models (or diagrams) illustrate our understanding of ecosystem components and processes and the interactions between them in a non-quantitative way
Contracting Parties	Countries that are Member States to the Ramsar Convention on Wetlands, 158 as of 2009. Membership in the Convention is open to all states that are members of the United Nations or are Parties to the Statute of the International Court of Justice, and to one of the UN specialized agencies or the International Atomic Energy Agency. http://www.ramsar.org/key_cp_e.htm
Critical stage	Refers to stages in the life cycle of wetland-dependent species where activities, if interrupted, may threaten the long-term survival of the species. Stages are likely to be breeding and migration stopovers, or moulting for Anatidae (Ramsar Convention 2005)
East Asian-Australasian Flyway	The East Asian-Australasian Flyway extends from the Arctic through Asia to Australia and New Zealand. Migratory birds fly through this route twice a year from north to south and back, travelling up to 25,000 kilometres per year
Ecological character	The combination of ecosystem components (species, communities and physical features), ecosystem processes and benefits/services that characterise the wetland at a given point in time. The phrase "at a given point in time" refers to Resolution VI.1 paragraph 2.1, which states that "it is essential that the ecological character of a site be described by the Contracting Party concerned at the time of designation for the Ramsar List, by completion of the Information Sheet on Ramsar Wetlands" (as adopted by Recommendation IV. 7)
Ecological communities	Any naturally occurring group of species inhabiting a common environment, interacting with each other especially through food relationships and relatively independent of other groups. Ecological communities may be of varying sizes, and larger communities may contain smaller ones (Ramsar Convention 2005)
Ecosystems	The complex of living communities (including human communities) and non-living environment (i.e. all ecosystem components) within a landscape that interact through ecological processes
Ecosystem components	In relation to wetlands, implies the physical characteristics, chemical characteristics, plant and animal species of the wetland and catchment (Millennium Ecosystem

	Assessment 2005). Genetic characteristic of species also form an ecosystem component
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)
Ecosystem services	The benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (*e.g.* food & water), flow regulation (*e.g*. flood control), cultural (*e.g.* spiritual, recreational) and supporting (*e.g.* nutrient cycling, ecological value). See also "Benefits"
Functions of wetlands	The activities or actions which occur naturally in wetlands as a product of interactions between the ecosystem structure and processes. Functions include flood water control; nutrient, sediment and contaminant retention; food web support; shoreline stabilisation and erosion controls; storm protection (Ramsar Convention 1996 Resolution VI.1). This term was replaced with "Ecosystem Services/Benefits" (Ramsar Convention 2005)
Introduced (non-native) species	A species that does not originate or occur naturally in the country under consideration (Ramsar Convention 2005)
JAMBA	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. www.environment.gov.au/biodiversity/migratory/waterbirds/index.html
Limits of Acceptable Change (LOAC)	The variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. Changes within LOAC do not represent change in ecological character that is likely to lead to a reduction or loss of the values for which the site was Ramsar listed (Phillips 2006)
List of Wetlands of International Importance ("the Ramsar List")	The list of wetlands which have been designated by the Contracting Parties as internationally important according to one or more of the criteria that have been adopted by the Conference of the Parties. http://www.ramsar.org/about/about_glossary.htm
Key components and processes	Components and processes that have the potential to cause a fundamental shift in ecological character of the whole site ("keystone species" *sensu* Phillips and Muller 2006). They include but are not restricted to attributes for which the site was Ramsar listed
Macrophyte	Macroalgae (*e.g.* seaweed, sea lettuce, filamentous greens) and submerged vascular plants. Vascular plants fall into two categories: submerged (*e.g.* seagrass, ribbonweed) or floating (*e.g.* pondweed, duckweed). Occasionally fringing emergent vascular plants (*e.g*. sedges, rushes) are referred to as macrophytes
Mangal	Mangrove community
Monitoring	Monitoring usually implies the regular collection of a series of measurements or samples to determine whether there is any change in the condition of a wetland over time. In Ramsar terminology, monitoring is given a narrower meaning and relates to regular collection of data to test hypotheses related to management whereas the more general collection of data to document condition is termed *surveillance*

Phytoplankton	Microscopic algae, including chlorophytes (green algae), diatoms (*e.g*. bacillariophytes), dinoflagellates (*e.g.* dinophytes) and cyanophytes (*i.e.* blue-greens = cyanobacteria)
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". http://www.ramsar.org/about/about_glossary.htm
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. http://www.ramsar.org/about/about_glossary.htm
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. http://www.ramsar.org/index_very_key_docs.htm
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. http://www.ramsar.org/about/about_glossary.htm
Ramsar List	The List of Wetlands of International Importance. http://www.ramsar.org/about/about_glossary.htm
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. http://www.ramsar.org/about/about_glossary.htm
Risk Assessment	A quantitative or qualitative evaluation of the actual or potential adverse effects of stressors on a wetland ecosystem
ROKAMBA	The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds, 2007. www.environment.gov.au/biodiversity/migratory/waterbirds/index.html
Taxa	A grouping of organisms given a formal taxonomic name such as species, genus, family *etc* (Phillips & Muller 2006)
Values of wetlands	The perceived benefits to society, either direct or indirect, that result from wetland functions. These values include environmental quality, wildlife support and human welfare (Ramsar Convention 1996, Resolution VI.1). This term was replaced by "Ecosystem Services/Benefits" (Ramsar Convention 2005).
Wetland	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.

Wetland Assessment	Identification of the conservation status of, and threats to, a wetland through collating its values. Can be used to identify information parameters that should be monitored to protect key wetland values (see Finaylson *et al*. 2001; Ramsar Convention 2002a, Resolution VIII.6)
Wetland Types	As defined by the Ramsar Convention's wetland classification system. http://www.ramsar.org/ris/key_ris.htm#type
Wise Use of Wetlands	The maintenance of their ecological character, achieved through the implementation of ecosystem approaches[1], within the context of sustainable development[2] (Ramsar Convention 2005 Resolution IX.1 Annex A). 1. Including the Convention on Biological Diversity's "Ecosystem Approach" (CBD COP5 Decision V/6) and that applied by HELCOM and OSPAR (Declaration of the First Joint Ministerial Meeting of the Helsinki and OSPAR Commissions, Bremen, 25-26 June 2003). 2. The phrase "in the context of sustainable development" is intended to recognize that whilst some wetland development is inevitable and that many developments have important benefits to society, developments can be facilitated in sustainable ways by approaches elaborated under the Convention, and it is not appropriate to imply that 'development' is an objective for every wetland.

LIST OF ABBREVIATIONS

ANZECC/ARMCANZ	Australian and New Zealand Environment and Conservation Council, and the Agriculture and Resource Management Council of Australia and New Zealand http://eied.deh.gov.au/water/quality/nwqms/volume1.html
CALM	Department of Conservation and Land Management; now Department of Environment and Conservation (DEC)
CAMBA	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 www.environment.gov.au/biodiversity/migratory/waterbirds/index.html
CMS	Convention on the Conservation of Migratory Species of Wild Animals, ratified in Bonn in 1983 www.cms.int/
CSIRO	Commonwealth Scientific & Industrial Organisation www.csiro.au
DAF	Department of Agriculture and Food (WA) www.agric.wa.gov.au/
DIA	Department of Indigenous Affairs (WA) www.dia.wa.gov.au/
DIWA	www.environment.gov.au/water/publications/environmental/wetlands/database/
DEC	Department of Environment and Conservation (WA) www.dec.wa.gov.au/
DEW	Australian Government Department of the Environment and Water Resources www.environment.gov.au/
DoE	Department of Environment (now Department of Environment and Conservation, WA)
DoW	Department of Water (WA) http://portal.water.wa.gov.au/portal/page/portal/home
DPI	Department of Planning and Infrastructure (WA) www.dpi.wa.gov.au/
EPA	Environment Protection Authority (WA) www.epa.wa.gov.au/
ILC	Indigenous Land Corporation
IUCN	The International Union for the Conservation of Nature and Natural Resources www.iucn.org/
JAMBA	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 www.environment.gov.au/biodiversity/migratory/waterbirds/index.html
MAFRL	Marine and Freshwater Research Laboratory, Murdoch University (WA) wwwscience.murdoch.edu.au/centres/mafrl/
NHT	Australian Government National Heritage Trust www.nht.gov.au/
NIOZ	Royal Netherlands Institute for Sea Research, www.nioz.nl/
NLWRA	National Land and Water Resources Audit, National Heritage Trust (Australian Government) www.nlwra.gov.au/
NRM	Natural Resource Management www.nrm.gov.au/

RAMSAR	Ramsar Convention on Wetlands, ratified in Ramsar, Iran in 1975. Officially known as The Convention on Wetlands of International Importance, especially as Waterfowl Habitat www.ramsar.org/
ROKAMBA	The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds, 2007 www.environment.gov.au/biodiversity/migratory/waterbirds/index.html
RBWG	Roebuck Bay Working Group
WAPC	Western Australian Planning Commission www.wapc.wa.gov.au/
WWF	Formerly World Wide Fund for Nature, Australia

APPENDICES

APPENDIX A AUTHOR CURRICULUM VITAE

Stuart Halse

B Sc (Hons) – University of Western Australia, 1977

Ph D – University of the Witwatersrand, 1982

Stuart spent 22 years undertaking research on wetlands for the Department of Environment and Conservation. He prepared the first nine Ramsar nominations for Western Australia and for many years he was the Western Australian government's principal source of management and policy advice. He has also been involved in preparation and implementation of management plans for both urban (e.g. Herdsman) and rural wetlands (e.g. Warden and Toolibin) and was a technical advisor to the Western Australian Natural Diversity Recovery Catchments program. Stuart currently sits as an independent scientist on the Wetlands Coordinating Committee, which is responsible for integrating wetland management across government agencies.

Stuart has undertaken and managed waterbird and aquatic invertebrate surveys across Western Australia to document wetland values and identify important wetland sites. He has first-hand experience of management issues in Kimberley wetlands, including Lake Gregory, Lake Argyle and the lower Ord, Eighty Mile Beach and Mandora, and Roebuck Bay. He has published about 100 scientific papers on ecology, taxonomy, and wetland and river management, and is an associate editor of *Hydrobiologia*.

Grant Pearson

Grant has worked in Roebuck Bay for the past 27 years on aspects of the ecology of shorebirds, benthic ecosystems, and the relationship of shorebirds and the intertidal zone. He is a co-author of the 1999 NIOZ report "Intertidal Sediments and Benthic Animals of Roebuck Bay, Western Australia" and the book "Life Along Land's Edge, Wildlife of the Shores of Roebuck Bay, Broome". He has also led or co-led a number of community based surveys that aimed to map the nature and distribution of the benthic invertebrates of Roebuck Bay, King Sound and Eighty-mile Beach. He is author or co-author of a number of reports on ecological processes at Roebuck Bay. He is one of a small team responsible for establishing the Broome Bird Observatory that has facilitated shorebird research at Roebuck Bay and 80 Mile Beach for the past 20 years. He has been a member of the Broome Bird Observatory management committee for the past 12 years. He is a member of the Roebuck Bay Working Group and recently established a RBWG sub-committee to investigate the presence and distribution of the cyano-bacteria *Lyngbya* that has become a focus of public attention in Roebuck Bay. He has studied the distribution and structure of benthic communities used by shorebirds in the Alaskan Yukon-Kuskokwim Delta, the Waddensea and the Geum and Salmangeum estuaries in South Korea.

Andrew Storey

BSc (Hons) University of Ulster (1981)

PhD Reading University (1986)

Andrew has 20 years experience in aquatic ecology, having worked in the UK, Papua New Guinea, Indonesia and Australia, specialising in the ecology and management of fish, invertebrate and waterbird communities of tropical and temperate freshwater systems. He has also coordinated monitoring of the response of groundwater-dependent systems to changing water levels (aquatic fauna of Yanchep & Leeuwin cave systems) as a precursor to developing EWRs. Andrew sits on the Ord River Scientific Panel, which developed an Interim EWR for the Lower Ord River. He has also directed numerous biological surveys, impact assessments, particularly of mining operations, published monitoring protocols for Australia's Wetlands of International Importance (Ramsar), been involved in setting QA/QC objectives for national monitoring programs, and assisted in Health and Ecological Risk Assessments on large mining operations.

Andrew is joint coordinator on a River Restoration course and guest lecturer on an Environmental Water Requirements course run by Edith Cowan University, detailing EWRs for freshwater fish and groundwater-dependent cave fauna. He is a member of various committees, including DEC's Threatened Ecological Communities Scientific Committee, Recovery Teams for Yanchep and Leeuwin caves, and the Steering Committee for a WWF project on managing Northern Rivers. He has authored over 75 project reports, and published over 35 scientific journal articles.

Tony Chiffings

B. Sc. (Zoology Major), University of Western Australia, 1971.

Ph. D., University of Western Australia, 1987.

Tony has extensive experience as a coastal systems ecologist and in the facilitation and synthesis of results from scientific research programs for management outcomes. He has considerable experience in coordinating the interface between stakeholder needs and research providers in both strategic and applied capacities across industry, research and the public sector.

Appointed as State Manager to DHI in January 2008, Tony has just completed 2 years as a Principal Research Fellow and Program Manager for the *Lyngbya* Research and Management Program of the Moreton Bay Waterways and Catchments Partnership at the Centre for Marine Studies, University of Queensland. Other recent activities include integrating scientific studies on nuisance algal blooms in the Noosa region, facilitation of a review on the impact of phosphorus loadings to Moreton Bay and input into policy development for nuisance algal blooms for the SEQ Regional Coastal Zone Management Plan. Tony is responsible for the development of an Environmental Health Monitoring Program (EHMP) for Tweed Shire Council as a pilot for the International Water. He has worked extensively in the Pilbara and participates in the recently established RBWG sub-committee to investigate the presence and distribution of *Lyngbya*. He is also a member of the Technical Advisory Panel for the Scientific Swan River Trust and sits on the Shark Bay World Heritage Property Ministerial Scientific Advisory Committee. He was a member of the CSIRO design team for the Port Phillip Bay Study and was program leader in the first Cockburn Sound study and the Dampier Archipelago study.

APPENDIX B ABORIGINAL SITES IN AND AROUND THE ROEBUCK BAY RAMSAR SITE

Source: Department of Indigenous Affairs, Register of Aboriginal Sites. Shading indicates sites located within or immediately adjacent to the boundary of the Ramsar site.

Codes

Status: L = lodged; I = insufficient information; P= permanent register; S= stored data.

Access: C = closed; O = open; V = vulnerable. Restriction: N = no restriction; m = male access only; F = female access only.

SITE ID	STATUS	ACCESS	RESTRICTION	SITE NAME	SITE TYPE
431	I	O	N	Jugurrugun	Mythological
432	I	O	N	Red Point	Mythological
433	I	O	N	Gantheaume Pt. 3	Mythological
434	I	O	N	Gantheaume Pt. 4	Mythological
12395	L	C	N	Nulungu	Mythological (& Water source)
12410	P	C	N	Lintapitjin / Lot 2065	Ceremonial, Mythological, Artefacts / Scatter, Midden / Scatter
12412	P	O	N	Thangoo Cemetery	Skeletal material / Burial
12416	I	C	N	Gantheaume Pt: Dog Dreaming	Mythological
12417	I	C	N	Nulungu	Mythological (& Water source)
12429	P	O	N	Gnh lot 1208	Skeletal material / Burial
12472	P	O	N	Budalgi	Artefacts / Scatter, Midden / Scatter (& Water source)
12475	P	O	N	Mararr	Artefacts / Scatter, Midden / Scatter (& Water source)
12522	P	O	N	One Mile camp	Camp
12552	P	C	N	Clementson St. Site Complex	Ceremonial, Mythological
12590	P	O	N	Red Bank	Mythological, Fish trap, Midden / Scatter (& Water source)
12591	P	O	N	Broome Old Jetty	Ceremonial, Mythological, Artefacts / Scatter, Midden / Scatter (& Water source)
12793	P	C	N	Undanda	Ceremonial, Mythological, Midden / Scatter, grinding patches / grooves
12839	P	C	N	Billingurru	Ceremonial, Mythological (Camp)
12840	I	C	N	Yarrarra	Mythological (Camp)
12841	I	C	N	Marnalakun	Skeletal material/Burial (Camp)
12872	P	O	N	Gantheaume Point 2	Artefacts / Scatter, Midden / Scatter (Camp)
12873	P	C	N	Entrance Point/ Yinara	Mythological, Artefacts / Scatter,

					Midden / Scatter (Camp)
12874	I	O	N	Roebuck Bay Midden	Artefacts / Scatter, Midden / Scatter
12886	I	C	N	Illangarami	Mythological
12887	I	C	N	Balliwanduna	Mythological
12917	P	C	N	Cable Beach 6	Midden / Scatter (Meeting Place, Camp, Water source)
12918	P	O	N	Cable Beach 4	Artefacts / Scatter, Midden / Scatter (Camp, Water source)
12919	P	O	N	Cable Beach 2	Artefacts / Scatter, Midden / Scatter
12920	P	O	N	Cable Beach 1	Artefacts / Scatter, Midden / Scatter
12921	P	C	N	Minyirr	Mythological
12922	P	C	N	Jungkurr	Mythological
12923	P	C	N	Ngakalyalya	Mythological
12924	P	C	N	Gantheaume Point 1	Mythological, Artefacts / Scatter, Midden / Scatter
13075	P	C	N	Mangalagun+iwalanganjdanj	Mythological, Artefacts / Scatter, Midden / Scatter
13320	P	C	N	Wundorda	Ceremonial, Artefacts / Scatter, Midden / Scatter
13321	P	C	N	Bulgurgun	Mythological, Artefacts / Scatter, Midden / Scatter
13351	P	C	M	Ngilirirrbanjin	Ceremonial
13463	P	C	N	Wullulong Ground	---
13729	P	C	N	Reserve 21801 Broome	Ceremonial, Mythological, Man-made structure, Artefacts / Scatter
14240	L	O	M	Fishermens Bend 2	Ceremonial, Mythological, Artefacts / Scatter, Midden / Scatter
12421	P	C	M	Fishermens Bend 3	Ceremonial, Mythological, Repository / cache
14242	P	C	M	Fishermens Bend 4	Mythological
14243	P	C	N	Fishermens Bend 5	Mythological
14291	P	C	N	Fishermens Bend 1	Mythological, Artefacts / Scatter, Midden / Scatter (Camp, Water source)
14321	P	C	N	Cape Villaret	Mythological
14444	P	O	N	Beacon Hill	Artefacts / Scatter, Midden / Scatter
14557	L	O	N	Cable Beach 5.	Ceremonial, Mythological, Artefacts / Scatter, Midden / Scatter (Camp, Hunting place)
14558	S	O	N	Broome Jetty	---
14559	I	O	N	Broome	Artefacts / Scatter
14560	P	C	M	Titirrkun/kennedy Hill.	Ceremonial, Mythological, Artefacts / Scatter, Midden / Scatter, Grinding patches / Grooves (Hunting place, Water source)
14561	P	C	N	Sacred Stores/ Broome	Ceremonial, Repository / cache
14609	I	O	N	Cable Beach 3.	Mythological, Artefacts / Scatter, Midden / Scatter (Camp)
17566	I	O	N	Cape Villaret Area 01	Midden / Scatter
17567	P	O	N	Cape Villaret Area 02 / Darrlarnarngaba	Midden / Scatter, Grinding patches / Grooves (Camp, Water source)

17568-73	P	O	N	Cape Villaret Area 03 to 08	Artefacts / Scatter, Midden / Scatter
17756-57	L	O	N	Yardoogara 1, 2 & 3	Fish trap
19799	P	O	N	Mungullagun Blackberry Tree Midden	Artefacts / Scatter, Midden / Scatter
19999	P	O	N	Broome Bird Observatory Solar Panel Site	Artefacts / Scatter, Midden / Scatter
21408	P	C	M	Broome Crocodile Farm	Ceremonial, Mythological

APPENDIX C INTERTIDAL BENTHIC FAUNA RECORDED FROM ROEBUCK BAY

Species list of the 311 taxa of intertidal macrobenthic invertebrates found in the quantitative samples during ROEBIM97, SROEBIM-02 and ROEBIM06.

Family	Species	1997	2002	2006
Foraminifera	*Foraminifera* sp.9771		x	
Foraminifera	*Foraminifera* sp.9772		x	
Porifera	*Porifera* sp.*9050*		x	
Spongia	*Spongia* sp.9051	x		
Spongia	*Spongia* sp.9061	x		
Anthozoa	*Actiniaria* sp.*9100*		x	
Actiniaria	*Edwardsia* sp.*9101*	x	x	x
Anthozoa	*Edwardsia* sp.*9102*			x
Anthozoa	*Edwardsia* sp.9103		x	
Actiniaria	*Actiniaria* sp.9111	x		x
Ceriantharia	*Cerianthes sp.9121*	x		
Actiniaria	*Stoichactis* sp.9131	x		
Actiniaria	*Actiniaria* sp.9141	x		
Actiniaria	*Actiniaria* sp.9151	x		
Pennatulacea	*Pennatulacea* sp.9161		x	
Pennatulacea	*Pennatulacea* sp.9162		x	
Pycnogonidae	*Pycnogonida* sp.9201	x	x	x
Platyhelminthes	*Platyhelminthes* sp.4001		x	
Nemertini	*Nemertini* sp.4101	x	x	x
Nuculidae	*Nucula* cf *astricta*	x	x	x
Nuculidae	*Nucula* cf. *Superba*		x	
Ledidae	*Ledella* sp.1121			x
Solemyidae	*Solemya* cf *terraereginae*	x	x	x
Arcidae	*Anadara granosa*	x	x	x
Mytilidae	*Modiolus micropterus*	x	x	x
Lucinidae	*Anodontia omissa*	x	x	x
Lucinidae	*Divaricella irpex or ornata*	x	x	x
Lucinidae	*Divaricella bardwelli*	x	x	
Lucinidae	*Ctena sp.*1421	x	x	
Lucinidae	*Ctena sp.*1422			x
Lucinidae	*Ctena sp.*1423		x	
Montacutidae	*Montacuta* sp. 1451.	X	x	
Galeommatidae	*Mysella* sp.1461			x
Lasaeidae	*Lasaea* sp. 1471		x	
Galeommatidae	*Galeomatid* sp.1472		x	
Galeommatidae	*Galeomna* sp. 1473			x
Erycinidae	*Scintilla* sp. 1501	x	x	x
Galeommatidae	*Galeomna* sp.1502		x	x

Family	Species	1997	2002	2006
Galeommatidae	*Galeomna* sp.1503			x
Galeommatidae	*Galeomna* sp. 1504			x
Galeommatidae	*Galeomna* sp. 1505			x
Galeommatidae	*Galeomna* sp.1506			x
Galeommatidae	*Galeomna* sp.1507			x
Galeommatidae	*Galeomna* sp.1508			x
Galeommatidae	*Galeomna* sp.1509			x
Mactridae	*Heterocardia gibbosula*	x	x	
Mactridae	*Mactra* sp.1602	x		
Mactridae	*Mactra* sp.1603	x		
Mactridae	*Mactra* sp.1604	x		
Mactridae	*Mactra* sp.1605			x
Mactridae	*Mactra* sp.1606			x
Mactridae	*Mactra* cf *abbreviata*			x
Mactridae	*Mactridae* sp.1611	x		
Mactridae	*Mactra grandis*	x		x
Mactridae	*Mactra pura*	x	x	
Mactridae	*Mactra* sp.1641		x	
Corbulidae	*Corbula* sp.1651	x	x	x
Corbulidae	*Corbula* sp.1652	x		
Cultellidae	*Cultellus cultellus*	x	x	x
Cultellidae	*Siliqua pulchella*	x	x	x
Semelidae	*Semele* sp.1751	x	x	
Semelidae	*Psammotaea* sp.1752	x	x	
Tellinidae	*Tellina* sp.1800	x	x	
Tellinidae	*Tellina capsoides*	x	x	x
Tellinidae	*Tellina piratica*	x	x	x
Tellinidae	*Tellina inflata*	x	x	x
Tellinidae	*Tellina amboynensis*	x	x	x
Tellinidae	*Tellina* sp.1805	x	x	
Tellinidae	*Tellina* sp.1806	x		
Tellinidae	*Tellina* sp.1807	x		x
Tellinidae	*Tellina* cf. *Sulcata*	x		
Tellinidae	*Tellina* sp.1809	x		
Tellinidae	*Tellina* sp.1811	x	x	
Tellinidae	*Tellina mysia*	x		
Tellinidae	*Tellina* sp.1813	x		
Tellinidae	*Tellina* sp.1818		x	x
Tellinidae	*Tellina* cf *serricostata*		x	x
Tellinidae	*Tellina* cf *exotica*	x		x
Tellinidae	*Tellina exotica* subsp.1822			x
Tellinidae	*Tellina exotica* subsp.1823		x	x
Tellinidae	*Tellina* sp.1824		x	x

Family	Species	1997	2002	2006
Tellinidae	*Tellina* sp.1825			x
Tellinidae	*Tellina* sp.1826			x
Tellinidae	*Tellina* sp.1827			x
Tellinidae	*Tellina* sp.1828			x
Tellinidae	*Tellina* sp.1829			x
Tellinidae	*Macoma* sp.1831	x		
Donacidae	*Mesodesmatidae* sp.1851	x	x	
Donacidae	*Donax* sp.1853			
Psammobiidae	*Gari lessoni*	x		
Psammobiidae	*Psammobiidae* sp.1872			x
Solenidae	*Solen* sp. 188*1*	x	x	x
Veneridae	*Anomalocardia squamosa*	x	x	x
Veneridae	*Veneridae* sp.1911	x		
Veneridae	*Placamen gilva*	x		
Veneridae	*Placamen gravescens*	x	x	x
Veneridae	*Placamen calophyllum*		x	x
Veneridae	*Tapes* sp.1931	x		
Veneridae	*Tapes* sp.1932	x	x	
Veneridae	*Marcia hiantum*		x	
Veneridae	*Clementia papyracaea*		x	
Veneridae	*Callista planatella*		x	
Veneridae	*Gafrarium dispar*	x	x	
Veneridae	*Venus* sp.1942	x	x	
Veneridae	*Dosinia* sp.1945	x		
Veneridae	*Dosinia* sp.1946	x	x	
Veneridae	*Veneridae* sp.1947			x
Laternulidae	*Laternula creccina*	x		
Stenothyridae	*Stenothyra* sp.2001		x	
Trochidae	*Clanculus* sp.2051	x		x
Trochidae	*Calliostoma* sp.2061	x	x	
Trochidae	*Isanda coronata*		x	
Trochidae	*Isanda* sp.2063		x	
Unknown sp.	Unknown sp.2101	x		
Neritidae	*Nerita* sp.2151	x	x	
Unknown sp.	Unknown sp.2201	x		
Cerithiidae	*Cerithidea cingulata*	x	x	x
Scaliolidae	*Finella* sp.2351		x	
Eulimidae	*Eulimidae* sp.2401	x	x	
Eulimidae	*Niso* sp.2411	x		
Naticidae	*Polinices conicus*	x	x	x
Naticidae	*Polinices* sp.2502		x	
Naticidae	*Natica* sp 2511		x	
Naticidae	*Natica* sp.2512	x		x

Family	Species	1997	2002	2006
Sigaretidae	*Sigaretus* sp.2516		x	
Unknown sp.	Unknown sp.2531	x		
Columbellidae	*Columbellidae* sp.*2551*	x		
Columbellidae	*Columbellidae* sp.2552	x	x	
Columbellidae	*Nitidella essingtonensis*		x	x
Columbellidae	*Mitrella* sp.2554		x	
Columbellidae	*Zafra* sp.2555			x
Nassariidae	*Nassarius dorsatus*	x	x	x
Nassariidae	*Nassarius* sp.2602	x	x	x
Nassariidae	*Nassarius* sp.2603	x		
Nassariidae	*Nassarius bicallosum*		x	x
Marginellidae	*Marginellidae* sp.2701	x	x	x
Costellariidae	*Vexillium radix*	x	x	x
Mitridae	*Vexillum* sp.2752			x
Mitridae	*Mitridae* sp.2771	x		x
Olividae	*Oliva australis*			x
Turridae	Turridae sp. 2801		x	x
Turridae	*Mangelia* sp. 2802		x	
Turridae	*Turridae* sp. 2803		x	
Terebridae	*Terebridae* sp. 2851	x	x	x
Haminoeidae	*Liloa* sp. 2900		x	
Cephalaspidea	*Haminoae* sp.2901	x	x	x
Glaucidae	*Glaucidae* sp 2911		x	
Actaeonidae	*Acteon* sp. 2941	x	x	x
Retusidae	*Tornatina* sp. 2951	x	x	x
Cylichnidae	*Cylichnidae* sp 295*2*			x
Melampidae	*Melampidae* sp.2971	x		
Amphibolidae	*Salinator* cf *burmana*	x	x	x
Onchodiidae	*Onchidium* sp. 2985	x		
Rissoellidae	*Rissoella* sp.2990		x	
Pyramidellidae	*Pyramidellidae* sp.299*1*	x		x
Pyramidellidae	*Leucotina* sp.2992	x	x	x
Pyramidellidae	*Chrysallida* sp.2993	x	x	
Pyramidellidae	*Turbonilla* sp.2994	x	x	
Pyramidellidae	*Syrnola* sp2995		x	x
Pyramidellidae	*Tiberia* sp.2997		x	
Dentalidae	*Laevidentalium* cf *lubricatum* (smooth)	x	x	x
Dentalidae	*Dentalium* cf *bartonae* (ribbed)	x	x	x
Cadulidae	*Cadulus* sp.3201		x	
Phoronida	*Phoronida* sp.4201	x	x	x
Sipunculida	*Sipuncula* sp.4501	x	x	
Sipuncula	*Sipunculus* sp.4502			x
Sipunculida	*Phascolion* sp.4511		x	x

Family	Species	1997	2002	2006
Sipunculida	*Ringed Sipunculus*	x	x	x
Echiuroidea	*Echiurus* sp.4601	x	x	
Hirundinea	*Hirundinea* sp.4801	x		
Enteropneusta	*Balanoglossus* sp.4901	x	x	x
Oligochaeta	*Oligochaeta* sp.5000.			x
Polychaeta	*Polychaeta* sp.5001.	x	x	x
Polychaeta	*Polychaeta* sp.5002		x	
Orbiniidae	*Orbiniidae* sp.5051	x	x	x
Polynoidae	*Polynoidae* sp.5101	x	x	
Polynoidae	*Polynoidae* sp.5111	x		
Polynoidae	*Polynoidae* sp.5121		x	x
Polynoidae	*Polynoidae* sp.5122		x	x
Polynoidae	*Polynoidae* sp.5123		x	
Polynoidae	*Harmothoe* sp.5125		x	
Sigalionidae	*Sigalionidae* sp.5151	x	x	x
Sigalionidae	*Sigalionidae* sp.5152		x	
Amphinomidae	*Amphinomidae* sp.5201	x	x	x
Onuphidae	*Onuphidae* sp.5301	x	x	x
Eunicidae	*Eunicidae* sp.5305		x	x
Lysaretidae	*Lysaretidae* sp.5331			x
Lumbrineridae	*Lumbrineridae* sp.5351	x	x	x
Arabellidae	*Arabellidae* sp.5371			x
Pilargidae	*Pilargidae* sp.5401	x	x	x
Hesionidae	*Hesionidae* sp.5411		x	x
Nereidae	*Nereidae* sp.5451	x	x	
Syllidae	*Syllidae* sp.5471	x	x	x
Phyllodocidae	*Phyllodocidae* sp.5501	x	x	x
Phyllodocidae	*Phyllodocidae* sp.5511	x	x	x
Pontodoridae	Pontodoridae sp.5551	x		
Nephtyidae	*Nephtyidae* sp.5601	x	x	x
Glyceridae	*Glyceridae* sp.5701	x	x	x
Glyceridae	*Glyceridae* sp.5711	x		x
Goniadidae	*Goniadidae* sp.5751	x	x	x
Spionidae	*Spionidae* sp.5801	x	x	x
Spionidae	*Spionidae* sp.5802		x	x
Chaetopteridae	*Chaetopteridae* sp.5901	x	x	x
Trochochaetidae	*Trochochaetidae* sp.5905		x	
Magelonidae	*Magelonidae* sp.5951		x	x
Cirratulidae	*Cirratulidae* sp.6001	x	x	
Paraonidae	*Paraonidae* sp.6101	x	x	x
Opheliidae	*Opheliidae* sp.6201	x	x	x
Capitellidae	*Capitellidae* sp.6301	x	x	x
Maldanidae	*Maldanidae* sp.6401	x	x	x

Family	Species	1997	2002	2006
Oweniidae	*Oweniidae* sp.6402		x	
Sternaspidae	*Sternaspidae* sp.6501	x	x	x
Oweniidae	*Oweniidae* sp.6601	x	x	x
Flabelligeridae	*Flabelligeridae sp.6701*	x		x
Ampharetidae	*Ampharetidae* sp.6801		x	x
Terebellidae	*Terebellidae* sp.6802		x	x
Trichobranchidae	*Trichobranchidae* sp.6811		x	x
Sabellariidae	*Sabellariidae* sp.6851	x	x	x
Pectinaridae	*Pectinaridae* sp.6861			x
Terebellidae	*Sabellidae* sp.6871			
Sabellidae	*Poecilochaetidae* sp.6901	x		x
Poecilochaetidae	*Poecilochaetidae* sp.6951	x		
Copepoda	*Copepoda* sp.7051	x		
Ostracoda	*Ostracoda* sp.7101	x	x	
Ostracoda	*Ostracoda* sp.7102		x	
Ostracoda	*Ostracoda* sp.7103		x	x
Amphipoda	*Gammarus* sp.7201		x	x
Amphipoda	*Amphipoda* sp.7211	x	x	x
Corophiidae	*Corophium* sp.7221	x	x	x
Amphipoda	*Caprellidae* sp.7251		x	x
Isopoda	*Anthura* sp.7301	x	x	x
Isopoda	*Eurydice* sp.7311	x	x	
Tanaidacea	*Tanaidacea* sp.7401	x	x	
Cumacea	*Cumacea* sp.7501	x	x	x
Anaspidae	*Anaspidae* sp.7502			x
Mysidacea	*Mysidacea* sp.7551	x	x	x
Squillidae	*Squillidae* sp.7601	x	x	x
Caridea	*Caridae* sp.7701	x	x	x
Palaemonidae	*Caridae* sp.7711	x		x
Alpheidae	*Alpheidae* sp.7751	x		x
Callianassidae	*Gourretia coolibas*	x		x
Caridea	*Callianassa* sp.7802		x	
Paguridae	*Paguridae* sp.7901	x	x	x
Crustacea	*Crustacea* sp.8001	x		
Dorippidae	*Dorippe* cf *australiensis*	x	x	x
Raninidae	*Raninidae* sp.8071		x	
Callapidae	*Matuta planipes*	x	x	x
Porcellanidae	*Porcellanidae* sp.8151	x	x	
Xanthidae	*Xanthidae* sp.8171	x		
Leucosiidae	cf. *Myrodes eudactylus*	x	x	x
Leucosiidae	*Nursia abbreviata*	x	x	
Leucosiidae	*Ebalia* sp.8221	x	x	x
Leucosiidae	*Leucosia* sp.8231	x	x	x

Family	Species	1997	2002	2006
Leucosiidae	*Leucosia* sp8241	x		
Leucosiidae	*Leucosia* sp.8251	x		
Portunidae	*Portunidae* sp.8291	x		x
Majidae	*Halicarcinus* cf *australis*	x	x	x
Myctiridae	*Mictyris longicarpus*	x	x	
Xanthidae	*Xanthidae* sp.8321	x		
Pinotheridae	*Pinotheridae* sp.8351			
Pilumnidae	*Pilumnidae* sp.8401	x	x	
Pilumnidae	*Pilumnidae* sp.8411	x		
Pilumnidae	*Pilumnidae* sp.8421	x		
Goneplacidae	*Hexapus* sp.8501	x	x	x
Ocypodidae	*Macrophthalmus* sp.8601.	x	x	x
Ocypodidae	*Scopimera inflata*		x	
Ocypodidae	*Ocypode* sp.8671	x		
Insecta	*Chironomidae* sp.8801			x
Brachiopoda	*Lingula* sp.9301	x	x	x
Ophiuroidea	*Amphiura* sp.9401	x	x	x
Ophiuroidea	*Amphiura (Ophiopeltis) tenuis*		x	x
Ophiuroidea	*Amphiura catephes*		x	x
Ophiuroidea	*Amphioplus (Lymanella) depressus*			x
Ophiuroidea	*Amphioplus* sp.9405		x	x
Ophiuroidea	*Ophiocentrus verticillatus*			x
Ophiuroidea	*Ophiotrix (Placophiotrix) melanosticta*	x	x	
Ophiuroidea	*Dictenophiura stellata*	x	x	x
Ophiuroidea	*Ophiocnemis marmorata*			x
Asteroidea	*Astropecten granulatus*	x	x	x
Asteroidea	*Astropecten monachanthus*		x	x
Asteroidea	*Temnapleuris alexandri*		x	
Echinoidea	*Peronella tuberculata*	x	x	x
Echinoidea	*Arachnoides tenuilus*		x	
Holothuroidea	*Holothuroidea* sp.9600		x	
Holothuroidea	*Leptopentacta grisea*	x	x	
Holothuroidea	*Synaptidae* sp.9602			x
Holothuroidea	*Synaptidae* sp.9604		x	
Holothuroidea	*Holothuroidea* sp.9608		x	
Holothuroidea	*Synaptidae* sp.9610			x
Holothuroidea	*Holothurian* sp.9611	x		
Holothuroidea	*Holothurian* sp.9621	x		
Holothuroidea	*Stolus buccalis*	x	x	
Holothuroidea	*Holothuroidea* sp.9641	x		
Holothuroidea	*Protankyra verrelli*	x		x
Holothuroidea	*Holothuroidea* sp.9675		x	
Ophiuroidea	*Ophiocentrus verticillatus*		x	

Family	Species	1997	2002	2006
Tunicata	*Tunicata* sp.9701	x	x	x
Tunicata	*Tunicata* sp.97011	x		
Tunicata	*Tunicata* sp.97021	x		
Tunicata	*Tunicata* sp.97022	x		
Tunicata	*Tunicata* sp.97023	x		
Tunicata	*Tunicata* sp.97024		x	
Tunicata	*Tunicata* sp.97025			x
Tunicata	*Tunicata* sp.97026			x
Branchiostoma	*Peronella tuberculata*	x	x	x
Periophthalmidae	*Periophthalmidae* sp.9801	x	x	x
Periophthalmidae	*Periophthalmidae* sp.9802	x		
Pisces	*Gobiidae* sp.9810		x	x
Gobiidae	*Gobiidae* sp.9811	x		
Pisces	*Pisces* sp.9815		x	x
Soleidae	*Soleidae* sp.9821	x		

APPENDIX D WATERBIRDS AND SHOREBIRDS OF ROEBUCK BAY

Migratory species listed under the DEWHA (EPBC) list for International Agreements are described as: C=CAMBA, J=JAMBA, R=ROKAMBA

Spp	Common_name	Scientific_name	Location	DEWHA
	CRAKES AND RAILS			
46	Buff-banded Rail	*Gallirallus philippensis*	Pindan Pool	
49	Australian Spotted Crake	*Porzana fluminea*	Roebuck Plains	
50	Baillon's Crake	*Porzana pusilla*	Roebuck Plains	
55	Black-tailed Native-hen	*Gallinula ventralis*	Broome Area	
58	Purple Swamphen	*Porphyrio porphyrio*	Broome Area	
59	Eurasian Coot	*Fulica atra*	Sewage Works Broome	
	GREBES			
60	Great Crested Grebe	*Podiceps cristatus*	Sewage Works Broome	
61	Australasian Grebe	*Tachybaptus novaehollandiae*	Broome Area	
62	Hoary-headed Grebe	*Poliocephalus poliocephalus*	Unknown	
	CORMORANTS AND ALLIES			
63	Wilson's Storm-Petrel	*Oceanites oceanicus*	Port of Broome	J
69	Wedge-tailed Shearwater	*Puffinus pacificus*	Tidal Creek System	C
71	Short-tailed Shearwater	*Puffinus tenuirostris*	Ocean Beach	J
95	Lesser Frigatebird	*Fregata ariel*	Port of Broome	C,J,R
96	Great Cormorant	*Phalacrocorax carbo*	Mangrove Community	
97	Little Black Cormorant	*Phalacrocorax sulcirostris*	Intertidal/Open Water	J,C
99	Pied Cormorant	*Phalacrocorax varius*	Not recorded	
100	Little Pied Cormorant	*Phalacrocorax melanoleucos*	Intertidal/Open Water	J,C
101	Darter	*Anhinga melanogaster*	Port of Broome	
102	Brown Booby	*Sula leucogaster*	Port of Broome	C,J,R
106	Australian Pelican	*Pelecanus conspicillatus*	Unknown	
	DUCKS AND ALLIES			
199	Magpie Goose	*Anseranas semipalmata*	Sewage Works Broome	
201	Green Pygmy-goose	*Nettapus pulchellus*	Roebuck Plains	
202	Australian Wood Duck	*Chenonetta jubata*	Roebuck Plains	
203	Black Swan	*Cygnus atratus*	Broome Area	
204	Wandering Whistling-Duck	*Dendrocygna arcuata*	Sewage Works Broome	
205	Plumed Whistling-Duck	*Dendrocygna eytoni*	Sewage Works Broome	
206	Radjah Shelduck	*Tadorna radjah*	Sewage Works Broome	
208	Pacific Black Duck	*Anas superciliosa*	Sewage Works Broome	
211	Grey Teal	*Anas gracilis*	Sewage Works Broome	
212	Australasian Shoveler	*Anas rhynchotis*	Roebuck Plains	
213	Pink-eared Duck	*Malacorhynchus membranaceus*	Sewage Works Broome	
215	Hardhead	*Aythya australis*	Sewage Works Broome	
	HERONS AND ALLIES			
177	Brolga	*Grus rubicunda*	Roebuck Plains	
178	Glossy Ibis	*Plegadis falcinellus*	Intertidal/Open Water	C
179	Australian White Ibis	*Threskiornis molucca*	Tidal Creek System	

Spp	Common_name	Scientific_name	Location	DEWHA
180	Straw-necked Ibis	*Threskiornis spinicollis*	Broome Area	
181	Royal Spoonbill	*Platelea regia*	Sewage Works Broome	
182	Yellow-billed Spoonbill	*Platelea flavipes*	Broome Area	
183	Black-necked Stork	*Ephippiorhynchus asiaticus*	Tidal Creek System	
185	Little Egret	*Egretta garzetta*	Tidal Creek System	
186	Intermediate Egret	*Ardea intermedia*	Broome Area	
187	Great Egret	*Ardea alba*	Tidal Creek System	C ,J
188	White-faced Heron	*Egretta novaehollandiae*	Tidal Creek System	
189	White-necked Heron	*Ardea pacifica*	Broome Area	
190	Pied Heron	*Ardea picata*	Roebuck Plains	
191	Eastern Reef Egret	*Egretta sacra*	Port of Broome	C
192	Nankeen Night Heron	*Nycticorax caledonicus*	Mangrove Community	
193	Striated Heron	*Butorides striatus*	Tidal Creek System	
	SHOREBIRDS			
129	Ruddy Turnstone	*Arenaria interpres*	Port of Broome	C,J,R
130	Pied Oystercatcher	*Haematopus longirostris*	Mangrove Community	
131	Sooty Oystercatcher	*Haematopus fuliginosus*	Intertidal/Open Water	
132	Red-kneed Dotterel	*Erythrogonys cinctus*	Sewage Works Broome	
133	Masked Lapwing	*Vanellus miles*	Sewage Works Broome	
135	Banded Lapwing	*Vanellus tricolor*	Golf Course	
136	Grey Plover	*Pluvialis squatarola*	Intertidal/Open Water	C,J,R
137	Pacific Golden Plover	*Pluvialis fulva*	Broome Area	R
139	Lesser Sand Plover	*Charadrius mongolus*	Intertidal/Open Water	C,J,R
141	Greater Sand Plover	*Charadrius leschenaultii*	Port of Broome	C,J,R
142	Oriental Plover	*Charadrius veredus*	Intertidal/Open Water	R
143	Red-capped Plover	*Charadrius ruficapillus*	Roebuck Plains	
144	Black-fronted Dotterel	*Elseyornis melanops*	Sewage Works Broome Area	
146	Black-winged Stilt	*Himantopus himantopus*	Intertidal/Open Water	
147	Banded Stilt	*Cladorhynchus leucocephalus*	Unknown	
148	Red-necked Avocet	*Recurvirostra novaehollandiae*	Tidal Creek System	
149	Eastern Curlew	*Numenius madagascariensis*	Tidal Creek System	C,J,R
150	Whimbrel	*Numenius phaeopus*	Tidal Creek System	C,J,R
151	Little Curlew	*Numenius minutus*	Broome Area	C,R
939	Asian Dowitcher	*Limnodromus semipalmatus*	Mangrove Community	C,R
152	Black-tailed Godwit	*Limosa limosa*	Mangrove Community	C,J,R
153	Bar-tailed Godwit	*Limosa lapponica*	Mangrove Community	C,J,R
154	Wood Sandpiper	*Tringa glareola*	Broome Area	C,R
155	Grey-tailed Tattler	*Heteroscelus brevipes*	Port of Broome	C,R
157	Common Sandpiper	*Actitis hypoleucos*	Port of Broome	C,R
158	Common Greenshank	*Tringa nebularia*	Mangrove Community	C,J,R
159	Marsh Sandpiper	*Tringa stagnatilis*	Intertidal/Open Water	C,R
160	Terek Sandpiper	*Xenus cinereus*	Mangrove Community	C,J,R
161	Curlew Sandpiper	*Calidris ferruginea*	Mangrove Community	C,J,R
162	Red-necked Stint	*Calidris ruficollis*	Mangrove Community	C,J,R
163	Sharp-tailed Sandpiper	*Calidris acuminata*	Intertidal/Open Water	C,J,R
164	Red Knot	*Calidris canutus*	Intertidal/Open Water	C,J,R

Spp	Common_name	Scientific_name	Location	DEWHA
165	Great Knot	*Calidris tenuirostris*	Mangrove Community	C,J,R
166	Sanderling	*Calidris alba*	Intertidal/Open Water	C,J,R
167	Broad-billed Sandpiper	*Limicola falcinellus*	Mangrove Community	C,J,R
169	Swinhoe's Snipe	*Gallinago megala*	Sewage Works Broome	C,R
170	Painted Snipe	*Rostratula benghalensis*	Roebuck Plains	C
171	Comb-crested Jacana	*Irediparra gallinacea*	Roebuck Plains	
172	Oriental Pratincole	*Glareola maldivarum*	All Weather Pindan	C,J,R
173	Australian Pratincole	*Stiltia isabella*	Sewage Works Broome	
174	Bush Stone-curlew	*Burhinus magnirostris*	All Weather Pindan	
175	Beach Stone-curlew	*Burhinus neglectus*	Ocean Beach	
	RAPTORS			
219	Swamp Harrier	*Circus approximans*	Intertidal/Open Water	
226	White-bellied Sea-Eagle	*Haliaeetus leucogaster*	Unknown	C
227	Brahminy Kite	*Haliastur indus*	Tidal Creek System	
241	Osprey	*Pandion haliaetus*	Ubiquitous	
	TERNS AND GULLS			
109	White-winged Black Tern	*Chlidonias leucopterus*	Intertidal/Open Water	C,J,R
110	Whiskered Tern	*Chlidonias hybridus*	Tidal Creek System	
111	Gull-billed Tern	*Sterna nilotica*	Sewage Works Broome	
112	Caspian Tern	*Sterna caspia*	Mangrove Community	C
113	Roseate Tern	*Sterna dougallii*	Broome Area	C
115	Crested Tern	*Sterna bergii*	Intertidal/Open Water	C,J
116	Lesser Crested Tern	*Sterna bengalensis*	Port of Broome	C
117	Little Tern	*Sterna albifrons*	Intertidal/Open Water	C,J,R
121	Bridled Tern	*Sterna anaethetus*	Intertidal/Open Water	C,J
125	Silver Gull	*Larus novaehollandiae*	Ubiquitous	C
	OTHER			
451	Yellow Chat	*Ephthianura crocea*	Roebuck Plains	

APPENDIX E POTENTIAL FOR CHANGES TO THE BAY FROM EXTREME WEATHER EVENTS

The impact of a major cyclone (Rosita) on Roebuck Bay

The ecological character of Roebuck Bay has been shaped and maintained through millennia by environmental influences such as cyclones. Many cyclones have passed through the Broome area (***Figure 1***).

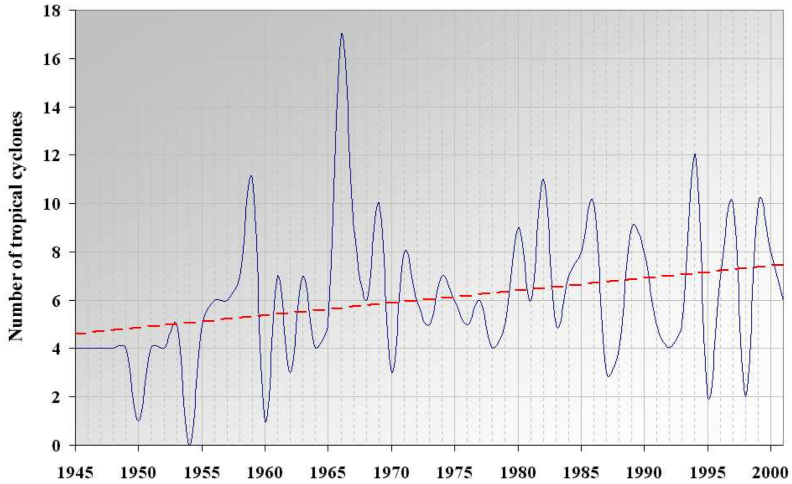
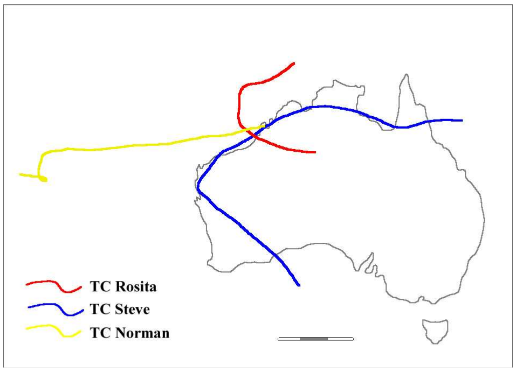


Figure 1. The number of cyclones that have occurred in Western Australian waters since 1945. Red line represents annual mean occurrence (after data from Hurricane Alley® for 1945 - 2000).

In April 2000, Cyclone Rosita crossed the coast 15 km south of the township of Broome (***Figure 2***), causing catastrophic damage to vegetation along the southern coast of Roebuck Bay and devastating Yardoogarra and Thangoo Stations and the Eco Beach Resort at Cape Villaret. Broome airport recorded official gusts at 153 km/h, but wind gusts closer to the centre were estimated to be in excess of 250 km/h with a maximum of 290 km/h.

Though tropical lows can result in high rainfall events in excess of 400 mm, Broome is not generally considered at high risk of major flooding owing to good drainage and the small catchment size of local creeks. However, particularly strong winds and high seas associated with cyclones can increase the risk of flooding from storm surges. During spring and cyclonic conditions, areas of the coastal flats on Roebuck Plain and other sites may be flooded. Although exact records are not available, it is thought that the plains are subject to extensive flooding about once every five years. The Bureau of Meteorology note that while Broome is largely protected from storm surge by the orientation of the coastline, a large cyclonic event crossing the coast at high tide is likely to cause significant storm surge at Roebuck Bay and inundate the lower parts of the town. The potential for significant coastal erosion and structural damage from cyclones was demonstrated in 2000 with the passage of Cyclone Rosita. ***Figure 3*** clearly illustrates the potential for weather systems to influence the extent of flooding from daily tide cycles. The extreme impact of Cyclone Rosita on tide height created a storm surge that caused sea water to be driven several kilometres inland along Roebuck Plains. There was severe coastal erosion along the eastern side of Roebuck Bay, just south of Broome (Plate 1). Further south the storm surge breached the coastal dunes (Plate 2). The value of the buffering effect of fringing mangrove systems is heightened during these events. Without the mangroves severe erosion can occur in the hinterland.



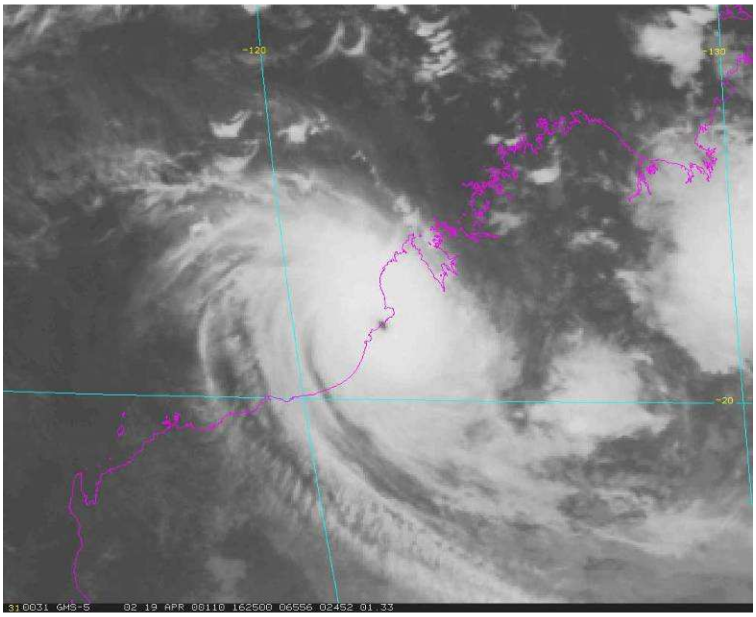


Figure 2. (left) Paths of tropical cyclones that passed within 100 km of Roebuck Bay in the 2000 cyclone season (after Hurricane Alley); (right) infra red satellite image showing eye of TC Rosita at landfall (source Japan Meteorological Agency courtesy Bureau of Meteorology).

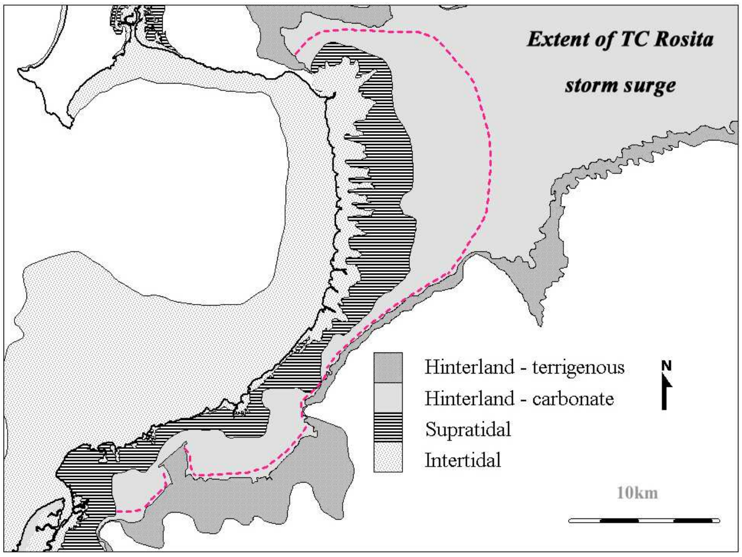


Figure 3. The estimated extent of storm surge during Cyclone Rosita (from Oldmeadow 2007). Geomorphic provinces are also indicated.

Plate 1. Erosion along Roebuck Bay due to storm surge associated with TC Rosita in 2000 (source Bureau of Meteorology).

Plate 2. Breach of coastal dunes on Thangoo station due to storm surge associated with TC Rosita in 2000 (source Bureau of Meteorology).